Environmental Science

Sunil Nautiyal · K. S. Rao
Harald Kaechele · K. V. Raju
Ruediger Schaldach *Editors*

Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change

Springer

Environmental Science and Engineering

Environmental Science

Series Editors

For further volumes:
http://www.springer.com/series/3234

Sunil Nautiyal · K. S. Rao
Harald Kaechele · K. V. Raju
Ruediger Schaldach
Editors

Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change

Springer

Editors
Sunil Nautiyal
K. V. Raju
Centre for Ecological Economics and Natural Resources
Institute for Social and Economic Change
Bangalore
India

K. S. Rao
Department of Botany
University of Delhi
Delhi
India

Harald Kaechele
Institute of Socioeconomics
Leibniz Centre for Agricultural Landscape Research
Müncheberg
Germany

Ruediger Schaldach
Centre for Environmental System Research
University of Kassel
Kassel
Germany

ISSN 1431-6250
ISBN 978-3-642-36142-5 ISBN 978-3-642-36143-2 (eBook)
DOI 10.1007/978-3-642-36143-2
Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2013942477

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Foreword

Responding adequately to climate change will pose tremendous challenges to any civilization anywhere in the world. While it is obvious that industrialized countries can afford the transition to sustainability, the challenges faced by decision makers in developing countries are daunting. Consequently, the initiative of the Alexander von Humboldt Foundation to sponsor the conference on “Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change” at the All India Institute for Social and Economic Change in Bangalore, India, was timely. As a major achievement, this conference brought together academics from various disciplines, decision makers and politicians from the Indian subcontinent and abroad, because tackling climate change needs concerted action on all levels.

It is now recognized that anthropogenic global warming is no longer an issue of the developed world only. Around the globe we see a copying of western lifestyles which is expressed in developing and emerging economies by fast economic growth. It is obvious that this will not lead to a climate-friendly future. Moreover, whatever the developed countries do in terms of climate protection, the pace of the growth in emerging economies will outpace the emission savings of the OECD countries. This will threaten livelihoods and constrain future development options, because it is well known that many countries in the South are most vulnerable. Climate change consequences would substantially add to the existing predicaments of poor and indigenous grassroots communities in South Asia which are inadequately prepared for adapting to unforeseen changes in their economic, social, and environmental contexts. Evidence of such vulnerability is already visible in India, which has faced extreme weather events over the last ten years and witnessed a decrease in foodgrain production. Nevertheless, climate change and its adverse consequences is not a regional phenomenon, but a problem of the global civilization.

There is no doubt that developing nations have a right to establish better living standards for their citizens, shape their infrastructure, and to alleviate poverty, but how this can be achieved without transgressing certain boundary conditions for environmental integrity in specific countries should increasingly be a matter for debate—and not for developing and emerging economies alone. All nations need to face a sea change in the coming decades under which priority shifts toward developing strategies for the sustainable management of resources, because the current economic paradigm tends to destroy our natural capital. Sustainability in this context means increasingly decoupling material input and consumption, far-sighted management of land and water, which includes the capacity of these resources to regenerate, and a less consumptive lifestyle for individuals. Nevertheless, even with perfect adaptation to the unavoidable consequences of climate change, accelerated global warming will constrain our steering options in the next decades considerably. Consequently, we need concerted action—action which helps to reconcile climate protection targets and development goals.

As a step in this direction, the participants of the Alexander von Humboldt conference in Bangalore 2011 brought together diverse expertise from their subject domains to discuss these challenges and explored the human capacity present in India and Germany for innovative and path-breaking research in the field of climate change. This volume integrates selected contributions addressing the various issues of social, economic, policy, and technological challenges related to a transition paradigm.

As a step in this direction, the participants of the Alexander von Humboldt conference in Bangalore 2011 brought together diverse expertise from their subject domains to discuss these challenges and explored the human capacity present in India and Germany for innovative and path-breaking research in the field of climate change. This volume integrates selected contributions addressing the various issues of social, economic, policy, and technological challenges related to a transition paradigm.

Potsdam, June 2013 Hans Joachim Schellnhuber

Message from Alexander von Humboldt Foundation

Maintaining a dynamic exchange of ideas and gaining new insights—this deep interest makes us human beings. Fostering und supporting people's scientific curiosity has been the Alexander von Humboldt Foundation's mission for 60 years now. Since its establishment in 1953, the Alexander von Humboldt Foundation sponsors top-level scientists and scholars from abroad who come to Germany with our fellowships and awards in order to work here in close cooperation with German colleagues. The fellowships and awards of the Alexander von Humboldt Foundation have earned a considerable reputation worldwide. We aim to support excellence and to create an expanding global network of cultural and scientific dialogue on the highest levels. Until today, the Alexander von Humboldt Foundation has sponsored more than 25,000 scientists and scholars from all over the world embracing over 130 countries and including 49 Nobel Prize winners. We never set any quota for countries of origin nor fields of research in the selection of future Humboldt fellows. Our only criterion is scientific excellence. So far, we have granted well above 5300 research fellowships and awards to excellent scientists and scholars from Asia, amongst them 1749 from India.

"Once a Humboldtian, always a Humboldtian"—from the very beginning this was the hallmark of the Alexander von Humboldt Foundation. The Humboldt sponsorship is enduring: the Foundation is a lifetime partner, maintaining the connections on a long-term basis through its alumni sponsorship programmes. Moreover, the Foundation encourages its alumni to undertake their own initiatives and collaborations across disciplinary and national borders. As a result, many Humboldtians make use of our extensive Alumni sponsorship programme. In this regard, in October 2011, the Humboldt Kolleg "Adaptive Management of Ecosystems: The Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change" took place in Bangalore. The Kolleg was hosted by Humboldt Alumnus Professor Dr. Sunil Nautiyal at the Institute for Social and Economic Change choosing a topic of major importance to the development in Asia. It served as a forum for scientific networking between Humboldtians and other young and experienced researchers. The Alexander von Humboldt Foundation especially appreciates Professor Nautiyal's initiative in the framework of the 60th anniversary of diplomatic ties between India and Germany under the motto

"Germany and India: Infinite Opportunities." Not only does this motto demonstrate the tight bonds of friendship existing between India and Germany, it is a friendship that exceeds the mere sphere of science and highlights the role of the two countries as global partners. It also holds the promise of further fruitful academic cooperation, which is being forwarded by initiatives such as the Humboldt Kolleg.

On behalf of the Alexander von Humboldt Foundation, I would like to thank Professor Dr. Sunil Nautiyal and the organizing committee at the Institute for Social and Economic Change, Bangalore, for their dedication and the initiative to conduct the Humboldt Kolleg whose scientific results are published, now. The Alexander von Humboldt Foundation is most grateful to its Humboldtians, who support our aims, our goals, and the next generation of researchers by living up to our motto "Once a Humboldtian, always a Humboldtian."—I wish you all the best of success and luck for your future plans.

February 2013

Dr. Judith Schildt
Asia Divison
Alexander von Humboldt Foundation
Bonn
Germany

Message from the German Consulate General in Bangalore

Climate change is one of the most difficult challenges facing humanity in the decades to come—with its effects already touching Indian livelihoods today. It is therefore most welcome that the presentations held at the International Humboldt-Kolleg in October 2011 in Bangalore on this subject are made available to a larger audience with this publication.

India, with its high population density, its rain-fed agriculture and its long coastlines, faces higher risks from climate change than most other nations. The effects of future sea-level rise, changes in the monsoon patterns or the melting of Himalayan glaciers threaten India's future development and the well-being of its citizens. I therefore, commend the Alexander-von-Humboldt alumni to have chosen to devote their 2011 Humboldt Kolleg to the impact of climate change, adaptation efforts and possible mitigating steps.

However, while India will need to undertake steps in adaptation and mitigation of climate change domestically, climate change is a global challenge and requires to be tackled globally. My own Government is fully aware of this and has set ambitious targets for Germany to mitigate climate change. This includes a reduction of 40% of its greenhouse gas emissions between 1990 and 2020, a cut of 20 % in its primary energy consumption from 2008 to 2020 and a share of 35 % of renewable energies in its electricity consumption by 2020.

Germany is also cooperating with India in its efforts to tackle climate change. Towards this end, Germany is supporting the work of the Indian Government's Bureau of Energy Efficiency, of the Ministry of New and Renewable Energy and of the Ministry of Environment and Forests. This support takes the form of loans, for example to launch new projects in solar energy, or of expert advice on issues such as analyzing solar radiation data. At the same time, a political dialogue takes place in the yearly Indo-German Energy Forum and its sub-groups, with a strong focus on renewables and energy efficiency.

It was an honour that the Humboldt-Kolleg could be organized in the prestigious Institute for Social and Economic Change. The Governor of Karnataka, H. E. Shri Hans Raj Bhardwaj and the then the Chief Minister of Karnataka, Shri D. V. Sadananda Gowda, graced the opening ceremony with their presence and remarks.

I congratulate Professor Dr. Sunil Nautiyal for his cooperative spirit and his strenuous efforts in putting this publication together. I wish him and his many contributors the large readership the publication deserves.

April 2013 Hans-Günter Löffler
Deputy Consul General of Germany, Bangalore

Contents

Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change: Prologue

Sunil Nautiyal, K. S. Rao, H. Kaechele, K. V. Raju and R. Schaldach

India and Germany, as a mark of 60 years of diplomatic relations between them, hosted year-long programmes in their respective countries during 2011–2012. To strengthen the relationship further, a Year of Germany in India was organised under the motto 'Infinite Opportunities—Germany and India 2011–2012' with the theme, 'StadtRäume—CitySpaces'. In this purview the International Humboldt Kolleg convened by Sunil Nautiyal at the Institute for Social and Economic Change, Bangalore, with the support of the Alexander von Humboldt Foundation towards strengthening the future research collaboration between Germany and India.

In the present context, anthropogenic climate change is a major concern from the perspective of long term sustainability. It is a common challenge faced by all the countries of the world. However, some of the developing countries are highly vulnerable to climate change effects as they do not possess adequate resources—both financial and otherwise—to cope with climate change (UNFCCC 2009). Therefore, our common aim should be to find solutions to mitigate climate change and but also to adapt to unavoidable consequences for conserving our planet Earth and to ensure a liveable environment to future generations.

S. Nautiyal (✉) · K. V. Raju
Centre for Ecological Economics and Natural Resources (CEENR), Institute for Social and Economic Change (ISEC), Dr. VKRV Rao Road, Nagarabhavi, Bangalore, Karnataka 560072, India
e-mail: nautiyal_sunil@yahoo.com

K. S. Rao
Department of Botany, University of Delhi, Delhi 110 007, India

H. Kaechele
Institute of Socio-Economics, Leibniz-Centre for Agricultural Landscape Research (ZALF), Eberswalder Straße 84, Müncheberg D-15374, Germany

R. Schaldach
Center for Environmental Systems Research (CESR), University of Kassel, Wilhelmshöher Allee 47, Kassel 34119, Germany

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_1,

The global climate pattern has been changing fast and observational evidence indicates that climate change in the 20th century have already affected a diverse set of physical and biological systems (IPCC 2001, 2007a). Scientific debates concerning the drivers of these changes have, over more than two decades of intensified research and discussions, reached the conclusion that there is no plausible explanation for the observed warming (of 0.1 °C per decade) for the last 50 years (IPCC 2007b) other than human activities such as the emission of greenhouse gases. With no changes in the current policy framework, the world appears set on a path of rising global temperatures of up to 6 °C, with catastrophic consequences on both the environment and livelihoods (OECD-IEA 2009). Even with respect temperature increases far below 6 °C, there is a broad consensus on the environmental challenges with far reaching implications for food production, natural ecosystems, freshwater supply and health care (IPCC 2007a). Climate change could also soon become a major security risk (WBGU 2008) in terms of large scale migration and conflicts over the existing resources (Reuveny 2007). Guiding the world through climate change effects and associated environmental uncertainties and maintaining its existing biodiversity may turn to be one of the most important political challenges of the 21st century. Our collective responsibility to effectively mitigate toughest climate change uncertainties requires global cooperation on an unprecedented scale (Stern 2009). The time frame available for avoiding potentially dangerous consequences is drawing to a close. In view of the fact that some of the industrialized economies have already started reducing emissions through a series of measures, the pressure has been increasing on the developing countries to agree to emission cuts of late particularly with respect to joint endeavours for protecting the environment. Many countries are still reluctant to commit themselves to legally binding CO_2 emission cuts mainly because of the lack of transparency observed in international climate policy. They have not adopted emission reduction targets so far, and as a result, the future impacts on the biological and physical systems of the planet Earth may turn out to become more catastrophic (UNFCCC 2009).

Climate change mitigation within the United Nations Framework Convention on Climate Change (UNFCCC), from Rio to Copenhagen (2009) to Doha (2012), has led to a set of policy responses. However, the present policy framework is dependent on reduction commitments/targets that the governments have agreed to; while keeping in view the opportunities for economic and social development. In the meantime, setting of reduction targets is driven by development considerations, i.e. it is for the governments to decide on the desirable reduction levels without compromising too much on economic development goals.

To help meet these reduction targets and also to make reductions more effective, there should be a degree of flexibility embedded in the mechanisms with a strong emphasis on international collaboration. The European Union (EU) has decided to follow a Burden Sharing strategy that includes all members of the Union which is highly appreciable. EU has developed an overall reduction scheme that while allowing some countries unable to reduce greenhouse gas emissions to benefit from Germany's reduction target of 21 % as compared to 1990 in the 1st commitment period of the Kyoto protocol (2008–2012). The German government has done very significant work in mitigating the potential threats associated with climate change. In this endeavor, Germany not only has reached the Kyoto target but aims at a 40 % reduction of greenhouse gases until 2020 as compared to 1990 through various instruments such as prioritizing renewable energy sources and also providing market incentives while moving ahead with the twin track strategy, for example, increasing renewable energy resources and reducing energy consumption through developing various energy efficient measures (European Commission 2007; WBGU 2008).

We strongly feel that a mechanism should be introduced for a functioning Emission Trading System that would limit the collective greenhouse gas emissions within certain regions so as to provide an opportunity for allocating tradable greenhouse gas certificates to enterprises. This is relatively well defined in the case of EU, but we need to do much more in respect of developing countries to help create incentives for innovations to save certificates that can be sold within the regions at national and international rates. Other mechanisms for increasing the efficiency of climate change mitigation measures include the so called Clean Development Mechanism (CDM), Joint Implementation (JI) and the newly established Green Climate Fund. However, the present policy does not sufficiently address a measurable environmental goal such as predefined atmospheric carbon content at a certain given time which, with a certain probability, can lead to certain climatic conditions (UNEP 2012). There is also a lack of enforcement element in the climate policy. Leading climate scientists today are convinced of the fact that our present political environment with regard to mitigating climate change effects is driving us into an unsafe future. We seek a process that facilitates a consolidated and contextualised understanding, evoking a strategic response from among the various key constituencies between developed and developing nations. This understanding can then bring differentiated roles/agendas in addressing and targeting short, medium and long term issues/benchmarks relating to climate change.

India, with a huge diversity in land, topography, climate and socio-economic conditions, is divided into 15 agro-climatic zones. Further, based on several indicators, such as water availability, soil types, rainfall and pattern of rain-fall, edaphic factors, land use and land cover, a total of 127 sub-zones (agro-climatic sub regions) have been identified in India mainly for carrying out location specific research and development projects at the micro level. Although, several climate models have predicted global and regional scenarios for climate in different parts of the world, however, the significance and practical implementation of such models at the micro level is yet to be validated. This leads us to the conclusion that research on climate change and its impact only at the national level may not be a sound approach towards adaptation and mitigation measures at the micro level. Therefore, this volume includes research results from across the disciplines in order to understand the patterns and processes of the complex adaptive systems linked to impacts of climate change.

The commonly agreed approach in case of Germany and India is based on the development methods and plans for preparing suitable strategies toward mitigation the threats related to climate change. First, this is in response to the suggestion made by India's Prime Minister and German Chancellor Angela Merkel to prepare a budget approach for climate action plans and the distribution of global carbon budget. Secondly, for combating potentially adverse impacts of climate change on food production, water supply, forestry and fisheries through adaptation and mitigation there is a need for an integrated interdisciplinary approach. India is highly vulnerable to projected climate change effects that affect millions in rural and urban areas, in addition to adversely impacting food production, water supply, fish production and forest biodiversity. Some sectors in Germany are also vulnerable to climate change that affects the relationship between human and ecosystems. Thus, there is a mutual need for developing and implementing programmes for adaptation and mitigation. Our joint endeavours should emphasize the following issues that need the involvement of State government, experts, institutions and stakeholders at national and international levels.

- Integrated efforts should aim at developing strategies for emission reductions, estimating vulnerability and uncertainties of different sectors on which peoples' livelihood is dependent and harmonising of development activities with respect to mitigation commitments.
- Efforts should be directed towards developing policies for livelihood sustainability and socio-economic development under projected climatic changes across agricultural landscapes of India and Germany. Considering Rural India as a key factor to coping with Climate Change is essential. Thus, there is a need for linking different agro-climatic zones of India to global problems. Technological support from Germany to India will further strengthen long term research programmes aimed at mitigating the potential threats of climate change.

In this light, the main objectives of this volume are: (i) to provide more meaningful ideas that help and support India's efforts towards handling climate change effects, particularly the implementation of Millennium Development Goals related to poverty and sustainable development; (ii) to promote effective two-way communication channels for enabling researchers to engage in integrated interdisciplinary research; (iii) to establish interdisciplinary research networks for carrying out integrated research towards strategies for the sustainable flow of ecosystem services and also for the economics of natural resource management, biodiversity conservation and sustainable livelihood in the context of changing climate. Issues related to traditional rights and the aspirations of people who are living in harmony with natural forested landscapes shall be discussed from the perspective of climate change; and (iv) to strengthen cooperation among researchers from different disciplines towards addressing the global climate change uncertainties.

We hope that the collection of research papers in this book will help developing better strategies to hybrid adaptation-mitigation responses, linking the 'science' and the 'practice' on the ground. Such efforts will certainly help increasing the resilience and coping capacity towards better policy formulation, policy implementation and policy assessment. This process should strategise to find entry points at national level and international level in order to plug into the preparation of multidisciplinary research, while linking into policy processes and integrating climate-smart socio-economic development concerns in the 21st century as a mitigation-adaptation hybrid response.

Prime Minister Manmohan Singh and Chancellor Angela Merkel had acknowledged the importance of the Scientific and Technological Collaboration (STC) for promoting a dialogue between scientists of both the countries. Based on the agreements signed by the two nations in 1971 and 1974, the collaboration continues to fund and support joint research projects, workshops, seminars and exchanges between universities and scientific organisations in India and Germany . To date, the collaboration has supported 1,000 joint Indo-German research projects, involving 4,000 scientists from both the countries. With inputs from both the sides, a total of more than 100 workshops have been completed and 1,500 scientific publications produced (Research in Germany online, p 1).

The International Humboldt Kolleg was inaugurated by the Governor of Karnataka, H.E. Dr. Hans Raj Bhardwaj and then Chief Minister of Karnataka, Shri D.V. Sadananda Gowda. Their presence had heightened the very spirit of the conference. We express our deep sense of gratitude to H.E. and Hon'ble Chief Minister for addressing the International Humboldt Kolleg at ISEC. We take this opportunity to express deep, sincere and whole-hearted thanks and gratitude to the Alexander von Humboldt Foundation (AvH) Germany and Hon'ble President Professor Dr. Helmut Schwarz, for giving us the privilege to organise an International Humboldt Kolleg at ISEC, Bangalore, India which culminated in to this volume. We extend our sincere thanks to Dr. Judith Schildt, Deputy Head and Programme Director, Division Asia, Alexander von Humboldt Foundation for her kind cooperation and whole-hearted support. We are thankful to Mr. Hans-Günter Löffler, Deputy Consul General, German Consulate Office, Bangalore for his kind support and cooperation. We are thankful to ISEC faculty and staff for their whole-hearted support and cooperation in organising this event.

References

Doha (2012) Doha Climate Change Conference, Nov 2012. http://unfccc.int/meetings/doha_nov_2012/meeting/6815.php

European Commission (2007) Communication from the commission to the council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions "Limiting global climate change to 2 degrees celsius—the way ahead for 2020 and beyond" COM(207)2; http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0002:FIN:EN:PDF

IPCC (Intergovernmental Panel on Climate Change) (2001) Third assessment report. Cambridge report. Cambridge University Press, Cambridge

IPCC (2007a) Climate Change: Impacts, Adaptation and Vulnerability. Contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, USA

IPCC (2007b) Climate Change: The Physical Science Basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, USA

UNEP (2012) The Emissions Gap Report 2012. United Nations Environment Programme (UNEP), Nairobi

OECD-IEA (2009) World energy outlook 2009. pp 1–696

Research in Germany (online) India and Germany—strategic partners for innovation. http://www.research-in-germany.de/dachportal/en/downloads/download-files/68324/india-and-germany.pdf)

Reuveny R (2007) Climate change-induced migration and violent conflict. Polit Geogr 26:656–673

Stern N (2009) The global deal. Bodly Head, UK. UNEP 2012. The emissions gap report 2012. United Nations Environment Programme (UNEP), Nairobi. http://www.unep.org/publications/ebooks/emissionsgap2012/

UNFCCC (2009) Decision 2/CP.15 Copenhagen accord. http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf#page=4

WBGU (2008) World in transition—climate change as a security risk. Earthscan, London

Accepting Climate Change Challenges: Gambling with the Future or Path-Finding for Long-Term Sustainability?

J. P. Kropp

1 Introduction

In recent 20 years, plenty of progress has been made in regard to climate impact and global change related research. While scientific knowledge about the unbridled process of global warming and its associated impacts has increased tremendously, societal and political responses to this challenge seems to be uncoordinated and not target driven. The failure of certain UNFCCC climate conferences (COPs) in discussing binding emission reductions is only one indication of this particular fact. Nevertheless, humanity is facing even more challenges in the 21st century. For example, marine resources are overexploited, tropical rainforests are disappearing, and fresh water resources are depleting (Ehrlich and Ehrlich 2013). While these processes alone cause gigantic problems, climate change will worsen and accelerate other processes like species extinction or vegetation change (cf., e.g. for fisheries: Perry et al. 2005; Brander 2007; Wernberg et al. 2013; vegetation change: Galbraith et al. 2010; Gottfried et al. 2012). Although the management of common property resources is difficult (cf. Eisenack et al. 2006), problems like overexploitation of natural assets can be solved regionally by establishing cooperation mechanisms (cf. Vollan and Ostrom 2010), however, the climate threat could add additional pressure to these life-supporting systems. Thus, climate change will define additional constraints for management regimes making the urgency for international climate agreement clear. Concerning international activities in climate research and climate policy, two different activities are prominent: (1) the negotiations about acceptable carbon budgets and burden sharing among countries (cf. e.g. WBGU 2009; Costa et al. 2011; Steinberger et al. 2012) and (2) insufficient research

J. P. Kropp (✉)
Potsdam Institute for Climate Impact Research, P.O. Box 601203 14412 Potsdam, Germany
e-mail: kropp@pik-potsdam.de

J. P. Kropp
Department of Geo- and Environmental Sciences, University of Potsdam,
Am neuen Palais 10, Potsdam, Germany

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_2,

on adaptation, unharmonized adaptation actions, and the establishment of adaptation funds, which shall support adaptation to the unavoidable consequences of climate change. Certainly, these discussion threads are not independent. As negotiations about internationally binding carbon emission budgets failed, stakeholders and policymakers began to focus on adaptation. The reasons are quite simple. While the reduction of atmospheric greenhouse gases (GHGs) is an undertaking whose benefits are associated with the global civilisation in coming decades, adaptation can create immediate effects on a local scale. However, another point is important in this context. Looking into human history, adaptation was undoubtedly a need during the past millenniums, otherwise homo sapiens would not have survived. Thus, adaptation is well rooted in our history and therefore is vital as response to changing environmental constraints. Adaptation can also be understood as an activity that makes use of our environment, i.e. for food production, ore exploitation, etc., although human history show that civilizations may fail to respond adequately. Examples are e.g. the breakdown of the Maya or the disappearance of the Khmer culture (cf. for example, Haug et al. 2003; Buckley et al. 2010; Medina-Elizalde and Rohling 2012; Kennett et al. 2012).

Considering these facts one question is still unanswered, namely whether mankind can draw the right conclusions from this kind of failed adaptation, even though nowadays the situation has changed completely in comparison to ancient times. Today, environmental problems are no longer local and in some regions environmental constraints are already changing very rapidly. Thus, an alteration of societal thinking in regard to resource utilisation is urgently needed. Despite these circumstances, past experiences show that humankind is primarily applying a trial and error process in terms of adaptation, instead of developing clear environmental targets in regard to sustainable resource use and climate protection. Mid- to long-term forward looking decision making does not yet exist and consequently adaptation has taken a major role in political responses in regard to the climate change challenges. The question must asked: why do we think that regional adaptation, which needs huge local cooperation and only allows limited concerted action on national or international level is suitable to take care of as safe future for human civilisations? The answer is that climate change became not only a scientific problem, but a political problem as well. Certain countries start from different points in the “climate game”. Due to the accumulation of greenhouse gases (GHG) in development economies, which is substantially less in comparison to industrialized countries, developing economies requested for compensation for expected or experienced damages. From a short-term oriented point of view this is understandable, because development economies argue that they have only a minor responsibility for the current GHG emissions. Nevertheless, such a strategy will not help the global civilisation in terms of the need to really make progress in regard to the sustainability transition. Up to now neither industrialized nor developing economies have any real answers how a transformation to a low carbon economy may look like and how national policy making can support or accelerate such a process. For example, although India invested a lot in low carbon development, actual policies are insufficient to contribute to an achievement of the 2 °C target (cf. Singh 2011). Moreover, recent policy plans to bring more than 450 coal fired plants on the grid (Ehrlich and Ehrlich 2013). Among some of the OECD countries, nations like Germany, Australia or Japan decided to implement energy turnarounds ("Energiewende"), but it is foreseeable that these efforts are by far too small to achieve the necessary, but ambitious climate protection. Concerning the time scale for climate action which is still around one decade, the postponing of necessary decisions and therefore a wait and see strategy is not an option, but may lead certain subsystems of the entire earth to the brink of collapse.

2 Are We Asking the Right Questions?

This rough description of processes is, of course, insufficient, because it is clear that we do not live in a homogenous world, e.g. with the similar livelihood conditions. In contrast, we observe large disparities over the entire earth in terms of livelihood conditions and development levels. While livelihood tries to define limits for a safe life for individuals, development policies often address the social and technological levels of societies and both facets of human life may be affected by climate change. However, we still need to ask the question, whether there is a need to bring all people to a similar livelihood or development level? This is a question which is clearly connected with the transition challenge. The simple copying of westernized lifestyles seems to be not an option. It is a fact that development agencies discover adaptation as a field for action causing huge investments in this area, but is it feasible that we tackle development and climate change adaptation challenges by such a strategy? At least some doubts remain because similar livelihoods have never existed everywhere on the earth and would not be desirable. This will, of course, neglect regional and cultural specificities. The central challenge is that any individual must have access to a sufficient amount of life supporting resources and how this associates to the exploitation and utilization of resources. There is a scientific debate about how to measure and define a sustainable lifestyle including the sink function of the atmosphere (cf., e.g. Bohringer and Jochem 2007; Dietz et al. 2009; Roy and Pal 2009). Is this, for example, a westernized lifestyle associated with cyclic resource use, or that of the people of Bhutan focusing more on individual happiness associated with less resource consumption?

Concerning these discussions, it is remarkable that our recent life-styles and even our development level are still dependent on fossil fuel use (Costa et al. 2011). A clear linear relationship has been identified clarifying the fact that transitions to low carbon societies are still pending in industrialized and developing countries (cf. Fig. 1).

Thus, the two unanswered questions still remain. First, how can we decouple our lifestyles from resource consumption. Second, how is it feasible to transform societies to low carbon societies. At the first glance both questions point in similar directions, but the problems are more difficult. While the first question can be

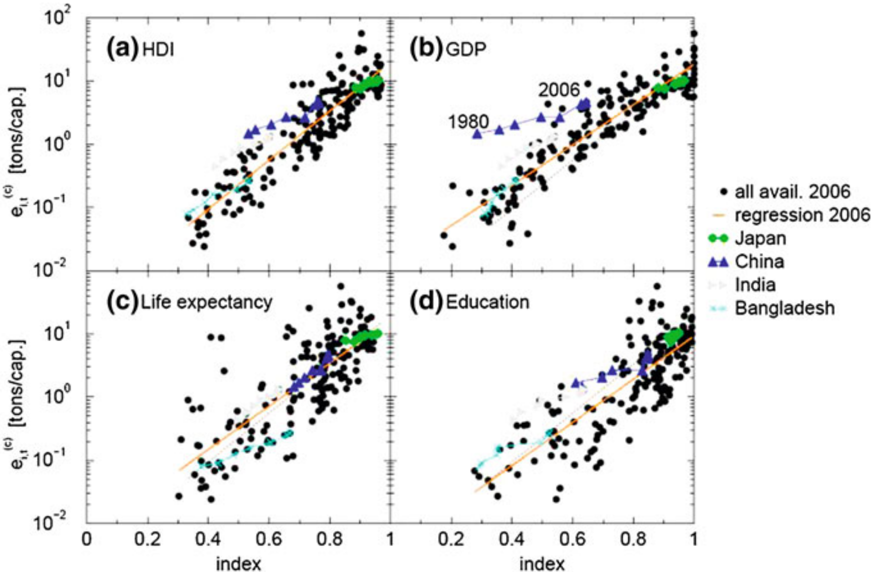


Fig. 1 Correlations between per capita emissions (CO_2) and the Human Development Index and its components. *Panels* **a–d** are cross-plots in semi-logarithmic representation, where each *filled circle* represents a country. **a** CO_2 emissions per capita versus the corresponding HDI values for the year 2006 (172 countries). **b–d** Depict the analogous for the HDI components, The Panels also include the trajectories (1980–2006) of Japan (*green*), China (*blue*), India (*grey*), and Bangladesh (*cyan*). For some countries, e.g. China, Japan efficiency gaining is observable, because the slope of the country trajectories is decreasing. For details cf. Costa et al. (2011)

answered via technological progress, e.g. via efficiency gains or the implementation of a circular flow economy, the second question requests nothing more than a new societal idea for the 21st century, i.e. people need to accept a completely new and sustainable lifestyle. Such societal changes are much more demanding than any technological challenge, because it needs time for implementation. Obviously, the latter challenge—how to transform societies—is not in the foreground of policy makers. As a consequence, adaptation is introduced as a kind of universal remedy. And it is not astonishing that development organisations like UNDP, GIZ, USAid, DFID, and others discovered that climate change may lead to hardships for everyone on the planet. Their major answer to climate change related challenges is adaptation. Nevertheless reviewing recent activities it must be stated here that a lot of these activities are often uncoordinated and less efficient in regard to the underlying root cause of climate change (cf. Ehrlich and Ehrlich 2013). In addition, very often climate change is used as an additional argument in order to support development action which is needed anyway, i.e. whether an action is motivated by climate change or not is indistinguishable from current management practices (cf. de Bruin et al. 2009). Consequently, development organisations try to influence climate policy and negotiations by putting adaptation into the center and often arguing that climate change may threaten official development aid, development successes and

Table 1 The systematic analysis of the ci: grasp adaptation database (www.ci-grasp.org) showed that for certain sectors the time horizon from the starting point until the finalization of an adaptation activity is around one decade (cf. for details Costa et al. 2013)

Adaptation sector	Understanding	Planning	Implementation	Average duration
Agriculture				
Soil conservation	–	4 years	5 years	9 years
Irrigation	2 years	2 years	3 years	7 years
Crop changes	2 years	2 years	5 years	9 years
Coastal adaptation				
Land use planning	2 years	–	8 years	10 years

will hit the poorest and marginalized people disproportionately (cf. OECD 2005; WB 2006). For development agencies this point of view is coherent, because they understand any process that improves the living conditions of the poor as adaptation, while climate change adaptation deals with the coping of the unavoidable consequences of climate change. Thus, is it appropriate to integrate adaptation, mitigation and development challenges? At least this is debatable. Some striking aspects of all adaptation activities are that a sound scientific basis for adaptation related research does not yet exist, the coordination efforts for any of these activities are at least similar to those of the climate negotiations, and it is foreseeable that climate funds will never be sufficient to solve the climate and development dilemma in parallel. Consequently, one mandatory prerequisite to the needs being fulfilled is comparable impact studies, which can answer the following: which regions or sectors are hit most by certain climate impacts and where consequently, adaptation funds can be utilised most efficiently. Thus, it is questionable whether an uncoordinated equal distribution of funds—even in developing countries—will lead us to a safe and sustainable world. Moreover, adaptation is often also understood as a learning process. This needs time (cf. Table 1), time which we do not have (cf. Peters et al. 2013), or in other words, a one-eyed orientation towards adaptation may disregard obvious solution options to the problem, which is to reduce greenhouse gases. Thus, adaptation without a clear orientation towards climate related problems will be less constructive. The real endeavor is not (economic and/or livelihood) equity for all, it is fairness in the international climate debates. Equity and fairness have similar meanings, but discussing them in detail make clear that there are differences and how far away we are from a real solution to the climate crisis. Equity is often applied in approaches dealing with the distribution of emission budgets among countries (WBGU 2009), fairness should recognize the different development stages, or even social targets, of the countries in regard to future transition pathways (cf. Costa et al. 2011), because economic growth is still on the top of the agenda of developing countries. Thus, although we need to change the neoclassical growth idea, this will not happen on a suitable time span, i.e. for a sustainability transition we need to make compromises.

3 What Happens When Westernized Lifestyles Spread Over Entire Planet

It is well-known that the westernized lifestyles consume resources and influence environmental quality. Rockström et al. (2009) showed that humanity is transgressing several physical boundaries of the entire planet already and made suggestions for binding thresholds. Economic growth, which seems to be our holy paradigm for human welfare, is a dearly bought advantage through the exploitation of human labor force in poorer countries and the utilization of cheap renewable and non-renewable resources from these countries. UNEP (2011) estimated that unsustainable lifestyles may triple resource consumption by 2050. Concerning four groups of resources, i.e. construction minerals, ores, fossil fuels, and biomass, UNEP (2011) suggested not to transgress 5–6 t/cap/yr. However, detailed analyses show that the intensity of resource consumption shows large regional disparities. In particular, the development status and population density seems to be important. It was stated that densely populated countries need fewer resources per capita for the same standard of living. This could be a spatial scale effect, which was also observed by Bettencourt et al. (2007a, b) for cities, but we need to be careful with hasty conclusions, because he showed also that there is a difference between basic and lifestyle related needs. However, focusing on certain countries the resource consumption differs broadly. While the global average is 8 t/cap/yr, i.e. above the UNEP suggestion, Canada consumes 24 t and countries like India or China consume 4 t/cap/yr. In particular, India or China show an overproportional economic growth that decreases environmental quality and resources and these examples make clear that changes are needed. Before one can decide to change policies or to apply readjustments one needs to measure the actual status of a country. Kuznets (1955) proposed an autonomous dynamics that during certain development stages environmental quality first decreases and then, after a considerable welfare level is attained (e.g. measured by gross domestic product (GDP) per capita), environmental consumption decreases (Kuznets hypothesis). This implies that for development, environmental quality is consumed for an increasing gross domestic product, while after the achievement of an acceptable livelihood level, technological progress cures environmental damages although GDP is still increasing. The problem with concepts like this is that they are valid for certain sectors or regions, but as a generalisation the concept is worthless. One reason is that it relies on GDP which measures just the value-added of an economy, but does not count for the costs of economic activities. Therefore, the development of more sophisticated indicators for global welfare was recently suggested (Fleurbaey 2009; Stiglitz et al. 2010), but not undisputed (Noll 2010). A temporary approach, before these suggestions will come into force, is therefore the idea to include the costs of environmental damages via emission trading which gives atmospheric pollution a price. Unfortunately, it has been not feasible to establish a global framework so far, thus the potential of such an instrument is less efficient than expected. Moreover, in the European Union the price for emission

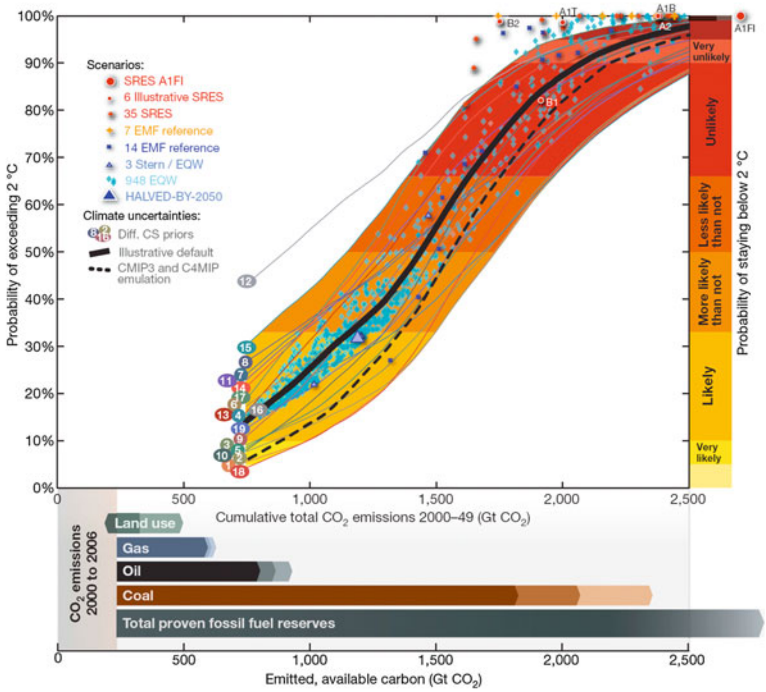


Fig. 2 The overshooting likelihood for a 2 °C warming versus CO_2 emissions in the first half of the 21st century. **a** Individual scenarios and smoothed (local linear regression smoother) probabilities for all climate sensitivity distributions (*numbered lines*). The proportion of CMIP3 AOGCMs26 and C4MIP carbon-cycle model emulations exceeding 2 °C is shown as *black dashed line*. Coloured areas denote the range of probabilities (*right*) of staying *below* 2 °C. **b** Total CO_2 emissions already emitted between 2000 and 2006 (*grey area*) and those that could arise from burning available fossil fuel reserves, and from land use activities between 2006 and 2049 (median and 80 % ranges). For details cf. Meinshausen et al. (2009)

certificates decreased to approx. 3 €/t (January 2013) as a result of too many certificates being on the market, which was caused by policy makers being afraid of overly negative effects for energy intensive industries. However, except for a few carbon trading systems, pricing concepts for environmental damage are still in their infancy. In order to support policy-makers, science can provide more valuable insights anyway by clarifying how the global (human) dynamics in certain sectors/region may threaten options for a safe life. Considering climate change we can clearly link this to the 2 °C target which keeps us away from the dangerous consequences of climate change (Fig. 2, cf. Meinshausen et al. 2009). For example, looking with more detail at other prominent sectors like food production, the dynamics of food production show alarming signs. It is undisputed that one result of the “green revolution” was to nourish millions of people and reduce the risk of hunger globally. Nevertheless, it is also a fact that the calorie intake shows quite different pattern globally. Moreover, food trading causes a lot of side effects, e.g. highly efficiently produced food in the OECD whose unusable components are exported to developing nations destroying local markets and income options there. The globalization of agriculture in fact produces enough food, but that food is not equally distributed over the entire world. Moreover, economic and often not human needs drive this market. These economic needs utilize nature in an unsustainable way neglecting environmental damages.

What does this have to do with climate? Detailed analyses of long-term FAO food data shows good news, i.e. low calorie diets are decreasing, but in parallel there is a tendency towards high calorie diets and moreover new nourishing styles have emerged (Prajal et al. 2013). Considering these mechanisms, which are mainly driven be lifestyle changes, it is likely that this progress will result in a tripling of the emissions from the agricultural sector (cf. Fig. 3).

Unfortunately this is not the end of the story, because the real attribution of emissions from certain sectors is hard to estimate. The globalization of markets, trade activities and the associated transport implies that any product has an additional backpack of embodied emissions (Steinberger et al. 2012) and thus, more sound assessments for emission surveillance and reporting are needed. However, previous sections showed that lifestyles and material consumption forces climate change and that combating climate change is one cardinal question for a safe future. The question is how we would like to live in the future and what we need to do to achieve this?

Another example is the debate on future urbanisation which is currently a hot topic in science. It is estimated that approx. 50 % of the global population was living in cities by 2008 and is likely that this growth will proceed at an

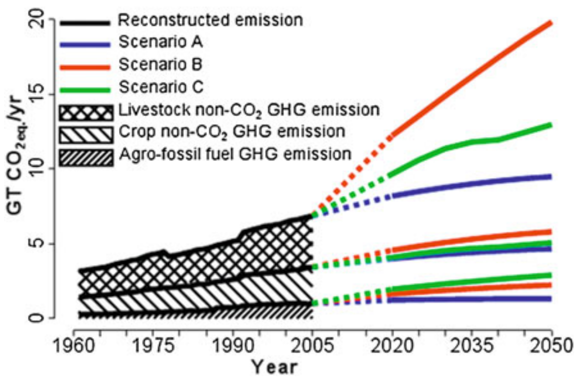


Fig. 3 Reconstructed and projected global total agricultural GHG emissions for three certain scenarios (*A* population growth only, *B* population growth and changes in dietary patterns, *C* change in population, diets and technology and management of agricultural land use). The total GHG emissions are decomposed into non-CO_2 GHG emission from livestock and crop and CO_2 emissions from use of fossil fuel in agriculture. The IPCC (2007) estimated a GHG emission from agriculture between 5 and 6 Gt CO_2. Considering changes in lifestyles and in the production style may lead to a tripling of agricultural emissions by 2050 (cf. Prajal et al. 2013)

unparalleled pace—mostly in developing countries. Moreover, it is estimated that cities are also responsible for approx. 80 % of the global emissions (UN 2007; Duren and Miller 2012). Other authors argued for a more detailed view and would not blame cities for their high emissions (cf. Dodman 2009; Satterthwaite 2008) and showed that in a lot of cities emissions are lower than those of the respective countries. Nevertheless, taking into account that cities concentrate human life, we need to discuss their climate relevance in the light of achievable sustainability. Cities are the location of human welfare, productivity, creativity, but also center of large social and economic disparities. It is still open whether sustainable cities are feasible or not and which kind of constraints we need to implement to get there. It is nothing more than the combination of two endeavours, i.e. how to develop an optimal city in physical terms and how to transform urban societies (cf. above). Unfortunately, due to the complexity of urban systems, it is not easy to define common planning and sustainability goals for cities which can diverge. For example, the heat wave burden from urban heat islands, which impacts human health in cities can be reduced, e.g. by introducing more open spaces, greens or white roofs (Lissner et al. 2012; Schubert and Grosman-Clarke 2012), but in parallel that may cause more traffic due to longer travelling distances, which could further increase emissions. In addition, systematic studies on cities performed by Bettencourt et al. (2007a, b) showed interesting effects for cities of certain sizes. It was emphasised that infrastructure volumes, like road surfaces, length of power grids, etc. grow sub-linearly with population and size, e.g. showing that cities really do provide a scale effect. Essential needs like water, housing and employment show a clear linear relation in regard to the population. The most important finding was that wealth volumes in terms of patents, electricity consumption, wages, bank deposits, etc. grow super linearly with the population. In particular, these latter points represent lifestyle changes and associated economic growth processes. What does this imply when discussing climate change? Hence for sustainability questions we need to define our analytical approaches carefully and with a systematic focus in order to assess gross effects. Coming back to food production, in this regard we can combine this with the challenge of emission reductions in cities as well. Which effects can be employed is shown by a study for the United Kingdom (Smith et al. 2005) making clear that food transport accounts for 25 % of all heavy goods vehicles causing 19 million tons of CO_2, while the overseas mileage for food transport is approx. four times higher than the UK mileage for ground transport. Transport of food by air has the highest CO_2 emissions per ton and is the fastest growing mode (140 % 1992–2002). Thus, emissions of CO_2 from the food transport sector are highly significant and growing. It can be assumed that this holds for other countries in a similar way. Consequently, it is obvious that more local food production may reduce transport emissions in this sector, but one need to assess how large the potential for urban food production really might be.

Kriewald et al. (2013) developed a methodology which describes urban regions and its hinterland as so-called urban-bioregions. By combination of certain databases, e.g. GRUMP population data, GlobCover land cover data, it was feasible

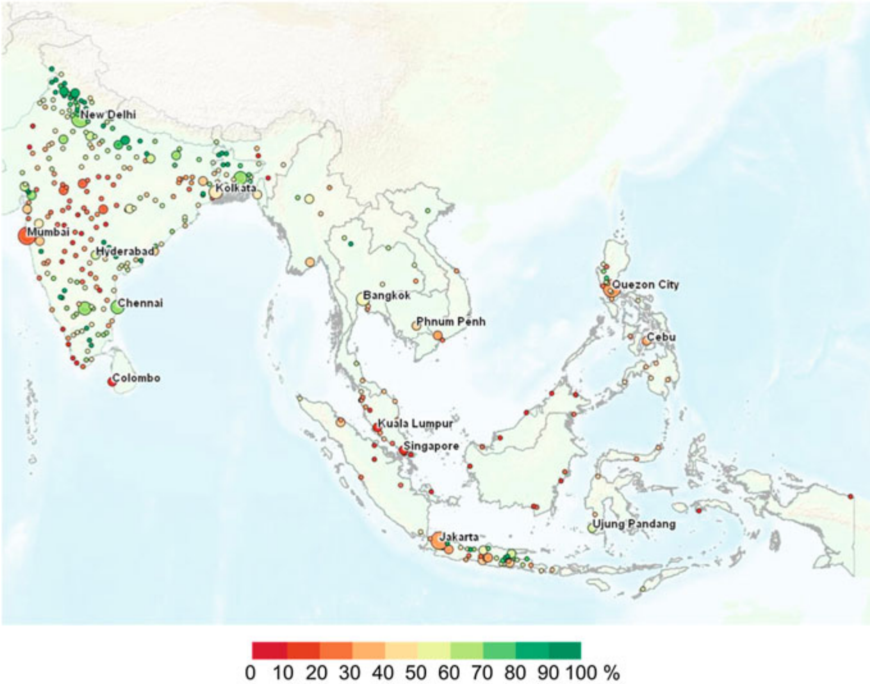


Fig. 4 Carrying capacity for the South–East Asian Urban-Bio-Regions. The *bullet* size represents the size of a region, while the *color coding* indicates how much of the urban region can be nourished by the urban hinterland under current climate conditions. In this case the maximum achievable yield is calculated (cf. Kriewald et al. 2013). For a huge amount of cities food can be produced in the direct vicinity of a city, which would reduce emissions from transport considerably. For large agglomerations like Delhi, Kolkata or Chennai more than 70 % of food needs can be sustained by the urban hinterland. Note that the calculation consider current dietary patterns and land use

to detect urban agglomerations and their hinterland automatically, by applying the city clustering algorithm (Rozenfeld et al. 2011). The advantage of this approach is the consideration of actual urban (mega-) regions, i.e. not only administrative entities. This is essential, because the effects of urban regions is not isolated to single cities (administrative entities), but to urban agglomerations, e.g. greater Mexico City, Greater London, Greater New Delhi, etc. In a second step the urban hinterland and its agro-potential is systematically estimated (cf. Kriewald et al. 2013, for details). Considering the current land use it is easy to calculate the potential for peri-urban food production under current and future climate constraints. As a result, the approach provides a systematic overview of the nourishing potential of cities by its hinterland (Fig. 4).

Concerning a reorganisation of cities in terms of their food allocation, a considerable amount of greenhouse gas emissions from transport can be saved by such an approach. Moreover, the closing of material cycles is also feasible, e.g. for

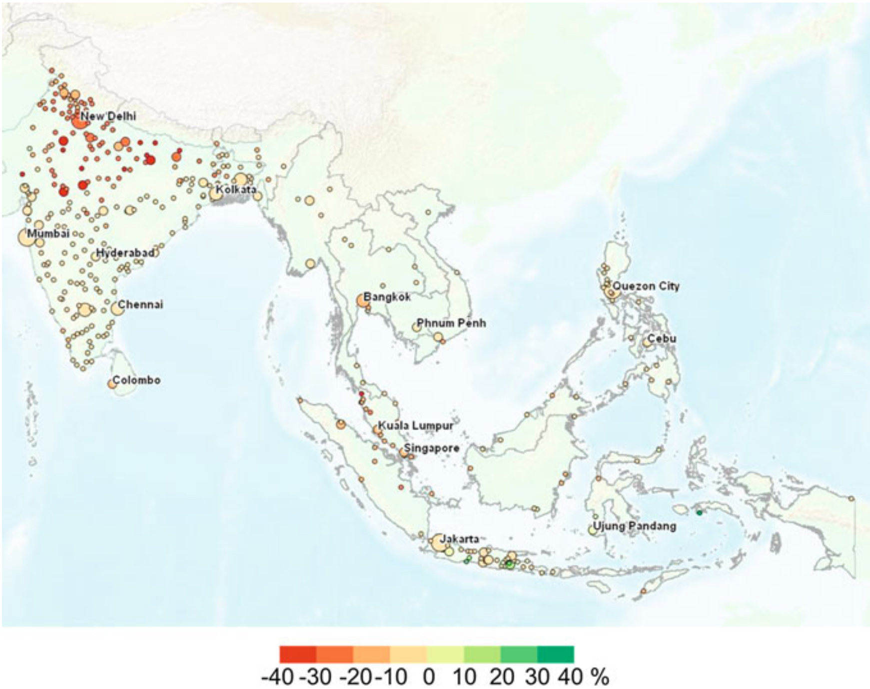


Fig. 5 Change of the carrying capacity in case of climate change in the year 2050 considering the A2/ECHAM4 scenario. Globally can be stated that approximately 80 % of urban-bio-regions will face a decrease in agricultural products', while most of the benefiting cities are located in the northern latitudes. In comparison to this situation the cities on the Indian subcontinent will suffer most from decreases in agriculture, for certain regions up to −40 %. Again the calculations refer to actual diets and actual land use (for details cf. Kriewald et al. 2013)

urban waste, which can be used as fertiliser in the urban-bio-regions. As shown by this example, a critical review of our current urban life, supply and demand chains is needed not only in regard to the food supply problem, but also in regard to water, energy and consumption. Solutions are feasible, but need a change in our urban life paradigm. Such an approach shows how adaptation and mitigation can be reconciled efficiently in order to create win-win effects.

That such ideas could have a stimulating effect for the climate negotiations is shown in Fig. 5. In case of the A2 scenario (SRES 2000) the potential for urban food production may change tremendously. This will hold, in particular, in the Indo-Gangetic-Plain, which is one of the most productive region worldwide in terms of agriculture. In addition, detailed analyses show that for most of the cities in SE Asia, urban hinterland is already is used for agriculture, i.e. an extension of urban agriculture is not really an option. Thus, when climate changes affects agriculture, these regions may approach their environmental limits, i.e. neither extension, nor irrigation may be a solution for agricultural adaptation.

4 Managing Transitions and Making Them Happen

In the previous sections the multi-dimensionality of climate related challenges has been discussed. It was shown that implemented actions need to consider this as well, and that one-sided orientation, e.g. on adaptation, will not solve the problem in general. Peters et al. (2012) stated that an annual mitigation rate of approx. 3 %/yr is needed in order to keep global warming below 2 °C. The time horizon to take action for a safe future is less than one decade (WBGU 2009). Nevertheless, a concerted action is needed and a fair and clearly defined labour share between mitigation, adaptation and development efforts. This implies that clear climate related targets need to be defined, which should not be superimposed by other political goals.

Adaptation to climate change is needed for particularly risk prone areas, but should clearly focus on unavoidable consequences related to climate change. The mixture of unclear adaptation and development targets are not productive in terms of tackling climate challenges. Moreover, the needed national/international coordination for adaptation activities, which combines senseful risk minimization with adequate climate protection in an optimal case, makes it at least debatable whether adaptation alone is an adequate response strategy to address global climate change challenges. In addition, to avoid that adaptation efforts are not being negated by an accelerated climate change implies that our attention should turn to the core problem first, namely to constrain greenhouse gas emissions (cf. WB 2012). Costa et al. (2013) estimated the time horizons of certain adaptation measures (Table 1). He found that adaptation activities often last around one decade before they are finalized. This decade can be better used when focusing more on emission reduction agreements.

On the other hand we have to recognise that the international negotiations regarding ambitious climate protection fail. The major outcome of the recent Doha conference of the United Framework Convention of Climate Change (COP18) was the agreement for a second commitment phase of the Kyoto Protocol through 2020. How the world’s two biggest greenhouse gas emitters—China and the United States-will be integrated is still an open issue. Moreover, it was agreed to work toward a universal climate change agreement covering all countries from 2020, to be adopted by 2015, and to find ways to scale up efforts before 2020 beyond the existing pledges to curb emissions. This is still a weak compromise because it does not take into account that we need to take action as soon as possible in the upcoming decade.

Why it is so difficult to implement an agreement? Despite the 2 °C target agreement equitable and fair burden sharing, i.e. in terms of national emission budgets, is generally unsolved. While development economies are still pointing out that they need to develop, the OECD mention that global civilization will never meet the targets without having the upcoming and existing larger emitters in the developing world on board. Of course, both is true, but what can be the way out of this trap? First, we have to ask how to account for the responsibility of developed countries regarding historical CO_2 emissions (WBGU 2009). Second, it is essential to determine to what extent technological and political inertia impose limits to the range of strategies envisioning the implementation of reduction schemes. For developing countries, social and economic development is of particular importance. In order to tackle these challenges, the CO_2 allocation and reduction approach should rely on the Human Development Index (HDI, cf. UNDP 2008) or on other more advanced measurements of global welfare (e.g. Genuine Progress Indicator (GPI), cf. e.g. Lawn 2003). The idea for why we make this suggestion is the following. Developing countries can gain certain benefits from fossil fuel use for their own economic growth. This neoclassical growth is (for the moment) the major forcing factor for development progress and cannot be changed immediately. For example, a mine worker in India gains a monthly salary of around 2,000 Rupees and India has a huge amount of domestic coal. The utilization of these resources provide an enormous economic surplus. But it is needed to take care of development issues. Thus, developing countries can take benefits from cheap energy, but need to implement transition plans to low carbon societies, when the country transgresses the 0.8 HDI, the official level for an OECD country.

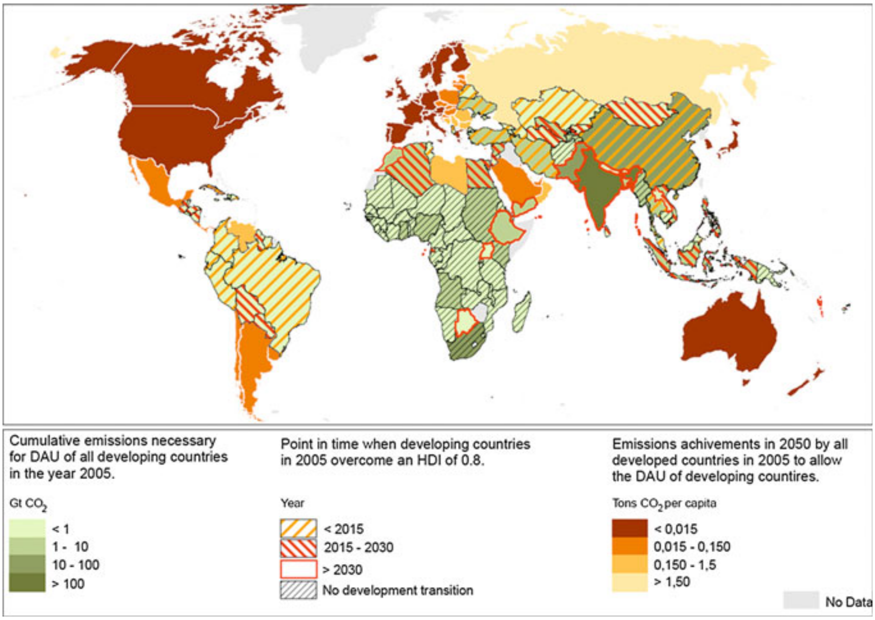


Fig. 6 Global distribution of allowed emissions for a development as usual scenario from developing countries (*green shading*) and per capita CO_2 targets in 2050 for developed countries (*brown shading*) under the proposed framework to keep temperatures *below* 2 °C target, i.e. 1,000 Gt CO_2 with a 25 % overshooting probability (cf. Meinshausen et al. 2009). The period in time when developing countries are expected to reach an HDI of 0.8 is represented by the colored hatches and frames. For several countries, mainly in Africa, not development transition will be achieved before 2050 (cf. Costa et al. 2011 for details)

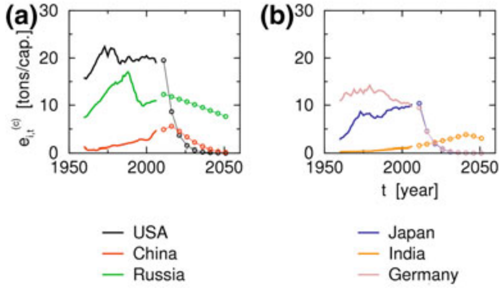


Fig. 7 Examples of extrapolated CO_2 emissions per capita in agreement with the proposed reduction concept shown in Fig. 6. *Solid lines* stand for the historical emission while the *connected circles* represent extrapolated emissions when countries follow the reduction needed reduction schemes (for details cf. Costa et al. 2011). While USA, Japan and Germany have to implement rapidly, India has time, approx. until 2040 and China until 2018

Taking this into account introduces fairness in regard to historical responsibility, but also equity, because it considers the technological development level of a country (cf. Fig. 6). The whole framework keeps the global climate below the 2 °C target until 2050. We would not state that this strategy is the only option, it can, for example, be accompanied by an efficient and transnational emission trading scheme (ETS) in order to achieve emission goals faster. However, the suggested approach shows transition pathways for countries, which will work (in principle) without emission trading and international funds for ambitious climate protection. Countries can develop their one energy strategy and have the possibility to use fossil fuel until the approach of 0.8 HDI, which offers developing countries more time for action (cf. Fig. 7). Such a suggested framework can pave a road towards an internationally binding agreement on carbon dioxide emission constraints because it includes implicitly the welfare question, which is clearly connected with the availability of cheap energy in developing countries. Nevertheless, the suggested framework puts additional pressure on the OECD countries.

Taking the climate challenge seriously and considering the fact that we still have around one decade to constrain global warming to an acceptable level, we still need additional instruments which may help to accelerate humanity's response capabilities. In comparison agreements under the rooftop of the World Trade Organisation, which establishes patent free zones for least developed countries for AIDS and Malaria pharmaceuticals, it is also imaginable that similar for zero carbon technologies can be implemented. Such an agreement would have immediate effects on emissions and money from ETS systems could help to fulfil compensation for the respective patent holders. This would be much more efficient as uncoordinated investments, e.g. in regional adaptation or afforestation.

5 Summary

It was shown in this contribution that the current political debates about climate change related challenges is mainly about climate funds and adaptation. It seems that the reduction of GHG play a only role during annual climate conferences (COPs). One reason why this happens is, of course, the failure of these conferences to come to binding agreements about carbon budgets. Nevertheless, this is a dangerous development because adaptation cannot guarantee a safe and climate proof development. It is acknowledged that the Green Climate Fund can play an important role in avoiding social disruptions which may potentially be caused by climatic threats, however, a clear prioritisation of activities is needed. In parallel it must be emphasized that current negotiations about carbon budgets need more dynamics in order to open paths to further options. This can be the smart handling of intellectual property rights for low carbon technologies, global strategies for future near-city food production, or by new budget approaches that recognize development levels and recent responsibilities. Concerning the interwoven aspects of adaptation and mitigation, clear climate related targets should be defined, i.e. the success of these actions should be measurable and quantifiable in terms of their "climate efficiency". This is important, because it can be expected that both, the climate negotiations and the implementation of adaptation will need at least a decade. A precondition for any of these activities is that science provides comparable impact assessments in the sense that policymakers can really decide where it is necessary to invest funds most efficiently.

Nevertheless, for humanity it is an ethical decision whether avoid the transgression of dangerous planetary boundaries keeping us in a range of acceptable changes or whether to take the risk of serious disruptions. Focussing on the latter decision, this bears a resemblance to a wait and see strategy. From the position of a local stakeholder it is understandable that adaptation is much more desirable as a response mechanism. Adaptation may help them to find local solutions, but most of them will not solve or support solving the major underlying problem, namely global warming. Mitigation should as well be in the focus of local decision makers, because several examples show that GHG reduction will reduce the risk of local damages considerably.

Science has made tremendous progress regarding the understanding of global processes and we are now entering a phase where scientific models can go down to smaller scales in order to calculate potentials and effects for regions. This allows the performing of more explicit assessments and helps highlight options for development or concrete solutions and opens time corridors for action. Humanity needs to come to a decision mode which proactively operates on sustainable options instead of just responding to recent experiences. In such a case, humankind is able to keep climate change related consequences to an acceptable level, when world leaders would like to do so.

Acknowledgements The author acknowledge the financial support of the German Federal Ministry of Education and Research (PROGRESS, Grant #03IS2191B) and Ministry for Environment, Nature Conservation and Nuclear Safety (International Climate Protection Initiative). We wish to thank L. Costa, S. Kriewald and P. Pradhan for their support during the preparation of this manuscript.

References

Bettencourt LMA, Lobo J, Helbing D, Kuehnert C, West GB (2007a) Growth, innovation, scaling, and the pace of life in cities. Proc Nat Acad Soc 104:7301–7306

Bettencourt LMA, Lobo J, Strumsky D (2007b) Invention in the city: increasing returns in patenting as a scaling function of metropolitan size. Res Policy 36:107–120

Bohringer C, Jochem P (2007) Measuring the immeasurable—A survey of sustainability indices. Ecol Econ 63(1):1–8

Brander KM (2007) Global fish production and climate change. Proc Nat Acad Sci 105(50):19709–19714

Buckley BM, Anchukaitis KJ, Penny D, Fletcher R, Cook ER, Sano M, Nam LC, Wichienkeeo A, Minh TT, Hong TM (2010) Climate as a contributing factor in the demise of Angkor, Cambodia. Proc Nat Acad Sci 107(15):6748–6752

Costa L, Rybski D, Kropp JP (2011) A human development framework for CO_2 reductions. PlosOne 6(12):e29262

Costa L, Kropp JP, Harmeling S, Kreft S, Kaloga A, Junghans L (2013) Assessing costs to climate change in developing countries. Final Report to the German Environmental Agency, Potsdam Institute for Climate Impact Research, Potsdam, FZK: 371041141, p 181

de Bruin K, Dellink R, Ruijs A, Bolwidt L, Buuren A, Graveland J, Groot RS, Kuikman PJ, Reinhard S, Roetter RP, Tassone VC, Verhagen A, Ierland EC (2009) Adapting to climate change in the Netherlands: an inventory of climate adaptation options and ranking of alternatives. Clim Change 95(1–2):23–45

Dietz T, Rosa EA, York R (2009) Environmentally efficient well-being : rethinking sustainability as the relationship between human well-being and environmental impacts. Hum Ecol 16(1):114–123

Dodman D (2009) Blaming cities for climate change? An analysis of urban greenhouse gas emissions. Environ Urban 21(1):185–201

Duren RM, Miller CE (2012) Measuring the carbon emissions from megacities. Nat Clim Change 2(8):560–562

Ehrlich PR, Ehrlich AH (2013) Can a collapse of global civilization be avoided? Proc R Soc B 280:20122845

Eisenack K, Scheffran J, Kropp JP (2006) Viability analysis of management frameworks for fisheries. Environ Model Assess 11:69–79

Fleurbaey M (2009) Beyond GDP: the quest for a measure of social welfare. J Econ Lit 47(4):1029–1075

Galbraith D, Levy PE, Sitch S, Huntingford C, Cox P, Williams M, Meir P (2010) Multiple mechanisms of Amazonian forest biomass losses in three dynamic global vegetation models under climate change. New Phytol 187(3):647–665

Gottfried M, Pauli H, Futschik A, Akhalkatsi M, Barančok P, Alonso JLB, Coldea G, Dick J, Erschbamer B, Fernández Calzado MR, Kazakis G, Krajči J, Larsson P, Mallaun M, Michelsen O, Moiseev D, Moiseev P, Molau U, Merzouki A, Nagy L, Nakhutsrishvili G, Pedersen B, Pelino G, Puscas M, Rossi G (2012) Continent-wide response of mountain vegetation to climate change. Nat Clim Change 2:11–115

Haug G, Günther D, Peterson LC, Sigman DM, Hughen KA, Aeschlimann B (2003) Climate and the collapse of Maya civilization. Science 299(6613):1731–1735

IPCC (2007) Climate change: mitigation of climate change. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds) Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change, Cambridge University Press, Cambridge

Kennett DJ, Breitenbach SFM, Aquino VV, Asmerom Y, Awe J, Baldini JUL, Bartlein P, Culleton BJ, Ebert C, Jazwa C, Macri MJ, Marwan N, Polyak V, Prufer KM, Ridley HE, Sodemann H, Winterhalder B, Haug GH (2012) Development and disintegration of Maya political systems in response to climate change. Science 338(6108):788–791

Kriewald S, Cantu Ros A, Pradhan P, Sterzel T, Kropp JP (2013) Feeding cities in the post-carbon age: can peri-urban agriculture reclaim a place in the climate context. Nature Climate Change. Submitted

Kuznets S (1955) Economic growth and income inequality. Am Econ Rev 45:1–28

Lawn PA (2003) A theoretical foundation to support the index of sustainable economic welfare (ISEW), genuine progress indicator (GPI), and other related indexes. Ecol Econ 44:105–118

Lissner T, Holsten A, Walther C, Kropp JP (2012) Towards sectoral and standardised vulnerability assessments: the example of heatwave impacts on human health. Clim Change 112:687–708

Medina-Elizalde M, Rohling EJ (2012) Collapse of classic Maya civilization related to modest reduction in precipitation. Science 335(6071):956–959

Meinshausen M, Meinshausen N, Hare W, Raper S, Frieler K, Knutti R, Frame DJ, Allen MR (2009) Greenhouse-gas emission targets for limiting global warming to 2 °C. Nature 458:1158–1162

Noll H-H (2010) The Stiglitz-Sen-Fitoussi-Report: old Wine in New Skins? Soc Indic Res 1:4–9

OECD (2005) Bridge over troubled water: linking climate change and development. OECD, p 154

Perry AL, Low PJ, Ellis JR, Reynolds JD (2005) Climate change and distribution shifts in marine fishes. Science 308:1912–1915

Peters G, Marland G, Le Quere C, Boden T, Canadell JG, Raupach MR (2012) Rapid growth in CO_2 emissions after the 2008–2009 global financial crisis. Nat Clim Change 2:2–4

Peters GP, Andrew RM, Boden T, Canadell JG, Ciais P, LeQuere C, Marland G, Raupach MR, Wilson C (2013) The challenge to keep global warming below 2 °C. Nat Clim Change 3(1):4–6

Prajal P, Reusser D, Kropp JP (2013) Embodied greenhouse gas emissions in diets. PlosOne 8(5):e62228

Rockström J, Steffen W, Noone K, Persson Å, Stuart Chapin F III, Lambin EF, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B, de Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sörlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Liverman D, Richardson K, Crutzen P, Foley JA (2009) A safe operating space for humanity. Nature 461:472–475

Roy J, Pal S (2009) Lifestyles and climate change: link awaiting activation. Curr Opin Environ Sustain 1(2):192–200

Rozenfeld HD, Rybski D, Gabaix X, Makse HA (2011) The area and population of cities: new insights from a different perspective on cities. Am Econ Rev 101(5):2205–2225

Satterthwaite D (2008) Cities contribution to global warming: notes on the allocation of greenhouse gas emissions. Environ Urban 20(2):539–549

Schubert S, Grosman-Clarke S (2012) The influence of green areas and roof albedos on air temperatures during extreme heat events in Berlin. Meteorologische Zeitschrift (in press)

SRES (2000) Special report on emissions scenarios. In: Nakićenović N, Swart RS (eds) A special report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press

Singh K (2011) India's emissions in acclimate constrained world. Energ Policy 39:3476–3482

Smith A, Watkiss P, Tweddle G, McKinnon A, Browne M, Hunt A, Treleven C, Nash C, Cross S (2005) The validity of food miles as an indicator of sustainable development, 7th edn. AEA Technology Environment Report, for DEFRA, no. ED50254

Steinberger JK, Roberts JT, Peters GP, Baiocchi G (2012) Pathways of human development and carbon emissions embodied in trade. Nat Clim Change 2:81–85
Stiglitz J, Sem A, Fitoussi JP (2010) Mismeasureinng of lives. The New Press, New York
UN (2007) City planning will determine pace of global warming, United Nations, UN-HABITAT (document A/62/8), New York
UNDP (2008) Human development report, technical note 1: calculating the human development indices. Technical report, United Nations
UNEP (2011) Decoupling natural resource use and environmental impacts from economic growth. A Report of the Working Group on Decoupling to the International Resource Panel. In: Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, P., Siriban Manalang, A., Sewerin, S (ed) United Nations Environment Programme
Vollan B, Ostrom E (2010) Cooperation and the commons. Science 330:923–924
WB (2006) Managing climate risks: integrating adaptation into World Bank Group Operation. World Bank, Washington DC, p 32
WB (2012) Turn down the heat: why a 4 °C warmer world must be avoided. World Bank, Washington DC
WBGU (2009) Solving the climate dilemma: the budget approach. German Advisory Board on Global Change, Berlin, p 58
Wernberg T, Smale DA, Tuya F, Thomsen MS, Langlois TJ, de Bettignies T, Bennet S, Roussoux CS (2013) An extreme climatic event alters marine ecosystem structure in a global biodiversity hotspot. Nat Clim Change 3(1):78–82

Ethics of International Action on Climate Change: How Would Mahatma Gandhi Have Looked at it?

M. V. Nadkarni

1 Moral Irony of Climate Change

There is a broad scientific consensus in the world about Earth warming due to climate change and even on its diagnosis that this has been mostly due to increase in the concentration of man-made Green House Gases (GHGs) in the Earth's atmosphere. There is an equally strong consensus that continued emission of GHGs, including CO_2 at the present rate, will only accelerate climate change and its impacts more than in the past. These impacts include increased frequency and intensity of floods and droughts, mounting uncertainties in agriculture, a long term tendency of rising scarcity of drinking water, desertification and land degradation, a rise in the sea level possibly leading to submergence of coastal areas and small island nations, massive migration, heightened incidence of diseases, and so on.[1] All this will make the task of economic development harder still for developing countries. In India, the implications of the melting of Himalayan glaciers are extremely dismal for future prospects of development and even for day to day living, and the present rates of economic growth would then be hardly sustainable. It would, therefore, be ironical to say (and act on it) that we need to give priority to economic development over controlling climate change. Equally ironical would be to take a stand that we continue to focus on economic growth on a (almost) business-as-usual basis on the ground that we need economic growth to reduce poverty and unemployment. While the distributional impacts of economic growth on the basis of business-as-usual policy are dubious for the poor, with some percolation or fringe benefits for them, if at all, the adverse impacts of climate change resulting from such growth will certainly be much harsher on the poor than

[1] Among several sources, see at least: Reports of the Intergovernmental Panel on Climate Change (IPCC) 2001 and 2007, Geneva: IPCC; International Scientific Steering Committee (2005); World Bank (2010).

M. V. Nadkarni (✉)
Samagama, 2nd Cross to West from ISEC, Nagarbhavi, Bangalore 560072, India
e-mail: mvnadkarni1968@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_3,

on others. Declining agricultural productivity, increasing uncertainties in agriculture, deforestation, floods and droughts, scarcity of drinking water, submergence of vast areas by rising levels of the sea—these are all consequences which directly hit the poor hardest. Deprivation and destitution that may increase with climate change reverse any gains from economic growth and can hardly be treated with complacency. Continuing a policy of focusing on economic growth on the basis of … business-as-usual, in the name of reducing poverty and unemployment, would amount to disowning one's moral responsibility for the consequences of own acts (present or past), betraying blind audacity. Thus, it violates a basic ethical principle, irrespective of whether it is done by developed or developing countries. Ethical principles are for all. They bear no exceptions.

To characterize, however, any countries' stand on climate change as negative and obsessed only with economic growth to the neglect of consequences of climate change, would be misleading. It is worthwhile first discussing the stand taken by different groups of countries and their moral justification for it in the international conferences on climate change. India's stand receives special attention here. India has been fairly consistent, though not rigid, in its stand at various international conferences on climate change, in particular, and environment, in general, right from the Stockholm Conference on Environment and Development in 1972. Indira Gandhi, the then Prime Minister of India, made it clear that India would not sacrifice the goal of economic development for the sake of environment, since its priority was to remove poverty through development. She asserted that poverty was the worst form of pollution, to be attended to more urgently than industrial pollution. The essence of her stand was that environmental problems could not be looked at or treated in isolation from the development context of respective countries. Right to a greater share in development space is linked with the right to equitable share in ecological space, in the context of low levels of development associated strongly with low levels of per capita emissions. Inequitable appropriation of ecological space can constrain development space where it is most needed and imposes the burden of ecological costs on shoulders least able to bear them. The emphasis on equity, therefore, is crucial. In contrast, the developed countries looked obsessed with environment as the most urgent issue, at least as far as the action to be taken by developing countries is concerned, while trying jealously to safeguard their own development gains and also their admittedly vast share in ecological space. For them the urgency of action on the environment front was more important than the issue of equity. Though Mrs. Gandhi sounded rhetorical, she deserves the credit for ushering in several measures with all seriousness, soon after returning from Stockholm, both in terms of legislations and institution building to prevent and control industrial pollution of both air and water. The 1970s were conspicuous for initiating an organized, institutionalized and comprehensive tackling of environmental problems in India, including starting the Ministry of Environment, combing it with that of Forests. Indira Gandhi set a role model for other developing countries in this regard.

By 1985, with the popular acceptance of Brundtland Commission (World Commission on Environment and Development) Report, *Our Common Future*, the perception regarding a conflict between environment and development changed to a philosophy of Sustainable Development, seeking to reconcile the two, without adverse impacts on reducing poverty. The popularity of this philosophy was no less in developing countries than in the developed. The UN Conference on Environment and Development at Rio de Janeiro in 1992 affirmed this principle of sustainable development in its Declaration, and the UN Framework Convention on Climate Change was adopted. The principle of common but differential responsibilities was accepted. Also, at the Rio Summit, while India showed its openness and willingness to adopt measures for mitigating climate change and its effects, it insisted at the same time that such measures voluntarily taken should not be made legally binding for developing countries. In the bargain, measures that found acceptance at the Rio Summit were not legally binding for any, including Agenda 21 which prescribed concrete guidelines at the local and national levels to meet global concerns (Damodaran 2010: 135, 285). However, participant countries committed themselves to have appropriate legislations and implement them, and this commitment had a great moral force.

In the meanwhile, in 1987, the Montreal Protocol on Ozone Depleting Substances was adopted. Under this, developed countries were expected to phase out CFCs that depleted ozone by January 1, 1996 and the developing countries by 2006. However, India, China and Brazil signed the protocol only in 1990 after provisions were made for a multilateral fund to assist developing countries to change over to safer alternatives to CFCs, as they involved higher costs. Interestingly, this meant the acceptance of the universally honoured 'Polluter Pays Principle' by implication. The developed countries had, by using CFCs, caused significant damage to ozone layer already, making it urgent for all countries to give up CFCs. It would not have been fair to ask developing countries now to share this moral responsibility without assistance. Besides, developed countries already had developed alternatives to CFCs, while developing countries were still dependent on them (Gupta 2000: 256–8). The moral strength of the stand taken up by the developing countries, thus, became obvious to developed countries.

Regarding climate change, also, the same moral issue was involved from India's standpoint, as also that of other developing countries like Brazil and China. The issue was who created the problem in the first place and how to allocate moral responsibility of mitigating it along with costs of doing so. In India's view, this was a major issue of equity and the logic required the application of Polluter Pays Principle. This issue was brought up conspicuously by the Centre for Science and Environment, New Delhi, and its founder—Anil Agarwal and his colleague, Sunita Narain, as early as around 1990. Their views greatly influenced the Government's stand too at the international forums on climate change. They argued that the problem of climate change was created in the first instance by the developed countries. They enjoyed the benefits of high economic growth without paying for its ecological costs. On the other hand, the developing countries needed ecological space to grow and develop. It would, therefore, be unfair to impose mitigation responsibilities equally on both types of countries. Pointing out at much higher per capita emission rates in developed countries, these two eminent environmental thinkers-cum-activists argued the case for assigning carbon emission rights on the basis of population size of different countries as on a historical date (so that there is no incentive to increase population size) and carbon trading between countries with a deficit of such rights and countries with a surplus. This would provide an incentive to save on carbon emission on both types of countries and contribute to creating a greener world. They insisted that carbon rights allotments should be based on equity and human rights, and not on the present level of carbon space appropriated without paying its costs (Agarwal and Narain 1991, 1992). Carbon trading can make developed countries, which are expected to have a deficit, to pay for their carbon emissions, satisfying to an extent the Polluter Pays Principle. Carbon trading also could generate revenues from the sale of surplus rights for developing countries, which could help them to adopt cleaner technologies and less carbon (and GHG)-intensive development. Carbon trading, however, is not without problems, including moral problems, as we shall be discussing later.

The Rio Summit, it may be recalled, had urged developed countries to reduce their emission levels to the level in 1990 by the year 2000, and also to help developing countries financially and technically in achieving the common goal of containing global emission levels. This induced some developed countries to take up ‘joint implementation’ with developing countries, under which the former claimed credit for reducing emissions, though it was actually achieved in developing countries. Developing countries, including India, protested against this as ‘fraudulent and dishonest’, involving export of sacrifices of developing countries to the developed. It actually led to increased emissions in the developed countries, instead of reducing them (Gupta 2000). It was felt that there ought to be legally clear and binding commitments, so as to make GHG emission cuts more effective.

2 Kyoto 1997 and After

The Kyoto Protocol of 1997 tried to achieve this to some extent, but did not go far enough. Under this Protocol, the Annexure-1 countries (developed countries) had the legally binding responsibility for mitigating GHG emissions, such that the average reduction of 5.2 % from the 1990 levels by the year 2012 would be achieved on the whole. The other countries (developing countries) were under no such obligation. The developed countries had varying targets. For example, Germany agreed to cuts by 21 %, and Great Britain by up to 12.5 % over 1990 levels. Russia and Ukraine agreed only to stabilize. USA refused to any cuts or any binding commitments, and did not sign the Protocol. It was opposed to the very principle of differential responsibility in achieving a common goal, and declined to accept any guilt for the historical emissions. The Protocol devised a flexible mechanism to meet the commitments made. To avoid controversies about Joint Implementation, a multilateral Clean Development Fund was set up under the Protocol to enable investment in developing countries in return for emission credits. Joint Implementation was allowed between developed countries, and so also trading emission reduction allowances amongst them. But the allocation of emission allowances was based on 'grand-fathering' rather than on the principle of equity; that is, allowances were derived from their current levels of emissions. This was not what India and other developing countries were arguing and struggling for. Moreover, allowing carbon trading among developed countries only meant allotting property rights on environment only to these countries, and not developing countries. This again grossly defied the principle of equity. Further, in the Clean Development Mechanism, India did not want to be seen only as a follower of or dependent on technologies of developed countries, but wanted to innovate on its own and be given the freedom of choice. Any aid under CDM tied to technology import from developed countries was resented, though financial and technical help needed by India through its own choice had to be facilitated under Clean Development Fund. The USA's not signing the Kyoto Protocol also upset India and other developing countries. USA was seen as a game-spoiler, and its moral image was seriously dented, at least among developing countries.

What little progress was achieved in Kyoto in 1997 was put in reverse gear in the Copenhagen Accord of 2009. The basic tension between developing countries, which saw the problem of climate change as one of equitably sharing the ecological and development space, and the developed countries, which insisted on grandfathering the rights over this space and on the principle of comparability of action, became more acute instead of being resolved. Both parties felt confident about the moral justification of their respective stands. The differences were so irreconcilable that the so-called Accord, which was one of the smallest of UN documents, could not even be 'adopted', but was only 'taken note of'. It did not even mention indicative targets for emission reduction to be adopted after 2012, though there is a consensus among scientists that unless Annex 1 countries reduce by 2020, their carbon emissions to 40 % lower than their 1990 levels, the planet will not be able to contain global warming to less than 2 °C over pre-industrial revolution levels, and that this failure could make climate change irreversible with calamitous consequences. Though the Kyoto Protocol was modest in its emission reduction targets, even this was dumped by the developed countries. Any hope of developing countries to have another binding treaty like Kyoto, after it lapses in 2012, was thus frustrated. India, on its part, tried to impress on the World forum that it was quite serious in its domestic policies to contain climate change. The then Environment Minister, Jairam Ramesh, announced particularly India's own voluntary resolve to decrease emission intensity of GDP by 20–25 % by 2020 on 2005 level, (though he was silent on emission levels in absolute terms). He outlined several measures, including constant monitoring to achieve this end. However, he also made it clear that India would not accept any legally binding commitment, nor any external monitoring, inspection or verification, which turned out to be what ultimately transpired for *all* countries. This was a dubious success for India's stand in the context of the collapse of Copenhagen negotiations. If USA was seen as a spoiler, India and other such countries in the BASIC group came to be seen as deal breakers. It was a defeat for all, symbolizing the unwillingness of the countries of the world to take up their due moral responsibility even in the face of a looming crisis. The blame heaped on developing countries, however, needs to be tempered by the fact that developed countries showed no evidence of any plan of accepting any binding commitments during the post-2012 second phase of Kyoto Protocol in any case, with or without developing countries joining in. What they were prepared to do (even without legal commitment) fell far short of what was required to deal with the crisis of climate change. There was neither any attempt towards convergence in per capita emissions, which the developing countries wanted, nor was there any alternative credible plan in sight to avert the crisis.

Such a global failure could not have continued unattended for long, and, thus, came the next UN Meeting on Climate Change at Cancun, Mexico, in December 2010. However, its major achievement was only that the Copenhagen Accord, which had only been 'noted' and not adopted, was now formally adopted, with some modifications and additions.[2] At the Conference, the group of countries led by Japan, Russia, Canada and Australia insisted on withdrawing from the second phase of the Kyoto Protocol. They wanted every country, rich or poor, to pledge voluntary actions on mitigation as per the Copenhagen Accord. On the other hand, the Group 77 of developing countries did not want the World Community to move away from the Kyoto Protocol. Ultimately, the developing countries had to give in. The compromise, which was at the cost of developing countries, meant writing off the historical debt of developed countries. India's then Environment Minister, Jairam Ramesh, proposed that *all countries* must take on 'binding commitments under appropriate legal forms'. It was insisted that this phrase was not just a word play for 'legally binding'. While for developed countries it would mean third-party verification of targets making them binding, for developed countries like India, it meant commitment to her own Parliament under relevant legislation (Pande 2011). It was agreed that pledges of developed countries would be measured, reported and verified (MRV system), but with no penalty for failure to honour the pledges; and that for developing countries, pledges would be put through an apparently softer procedure of international consultation and analysis (ICA system). It is estimated, however, that even if the pledges are implemented in good faith, it could 'bring down emissions to around 49 Gt (giga-tons—billion tons) of CO_2 equivalent by 2020, against business-as-usual emissions of 56 Gt. This would leave an emission gap of around 5 Gt of CO_2 equivalent between where nations might be in 2020 against where the science indicates they need to be. In the worst case, the global emissions could be as high as 53 Gt in 2020' (Dutta and Ghosh 2011). The reason for this lies in weak pledges by developed countries. For example, USA and Canada pledged (pending legislation) to cut emissions only 17 % below 2005 levels, which would mean only 3 % below 1990 levels, as against the required 40 % cut below 1990 levels. The Accord put greater burden on the developing countries than on the developed, which is clearly unfair and regressive. It was

[2] The following is a summary of what transpired at Cancun is based on Dutta and Ghosh (2011:26–34).

estimated that 'while they [the latter] cut 0.8–1.8 Gt by 2020, developing countries pledge to cut their emissions by 2.8 Gt'. The overall result of this is expected to a rise in global temperatures by 3.5–4 °C, as against the requirement to keep it below 2 °C. Key decisions about continuation of the second phase of the Kyoto Protocol commitments were deferred till the Durban summit next. On the part of developed countries, it was agreed to generate a $100 billion long term fund, with $30 billion in 2010–2012 to facilitate technology transfer and economic aid to developing countries in implementing their pledges.

3 Outcome of Action

After wading through the treacherous waves of these international agreements where short term national interests prevailed over the long term and global interests, cleverness and wile of the rich dominated over honesty of purpose, and sheer money power overwhelmed human numbers, it is worth seeing what the outcome of action on the climate front was in practice. The data providing this picture also help us to appreciate the inequity in the ecological or carbon space enjoyed by the rich as compared with the poor countries.

The relevant data are presented in three Tables. Table 1 presents a picture of CO_2 emissions, while Table 2 presents Non-CO_2 emissions. Table 1 starts with shares of selected countries in world population, as also those of High Income Countries (HICs), Middle Income Countries (MICs) and Low Income Countries (LICs), for comparison with shares in CO_2 and Non-CO_2 emissions of respective countries or types of countries. Table 3 shows who contributed and how much to the *increase* in both types of emissions between 1990 and 2005. We may briefly note a few points that emerge from Tables 1, 2 and 3.

1. Inequity in the sharing of carbon space comes out clearly from the shares of respective country types in historically accumulated emissions as compared with their shares in population. Developing countries are not a homogeneous block. LICs show a pattern distinct from MICs, the former facing much more inequity than the latter.
2. Annual total CO_2 emissions *increased* between 1990 and 2005 in HICs, MICs and understandably in LICs. This increase was in evidence in most of the countries with a few honourable exceptions like Germany. China and USA showed a substantial increase in absolute terms.
3. Annual total Non-CO_2 emissions increased between 1990 and 2005 in MICs and LICs, but declined slightly in HICs and significantly in Germany.
4. There has been no sign of convergence in per capita CO_2 emissions, which have increased both in HICs and MICs. Contrary to what might be expected, per capita emissions *declined* in LICs, though slightly. This is ironical when contrasted with the *increase* in per capita emissions among HICs, including USA, between 1990 and 2005, though they were the ones expected to record a decline.

Table 1 Shares in carbon dioxide emissions and world population

		India	China	USA	Germany	HICs	MICs	LICs	World
1	Share (%) in world population								
	(2008)	17.0	19.8	4.6	1.2	16.0	69.5	14.5	100
2	Share (%) in cumulative emissions								
	(1850–2005)	2.4	8.1	27.8	10.1	64.2	33.8	2.0	100
3	Annual total in carbon emissions (million metric tons)								
	1990	597	2,211	4,874	968	10,999	9,150	549	20,693
	2005	1,149	5,060	5,841	814	13,207	12,631	707	26,544
4	Share (%) in (3.)								
	1990	2.8	10.7	23.5	4.7	53.1	44.3	2.6	100
	2005	4.3	19.1	22.1	3.1	49.7	47.6	2.7	100
5	Per capita CO_2 emissions (metric tons)								
	1980	0.5	1.5	20.4	na	12.2	3.4	0.9	3.8
	1990	0.7	1.9	19.5	12.2	11.8	2.6	0.7	4.0
	2005	1.1	3.9	19.7	9.9	12.7	3.0	0.6	4.2
6	Carbon intensity—metric tons of CO_2 per thousand $ of GDP								
	1990	0.58	1.77	0.61	0.49	0.47	0.80	0.46	0.57
	2005	0.47	0.95	0.47	0.32	0.39	0.61	0.38	0.47

Source World bank's *World Development Report* 2010, p. 362; and UNDP's *Human Development Report 2004*, pp. 208–210 (for per capita emission in 1980)
Note HICs High Income Countries, *MICs* Middle Income Countries, *LICs* Low income countries, *na* data not available

Table 2 Non-CO_2 emissions (CH_4, N_2O)

		India	China	USA	Germany	HICs	MICs	LICs	World
1.	Annual total—metric tons of CO_2 equivalent (millions)								
	1990	53	193	299	48	577	1,168	116	1,861
	2005	89	219	243	29	557	1,279	256	2,092[a]
2.	Share (%) in 1								
	1990	2.8	10.4	16.1	2.7	29.9	62.8	7.3	100
	2005	4.3	10.5	11.6	1.4	26.6	61.1	12.2	10

Source World Bank—*World Development Report* 2010, p. 362
Note Shares (%) in World Population are given in row 1 of Table 1 for comparison
[a] This is total of HIC, MIC and LIC emissions, which differs from the WDR figure given as 1979 million metric tons

Table 3 Absolute increase in emissions between 1990 and 2005 and percent shares therein

	India	China	USA	Germany	HICs	MICs	LICs	World
CO_2								
Million metric tons	552	2849	967	−154	2208	3481	158	5851
Per cent shares	9.5	48.7	16.5	−2.6	37.7	59.5	2.7	100
Non-CO_2:								
Million metric tons	36	26	−56	−19	−20	111	140	231
Percent shares	15.6	11.3	−24.2	−8.2	−8.7	48.1	60.6	100

Source Derived from Tables 1 and 2

5. The shares of HICs in world CO_2 emissions have remained much higher than their respective shares in world population, though they have shown a tendency to decline slowly. Shares of both India and China have significantly increased, though they have remained lower than their respective shares in population. However, in China's case, the shares in world population and CO_2 emissions are fast converging, and under a business-as-usual situation, the latter share is now poised to exceed the former as in HICs.
6. While the shares of HICs and MICs in non-CO_2 emissions have slightly declined between 1990 and 2005, the share of LICs has significantly increased, though still below their share in population.
7. Of the absolute *increase* in annual total CO_2 emissions between 1990 and 2005, the MICs contributed nearly 59 %, followed by HICs contributing nearly38 %, and LICs a mere less than 3 %. China alone contributed nearly 49 %. And this is what bothers HICs the most. More than the present shares of MICs in CO_2 emissions, it is the trends in their shares which worry the HICs more.
8. Of the total increase in Non-CO_2 emissions, MICs contributed 48 %, and LICs as much as 61 %. In contrast, HICs achieved a decline, thus offsetting some of the increase in MICs and LICs. India contributed more than China to the increase in these emissions, while both USA and Germany showed a decline. However the size of Non-CO_2 emissions is much smaller than that of CO_2 emissions. For example, in 2005, the annual world total CO_2 emissions were 26.5 billion tons, while that of Non-CO_2 emissions was only 2.1 billion tons.
9. With a decrease in 2008 and a 5 % surge in 2010, the past decade saw an average annual increase of 2.7 %. The top 5 emitters are China (share 29 %), the United States (16 %), the European Union (EU27) (11 %), India (6 %) and the Russian Federation (5 %), followed by Japan (4 %) (Olivier et al., 2012 p 6).

4 An Ethical Assessment

Let us now make an ethical assessment of policy and action taken on Climate Change, particularly from the view point of how Mahatma Gandhi would have looked at it. Ethical principles are universal and apply to all countries. Gandhi emphasized moral responsibility of each agent—persons as well as institutions—for actions taken and consequences flowing from them. It is a fundamental principle of ethics. Moral responsibility for mitigating climate change has to be accepted by both the developed and developing countries. But this responsibility is clearly in proportion to the carbon space appropriated by different countries, in the past as well as the present. The developed countries did not pay for their historical accumulation of carbon emissions, but this does not mean that they don't have to pay for it now. They should gracefully accept their moral responsibility and pay for it now by contributing adequately and expeditiously to funds for developing countries to adopt clean technologies and in other ways. Polluter Pays Principle follows directly from the principle of moral responsibility. It is a moral principle, besides making economic sense.

The principle of equity has been much emphasized, and rightly so, at the international meets on climate change. This would have sounded very convincing and honest, if the same equity, which has been insisted upon between countries, had been followed within countries too. This is what Mahatma Gandhi would have insisted. If India is among the lowest per capita emitters of carbon emissions, it is mainly because of poverty of the masses, which have little access to proper energy use, and not because of the virtue of simple living among all Indians. The role of the poor, as lowest per capita emitters, in creating carbon space for appropriation by the rich, is hardly appreciated in policy making, both within and between countries. In pushing for greater share in carbon space, the rich in the developing countries seem to exploit the deprivation of the poor in the same carbon space. India's elite are several times more energy-intensive in consumption and styles of living than its poor, though not perhaps as much as the rich in rich countries (Parikh et al., 2009). The HICs have much lower proportions of poor people who hold back abundant energy use. Unfortunately, the benefits of higher economic growth in India have not gone much to the poor, whose numbers have only increased instead of declining, though the proportion of the poor may have shown some decline. This shows that ecological and development space within India also has been subjected to the same inequity about which India is so bitter in the international context. Inequity within the country does not of course justify inequity between countries, but if India were an exemplar, it would have really boosted its moral prestige and persuasiveness. Secondly, while equity means comparability in emission rights for developing countries, for the developed countries it means comparability of action in mitigating carbon emissions. There is a need to appreciate both these aspects of equity.

Gandhi would have expected India to be an exemplar, not only in mitigating emissions, but also in the development path chosen as the two are closely linked. Gandhi did not believe in a path of development which merely means multiplication of wants. It is this multiplication of wants which is at the root of the ecological crisis. He preferred giving utmost priority to needs. Instead of simply taking to the Western model in an ape-like fashion, Gandhi would have liked India to take to its own employment-promoting and energy-saving path of development, shunning consumerism and economism.[3] It is not just a question of finding new energy-saving technologies, but also one of changing our lifestyles. A cardiologist does not tell a heart patient to have any lifestyle she or he pleases on the ground that the doctor has the right technology, including surgery to correct any heart problem. The cardiologist instead emphasizes changing the lifestyle of the patient, including right food and exercise, the role of the cardiologists' technical expertise notwithstanding. It is good that both India and China have committed themselves to reducing carbon intensities of their economic growth and they have shown some

[3] I have discussed this issue at greater length in Nadkarni (2011) especially in Chapters 3 and 4.

success in this already (see Item 6 in Table 1). But this evidently is not enough in Gandhian expectations. Gandhi had warned against blind imitation of the Western model as early as in 1928. He wrote then, ‘God forbid that India should ever take to industrialization after the manner of the West. The economic imperialism of a single tiny island kingdom [England] is today keeping the world in chains. If an entire nation of 300 million [India’s population at the time] took to similar economic exploitation, it would strip the world bare like locusts.’[4] His conception of *swaraj* was not confined to ending foreign political rule, but in achieving self-rule in science and technology and in development strategy (KICS 2011). It was not economic or material development alone that concerned him, but also moral and human development. He certainly did not approve the Western concept of growth or development that depended on endless multiplication of wants as its motive force. He strove for an alternative concept.

An anecdote from the early life of Gandhi illustrates his strong moral fibre and independence of approach which he was to preach later to the world. When he was barely 10 years old, he was beaten up by another boy. Mohandas complained to the boy’s father, who only reprimanded him lightly. Putlibai, mother of Mohandas, asked him why he did not hit back. The young Gandhi asked in return, ‘why should I be like him?’[5] Yes, why shouldn’t we create our own path of sustainable eco-friendly development, instead of taking up the resource-and-energy intensive historical Western path?

But he was not an anti-Western bigot. Just as self-rule in polity did not mean for him political isolation, self-rule in economy, science and technology did not mean isolation in these spheres from foreign influences. What is crucial to self-rule is its rejection of helpless dependence, and assertion of one’s own command. Though this does not mean totally shunning foreign technologies or learning from them, we need to develop our own technologies for clean development. While scientists and technologists would normally be expected to lead in this, the role of learning from traditional knowledge and technology systems, and promoting them further, should also receive due emphasis. Journals like *Down to Earth* and *Honey Bee* in India have been documenting knowledge and technology from below, at the level of common farmers and artisans, who are found to be more creative than what normally the formally educated elite would care to admit. While we are keen to update ourselves on science and technology emanating from the West, we tend to be oblivious to the need for tapping our own indigenous knowledge systems and promoting them.

To encourage a simpler, less energy-intensive and sustainable living, there is need to provide for an incentivizing mechanism. From this point of view a proposal put forward by the German Advisory Board of Global Change (WBGU), contained in a paper by (Kaechele et al. 2011) merits due attention. It is really nice of Germany to have recognized the ethical justification for an equal per capita basis for allotment

[4] Quoted in Guha (2000: 22). Parentheses added by Guha.

[5] As narrated in TOI Team (2011: 2).

of carbon rights. Germany has been in the forefront in reducing GHGs (as can be seen from the three Tables 1, 2, 3), and if it preaches, it has also been practicing what it preaches. It is fitting that an interesting and practical proposal has emerged from such a country. Anil Agarwal and Sunita Narain had made a similar proposal (referred above) in 1991. The WBGU proposal allocates national emission allowances on per capita basis, arguing for a per capita distribution of a carbon budget and universal participation of all nations. For the period 2010–2050, it proposes an average annual emission allowance of 2.7 t per capita per year for the whole world, which is expected to meet the 2 °C guard rail. Scientists are agreed that allowing the world average climate to rise above this could have serious consequences. The proposal then argues for carbon trade among countries of the world, enabling countries having current emission rates above 2.7 t per capita to trade carbon rights with countries whose emission rates are below this level. Provided that the carbon rights are appropriately priced, such a trade would give incentives to both buyers and sellers to economize on carbon emissions. If on the other hand, their prices are pushed lower by buying countries which are richer and more powerful than selling countries, with the former acting like a monopsonistic cartel, the whole game would be defeated and may break down.

The proposal, thus, needs to face some ethical issues. Will the revenues from the sale of carbon rights be allowed to be appropriated at the government level only, or will the benefits of this be equitably shared with the people who, in the first instance, economized on emissions and followed a low-energy lifestyle. This is not only a question of ethics, but is also a practical one of giving incentive to energy saving by individuals, households and organizations. A second issue, already referred to in the preceding paragraph, is the question of the right price. Will the markets for carbon rights be fair? What is the criterion for fairness or just price here? What would be the type of competition for carbon rights? Thirdly, can there be a transparent mechanism for counting carbon rights and credits? In other words, can we assure fair trade practices in this, and how? A fourth issue is one of denying any incentive for increasing population size. Though emission rights can be allotted on the basis of a historical benchmark and not on the basis of current population size, countries would know that the allotments would be periodically revised and more populous countries would gain. A complicating issue is that population in a country can increase not only due to natural factors like birth rate, but also due to immigration. It would not be desirable to create further deterrents to immigration, by rigidly adhering to a historical benchmark of population. These issues are raised not to resist the proposal, but to make it fair and workable to the satisfaction of all and, above all, to really achieve the target of keeping temperature rise below 2 °C, keeping climate change within bearable limits, and ensuring sustainable living across the globe for all. It would help if each country follows Gandhi's principle 'to serve the country in a way that would not be inimical to universal interests.'[6]

[6] Cited in Foreword by Narayanbhai Desai in TOI Team (2011).

There is, however, a further dilemma. What if the worst case scenario held out by IPCC scientists and many others, consisting of catastrophic consequences of climate change, is exaggerated significantly? *The Hindu* dated October 15, 2011 (Bangalore Edition: 24) reported the findings of a Swedish scientist, Prof Niels-Axel Morner, who claimed that the sea levels were not rising as feared and island nations like the Maldives do not show evidence of being in danger. Should we then take climate change seriously, knowing well the costs of mitigating it? Would not forgoing the gains of development then mean an unnecessary sacrifice which the world can ill afford?

Morner, at least as reported in the press, spoke only of sea level rise and not of all the adverse consequences expected from climate change. Further, his findings are yet to be verified and accepted by a majority of scientists. It hardly amounts to a consensus at this stage. It is then prudent to compare the two maximum costs in alternative scenarios—one, where the optimists like Morner are right and the costs of a clean and cautious development strategy turn out to be a 'waste', particularly for the profit-minded rich; the second, where the pessimists are right and the costs of pursuing a business-as-usual policy turns out to be excruciatingly huge, particularly impacting the poor. If between these two costs, our reasoned guess suggests that the latter is going to be much higher and socially more unbearable, then prudence demands erring on the side of caution rather than follow the seemingly rosy path of business-as-usual. Particularly so when the majority view of scientists favours caution. This is nothing but the minimax strategy of economists faced with such situations, duly taking note of distributions considerations too. We have to avoid the greater and more unbearable of the two costs.

References

Agarwal A, Narain S (1991) Global warming in an unequal world: a case of environmental colonialism. Centre for Science and Environment (CSE), New Delhi

Agarwal A, Narain S (1992) Towards a green world—should global environmental management be built on legal conventions or human rights?. CSE, New Delhi

Damodaran A (2010) Encircling the seamless: India, climate change and the global commons. Oxford University Press, New Delhi

Dutta AP, Ghosh A (2011) Cover story COP16 Cancun 2010, in which poor countries gave. Down to earth, 1–15:26–34

Guha R (2000) Environmentalism: a global history. OUP, New Delhi

Gupta J (2000) Global environmental issues: impact on India. In: Chary SN, Vyasulu V (eds) Environmental management: an Indian perspective. Macmillan, Delhi, pp 253–81

International Scientific Steering Committee (2005) Avoiding dangerous climate change: international. Symposium on the stabilization of greenhouse gas concentrations. Hadley Centre Met Office, Exeter

Kaechele H, Amjat-Babu TS, Cutter T, Specht K, Nautiyal S, Muller K, Raju KV (2011) Confronting the climate change challenge: discussing the role of rural india under cumulative emission budget approach. Environ Sci Policy 14:1103–1112

KICS (2011) Knowledge Swaraj: an Indian manifesto on science and technology. Knowledge in Civil Society, Secunderabad

Nadkarni MV (2011) Ethics for our times—essays in gandhian perspective. Oxford University press, New Delhi
Olivier JGJ, Janssens-Maenhout G, Peters JAHW (2012) Trends in global CO2 emissions. 2012 report. PBL Netherlands environmental assessment agency, The Hague. Joint Research Centre, Ispra
Pande V (2011) India at cancun: emergence of a confident dealmaker. Economic and Political Weekly 46(4):14–15
Parikh J, Pande M, Ganesh Kumar A, Singh V (2009) CO_2 emissions structure of Indian economy. Energy 34:1024–1031
TOI (Times of India) Team (2011) Gandhi's Ahmedabad , New Delhi: Times Group Books
World Bank (2010) World Development Report 2010: Washington DC: The World Bank

Author Biography

The author is Hon. Visiting Professor at the Institute for Social and Economic Change (ISEC), Bangalore, and formerly Professor and Head of its Ecological Economics Unit (now CEENR) since its inception from 1981 to 1999. He is a former Vice Chancellor of Gulbarga University in Karnataka and National Fellow of ICSSR. He heartily thanks Sunil Nautiyal for filling gaps in information and getting some of the literature needed.

Ethical Analysis of the Global Climate Dilemma

S. L. Rao

1 What is an Ethical Analysis

Prof MV Nadkarni in 'Ethics for our Times' says that ethical propositions apply to everyone. Ethics like Economics, involves choice between different kinds of life. It promotes the welfare of all. Ethics is not meant only for individuals acting in isolation. It is in the 21st century that people have realized the true interdependence of all people in the world. Carbon emissions and climate change have led to understanding that development in one part of the world can harm others and in the future as well.

2 Developed Countries: Lifestyles and Carbon Emissions

The real crisis in the developed world, exemplified by the USA, is about the unwillingness of the American people and their Leaders to take the measures that will change the psychology and behaviours that have led to the crisis of the new millennium.

For at least the last decade, the USA (many developed countries have followed suit) has taught its citizens that saving is unimportant, that there need be no limits to household or government borrowing, and that otherwise unaffordable luxuries

The author is the first Chairman of the Central Electricity Regulatory Commission, Govt. of India. He was Director-General of NCAER (National Council of Applied Economic Research) from 1990–1996. He was also Chairman of the Institute for Social and Economic Change, Bangalore, (2004–2010). For more detail see: http://www.slrao.com

S. L. Rao (✉)
Distinguished Fellow, Emeritus, The Energy and Resources Institute (TERI), New Delhi,
D-1, Chartered Cottage, #8, Langford Road, Bangalore 560025, India
e-mail: surendral.rao@gmail.com
URL: http://www.slrao.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_4, © Springer-Verlag Berlin Heidelberg 2013

can be had today. This was a transformation from the thrifty American pioneers who made the United States. Brilliant minds in New York created financial products that nobody quite understood. Sub-prime packages, options and derivatives, and many other products built by packaging and repackaging the original debt instruments, ultimately led to the collapse in 2008. It was government money that stopped the collapse from going further and to some stability among banks and financial firms. But the American economy took a bad hit.

Manufacturing had already migrated largely overseas, especially to China. Imports were a major portion of American household consumption, especially from China, paid for by China accumulating (in 2011) over 3 trillion dollars of American Treasury bonds. It helped make China the second largest economy in the world and soon to overtake the USA. The USA was, and remains, a vibrant, highly productive and very innovative economy. It also has a substantial government or employer funded social security system. That combined with easy access to credit, has led to almost zero household savings. Government also spent massively on keeping peace in the world and spreading democracy under force of arms. In addition, the USA has always kept energy prices low under a regime of low taxes, encouraging gas guzzling cars, excessive air conditioning, powerful lighting, etc.

American household debt in annual disposable personal income was 127 % in end 2007, versus 77 % in 1990. The US home mortgage debt to gross domestic product (GDP) rose from an average of 46 %, during the 1990s, to 73 % during 2008. In 1981, US private debt was 123 % of GDP; by the third quarter of 2008, it was 290 %. (Much higher later year figures were not easily available). The USA is a debtor economy.

Low interest rates stimulated the economy, and also reduced government interest payments. Budgeted net interest on the public debt was approximately $240 billion in 2007 and 2008, 9.5 % of government spending. Interest was the fourth largest single budgeted disbursement category, after defence. Despite higher debt levels, this declined to $189 billion in 2009 or approximately 5 % of spending, as average interest rates declined from 1.6 % in 2008 to 0.3 % in 2009.

In January 2011, foreigners owned $4.45 trillion of U.S. debt, approximately 32 % of the total debt of $14.1 trillion, largest holders being the central banks of China, Japan, United Kingdom and Brazil. The share held by foreign governments has grown from 25 % of public debt in 2007 and 13 % in 1988. Not surprisingly, these creditor countries are flabbergasted at the American economic decline since it will result in a decline the American dollar value and in the value of their American holdings.

The Laffer curve was the Bible for Reagan and the Bush junior. It focused on reducing tax rates but without controlling expenditures. Reagan and Bush junior greatly increased government deficits, but also cut taxes. Clinton balanced the budget, and left a budget surplus that was squandered by the junior Bush. The conservative 'Tea Party' Republicans want government expenditures to fall sharply, mainly on measures that help the poor and the aged, but tax loopholes and rates for the rich should be untouched. Obama would like to cut defence expenditures, collect more from the rich, and save on social expenditures with more efficiency. But he had squandered two years when Democrats controlled both Houses. Instead of pushing ahead with his programme, he tried for bipartisan support, and failed.

If the Americans are to emerge from this crisis of overspending, there must be sacrifices in spending, both at the household and the government levels. This will mean a reduction in living standards and some social benefits. Overseas, the USA can no longer be the unilateral superpower, and must develop allies that it listens to and who participate in sharing the cost of keeping the peace. Grand ideas of spreading democracy must be given up. Energy and carbon taxes must be introduced as well as incentives for improving productivity and innovations. A more insular inward-looking USA is inevitable. America's demographic composition and vibrancy will raise the American economy as past bad economic habits of households and governments are abandoned. Before these happen, there will be considerable political and economic disruption.

The USA's economic policies ignored their effects on the rest of the world. It also ignored the vast additions its policies have made to the carbon stock in the environment. One can say that American economic policies have been unethical. The same comment can be made about all developed countries. It could also be made of the imitation of their lifestyles in developing countries, in the sure knowledge that they will further increase the prospects for severe climate change.

Developed countries have to move towards maximum efficiency in energy use, making maximum use of renewable energy instead of carbon emitting energy, and to make technologies available easily and cheaply to developing countries as well so that their development is with least addition to the carbon stock in the atmosphere.

3 India

In this Section we consider the developments in the Indian economy and the directions in which they will affect accelerated climate change.

4 Global (Climate Change) Adaptation Index

The Global Adaptation Index (GaIn) summarizes a country's Vulnerability to climate change and other global challenges on the one hand and its Readiness to improve resilience on the other hand. It aims to help businesses and the public sector better prioritize investments for a more efficient response to the immediate global challenges ahead (Table 1).

Table 1 Global adaptation index country rankings (higher scores are better)

Country	Score	Rank	Country	Score	Rank
Top 5 countries			*Bottom 5 countries*		
Denmark	85.3	1	Ethiopia	40.3	157
Switzerland	83.5	2	Chad	38.4	158
Ireland	82.2	3	Burundi	38.1	159
Australia	82.0	4	Zimbabwe	38.0	160
New Zealand	81.6	5	Central African Republic	37.6	161
Position of China and India					
China	60.3	96	–	–	–
India	53.6	117	–	–	–
Vulnerability			*Readiness*		
China	0.262[a]	70	China	0.470	17
India	0.480[a]	59	India	0.480	18

Source India and China like the developed countries are in between. Except for the five most adapting countries mentioned above, developed countries have yet to go a long way. They have yet to resolve the ethical dilemma of doing something to mitigate the acceleration of carbon emissions and climate change created by them

Note [a] indicates time series vulnerability scores showing upward trend

5 India: Growth and Inflation

India has shown high but erratic growth except in transport, storage, and communication, which have been consistently high since the liberalization of the economy in the 1980s. However, inflation has invariably and periodically stunted growth. Indian policy-makers have been in search of the growth rate that does not create unacceptable levels of inflation. Since the turn of the century, this level has been rising as can be seen from the Charts. Between 2005 and 2008 when growth was 8.6, 8, 7 and 8.0 %, respectively, inflation was moderate at or below 6 %. Inflation spurted from 2007 to 2008 and with the global recession, in 2008, growth declined in 2008–2009 to 6.7 %. Inflation has remained high and growth moderate. Inflation, especially of food products, hurts the poor and there is a major dilemma in allowing persistent inflation in order to maintain high economic growth (Fig. 1).

The proximate causes of inflation have been energy prices, food prices, capacity utilization, investment activity, and business and consumer confidence in the economy and government policies, energy imports of petroleum, oil and lubricants, account for 30 % of total imports. Because the retail prices of petroleum diesel, kerosene, are controlled by government, their prices have not always changed with prices of crude. Instead, the government has absorbed the higher costs because of higher crude prices in its budgets or as a loss to the public enterprises that refine and are principal suppliers domestically. This obviously has pushed up government's fiscal deficits and maintained a strong underlying pressure on overall prices in the economy. The rise in crude prices is largely due to relatively inelastic supplies and growing demand, especially because developing

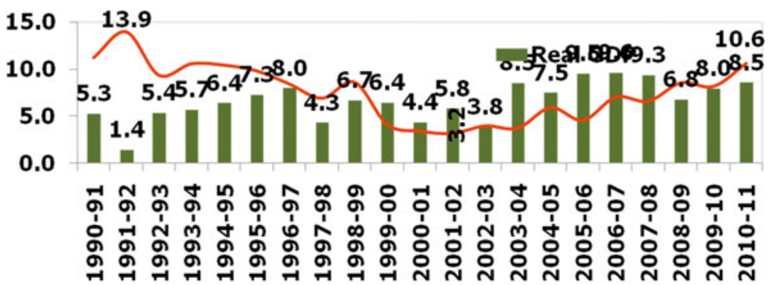
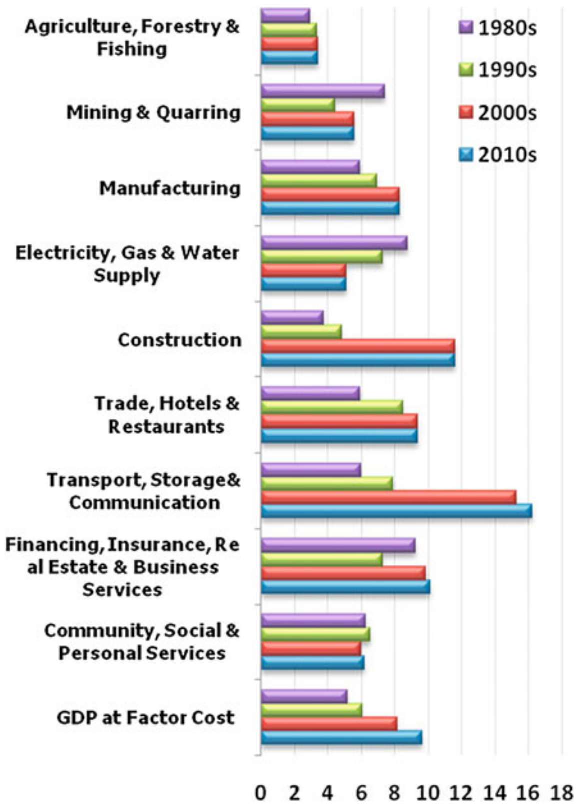


Fig. 1 Overall performance of Indian economy—year to year changes in real GDP and inflation rate: 1990–1991 to 2010–2011. *Note* Based on figures from handbook of statistics on Indian economy 2010–2011, RBI. Real GDP at 2004–2005 constant prices

countries were increasing consumption, while developed countries kept their consumption at extremely high levels (Fig. 2).

Food prices have been another cause of inflation. Productivity of agriculture has generally been declining in India and particularly so in food grains. However, dramatic changes in Indian diets at all income levels have put pressure on demand

Fig. 2 Decade-wise GDP growth of India (Based on data from Annual Economic Surveys, Government of India)



for pulses, vegetables and, particularly, staples like onions, and sugar, and the erratic behaviour of their prices have reflected this. They have been affected also by exports and speculation. There are some doubts about the motives for allowing exports even when prices were rising. During 2011, when onion prices rose sharply with exports and government stopped exports, producers and intermediaries held on to stocks in the knowledge that government could be pressed to resume exports.

India had the great advantage in the new century of a sharp rise in domestic savings rates, mainly due to high corporate savings due to high corporate profits. This also led to high rates of investment which stimulated growth. Since much of this high profitability was in services, especially the information technology sector, considerable investment went there.

Indian growth has been skewed towards services and not to the 'real' economy of agriculture and industry, particularly manufacturing. Agriculture growth rates have been lower than the overall average GDP growth, erratic from year to year, and lower than industry and services. Industry has shown lower growth than services, and has been inconsistent from year to year. Service sectors in infrastructure like transport, and construction have shown better growth, largely driven by public investment. The relatively high capacity utilization in consumer products also meant that a surge in demand would raise their prices (Table 2).

With further and continuing massive investments in infrastructure, transport, and manufacturing, India can expect demand for manufactured goods to zoom and the contribution of industry, including manufacturing, to GDP to rise. Inevitably, this will require much more carbon intensive products. Low carbon emissions by India are mainly a reflection of the manufacturing capacities of consumer goods not having risen very fast. Similarly, the output of agricultural products has also not risen fast. This has meant that any supply constraint is quickly transmitted to prices since there is little excess capacity to meet demand. As the capacity rises, as it should, carbon emissions will also rise sharply.

6 Employment and Poverty

The pattern of growth in past years has resulted in employment growth being concentrated in the service and infrastructure sectors, and not in agriculture which has over 60 % of the population dependent on it. This has led to wide inequalities in income distribution. While overall poverty levels defined in calorie consumption terms have declined, there are still over 300 million extremely poor people in India. With limitations on cultivable land availability, agricultural growth must come from significant improvements in productivity which will need more water, fertilizers, pesticides, etc., all of which require substantial additional energy.

Table 2 Sector-wise GDP growth rates (%) at 2004–2005 constant prices

Item	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010[a]	2010–2011[b]
Agriculture, forestry and fishing	*5.1*	*4.2*	*5.8*	*−0.1*	*0.4*	*6.6*
Industry	*9.7*	*12.2*	*9.7*	*4.4*	*8.0*	*7.9*
Mining and quarrying	1.3	7.5	3.7	1.3	6.9	5.8
Manufacturing	10.1	14.3	10.3	4.2	8.8	8.3
Electricity, gas and water supply	7.1	9.3	8.3	4.9	6.4	5.7
Construction	12.8	10.3	10.7	5.4	7.0	8.1
Service	*11.0*	*10.1*	*10.3*	*10.1*	*10.1*	*9.4*
Trade, hotels, transport and communication	12.2	11.6	11.0	7.5	9.7	10.3
Financing, insurance, real estate and business services	12.7	14.0	11.9	12.5	9.2	9.9
Community, social and personal services	7.7	2.9	6.9	12.7	11.8	7.0
GDP at factor cost	*9.5*	*9.6*	*9.3*	*6.8*	*8.0*	*8.5*

[a] Quick estimates
[b] Revised estimates
Source Economic outlook 2011–2012, Economic advisor council to prime minister, New Delhi—GoI

Table 3 Water requirements for different uses in India (Qty in billion cubic meter)

Different uses of water	1990	2000	2010[a]	2025[a]	2050[a]
Domestic	32 (6.4)	42 (6.6)	56 (6.9)	73 (6.7)	102 (7.0)
Irrigation	437 (87.1)	541 (85.3)	688 (84.6)	910 (83.3)	1072 (74.1)
Industry	–	8 (1.3)	12 (1.5)	23 (2.1)	63 (4.4)
Energy	–	2 (0.3)	5 (0.6)	15 (1.4)	130 (9.0)
Others	33 (6.6)	41 (6.5)	52 (6.4)	72 (6.6)	80 (5.5)
Total	*502*	*634*	*813*	*1093*	*1447*

Note Figures in parenthesis are percentages to total and [a] Forecasted estimates. Figures from Government of India (2002), Compendium of Environment Statistics, 2002, Ministry of Statistics and Programme Implementation

7 Ground Water Use

India has the highest usage of ground water in the world with an estimated use of 230 cubic kilometres of groundwater every year—more than a quarter of the global total. In fact, groundwater use has been steadily increasing in India over the last 4–5 decades. Today, groundwater supports approximately 60 % of irrigated agriculture and more than 80 % of rural and urban water supplies (World Bank). However, groundwater resources are being depleted at an alarming rate. Today, 29 % of groundwater blocks are semi-critical, critical, or overexploited, and the situation is deteriorating rapidly. By 2025, an estimated 60 % of India's groundwater blocks will be in a critical condition, while overall water usage will rise by 25 %. As poverty reduces, the real economy of agricultural and industrial products must show greater growth. This will further accelerate energy usage and carbon emissions. Most ground water extraction uses electricity which is supplied either below cost or free for the purpose. Climate change will further strain ground water resources (Table 3).

8 The Burden of Traditional Fuels in Rural India

Over 500 million people are not connected to electricity and burn dry leaves, twigs and branches in squalid and unventilated huts. This adversely impacts on the health of women and children. India has the highest incidence of tuberculosis in the world. Respiratory symptoms are prevalent among 24 million adults of which 17 million have serious symptoms. 5 % of adults suffer from bronchial asthma, 16 % from Bronchitis, 8.2 % from Pulmonary TB and 7 % from chest infection. India has the highest incidence of tuberculosis in the world (138 per 100,000 households versus 99.7 for the world. The risk of contracting respiratory diseases and eye diseases increase with longer duration of use of bio-fuels.

Forests contribute 39 % of the fuel wood needs and 314 Mt of bio-fuels are gathered annually. About 85 million households spend 30 billion hours annually in fuel wood gathering. The total economic burden of dirty biomass fuel was estimated to be Rs 299 billion. Obviously, depletion of forests is also a factor in climate change and must be reduced.

Biomass added 577 million tonnes to emissions. Women and girls bear the drudgery of collecting biomass, and the health impact of burning biomass is on women and children, who are usually indoors. The lack of safe and convenient energy leads directly or indirectly to illiteracy, gender inequality, disempowerment, high infant and maternal mortality. To eradicate such abysmal poverty of so many, India needs consistent and inclusive GDP growth of 8 % per annum over the next 25 years and must improve access to modern commercial energy for all (*Source survey of a Sample of 15,293 rural households from 148 villages in three states of rural North India and one state in South India*).

9 Economic Growth and Requirements of Commercial Energy

It will be seen from the table below that at 9 % annual growth of GDP, the installed capacity of commercial energy, assuming a declining elasticity of use, will rise from 155 GW in 2006–2007 to 960 GW in 2031–2032 (Studies by TERI-The Energy and Resources Institute, New Delhi). Even this growth will leave per capita consumption far behind that of many other countries. Energy consumption in 2003 and that projected for India in 2031 by TERI are compared with some others in Table 4.

The present ratios between different energy sources are given in the next diagram. A sharp increase in manufacturing to 40 % of GDP will change the energy requirements considerably upwards. Among the electricity sources, the potential

Table 4 Per capita energy consumption by country—2010

	TPES (Kgoe)	Electricity consumption (KWh)	Oil (Kgoe)	Gas (Cu.m.)	Coal (Kg)	Nuclear (KWh)	Hydro (KWh)
India	447	786	133	53	237	20	95
India[a]	1250	2471	331	149	925	256	273
China	1829	3162	322	82	1288	56	542
Japan	3950	9032	1590	745	976	2306	671
OECD	4534	8880	1721	1259	899	1875	1114
U.S.A.	7368	13944	2740	2203	1691	2738	837
South Korea	5242	10223	2171	882	1563	3039	77
World Av.	*1751*	*3112*	*588*	*462*	*519*	*404*	*500*

Note [a] for year 1931–1932 projected at 8 % GDP growth. Per capita coal consumption of India has been estimated based on cabrific value of lard coal used internationally (6,000 kcal/kg) to maintain uniformity

Source Integrated Energy Policy—Report of Expert Committee Pg. 32, BP Statistical Review of World Energy 2011, International Energy Statistics, IEA database

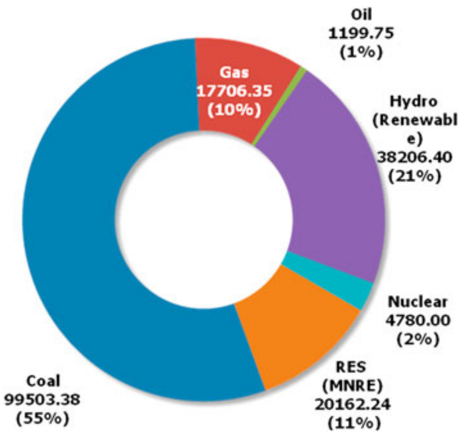


Fig. 3 Energy sources—installed capacity—as on August 31, 2011 (figures in MW) (*Source* Ministry of power, government of India)

growth for hydro is limited by land shortages, environmental considerations, geological, political, and resettlement and rehabilitation problems. Flexibility in supplies is possible from the use of coal, gas, nuclear and renewable energy. Of these, coal is the highest carbon emitter and India will need considerable quantities of coal in the coming years (Fig. 3).

The chief fuel for India's power needs is coal. Uranium could contribute a large quantity. It is 3 % now because India has been a loner, shunned by the nuclear suppliers' group for some years, depending on the Soviets for some technology and India's scientists for developing technologies. Financing nuclear generation is expensive and India has not allowed private sector entry into this sector. This has been another limitation on expanding capacity. The agreement with the Bush Administration brought India out of the cold. There are plans now to add substantially to nuclear power capacity. After the Fukushima accident in Japan, additional safety features are expected to add significantly to costs of nuclear power, adding the fresh dilemma of high cost electricity in a country where electricity costs are already unaffordable to a large number (Table 5).

Table 5 possible development of nuclear installed capacity—2010 to 2050 (In Giga watts of electricity)

Years	Optimistic	Pessimistic
2010	11	9
2020	29	21
2030	63	48
2040	131	104
2050	275	208

Note It is assumed that (a) Successful Fast Breeder Reactor (FBR) Technology by 2011, (b) 8 Giga watts of Light Water Reactor acquired through imports by 2017, and (c) Developed Advanced Heavy Water Reactor using Thorium by 2020

Source Department of Atomic Energy, Govt. of India

Projections of Energy Requirements

This increase in energy requirements will still leave India as a relatively energy efficient economy. But, while it will use less energy in relation to output growth, it will still add to the carbon stock (Fig. 4, Tables 6, 7).

The fuel sources required for the purpose are given in the next slide. But from the slide above it is clear that India will not become an energy intensive economic power in the coming decade. India's GDP in 2019–2020 would be about 4.5 times what it was in 2001. However, total energy requirement would have barely doubled since then. Endemic lack of energy has created an economy that is not as energy dependent as (say) China. India's growth relies more on services that are typically less energy intensive than manufacturing (Table 8).

Coal (from domestic sources and imports) will continue to dominate. Gas might grow a little faster because of large gas discoveries on and offshore in India. Nuclear energy will continue to be a small fraction of our needs because of the high cost of equipment and technology, as well as the anticipated rise in uranium prices. While India does not have uranium in any quantity, its gas reserves have increased recently but can meet only some of the additional demand, most of which will continue to have to be met from coal, which is going to be in short supply domestically. Uranium, coal, gas, will all have to be imported, leaving the economy at the mercy of international market prices and India's ability to export its goods and services to earn the foreign exchange needed.

India has substantial indigenous capability in nuclear energy developed over the last 60 years, strong research and scientific institutions, and a growing team of well trained research scientists and engineers in the field. India has been unable to make nuclear energy its best alternative to increasing use of coal and, thus, limit carbon emissions. Until the agreement during the Bush Administration, this was

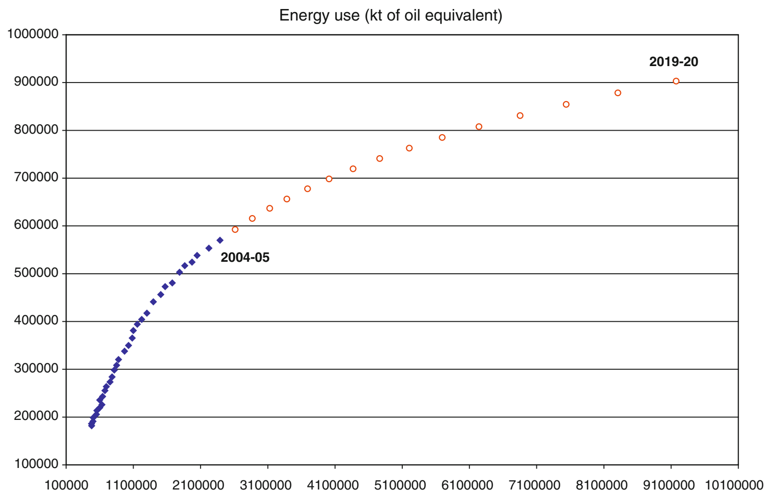


Fig. 4 Expected energy demand *Source* Analytics Pvt. Ltd

Table 6 Economic growth and energy requirements: projected commercial primary energy requirements (based on falling elasticities)

	Total energy requirement (BkWh) @ GDP growth rate		Energy required at bus bar (BkWh) @ GDP growth rate		Projected peak demand (GW) @ GDP growth rate		Installed capacity required (GW) @ GDP growth rate	
	8 %	9 %	8 %	9 %	8 %	9 %	8 %	9 %
2003–2004	633	633	592	592	89	89	131	131
2006–2007	761	774	712	724	107	109	153	155
2011–2012	1,097	1,167	1,026	1,091	158	168	220	233
2016–2017	1,524	1,687	1,425	1,577	226	250	306	337
2021–2022	2,118	2,438	1,980	2,280	323	372	425	488
2026–2027	2,866	3,423	2,680	3,201	437	522	575	685
2031–2032	3,880	4,806	3,628	4,493	592	733	778	960

Note Electricity generation and peak demand in 2003–2004 is the total of utilities and non-utilities above 1 MW size. Energy demand at bus bar is estimated assuming 6.5 % auxiliary consumption. Peak demand is estimated assuming system load factor of 76 % up to 2010, 74 % for 2011–2012 to 2015–2016, 72 % for 2016–2017 to 2020–2021 and 70 % for 2021–2022 and beyond. The installed capacity has been estimated keeping the ratio between total installed capacity and total energy required constant at the 2003–2004 level. This assumes optimal utilisation of resources bringing down the ratio between installed capacities required to peak demand from 1.47 in 2003–2004 to 1.31 in 2031–2032

Source Integrated Energy Policy—Report of Expert Committee Pg. 30

Table 7 Expected growth in GDP and energy

Years	GDP[a]	Energy use[b]
1971	478,918	181,983
1981	678,033	255,362
1991	1,099,072	381,117
2001	1,972,605	524,257
2009	3,691,518	677,641
2019	9,176,341	902,960

[a] at factor cost (constant prices) ….. in Rs.crores

[b] Kt of oil equivalent

Source The Energy and Resources Institute (TERI), New Delhi

due to strict curbs on India's imports of uranium and limited access to nuclear technology. It is now planning significant additions to nuclear energy capacity.

India will, in coming years, add substantially to nuclear power capacities but will continue its high dependence on coal. This is necessary since using coal as a dominant fuel for economic growth will make India's carbon emissions unacceptably high to the developed countries. To combat climate change, India requires substantial nuclear energy capacity. India expects to raise nuclear generation capacity from 4,120 to 20,000 MW by 2020, to 63,000 MWe by 2032, and aims to supply 25 % of its electricity from nuclear power by 2050. India bases its projections not merely on imported technologies and uranium, but hopes in a decade or so to breakthrough in using its large reserves of thorium (Table 9).

Table 8 Commercial energy requirements: one scenario—coal dominates; Oil next; Gas could rise (figures in MToe)[a]

	Hydro	Nu-Clear	Coal		Oil		Natural Gas		TPCES	
			8 %	9 %	8 %	9 %	8 %	9 %	8 %	9 %
2011–2012	12	17	257	283	166	186	44	48	496	546
2016–2017	18	31	338	375	214	241	64	74	665	739
2021–2022	23	45	464	521	278	311	97	111	907	1011
2026–2027	29	71	622	706	365	410	135	162	1222	1378
2031–2032	35	98	835	937	486	548	197	240	1651	1858
CAGR[b] (per cent)	*5.9*	*11.2*	*5.9*	*6.3*	*5.1*	*5.6*	*7.2*	*8.0*	*6.0*	*6.4*
PC[c] in 2032	24	67	569	638	331	373	134	163	1124	1266
PC[c] in 2004	6.5	4.6	157	157	111	111	27	27	306	306
Ratio 2032/2004	*3.7*	*14.6*	*4.1*	*2.9*	*2.9*	*3.4*	*5.2*	*6.3*	*3.7*	*4.1*

Note a = Million Tonnes oil equivalent
[b] CAGR = Compound Annual Growth Rate
[c] PC = Per Capita Consumption in Kg
Source Integrated Energy Policy: Report of the Expert Committee: 28

Table 9 Maximum values of domestic coal availability—not enough for needs (in million tonnes) Source National Energy Map for India: Technology Vision 2030

Fuel	2001–2002	2036–2037
Coking coal	27	50
Non-coking coal	299	550
Lignite	25	50

10 Indian Emissions

The table below shows Indian emissions as of now and as projected. The Hybrid scenario assumes lower energy requirements due to higher efficiencies. Indian emissions must be seen in relation to emissions in other countries, including China. India's emissions today and in future years will remain a fraction of the others (Table 10).

Figure 5 shows the per capita carbon emissions by India as compared to some developed countries. The contrast even by 2020 is stark. The nature of the ethical dilemma is clear. A better life for many hundreds of millions will not get them anywhere near that of the people in developed countries. But it will require a reduction in emissions by them and in their use of energy that produces carbon emissions.

Table 10 CO_2 emission profile (in million tonnes)

Sectors	2001	2011	2021	2031
BAU (business as usual)	917	1663	3332	7267
Hybrid	917	1479	2443	4774
Sectors in 2031	*BAU*	–	*HYB*	–
Power	2879	–	1329	–
Industry	2830	–	2510	–
Transport	1377	–	759	–
Others	181	–	176	–
Total	*7267*	–	*4774*	–

Source The Energy and Resources Institute (TERI), New Delhi

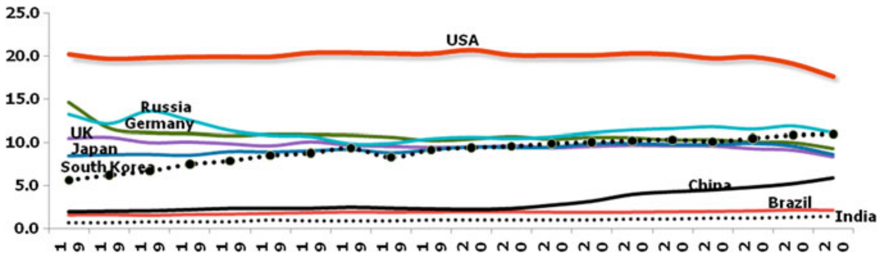


Fig. 5 Per capita of CO_2 emission from consumption of energy (in metric tonnes per person) (*Source* Based on international energy database)

11 Domestic Political Concerns

The large number of poor in India will need to be supplied electricity at prices affordable to them, if not free. The farmer community in India has for long suffered lower prices for agricultural output as compared to international prices, principally to protect the urban industrial working class who would get cheaper food. This has led to farmers being supported by the government with fertilizers supplied at lower than market prices, and electricity free or below cost to extract ground water. This has made electricity distribution entities mostly owned by state governments, suffer massive losses (estimated at Rs 100,000 crores in 2011) that are supported from state government budgets at the sacrifice of investment in physical and social infrastructure. An increase in manufacturing to GDP will also affect energy requirements.

The retail prices for electricity have, thus, been un-remunerative and have for long kept private investors out of the generation business, which is dominated by central and state governments (34, 52 % and the rest with private generators). In recent years, a set of pricing and market options as a result of imaginative government policies have allowed private investors to invest in energy for trading purposes and also for supplies to government distribution enterprises at acceptable prices. Payments have been ensured by letters of credit and escrow accounts.

All fuel prices the world over have been rising in sympathy with those of oil and gas. As the country moves to protect its energy security, more expensive sources of fuels, like imported coal, LNG, uranium, etc., are inevitable. This will raise input costs further, along with the rising costs of equipment. Thus, the tariff subsidies that are eating big holes into the state government budgets will have to come down. At the same time, more precise targeting of beneficiaries is inevitable, to limit the subsidy costs to vulnerable consumer groups. This will become easier with the project to provide unique identity numbers to all Indians. Higher tariffs will make investment more attractive for the private investor.

Energy consumption is unlikely to fall despite higher tariffs. The poor and vulnerable groups will need to be subsidized and government budgets must provide for it. In contrast with wasteful energy use in developed countries, many in India have either no access or cannot afford the cost of clean energy.

The Indian concern with energy security will also lead to a scramble for overseas assets in coal, oil, gas and uranium (if that were possible). This will also add to the pressure on tariffs domestically.

12 Renewable Energy

The following table shows the potential availability and present exploitation of renewable energy sources in India. It must be recalled that renewable energy capacity is always much larger than how much it can actually deliver. It is variable in supply as far as wind and solar are concerned (because of wind speed and the sun rays being available only in the day) and there is yet no inexpensive way to store and use the energy later. At present, all renewable energy is expensive as compared to the present ones. It is unlikely, in the foreseeable future, that renewable energy can meet the vast additional needs of energy in India. It can only supplement supplies (Table 11).

The central government has announced a national renewable energy policy which envisages 10 % of additional grid power from renewable energy generation capacity. The installed capacity from grid-interactive renewable power, which stood at 3,500 MW in 2005, has now risen to around 6,050 MW. As much as 18 %

Table 11 Renewable energy source: potential/availability and exploited

Source/technology	Units	Potential/availability	Potential exploited
Biogas plants	Million	12	3.22
Biomass—based power	MW	19,500	384.00
Efficient wood stoves	Million	120	33.86
Solar energy	MW/km^2	20	1.74
Small hydro	MW	15,000	1398.00
Wind energy	MW	45,000	1367.00
Energy recovery from wastes	MW	1,700	16.20

Source The Energy and Resources Institute (TERI), New Delhi of the additional grid interactive renewable power capacity, i.e., 2,602 MW that was commissioned during the first 3 years of the 10th Plan came from renewables. Of this, 13.5 % has come from wind power with the balance 4.5 % coming from small hydro power (2 %) and bio energy (2.5 %). The constraints are that the actual energy available is around 30 % of capacity in wind and solar, there is an erratic availability, no storage is possible, and the costs are high. Despite this, the state regulators have imposed a requirement on distribution companies to buy specified proportions as renewable and this of course raises costs. The central regulator is also making it possible for states with low renewable energy potential to buy the performance of other states and offer that as their contribution.

A more certain way to enhance renewable energy supplies is to use waste heat recovery and co-generation. India has also the possibility of using the hydro resources available in Bhutan and Nepal. While Bhutan is already supplying power to India and benefitting its economy and the living standards of its people, any possible Nepal supplies are mired in Nepal politics. But this is a source that might be useful to reduce India's use of carbon emitting energy. However, the water in these countries is from Himalayan Rivers and will be affected by melting glaciers due to global warming.

13 Green House Gas Mitigation

Industry can also do a lot to reduce emissions. Targeted industries that are high emitters can be taught to bring it down and also be given incentives for the purpose. The principal industries that are being targeted under the PAT scheme are: Power, Fertilizer, Chlor-Alkali, Iron & Steel, Cement, Textile, Pulp & Paper, Aluminium and Railways.

Energy efficiency improvement can also make for more power becoming available by using less for the same output. The Bureau of Energy Efficiency (BEE) has launched the Perform Achieve and Trade (PAT) initiative, under the National Mission for Enhanced Energy Efficiency, which is a market based mechanism to enhance cost effectiveness of improvements in energy efficiency in energy-intensive large industries and facilities, through certification of energy savings that could be traded. This scheme is part of the National Action Plan on Climate Change (NAPCC) which was introduced on June 30, 2008 to outline India's strategy to meet the challenge of Climate Change. The BEE is setting targets for efficiency and there is a proposal to enable it to impose stringent penalties for non-performance.

14 Technology

If India is to accelerate economic growth and also mitigate carbon emissions, it will require cheap and quick access to technologies for reducing costs of solar and wind power, access to new and efficient storage technologies, efficient power generation equipment, nuclear technology with safeguards and insurance against accidents, and also at affordable costs, as well as other technologies to improve the efficient use of energy. These must come from developed countries and will also require their financial support.

15 Conclusion

A democracy with many poor people, economic growth as a paramount consideration, consequent need for substantially more energy, severe limits on domestic fuel resources, and constraints on foreign exchange for importing fuels, gives little choice to India except to use coal as the major fuel. Reducing and mitigating emissions, while enabling a better life for its people, requires a high economic growth rate to lift people out of poverty, and coal as the only fuel that can produce enough energy for its needs. Nuclear, gas, etc., are supplementary, not replacements for coal. India has many policies to mitigate carbon emissions. It is getting ready to charge higher tariffs to the consumer, politically a great challenge. At best, India can maintain its carbon emission levels in relation to GDP, but they will certainly not reduce. It would be unethical to deprive so many millions from a better life.

Developed countries face a monstrous ethical dilemma. Their people have to make drastic changes in lifestyles. A carbon tax on exports from India and China would be very unfair, making these countries pay for perpetuating lifestyles of the rich. India could be more efficient in its use of electricity and it's pricing. However, the gap between need and usage is extremely wide and policy changes will make little difference to India's carbon emissions. One way that countries like India can reduce carbon emissions in relation to GDP is by developing more modest lifestyles, not imitating the rich countries. Whether this is possible in an increasingly integrated world, is doubtful.

It is the lifestyles of the rich countries, the enormous energy and emissions required to sustain them that stand out in comparison. If carbon emissions are to be controlled, it is the rich that have to do most of the running since developing economies will only consume more over the years as their poor improve their living standards.

Ecosystem-Resilience: A Long Journey to Nature Policy

Giridhari Lal Pandit

Dedicated to the Memory of my Mother Schobhawati (Dhanai Razdan) Pandit (1925-2004)

1 A Philosophy of Ecology-Based Resource-Management and Development Policy

Does nature have her own well-being interests, just as children or future generations have? If humans are part of nature, are they responsible for nature? If the answer is yes, then there arise two fundamental questions. First, is it enough to leave it to science to understand nature and her well-being interests? Is it enough to leave it to science to understand *how* we might fulfil our responsibility for safeguarding nature's or our own well-being interests? Secondly, who will protect nature's well-being interests, if nature cannot do it herself in those situations where she comes under the destructive impact of human activity? Similar questions arise regarding children and the future generations.

By bringing nature's well-being interests *back in*, as I propose to do here, ethics gets its *new* and proper foundations in a single step. There is not only a similarity between nature and children, and the future generations, as regards the ethical question of how best to understand and fulfil our responsibility to safeguarding their well-being interests and our own well-being interests. We must remember that there is an *asymmetry* between nature and humanity, between the living planet Earth and the species *Homo sapiens* (Pandit 1996, 1999a, 2007a, d, 2009b). By fulfilling the responsibility to protect nature's well-being interests, humanity could also fulfil its responsibility to protect its own well-being interests. It does not work the other way round. If humanity has to protect its well-being interests, it becomes

G. L. Pandit (✉)
University of Delhi South Campus, New Delhi 110020, India
e-mail: giripandit@yahoo.co.in

G. L. Pandit
Centre for Ecological Economics and Natural Resources, Institute for Social and Economic Change, Bangalore 560072, India

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_5, © Springer-Verlag Berlin Heidelberg 2013

its *duty* to protect nature's well-being interests. By engaging in destructive and harmful activities which have a destructive impact on environment, we would be only destroying nature and her life-supporting ecosystems. Think of a cancerous cell which destroys the entire host organism in which it grows and proliferates. Thus, the best way to protecting humanity's well-being interests is to pursue our development goals and natural resource management strategies by working *with*, but not *against* nature. But how should we go about this most challenging task?

Humanity today stands at the crossroads, facing so many challenges, locally and globally. Measuring the impact of man's ecological footprint on the biosphere and the extent of humanity's current demand on the planet's bio-productive capacity, so as to draw common lessons on how we might live within the regenerative capacity of the biosphere, pose a formidable global challenge. The biggest common challenge comes from the question: How to pursue our developmental goals without violating the principle of sustainability, or without violating our nature policy if we have one? Answers to this question will naturally vary according to the varied *perspectives* from which we may look at the principle of sustainability as part of our nature policy, or at the progress mankind has made over the past two hundred years and at the impact human activity has had on the biosphere and on the regenerative bio-productivity of Earth's ecosystems. Their formulation will also depend on *how* we relate ourselves, whether individually or collectively, ecologically or economically, to nature or Earth as a whole as we journey forward along the future developmental scenario-building activity. However, no serious attempt to find a reasonable answer to this question can ignore the intimate connection between development and environment (Bruntland WCED 1987), between ecological knowledge of nature and natural resource management. Accordingly, we might say that the biggest common challenge before humanity at the beginning of the 21st century is to find a common way to *nature policy* which can constrain as well as guide each society to pursue its developmental goals as *wisely* and *sustainably* as possible.

As a necessary ecological condition for sustainability, a sound nature policy can teach humanity the ethical value of the humanity's need to keep human demand on nature's resources, including the resource-needs of future generations, within the amount that nature can supply. It can teach humanity the self-destructive consequences of *ecological overshoot*. Above all, it can teach humanity to view and understand nature from different perspectives, depending on our ability to distinguish between the intrinsic and extrinsic values of nature. Thus, it can guide humanity in learning to *de-domesticate nature*, i.e., to decelerate the processes of domestication of nature by the market-dominated processes of creative destruction (Pandit 2004b, 2011).

What humanity needs urgently, therefore, is nothing short of a nature policy, i.e., a philosophy of ecology-based development policy which allows us to *wisely* rethink our individual or collective options for developmental scenario-building and natural resource management. As a key to the new paradigm on the horizon, a nature policy can help humanity in retrieving its lost connections with nature by building interfaces between society, economy, policy and ecology so as to enable humanity to work *with* and not against nature. It can also help us in closing the gap between ecology as a science and the natural resource management.

Despite scientific and technological progress, humanity is still asking the question: What is nature? How and under which perspectives should we understand her (Honnefelder 2011a, 2011b, Pretty 2007)? How should we develop ecological knowledge about nature in order to manage earth's ecosystems, of which we are only a tiny part (Pandit 1995, 1999a, 2000a, 2001a; Schwarzburger 1998; Wagner 2000)? If humanity has separated itself from nature, thanks to our scientific achievements and intellectual arrogance, how should we reconnect ourselves with nature? These questions are now being seriously asked by different disciplines (Pretty 2007). However, their simplicity is deceptive. They are not easy to answer. This shows clearly that it is not *wise* to depend on science and technology alone to understand nature and to fulfil our responsibility to nature. Despite domestication of nature by man, we must remember that science can no longer aim at conquering nature in order to discover her secrets and to manage her abundant resources. No doubt, science and technology are responsible for much progress which mankind has made. But they have made us arrogant in our approach to natural resource management in so far as, with the help of scientific knowledge (Pandit 1982, 1991), humanity seeks to dominate nature, using her resources exclusively for its own benefit. It is true that science and technology provide us the tools to domesticate nature by creative destruction, resulting in the loss of biodiversity and loss of harmony and balance between nature and man.

Consider how relentlessly humanity has domesticated nature by creative destruction—deforestation, growing commercial crops, burning fossil fuel, accommodating infrastructure for housing, transportation, industry, and hydroelectric power, fishing, harvesting timber and grazing animals—exclusively for the human benefit. Consider how radically we have altered Earth's ecosystems during the past centuries, with individuals and societies thinking and acting exclusively in their own interest (Kareiva et al. 2007), leaving a huge ecological footprint and causing loss of ecosystem resilience on the one hand and raising serious questions regarding natural resource management on the other. Is domestication of nature in this sense an inevitable path to growth and progress for the future generations? Or, is it the biggest obstacle to sustainable development? I think that humanity has still a long way to go before it can truly claim to understand its own place in nature. And it has a long way to go before it can claim to have the *wisdom* how to understand and manage the ecosystem complexity and resilience in all their dynamic richness.

Think of the changes in Earth's ecosystems due to the accelerated domestication of nature (ADN) in the last half a century (Pandit 2011, 2012), driving species diversity out of existence due to habitat loss, causing unsustainable harvesting in the 60 % of fish ecosystems and plundering of ground water sources beyond their replenishment rates in most regions of Earth. As a result, more land has been converted after the Second World War than in the previous two centuries combined (Dalby 2009). Half of the artificial fertilizer used on Earth, since its introduction in 1913, was used in the two decades after 1985 (Dalby 2009). More than a third of the mangroves on Earth have been destroyed since 1945 (Dalby 2009). And if we think of the future generations, the task of dynamic scenario-building for purposes of designing sustainable development strategies or natural resource management strategies becomes far more complicated and challenging. Nothing short of development ethics and Wisdom Inquiry (Pandit 1995, 2007b, c, d, 2008a, 2009b, 2010a, c) can help us in articulating and putting in practice the sustainability principle that each generation has an obligation to protect productive ecological and physical processes necessary to support options necessary for future human freedom and welfare (Norton 2003: 63).

If the latter half of 20th century witnessed a displacement of science from its dominion over nature, thanks to relentless questioning of science policy, the beginning of 21st century is inaugurating a displacement of classical economics, particularly the Adam Smith's model of *The Wealth of Nations*, radically altering our ideas of common wealth and development. There are visible trends of interrogation of the traditional model of business and market mechanism which encourage us to explore how markets can be reformed to fulfil both our individual desires as well as our need to serve the common good.

Contrary to popular belief, development in any context of improvement of the quality of human life is not a value-neutral concept. The simple reason for this is that development is inseparable from environment and natural resource management, involving as it does man-nature interactions. Therefore, issues of sustainable development cannot be tackled in isolation from discussions of ethical and ecological dimensions of human impact on environment and on Earth's fragile ecosystems. In particular, the most important issue concerns the kind of nature policy, the kind of philosophy of ecology, within which alone societies or policy makers can wisely pursue various kinds of context-dependent development goals. The question is what should be the humanity's value-framework, addressing basic issues of balance and harmony between nature and man, within which, particular societies can pursue context-dependent development goals?

We humans are overawed by nature's beauty and by the abundance of her resources. But we fail to perceive her vast ecological complexities. With increasing interrogation of policy, or lack of it, in a science and technology-driven market society (Pandit 2004c, 2007b, c, d, 2008, 2009b, 2010a, b, c, 2011), I think that our journey, long and thorny, towards nature policy, towards the goal of integrated human and non-human interests' studies, has just begun. While focusing on the problems of ecosystem resilience, development and nature policy, in this article I will support my claim by describing very briefly some exemplary steps taken by individuals and by institutions during the last 50 years, seeking to unravel the complexity and interconnectedness which reign supreme at the interface of science, ecology, society, economy, ethics, and population biology. In particular, the research done by individuals, I am going to cite, may have had many unintended consequences, positively impacting the humanity's journey to nature policy. They may have played a decisive role in slowly bringing about a radical change in our perspective, in our long but un-ended journey to nature policy, making it necessary to *rethink* nature as well as science (Pandit 1999b, 1999c, 1995). And they may have brought to the forefront of research, the subject of ecosystem complexity/ecosystem resilience into which the problems confronting humanity are interwoven, thereby, opening up new horizons at the new frontiers of ecological-environmental-developmental problem-solving. I shall conclude with a word on Umweltrealismus/ecological-environmental realism (Pandit 1995) as yet another step in this long journey. Thus, the important question in focus is: Having domesticated nature by creative destruction, using science and technology, is it still within humanity's reach to learn to admire nature from different perspectives, while aiming at ecologically based natural resource management?

Our world today is so much tormented and challenged by global problems, on the one hand, and simultaneously so much dominated by the arrogance of man, on the other. Think of a world somewhat different from our world. Think of a world which is not dominated by Knowledge Inquiry (Pandit 1982, 1991), i.e., by science and technology-based market rationality. Imagine a world, dominated by Wisdom Inquiry, where all the universities, academic institutions and research organizations, on the one hand, and economy and society as well as international institutions, on the other, are highly reformed and revolutionized, with scenario-building at their very core (Pandit 2008a, 2010b).

A nature policy would help us recognize the importance of the method of scenario-building as a method of optimistically exploring the global futures for humanity and the world, for the future generations and, above all, for Earth's ecosystems themselves, all of which are currently challenged by climate-change risks, by unpredictable global futures, and by problems of sustainable development. Therefore, it will not be surprising if in the 21st century, scenario-building, as a paradigm, assumes an increasing role in *rethinking* our world and its institutions.

Scenario-building is a method of exploring possibilities for the global future where complexity and uncertainty reign supreme. Rethinking science and nature, we must remember that science cannot be the sole guide to humanity in the task of meeting the global and regional ecological or environmental challenges. This situation invites the intervention of Wisdom Inquiry (Pandit 1982, 1991, 2007b, d, 2008a, 2009b, 2010b, 2012), which should guide humanity in its collective efforts to work for the best possible scenario for the global future.

1.1 Domestication of Nature

In the present article, 'domestication of nature' refers to Earth's ecosystems being dominated and altered by humans, exclusively in pursuit of self-interest, seeking dominion over nature and leaving a large creative destructive footprint. This is illustrated by land-use practices, clearing of land and water for human use, clearing of forests for agricultural production, for urban planning, for raising cattle, for infrastructure development, and so on and so forth. The twentieth century Aral Sea Catastrophe (Pandit 2004a) illustrates domestication of nature in this sense. Deforestation is another example. Thus, domestication of nature by creative destruction has many adverse consequences. One of these is habitat loss, adversely impacting biodiversity, rendering land inaccessible for habitation by environmental nesting (Pandit 1995), by future generations and by diverse species. While domestication of nature has received some attention recently (Kareiva et al. 2007), accelerated domestication of nature (ADN) has not been researched at all. In fact, no attention has been paid to it.

As an example of ADN, consider "how Around 1.7 million years ago, armed with fire and tools, our ancestors moved out of Africa and across the planet; wherever they went, large mammals disappeared. Culture, in the form of technology, enabled our kind to migrate relentlessly, reproduce without check, and then kill and eat at a rate far beyond the bounds of any local ecosystem (Small 1996: 88B)."

Again, "The shift to sedentary agriculture 10,000 years ago is, to Eldredge, the watershed moment when humans became finally and totally disengaged from nature. Once settled, our forebears used their cultural acumen to build cities, weave complex societies and construct civilizations. We now see this ability as a kind of dominion, and many feel we have a right over the earth and over all creatures in all habitats. As Eldredge puts it, 'We told Mother Nature we didn't need her anymore.' More frightening, he thinks that in recent years, humans have moved even further away from the natural processes of life by becoming globally linked—economically, politically and culturally. No other species has defied nature in this way, and Eldredge suspects there will be hell to pay.'"

As yet another example, consider the fact that between 1982 and 1997, the amount of land consumed for urban development in the United States increased by 47 % while its population grew by only 17 %. Among the indicators of ADN, biodiversity loss, loss of ecosystem complexity due to loss of species habitating by environmental nesting, ecosystems-in-distress, Earth's decreasing bio-productivity, disturbed ecosystem services, global warming, climate change, and the like can be taken as reliable indicators.

In its simplest form, domesticated nature, Kareiva et al. (2007) argue, means nature exploited and controlled for human benefits. What is alarming is that 'Humans have so tamed nature that few locations in the world remain without human influence. Global maps of human impact indicate that, as of 1995, only 17 % of the world's land area had escaped direct influences by humans' (Kareiva et al. 2007: 1866). In this context, the indicators of the global footprint of humans are: human population density; agricultural land use; towns or cities, access within 15 km of a road, river, or coastline; or night time light detectable by satellite (ibid).

De-Domestication, a concept newly introduced by the author (Pandit 2011), signifies deceleration of domestication of nature by resorting to philosophy of ecology-based policies and strategies of (sustainable) development which leave land and water for habitation by *environmental nesting* by diverse species and by future generations, thereby, making a contribution not just to long term conservation of natural resources and habitats threatened by humans, but ecosystem resilience itself. However, a note of caution on de-domestication in my sense must be added here. It should not be confused with 'De-Domestication' defined by Christian Gamborg (Gamborg et al. 2010) so differently as follows:

'De-domestication is the deliberate establishment of a population of domesticated animals or plants in the wild. In time, the population should be able to reproduce, becoming self-sustainable and incorporating 'wild' animals. Often de-domestication is part of a larger nature restoration scheme, aimed at creating landscapes anew, or re-creating former habitats.'

1.2 How Can We at Last Learn to be Domestication Wise?

No surprise, mankind has achieved a lot in the name of economic, technological and scientific progress. Humanity is still focused on producing more and more of knowledge and technology. No surprise, if humanity's success has made us arrogant, as scientists, as law makers in the government, as policy planners, as technocrats, as educationists and as economists.

Like the cancer cells spreading in the entire host organism, we the members of *Homo sapiens* have arrogantly been seeking to dominate and domesticate the whole of nature, with the sole purpose of serving humanity's divided interests. No surprise if we are confronted with the danger of paralyzing the very ecosystems and ecosystem services without which humanity cannot survive. The humanity is confronted with ecological crisis: There is a need for an emergency response to arrest the haemorrhage of natural systems and stabilize the global climate by bringing down atmospheric concentrations of greenhouse gas pollution.

Having produced knowledge and technology, having fragmented the world into the developed and developing world, having divided the world's populations into the rich and poor sections, having plundered the Earth's resources, having created wealth unevenly and structural violence simultaneously in every society, can we be at last *domestication wise* (Pandit 2011) to ask the right kinds of questions as to where do we go from here in understanding nature and fulfilling our collective responsibility to her?

In a nutshell: having produced scientific knowledge and technology with a view to making economic and social progress, can we now at last pause to focus on wisdom? Optimism, as a duty, allows us to answer this question in the affirmative. The way ahead to wisdom, rather than to more and more knowledge and technology (i.e., technological totalitarianism) in the service of business as usual, lies in our capacity to rethinking our world, rethinking development, rethinking science and technology, rethinking science and technology studies, rethinking economy-society-ecology interface (Pandit 2004c).

There are strong reasons why we must rethink science (Pandit 1982, 1991), technology and science studies. There are reasons why we must rethink our world and rethink economy, society and ecology. If this is so, there are strong reasons to rethink development by ‘ecological overshoot’. The question is how to achieve all this and much more.

2 Learning from History: Is Growing Prosperous the Main Key?

To take an example, according to Lomborg (2011: 27), growing prosperous instead of ‘reining in growth and making do with less than we could have otherwise’ is the key to solving global problems like global warming which ‘overshadows any discussion of the environment.’ His reasoning is that, ‘The way we have made progress against disease, malnutrition, and environmental degradation in the past is by growing, by discovering, and by innovating.’ If learning from history is the key to a better future, then we must look back to humanity’s journey of the past centuries as a journey in developing better technology, securing better lives and less pollution. From this long journey, we know ‘that more prosperous countries are more able to respond to the challenges that climate change will pose. They are much more resilient to natural disasters while more able to invest in measures such as greener cities and flood protection. Yet instead of first making sure that everybody is better off and more resilient, our response to global warming has been to try to cut back carbon emissions too soon (ibid).’

What is worse, Lomborg argues: ‘Not surprisingly, since industrialized nations first promised with great fanfare in Rio de Janeiro to cut emissions to 1990 levels by 2000, our approach of early and substantial cutbacks has failed repeatedly. Despite not meeting emission-cut promises in Kyoto and failing even to agree on promises in Copenhagen in 2009, negotiators plan to try again in South Africa later this year. Making empty promises does not make us sustainable.’

Briefly, Lomborg’s argument boils down to this: Mankind can prosper and societies can make progress only by trial-and-error, by innovating while learning from history, by learning from our mistakes. But the question which he fails to ask is this: Is all this enough? Is learning from history enough in order to innovate and pursue the goals of development? How does all this enable us to deal with the unforeseen challenges or manage ecosystems? It is not clear at all why Lomborg does not speak of a nature policy *within* which the goals of economic growth and prosperity can be *wisely* pursued. Is it because neither the developing countries nor the developed world have any experience in this field? Is there nothing here to learn from history? Is humanity only now ready to begin a long journey to arrive at a nature policy which could bind one and all in a more *wise* pursuit of the goals of economic and technological prosperity?

2.1 Whale Oil as a Source of Lighting

It can very well be argued against the kind of argument put forward by Lomborg (2011) that in the case of whale oil as a source of energy, the search for alternatives was not prompted by the *wisdom* of culture but by the rationality of the market and consumerism. It was prompted, on the one hand, by the necessity to avoid high costs and, on the other hand, by the fear of un-sustainability of society and economy. In other words, there arose an urgency to *rethink* whale oil as a source of energy and to shift to less costly alternative ways of organizing society and economy, mainly owing to the high costs the dependence on whale oil imposed on sustainable development: What would the future generations do if the costs kept on soaring with the resources declining but demands increasing. That is simple economic or market rationality. So the search for an alternative resource for lighting was not prompted by the ecological or ethical consideration that the mass killing of whales is barbarous with catastrophic consequences for the relevant ocean ecosystems. Clearly, there are no values, no nature policy, no wisdom of culture, playing a role in this context. On the contrary, Lomborg's example reminds us how history repeats itself. Today, there is similarly an urgent need to rethink the role atomic energy plays in economy and society.

2.2 Nuclear Energy: The Atomic Power Plants

On 11 March 2011, in the wake of the severest earthquake in Japan's history, a tsunami flooded large parts of the northeast of the island nation. A magnitude 9.0 earthquake and a roughly 10 m-high wave left more than 20,000 people dead and the nuclear power plant at Fukushima seriously damaged. The catastrophe has triggered a debate on the safety of nuclear energy. And in early summer 2011 in Germany the Federal Government decided to phase out nuclear power by the end of 2022.

What do the Chernobyl disaster, of 1986, and the catastrophe of Fukushima, in 2011, symbolize today for humanity? What lesson do they teach us? We are not talking of the potential or actual threat of nuclear or hydrogen bombs. Chernobyl and Fukushima raise the basic question of safety and sustainability: Is nuclear energy a safe and sustainable source of energy? Can we answer this question without addressing the radiological concerns? Besides these concerns, there are other questions which must be addressed too: Can uranium mining go on and on indefinitely on our planet, given the finite resources? What about the safe disposal of the nuclear waste? The world is still without a solution to the problem of hazardous nuclear waste. As to the question, how safe is nuclear energy or how safe are the nuclear power plants, think of countries, like Iran and Israel, which are not only at war but which are housing the largest nuclear power plants. An attack on the nuclear facilities by either country could release unpredictable quantities of radioactive contents and lead to catastrophic consequences. Imagine the catastrophic consequences such a scenario would have for the local population and for the world as a whole. No surprise that Germany has decided to shut down all its atomic energy plants by 2022.

As Bennett Ramberg (2011: 6) points out: ‘Chernobyl and Fukushima showed us that the human costs and economic fallout of an attack would be huge.’ In a region filled with high nuclear tension, ‘the risk of tit-for-tat attacks raises a spectre few seem to recognize: the first radiological war in history (ibid).’ Drawing the world’s attention to the nuclear tension in the region, he argues that ‘Given the dangers, Israel and Iran would do well to ask if opening a radiological Pandora’s box serves either’s interest.’ The catastrophic scenario described by Ramberg itself serves as a warning as follows:

‘Radiological effects would depend on the volume and nature of nuclear isotopes released, seasonal winds and protective measures. Computer models suggest that well beyond the zone immediately in and around the reactor and nearby communities, even the plant’s relatively small inventory of radioactive material could lead to a vast increase in cancers, birth defects and other related illnesses. There would also be many troubling socioeconomic consequences. Public officials would have to restrict the consumption of foodstuffs from even modestly contaminated zones, and require the evacuation of commercial, industrial and residential districts in radioactive hot spots. The nuclear accidents in Ukraine and Japan suggest a huge increase in stress-related illnesses. Addressing such matters would add to the billions of dollars governments would have to spend on nuclear cleanup (ibid).’

We should not fail to ask the question: In pursuing the goals of sustainable development, is learning from past mistakes enough? Is learning from history enough? As all the above examples show, sustainability and prosperity considerations alone are not enough in the context of development. Unless these are integrated with a sound nature policy—a policy regarding how best to work *with* and not against nature, i.e., a policy which allows us to understand nature and fulfil our responsibility to her while leaving ecosystems as resilient and sustainable as before—the search for alternative technologies, for innovation, cannot only lengthen our journey to a sound nature policy, it can also damage long term human and non-human interests while imposing high costs on future generations. A development ethics, a philosophy of ecology, to guide humanity in its journey to prosperity is imperative.

2.3 Building Resilience Through Access to Rights, Resources and Public Understanding of Science

However, Lomborg's argument is instructive in many ways. There is an important lesson to learn, a lesson particularly for the developing countries with democratic traditions. It is after all these countries where, election after election, making false promises has become a way of life, with a long and tortuous history of human rights deprivation among urban and rural poor communities (Pandit 1998, 2000b, 2001d, 2001c, 2005a, 2006b, 2008b, 2010b, 2013). The countries of South Asia provide a good example (Dodman et al. 2009: 152). Building resilience is one of the approaches to building and working for the best possible global future where vulnerability of communities and countries to threats of climate change can be reduced to the minimum. While a large proportion of the world's population is vulnerable to such threats, the risks are not distributed evenly. In the words of Dodman et al. (2009: 152),

'This reflects profound global inequalities: the countries that have profited from high levels of greenhouse gas (GHG) emissions are the ones that will be least affected by climate change, while countries that have made only minimal contributions to the problem will be among the most affected… Taken together, these countries form a group of 100 nations, collectively housing more than a billion people but with carbon dioxide emissions (excluding South Africa's) accounting for only 3.2 % of the global total.'

If we recognize how complex and dynamic the interactions between the human and natural systems are, it will be easier to recognize important correlations and dependencies between ecosystem resilience and social system resilience. This can also facilitate the process of building ecosystem resilience and offering guidance in pursuing development goals.

By simple generalization, climate change risk related global inequalities reflect the natural disaster risk related inequalities. Communities and individuals who enjoy a better quality of life with access to human rights are less at risk from natural disasters than the human-rights deprived communities. The same applies in the case of climate-change related risk. To quote Dodman et al. (2009: 154):

'Many aspects of resilience are closely associated with a holistic approach to development. Individuals who have access to adequate food, clean water, health care, and education will inevitably be better prepared to deal with a variety of shocks and stresses—including those arising from climate change. Communities and cities that are served by appropriate infrastructure—particularly water, sanitation, and drainage—will also be more resilient to these shocks. Indeed, one of the most significant reasons poor people in developing countries are more at risk from climate change is because they are inadequately served by day-to-day services that are taken for granted in more-affluent locations.'

This is true of India, the world's largest democracy. India has her share of rural and urban poor, with 70 % of its population living in the rural areas and 445 million Indians still living on less than Rs. 26 a day. Focusing on sustainability and the impact of environmental degradation on the poor, the 2011 UNDP Human Development Index tells us that 'By 2050, the average HDI could drop by 12 % in South Asia due to the effects of global warming on agricultural production, access to clean water and pollution.' Rethinking human development, as we all must, for developing countries in general, it is imperative to be guided by other indicators of human development, over and above economic growth, the latter being a necessary but not sufficient indicator of human development. They must also look to indicators of moral progress' (Pandit 2007a).

Let us now consider briefly what has changed and what has not changed in society's expectation from its investment in science, while science suffers a displacement in public understanding (Pandit 2007d, 2009a, b, 2010a). There are two important goals of science which remain unchanged (Lubchenco 1998: 494)[1]: The first is the production of the best possible science regardless of area; the second is the production of something useful (Nuetzlichkeit). The first goal implies a commitment of science to the search for the truth about how nature works (Pandit 1982, 1991). Progress on this front brings about improvements in our understanding of the world. The second goal implies an equally firm commitment to fulfilling the needs of society, e.g., developing new medical diagnoses and treatments to conquer disease, improving the quality of life and public health, improving the economy and communication, producing newer and strategic arms for national security, producing sustainable technologies, and producing new products for automobile industry. In a sense, investment in science by the market-driven society brings not only monetary returns but larger social and economical benefits.

What is it then which has changed, or which is new, at the interface of science and society? We find an answer to this question in Lubchenco (1998: 495) as follows: 'The current and growing extent of human dominance of the planet will require new kinds of knowledge and applications from science—knowledge to reduce the rate at which we alter Earth's systems, knowledge to understand Earth's ecosystems and how they interact with the numerous components of human-caused global change, and knowledge to manage the planet'.

Thus, what is new is the need for a different kind of investment in science, an investment in informed public policy, in informed science and technology policy, because the needs of society have changed rather dramatically. In other words, science has assumed a new role as the society's need for scientific knowledge has undergone a tremendous change (ibid). There is a need for scientific knowledge that can help society and science arrive at informed policy and management decisions: A better understanding of the likely consequences of different policy options will allow more enlightened decisions. Many of the choices facing society

[1] See Pandit GL (2009a) Ethics in Public Domain: Biomedical Research and Beyond. In: Alok Srivastava and Ipsita Roy (eds) Bio-Nano-Geo Sciences: The Future Challenge, Humboldt-Kolleg-Palampur (India), Anne Books: New Delhi/Chennai/Mumbai 2009, pp. 187-208. A preprint is accessible in Indo-German Science Circle Website of the Embassy of Federal Republic of Germany, New Delhi: (www.science-cooperation.org/www.science-circle.org).

are moral and ethical ones, and scientific information can inform them. Science does not provide the solutions, but it can help understand the consequences of different choices (ibid).

In this context, a frequently asked question concerns the relationship between the scientific community and the general public (Haerlin and Parr 1999)[2]: How to restore public trust in science? Think of the disasters at Chernobyl and Bhopal, the crisis over BSE and the public controversy in Europe over GM foods, which have led to a crisis in public trust in the statements of scientists. Science and scientific communities worldwide inevitably suffer displacement in the public understanding and estimation of their role, since they are 'no longer perceived exclusively as guardians of objective truth, but also as smart promoters of their own interests in a media-driven marketplace' (Haerlin and Parr 1999: 499). There is a need for a kind of Hippocratic Oath to strengthen the moral standing and responsibility of scientists within corporate and institutional systems. It is not enough to extend codes of conduct to 'companies and institutions to communicate information on environmental and health impacts of products, and to oblige individual scientists to communicate relevant findings (ibid)'. There is, rather, a need for diversification of investment on research and development strategies in the universities and industries so that research on equal and informed access to new technologies not only receives the same attention but is accorded the same priority as research on the development of new technologies themselves (Pandit 2007a, b, c, 2009a, 2010a). The displacement of science and an increasing public scrutiny of the research and results of science have made scientific research more responsive to the public and social demands. Think of the pressure the AIDS activists have exerted on medical science to increase research on that disease. And think of the work done by environmentalists in creating and sustaining wildlife habitats alongside fishing or agricultural needs.

3 Recognizing the Scales of Ecological Complexity

Humanity needs to draw important lessons from the work of those individual scientists who have advanced our understanding of nature, making an exemplary impact on the environmental discourse during the second half of the 20th century. If there is a lesson to draw from their work, it is a lesson in ecological-environmental realism as formulated in (Pandit 1995), a lesson how the humanity might *rethink* nature. It is this which I will briefly restate at the end.

In 1962, Rachel Carson (Carson 2002, first edition 1962) published her remarkable book '*Silent Spring*.' The book is woven around the recognition of

[2] See Pandit, G. L., 'Quantum Technology on the Horizon: The Evolution of the Quantum Core-Context of Scientific Development', an invited contribution to the Ruperto-Carola-Symposium: Hybrid Quantum Systems: New Perspectives on Quantum State Control (University of Heidelberg: 12-15 May 2010a, IWH, Heidelberg), unpublished.

enormous dynamic complexities that are built into the Earth's delicately balanced ecosystems and the species diversity these systems support. Thus, Carson (2002) drew public attention to the life-threatening effects of pesticides and other toxic chemical pollutants on the fragile ecosystems, on the environment and public health. Carson not only advanced the public understanding of science, she also exposed to criticism ecologically unhealthy and harmful practices of domestication of nature based on science and technology. And she did this at a time when ecology was still excluded from scientific and economic models of development and natural resource management (Pandit 2011).

How thinking and acting in self-interest, while failing to distinguish between different scales of ecological complexity, can result in natural resource management failure may be clearly seen in the following case cited by Bryan Norton (2003: 293):

'German foresters of the 19th century emphasized production of timber and converted huge areas of the German forest to monocultural spruce. Initially, yields of high quality timber increased. After three or four iterations, however, yields plummeted. Young trees could not penetrate the soil with their roots and a condition called 'soil sickness' (Meine 1988: 293) developed. Analysis showed that soil composition had been altered because essential microorganisms had been lost. In this example, descriptions at a particular scale—the scale of economic forestry—has been assumed to provide a complete and unique description of reality. Failure to recognize that timber production is a process that exists as a part of a system that has evolved over centuries, and that that system is supported by processes existing on a longer scale than is registered in the language of production forestry, resulted in a serious management failure.'

A relatively more recent example of natural resource management failure is provided by the Aral Sea Catastrophe (Pandit 2004a). The failure to recognize different scales of ecological complexity can easily result in a process of separation between man and nature, between economic theory and economic policy, a process which is so much characteristic of our age and which has its origin in those beliefs about nature and natural resources that have been fostered by the successes of the scientific revolution of the 16th, 17th and 18th centuries.

The Aral Sea, on whose waters the central Asian populations always depended, lies on the border between Kazakhstan and Uzbekistan. Since early 1960s, the Aral Sea Catastrophe has completely altered the local climate and the livelihoods of as many as 1 million people. But what is it which has caused one of the world's biggest ecological disasters? The radical changes introduced in the 1950s in the traditional agricultural practices, expanding and mechanizing the Central Asian irrigated agriculture and orienting it to the production and export of cotton, led to the destruction of the Aral Sea ecosystem where for thousands of years the earlier generations had made sustainable use of the same waters, thanks to their basic choices.

The worst part of the tragedy is how the impact of the drying-up of the once great Aral Sea, until recently the world's fourth largest lake, on the local highly dependent populations was just ignored. I believe that any serious attempt to use geographic information systems and simulation models for research and decision support in the central Asian river basins would go a long way to expose this and to confirm how crucial the *ecologies of environmental nesting* (Pandit 1995) have been to sustainable development locally, particularly in the developing economies.

What we must learn from our past mistakes is that it is not in our long-term interest to reduce nature's wonderful ecosystems to a mere economic resource base of marketable commodities. The wider cultural and moral aspects of the man-environment interactions in traditional societies remind us of our original multiple images of nature that were life-enhancing, yielding a deeper understanding of the environment.

Economic and social prosperity was the basic consideration behind the cotton industry in the former Soviet Union. All of us know now what consequences the Aral Sea ecological catastrophe has meant for the local population which was dependent on its ecosystems services. Imagine what would have been the consequences if a nature policy had accompanied and guided the then economic policies. In all probability, the Aral Sea would have survived any catastrophe.

3.1 The Whole Question of Earth's Carrying Capacity

The 1960s also registered accelerated population growth globally, reminding humanity of Thomas Malthus (1970, first published 1798). In a step beyond Malthus, in 1968 Paul Ehrlich (1968) published his book '*The Population Bomb*'. The book presented a bleak scenario of inevitable famine for the world's poor, arguing from the accelerated population growth and shortages of land, fertilizers and other inputs. Around the same time there were voices of optimism which countered all this, citing technological innovations and the adoption of the new hybrid varieties of wheat and rice emerging from the 'green revolution' and mechanized farming. However, despite many starving populations, population growth accelerated unchecked, inviting accelerated domestication of nature.

In 1960, the global population was three billion. In the last quarter of the twentieth century it increased from four to six billion. It was about 6.6 billion in 2007. In July 2010, it stood at 6.85 billion. A century ago, only a tenth of the world's population lived in cities. In 2010, there are more than three billion people dwelling in urban settlements globally. Very soon it will go up to more than half. The country-wise 'ecological footprint'—the amount of land and sea resources the human populations need to provide the food, clothes and other goods they consume and to absorb the carbon dioxide they emit—shows an alarming rate of over-consumption of resources. With average farm size fast decreasing, farmers find it difficult to make a living. Urbanization seems inevitable. All this is indicative of an accelerated domestication of nature by man. By 2030, humanity's demands on natural resources will far exceed what the Earth can provide or cope with. Globally, humanity will need the capacity of two Earths to meet its demands for resources. If all of world's population adopted the modern lifestyles (and economies), humanity would need six–eight Earths to meet its demands for resources. With the falling populations of wild life, loss of bio-diversity, the present patterns of human lifestyle, land use practices and water consumption across the globe, the human survival scenarios of the future look quite *unsurprisingly* so bleak. A study by the International Union for the Conservation Nature warns that a fifth of the world's species is facing the threat of extinction.

By the end of 1960s, collective efforts at scenario-building to envision the future of humanity were made. The first Report of the project entitled 'The Limits to Growth', commissioned by the Club of Rome, was published in 1972: The project built a formal mathematical model of the world 'to investigate five major trends of global concern—accelerating industrialization, rapid population growth, widespread malnutrition, depletion of non-renewable resources and a deteriorating environment' (Meadows et al. 1974: 21).[3] As an effort in scenario building for working for humanity's future, *The Limits to Growth* report warned the humanity (Meadows et al. 1974: 23–24):

1. If present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity.
2. It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realize his individual human potential.
3. If the world's people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success.

3.2 The Tragedy of the Commons

In 1968, Garrett Hardin (1968: 162) published his article entitled 'The Tragedy of the Commons'. In a welfare state, and under the policies promoted by the UNO, writes Hardin, there is a real dilemma how to deal with the family, the religion, the race, or the class that adopts over breeding as a policy to secure its own aggrandizement. To couple the concept of freedom to breed with the belief that every one born has an equal right to the commons is to lock the world into a tragic course of action.

To quote Hardin (1968), 'Every new enclosure of the commons involves the infringement of somebody's personal liberty. Infringements made in the distant past are accepted because no contemporary complains of a loss. It is the newly

[3] See Dalby S (2009: 18–19).

proposed infringements that we vigorously oppose; cries of ‘rights’ and ‘freedom’ fill the air. But what does ‘freedom’ mean? When men mutually agreed to pass laws against robbing, mankind became freer, not less so. Individuals locked into the logic of the commons are free only to bring on universal ruin; once they see the necessity of mutual coercion, they become free to pursue other goals. I believe that it was Hegel who said, ‘Freedom is the recognition of necessity.’

Again Hardin (1968) says: ‘The most important aspect of necessity that we must now recognize is the necessity of abandoning the commons in breeding. No technical solution can rescue us from the misery of overpopulation. Freedom to breed will bring ruin to all. At the moment, to avoid hard decisions many of us are tempted to propagandize for conscience and responsible parenthood. The temptation must be resisted, because an appeal to independently acting consciences selects for the disappearance of all conscience in the long run, and an increase in anxiety in the short.’

Hardin concludes: ‘The only way we can preserve and nurture other and more precious freedoms is by relinquishing the freedom to breed, and that very soon. ‘Freedom is the recognition of necessity’—and it is the role of education to reveal to all the necessity of abandoning the freedom to breed. Only so can we put an end to this aspect of the tragedy of the commons.’ In another article (Hardin 1998: 682–683), Hardin urges humanity to heed the message: ‘Individualism is cherished because it produces freedom, but the gift is conditional: The more the population exceeds the carrying capacity of the environment, the more freedoms must be given up.’

I look at Hardin’s contribution as yet another step forwards in recognizing universal interconnectedness and complexity across nature. If we now ask: what are the main drivers of ADN? The answer is as follows. One of the important drivers of ADN is the growing population on Earth, one of the factors of global ecological footprint. The amount of land humans require depends on (1) population (2) living standards/affluence and (3) agricultural production/yields. World’s population has increased fivefold since 1850—from one billion to more than 5 billion. The improvements in public health, nutrition and medicine, generated by science and technology, are mainly held responsible for this enormous growth. Obviously, there are other causal factors.

3.3 Adam’s Fallacy: A Guide to Economic Theology

Adam’s Fallacy[4] refers to the dualism between the economy and the rest of society that Adam Smith’s (*The Wealth of Nations*) ‘invisible hand’—the belief in the economic rationality of self-interested individual behaviour being guided to socially beneficent outcomes through competitive market forces—creates. So

4 See also Foley (2006); Peterson (2008); Storm (2008).

understood, Adam's fallacy captures the 'idea that it is possible to separate an economic sphere of life, in which the pursuit of self-interest is guided by objective laws to a socially beneficent outcome, from the rest of social life, in which the pursuit of self-interest is morally problematic and has to be weighed against other ends (Foley 2006: xiii).' In a nutshell, 'Adam's Fallacy' is the fallacy of answering in the affirmative the question whether it is possible to conceive of economic rationality as consisting in being good to our fellow human beings by being selfish within the rules of capitalist property relations (Foley 2006: 2).

There is no doubt about how paradigmatically dominant 'Adam's Fallacy' has been in the development of economic thought, in the classical economics of Thomas Malthus and David Recardo and others, and in the shift to neoclassical economics. In his book, Foley (2006) examines the consequences of Adam Smith's 'invisible hand' for the development of economic theory and policy, and for the contemporary relevance of economics in a globalizing world, exposing to criticism the myth of value-free economics so forcefully fostered by 'Adam's Fallacy'.

It is not surprising if we hear an echo of 'Adam's Fallacy' in Philip A. Klein (Lee 2008, Klein 2006, Foley 2006), arguing that neoclassical economists have for the last half-century 'trivialized economic theory by making it useless for contributing to the making of public policy and thereby making public policy incapable of affecting the economy.'

4 Rethinking Sustainable Development

Think of the global inequalities between the developed and the developing countries of the world. The former, the industrialized countries, which are said to have benefited from high levels of greenhouse gas emissions, are the ones that are socially and ecologically resilient enough to cope with challenges of climate change (Dodman et al. 2009: 152) and other natural disasters. The latter, the countries which can be held accountable for only 3.2 % of the total global greenhouse gas emissions are the least resilient and, hence, highly vulnerable to challenges like climate change (ibid). In the context of this global divide between the poor and the rich societies, between the human-rights deprived communities and the communities that enjoy high quality of life and human rights, what exactly can we mean by sustainable development? Today, when the crises-ridden Western World with almost all international institutions dominated by it are crying for reform, can sustainable development mean the same thing for the world divided between the rich and the poor? Can we define it without assuming a value-framework including a sound nature policy, i.e., without taking into account the wisdom of culture? The wisdom of culture pays attention not just to the resources and the wealth that can support human societies and economies around the world but to nature and her resilient or fragile ecosystems. It is at its best when it inculcates in us a respect for nature and her beauty, a respect for nature's ecosystems, where humanity and the world beyond humanity find their common nest.

Over 20 years ago, as Gro Harlem Bruntland (WCED 1987: p. 2) put it in her Address as its Chairman, the World Commission on Environment and Development (WCED 1987, pp. 1-4), "grew out of an awareness that over the course of this century, the relationship between the human world and the planet that sustains it has undergone a profound change." According to the WCEĎs Tokyo Declaration (WCED 1987: p. 4): "Our Common Future", sustainable development 'can be defined simply as an approach to progress which meets the needs of the present without compromising the ability of future generations to meet their own needs.'

Does sustainable development then simply mean that the measure of success of our economic policies lies in 'whether or not we give future generations same opportunities that we have had (Lomborg 2011: 26)?' I think that there is a serious flaw in this definition. For with greater or equitable opportunities should come also quality of life. And quality of life cannot come only with successful economic or market rationality, i.e., with economic prosperity. On the contrary, it can come with all this but within the wisdom of culture (Pandit 2007b, c, d).

4.1 Building Ecosystem-Resilience

What determines the resilience of an ecosystem to threats like climate change? According to Colleen T. Webb (2007, 470):

> The concept of resilience, as applied to an ecosystem, is loosely defined as the ability of the system to maintain its function when faced with novel disturbance. The concept is related to stability, but with its focus on maintenance of function and novel disturbance, resilience uniquely encompasses aspects of society's reliance on ecosystem services and increasing anthropogenic change. Thus, scientists from many different backgrounds recognize the societal importance of resilience and are intellectually intrigued by resilience concepts.
>
> While ecologists generally seem to share this perspective, many are also frustrated by the diversity of definitions for resilience and the complex role of ecology in this area. These issues arise partially from the history of resilience research, which has been performed by very different groups of scientists, and partially from the inherent difficulties of integrating interdisciplinary research. Indeed, resilience is still an evolving concept. Since resilience research is not driven solely by ecology, the challenge for ecologists is to understand resilience perspectives from multiple fields in order to better integrate traditional ecology with modern perspectives and research on resilience.

What is decisive is how vulnerable the relevant ecosystems have become due to the stresses they are already facing directly, e.g., under the impact of human activity, under the domestication of natural systems by creative destruction. The less vulnerable an ecosystem is in this sense, the greater will be its capacity to survive the threats of climate change. In a sense, ecosystem resilience cannot be defined independently of sustainable development. Thus, with Dodman et al. (2009: 155), we can say that 'an ecosystem is more resilient when resources are used sustainably and its capacity is not exceeded. It is more resilient when the ecological footprint of man does not indicate ecological overshoot. Consider the following examples (ibid):

> …chronic over fishing, blast fishing techniques, and the pollution of water around coral reefs in South Asia have made them more vulnerable to cyclones and warmer sea temperatures. In this sense, social resilience to climate change may sometimes be at odds with ecological resilience: human adaptive strategies for socioeconomic development may increase pressure on marine and terrestrial ecosystems through changes in land management practices, shifts in cultivation and livestock production, and changes in irrigation patterns. In addition, more resilient and developed communities may have a greater capacity to exploit natural resources to support their adaptive strategies.

Since climate change threatens the sustainability of the world's most vulnerable ecosystems, building resilience in social-ecological systems[5] is the key to sustainable development (ibid pp. 151–168). Clearly, seeking wealth and prosperity would not be enough for such a task. Seeking ever new alternative technologies to promote prosperity would not be enough either. A sound knowledge of ecosystem-resilience and a sound approach to building such resilience wherever it is threatened is necessary, though it is again not enough (Dodman et al. 2009: 156). Finding a sound nature policy, therefore, assumes great significance. Without a sound nature policy, we cannot enhance and safeguard either ecosystem-resilience or ecosystem-social system resilience. Nor can we engage in ethically sound developmental activities. Consider the possibility that 'more resilient and developed communities may have a greater capacity to exploit natural resources to support their adaptive strategies' (ibid p.155). To quote Dodman et al. (2009: 156–157):

> When considering how to build resilience in the face of climate change,…it is necessary to consider not only the direct impacts of a changing climate on the environment but also the implications this has for social resilience, the feedbacks on ecological vulnerability it may entail, and the wider institutional mechanisms that can enable this cycle to be broken. Building ecological resilience is essential, although not sufficient, for achieving social resilience. But achieving social resilience through sustainable development is essential for reducing pressures on ecosystems so they can adapt in the face of climate change.

4.2 Rural Resilience

The problem of rural resilience is best posed by the following statement (Barbier 2010: 655): '…as rural populations of the developing world continue to increase, the problem of growing numbers of asset less poor and their concentration in less favoured areas remains a major development challenge. Although the rural poor

[5] See also Barbier Edward B (2010) Poverty, development, and environment. Environment and Development Economics 15: 635–660.

are less likely to be responsible for much of the environmental degradation in the developing world than as previously believed, the difficulties posed by poverty-environment traps and labour, asset, and market constraints are considerable. Only by formulating novel policies targeted specifically at reducing these constraints for the rural poor in less favoured areas will significant progress in reducing global poverty occur.'

The village, which is in its turn sustained by rural resilience, exemplifies at its best the idea of domestication of nature by *environmental nesting* as opposed to the idea of domestication of nature by creative destruction, which is, in its turn, best exemplified by industrialization and urbanization. The latter is sustained by science, innovation, technology, market forces and globalization. One of the biggest challenges humanity faces is: How to remove global poverty of the vulnerable poor rural communities without turning them into displaced communities, without turning them into insecure urban dwellers?

This is a task yet to be addressed. Think of South Asia. India's 72 % population lives in rural areas. Sixty years back at least 80 % of its population lived in the villages. Nepal's 85 % population still lives in rural areas, with rural populations of Pakistan, Bangladesh and Sri Lanka making up 66, 76 and 79 %, respectively. The question above raises the problem of development ethics which is not just one of which technologies to develop in the future to solve global problems. It is easily forgotten that sustainable development is partly a matter of building resilience. So, rural resilience matters for development. But the question is how to develop rural resilience? Man-environment interaction is most intimate, complex and creative in the world's rural regions. A closer look at rural resilience can, therefore, throw much light on how to build ecosystem resilience which could, in its turn, contribute to social resilience, particularly in resource dependent rural communities (Dodman 2009: 156). While urging an integrated approach to building resilience, given social resilience-ecological resilience-development correlations, Dodman et al. 2009 (ibid) point out:

'The close association between people and the environment is perhaps most apparent in poor rural societies in low-income countries that rely directly on ecological systems for environmental goods and services…the strength of association between ecological and social resilience is closely tied to the development context and is mediated by a variety of other factors, including wealth, ownership of land and the means of production, and social networks.'

5 Interface-Building Across Disciplines: Millennium Ecosystem Assessment

More recently, a decisive step forward emerged from the United Nations Millennium deliberations focusing on the biosphere and its component ecosystems. The project of Millennium Ecosystem Assessment (MA 2005a, b) focuses on global economic health and human well-being: 'The conceptual framework for the MA posits that people are integral parts of ecosystems and that a dynamic interaction exists between them and other parts of ecosystems, with the changing human condition driving, both directly and indirectly, changes in ecosystems and thereby causing changes in human well-being' (MA 2005a: 9).

Recognizing complexities inherent in ecological knowledge, MA methodological framework seeks to go beyond the established epistemologies of the West: Normally 'Scientific assessments are based on a particular Western epistemology (way of knowing), one that often excludes local knowledge, ignores cultural values, and disregards the needs of local communities. Scientists and policy-makers alike have become aware that there is a need to establish new assessment processes that are robust enough to accommodate and value these different 'ways of knowing' and the multi-scale and multi-stakeholder nature of environmental concerns. A significant challenge for the multi-scale approach of the MA is to effectively bridge these traditional and scientific ways of knowing the world. A rich body of knowledge concerning the history of ecosystem change and appropriate responses exists within local and traditional knowledge systems. It makes little sense to exclude such knowledge because it is not published. Moreover, incorporation of traditional and local knowledge can greatly strengthen the legitimacy of an assessment process in the eyes of local communities. Finally, particularly at the scale of the local sub-global assessments, traditional knowledge may often be the primary source of historical information for the component MA assessments. The MA has established procedures (described in the document Procedures for the Preparation, Peer Review, Approval and Publication of Millennium Assessment Reports) that will enable the inclusion of traditional knowledge at all scales of the assessment process (Walter Reid, Neville Ash, Elena Bennett, Pushpam Kumar, Marcus Lee, Nicolas Lucas, Henk Simons, Valerie Thompson, Monika Zurek, Millennium Ecosystem Assessment Methods, October 18, 2002).'

MA (2005a, b) recognizes that by damaging numerous ecosystems by its activities humanity has already driven many species out of existence, causing a considerable biodiversity loss. About 60 % of the Earth's ecosystems are not being used sustainably. The costs of disruptions caused by human activities are borne by the world's poor and disadvantaged. They will also be borne by the future generations. What is remarkable is MA's recognition that humanity is now beginning to understand its place in nature better than before by recognizing its dependence on Earth's ecosystems:

'Everyone in the world depends completely on earth's ecosystems and the services they provide, such as food, water, disease, management, climate regulation, spiritual fulfilment, and aesthetic enjoyment. Over the past 50 years, humans have changed these ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly the growing demands for food, fresh water, timber, fibre, and fuel. This transformation of the planet has contributed to substantial net gains in human wellbeing and economic development. But not all regions and groups of people have benefited from this process—in fact, many have been harmed. Moreover, the full costs associated with these gains are only now becoming apparent.' (MA 2005a: 16).

5.1 Bringing Nature Back in: A Long and Thorny Journey to Nature Policy

Earth's biodiversity, in the sense of species richness, is generally regarded as the main source of ecosystem resilience (ER) and ecosystem stability (ES). But biodiversity alone cannot provide the key to ER, if it is taken to refer to the total number of species inhabiting in a given area. The most challenging question we should ask is this: What is the dynamics of species-interactions which maintains ER within an ecosystem? How do ecosystems rebuild their resilience when it is threatened, given their inner dynamics? And how to build ER where it is destroyed under the impact of man-environment interactions? The human intervention of protecting biodiversity through species introductions may not be a way out. Understood dynamically, biodiversity protection demands complex interactions within natural habitats and life support systems. The dynamic processes of how deep inside the ecosystems species *interact* with one another and with their environment, building nested dependencies, i.e., the processes of *environmental nesting* (Pandit 1995) as a strategy of habitation by diverse species play a dynamic role in maintaining and building ER. Such processes take place across nature very naturally (Pandit 1995). But it is an open question whether we humans have learnt anything at all from the 'wisdom' of nature, the 'wisdom' its ecosystems use in repairing damages which are not caused by the processes of domestication of nature by creative destruction.

Consider the fact that until now mankind has been concerned only with serving its own interests, plundering Earth's ecological resources and arrogantly accelerating the domestication of nature by creative destruction (Pandit 2004c). It is like being the greedy fishermen who keep sailing in their boats until they have plundered all fish from the very ecosystem which hosts their own habitat, or cutting the very branch of the tree on which one is sitting. What is now the way forwards, if we want to engage in optimistic scenario-building and explore global futures for humanity? How long and how thorny is humanity's journey to nature policy going to be?

Journeying from Rachel Carson (Carson 2002), Paul Ehrlich (1968) and Garrett Hardin (1968, 1998) to the first Report of the project '*The Limits to Growth*' commissioned by the Club of Rome (Meadows et al. 1974) and World Commission on Environment and Development: *Our Common Future* (WCED 1987), I think that the humanity has come a long way, finally *recognizing* the urgency of the task of understanding nature and fulfilling its responsibility to nature. We are now back to the fundamental question: What is nature? How can humanity avoid its sole dependence on science and technology in its task of understanding nature and fulfilling its responsibility to nature? Let me indicate my answer to this question with a word on what I call ecological-environmental realism, or Umweltrealismus as originally formulated in (Pandit 1995, 2005b). There is an urgent need to recognize that there are enormous complexities both within and outside our habitats, which we cannot see with our naked and greedy eyes. It is this to which ecological-environmental realism (or eco-environmental realism) as a philosophy of ecology urges us to pay our attention. Think of a policy, or a framework principle, which requires us to treat our habitat (our nest), and its local environment, as if it was a *world* in itself, although deeply embedded in *the* larger world, i.e., a world full of enormous complexity, including biodiversity. Thus, eco-environmental realism refers to the policy or framework principle within which we the members of the species *Homo sapiens* are urged or required to interact with nature and Earth's ecosystems locally, without the arrogance of treating our habitats as if they were separable from *the* world, just meant to be exploited and controlled for human benefit. Universal interconnectedness across nature and the universe reigns supreme (Pandit 2001b, 2006a, 2012). Thus, with the ecological-environmental-realistic turn comes an epistemological turn.

Before we domesticate what now remains of nature, we must heed eco-environmental realism. Eco-environmental realism, as a philosophy of ecology, does not demand prior fulfilment of the epistemologist's requirement of observability of nature's complexities, using our naked eyes, as a condition for our recognition of enormous complexities underlying ecologically significant realities across nature. It rather demands that anything which dynamically *participates* in these complexities, contributing to the ecosystem resilience and sustaining ecosystem services, should be regarded as part of ecologically complex world, whether accessible to unaided observation or not. From a scientific point of view, the complexities of biosphere and its ecosystem types include the enormously complex bio-diversities of nature. Nature's bio-diverse species are sustained by dynamic processes of habitation by *environmental nesting* (Pandit 1995). The enormously complex processes of *environmental nesting* cannot always be perceived by us, using our unaided sense organs.

If it were easier for us, humans, to be realistic, to consistently perceive and recognize the enormous complexities and dynamic interactions within and across the ecosystems that we inhabit and that we seek to domesticate out of greed more than out of need, we could easily distinguish between habitation by *environmental nesting* and habitation by creative destruction. The question is whether we can still save Earth, saving from humanity's arrogant and creative destruction what still remains of nature. If the answer is yes, then it should also be possible to save humanity's future interests. There is no other way. It is not possible to think of first saving humanity in order to save our living planet Earth.

Besides its local side, eco-environmental realism brings universal interconnectedness across nature (or universe) to bear upon our attitude to and policy regarding ecosystem resilience and environmental resource management. This universal side of eco-environmental realism is expressed by thinking of *the* world as if it was a nest. If treating the *nest* as a world, embedded in *the* world, allows us to recognize the nest, i.e., our habitat and its local environment, in its vast ecological complexity, then treating the world, i.e., the whole universe, as a *nest* ensures that we recognize how important universal interconnectedness, across nature and universe as a whole, is to our consciousness or to the ecology of consciousness and to our very existence.

In this way, learning the lessons from nature, eco-environmental realism gets rooted in the ecological self, recognizing the urgency for nature policy, given the ecologically complex realities and the universal interconnectedness (Pandit 2001b, 2006a, 2007c, 2008a , 2010a, 2010c, 2012) across the universe as a whole, beyond all that which our minds can perceive. Alteration of nature and creative destruction of ecosystems may be inevitable, as some think, as a result of domestication of nature. Eco-environmental realism requires that any alterations humans make be consistent with environmental resource management policy and scenario building based not just on our knowledge of ecological complexity, on our knowledge of the living planet Earth and its bio-diverse ecosystems but on Wisdom Inquiry (Pandit 2012). In other words, it reminds us of the irreversible loss of knowledge of ecological complexity as a result of adopting domestication of nature as a policy, simply dictated by the arrogance of man.

An eco-environmental realist will always ask:

1. How best can we work *with*, and not against, nature?
2. Is it possible to work with nature without presupposing the acquisition of ecological knowledge of nature's complex ecosystems?

The questions (1) and (2) can be answered as follows: It is only after ecological knowledge is acquired that we can use it for thinking and acting in the interest of ecosystem health. Being ourselves a part of that whole, which we call nature, sharing the structure–property correlations across the nested dependencies in her ecosystems, thinking and acting in the larger interest of ecosystem health should take care of human well-being interests as well. Long term human interests, including the well-being interests of future generations, cannot be in conflict with long term ecosystem interests. The conflict arises only when we think exclusively of our short term human interests, assuming wrongly that in the long run nature will take care of her ecosystems and ecosystem services.

If we want to put as much of science and technology as possible to use for sustainable development, then technology-driven domestication of nature cannot be our future policy, even if we know by now that domestication as a phenomenon is an inevitable consequence of development. Instead of domestication, it is the policy of development by *environmental nesting* within eco-environmental realism (Pandit 1995) which should guide us both in the development and use of new technologies. Following eco-environmental realism as a philosophy of ecology, we will still doubtlessly have to cope with domestication of nature as a consequence of the technologies we choose to deploy for development. While we avoid domestication as a policy by opting for De-domestication, we would be safeguarding the interests of both man and nature by saving nature from the onslaughts of ADN as a totalitarian policy.

Note: For their invitation to participate and contribute, the author thanks the organizers of the International Conference Strengthening Cooperation Between Germany and India—International Humboldt Kolleg on *Adaptive Management of Ecosystems*: *The Knowledge Systems of societies for adaptation and mitigation of impacts of climate change* (19th–21st October 2011) held at the Centre for Ecological Economics and Natural Resources, Institute for Social and Economic Change, Bangalore, India. He wishes to thank them for their hospitality during the International Conference. The author's present contribution is a part of an independent research programme in progress.

References

Barbier Edward B (2010) Poverty, development, and environment. *Environment and Development Economics* 15: 635–660.

Bruntland Harlem G (1987) Address at the closing ceremony of the eighth and final meeting of the world commission on environment and development', Tokyo, Japan 27th February 1987: pp. 1–7

Carson R (2002) Silent spring. Mariner's books (ed), Houghton Mifflin Company, Boston/New York (first published in 1962)

Dalby S (2009) Security and environmental change. Polity Press, Cambridge, pp 18–19

Dodman D, Ayers J, Huq S (2009) Building resilience, chapter 5. State of the World: Into a Warming World, The Worldwatch Institut: pp. 151–168. Available at www.worldwatch.org. See also Barbier, Edward B., (2010): 'Poverty, development, and environment', Environment and Development Economics 15: 635–660

Ehrlich Paul R (1968) The population bomb. Ballantine, New York

Foley Duncan K (2006) Adam's fallacy: a guide to economic theology. Harvard University Press, Cambridge

Gamborg C, Gremmen B, Christiansen SB, Sandoe P (2010) Ethics at the intersection of landscape restoration and animal welfare. Environ Values 19(1):57–78(22)

Haerlin B, Parr D (1999) How to restore public trust in science? Nature 400:499

Hardin G (1968) The tragedy of the commons, Science 162, December 13, 1968: 1234–1248

Hardin G (1998) Extensions of 'the tragedy of the commons'. Science 280(1): 682–683. Available at www.sciencemag.org

Honnefelder L (2011a) Das Eigene und das andere: Ueber unseren Umgang mit der Nature. Die Politische Meinung, Konrad Adenauer Stiftung, Nr. 499, Juni 2011 (56. Jahrgang), S. 10–14

Honnefelder L (2011b) Ueber die Natur des Menschen und die ihn umgebende Natur. Berlin University Press, Berlin

Kareiva P, Sean W, Robert M, Tim B (2007) Domesticated nature: shaping landscapes and ecosystems for human welfare. Science 316:1866–1869

Klein Philip A (2006) *Economics Confronts the Economy*, Cheltenham: UK and Northampton, MA: Edward Elgar. See Lee FS (2008) Review of 'economics confronts the economy' by Philip A. Klein. J Econ Issues XLII: 276–277

Lomborg B (2011) A roadmap for the planet. Newsweek 2011:24–27

Lubchenco J (1998) Entering the century of the environment: a new social contract for science. Science 129 (23 January 1998): 491–497. See Pandit, GL (2009a) Ethics in public domain: biomedical research and beyond'. In: Alok Srivastava and Ipsita Roy (eds.), Bio-Nano-geo sciences: the future challenge, Humboldt-Kolleg-Palampur (India), Anne Books: New Delhi/Chennai/Mumbai 2009, pp 187–208. A pre-print is accessible in Indo-German Science Circle

Website of the Embassy of Federal Republic of Germany, New Delhi: (www.science-cooperation.org/www.science-circle.org)

Malthus T (1970) An essay on the principle of population. Penguin, Harmondsworth (first published in 1798)

McPherson GR, DeStefano S (2003) Applied ecology and natural resource management. Cambridge University Press, Cambridge

Meadows DH, Meadows DL, Randers J, Behrens WW III (1974) The limits to growth. Pan, London, pp 23–24

Meine C (1988) Aldo Leopold: his life and work. University of Wisconsin Press, Madison, p 293

Millennium Ecosystem Assessment (2005a) Synthesis report. Available at www.millenniumassessment.org

Millennium Ecosystem Assessment (2005b) Ecosystems and human wellbeing, vols 5. Island Press, Washington DC

Norton BG (2003) Searching for sustainability: interdisciplinary essays in the philosophy of conservation biology. Cambridge University Press, Cambridge, p 293

Pandit GL (1982) The structure and growth of scientific knowledge—a study in the methodology of epistemic appraisal. boston studies in the philosophy of science, vol 73 (with an Editorial Preface written by Robert S. Cohen and Marx W. Wartofsky). Dordrecht/Boston/London: D. Reidel Publishing Company/Springer Verlag, Netherlands

Pandit GL (1991) Methodological Variance: Essays in Epistemological Ontology and the Methodolohy of Science. Boston Studies in the Philosophy of Science vol 131, xxiv+422 pp Dordrecht/Boston/London: Kluwer Academic Publishers/Springer Verlag, Netherlands. Dedicated to Karl R. Popper (1902–1994), this work was completed by the author during his first research stay in the Federal Republic of Germany (Berlin/Heidelberg, 1986–1987)

Pandit GL (1995) Von der Oekologie des Bewusstseins zum Umweltrealismus—Die Wiederentdeckung menschlicher und nicht-menschlicher Interessenssphaeren.Wiener Vorlesungen Band 41. Picus Verlag, Wien

Pandit GL (1996) Bewusstsein und seine Existenzformen: zurueck zum moralisch ungeteilten Universum', in Christoph Hubig und Hans Poser (Hrsg.) Cognitio humana—Dynamik des Wissens und der Werte—XVII. Deutscher Kongress fuer Philosophie: Workshop-Beitraege Band I, Leipzig, pp 34–41)

Pandit GL (1998) Review of Huntington, Samuel P (1997) The clash of civilizations and the remaking of world order. Viking: Penguin India, pp. 367, in *World Affairs* **2** (Jan–Mar 1998, 135–137)

Pandit GL (1999a) Paradoxes of progress: how can humanity improve environmental thinking and environmental action? Politics Life Sci 18:241–242

Pandit GL (1999b) Weltumfrage zur Situation der Philosophie am Ende des 20.Jahrhunderts. In: Raul Fornet-Betancourt (Hrsg.) Quo vadis, Philosophie? Antworten der Philosophen: Dokumentation einer Weltumfrage. Wissenschaftsverlag Mainz in Aachen, pp 222–227

Pandit GL (1999c) L'impact de la pensee de Sir Karl Popper sur notre comprehension du monde naturel et du monde des home. Quo vadis: Revue Internationale de Philosophie 35 (1999, 82–94)

Pandit GL (2000a) Environmental actions: can a part control the whole? J Dutch Syst Group 12: 351–368. In: Proceedings of the international conference held in Amsterdam, the Netherlands, problems of action and observation, a special issue of systemical

Pandit GL (2000b) Review of Strange, Susan (1998) The retreat of the state: The diffusion of power in the world economy. Cambridge University Press, Cambridge: xvii+218. In: World Affairs 4 (Jan–Mar 2000), pp 113–115

Pandit GL (2001a) Participate and reconnect: the problem of improving the human condition. In: Gerard de Zeeuw, Martha Vahl and Ed Mennuti (eds) Problems of participation and connection, a special issue of systemica, vol 13. pp 337–341

Pandit GL (2001b) Leibniz and the changing images of universal interconnectedness. In: Hans Poser et al (Hrsg.) VII. Internationaler Leibniz-Kongress 'NIHIL SINE RATIONE—Mensch, Natur und Technik im Wirken von G. W. Leibniz', Vortraege 2. Teil. Technische Universitaet Berlin: 942–947

Pandit GL (2001c) Tradition and innovation in Asian culture: India', in Raul Fornet-Betancourt (Hrsg.) Kulturen zwischen Tradition und Innovation: Stehen wir am Ende der traditionellen Kulturen? IKO—Verlag fuer Interkulturelle Kommunikation: Frankfurt, (2001, 48–64). Dokumentation des III. Internationalen Kongresses fuer Interkulturelle Philosophie: Aachen, 22–25 Nov 1999

Pandit GL (2001d) Review of von Welck, Stephan F. (ed) Crossing borders, stretching boundaries: the bose-einstein lectures on indo-german cooperation in science, technology and environment. Manohar Publishers and Distributors, New Delhi, 2000 pp 237. In: World Affairs 5 (Oct–Dec 2001), pp 126–130

Pandit GL (2004a) Ecologies of environmental nesting. In: Karimo Bakhtiyor (ed.) Proceedings of Humboldt-Kolleg (July 6–10, 2004), Uzbekistan—use of geographic information systems and simulation models for research and decision support in central Asian river basins. Tashkent, p 154

Pandit GL (2004b) Review of Stevis, D. & Assetto, V. J. (Eds.) The International Political Economy of the Environment—Critical Perspectives. Lynne Rienner Publishers, Boulder/London, 2001, pp viii+309. In: World Affairs 8 (July–Sep 2004) pp 131–135

Pandit GL (2004c) Review of Maude Barlow and Tony Clarke, Blue Gold: The Battle against corporate theft of the world's water. Earthscan: London, 2002, pp xviii+278, in World Affairs 8, Oct–Dec 2004, pp 119–122

Pandit GL (2005a) World's refugees: What humanity owes to them. World Affairs, J Int Issues 9:148–156. A Review Essay based upon on Dagmar Bernstorf and Hubertus von Welck (Eds.) Exile as Challenge: The Tibetan Diaspora', Orient Longman 2003, pp.vii+488; B

Pandit GL (2005b) Consciousness in search of its ecology. In: Chattopadhayaya DP (ed) Self, society and sciences: theoretical and historical perspectives (history of science, philosophy and culture in indian civilization), vol. XI/part 2. Centre for Studies in Civilizations, New Delhi, pp 70–76

Pandit GL (2006a) Leibniz's Weltbild of Universal Interconnectedness. In: Herbert Breger, Jürgen Herbst und Sven Erdner (Hrsg.) Einheit in der Vielheit. Vorträge 2. Teil, VIII. Internationaler Leibniz-Kongress Vorträge: 769–779

Pandit GL (2006b) Exclusion and uprootment in Kashmir: from a political tragedy to an ecological catastrophe. World Affairs. J Int Issues 10:150–169

Pandit GL (2007a) Emergence of the human interests studies: the environmental dimension'. In Gerard de Zeeuw, Martha Vahl and Ed Mennuti (eds) Problems of Individual Emergence, special issue Systemica, vol 14. pp 295–312

Pandit GL (2007b) Ethical tasks of media advocacy in the 21st century. In: Philosophie der Informationsgesellschaft/Philosophy of the Information Society, Beitraege des 30. Internationalen Wittgenstein Symposium (5–11 Aug 2007), Band XV, edited by Herbert Hrachovec, Alois Pichler and Joseph Wang, pp 169–173, Kichberg am Wechsel: Austrian Ludwig Wittgenstein Society. See UNICEF report on childhood in industrialised countries, News item 14 February 2007: see http://www.unicef.org.uk/press/news_detail.asp?news_id=890

Pandit GL (2007c) Rethinking Science-Studies with a Return to Natural Philosophy. Friends of Wisdom News Letter (No. 1, Nov. 2007c: pp. 28–32), A Review Essay based on Nicholas Maxwell: Is Science Neurotic? Imperial College Press: 2004, pp. xx+240. For details, visit FOW archive at: www.jiscmail.ac.uk/lists/friendsofwisdom.html

Pandit GL (2007d) Philosophy, science and environmental realsm: educational, ethical and environmental issues of concern to mankind. XIX. Heidelberg physics graduate days (8–12 October 2007), invited lectures at the Graduate School of Fundamental Physics, Department of Physics and Astronomy, University of Heidelberg (unpublished)

Pandit GL (2008a) Universities with a room for wisdom inquiry. Friends of Wisdom News Letter 3:4–9

Pandit GL (2008b) Unrecognized Minorities. Combat Communalism Forum 14(128):1–3

Pandit GL (2009b) Rethinking science studies, methodology, ethics and international political economy of the environment. XXII. Heidelberg physics graduate days (23rd–27th Mar 2009), invited Lectures at the Graduate School of Fundamental Physics, Department of Physics and Astronomy, University of Heidelberg (unpublished)

Pandit GL (2010a) How simple is it for science to acquire wisdom according to its choicest aims? Philosophia 38:649–666

Pandit GL (2010b) State of collective crimes: beyond the south asian political ritual dynamics. World Aff: J Int Issues 14:164–176

Pandit GL (2010c) Aim Oriented Empiricism: How We Might Improve the Aims and Methods of Science, Making it More Rational, Responsible and Far Reaching', Friends of Wisdom Newsletter, No.6, January 2010c, pp. 30–37, a Review Essay based on Nicholas Maxwell: What is Wrong with Science? Second Edition, Pentire Press, London (first published by Bran's Head Books 1976)

Pandit GL (2011) Accelerated domestication of nature (ADN): rethinking development by ecological overshoot. XXVI Heidelberg Physics Graduate Days (04–08 April 2011a), Department of Physics and Astronomy of the University of Heidelberg (unpublished)

Pandit GL (2012) A Science of universal interconnectedness: rationality of wisdom inquiry. In: IX. International Leibniz-Kongress: Nature and Subject, Nachtragsband: Herausgegeben von Herbert Breger, Juergen Herbst und Sven Erdner, Hannover: September 26–1 October 2011, S. 214–225. Herstellung: Druckerei Hartmann GmbH, Weidendamm 18, 30167 Hannover Hannover

Pandit GL (2013) Against the state of collective crimes: The Way Ahead to Improving Human condition. World Affairs, J int Issues 17:April–June (in press)

Peterson J (2008) Review of 'Adam's Fallacy: a guide to economic theology, by Duncan K. Foley. Harvard University Press, Cambridge, J Econ Issues XLII:272–273

Pretty J (2007) The earth only endures—on reconnecting with nature and our place in it. Sterling, London

Ramberg B (2011) A pandora's box in the middle east. International Herald Tribune, 27 Dec 2011

Schwarzburger Heiko (1998) Kein blindes Technik-Vertrauen—Indischer Philosoph fordert Umweltrealismus und neue Ethik—Bildung und Wissenschaft—Der Tagesspiegel (Berlin): Sonntag, 7. Juni 1998, s. 44

Small Meredith F (1996) Review of dominion, by Niles Eldredge. Henry holt and company; 1995. Scientific American March 1996: 88B

Storm S (2008) Review of 'Adam's Fallacy: A Guide to Economic Theology' by Duncan K. Foley. Harvard University Press, Cambridge. Development and Change 39:336–338

Wagner M (2000) Rezension: Giridhari Lal Pandit, Von der Oekologie des Bewusstseins zum Umweltrealismus: Die Wiederentdeckung menschlicher und nichtmenschlicher Interessenssphaeren (Wiener Vorlesungen im Rathaus Band 41), Picus-Verlag Wien, 1995, Forum TTN-Fachzeitschrift des Instituts Technik-Theologie-Naturwissenschaften an der Ludwig-Maximilians-Universitaet Muenchen, S. 87–88

Webb CT (2007) What is the role of ecology in understanding ecosystem resilience? BioScience 57(6):470–471. Available at www.biosciencemag

World Commission on Environment and Development (WCED 1987) Tokyo Declaration: Our Common Future. Oxford University Press, 1987:1-4

Climate Change Induced Coral Bleaching and Algal Phase Shift in Reefs of the Gulf of Mannar, India

J. Joyson Joe Jeevamani, B. Kamalakannan, N. Arun Nagendran and S. Chandrasekaran

1 Introduction

Coral reefs are the most diverse and complex of all marine ecosystems which normally flourish in tropical and semitropical regions of the world where water temperatures range between 16 and 30 °C. Coral reefs are most productive and provide various goods and ecological services (Moberg and Folke 1999) to human as well as marine biota. On other hand, throughout the world, there are many threats to existing coral reefs. Global warming, over fishing, mining, sedimentation, pollution, and diseases all threaten the viability and health of coral reefs. Coral bleaching is considered one of the biggest threats to coral reefs which accompanies coral mortalities (Brown 1997; Glynn 1993). Bleaching is a natural phenomenon in which the symbiotic intracellular algae (*zooxanthellae*) of reef-building corals is expelled under stressful environmental conditions causing corals to lose their color. Such conditions are now more frequent due to global warming (Donner et al. 2005; Hoegh-Guldberg et al. 2007). Global warming and associated increases in sea surface temperatures (SSTs) are now projected to be very likely in the coming decades (IPCC 2007; Phinney et al. 2006). Incidence of coral bleaching reports, primarily due to SST rise, has increased considerably since the early 1980s (Glynn 1993; Hoegh-Guldberg 1999; Hoegh-Guldberg et al. 2007; Hughes et al. 2003). More often, mass coral mortality due to bleaching is followed by an invasion of macro algae which ultimately results in shifted algal dominated system (Done 1992). Such shift from coral reefs to high cover of macro algae is

J. Joyson Joe Jeevamani
Department of Botany, Thiagarajar College, Madurai 625009, India

N. Arun Nagendran
Department of Zoology, Thiagarajar College, Madurai 625009, India

B. Kamalakannan · S. Chandrasekaran (✉)
Department of Plant Sciences, School of Biological Sciences, Madurai Kamaraj University, Madurai 625021, India
e-mail: invasionecology@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_6,

referred as 'coral-algal phase shift'. Regional scale studies are highly necessary to investigate the process of coral-algal phase shift after the bleaching phenomenon. Reefs of India also experienced severe bleaching events in 1998 and 2002. Increase in SST appears to be the main stress for these events (Arthur 2000; Kumaraguru et al. 2003). The present study reports algal phase shift after a bleaching event in 2010 in reefs of the Gulf of Mannar (GoM), India.

2 Materials and Methods

Visual observations of the bleaching event were observed during April 2010 in reefs of Kurusadai Island (9°15′ N; 79°12′ E) at Gulf of Mannar, Southeast coast of India (Fig. 1). Bleaching occurred in both massive and branching forms of corals. Photographic records were taken at first and bleached coral cover was estimated using transects. Totally, 10 transects, each of 5 m in length, were laid on selected bleached locations at a depth range from 0.25 to 2 m. Transects were marked using a Geographical Position System (GPS) device and revisited periodically at least once in a month from April to July 2010. Biophysical status of coral reefs were assessed based on observation of live coral cover, bleached coral (massive and branching forms), algal mat cover (algal turfs, macro-algal cover) and sand/coral rubble. SST was measured in situ using mercury bulb thermometer. To correlate SST with bleaching, satellite SST dataset obtained from National Oceanic and Atmospheric Administration's Coral Reef Watch (NOAA/CRW) satellite bleaching alert (SBA) system (http://coralreefwatch.noaa.gov) specifically derived for the Gulf of Mannar region from January 2001 to October 2010 was used (Gang Liu, "personal communication"). The SST data is based on the NOAA 0.5° (approximately 50 km) resolution using Advanced Very High Resolution Radiometer (AVHRR) with weekly twice time interval. The data was subjected to appropriate statistical analyses.

3 Results and Discussion

Results show that both massive (*Porites* sp.) and branching (*Acropora* sp.) corals have been affected during the bleaching event of 2010 (Plate 1). Around 57 % of corals were found to be bleached in Kurusadai Island during April to June 2010. *Porites* species were affected more compared to *Acropora* species. SST results shown that mean SST of the Gulf is 28.7 °C in 2010 with a maximum temperature of 31 °C in May and minimum temperature of 27.0 °C in February (Fig. 2). Sudden increase of temperature was observed (Fig. 2) from 29.9 to above 30.9 °C in April (16th week) and the existence of high temperature (up to 31 °C) for 7 weeks (April to May). Anomalies of mean SST for these weeks were also shows a great increase range from +1 to 2.2 °C (Fig. 3) relative to the 1950–1979 base

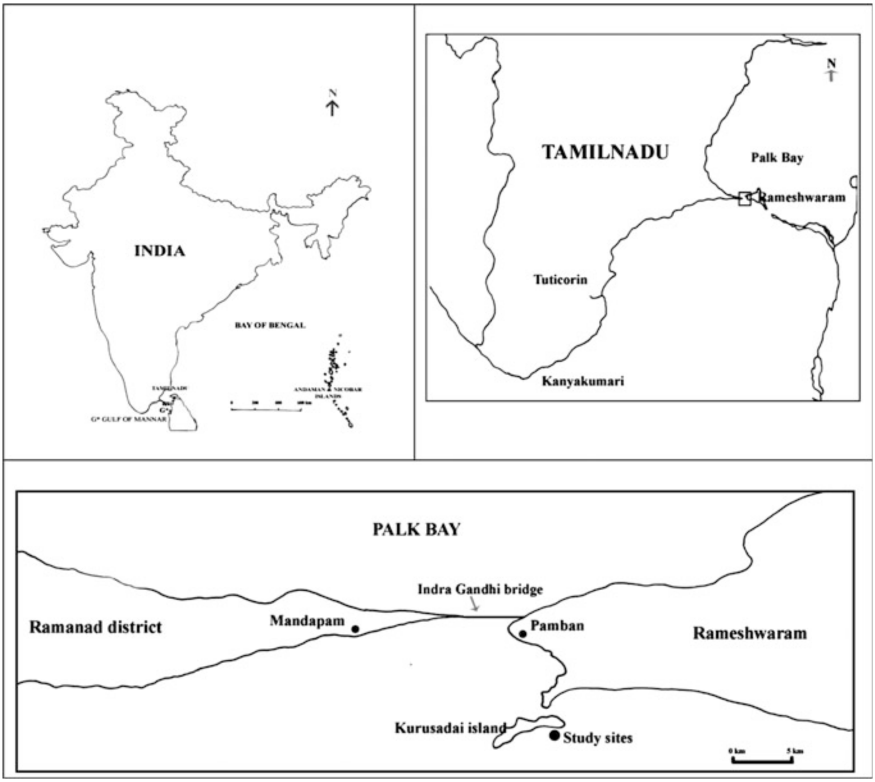


Fig. 1 Map of the Gulf of Mannar (*GoM*) Biosphere Reserve showing Kurusadai Island and study site

periods. Prolonged existence of inexperienced increased SST for nearly 50 days caused the corals to bleach. Decadal mean SST of Gulf of Mannar varied from 28.2 to 28.7 °C with a maximum temperature of 31.2 °C in 2002 and minimum temperature of 25.7 °C in 2004 (Fig. 4). The mean SST of the Gulf of Mannar has been growing at 0.02 °C per decade along with 0.1 °C increase per decade in minimum SST temperature.

Observation in July 2010 indicates that recovery was also rapid as that of bleaching. Nearly 15 % of bleached corals were found to have recovered. Recovery patterns differed between the two forms of corals. Recovery process is fast and effective in massive (*Porites*) rather than branching forms (*Acropora*). The increase in live coral cover (from 11.23 to 44.87 %) was mainly contributed by massive corals (Table 1). Significant recovery of branching corals was not observed. As a consequence, these corals were overgrown by algal mats (*Sargassum* sp., *Turbinaria* sp., *Ulva* sp., *Caulerpa* sp., *Kappaphycus alvarezii)* or algal turfs (Plate 1e and f) which increased the algal assemblage in branching forms from 10.9 to 18.36 %.

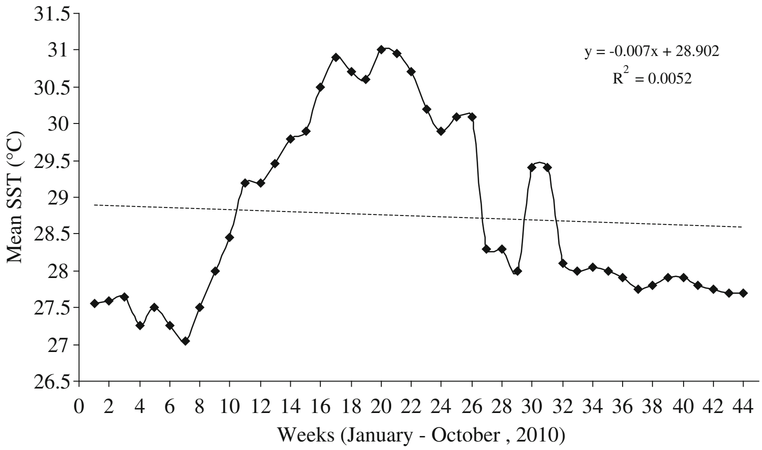


Fig. 2 Weekly mean SST occurred in Gulf of Mannar in the year 2010

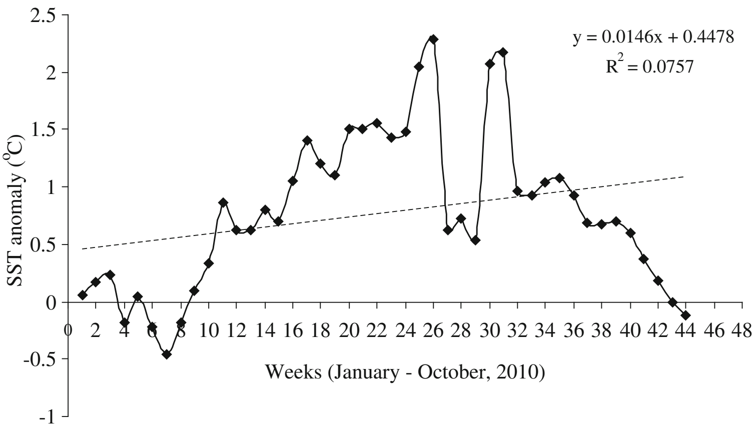


Fig. 3 Weekly mean SST anomaly occurred in Gulf of Mannar in the year 2010

Similar to 1998 and 2002, the bleaching event in 2010 is driven by the increased effect of SST which was also recorded in other parts of world during the summer season (Harrison et al. 2011). Our results of this SST anomaly were also correlated with the prediction of McWilliams et al. (2005) who stated that maximum bleaching extent and intensity will occur at regional SST anomalies of less than +1 °C level. In our study, the mortality rate was high and recruitment rate was low in branch coral forms rather than in the massive and encrusting coral forms. Similar results were also reported earlier, which demonstrated that scleractinia corals with branching colony morphologies generally suffer higher rates of mortality than species with massive and encrusting morphologies (Hoegh-Guldberg and Salvat 1995; Jokiel and Coles 1990; Marshall and Baird 2000; McClanahan

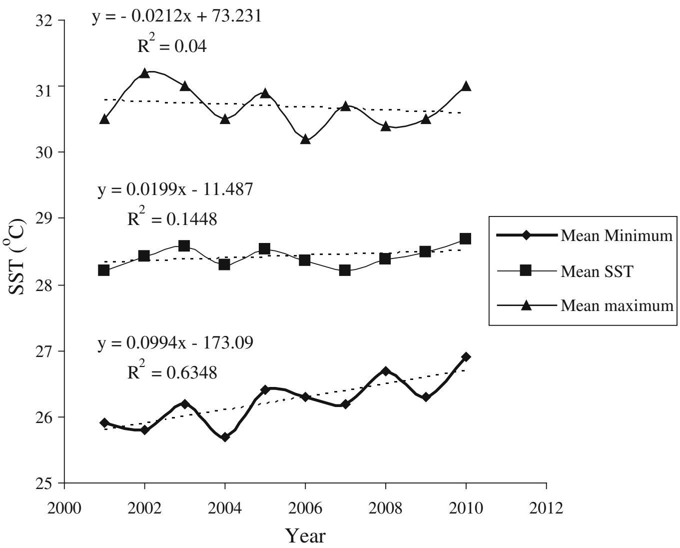


Fig. 4 Average minimum, maximum and mean SST at Gulf of Mannar for 2001–2010

Table 1 Status of coral life forms after bleaching event on April 2010 and during recovery on July 2010 in Kurusadai Island, Gulf of Mannar, India

S. No.	Life forms[a]	April 2010		July 2010		t—test[b]	
		Mean (SE) (n = 10)	Cover (%)	Mean (SE) (n = 10)	Cover (%)	t value	P[c]
1.	BMC	2.25 (0.24)	45.10	0.57 (0.06)	11.43	6.57	**<0.05**
2.	BBC	0.59 (0.06)	11.74	0.16 (0.02)	3.16	7.26	**<0.05**
3.	AMC	0.40 (0.04)	7.95	0.44 (0.04)	9.05	6.14	**<0.05**
4.	ABC	0.55 (0.06)	10.90	0.92 (0.10)	18.36	3.59	**<0.05**
5.	LC	0.56 (0.06)	11.23	2.23 (0.23)	44.87	8.08	**<0.05**
6.	SA	0.65 (0.07)	13.08	0.66 (0.07)	13.13	1.00	0.922

[a] *BMC* Bleached massive type corals, *BBC* Bleached branching type corals, *AMC* Algal assemblage over massive type corals, *ABC* Algal assemblage over branching type corals, *LC* Live coral, *SA* Sand area
[b] Paired t—test
[c] Bold faced values are highly significant

and Maina 2003). Bleaching incidence, caused by global warming, has resulted in replacement of hardier coral species by less hardy corals (Glynn and De Weerdt 1991) and corals by macro algae (Shulman and Robertson 1996). Our results synchronize with the above reported changes. Bleaching has significantly induced occurrence of phase-shift from coral to algae in the study site as previously observed in other regions of the world (Aronson et al. 2002, 2004; Hughes 1994). Baker et al. (2008) suggested that changes in coral community structure following

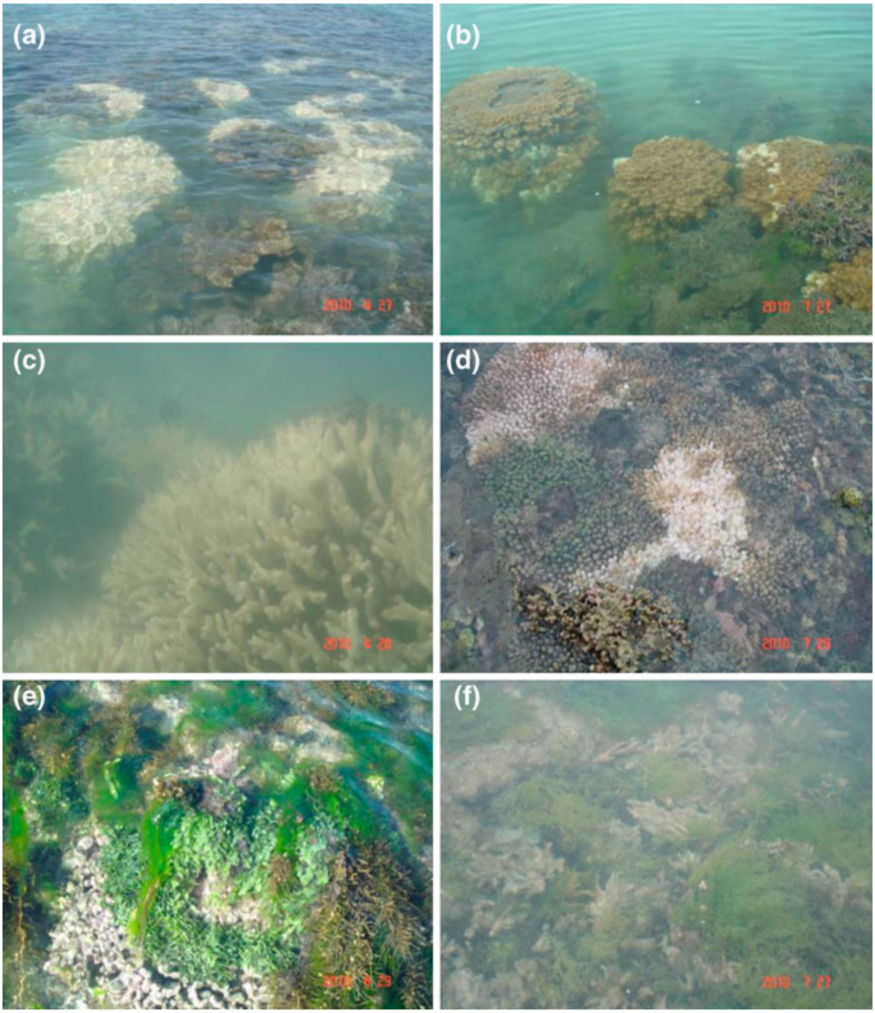


Plate 1 **a** Bleaching in massive corals (*Porites* sp.). **b** Recovered massive corals. **c** Bleaching in branching corals (*Acropora* sp.). **d** Algal turfs over bleached *Acropora* corals. **e** and **f** Algal phase shift dominated in branching coral forms

bleaching can take two forms, *viz*., changes in the relative abundance of coral surviving *zooxanthellae* and changes in the dominance of non-coral taxa associated with reef assemblages. When bleaching long lasts with pronounced effect, coral-algal phase shift results and can lead to fundamental differences in the structure of reef communities. So it is inferred from this study that if increase in SST continues into the future, it will definitely impact the coral communities in the Gulf of Mannar and, thereby, affect the unsubstituted ecosystem services obtained from them.

4 Conclusion

Existence of shift from coral dominance to algal dominance, following a bleaching incident in reefs of Gulf of Mannar is clear from the study. Once these communities have shifted, it will require a long time to return to their original status. Coral reefs of the Gulf of Mannar are already under serious threats like pollution, sedimentation, destructive fishing practices, biological invasion (Chandrasekaran et al. 2008; Kamalakannan et al. 2010), etc. Now coral-algal phase shift is also adding stress to the environment. Immediate mitigation measures have to be taken in order to protect the enriched coral diversity of Gulf of Mannar from recent climate change.

Acknowledgments We are thankful to the UGC and CSIR, New Delhi for the financial assistance to carry out this work. We also thank the Forest Department, Government of Tamil Nadu for providing permission and their encouragement to carry out this work. We are thankful to Mr. M. R. Anbarasan, Madurai for his valuable help in data mining.

References

Aronson RB, Macintyre IG, Precht WF, Murdoch TJT, Wapnick CM (2002) The expanding scale of species turnover events on coral reefs in Belize. Ecol Monogr 72:233–249

Aronson RB, Macintyre IG, Wapnick CM, O'Neil MW (2004) Phase shifts, alternative states, and the unprecedented convergence of two reef systems. Ecology 85:1876–1891

Arthur R (2000) Coral bleaching and mortality in three Indian reef regions during an El Niño southern oscillation event. Curr Sci 79:1723–1729

Baker AC, Glynn PW, Riegl B (2008) Climate change and coral reef bleaching: an ecological assessment of long-term impacts, recovery trends and future outlook. Estuar Coast Shelf Sci 80:435–471

Brown BE (1997) Coral bleaching: causes and consequences. Coral Reefs 16:S129–S138

Chandrasekaran S, Nagendran NA, Pandiaraja D, Krishnankutty N, Kamalakannan B (2008) Bioinvasion of *Kappaphycus alvarezii* on corals in the Gulf of Mannar, India. Curr Sci 94:1167–1172

Done TJ (1992) Phase shifts in coral reef communities and their ecological significance. Hydrobiologia 247:121–132

Donner SD, Skirving WJ, Little CM, Oppenheimer M, Hoegh-Guldberg O (2005) Global assessment of coral bleaching and required rates of adaptation under climate change. Glob Change Biol 11:2251–2265

Glynn PW, De Weerdt WH (1991) Elimination of two reef-building hydrocorals following the 1982–83 El Niño warming event. Science 253:69–71

Glynn PW (1993) Coral reef bleaching: ecological perspectives. Coral Reefs 12:1–17

Harrison PL, Dalton SJ, Carroll AG (2011) Extensive coral bleaching on the world's southernmost coral reef at Lord Howe Island, Australia. Coral Reefs 30:775

Hoegh-Guldberg O, Salvat B (1995) Periodic mass-bleaching and elevated sea temperatures: bleaching of outer reef slope communities in Moorea, French Polynesia. Mar Ecol Prog Ser 121:181–190

Hoegh-Guldberg O (1999) Climate change, coral bleaching and the future of the world's coral reefs. Mar Freshw Res 50:839–866

Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, Gomez E, Harvell CD, Sale PF, Edwards AJ, Caldeira K, Knowlton N, Eakin CM, Iglesias-Prieto R, Muthiga N, Bradbury RH, Dubi A, Hatziolos ME (2007) Coral reefs under rapid climate change and ocean acidification. Science 318:1737–1742

Hughes TP (1994) Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science 265:1547–1551

Hughes TP, Baird AH, Bellwood DR, Card M, Connolly SR, Folke C, Grosberg R, Hoegh-Guldberg O, Jackson JBC, Kleypas J, Lough JM, Marshall P, Nyström M, Palumbi SR, Pandolfi JM, Rosen B, Roughgarden J (2003) Climate change, human impacts, and the resilience of coral reefs. Science 301:929–933

IPCC (2007) Climate change 2007: the physical science basis. Summary for policy-makers. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Available via:http://www.ipcc.ch

Jokiel PL, Coles SL (1990) Response of Hawaiian and other Indo-Pacific reef corals to elevated temperature. Coral Reefs 8:155–162

Kamalakannan B, Jeevamani JJJ, Nagendran NA, Pandiaraja D, Krishnan Kutty N, Chandrasekaran S (2010) *Turbinaria* sp. as victims to *Kappaphycus alvarezii* in reefs of Gulf of Mannar, India. Coral Reefs 29:1077

Kumaraguru AK, Jayakumar K, Ramakritinan CM (2003) Coral bleaching 2002 in the Palk Bay, southeast coast of India. Curr Sci 85:1787–1793

Marshall PA, Baird AH (2000) Bleaching of corals on the Great Barrier Reef: differential susceptibilities among taxa. Coral Reefs 19:155–163

McClanahan TR, Maina J (2003) Response of coral assemblages to the interaction between natural temperature variation and rare warm-water events. Ecosystems 6:551–563

McWilliams JP, Côté IM, Gill JA, Sutherland WJ, Watkinson AR (2005) Accelerating impacts of temperature-induced coral bleaching in the Caribbean. Ecology 86:2055–2060

Moberg F, Folke C (1999) Ecological goods and services of coral reef ecosystems. Ecol Econ 29:215–233

Phinney JT, Hoegh-Guldberg O, Kleypas J, Skirving W, Strong A (2006) Coral reefs and climate change: science and management, coastal and estuarine studies, vol 61. American Geophysical Union, Washington DC

Shulman MJ, Robertson DR (1996) Changes in the coral reefs of San Blas, Caribbean Panama: 1983 to 1990. Coral Reefs 15:231–236

Economic Valuation and Sustainability of Dal Lake Ecosystem in Jammu and Kashmir

M. H. Wani, S. H. Baba, Shahid Yousuf, S. A. Mir and F. A. Shaheen

1 Introduction

Natural resources are capital endowments that determine a nation's wealth and its status in the world economic system. A natural resource is characterized by amounts of biodiversity and geo-diversity existing in various ecosystems. Considering the necessity of these resources, the major concern is to operate an economy within the ecological constraints of earth's natural resources. Among various resources, water is of immense importance and its various uses include agriculture, industrial, household, recreational, and environmental activities. The water resources in ecosystems have been subject to stress (Khan et al. 1999; Ruibal Conti et al. 2005; Bondavalli et al. 2006; Massoud et al. 2006; Mustafa et al. 2008). Awareness of the global importance of preserving water for ecosystem services has only recently emerged as more than half the worlds' wetlands have been lost along with their environmental services during the 20th century. Lake ecosystems, undoubtedly, represent valuable environmental resource with consequently high preservation, conservation and utilization value (Marothia 2004), and that outdoor recreation has received considerable attention in environmental economics but this very aspect has been found to be a completely neglected research area in India (Marothia 1979, 1988, 2000, 2001; Hadker et al. 1995; Chopra 2001). Studies have reported a gradual contamination of lakes resulting into eutrophication. Further good performance of agriculture and tourism (Raza and Bano 1985; Korn 2001; Sharma et al. 2006; Semwal and Akolkar 2006; Atapattu and Molden 2006) in turn enhance algal growth (Hadwen et al. 2005; Gulbahar and Elhatip 2005; Rimpy and Ahluwalia 2007; Dhamotharan et al. 2008). Even the plans to upgrade the present limited facilities for tourism development also threaten the lake ecosystem and fishing within it (Yusoff et al. 1994;

M. H. Wani (✉) · S. H. Baba · S. Yousuf · S. A. Mir · F. A. Shaheen
Division of Agricultural Economics and Marketing, SKUAST-K, Shalimar,
Srinagar, J&K 191121, India
e-mail: rgckashmir@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_7,

Singh et al. 1995; Lopez Rios and Lechuga Anaya 2001; Moiseenko and Sharova 2006; Mustafa et al. 2008). Local residents were observed to threaten the ecological integrity of lakes by discharging organic wastes that encourage aquatic weeds (Sitonyte et al. 2006; Kumari et al. 2007; Uzun et al. 2008). Despite this, however, existing evidence strongly suggest that lake ecosystems in India are still not being managed sustainably. The notion of overall satisfaction can be understood in terms of user evaluations of specific elements of recreation experience (Drogin 1991) and the evaluation of ecosystem services are important for applying the correct model for development (Zheng et al. 2008). While a few attempts have been made in India to understand the causes and consequences of ecosystem degradation of large water bodies, there is little explicit research conducted to restore the complexities of interdependencies between economic, social and environmental attributes and processes (Marothia 1995, 1997). Himalayan states in India are fragile ecosystems characterized by marginality, inaccessibility and fragility in addition to various mountain specificities. The Kashmir region of Jammu and Kashmir, a northern hill state of India has a distinct identity owing to its aesthetic and environmental values. Dal, a fresh water lake amidst Kashmir valley, appears a beautifying pearl over attractive valley landscape. It has, however, been observed that a large area of this lake have been converted into floating gardens and large number of residences, hotels, etc., have come up within it owing to increasing influx of tourists that have raised a number of sustainability issues related to the Dal lake. Accordingly, it becomes imperative to evaluate the Dal lake in relation to various sustainability measures. This paper, therefore, makes an attempt to assess the returns that accrue to stakeholders in and around the Dal lake, chemical health of the lake, tourist behaviour and to examine issues of sustainable management of this ecosystem.

2 Methodology

The study is based upon both secondary and primary data. While the secondary data were collected from various publications of Government of Jammu and Kashmir, the primary data were obtained on well-designed, pre-tested schedules from stakeholders, like farm households, houseboat, *shikara/naav* owners, hoteliers, transporters, parking owners, etc. (Annexure I). Separate schedule was prepared for each type of respondents. As far as the tools of evaluation are concerned, under certain circumstances, the market for environmental goods and services do not exist or are not well-designed. A viable alternative could be a twin use of the constructed or hypothetical market approach, i.e., the direct method and another, i.e., indirect method is a model based on revealed preference or related/allied market approach to which the visitation rate to Dal lake for parks or boating and/or activities together could be taken as an indirect measure to the value that people attribute to the Dal lake ecosystem. Such a valuation approach is known as the travel cost method (TCM). The Contingent valuation method (CVM) elicits consumer preferences of goods and services that are not traded directly to the consumer in the market. Monetary values of the environmental goods and services are established through the setting up of a ‘hypothetical’ market. A survey question is used to elicit willingness to pay (WTP) for a hypothetical provision of environmental goods and services. CVM is a tool to place an amount or value on goods and services that are typically not exchanged in the market place (Ajzen and Driver 1992) The CVM tool has been the subject of methodological research and applied in estimating both use values and non-use values of environmental goods (Cummings et al. 1986; Mitchell and Carson 1989). It is called ‘contingent’ because respondents are asked how they would they act if they were placed in certain situations (Mathews et al. 2001). CVM is a questionnaire-based approach that is designed to estimate the economic value of non-market goods (Cummings et al. 1986; Mitchell and Carson 1989). One of the most important concepts in CVM is willingness to pay (WTP). WTP is ‘the maximum amount consumers are prepared to pay for a good or service’ (ADB 2007). More specifically, WTP is the amount of money that a person is willing and able to pay to enjoy recreational facilities (McConnell 1985). It measures whether an individual is willing to forego their income in order to obtain more goods and services, and is typically used for non-market goods.

2.1 Specification of Travel Cost Model and Variables

The individual travel cost method (ITCM) was applied to determine value of recreation and the nature of demand for Dal Lake. The following demand function was estimated using ITCM:

$Y = f(X_1, X_2, X_3, X_4, X_5, X_6, X_7)$ where

Y Number of visits made by each visitor per period

X_1 Distance from residence to Dal lake (km)

X_2 Total travel cost from place of residence and expenses of parking, boating and eating within the surroundings of Dal lake, defined in (US$/capita)

X_3 Household income per family (US$)

X_4 Per capita household income per day corrected for number of hours spent in Dal lake for park and recreation (opportunity cost of time)

X_5 Education of the respondent is defined in five levels. 1. Illiterate, 2. Primary, 3. High School, 4. College, 5. University

X_6 Time spent in Dal lake (hours) per visit

X_7 Dummy variable coded

(a) Unity if unsatisfied with present management

(b) Zero if satisfied with present management

2.2 Specification of Willingness to Pay Function and Variables

To estimate the willingness to pay of the visitors to Dal Lake, contingent evaluation was used. The willingness to pay function is expressed in the following form:

$W = f(Y, X_2, X_3, X_4, X_5, X_6, X_7)$ where W is willingness to pay for maintenance of Dal lake and the other variables are as defined above. Both the functions 2.1 and 2.2 were estimated through ordinary least squares.

3 Results and Discussion

The results of the study have been detailed under various sections starting with the profile of the Dal Lake, its chemical health, economy, visitation rate/willingness to pay, non-use values, economies after its restoration and resultant anticipated potential gains, government interventions for its restoration, conclusion and policy implications.

3.1 Profile of Dal Lake

Dal, a natural lake is located in the Srinagar city, the summer capital of Jammu and Kashmir (J&K) at an altitude of 1,584 masl. With a mean latitude of $34^{0}7^{1}$ N and of $74^{0}52^{1}$ E longitude. In 1,200 AD, the lake covered an area of 75 km^2 and by the 1980s, it has shrunk to a mere 25 km^2. Yet again, owing to drastic geographical change this lake now stretches barely over a surface area of 11.4 km^2 (Qadri and Yousuf 2008). This urban lake, the second largest in the state, was renamed as the 'Jewel in the crown of Kashmir' or 'Srinagar's Jewel'. The shore line of the lake, about 15.5 km long, is encompassed by a boulevard lined with Mughal era gardens, parks, houseboats and hotels. During the winter season, the temperature sometimes reaches −11 °C (12 °F) which freezes the lake. At the periphery of the lake there are floating gardens, known as 'Rad' in Kashmiri, blossom with lotus flowers during July and August. The Dal lake is also an important source for commercial operations in fishing and water plant harvesting. Floating gardens of the Dal Lake, according to Lawrence (1895) resemble the 'Chinampas' of old Mexico, divided by causeways into four basins; Gagribal, Lokut Dal, Bod Dal and Nagin (Also considered as an independent lake). Lokut-dal and Bod-dal each have an island in the centre, known as Rup Lank (or Char Chinari) and Sona Lank, respectively. The houseboat site is a prime tourist attraction, especially for foreign and outside valley tourists. A barge known as *Doonga* and *Shikara* services that each houseboat carries are used to provide to and fro water transport services to the tourists. Transportation and parking owners are also engaged throughout the year during peak tourist season.

The lake now shelters about 50 hamlets with a population of over 50,000 people, who have property rights over 300 ha (6,000 kanals) of agricultural land and 670 ha (13,400 kanals) of water area (LAWDA 2000, 2004–2005). Besides this, a large number of commercial and residential buildings such as hotels, guesthouses, restaurants and houseboats have sprung up in and around the Dal. The Lake is popular as a visitor attraction and a summer resort. The macrophytes and plankton removed from the lake annually provide rich manure for cultivation. There are about 750 houseboats in Dal Lake, registered with the 'Tourism Department.' Its other uses are fisheries and harvesting of food and fodder plants. Weeds from the lake are extracted and converted into compost for the gardens. It also serves as a flood lung of the Jhelum river. Swimming, boating, snow skiing (particularly when the lake is frozen during severe winters) and canoeing are some of the popular water sports activities seen on the lake. All these services provide livelihood to thousands of stakeholders. The floating gardens produce fruit and vegetables, which are supplied to the Srinagar city, contributing towards fulfilling a part of the demand for vegetables for the city populace. Vegetables such as tomatoes, gourds, capsicum, chillies, cabbage, turnips, cucumbers and lotus stalk called *Nadru*, (also used as a vegetable) are produced in the lake. Among the varieties of fruits produced are watermelons and water chestnuts. The Dal Lake has a large number of floating gardens formed by anchoring lumps of weeds with poplar and willow saplings pushed into the lakebed. With constant layers of additional weeds, the floating gardens slowly solidify and in many areas of the lake have been transformed into dry land several feet above the lake surface. The reduction in the size of the lake is mostly on account of encroachments by hamlets and floating gardens. An alarming rate of sediment deposition is due to catchment area degradation. The lakes water quality has deteriorated due to intense pollution caused by the untreated sewage and solid waste that is drained into the lake from the peripheral areas, and from the settlements and houseboats, and agriculture return flow from catchment. The Hamlets on which they reside within the lake have been discharging uncontrolled and untreated liquid and solid waste into the lake which has caused its pollution and subsequent degradation.

After knowing the profile of Dal lake, it was imperative to know the profile of Dal lake dwellers, whose socio-cultural and economic development has a close association with Dal. The Dal dwellers have property rights over certain area of the Dal lake, which includes both land and water based area. All of the selected respondents were not residing in Dal lake, nevertheless, all agriculturists, *Shikara* owners and fishermen were observed to reside within the lake, whereas others were observed to have shifted away from the lake, though they were still owning some land in Dal. Total land owned by each stakeholder was observed to range from a minimum of 1.09 by fishermen to a maximum of 4.30 kanals by hoteliers. Agriculturists, *Shikara* owners and fishermen were observed to have most of their land under cultivation which ranged from 3.31 for agriculturists to 0.60 for fishermen. On the other hand hoteliers, houseboat owners and transporters were having most of their land under residential or commercial purposes. The non agricultural area owned by each stakeholder ranged from 0.45 kanals by agriculturists to

Table 1 Socio economic characteristics of Dal Lake dwellers in the state of J&K

Particulars	Agriculture	House boat	Shikara	Fisherman	Hotels	Transport
Land possession (kanals)						
Total Land	3.76	3.58	1.69	1.09	4.3	1.73
Total land including water area	8.67	4.11	3.28	2.45	4.48	2.05
Agricultural land	8.22	1.44	2.73	1.96	0.54	0.91
Land based	3.31	0.91	1.14	0.6	0.36	0.59
Water based	4.91	0.53	1.59	1.36	0.18	0.32
Residential/others	0.45	2.67	0.55	0.49	3.94	1.14
Educational status (%)						
Illiterate	37.57	19.5	18.09	57.62	0	9.09
Literate	62.43	80.5	81.91	42.38	100	90.91
Without formal education	12.72	0	13.83	1.69	0	6.06
Primary level	16.18	6.35	12.77	20.33	0	9.09
Middle level	19.08	12.7	15.96	16.94	10.53	18.18
Hr. secondary level	13.29	50.79	24.47	3.38	26.32	21.21
Graduate and above	1.16	11.11	14.89	0	63.16	36.36
Family composition (average per family)						
Family size	10.89	9.98	9.42	8.21	7.90	8.26
Male	5.90	5.36	4.97	4.55	4.30	4.60
Female	4.99	4.62	4.45	3.66	3.60	3.66
Sex ratio	**846**	**862**	**895**	**804**	**837**	**796**
Below 15	4.15	3.10	3.23	3.18	2.85	1.97
Male	2.38	1.71	1.73	1.82	1.56	1.08
Female	1.77	1.39	1.50	1.36	1.29	0.89
Sex ratio	**744**	**813**	**867**	**747**	**827**	**824**
15–50	5.75	4.40	4.10	3.18	3.97	4.63
Male	2.98	2.40	2.07	1.73	2.18	2.65
Female	2.77	2.00	2.03	1.45	1.79	1.98
Sex ratio	**930**	**833**	**981**	**838**	**821**	**747**
Above 50	0.99	2.48	2.09	1.85	1.08	1.66
Male	0.54	1.25	1.17	1.00	0.56	0.87
Female	0.45	1.23	0.92	0.85	0.52	0.79
Sex ratio F/M	**833**	**984**	**786**	**850**	**929**	**908**

3.94 kanals by hoteliers. Though all stakeholders were also having some water area under possession, but it was significantly lower for hoteliers, transporters and houseboat owners and higher for agriculturists (Table 1).

The educational status of the respondents revealed that illiteracy was significantly higher in agriculturists, *Shikara* drivers and fishermen as compared to other groups. Hoteliers were observed to have 100 % literacy rate with a little less for transporters and houseboat owners, i.e., 90.91 and 80.5 %, respectively. These groups were also having higher number of highly qualified persons. All the members of hoteliers were qualified above the middle standard including about

63 % graduates and above. The agriculturists and *Shikara* drivers were having 1.6 and 15 % members above graduate, whereas, fishermen had none. About 13, 14, 2 and 6 % members of agriculturists, *Shikara* drivers, fishermen and transporters were literate but without any formal education. High literacy rate among hoteliers, houseboat owners and transporters is obviously owing to their high income profile as compared to others.

The average family size of the stakeholders was found to be in the range of 7.90 in hoteliers to 10.89 in agriculturists. The males outnumbered females in each group, as the number of females per 1,000 males ranged from a minimum of 804 in fishermen and transporters to 895 in *shikara* drivers. The age-group wise comparison reveals that most of the members belonged to 15–50 years of age (i.e., working population) in each community; however, in the fishermen category these equalled those below 15 years. The population below 15 ranged from lowest of 1.97 in transporters to 4.15 in agriculturists, whereas, those of 15–50 and above 50 ranged from 3.18 in fishermen to 5.75 in agriculturists, and 0.99 in agriculturists to 2.48 in houseboat owners, respectively.

3.2 Chemical Health of Dal Lake Water

The data on various physico-chemical characteristics of Dal Lake was collected from the secondary sources that included reports of various agencies and research papers. These data were collected for the parameters that are considered most important for determining the quality of Lake Water and for two different periods of time, viz., 1990–2000 and 2000–2010. These figures were further averaged in order to explain the decadal changes that have accrued to the Dal Lake water and later compared with the Indian standard range of acceptable values used for assessing the deterioration of the Lake water. The figures, thus, arrived at have been presented in the Table 2 for each of the identified parameters. The results reveal that remarkable changes have occurred in the water chemistry across Dal Lake over a period of time.

The parameter wise changes occurred in Dal Lake revealed that the decrease in pH by 2.5 % could be due to the decomposition of biological wastes discharged into the lake. The dissolved oxygen, an important determinant for aquatic life, has decreased by 25 % while nitrogen in nitrate and ammoniacal forms and potash increased by 43, 16 and 5.18 %, respectively. These figures are indicative of the fact that eutrophication of lake has increased in terms of the growth of algal and other aquatic weeds, especially Azolla which is growing fast, and environmentalists warn that if conservation measures were not taken immediately it can engulf the lake completely.

Table 2 Physico-chemical characteristics of Dal Lake

Parameter	Unit	1990–2000		2000–2010		Difference[b]
		Range	Averages	Range	Averages	
Air Temp.	°C	14.2–19.4	17.05	17.87–18.2	17.98	+5.45
Water temp.	°C	15–18.1	16.525	15.80–16.62	16.34	−1.11
Depth	m	0.8–1.3	1.1	1.3–1.15	1.2	+9.09
pH	–	7.3–8	7.575	7.2–7.47	7.38	−2.58
Conductivity	µS/cm[a]	681–947	800	621–762.17	715.11	−10.62
D.Oxygen	mg/l	1.7–2.8	2.175	1.1–1.9	1.63	−25.06
Calcium	mg/l	62.1–74.1	65.675	71.95–97.9	80.6	+22.73
Magnesium	mg/l	6.6–9.4	8.125	10–14.6	11.53	+41.90
Nitrate–Nitrogen	µg/l	196–750	404.25	530.67–676	579.11	+43.26
Amm–Nitrogen	µg/l	1,735–4,634	2,945	3,014.17–4,225	3,417.78	+16.05
Phosphates	µg/l	1,204–2,920	2,037.5	2,078–2,273	2,143	+5.18

[a] at 25 °C; [b] (+) indicates increase and (−) indicates decrease

Source LAWDA (2000, 2004–2005), Qadri and Yousuf (2008), Murtaza et al. (2010)

3.3 Dal Lake Economy

Dal Lake has been a regular source of income to Dal dwellers like farmers, fishermen, *Shikara* drivers and other stakeholders. An attempt was made to estimate the annual income that each of them earn in ventures related with Dal and are discussed in the ensuing sections.

3.3.1 Crop and Livestock

Vegetables are the main, rather only agricultural component, being cultivated in Dal Lake. The small land patches covered with water are ideal for vegetable cultivation. Besides, the floating gardens, an old practice by Dal farmers, provide a suitable environment for production of quality vegetables, especially cucurbits and tomato. Interestingly, the farmers also own some water area in which they cultivate the very famous and hot selling *Nadroo* (Lotus stem or Nellubia). Total cropped area under *Nadroo* and vegetables rounded to 12.50 kanals, which included 61 % under vegetables and 39 % under *Nadroo*. The year round vegetable cultivation resulted in higher cropping intensity of about 230 %. The major vegetables grown by sampled farmers are kale, radish and turnip as they occupied about 25, 24 and 18 %, respectively, of total cropped area under vegetables (Annexure II). *Nadroo*, on the other hand, is grown once a year. The cost and return estimates of vegetable cultivation in Dal revealed that gourd provide highest net returns per unit of land (US $149.70 per Kanal) followed by turnip (US $121.54 per kanal) and *karela* (US $95.34 per Kanal). All the vegetables together were more productive than *Nadroo* as the net returns per kanal were US $97.19 in the former and US $57.17 in the latter. The per farm and per kanal net revenue out of all vegetables including *Nadroo* grown by selected agriculturists averaged to US $1019.42 and US $81.48, respectively.

A few animals were also found visible at the farms of Dal, however, their domestication was given least attention owing to the non-availability of fodder and space at the farm level, restricting the farmers from rearing the livestock, which is a major reason for their lower economic importance in the Dal.

3.3.2 Fishery

Fishing inside the Dal or on the banks has ever since been an attraction for locals, and tourists as well. Besides, this has been one of the major economic activities for the Dal inhabitants. As per LAWDA report, there are about 250 fishermen living in the Dal premises. Common and mirror carps are the main fish strains captured in the Dal lake. Though the fishing practice continues round the year, the total catch varies between the seasons. As reported, the total catch is higher in summers than in winters, because in hot summers, fishes float to shallow heights from the depth, whereas, in winters they escape the chill by hiding into the water underneath the weeds/shrubs. Since the catch is meagre and laborious during the chilly winters, the fish prices generally inflate giving good returns to the labour during winter. With an intention to find out the total fish capture by each fisherman, quarterly data on their working days, fish catch per day and associated costs were collected. The results reveal that employment days and income derived during 1st and 4th quarter (winters extending from October to March) were more than those derived during 2nd and 3rd quarter (summers extending from April to September). Out of the 175 working days in a year, an average of 96 days (49 and 47 in 1st and 4th quarter, respectively) were derived during winters, whereas it was low by about 17 days during summers (Annexure III). Higher prices and lower capture during winters and vice versa is a substantial reason for such a trend, though better employment opportunities due to tourist rush during summers also detracts fishermen from fishing during summers. The returns to total cost (NR) and variable cost (RTVC) were also observed to be lower during summer as compared to the winter season. Though the capture was almost at par between the two seasons, the lower price during summer resulted in decreased net earnings during this season.

The interesting features related to fishing as an economic activity is that the catching practice is completed mostly before dawn and is accomplished by men folk, which allows them to exploit other economic opportunities. Yet another interesting feature is that marketing is done by fisherwomen, who, as hawkers with fish as head load in specialized tin/wooden baskets, very skilfully move towards adjoining colonies or special commodity markets in the city centre. Such an efficient economic utilization of time and proper division of labour among fishermen communities helps them earn a handsome amount.

3.3.3 Shikaras

Shikara driving is yet another important pro-poor economic activity exploited by a good number of resource poor Dal dwellers. *Shikara* is a specialized boat, the ride on which has been a major attraction for most of the tourists visiting Dal Lake. *Shikaras*, as an exclusive type of local transport within the Dal, serve the houseboats by way of providing to and fro conveyance to the tourists who stay in the houseboats. There are several *Shikara* points across the Boulevard line which carry the tourists to few specialized destinations within the Dal (like Char-Chinar) or as desired by visitors. There are about 720 *Shikaras* in Dal. Unlike fishing, *Shikara* driving is mainly a tourism oriented activity and is mostly visible in peak tourist season. The economic evaluation of *Shikara* driving revealed that the number of working days and income earned varies and depends upon the tourist flow. Whereas, 1st and 4th quarter provide only 45 and 73 working days, respectively, the working days go as high as 80 and 84 during the 2nd and 4th quarters, respectively (Annexure IV). Accordingly, the returns to total cost (NR) and variable cost (RTVC) are multiple times higher in summer season than in winters.

3.3.4 Hotel and Houseboats

There are about 216 hotels in the valley, out of which four have 5-star and 5 have 3-star rank (LAWDA 2004–2005). Dal Lake is surrounded by different hotels on its southern side along the boulevard, which provides ample space for tourist accommodation during peak seasons. Similarly, Dal accommodates about 1,089 houseboat ranked as Deluxe (324), ‘A’ class (137), ‘B’ class (124), ‘C’ class (127) and ‘D’ class (377). For economic evaluation of this industry, the quarter-wise number of available rooms, their occupancy rate, approximate costs and returns were collected, the results of which are presented in table (Annexure V). The results reveal that the occupancy rate, the costs and returns in hotels vary between the quarters and touch the highest during 3rd quarter. The occupancy rate of suites in the hotels varied from about 66 % in the 3rd quarter to about 4 % in the 1st quarter, whereas, it was about 70 and 28 % for deluxe rooms in the respective quarters. The variable costs also increased with the occupancy rate, so did the returns. The annual returns to the total cost (NR) and variable costs (RTVC) were up to the tune of about 84.39 and 96.96 thousand US Dollars, respectively. The quarter wise break-up reveals a huge difference between the earning during summer and winter seasons.

Similarly, in case of houseboats, the occupancy rate was as high as 98 % during the 3rd quarter to as low as about 29 % in the 1st quarter. The quarter wise trend revealed by houseboats resembled to that of hotels. However, owing to the less average number of rooms available (3.3 rooms per houseboat, as compared to about 25 in hotels,) the annual returns were accordingly lower (see Annexure VI). The annual returns over total cost (NR) and variable cost (RTVC) were estimated at around 21.54 and 23.34 thousand US Dollars, respectively, though with significant variation between the quarters.

3.3.5 Transporters and Parking

Most of the tourists came to the valley in pre-booked transport vehicles with transporters from outside the state. Only few tourists that were observed to have visited the valley earlier visit the valley on their own and hire vehicles for local conveyance within the valley. As many as 755 taxis were reported to be associated with the taxi stands/parking around the Dal.

The selected transporters reported an average of 775 trips a year per taxi, with a significant variation over different quarters. These trips were mostly airport bound, though occasional trips were also reported from the place of stay to various destinations around the Dal. Average number of trips per respondent per quarter ranged from 150 in 1st quarter to the highest of 237 in the 2nd quarter. As expected, the average number of trips reported was highest in the 2nd quarter followed by 3rd, 4th and 1st quarter. Such a variation in number of trips between different quarters is on account of the variation in rush of tourists, which is higher in summers and very low in winter. Accordingly, the revenue earned varied between the seasons. The net revenue (NR) recorded during winters (1st and 4th quarter) was negative and reduced their total net revenue per year to 1.30 thousand US Dollars. Total returns to variable cost (RTVC), however, has jumped to more than seven lakh rupee per annum which means that transporters earn a handsome amount on their operational costs.

The annual earnings by all the sampled stakeholders, as discussed above, have been summarized in Table 3, which reveals that gross revenue out of total selected stakeholder's sums up to the tune of about 198.9 thousand US Dollars. Hoteliers are atop the list and are followed by houseboat operators and transporters. While taking into account their fixed and variable costs, the returns to variable cost (RTVC) and total cost (NR) were estimated to be around 136.7 and 111.3 thousand US Dollars, respectively.

Table 3 Estimated annual net revenue generated by sampled stakeholders (000′ US$)

Stakeholders	GR	RTVC	NR
Fisherman	1.1	0.4	0.4
Shikara	2.7	1.6	1.5
Transport	16.7	12.6	1.3
Houseboat	30.0	23.6	22.0
Hotels	145.4	96.7	85.1
Agriculture			
Vegetables	1.9	1.1	0.7
Nadroo	1.0	0.7	0.3
Total	**198.9**	**136.7**	**111.3**

3.3.6 Tourists

The tourist inflow into the state has been increasing over the years, though a substantial decline was observed during 1990s owing to the political instability in the valley. Dal has always been one of the most frequently visited and preferred destination for the local/domestic and for foreign tourists, especially during summers. The number of tourists visiting Dal and the extent of their stay has a direct bearing on the Dal Lake economy. Therefore, the estimation of expenditure by these visitors forms an important component of the Dal lake economy, and was, therefore, assessed by surveying Dal bound tourists which included foreigners, domestic, and locals as well. Out of the total surveyed tourists, foreigners constituted only 6.67 %, whereas, 14.66 % were locals and the rest were domestic but from outside the valley. The outsiders were found to visit the valley either as a group or as individuals. About one-third of the visitors reported to have opted for visiting through agencies/tour packages and included mostly those who were visiting the valley for the first time. Tourists belonged to all age groups and included mostly youngsters falling within the age group of 18–40 years. A number of surveyed domestic tourists visiting the valley were from Gujarat, Delhi, UP, MP and Maharashtra, whereas, the surveyed foreigners belonged to Iran, Switzerland and Columbia. Few cases with single respondents from Mexico, Australia and European countries were also reported.

The data on expenditure incurred by tourists exclusively within the Dal premises was collected, the results of which reveal that per day spending by foreigners was about 1.5 times more than domestic tourists. Needful to mention that the expenditure on travelling from place of residence to Dal was not accounted for either category of tourists. The results show that average per day expenditure per foreign tourist was about US $50, whereas, the corresponding figure for domestic tourists was about US $32.2. Among the various expenditure components, shopping exceeded other items for both domestic and foreign tourists. Expenditure on shopping summed up to around US $7.2 and US $11 for domestic and foreigners, respectively, whereas, the other major items including accommodation, food, water sporting and local travel consumed about US $ 5.6, $4.6, $4 and US $3.8 for domestic tourists and US $8.5, US $7.4, US $4.5 and US $6.5 for foreign tourists, respectively (Table 4). The proportion of expenditure on each item by either category was almost comparable; however, little higher proportion in travel and communication for foreigners was observed which was compensated by higher proportion of expenditure on sporting by domestic visitors. Little expenditure by foreigners on sporting is expected as they might have better and more hygienic sporting facilities available in their home countries.

Table 4 Extent of expenditure incurred by visitors (US$/visitor/day)

Item	Domestic	International
Food	4.6	7.4
Shopping	7.2	11.0
Travel[a]	3.8	6.5
Accommodation	5.6	8.5
Communication	0.7	2.0
Entry fee	1.0	1.5
Sporting	4.0	4.5
Shikara ride	3.4	4.7
Other expenses	1.9	3.9
Total	**32.2**	**50.0**

[a] These are the travel charges exclusively within the Dal lake

4 Demand Functions for Dal Lake Visitation Rate and Willingness to Pay

The regression estimates of the distance and total cost were negatively significant (Table 5) and, as such, it could affect the visitation rate while as the household income per family, education and time spent were positively significant, and could have a positive impact on visitation rate. While most of the visitors either domestic or foreign and locals too usually prefer to stay in the Srinagar city as such the opportunity cost of time and their visiting hours spent on the lake indicate their preference for Dal Lake as a recreation site. The level of variation explained to the tune of 63 % can be considered fair though not extraordinary. The levels of significance are consistent with the earlier studies (Cesario 1969; Chopra 2001; Isangkura 1998) who estimated similar functions with similar type of variables.

The results presented in the table for willingness to pay estimated by contingent evaluation method indicate that the travel cost, education and time spent on the

Table 5 Regression estimate of visitation rates and willingness to pay

Variables	Visitation rate	Willingness to pay (WTP)
Y/W	–	0.031 (0.621)
X_1	−0.0097 (0.0003)[a]	–
X_2	−0.021 (0.010)[a]	−0.121 (0.012)[a]
X_3	0.076 (0.011)[a]	−0.0002 (0.012)
X_4	0.121 (0.011)	−0.001 (0.021)
X_5	2.22 (0.37)[a]	11.31 (9.61)[a]
X_6	2.795 (0.271)[a]	61.21 (8.65)[a]
X_7	3.121(2.791)	119.21 (11.21)[a]
Constant	625.34	213.16
$\bar{R}^2$	0.6320	0.5997

Figures in the parenthesis indicate standard error
[a] denotes significance at 1 % level

lake and the dummy variables were positive and significant determinants of willingness to pay and indicate that their level have a positive impact on willingness to pay. However, the travel cost turned out negatively significant, indicating that it contributed negatively to the willingness to pay owing to the fact that long distances do not make people able to visit the lake frequently and they were reluctant to contribute voluntarily for restoration of the Lake.

4.1 Non-Use Value from Dal Lake

The degrading Dal and need for its restoration is realized by every individual. In this section, an analysis of the perception of main stakeholders and other sections of the society like NGOs, conscious citizens and scientists/intellectuals was recorded, who were willing for Dal ecosystem restoration through their voluntarily contributions as lump sum and/or on monthly basis for different periods of time. The figures registered in the Table 6 reveal that visitors were willing to pay an average amount of US $8.69 in lump sum for starting restoration process in Dal. Among the stakeholders, the hoteliers and houseboat owners were willing to pay US $120.6 and $39.7, respectively, and even wanted to contribute monthly an amount of US $25.19 and US $19.92 regularly up to a period of 15 and 12 years, respectively.

The willingness to pay for Dal restoration was observed to be minimum in fishermen and averaged around US $0.58 in lump sum and US $0.22 as monthly contribution. Many NGOs, conscious citizens and scientists also showed great willingness to pay, and their corresponding figures were US $25.09, 16.29 and 36.11, respectively. They were also ready to contribute regularly on per month basis for the maximum of 10 years.

Table 6 Willingness to pay for Dal eco-system restoration (US$/respondent)

Respondent	Lump sum	Routine contribution	
	Amount	Monthly	Duration
Visitors	8.69		–
Stakeholders			
Hoteliers	120.62	25.19	10–15 years
Houseboats	39.70	19.92	7–12 years
Shikara	1.90	2.12	5–8 years
Fishermen	0.58	0.22	1 year
Transport	2.32	2.00	2–5 years
Residents	9.05	2.47	2–5 years
Other sections			
NGO's	25.09	11.00	5–10 years
Conscious citizens	16.29	6.79	1–5 years
Scientists/Intellectuals	36.11	5.51	4–8 years

5 Economies of Dal Lake Restoration

Dal, one of the world's largest natural lakes, was spread over 75 km^2 in 1200 AD Unfortunately due to human interference and negligence, its area had shrunk up to 25 km^2 in the 1980s, whereas, the depth had reduced from 45 to 4 feet during this period (LAWDA 2000). The rate of shrinkage (encroachment) has accelerated since the recent past as the latest figures report this area to have shrunk finally up to 11.4 km^2 (Qadri and Yousuf 2008). The LAWDA reports that the lake shelters about 50 hamlets with a population of over 50,000 people, who have property rights over 300 ha of agricultural land and 670 ha of water area (LAWDA 2000), besides an increasing number of tourists and a large number of people and establishments in their service are exerting a great stress on Dal ecosystem and threatening the livelihood of thousands of stakeholders. Keeping this in view, this section attempts to justify the restoration of lost Dal area taking into account the economic value of the ecosystem at existing level, and approximates the benefits that could accrue after its restoration at various levels of use. The figures presented in the Table 7 documents the estimates of the revenue generated by all stakeholders deriving their livelihood from Dal. The actual number of stakeholders was collected from the concerned authority (LAWDA) and was multiplied to the average income estimates of the sampled respondents. In this way, the gross revenue attributable to Dal ecosystems summed up to about US $61.64 million. While accounting the variable costs, the returns (RTVC) reduced to US $45.03 million, which further reduced by about US $12.21 million if total costs were accounted. The comparison of different stakeholders reveals that revenue earned by houseboats was highest and contributed more than half of gross or net revenue generated by all stakeholders together. Hoteliers followed by *Shikara* drivers turned out to be 2nd and 3rd major contributors (Table 7), whereas fishermen were the lowest contributors.

Table 7 Estimated annual net revenue generated by Dal Lake (million US dollars)

Stakeholders	Number	GR	RTVC	NR
Fisherman	250	0.29	0.11	0.10
Shikara	720	1.96	1.17	1.09
Transport	755	12.61	9.52	0.99
Houseboat	1089	33.79	25.65	23.97
Hotels	66	9.60	6.38	5.62
Agriculture				
Vegetables	6370	1.56	0.90	0.62
Nellubia	9276	1.83	1.30	0.53
All sources		*61.64*	*45.03*	*32.85*
Revenue generated excluding agriculture		*58.25* 5.49	*42.83* 4.88	*31.7* 3.50

Note Figures in parenthesis indicate percent change over total; Figures against agriculture are calculated on per kanal basis; Actual number of transporters was not available from source, the given number however is based on realistic assumption

Table 8 Estimated income generation through restoration of encroached Dal area[a] (million US dollars)

Particulars	GR	RTVC	NR	% increase
Total revenue generated by Dal at existing area (11.4 km^2)	57.16	42.83	31.76	–
Average revenue attributable to 1 km^2 of existing Dal	5.02	3.76	2.79	–
Additional revenue expected through restoration of encroached area (13.6 km^2)				
25 % restoration	17.05	12.77	9.47	29.82
50 % restoration	34.10	25.55	18.94	59.65
100 % restoration	68.20	51.10	37.89	119.30

[a] Actual area of Dal in 1980s was 25 km^2

It would be worthy to mention that the agriculturists are the prime encroachers of Dal lake and, as such, it is illogical to give due consideration to their earnings while evaluating the economy of Dal eco-system restoration. However, there can be some permissible limits to allow cultivation of vegetables/*nadroo* for promotion of agro-eco-tourism. Assuming that these (agriculturists) are rehabilitated to some other place, as is under process, the gross revenue and the returns to total cost (NR) and variable cost (RTVC) will be reduced by a little margin of about 5.49, 4.88 and 3.50 %, respectively.

This paper also attempts to estimate the possible gains in the economic value of Dal ecosystem by assuming, 25, 50 and 100 % restoration of the encroached Dal area. For estimating this, an approximate income attributable to 1 km^2 of Dal was calculated by dividing the current total revenue from Dal by its existing area (11.4 km^2). The value, thus, reached was multiplied with the extra area added due to restoration at three different levels. The results presented in Table 8 reveal that the restoration can yield up to a maximum of about US $68.20 million if Dal is restored to its 1980s level. The proportional gain would be about 30, 60 and 119 % on 25, 50 and 100 % restoration, respectively. The restoration will not only create additional income opportunities through extra productive acreage, but will also enhance the earning potential through increasing productivity per unit of Dal area. As revealed earlier, the tourists have shown willingness to pay extra visits to Dal after its restoration. In such a case, on an average, a tourist was expected to pay 1.72 extra visits to Dal Lake in 5 years' duration.

The corresponding figure for foreigners was lower (1.08 only) than domestic tourists. The tourists also revealed that during their visit they will choose to have extended stay of 1.98 and 3.09 days for domestic and foreign tourists, respectively (Table 9).

The extra stay will be associated with additional visits to Mughal Gardens/other cities and enjoying more *Shikara* rides and boating. The foreigners were observed to have more willingness for extra stay and extra recreation than domestic tourists. Tourists opined to extend invitation and recommend others to visit Dal Lake after its restoration. The proportion of such tourists was calculated to be 76.54 % for domestic tourists and 82.14 % of foreigners.

Table 9 Potential gains through tourism after Dal restoration

Ways of gains	Unit	Magnitude	
		Domestic	International
Extra visits	Per 5 Years	1.72	1.08
Extra events	Per visit		
Visit to Mughal gardens/other sites	–	1.51	1.89
Shikara ride	–	2.37	3.38
Water sporting	–	1.28	2.19
Extra stay	Days/visit	1.98	3.09
Invite others (Yes)	% respondents	76.54	82.14
Value of gains (US$)[a]			
Extra visits		–	–
Extra events of			
Visit to Mughal gardens/other sites		1.50	2.89
Shikara ride		8.10	15.99
Water sporting		7.45	18.35
Extra stay		43.42 **60.47**	109.31 **146.54**
Sub total			
Invite others		46.29	120.37
Total gains per person		**106.76**	**266.91**
Percent gains per tourist over reference year		**231.93**	**433.67**

[a] Based on calculation in Table 4

The positive response of tourists for restoration was monetized to estimate the economic gain of restoration, which revealed that per day extra stay in Dal will lead to an additional expenditure of US $60.47 and US $146.54 per domestic and foreign tourists, respectively. Their income will be generated through their extra stay, extra expenses on food, travel and recreation. Since the respondents showed a willingness to invite others, the additional expenditure per invited tourist would sum up to around US $46.29 for domestic and US $120.37 for foreigners, respectively. Further, if a responding tourist will get along at least one more tourist with him, the total gains per person would be US $106.76 and US $266.91 for domestic and foreigners respectively, thereby, realizing an increase of 232 and 434 % per day expenditure of a visitor.

6 Govt Intervention

At present, the Dal Lake and its Mughal gardens, Shalimar Bagh and Nishat Bagh on its periphery are undergoing intensive restoration measures to fully address the serious eutrophication problems experienced by the lake. The long-term development plans cover reforestation of the catchment area to reduce erosion and control of grazing, construction of bunds and pedestrian wall to stop further encroachment into the lake area, and, additionally, sewage treatment has been suggested. These include construction of siltation tanks, mechanical de-weeding, regrouping of houseboats, deepening of outflow channels, removal of bunds and barricades, including some floating gardens and, in addition, a moratorium has been imposed on new construction works close to the lakefront. Also, addition of house boats has been banned. Resettlement plans for shifting of population from the lakefront have also been developed. The restoration and rehabilitation measures envisaged under the Conservation and Management of Dal Lake are under various stages of implementation with the funds allocated by the Government of India for the purpose. Some of the measures for rehabilitating the lake to bring it to its original eutrophication free status are listed below.

- The Union Ministry of Environment and Forests had launched a US $898 million 'Save Dal' Project in the year 1997.
- The state government under various projects shifted 666 families from 1978 to 1999.
- The Hon'ble Supreme Court and High Court of Jammu and Kashmir pursued restoration of Dal under various directions given to the concerned authorities for its restoration since 2000 till date.
- The central government approved a project costing US $42.68 million to conserve the lake in 2005.
- In 2007, the state government transferred 376 ha of land to the Lakes And Waterways Development Agencies (LAWDA) and Srinagar Development Authority for its conservation and rehabilitation of displaced families.
- The state government, since 2009, is developing 14,000 plots at Rakh-Arth in central Kashmir for a population of 80,000 Dal dwellers, affected due to a massive drive launched by the State government to restore the pristine glory of the Lake.
- In 2009, the Prime Minister of India sanctioned a new grant of US $63.9 million for rehabilitation of Dal dwellers.
- During 2011, high level committee appointed by the High Court for monitoring the Dal conservation cleared 65 rehabilitation cases paving way for acquisition of the 290 kanals of land and its conversion into water.

7 Conclusion and Policy Implications

The study concludes that the Dal Lake ecosystem has deteriorated on account of its land and water area being put under agricultural use and the increasing inflow of floating population (tourists) adding to the production of effluents that has significantly affected its water biology. While the pH has increased and dissolved oxygen has decreased. Phosphates and nitrogen (both nitrate and ammoniacal) have increased which explains the increasing eutrophication during the past two decades. The main environmental issues like excessive weed growth, reduction in water quality, enrichment of waters and high microbial activity besides rapid and unplanned urbanization in and around Dal Lake has resulted in large quantities of raw-sewage which could contribute heavily to the ecosystem deterioration. The important stakeholders and NGOs/scientists, and intellectuals/environmentally conscious people have voluntarily expressed their desire to contribute for Dal restoration and, based on the estimates, it was concluded that the revenue from the lake could increase by 30, 60 and 119 %, respectively, if we could restore the encroached Dal area by 25, 50 and 100 %, respectively. Based on the results of the study, the following policy interventions are proposed;

- Holistic and integrated approach with public private partnership should be adopted to maintain the value of Dal Lake ecosystem.
- Research and Development institutions need to be involved to evolve mechanism that could link social and ecological system for sustainability of Dal Lake ecosystem.
- Comprehensive policy to prohibit exploitation of the Dal land/water area for agricultural uses/construction of all kinds of structures.
- Strong legislation prohibiting disposal of municipal/domestic wastes into the Dal which are responsible for its eutrophication need to be passed by the state Legislative Assembly.
- Comprehensive scheme for treatment of sewage and waste water need to be designed so that it can be made available to grow pisciculture and lotus cultivation to encourage agro-eco-tourism.
- A specific, comprehensive and time bound master plan should be formulated for rehabilitation of displaced Dal dwellers by providing them reasonable compensation and alternative source of livelihood.

Annexure I: Sample Structure

Category	Sample areas						Actual number in Dal lake
	Gagribal	Lakut dal	Bod dal	Nigeen lake	Boulevard line	Total	
House boat	35	15	31	15	–	96	1,089
Shikaras	45	10	10	10	–	75	720
Nav wala	10	–	–	–	–	10	200
Hawkers	–	5	–	–	–	5	50
Agriculturalists	–	–	55	15	–	70	9,276
Fisherman	–	–	35	–	–	35	250
Hotels	–	–	–	–	10	10	66
Tourists	–	–	–	–	75	75	–
Shops	–	–	–	–	40	40	N.A.
Parking's	–	–	–	–	5	5	5
Transport	–	–	–	–	40	40	755
	90	30	131	40	170	461	–

Annexure II: Quarter-Wise Estimated Costs and Returns of Sampled Farms (Average Per Farm) in Dal Lake

Crop	Turnip	Radish	Gourd	Kale	Karela	Others	Sub total	Nelubia	All
Area (Kanals)	1.38 (18)	1.82 (24)	0.76 (10)	1.93 (25)	0.83 (11)	0.88 (12)	7.6 (61)	4.91 (39)	12.51
Production (Kg)	2,085	2,283	2,044	3,554	717	902	11,585	770	12,355
Returns									
GR	16,680	17,124	20,440	24,878	10,750	13,710	103,582	53,900	157,482
RFFR	11,763	11,670	10,285	12,877	6,183	6,800	59,579	38,269	97,848
NR	9,341	8,733	6,336	8,210	4,408	4,113	41,141	15,631	56,772
Returns per kanal									
GR	12,087	9,409	26,895	12,890	12,952	15,579	13,629	10,978	12,589
RFFR	8,524	6,412	13,533	6,672	7,450	7,727	7,839	7,794	7,822
NR	6,769	4,799	8337	4,254	5,310	4,674	5,413	3,184	4,538

Figures in parenthesis indicate percentage of respective total

Annexure III: Quarter-Wise Estimated Costs and Returns of Sampled Fishermen in Dal Lake

Particulars	Q1	Q2	Q3	Q4	Total
No. of days	49	42	37	47	175
Fish catches	178	166	167	141	652
Gross revenue	21,203	15,725	12,498	14,333	63,759
Net revenue	9,926	4,730	1,746	5,106	21,508
RFFR	10,598	5,402	2,418	5,779	24,198

Annexure IV: Quarter-Wise Estimated Costs and Returns of Sampled Shikara Owners in Dal Lake

Quarter	Q1	Q2	Q3	Q4	Total
No. of days	45	80	84	73	282
Gross revenue	6,043	53,339	57,011	34,944	151,336
Net revenue	−6,190	34,934	37,845	17,765	84,354
RFFR	−4,615	36,509	39,420	19,340	90,654

Annexure V: Quarter-Wise Estimated Costs and Returns of Sampled Hotels in Dal Lake

Quarter		Q1	Q2	Q3	Q4	Total
No. of rooms available	Suits	2.15	2.15	2.15	2.15	2.15
	Deluxe	23.5	23.5	23.5	23.5	23.5
Rooms occupied	Suits	0.09	0.83	1.41	0.37	0.675
	Deluxe	6.67	15.5	16.5	8.5	11.79
Occupancy rate	Suits	4.19	38.6	65.58	17.21	31.39
	Deluxe	28.38	65.96	70.21	36.17	50.18
Gross revenue		1,034,274	2,639,229	3,009,401	1,414,983	8,097,887
NR		504,747	1,589,224	1,873,466	770,700	4,738,137
RFFR		666,622	1,751,099	2,035,341	932,575	5,385,637

Annexure VI: Quarter-Wise Estimated Costs and Returns of Sampled House Boat in Dal Lake

Particulars	Q1	Q2	Q3	Q4	Total
Rooms available	3.33	3.33	3.33	3.33	3.33
Rooms occupied	0.95	2.48	3.26	1.18	1.97
Occupancy rate	28.53	74.47	97.9	35.44	59.09
Gross revenue	87,979.5	628,531	856,435	100,147	1,673,093
Net revenue	22,809	493,126	685,224	24,418	1,225,577
RFFR	44,370	514,687	706,785	45,979	1,311,821

Annexure VII: Quarter-Wise Estimated Costs and Returns of Sampled Transporters in Dal Lake

Particulars	Q1	Q2	Q3	Q4	Total
Av. Trips	150	237	210	178	775
GR	152,705	294,692	354,393	170,359	930,209
NR	−529,248	71,759	94,920	−40,874	72,857
RFFR	104,445	229,152	252,313	116,519	702,429

References

Ajzen I, Driver BL (1992) Contingent value measurement: on the nature and meaning of the willingness to pay. J Consum Psychol 1:297–316

Asian Development Bank (ADB) (2007) Retrieved from http://www.adb.Org/Documents/Guidelines/Eco_Anályis/glossary.asp. Accessed on 19 Mar 2007

Atapattu S, Molden D (2006) Achieving food and environmental security: better river basin management for healthy coastal zones. Environment and livelihoods in tropical coastal zones: managing agriculture fishery aquaculture conflicts 293–301

Bondavalli C, Bodini A, Rossetti G, Allesina S (2006) Detecting stress at the whole ecosystem level: the case of a mountain lake (Lake Santo, Italy). Ecosystems 9(5):768–787

Cesario Jr FJ (1969) Operational research in outdoor recreation. J Leisure Res 1(1):33–50

Chopra K (2001) Shared management of protected areas: possibilities and constraints in Keoladeo National Park, Bharatpur. In: Marothia DK (ed) Institutionalizing common poor resources. Concept Publishing Company, New Delhi

Cummings RR, Brookshire DS, Schulze WD (1986) Valuing environmental goods: an assessment of the contingent valuation method. Rowman Allanheld, Totowa

Dhamotharan R, Manigandan A, Murugesan S (2008) Biotreatment of sewage (Cooum) wastewater by Cyanobacteria. Biosci Biotechnol Res Asia 5(1):349–354

Drogin EB (1991) Evaluating the boater experience: the interrelationship of recreational use, user contacts, experimental impacts, satisfaction and displacement. Dissertation Abstr Int A Humanit Soc Sci 52(4):1518

Gulbahar N, Elhatip H (2005) Estimation of environmental impacts on the water quality of the Tahtal dam watershed in Izmir, Turkey. Environ Geol 47(5):725–728

Hadker N, Sharma S, David Ashish, Muraleedharan TR, Geeta S, Babu PG (1995) Are people in developing countries willing to pay for natural resource preservation? Evidence from a contingent valuation of the Borivli National Park. Discussion paper no. 121, Indira Gandhi Institute of Development Research, Mumbai

Hadwen WL, Bunn SE, Arthington AH, Mosisch TD (2005) Within lake detection of the effects of tourist activities in the littoral zone of oligotrophic dune lakes. Aquat Ecosyst Health Manage 8(2):159–173

Isangkura A (1998) Environmental valuation: an entrance fee system for national park in Thailand. Economy and environmental programme for South East Asia, Research report series, Singapore

Khan TA, Bhise MP, Shabnam AA (1999) Dal lake calls for conservation. INFOFISH Int 5:51–56

Korn N (2001) The water framework directive of the EU foreseeable consequences for planners and experts. Naturschutz und Landschaftsplanung 33(8):246–248

Kumari S, Sahu K, Mehta A, Shruti Shukla (2007) Assessment of Physico-chemical parameters of Sagar lake, India. Asian J Biosci 2(1/2):76–78

Lopez Rios O, Lechuga Anaya M (2001) Population, environment and health: pollution in water bodies in the south of Sonora. Salud Publica Mex 43(4):298–305

LAWDA (2000) Detailed project report for conservation and management plan of Dal-Nageen Lake. Lakes and waterways development authority, Government of Jammu and Kashmir p 1–276

LAWDA (2004–2005) Annual Report. Lakes and waterways development authority, Government of Jammu and Kashmir 4

Lawrence WR (1895) The Valley of Kashmir. Oxford University Press, Ware house, Amen Corner, E.C , London

Marothia DK (1979) Estimating outdoor recreation demand using the hotelling-clawson-knetsch travel cost method. Natural resource economics paper, department of rural economy, University of Alberta, Edmonton

Marothia DK (1988) Teaching of natural resource economics in Indian Agricultural Universities. Department of Agricultural and Natural Resource Economics (DANRE), Indira Gandhi Agricultural University, Raipur(C.G), DANRE Teaching Bulletin No 1, October (1988)
Marothia DK (1995) Urban lake pollution: issues of property rights and institutional arrangements. Invited paper presented to Beijer Research Seminar organized by the Beijer Institute. The International Institute of Ecological Economics. The Royal Swedish Academy of Sciences, Stockholm, Sweden, held at Kota Kinabalu, Malaysia, 16–19 May 1995
Marothia DK (1997) Property rights, externalities and environmental pollution. In: Agarwal A (ed) The challenge of the balance. Centre for Science and Environment, New Delhi
Marothia DK (2000) Outdoor recreation under alternative property rights regimes: valuation and management issues. Department of agricultural and natural resource economics (DANRE), Indira Gandhi Agricultural University, Raipur (C. G), DANRE working paper no 3
Marothia DK (2001) Valuation of a day-use recreation site: application of alternative estimation techniques. Indian J Agric Econ 56(3)
Marothia DK (2004) Restoration of lake ecosystem: an environmental economics perspective. Int Ecol Environ Sci 30(3):197–207
Massoud MA, El Fadel M, Scrimshaw MD, Lester JN (2006) Factors influencing development of management strategies for the Abou Ali River in Lebanon. I: spatial variation and land use. Sci Total Environ 362(1/3):15–30
Mathews LG, Kask S, Rotegard L, Stewart S (2001) Using economics to inform national park management decisions: a case study on the Blue Ridge Parkway. Available at http://www.georgewright.org/56mathew.pdf. Accessed on 13 April 2001
McConnell KE (1985) The economics of outdoor recreation. Elsevier Science, Amsterdam
Mitchell RC, Carson RT (1989) Using surveys to value public goods: the contingent valuation method. Resources for the Future, Washington DC
Moiseenko TI, Sharova ON (2006) Physiological mechanisms of degradation of fish populations in acidified water bodies. Russ J Ecol 37(4):257–263
Murtaza S, Malik AA, Syed M, Fazili Ali, Hussain SA (2010) Impact of pollutants on phsicochemical characterists of Dal Lake under temperate conditions of Kashmir. Available at www.forestrynepal.org. Accessed on 6 Aug 2010
Mustafa G, Kashmiri MA, Shahzad A, Mumtaz MW, Arshad M (2008) Estimation of pollution load at critical points in stream water using various analytical methods. Int J Appl Environ Sci 3(1):97–105
Qadri H, Yousuf AR (2008) Dal Lake ecosystem: conservation strategies and problems. In: Sengupta M, Dalwani R (eds) Proceedings of Taal 2007: the 12th world lake conference, pp 1453–1457
Raza M, Bano H (1985) Ecological burden of tourism: a case study. Geographer 32(2):13–20
Rimpy Dhingra, Ahluwalia AS (2007) Cyanobacterial blooms in ponds of Punjab, India. Vegetos 20(1):79–82
Ruibal Conti AL, Guerrero JM, Regueira JM (2005) Levels of microcystins in two argentinean reservoirs used for water supply and recreation: differences in the implementation of safe levels. Environ Toxicol 20(3):263–269
Semwal N, Akolkar P (2006) Water quality assessment of sacred Himalayan rivers of Uttaranchal. Curr Sci 91(4):486–496
Sharma K, Agarwal SP, Agarwal PK (2006) An assessment of pollution load in holy lake Manasi Ganga at Goverdha Distt. Mathura, UP. Flora and Fauna Jhansi 12(2):189–192
Singh LB, Pandey OP, Nagpure NS, Singh SP, Pandey AK, Lal Shyam (1995) Problems in fisheries through the use of pesticides and possible measures. New Agriculturist 6(2):215–223
Sitonyte J, Linkute R, Tricys V (2006) Research of pollution in the Vijole River. Environ Res Eng Manage 1:26–31
Uzun A, Tabur MA, Ayvaz Y (2008) Birds of lake Acariar and environment problems. Ekologi 17(66):1–14
Yusoff FM, Zaidi MZ, Ambak MA, Petr T, Morris M (eds) (1994) Fisheries and environmental management of Lake Kenyir Malaysia. Indo-Pacific Fishery Commission, papers contributed

to the regional symposium on sustainable development of inland fisheries under environmental constraints, Bangkok, Thailand, 19–21 October and country reports presented at the sixth session of the IPFC working party of experts on inland fisheries, Bangkok, Thailand, 17–21 October 1994

Zheng B, Duan J, Jia JS, Liu F, Yan Y (2008) Assessment of ecosystem services of Lugu Lake watershed. Int J Sustain Dev World Ecol 15(1):62–70

Biodiversity Conservation, Sustainable Agriculture and Climate Change: A Complex Interrelationship

I. S. Bisht

1 Introduction

Biodiversity means a variety of life forms. Regions, home to many different species, are high in biodiversity. Ecosystems with high biodiversity are characterized by complex interactions between different species, which can help the ecosystem remain intact and healthy in the face of disturbance and environmental change. For this reason, looking at biodiversity is a good parameter for assessing the overall health of an ecosystem. Beside habitat loss and fragmentation, over-exploitation, pollution, and the impact of invasive alien species, climate change is a serious environmental challenge that could undermine the drive for sustainable development. As a result, governments, communities, and civil society are increasingly concerned with anticipating the future effects of climate change while searching for strategies to mitigate, and adapt to, it's ill effects.

Agro-biodiversity focuses on that part of biodiversity which has been selected and modified over millennia of human utilization to better serve human needs. It is no easier to define than biodiversity itself (Heywood 1999a). It can be generally regarded as biodiversity, in an agricultural context, and can be described as the variety and variability amongst living organisms (of plants, animals and micro-organisms) that are important to food and agriculture, in the broad sense, and associated with cultivating crops, and rearing animals and ecological complexes of which they form a part. The components of agro-biodiversity cover not only the whole gamut of genetic resources (from advanced cultivars to primitive landraces, domesticates, semi-domesticates, wild and weedy relatives) but the diversity of ecosystems and agro-ecosystems within landscapes that are exploited in some way for agriculture and forestry, and the complex set of human interactions.

Sustainable agricultural development is essential for the well-being of humankind, but it must be reconciled with the need to conserve biodiversity.

I. S. Bisht (✉)
National Bureau of Plant Genetic Resources, Pusa Campus, New Delhi 110012, India
e-mail: bishtis@nbpgr.ernet.in

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_8,

A holistic approach to biodiversity conservation and use, covering both wild and domesticated plants and animals, is needed. While it is recognized that protected areas are crucial for conservation, their sustainability will depend on what happens to human managed habitats.

2 Mitigating and Adapting to Climate Change: The Role of Biodiversity

Climate change is already impacting on natural systems, weather events, and crop productivity. Mitigation involves reducing greenhouse gas emissions from energy generation and biological sources or enhancing the sinks of greenhouse gases. Conservation of existing carbon pools (e.g., avoiding deforestation); sequestration by increasing the size of carbon pools (e.g., through afforestation and reforestation), and substitution of fossil fuel energy may result in biological mitigation of greenhouse gases.

In the past human history, societies have been managing the impacts of weather events and changing climatic conditions, but the pace of global change is now so rapid that additional measures will be required to reduce the adverse impacts of projected global climate change in the near and long term. Vulnerability to climate change can be aggravated by other stresses, including the loss of biodiversity, damage to ecosystem services, and land degradation. Vulnerability to climate change can be aggravated by other stresses, including the loss of biodiversity, damage to ecosystem services, and land degradation. Enhanced protection and management of natural ecosystems and more sustainable management of natural resources and agricultural crops can play a critical role in adaptation strategies. Adaptation activities can have positive impacts on biodiversity through maintaining and restoring native ecosystems; protecting and enhancing ecosystem services; actively preventing, and controlling, invasive alien species; managing habitats for rare, threatened, and endangered species; developing agro-forestry systems in transition zones between ecosystems, and monitoring results and changing management regimes accordingly (MacKinnon et al. 2008).

Awareness about the close relationship between climate change, food security and the role of agro-biodiversity has to be raised. Agro-biodiversity conservation must become a basic component of adaptation strategies to climate change. A new understanding of appropriate conservation strategies for agro-biodiversity is necessary, by which *in situ* concepts play a leading role.

Recent global initiatives (MacKinnon et al. 2008) are, however, addressing the effects of agricultural policies, practices, technologies and organizational arrangements on ecosystems and their goods and services, including biodiversity. Some of the questions that are being addressed include:

- How can biodiversity be mainstreamed into the production landscape?
- How do initiatives, such as training in sustainable harvesting or pest ecology, affect the capacity of small scale or subsistence producers to utilize threatened habitats without inflicting further harm?
- What are the economic and environmental (including species biodiversity) concerns surrounding biomass production?
- How are intellectual property rights important to conservation and the sustainable use of biodiversity?
- How have past changes in agricultural biodiversity affected rural livelihoods and nutritional security?
- What are the impacts of climate change on agricultural biodiversity and loss of agricultural biodiversity on adaptability to climate change?

The knowledge generated through these endeavours will strengthen the capacity of institutions to design and implement integrated management approaches, appropriate policies, and incentive structures that could contribute to reducing the overall rate of natural resource loss and land degradation, as well as enhancing landscape biodiversity, in both production and protected areas. Sustainable agricultural practices and improved natural resource management will contribute to improving livelihoods, food security, and health.

3 Adaptation in Agricultural Landscapes

Climate change and expected rainfall patterns are expected to have significant impacts on agricultural productivity, especially in arid and semi-arid regions. Most climate modelling scenarios indicate that the dry-lands of West Asia and North Africa, for instance, will be severely affected by droughts and high temperatures in the years to come. A greater frequency of droughts and flash floods has already been observed in recent years. These largely rainfed agricultural areas are the most vulnerable to the impact of climate change. A new suite of World Bank projects (MacKinnon et al. 2008) are helping countries to adapt agricultural practices to cope with changing climatic patterns, often building on traditional knowledge and management practices as listed below:

Agro-biodiversity and local knowledge assessment: Document farmers knowledge on adaptive characteristics of local landraces and their wild relatives in relation to environmental parameters to develop vulnerability profiles for the crops.
Climate modelling assessment: Develop initial local predictive capacity of weather patterns, climatic changes, and longer term climate change scenarios for these rainfed areas.
Enhancement of coping mechanisms: Identify a menu of coping mechanisms (such as *in situ* conservation, improved terracing with soil and water conservation practices, choice of crops and cropping patterns) designed and piloted to increase

resilience of farmers to climate variability and reduce vulnerability to climatic shifts.

Enabling policies, institutional and capacity development: Improve the capacity of key line agencies and stakeholders to collect and analyze data, improve climate predictions, and systems of information and information flow for enhanced uptake of coping mechanisms in the agricultural sector.

Indigenous Peoples have played a key role in climate change mitigation and adaptation. A climate change agenda fully involving Indigenous Peoples has many more benefits than if only government and/or the private sector are involved. Indigenous Peoples are some of the most vulnerable groups to the negative effects of climate change. Also, they are a source of knowledge for solutions that will be needed to avoid or ameliorate those effects. Over the millennia, Indigenous Peoples have developed adaptation models to climate change. They have also developed genetic varieties of crops, medicinal and useful plants, and animal breeds with a wider natural range of resistance to climatic and ecological variability.

4 Climate Change, Agriculture and Food Security

Climate change impacts will disproportionately affect the rural communities who rely on agriculture through increased risk of crop failure, pest infestation, water scarcity, and livestock deaths. These impacts are already imposing economic losses and undermining food security, and they are likely to get far more severe as global warming continues. According to crop-climate models, in tropical countries, even moderate warming can reduce yields significantly (1 °C for wheat and maize and 2 °C for rice) because many crops are already at the limit of their heat tolerance (MacKinnon et al. 2008).

For temperature increases above 3 °C, yield losses are expected to occur everywhere and be particularly severe in tropical regions. Areas most vulnerable to climate change—centred in South Asia and Sub-Saharan Africa—also have the largest number of rural poor and rural populations dependent on agriculture. This makes climate change a core development problem, and biodiversity actions a critical part of the solution.

The global response (MacKinnon et al. 2008) to the threats presented by climate change to agriculture focus on both mitigation and adaptation efforts and can be divided into four strategic objectives:

- Monitoring impacts of climate change on crops, forests, livestock and fisheries (adaptation);
- Providing risk management strategies for farmers and lenders against climate change impacts (adaptation);

- Preventing crop and livestock losses due to changing climatic factors and increased pest pressure through improved management techniques and tolerant crop varieties/livestock breeds (adaptation);
- Improving land and resource management to prevent degradation of the sustainable production base (mitigation).

As agricultural programmes take account of climate change and changing rainfall patterns, there is an increasing emphasis on community-driven development. This is encouraging more sustainable agriculture to avoid overgrazing and land degradation and promote new agro-forestry systems and multi-species cropping. Increased attention is also being paid to conserving agro-biodiversity in crop gene banks and to traditional agricultural practices, which maintain diversity of varieties and crops for food security.

5 Biodiversity and Sustainable Agriculture

Biodiversity is both a product of past evolutionary processes and essential raw materials of future evolution. The idea of evolutionary process, leading to organized structure and inter-relationships rather than random variation and chaos, is a key concept for conservation and utilization of biodiversity. Agro-biodiversity focuses on that part of biodiversity that occur in agricultural landscapes under human management (Wood 1993).

Three stages of agro-biodiversity generation can be recognized. The first level: the progressive modifications of ecosystems resulting from hunting-gathering, collecting plant propagules as food, and, thereby, favouring some species over others. The second level: weeds could flourish as a result of disturbance, the expansion of grassland over forest, and spread of weedy species, led to the major stage in human modification of biodiversity, herding and crop production, with direct and indirect selection of a wide range of plant and animal species for features of value. The third level: the stage of generating and manipulating agro-biodiversity, at the level of the gene, with directed plant breeding and genetic engineering to produce organisms for further servicing of human needs.

Transition from one level to the next depends on resources of agro-biodiversity of the previous stage. The move to the second stage depended on the ecosystems modified during the first stage; the transition from the second stage to the third stage depends, at least initially, on the useful diversity of species of domesticated plant and animals generated by the second stage. Unfortunately, transition has tended to destroy the human and biotic resources of the former stages. For example, evolution of the second stage (agricultural expansion) forced hunter-gatherers to the fringes of world history and severely threatened the often marginal ecosystems on which these diverse peoples depended. The evolution of the third stage, plant breeding and biotechnology, has caused great concern over loss of landrace resources generated by the second stage. Opportunity to study and use species and varietal agro-biodiversity is rapidly passing with the loss of traditional farming systems and their dynamic management of associated species, varieties, and indigenous knowledge systems. In order to better serve the interests of resource rich developing countries, a greater emphasis on agro-biodiversity is urgently needed.

5.1 Origin of Landrace Agro Biodiversity

Hunger and the constant search for food have forced primitive peoples to select for their food all plants suitable for cultivation in temperate and sub-tropical climates. Great accomplishments have been made in this direction throughout past centuries by unknown breeders. One can only marvel at the diversity of varieties and species of wheat, barley, corn, sorghum and legumes, all of which were known in primitive civilizations and there are no competitors to our present cereals; it would be very difficult to replace wheat, rice, and corn by other cultivated plants. Traditional farming systems are by far the richest source of agro-biodiversity: around 60 per cent of the world's agricultural land is still farmed by traditional or subsistence methods (Wood 1993).

It has been estimated that more than three million hectares survive under traditional agriculture as raised fields, terraces, swidden fallows, polycultures, home gardens, and other agro-forestry systems (Altieri 1998) and while these seldom have the potential to produce marketable surpluses, they do make a major contribution to food security (Heywood 1999b) and traditional cropping systems are said to provide as much as 20 % of the world's food supply.

5.2 Distribution of the Agro-Biodiversity of Wild Relatives

While a great part of global biodiversity is found in the lowland tropical forests, these are not the most important regions for agro-biodiversity. This inverse relation between species richness and crop origins has been noted. Many of the world's most economically important species are found in areas where species diversity is not great. None of the world's major food crops originated in tropical rain forests. Most important food crops appear to have originated where seasons are pronounced, so it makes sense to look there (and not in tropical rain forests) for promising new crops.

Drier ecosystems are far more important than rain forests for crop resources and are relatively neglected. Harlan considered that the most productive formations, in terms of agricultural development, were the Near Eastern woodlands and the tropical savannas, and dry forests. Both formations are rich in species including trees and grasses. Climates with long dry seasons appear to be necessary for the most productive ecosystems for plant domestication.

Undisturbed ‘natural’ ecosystems were of little importance in the origin of crops. Cultivation and the disturbances associated with it are factors of major importance leading to genetic variability, and are of exceptional interest. Cultivated cereal species are annuals, and their closest wild relatives are aggressive annual colonizers of disturbed habitats. Colonizing ability is essential in domestication. The success of the grasses lies primarily in the evolution of a versatile lifestyle adapted to unstable or fluctuating environments, particularly those associated with strongly seasonal rainfall regimes or the early stages of succession following disturbance. This life-form then proved readily adaptable to a partnership with fire and herbivores, creating the highly competitive grassland ecosystem. Finally, their propensity for exploiting instability has made them partner to the revolutionary changes in landscapes induced by man. Lastly, there came man, to exploit the unique nutritional and keeping qualities of the grass endosperm. Most terrestrial ecosystems have been profoundly modified by human intervention to better serve human needs, and are not ‘wildlands’. There is increasing evidence that conservationist perceptions of the ‘naturalness’ of tropical vegetation may be mistaken (Wood 1993).

Oryza nivara (an important source of resistance to rice grassy stunt virus, and often given as an example of the need to preserve wild ecosystems) is a weed needing open areas and the disturbance of agro-ecosystems for survival. In addition to incorrect management decisions based on false assumptions of ‘naturalness’, conservationist concerns over species numbers and levels of endemicity, which are proposed as the main criteria for attention, will divert attention away from the far more important agro-biodiversity. Similarly, a notable wild relative of maize, *Zea diploperennis*, depends on the survival of a traditional agricultural systems in the valley of San Miguel, Mexico, where almost all of the 320 ha rare under cultivation. For the purpose of *in situ* conservation, *Z. diploperennis* and its agro-ecosystem are, therefore, inseparable.

5.3 Sustainable Conservation for Sustainable Use

There have been substantial critiques of the concept of sustainable development. For example, Beckerman (1992) has argued that sustainability is a goal that cannot be defined: therefore, there is no answer to questions such as ‘how do we achieve sustainable development?’ Sustainable utilization of organisms is the best way of demonstrating the value of biodiversity and, thereby, ensuring its conservation. The protection of the world’s biological diversity can only be accomplished if it is integrated within multipurpose land use, with sustainable benefits to humanity seen to be derived from an appropriate part of the managed areas. To be effective, control of land use has to be substantially vested in local institutions, with the participation of local people, who have been enabled to perceive that management for sustainable use is in their own self-interest (McNeely 1989).

5.4 Appropriate Breeding

There is increasing recognition that the diverse needs of resource-poor farmers cannot be addressed by the breeding of a restricted range of high-yielding, high-input varieties. Yields of improved varieties in favourable conditions have reached a plateau in many countries (Win and Win 1990) or even, subsequently, declined. It has been suggested that a range of varieties are needed to fulfil specific socio-economic as well as agro-ecological needs in the small farm system and that breeding methods need to be reassessed urgently to increase the ability of formal sector agricultural research to produce varieties useful to small farmers (Cromwell 1990).

In a broad review of plant improvement for sustainable agriculture, Ceccarelli et al. (1992) noted that plant breeders must adopt an overall strategy that differs from present strategies in national and international breeding programmes. Requirements include concerted efforts on plant genetic resource management, evaluation under farmer conditions, adaptation to unfavourable conditions, and re-examining the role of diversity (mixed cropping and genetic variability within crops) to achieve production stability. There are already successful examples of appropriate breeding techniques that can be adopted and expanded from developing country breeding programmes. It is well known that farmers can often actively manage a large number of crop varieties than they have. However, farmer access to a wide range of varieties may be limited, and is certainly never encouraged by the formal breeding sector, which reduces variation, rather than amplifies it. Allowing farmers to participate in the varietal selection process resulted in the use of varieties tailored to localized conditions.

A rigid system of variety trials may even prevent useful varieties getting to farmers. The rice variety ‘Mahsuri’, introduced from Malaysia, was rejected in All-India trials, but spread informally from farmer cultivation in Andhra Pradesh to become the third most popular variety in India. The great interest and ability of farmers in managing variation should be encouraged as a location-specific complement to the work of institutional breeders (Wood 1993).

The World Bank review of small-scale farming in Africa, provides a strong justification for the direct use of germplasm collections by farmers, in their attempt to overcome constraints, by pointing to the need for the development of a greater awareness of the potential for indigenous material and the possibilities that exist for moving locally developed cultivars to other comparable areas (Carr 1989).

There will be environmental benefits from promoting a greater use of landraces. Landraces, developed over thousands of years of zero application of agrochemicals, are pre-adapted to grow without chemical inputs and, therefore, of value to the future needs of all countries, developing or developed. Traditional knowledge of adaptation to low nutrients or high disease pressure may be of global value. Farmers in Rwanda select bean mixtures that are known to perform better in poor soils (Voss 1991). Andean potato farmers practice ‘cultivation of certain frost-resistant varieties in flat bottom areas of the high valley, where frost, but not late blight is common. Other varieties are planted on hillsides where late blight, but not frost is common' (Brush 1977). The recognition, dissemination and wider use of landrace varieties may be both more relevant to the needs of poor farmers and also less damaging to the environment than the use of improved varieties.

Several crops used in traditional agriculture are multipurpose, most commonly with requirements for grain and straw yield, for example, sorghum. While there has been a considerable promotion of multipurpose trees, multipurpose crops have been neglected. Germplasm and information about the specific uses of the crops are needed, both for conservation and for utilization (Wood 1993).

The very great importance of intercropping in many traditional agricultural systems dictates that emphasis is given to germplasm from intercrop systems, and for intercrop systems. Intercropping and multiple cropping systems, where there is a close spatial or temporal association between different crops, account for a great proportion of crop production in many countries. There is considerable evidence that low resource farmers prefer to retain complex mixtures of crop species. It has been noted that, in many cases, crops have become coadapted to each other as a result of practices such as intercropping. Such methods (essential to subsistence agriculture) may be lost when materials are collected and stored apart from their native surroundings' (Pino and Strauss 1987).

The involvement of farmers in the management of agro-biodiversity is now starting to receive the attention it deserves. If these initiatives combining *in situ* conservation with utilization are to be free of problems of the kind that have reduced the effectiveness of *ex situ* conservation, then close technical monitoring will be necessary. There is considerable evidence that low resource farmers prefer to retain complex mixtures of crop species, in many cases, crops have become coadapted to each other as a result of practices such as intercropping. Such methods (essential to subsistence agriculture) may be lost when materials are collected and stored apart from their native surroundings.

5.5 Appropriate Conservation

Given the problems of *ex situ* germplasm management, what advantages are offered by *in situ* conservation? There is a growing literature on the role of traditional farming and conservation (Brush 1986; Altieri et al. 1987; Bisht et al. 2006, 2007). In the context of on-farm maintenance of agro-biodiversity, the term 'living gene banks' has been used (Barnes-McConnell 1987), with the argument that farmers are dynamic partners in conservation and should be paid to maintain diversity. It has been noted that more than simple maintenance is involved: farmers actively manage and enhance germplasm by selecting for a changing spectrum of needs. Farmers have been dedicated plant and animal breeders for thousands of years, although not in the precise manner of modern genetics. They have consciously maintained diversity, planted mixed fields systematically to achieve natural crosses, practised selection and set up their own personal gene banks as well as far-flung exchange systems for acquiring genetic resources (Rhoades 1989). *In situ* conservation of agro-biodiversity realistically combines both the conservation and the utilization of agro-biodiversity relevant to the farmer.

Until recently, the *in situ* conservation of wild relatives of crops of high strategic importance has been relatively neglected. This, in spite of the recommendation of the 1972 UN Stockholm Conference that wild germplasm of use in agriculture and forestry, should be maintained within its natural communities. The value of, and possibilities for, *in situ* conservation of wild relatives has been duly emphasized (Lenné and Wood 1991).

The interface between varietal agro-biodiversity and ecosystem agro-biodiversity needs to be further emphasized in *in situ* conservation. A review on sustainable agriculture noted that there has been a lack of creative thinking about how traditional agro-ecosystems and natural environments of wild crop relatives could be preserved (Pino and Strauss 1987). Many of the outstanding uses of wild relatives by modern breeders (for example, in potato and wheat) followed earlier natural introgression of characters under traditional farming, where crops, weeds, and wild relatives co-exist. Modern farming prevents the necessary close mixing of components, and modern seed production prevents the persistence of any location-specific adaptive changes resulting from introgression. It is, therefore, important to give priority for study and collection (and *in situ* conservation) of remaining complexes associated with subsistence farming (Lenné and Wood 1991). However, the past contact between crops and their wild relatives, which has been essential for crop evolution, is now seriously threatened by conservationist proposals.

5.5.1 The Future of Small Farms: Policy Support

The hallmark of traditional agriculture is precisely its dynamism: farmers' selection yields a constant stream of new varieties, adapted to changing needs and changing environmental circumstances (Wilkes 1995). But to say that not all small farms, or all crop varieties, can or should survive is not to say that a world of large, monocultural farms is desirable or feasible as the endpoint of agricultural history. Productive and resilient world agriculture requires a diverse mix of crop varieties, agricultural techniques, and farming systems. In this mix, there is a future for small farms (Boyce 2004).

Today, perhaps the single most important examples of humans acting as a keystone species are the agro-ecosystems that maintain the world's crop genetic diversity. Most of the 'keystone' people are small farmers. In part, this is because agricultural biodiversity is concentrated in regions of the world where small farms still predominate. In part, too, it is because small farmers have comparative advantages in the cultivation of diversity (Boyce 2004).

There is a fundamental tension between the 'efficiency' promoted by markets as market puts little value on crop genetic diversity. Instead, it dictates that, in any given time and place, all farmers should grow the same 'optimal' variety, tempered only by local differences in soils, climate, and so on. Apart from some variations in response to local differences, the market puts no value on diversity *per se*: less profitable varieties are driven out by more profitable varieties. Yet in the long run, diversity is crucial if agriculture is to be resilient. The farmers who maintain diversity, thus, provide a positive externality, a social benefit that the market fails to reward.

A wide range of policies can be envisioned that would reward small farmers for sustaining agricultural biodiversity, viz., removal of anti-small farmer policy distortions; social recognition; market development; provision of local public goods; payments for environmental services; policies to encourage part-time farming, etc. Such policies would both strengthen rural livelihood security and provide incentives for continued *in situ* conservation. In other words, rather than posing a trade-off between poverty reduction and environmental protection, these are policies that would advance both goals simultaneously (Boyce 2004).

5.6 Diversity Through Sustainable Agriculture: Principles and Practices

Sustainable agriculture, while it cannot be rigidly defined, is widely interpreted as consisting of practices that are ecologically sound, socially responsible, and economically viable (Thrupp 1996). Daily et al. (1998), for example, have drawn attention to the need to take into account the environmental and social costs of agricultural production as well as the direct farming costs.

To achieve such transformations for the conservation and enhancement of agricultural biodiversity, the following strategic principles are critical (Thrupp 2003):

1. Application of agro-ecological principles helps conserve, use and enhance biodiversity on farms and can increase sustainable productivity and intensification, which avoids extensification, thereby, reducing pressure on off-farm biodiversity;
2. Participation and empowerment of farmers and indigenous peoples, and protection of their rights, are important means of conserving agricultural biodiversity in research and development;
3. Adaptation of methods to local agro-ecological and socio-economic conditions, building upon existing successful methods and local knowledge, are essential to link biodiversity and agriculture and to meet livelihood needs;
4. Conservation of plant and animal genetic resources—especially *in situ* efforts—help protect biodiversity for current livelihood security as well as future needs and ecosystem functions;
5. Reforming genetic research and breeding programmes for agricultural biodiversity enhancement is essential and can also have production benefits; Creating a supportive policy environment—including eliminating incentives for

uniform varieties and for pesticides, and implementing policies for secure tenure and local rights to plant genetic resources—is vital for agricultural biodiversity enhancement and for food security;
6. Development of markets and business opportunities for diverse organic agricultural products; and,
7. Changing consumer demand to favour diverse varieties instead of uniform products.

6 Managing Traditional Crop Diversity for Sustainable Agricultural Production: A Scientific Approach for *in situ* Conservation On-Farm in the Indian Himalayas

Over the last three to four decades, large scale *ex situ* build up of plant genetic resources (PGR) collection has been clearly seen across the globe. The gene banks have been helpful in successfully conserving crop seed viability and safeguarding against genetic erosion resulting from technological changes and agro-ecological destruction. However, soon after the inception of *ex situ* conservation, both biological and social scientists have started questioning the adequacy of *ex situ* conservation strategy, mainly on grounds of being static and for detaching the collection from local knowledge systems. As a result, *in situ* conservation has been considered as a back-up and complementary strategy to *ex situ* conservation and models for its implementation have also been suggested (Maxted et al.1997, 2002). *In situ* conservation has now been considered as enhanced PGR utilization at the local level and consistent with agricultural development (Worede and Mekbib 1993; FAO 1998; Worede et al. 1999; Feyissa 2000). As it stands now, there seems to be a *de facto* conservation of landraces that farmers have been practicing for centuries as part of their farming system (Seboka and van Hintum 2006). Despite the surge of support for on-farm conservation of PGRs on a global scale, no agreed set of scientific principles yet exists for its implementation. It is worthwhile to state that not only the consequences of *ex situ* and on-farm conservation strategies have not been studied and resolved, but also, methods of researching, understanding and quantifying the complementary role of these strategies have not been well developed. Even the baseline data on the original composition of landraces is not available to assess the trend of genetic change in space and time.

6.1 *On-Farm Conservation of Crop Diversity in Himalaya*

The NBPGR has recently undertaken some case studies on on-farm conservation of agro-biodiversity at selected sites in the Uttarakhand Himalayas (Bisht et al.

2006, 2007). Existing crop genetic diversity at inter- and intra-species level was assessed, and factors for changes in crop compositions and farming systems during the recent past were studied. The Himalayan highlands are the reservoir for a large number of crop genetic resources because of the preponderance of locally developed traditional crop varieties owing to high agro-climatic heterogeneity and high local socio-cultural diversity. Valleys, in general, are more intensively cropped than the hilly slopes. Traditional agro-ecosystems in the Himalayan region are very diverse and crop husbandry, animal husbandry, and forests constitute complex and interlinked production systems. However, there has been gradual reduction of traditional crop diversity in this region during the last three to four decades, which requires adequate attention of researchers and policy makers for its safe conservation on-farm and sustainable utilization for agricultural production (Singh et al. 1984; Maikhuri et al. 1996, 1997, 2001; Palni et al. 1998; Bisht et al. 2006, 2007).

6.2 Crop Diversity in Traditional Agro-Ecosystems

Existing crop genetic diversity at the inter- and intra-species levels was assessed and factors for changes in crop compositions and farming systems during the recent past were studied. Decline in area under cultivation of most of the traditional crops, except rice and wheat, by 20–50 % was recorded. Area under many of these crops and their traditional landraces is being replaced very fast by several cash crops, such as off-season vegetables, common bean and pea. It is also noticeable that crop yields, in general, during the past two–three decades, for most of the traditional crops, have been more stable than that of the common food crops like wheat and rice. Unfortunately, human preferences for consumption of wheat and rice are recent changes in food habits in the region. The main nutritional value of traditional crops like finger millet, foxtail millet and barnyard millet lies in their potential ability to provide one of the cheapest sources of dietary energy in the form of proteins and carbohydrates in the Himalayas. Majority of the traditional grain and pulse crops of the mountains, viz. *Hordeum vulgare* (naked barleys), *Fagopyrum* spp., *Amaranthus* spp., *Panicum miliaceum*, *Eleusine coracana*, *Setaria italica*, *Echinochloa frumentacea*, *Macrotyloma uniflorum*, *Glycine max* (local black seeded types) and *Vigna mungo* have high calorific values (Maikhuri et al. 1996). Traditionally, in the Himalayas, many of these local crops supplement the wheat and rice meal. Mixed cropping of *Fagopyrum* spp.+potato, *Amaranthus* spp.+*Phaseolus vulgaris*, *Perilla frutescense*+*Vigna mungo*, *Macrotyloma uniflorum*+*Eleusine coracana* in mid and high altitude areas has shown very high energy output/input and efficiency ratio (Maikhuri et al. 1996; Bisht et al. 2006, 2007). The cultivation and processing of the traditional crops are simple. Traditional agriculture can, therefore, help conserve biological diversity and maintain healthy relationships between rural people and the land.

6.3 On-Farm Conservation of Underutilized Crops

A change in attitude has been noticeable over the last 5–10 years among policy-makers and the public with regard to the quality of life, as related to the quality of food as well as diverse sources of food. Vitamins and other micronutrients are, for instance, being searched for in crops and plant species with greater emphasis than in the past, in recognition of their role in combating diet imbalances. The minor millets and several underutilized crops have been included in worldwide plans of action after having successfully raised the interest of decision-makers. Some of the underutilized crops of Indian Himalayas such as amaranths, buckwheat, perilla, barley (both hulled and naked), etc. have been extensively investigated in the recent past at NBPGR (Manjunatha et al. 2007, 2011; Senthilkumaran et al. 2008; Verma et al. 2010). If the 20th century witnessed the undertaking of systematic collecting to rescue the genetic resources of staple crops, the 21st century has started with the awareness of the need to rescue and improve the use of those crops left aside by research, technology, marketing systems as well as conservation efforts.

6.4 Factors Affecting Farmers' Crop and Variety Choices

Agro-ecology, market structure and various household socio-economic characteristics like economic status of households, income sources, family structure, gender roles, land tenure system and local seed system are important factors dictating farmers' crop/variety choices (Table 1).

The detailed documentation of rice landraces in the present study indicated that information collected at the level of household or farmers' plot may not be an appropriate scale for analyzing diversity or for crop diversity conservation. Even one single village may not maintain a sufficiently large population for effective conservation over time. More likely, it will be the network of villages or even a region that will be the approximate level for understanding the maintenance of crop genetic diversity on-farm in the Himalayan highlands. Documentation of rice landraces suggests that many of the rice landraces are adapted to marginal niche environments (common or rare localized landraces), the conservation strategy must therefore target these regions. Understanding farmers' system of classification for the different features of their agro-ecosystems may yield insights into the processes fostering conservation of diverse landraces (Martin 1995).

6.5 Benefit Enhancing Options for Farmers from Local Crop Diversity

Various benefit enhancing options for farmers from local crop diversity were scrutinized based on farmer perceptions and priorities for efficient management of local crop diversity on-farm and its sustainable utilization for agricultural

Table 1 Explanatory factors and variables for farmer crop and variety choices in Uttarakhand Himalaya

Factor	Important variables	Impact assessment
Agro-ecology	Irrigation resources, land quality, soil type	About 15–20 % of the total cropped study area is irrigated. The high yielding rice and wheat landraces are monocropped under irrigated conditions. Most of the traditional coarse grains are grown under rainfed conditions in poor soil as complete mixtures or intercropped. Many of the rare rice landraces under rainfed conditions are grown in very small patches adapted to specific soil types and microclimatic niches
Market infrastructure	Distance to nearest market, price differentials	Cash crops like off-season vegetables, potato and pea are grown for both local and distant market needs. *Phaseolus vulgaris* (seed types) and *Amaranthus* spp. are grown for distant market needs as these can be stored for a longer period and there has been considerable increase in total cropped area under these crops. Some local landraces of *Phaseolus vulgaris* are sold at premium prices and farmers have the market incentive in growing them. Most of the other local crops are grown for self consumption needs. Not much seed is acquired from off-farm sources
Household characteristics Economic status and objectives	Farm size, number of months food self-sufficient, percent of harvest sold	About 66 % households are marginal farmers (<0.5 ha land holding) and they are self-sufficient in food requirement for only 6–7 months in a year and mainly grow coarse grains. Farmers with large holdings (>1 ha) grow more cash crops and self sufficient in their food requirement, a substantial portion of the harvest of cash crops sold in market including farm-saved seeds for sale to resource poor marginal farmers. Only big farmers can afford to maintain locally rare landraces mainly for aesthetic reasons
Income sources	Seasonal migration, crop share of farm income to total income, off-farm income	Small farmers largely rely on off-farm jobs for subsistence and mainly grow coarse grains under mixed cropping; the ratio of farm income to total income was 1:1 for average resource poor marginal farmer
Human resources	Family size, household composition	Farmers with large family size invariably grow coarse grained landraces with high yield potential regardless of their wealth status and farm size. Farmers with more women members in household grow more traditional coarse grained millets as these crops require special women-related skill for processing and food preparation
Land resources	Fragmentation	There is high degree of land fragmentation as per the existing land tenure system in the Kumaon Himalayas. Farmers with large farm area can afford to maintain more landraces per household basis for market incentives and also for aesthetic reasons

Source After Bisht et al. (2007)

production. Increasing consumer demand, increasing farmers' access to genetic materials, improving the material itself and policy support were the important add-value options (Table 2).

6.6 Scientific and Institutional Challenges for Managing Crop Diversity On-Farm

Important scientific and institutional challenges for managing crop diversity on-farm based on farmers' perceptions are listed in Table 3. Careful analysis and evaluation of various socio-economic, environmental and scientific challenges is essential so that agricultural activities could be reoriented towards better use of local resources and their sustainable management in agro-ecosystems. Conservation of traditional crops could succeed when these crops are linked with the economic development of hill farmers. Pragmatic multi-disciplinary research and policy support are needed to evolve farming systems which can provide enough quality food and economic security for the people of the region and encourage them conserve and enhance crop diversity in the traditional ecosystems.

In situ conservation and crop improvement can complement one another in marginal areas. Breeding programmes that evaluate landraces and use them in local improvement efforts are expected to produce material of direct value for marginal agro-climatic zones as well as achieve significant local conservation (Brush 1999). By including decentralized breeding as part of an *in situ* programme, farmers and crop biologists can become partners in local crop improvement efforts for marginal agro-climatic zones and for crops without the need for national breeding programmes. This 'grassroots breeding' can build upon existing knowledge and skills of farmers and link farmers from different regions through the exchange of information and landraces (Cooper et al. 2001). *In situ* (on-farm) conservation can also be seen as a conservation strategy that is complementary to *ex situ* conservation (Visser and Engels 2000).

6.7 Role of Informal Seed System in Promoting Landrace Diversity and Their On-Farm Conservation

Role of informal seed system in landrace diversification, *in situ* conservation on-farm and sustainability in production were investigated as a case study for rice diversity in the Indian Himalayas. The diachronic pattern of landrace occurrence revealed substantial increase, both in landrace number and frequency, in time. The local level seed supply in Uttarakhand Himalaya revealed that about 96 % seed supply originated from the informal system and a mere 4 % seed supply is met from formal seed supply networks (Table 4). In higher elevation ranges, beyond

Table 2 Benefit enhancing options for farmers from local crop diversity in Uttarakhand Himalaya

S. No.	'Add value' options	Probable actions
1.	Increasing consumer demand	Many traditional landraces of rice, millets, food legumes and local vegetables have great potential for processing, packaging and marketing. Potential consumers need to be made aware of the range of available crops and the positive features (taste, nutrition, etc.) of particular varieties
		Marketing of products made from local crops that have a special value for local food culture and a market niche for tourism. Local products from rare medicinal rice landraces, buckwheat, amaranths, horse gram, millets may be processed and marketed. Chefs in hotels and restaurants need to be sensitized to use local products in daily cuisines and local recipes making best use of the new products
		The Himalayan agriculture with very little use of purchased inputs has a great potential for organic farming. Public awareness through media campaign initiatives to educate consumers about the value of agro-biodiversity and linking it with a greater demand for organic produce can add value to the local crop diversity. Organic farming shares many of the goals of on-farm conservation such as agro-ecosystem health, sustainable production and low input and locally adapted farming systems
2.	Increasing farmers' access to genetic materials	Strengthening seed exchange networks and linking farmers' seed supply to the formal sector could serve to broaden farmers' option regarding variety choice while fostering diversity conservation
		Farmers' access to new and diverse varieties can be improved through community gene-banks and community biodiversity registers
		Incorporation of landraces into agricultural extension packages and training extension personnel to recognize the importance of local landraces for conservation and local livelihood
		Organising community-level diversity fairs on regular basis as an important forum for public recognition of farmers and their crop diversity
3.	Improving the material itself	'Grassroots breeding' or participatory plant breeding can improve diverse crop populations or the production systems in which they are grown according to farmers' interests
		Seed storage practices could be strengthened to prevent loss due to diseases, pests and deterioration
		Particular agro-ecological management practices may also serve to support production of crop diversity. Low chemical input or organic farming with local varieties can serve to promote agro-ecosystem stability and health. Such improvement strategies must necessarily be local in order to be used for a diversity of landrace materials
4.	Policy support	Farming systems maintaining very high genetic diversity may be supported through government subsidies if the opportunity cost of conservation becomes too high for farmers' to continue cultivating diverse landraces. Further, integrated and expert forest management in the region has to be strengthened as 6–8 ha of well managed forests are required to support 1 ha of farm land in Himalayan agro-ecosystems

Source After Bisht et al. (2007)

Table 3 Scientific and institutional challenges for managing crop diversity on-farm based on farmers' perceptions in the Uttarakhand Himalayas [listed in decreasing order of importance]

Issues	Action points
Socio-economic and policy issues	
1.	Developing niche markets for traditional crops and promoting agro-processing industries for local produce including the wild edibles
2.	Land consolidation and development of village marketing cooperatives through appropriate policies so as to avoid exploitation through middleman
3.	Improving seed management of local landraces and access of farmers to crop genetic diversity for increased use
4.	Empowerment of women and benefit sharing by the gender which is the main conserver and manager of agro-biodiversity
Scientific challenges	
1.	Improvement in scientific understanding on ecological and socio-economic functions of biodiversity in traditional agro-ecosystems
2.	Identification of elite germplasm with the potential for use in food industry and multiplication of these seed types for both local and urban consumption
3.	Increased use of local crop resources for value addition based on traditional knowledge and farmer participation in crop breeding
4.	Promotion of organic recycling for maintaining soil fertility and integrated nutrient management for promotion of organic food
5.	Development of community seed bank and linking the community conservation with *ex situ* conservation
6.	Promotion of wild edibles and search for new crops

Source After Bisht et al. (2006)

1,200 masl, largely landrace cultivation is practiced and a greater landrace diversification in traditional production was observed. Substantial variations due to environmental adaptations in niche habitats help provide important donor germplasm for crop improvement to users. Further, the population genetic structure also indicated enough diversity being maintained on-farm. Developing pathways for strengthening local level seed system for landrace diversification linked to sustainability in food production and conserving agro-biodiversity has been emphasized (Pandey et al. 2011).

Further, a recent study (Kumar et al. 2010) demonstrated farmer management of crop population structure and temporal evolution of rice genetic diversity in traditional production systems of the Uttarakhand Himalayas. The study also compared genebank-conserved populations and on-farm managed landrace populations of same named landrace *Jaulia* and *Thapachini*, and revealed greater diversity for on-farm managed populations as compared to the populations under static management. A substantial number of alleles specific to populations under dynamic management could be recorded. Further, the rare landrace populations included in the present study were more diverse than the common landrace populations. The rare landraces were distinct genetic entities largely representing locally common alleles. Investigating the population genetic structure is therefore helpful in monitoring change in diversity over time and space, and also for devising a rational plan for management of farmer landraces on-farm.

Table 4 Rice landrace scenario in traditional productions during 1970s and 2000s in Uttarakhand Himalaya

Elevation (masl)	Landrace scenario	Common		Rare	
		1970s	2000s	1970s	2000s
<1200	Average no. of landraces per household per site	2.0	3.0	4.0	6.0
	Frequency	70.0	80.0	10.0	22.0
	Total named landraces grown at all study sites	13.0	18.0	22.0	34.0
	Total no. of improved varieties grown	5.0	7.0	–	–
1200–1800	Average no. of landraces per household per site	3.0	4.0	7.0	8.0
	Frequency	60.0	73.0	17.0	33.0
	Total named landraces grown at all study sites	18.0	26.0	31.0	46.0
	Total no. of improved varieties grown	3.0	5.0	–	–
>1800	Average no. of landraces per household per site	3.0	3.0	7.0	9.0
	Frequency	53.0	67.0	21.0	32.0
	Total named landraces grown at all study sites	11.0	23.0	27.0	49.0
	Total no. of improved varieties grown	–	–	–	–
Average (at all elevations)	Average no. of landraces per household per site	2.7	3.3	6.0	7.7
	Frequency	61.0	73.3	16.0	29.0
	Total named landraces grown at all study sites	14.0	22.3	26.7	43.0
	Total no. of improved varieties grown	2.7	4.0	–	–

Source Pandey et al. (2011)

7 Harmonizing Biodiversity Conservation and Agricultural Intensification by Integrating Plant, Animal and Fish Genetic Resources in Himalaya: A Case Study

Conservation of agricultural biodiversity in production systems through protected areas is often rendered less relevant because of high degree of human management. Further, when on-farm conservation research has identified genetically important populations of crops and farming systems that are priorities for conservation, it may be appropriate to assess different options for 'adding value' to these populations, or, in other words, increasing the benefits that farmers get from cultivating diverse local crops or animal breeds in a given social, economic and ecological context. By understanding their importance in farming systems, farmers have to continue cultivating/maintaining local crops/animal breeds resulting in on-farm conservation and enhanced livelihood security on sustainable basis. An important component of on-farm research will, therefore, be to investigate which strategies can be used to add value to local diversity and support farming systems associated with high genetic diversity. A project entitled, 'Harmonizing biodiversity conservation and agricultural intensification through integration of plant, animal and fish genetic resources for livelihood security in fragile ecosystems' has recently been started with financial support from World Bank (GEF) aided National Agricultural Innovation Project (NAIP) with NBPGR as the Lead Consortium. The programme is being operated in three disadvantaged districts, the Chamba district in Himachal Pradesh (representing the Hill and Mountain agro-ecosystem), Udaipur in Rajasthan (Irrigated and rainfed agro-ecosystem in Arawali hills with semi-arid climate), and Adilabad in Andhra Pradesh (Deccan Plateau and Sahyadri Hills with sub-tropical climate) are the districts included in the study. In order to enhance livelihood security of the farmers, it has been envisaged to link conservation and use of traditional crops, livestock breeds and fish resources with their economic development.

The potential methods for 'adding benefits' for farmers, i.e., integrating plant, animal and fish genetic diversity, if any, remain to be tested. These methods, which are associated with the maintenance of high genetic diversity over time and general means of enhancing the benefits to farmers, include:

a. Improving the landrace material and production system (through farmers' participation, strengthening farmers' seed management, agro-ecosystem health, etc.), increasing farmers' access to a diversity of varieties (community biodiversity registers and gene banks, seed exchange networks, linking farmers' seed supply systems to the formal sector, incorporating local crop resources into agricultural extension packages, diversity fairs etc.), and increasing consumer demand for products using a diversity of varieties (adding value through processing, organic farming etc.).
b. Similarly the 'adding value' initiatives for animal genetic resources include genetic improvement of local livestock through use of superior germplasm of extant indigenous breeds of livestock, health management practices through prophylactic vaccination and de-worming and improving the nutrient utilization of locally available feed and fodder resources.
c. 'Add value' options for fish genetic resources include propagation assisted rehabilitation of indigenous fishes for conservation and stock enhancement, integrated fish farming model with rabbitary, poultry and vermin-composting, promotion of trout farming, ornamental fish breeding and culture including exotics and indigenous species.
d. Development of an information management system to facilitate planned interventions for conservation and sustainable utilization of targeted species/populations.

e. Capacity building in agro-biodiversity management for livelihood security through organization of the grassroots level trainings for awareness generation on agro-biodiversity conservation and use, providing post-harvest management and marketing support for agriculture, livestock and fisheries through creation of self-help and community level farmer cooperatives.

8 Conclusion

To ensure that there can be sustainable agriculture, it is imperative that priority be given to the sustainable conservation of the resources of agro-biodiversity on which agriculture depends. Deployment of greater genetic diversity in production systems is expected to take care of both their sustainable use and conservation. *In situ* conservation on-farm and crop improvement can complement one another in marginal production systems. Breeding programmes that evaluate farmers' landraces and use them in local improvement efforts are expected to produce material of direct value for marginal agro-climatic zones as well as achieve significant local conservation. New approaches to agricultural research and development are being tried in various places around the world, and virtually all of them emphasize a much better harnessing and management of biological resources than has prevailed in the past. Although many institutions are already actively involved, more coordination is needed at all levels to ensure effective reforms and agricultural biodiversity conservation policies that benefit the public, especially the poor and small farmers. Policy changes that attack the roots of problems and ensure peoples' rights are needed. We need to ensure public participation in the development of agricultural and resource use policies, develop markets and business opportunities for diverse organic agricultural products and change consumer demand to favour diverse varieties instead of uniform products. Building complementarities between agriculture and biodiversity will also require changes in agricultural research and development, and land use. Efforts on agro-biodiversity conservation and characterization and development of better adapted and resistant crops to the fluctuating environment will add to food security strategy and help coping to climate change. *In situ* conservation on-farm continues to get emphasis for adaptation measures. Strategies for adaptation to climate change will need to embrace different sectors, support development and will be interdependent, requiring collaboration amongst stakeholders, ranging from resource managers to policy makers. There is a need to be more proactive than reactive and to focus on measures that achieve multiple targets. Planning for biodiversity-inclusive impact assessment will ensure mitigation of biodiversity loss and secure economic development and human well-being. A wide range of policies envisioning rewarding small farmers for sustaining agricultural biodiversity management and use would be required.

References

Altieri MA (1998) The agroecological dimensions of biodiversity in traditional farming systems. In: Posey DA (ed) Cultural and spiritual values of biodiversity. UNEP, Nairobi, pp 291–297

Altieri MA, Merrick LC, Anderson MK (1987) Peasant agriculture and the conservation of crop and wild plant resources. Conserv Biol 1:49–58

Barnes-McConnell P (1987) Keepers of the trust. Diversity 12:22–24

Beckerman W (1992) Economic growth and the environment: whose growth? Whose environment? World Dev 20:481–496

Bisht IS, Rao KS, Bhandari DC, Nautiyal S, Maikhuri RK, Dhillon BS (2006) A suitable site for in situ (on-farm) management of plant diversity in traditional agro-ecosystems of western Himalaya in Uttaranchal state: a case study. Genet Resour Crop Evol 53:1333–1350

Bisht IS, Mehta PS, Bhandari DC (2007) Traditional crop diversity and its conservation on-farm for sustainable agricultural production in Kumaon Himalaya of Uttaranchal state: a case study. Genet Resour Crop Evol 54:345–357

Boyce JK (2004) A future for small farms? Biodiversity and sustainable agriculture. Working paper series No 86, PERI, University of Massachusetts, Amherst

Brush SB (1977) Farming the edge of the Andes. Nat Hist 6(5):32–40

Brush SB (1986) Genetic diversity and conservation in traditional farming systems. J Ethnobiol 6:151–161

Brush SB (1999) Genes in the field: on-farm conservation of crop diversity. Lewis Publishers, Boca Raton

Carr SJ (1989) Technology for small-scale farmers in Sub-Saharan Africa: experience with food production in five major ecological zones. World Bank technical papers no 109: pp 13, 106

Ceccarelli S, Valkoun J, Erskine W, Weigand S, Miller R, van Leur JAG (1992) Plant genetic resources and plant improvement as tools to develop sustainable agriculture. Expl Agric 28:89–98

Cooper HD, Spillane C, Hodgkin T (2001) Broadening the genetic base of crops: an overview. In: Cooper HD, Spillane C, Hodgkin T (eds) Broadening the genetic base of crop production: 1–23. IPGRI/FAO, Rome

Cromwell E (ed) (1990) Seed diffusion mechanisms in small farm communities. ODI Agricultural Administration Unit, Network paper No 21: pp 54

Daily G, Dasgupta P, Bolin B, Crosson P, du Guerny J, Ehrlich P, Folke C, Jansson AM, Jansson BO, Kautsky N, Kinzig A, Levin S, Maler KG, Pinstrup-Andersen P, Siniscalo D, Walker B (1998) Global food supply: food production, population growth and the environment. Science 281:1291–1292

FAO (1998) The state of the world's plant genetic resources for food and agriculture. Rome

Feyissa R (2000) Community seed banks and seed exchange in Ethiopia: a farmer-led approach. In: Friis-Hansen E, Sthapit B (eds) Participatory approaches to the conservation of and use of plant genetic resources. IPGRI, Rome, pp 142–148

Heywood VH (1999a) Trends in agricultural biodiversity. In: Jenick J (ed) Perspectives on new crops and new uses. ASHS Press, Alexandria

Heywood VH (1999b) Use and potential of wild plants in farm households. FAO, Rome

Kumar S, Bisht IS, Bhat KV (2010) Population structure of rice (*Oryza sativa*) landraces under farmer management. Ann Appl Biol 156:137–146

Lenné J, Wood D (1991) Plant diseases and the use of wild germplasm. Annu Rev Phytopathol 29:35–63

MacKinnon K, Sobrevila C, Hickey V (2008) Biodiversity, climate change and adaptation: nature based solution from the World Bank Portfolio. The International Bank for reconstruction and development/TheWorld Bank

Maikhuri RK, Rao KS, Saxena KG (1996) Traditional crop diversity for sustainable development of Central Himalayan agroecosystems. Int J Sustain World Ecol 3:8–31

Maikhuri RK, Semwal RL, Rao KS, Saxena KG (1997) Eroding traditional crop diversity imperils the sustainability of agriculture systems in central Himalaya. Curr Sci 73:777–782

Maikhuri RK, Rao KS, Semwal RL (2001) Changing scenario of Himalayan agroecosystems: loss of agrobiodiversity, an indicator of environmental change in Central Himalaya, India. Environmentalist 21:23–29

Manjunatha T, Bisht IS, Bhat KV, Singh BP (2007) Genetic diversity in barley (*Hordeum vulgare* ssp v*ulgare*) landraces from Uttaranchal Himalaya of India. Genet Resour Crop Evol 54:55–65

Manjunatha T, Bisht IS, Bhat KV (2011) Genetic structure of hull-less barley (*Hordeum vulgare* L subsp *vulgare*) landrace populations from North-western Indian Himalayas. Indian J Biotechnol 10:25–32

Martin GJ (1995) Ethnobotany. 'People and plants' conservation manual series. Chapman and Hall, London

Maxted N, Hawkes JG, Ford-Lloyd BV, Williams JT (1997) A practical model for in situ genetic conservation. In: Maxted N, Ford-Lloyd BV, Hawkes JG (eds) Plant genetic conservation: the in situ approach. Chapman & Hall, London, pp 339–367

Maxted N, Guarina L, Myer L, Chiwona EA (2002) Towards a methodology for on-farm conservation of plant genetic resources. Genet Resour Crop Evol 49:31–64

McNeely JA (1989) Conserving biological diversity—a decision-maker's guide. IUCN Bulletin 20(4–6):7

Palni LMS, Maikhuri RK, Rao KS (1998) Conservation of the Himalayan agroecosystems: issues and priorities. In: Eco-regional cooperation for biodiversity conservation in the Himalaya, UNDP, New York, pp 253–290

Pandey A, Bisht IS, Bhat KV, Mehta PS (2011) Role of informal seed system in promoting landrace diversity and their on-farm conservation: a case study of rice in Indian Himalayas. Genet Resour Crop Evol 58:1213–1224

Pino J, Strauss MS (1987) The preservation of germplasm. In: Davis TJ, Schirmer IA (eds) Sustainability issues in agricultural development. The World Bank, Washington, pp 252–266

Rhoades R (1989) The Role of Farmers in the creation of agricultural technology. In: Chambers RA, Pacey A, Thrupp LA (eds) Farmer first, farmer innovation and agricultural research London: Intermediate Technology Publications: London, p 218

Seboka B, van Hintum T (2006) The dynamics of on-farm management of sorghum in Ethiopia: implication for the conservation and improvement of plant genetic resources. Genet Resour Crop Evol 53:1385–1403

Senthilkumaran R, Bisht IS, Bhat KV, Rana JC (2008) Diversity in buckwheat (*Fagopyrum spp*) landrace populations from north-western Indian Himalayas. Genet Resour Crop Evol 55:287–302

Singh JS, Pandey U, Tiwari AK (1984) Man and forests: a Central Himalayan case study. Ambio 13:80–87

Thrupp LA (1996) Agriculture, cooperative; agricultural innovations; agricultural productivity; sustainable development; case studies. World Resources Institute, Washington, DC,p 136

Thrupp LA (2003) The central role of agricultural biodiversity: trends and challenges. In: Conservation and sustainable use of agricultural biodiversity. A sourcebook compiled by CIP-UPWARD in partnership with GTZ, IDRC, IPGRI, SEARICE

Verma N, Rana MK, Negi KS, Kumar G, Bhat KV, Park YJ, Bisht IS (2010) Assessment of genetic diversity in Indian Perilla [*Perilla frutescens* (L) Britton] landraces using STMS markers. Indian J Biotechnol 9:43–49

Visser B, Engels J (2000) Synthesis: the common goal of conservation of genetic resources. In: Almekinders C, de Boef W (eds) Encouraging diversity the conservation and development of plant genetic resources. Intermediate Technology Publication, London, pp 145–153

Voss J (1991) Farmer management of varietal bean mixtures in Central Africa: implications for a technology development strategy. Rockefeller-CIP Workshop, Farmers and food systems, Lima, Peru (Sept 1988)

Wilkes G (1995) The ethnobotany of artificial selection in seed plant domestication. In: Schultes RE, Von Resi S (eds) Ethnobotany: evolution of a discipline. Dioscorides Press, Portland, pp 203–208
Win K, Win K (1990) Myanmar's experience in rice improvement. 1830'1985 IRRI Research paper No 141: 10
Wood D (1993) Agrobiodiversity in global conservation policy biopolicy International. African centre for technology studies, vol 11, pp 1–32
Worede M, Mekbib H (1993) Linking genetic resources conservation to farmers in Ethiopia. In: de Boef W, Amanor K, Wellard K, Bebbington A (eds) Cultivating knowledge: genetic diversity, farmer experimentation and crop research. Intermediate Technology Publications, London, UK, pp 78–85
Worede M, Tessema T, Feyissa R (1999) Keeping diversity alive: an Ethiopian perspective. In: Brush SB (ed) Genes in the field: on-farm conservation of crop diversity IPGRI and IDRC, Lewis publishers, CRC Press LLC, New York, pp 143–161

The Potential Impacts of Climate Change on Insect Pests in Cultivated Ecosystems: An Indian Perspective

A. K. Chakravarthy, B. Doddabasappa and P. R. Shashank

1 Introduction

Climate change is a variation either in the mean state of the climate or variability in its components, persisting for an extended period. It encompasses temperature increase; sea-level rise, changes in precipitation patterns and increases in the frequency of extreme weather events (Hamilton et al. 2005). These changes have drastic impacts on the economy of agriculture based, biodiversity rich countries like India (Sharma 2010; Dhaliwal et al. 2004). Biodiversity and climate change are closely linked and each impacts upon the other. Sustained biodiversity resources can reduce the impacts of climate change on populations and ecosystems. Insects are cold blooded, most speciose animals (Coviella and Trumble 1999). The temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor influencing insect behavior, distribution, survival and reproduction. Insect life stages predictions are most often calculated using accumulated degree—days from a base temperature and biofix point. Some researchers believe that the effect of temperature on insects largely overwhelms the effects of other environmental factors (Bale et al. 2002). It has been estimated that with a 2 °C temperature increases, insects might experience one to five additional life cycles per season (Yamamura and Kiritani 1998). Moisture and CO_2 effects on insects can potentially have important considerations in a global climate change setting (Hamilton et al. 2005; Coviella and Trumble 1999; Hunter 2001; Sharma 2010; Dhaliwal et al. 2004, 2010).

Human activities have been identified as likely contributors to global as well as regional climate change (IPCC 2001). To understand the impact of climate change,

A. K. Chakravarthy (✉) · B. Doddabasappa · P. R. Shashank
Department of Agricultural Entomology, University of Agricultural Sciences,
Gandhi Krishi Vignan Kendra (GKVK), Bangalore 560 065 Karnataka, India
e-mail: chakravarthyakshay@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_9,

it is essential to assess the climate's sensitivity to a variety of factors, both human and natural. In this paper the focus is on the impact of climate change on insect pests and pest management in India.

2 Materials and Methods

Observations for about two decades (1990–2010) in opportunistic surveys on insects in relation to weather parameters in select cultivated ecosystems were recorded in South Karnataka, south India (Table 1). Shifts in the insect pests on cultivated crops, patterns of their distribution and intensity of pest infestation on cultivated crops were monitored. For the purpose, standardized procedures of insect sampling, insect counting and damage assessments were made. Details of the techniques and procedures are available in Kogan and Herzog (1980). The observations will focus issues of climate variability at the regional or local level. But our interest has been in inventing broad policy recommendations. Our hypothesis is that understanding local perceptions of farmers of climate variability will yield useful insights into impact of climate change in the long term.

As documented information on impact of climate change on insects in India is scanty, efforts were made to review the literature on implications of climate change on insect pests and pest management from electronic media: web sites, networks, e-journals and through e-mails. Information was also collected through print media: books, journals, broachers, leaflets, manuals and practical kits. In addition, interactions with entomologists working on insect pests and pest management in India on select crops were made. Several interactive sessions with experts on climate change from Indian Institute of Science, University of Agricultural Sciences, Meteorological Department, Indian Meteorological Department (IMD), Government of India and scientists from Atmospheric sciences, in Bangalore were held. The information is consolidated, analyzed and surmised.

3 Results and Discussion

3.1 Observations

The changes in pest status of certain insect species in south Karnataka are summarized in Table 1. Brown Planthopper, *Nilaparvatha lugens* Stal. (Delphacidae: Hemiptera) is a major pest occurring in outbreak form in certain rice cultivated patches. Factors contributing for increase in the BPH population are application of nitrogenous fertilizers in excess, closer spacing, cultivating BPH susceptible rice cultivars, cultivating rice after rice and rising temperatures from the last two decades. Similarly in Cauvery Command Area (CCA) the numbers of white

Table 1 Crops and insect pests impacted by climate change from 1990 to 2000 and from 2000 to 2010 in South Karnataka[a]

Crop (location)	Insect pests	Change in weather		Impact/infestation	
		1999–2000 (Max. and min. tem. °C)	2000–2010 (Max. and min. tem. °C)	1999–2000	2000–2010
Rice (Mandya)	BPH Numbers/hill (Mean of 10 × 4 hills)	32.00 and 24.50	33.82 and 25.70	5 winged and 6–8 apterous hoppers per clump	11 winged and 8-12/ clump apterous hoppers
	WBPH Numbers/hill (Mean of 10 × 4 hills)	32.00 and 24.50	33.82 and 25.70	Not recorded/recorded in rainfed rice in negligible numbers during summer only	2-3/clumps in kharif, rabi and summer
Mandya Srirangapatana (Var: Jaya)	Hispa (km^2 spread)/ year	32.00 and 24.50	33.82 and 25.70	Restricted to Majjigepura and two adjacent villages and Spread in 1,180 ha	Spread over 3,000 ha
Cotton (Arboreum) (Hunsur) (Mean of 10 × 5 Pls/insect pest/field/2 Shimoga (Jayadhar)	Whitefly and mealy bug (% plants infested) (Mean of 10 × 5 plants/insect pest/ field × 2)	30.20 and 21.40	33.85 and 28.00	Whitefly = 69.90 Mealy bug = 2.40	17.80 % 13.50 %
Mango Chickballapura (Local)	Leaf hoppers (% infestation) (Mean of 10 × 5 plants/field × 2)	30.45 and 22.00	33.65 and 26.70	Low to moderate levels of infestation (about <25 % damage)	Higher (>30 % damage)
Pigeonpea GKVK, Bangalore (TTB-7)	Pod borer (% pod infestation) (Mean of 10 × 5 plants/field × 2)	25.60 and 31.50	26.00 and 32.00	Low to moderate levels of infestation (about <20 % damage)	Higher (>20 % damage)
	Brown scale (% infestation)	25.60 and 31.50	26.00 and 32.00	23.00	0.0
Chilli/Onion (Hiriyur)	Thrips (% infestation)	26.50 and 33.50	27.20 and 34.20		
Groundnut (Tumkur)	Aphids (% infestation)	29.40 and 34.60	30.50 and 37.00	14.50	26.30
Sunflower GKVK, Bangalore	Thrips (%infestation)	25.60 °C	32.70 °C	8.30 %	21.50 %

[a] The weather data are recorded at specific local weather stations for specific periods and sampling of insect pests was under taken in limited cultivated fields

backed planthopper, *Sogatella furcifera* (Horvath) is increasing especially on rainfed, summer paddy. The chrysomelid beetle, Hispa which was not a pest on paddy prior to 1990's, in Srirangapatna, Mandya covered over 3,000 ha of paddy after 2000, spreading @ 150–175 ha/year (Fig. 1), incurring yield loss.

Sucking pests, viz, whitefly and mealy bugs increasingly appeared on cotton from beginning of 2000 in Hunsur and Shimoga. Under normal pattern of rainfall, the podborers damage to pigeonpea will be lower than when rains fail in June–July and subsequently heavy showers are received in October–November (Yelshetty et al. 2003). Closer spacing of pigeonpea attracts brown scales, *Coccus longulus* (Douglas) compared to wider spacing because of a change in microclimatic conditions (Fig. 2) (Narasimhamurthy et al. 2011).

Table 2 provides insect pests that would exacerbate in India under warmer conditions. Likewise entomologists in Tamil Nadu have predicted four sucking pests and mites to become severe with temperature rise (Table 3).

Depending on the development "strategy" of an insect species, temperature exerts different effects (Bale et al. 2002). Insects like cicadas, Eupterote moths in hill region of Karnataka take several years to complete one life cycle will tend to moderate temperature variability over the course of their life history.

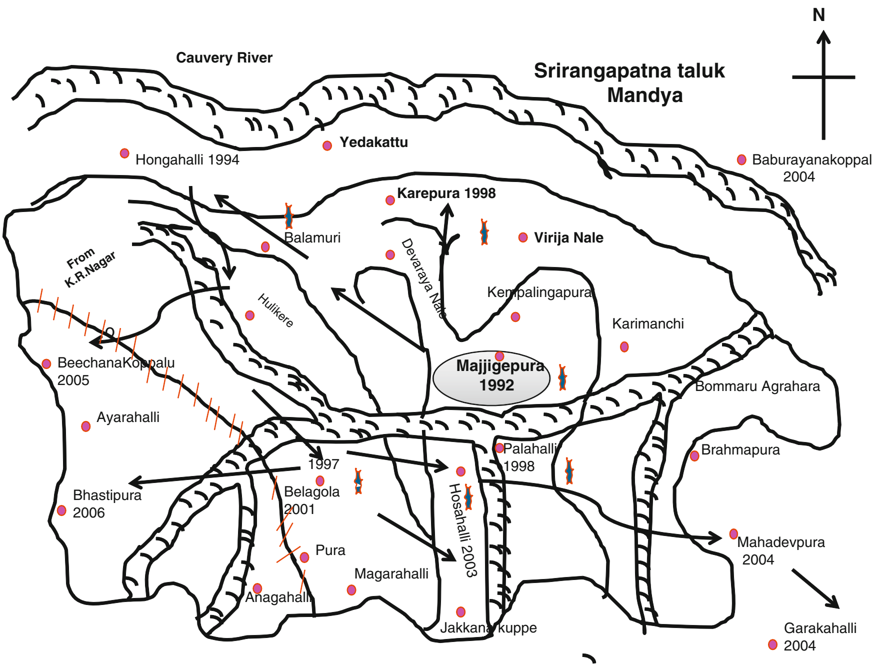


Fig. 1 A map (not drawn to scale) of Srirangapatna showing Hispa Beetle spread on paddy

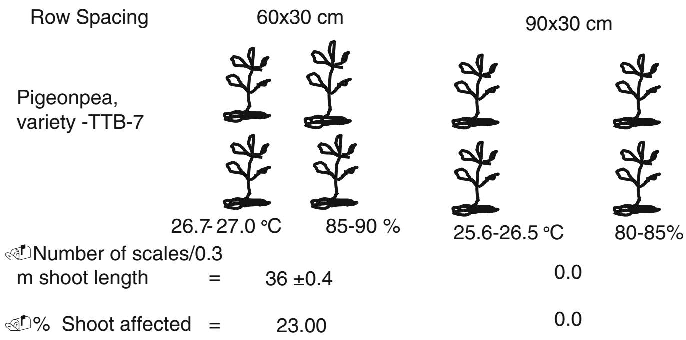


Fig. 2 Long brown scale infestation on pigeon pea in Bangalore in response to spacing

Table 2 Insect pests that would intensify on important agricultural crops by climate change in India

Crop	Insect pests
Cotton	Mealy bug, Phenacoccus solenopsis Tinsley
	Whitefly, Bemisia tabaci Gennadius
	Tobacco caterpillar, Spodoptera litura (Fabricius)
Wheat, Barley, Oats	Cereal aphids, Sitobion avenae (Fabricius)
	Rhapalosiphum maidis (Fitch), R.padi (Linnaeus)
	Schizaphis graminum (Rondani), Macrosiphum misanthi (Takahashi)
Rice	Brown planthopper, Nilaparvata lugens (Stal) White-backed planthopper, Sogatella furcifera (Harvath), Leaf folder, Cnaphalocricis medinalis (Guenee)
Pulse crops	Lepidopterous pod borers and coleopterous defoliators
Maize, Sorghum	Shootfly, Atherigona spp. Pyrilla, Pyrilla perpusilla (Walker) Stem borer, Chilo pertellus (Swinhoe) Tobacco caterpillar, S.litura
Oilseed crops	Cabbage caterpillar, Pieris brassicae (Linnaeus)
Vegetable crops	S.litura, Helicoverpa armigera (Hubner) Aphids, Whitefly, Leafminer, spider mites
Fruit crops	Fruit piercing moth, Eudocima materna, Mealy bugs

Source Arora and Dhawan (2011a, b)

3.2 *Review*

3.2.1 Density, Distribution and Population Dynamics

The reproductive capacity of insects is affected by moisture. But there are great differences in the capacity of different insects to tolerate conditions ranging from extreme dryness to near saturated environments. For example, incidence of Rice Hispa, *Dicladispa armigera* Olivier in Telangana region of Andhra Pradesh has increased in the last two decades due to prevailing dry situations. Increasing temperatures may result in a greater ability to overwinter in insect species limited

Table 3 Changing pest scenario in Tamil Nadu, South India due to climate change

SI. No.	Common/scientific name	Major pest		Impact
		Crops	Location	
1.	Serpentine leaf miner, *Liriomyza trifolii Burgess*	Solanaceous, leguminous, cucurbitaceous vegetables	Tamil Nadu	The infestation is severe on ornamental avenue trees. Spread to other states in India
2.	Coconut Eriophid Mite, *Aceria guerreronis* (Keifer)	Coconut	South India	It has caused heavy losses, still persisting as a major pest in certain pockets
3.	Spiralling Whitefly, *Aleurodicus dispersus Russell*	Cassava, chillies, guava, mulberry, banana, papaya, groundnut	South India	–
4.	Sugarcane woolly aphid, *Ceratovacuna lanigera Zehntner*	Sugarcane	Maharashtra, Karnataka and Tamil Nadu	–
5.	Papaya mealy bug, *Paracoccus marginatus Williams and Granarade Willink*	Cassava, papaya, eggplant, melons, hibiscus, pepper, tomato, mango, guava and mulberry	Tamil Nadu	Currently it enjoys wider spread distribution, but the populations are shrinking due to the inundative release of parasitoid *Acerophagus papayae*

Source Ramaraj (2009)

by low temperatures at higher latitudes, extending their geographical range (Elphinstone and Toth 2008). This may be true of the root grubs (*Holotrichia* and *Leucopholis* spp.) in parts of India. Many insects such as *H. armigera* and *Spodoptera litura* are migratory. These insects may well be adapted to exploit new opportunities by moving rapidly into new areas as a result of climate change (Sharma 2005).

Insects are sensitive to precipitation and are killed or removed from crops by heavy rains (e.g., aphid, leafhopper, whitefly and thrips) Jagadish et al. (2005). One would expect more frequent and intense precipitation events forecasted with climate change to negatively impact these insects. Other insects such as pea aphids are not tolerant to drought. Entomologists in India predict additional generations of important pest insects like Brown planthopper, leaf hoppers, aphids, thrips and whitefly as a result of increased temperatures, probably necessitating more insecticide applications to maintain populations below economic damage thresholds. With more insecticide applications the probability of insects developing resistance to insecticides will increase.

In Tamil Nadu and Karnataka, South India pests like leaf miner (*Liriomyza* sp.), whitefly (*Bemisia* sp.), woolly aphid (*Ceratovacuna lanigera*), mealy bug (*Paracoccus* sp. and *Planococcus* sp.) and mite (Eriophid, *Aceria* sp) (non-insect) have

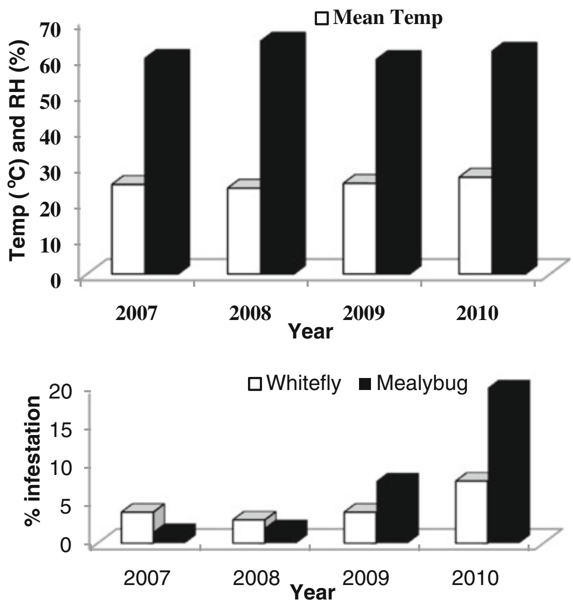


Fig. 3 Incidence of cotton mealy bug and whitefly in Faridkot, Punjab during 2007–2010 (*Source* Pandher et al. 2011)

increased. The reason for the increased incidence is not clear. But the higher pest incidence is related to increased temperature in the region (Table 3). In Faridkot, Punjab, North India infestation of cotton mealy bug and whitefly was related to temperature, rainfall and relative humidity (Fig. 3).

More than a dozen insect pest species like Serpentine leafminer (*Liriomyza trifolii* Burgess), Coffee berry borer (*Hypothenemus hampei* Ferrari), Papaya mealy bug (*Paracoccus marginatus* Williams), Spiralling whitefly (*Aleurodes dispersus* Russell), Erythrina gall wasp (*Erythrina* spp.) and Subabul psyllid (*Heteropsylla cubana* Crawford) have been introduced into cultivated ecosystems in South Karnataka from past two decades (1990–2010) and these are invasives having impacts on local crop productivity. These insect pests have expanded geographical range due to availability of susceptible host plants. Currently these pests are difficult to manage in wild and cultivated patches as there are no intimidating natural factors. Spatial shifts in distribution of crops under changing climatic conditions will also influence the distribution of insect pests in a geographical region (Parry and Carter 1989).

An increase of 2 °C will reduce the generation turnover of the bird cherry aphid, *Rhopalosiphum padi* (L.) by varying levels, depending on the changes in mean temperature (Morgan 1996). An increase of 1 and 3 °C will cause northward shifts in the potential distribution of the European corn borer, *Ostrinia nubilalis* (Hub.) up to 1,220 km, with an additional generation in nearly all regions where it is currently known to occur (Porter et al. 1991).

Sudden outbreaks of insect pests can wipe out certain crop species and encourage the invasion by exotic species (Kannan and James 2009). Some plant

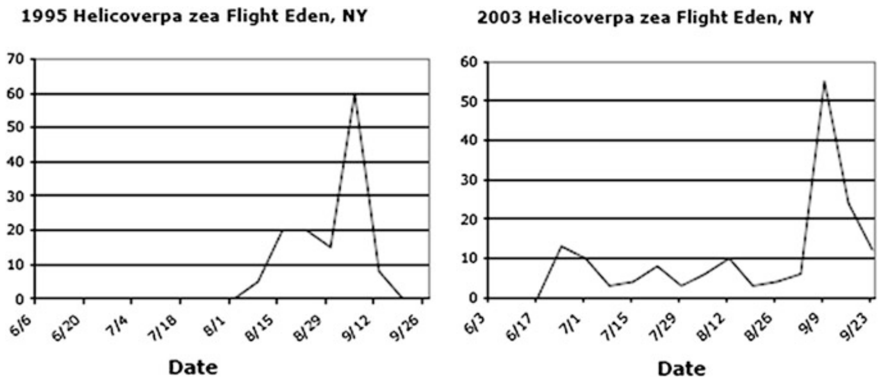


Fig. 4 Trap catch data indicating possible over wintering of corn earworm in western New York [*Source* Petzoldt and Seaman (2007)]

species may be unable to follow the climate change, resulting in extinction of species that are specific to particular hosts (Thomas et al. 2004). However, whether or not an insect pest would move with a crop into a new habitat will depend on environmental conditions e.g., populations of the corn earworm, *Heliothis zea* (Boddie) in North America might move to higher latitudes/altitudes, leading to greater damage on maize (Environmental Protection Act 1989). For all the insect species, higher temperatures, below the species upper threshold limit, will result in faster development and rapid increase in pest populations (Fig. 4).

In addition to the direct effects of temperature changes on development rates, improvement in food quality due to abiotic stress may result in dramatic increases in growth of some insect species (White 1984). While the growth of certain insect pests may be adversely affected (Maffei et al. 2007). Pest outbreaks are more likely to occur with stressed plants as a result of weakening of plants defensive system and thus, increasing the level of susceptibility to insect pests (Rhoades 1985).

Increased temperature will lead to earlier infestation of *Helicoverpa armigera* (Hub.) in North India (Sharma 2010), resulting in increased crop loss. Rising temperatures are likely to result in availability of new niches for insect pests. Temperature has a strong influence on the viability and incubation period of *H. armigera* eggs (Dhillon and Sharma 2007). Egg incubation period can be predicted based on day degrees required for egg hatching, which decreases with an increase in temperature from 10 to 27 °C, and egg age from 0 to 3 days (Dhillon and Sharma 2007). An increase of 3 °C in mean daily temperature would cause the carrot fly, *Delia radicum* (L.) to become active a month earlier than at present (Collier et al. 1991) in Europe. Temperature increases of 5–10 °C would result in completion of four generations each year, necessitating adoption of new pest control strategies.

Temperature is probably the single most important environmental factor influencing insects as it directly affects timing of diurnal activity patterns, account for genetic variations and inheritance of innate recognition of environmental signals, migratory routes and survival thresholds. Latitude affect temperature because the farther away one moves from the equator, the less direct sunlight one gets. At higher latitudes insects will move farther away from equator with less direct sunlight. Altitude affects temperature because atmosphere becomes thinner high up making it colder—air is thinner so there is less medium to transmit heat. Longitude doesn't affect temperature much. A state-of-art regional climate modeling system, known as PRECIS (Providing Regional Centre for Climate Studies) projects warming to be monotonously widespread over India. There will be substantial spatial differences in the rainfall changes (Rupa Kumar et al. 2006). These changes will considerably affect pest insects that require soil to complete life cycle.

Differences in the pattern of responses to temperature changes would disrupt synchronization in phenology between insects and host plants or natural enemies (Kiritani 2006). In Southern Karnataka on cotton and rice there is a shift observed from the leaf/fruit eating caterpillars to sucking pests in recent years. While monoculture and chemical pest management practices understood to have resulted in such pest shifts, climate change has also contributed for such shifts. For example on cotton there is a shift towards sucking pests (mealy bugs, jassids) and mirid bug, *Creontiodes biseratense* (Distant) particularly after the introduction of *Bt* cotton (Table 1). Similarly, aphid (*Aphis craccivora* Koch) incidence on groundnut in south Karnataka has increased in recent years. Thrips, *Scirtothrips dorsalis* Hood and yellow mites, *Lorryia formosa* Cooremann are increasingly observed on chillies now-a-days. Most of these sucking pests are also vectors of viral diseases. With increasing incidence of sucking pests, viral diseases are also increasing. For example, bud necrosis in groundnut, tobacco Streak Virus incidence on cotton and similar viral diseases in most of the fruit and vegetables crops (http://www.reuters.com/article).

Depending on the physiological adaptations of the concerned species, temperatures above or below optimum limits can prove lethal. Exposure to lethal high or low temperatures may result in instant killing or failure to grow and reproduce. Harmful effects of exposure to sub-lethal temperatures may be manifested at later critical stages like molting or pupation. For instance, in dry tracts of South Karnataka like in Berur, Hiriyur, Sira, Kadur and parts of Hassan and Chitradurga where onions are cultivated, incidence of thrips, *Thrips tabaci* Lindeman and diseases transmitted by it have increased. The pest has developed insecticide resistance against conventional insecticides and increased temperature effects are manifested in increased incidence.

3.2.2 Insect Diversity and Biodiversity

Arthropods particularly insects are sensitive to changes in climatic determinants. This is because insects occupy a wide variety of microhabitat niches. Monitoring of terrestrial arthropods can provide early warnings of ecological changes due to climate change. Documented data on monitoring and arthropod diversity in relation to global warming is meager in India. Sharma (2010) reviewed the literature on the impact of global warming on arthropods and extinction of species. In view of the large scale cultivation and mechanization there has been a decline of agrobiodiversity in India, in general. Climate change may be another factor impinging on arthropod diversity. Arthropods can be used as indicators of environmental change more rapidly than the vertebrates (Scherm et al. 2000; Gregory et al. 2009). Realistic information on arthropod diversity must be integrated into policy planning and management practices if ecosystems are to be managed for use by future generations. Ecosystem baselines that document arthropod species assemblages in a manner comparable in space and time are key to interpretation and implementation of strategies designed to mitigate the effects of global warming and climate change on biodiversity.

Main effects of climate change and pollution on arthropod communities result in decreased abundance of decomposers and predators, and increased herbivory, which may have negative consequences for structure and services of ecosystems. The incidence of leaf hoppers (species of *Amritodus and Idioscopus*) on mango (*Mangifera indica*) and whitefly, *Bemisia tabaci* on ornamental plants and vegetable crops has considerably increased in south India with depauparated arthropod faunas. Similarly, in paddy fields injudicious application of insecticides coupled with global warming (liberation of methane, CO_2 etc. with increased temperature), the arthropod diversity has declined (Myers et al. 2000; Earn et al. 2000). Biodiversity is continually transformed by a changing climate. Conditions change across the face of the planet. But now a type of climate change, brought about by human activities, is being added to this natural viability, threatening to accelerate the loss of biodiversity (Peters and Lovejoy 1992).

At the same time exotic species have been introduced beyond their natural biogeographic boundaries and a host of chemical for which many species have no evolutionary experience have been released (Mooney and Hobbs 2000). For instance, more than a dozen insect pest species like serpentine leafminer (*Liriomyza trifilii* Burbess), coffee berry borer (*Hypothenemus hampei* Ferrari), papaya mealy bug (*Paracoccus marginatus* Williams), spiraling whitefly (*Aleurodes disperses* Russell), Erythrina gall wasp (*Erythrina* spp) and others have seen introduced into cultivated ecosystems in southern Karnataka from the past two decades (1990–2010) and these are invasives having impacts on local biodiversity. The synergy between climate change and habitat fragmentation is the most threatening aspect of climate change for biodiversity, and is a central challenge facing conservation (Peters and Lovejoy 1992; IPCC 2001).

Since climate change has recently become a global issue, impacts on biodiversity are yet to be documented. However, the impact of climate change has become very evident in marine ecosystems. Tropical developing countries like India can examine invertebrates viz., centipedes, millipedes and earthworms and associate micro flora like litchens and algae. The impacts of climate change on earth's natural resources are manifested in several ways. For instance, composition of vegetation along the routes the birds fly have drastically changed. Climate change has also affected soil fauna. It has been estimated that with a 2 °C increase insects might experience one to five additional life cycles per season (Yamamura and Kiritani 1998; Hunter 2001). So, one can use insects as indicator species for detecting climate change.

Biodiversity plays an important role in abundance of insect pests and their natural enemies (Alteiri 1994; Sharma and Waliyar 2003). There is a need to increase functional diversity in agro-ecosystems vulnerable to climate change to improve system resilience and decrease the extent of losses due to insect pests (Newton et al. 2009). However, changes in cropping patterns as a result of climate change will drastically affect the balance between insect pests and their natural enemies (Sharma and Waliyar 2003; Newton et al. 2009; Maiorano et al. 2008).

3.2.3 Host Plant Resistance

In tropical regions, cultivation of insect pest resistant/tolerant plants form the most ideal method of pest suppression. This is because it obviates the need for insecticide applications vis-à-vis conserves beneficials. However, climate change may modify the interactions between the insect pests and their host plants (Bale et al. 2002; Sharma 2010; Arora and Dhawan 2011a, b). Global warming may also change the flowering and fruiting times, leading to ecological consequences such as introduction of new insect pests, and attaining of a pest status by non-pest insects (Parmesan and Yohe 2003; Fitter and Fitter 2002; Willis et al. 2008). Global warming may result on breakdown of resistance to certain insect pests. In Karnataka, South India, cultivation of rice cultivars of IET series resistant to Brown planthopper, resulted in breakdown of resistance within two years. Sorghum varieties exhibiting resistance to sorghum midge, *Stenodiplosis sorghicola* (Coq.) in India became susceptible to this pest under high humidity and moderate temperatures in Kenya (Sharma et al. 1999). There will be increased impact on insect pests which benefit from reduced host defenses as a result of stress caused by the lack of adaptation to sub-optimal climatic conditions. Chemical composition of plant species change in direct response to biotic and abiotic stresses as a result, their tissues become less suitable for growth and survival of insect pests (Sharma 2002). However, problems with new insect pests will occur if climatic changes favor the introduction of insect susceptible cultivars or crops. For example, cultivation of photoinsensitive field beans (*Lablab niger*) hybrids in south Karnataka exacerbated the problem due to lepidopterous, pulse crop pod borers, mainly *H. armigera*. The introduction of new crops and cultivars to take advantage of the new environmental conditions is one of the adaptive methods suggested as a possible response to climate change (Parry and Carter 1989). Insect—host plant interactions will change in response to the effects of CO_2 on nutritional quality and secondary metabolites of the host plants. Increased levels of CO_2 will enhance plant growth, but may also become vulnerable to select phytophagous insects (Gregory et al. 2009).

In atmospheres experimentally enriched with CO_2, the nutritional quality of leaves declined substantially due to dilution of nitrogen by 10–30 % (Coley and

Markham 1998; Coviella and Trumble 1999). Increased CO_2 may also cause a slight decrease in nitrogen-based defenses (e.g., alkaloids) and a slight increase in carbon-based defenses (e.g., tannins). Acidification of water bodies by carbonic acid (due to high CO_2) will also affect the floral and faunal diversity (Gore 2006). Lower foliar nitrogen content due to CO_2 causes an increase in food consumption by the herbivores up to 40 %, while unusually severe drought increases the damage by insect species such as spotted stem borer, *Chilo partellus* in sorghum (Sharma 2005). Endophytes, which play an important role in conferring tolerance to both abiotic and biotic stresses in grasses, may also undergo a change in response to disturbance in the soil due to climate change (Newton et al. 2009).

3.2.4 Transgenic Crops for Pest Management

Environmental factors such as soil moisture, soil fertility and temperature have strong influence on the expression of *Bacillus thuringiensis* (*Bt*) toxin proteins deployed in transgenic plants (Sachs et al. 1998). Cotton bollworm, *Heliothis virescens* (F.) destroyed *Bt*-transgenic cottons due to high temperatures in Texas, USA (Kaiser 1996). Similarly, *H. armigera* and *H.elicoverpa punctigera* (Wallen.) destroyed the *Bt*-transgenic cotton in the second half of the growing season in Australia because of reduced production of *Bt* toxins (Hilder and Boulter 1999). Cry1Ac levels in transgenic plants decrease with the plant age, resulting in greater susceptibility of the crop to insect pests (Sachs et al. 1998; Greenplate et al. 2000; Sharma and Ortiz 2000; Adamczyk et al. 2001; Kranthi et al. 2005). It is important to understand the effects of climate change on the efficacy of transgenic plants for pest management.

3.2.5 Beneficial Insects

Relationships between insect pests and their natural enemies change as a result of global warming, resulting in both increases and decreases in the status of individual pest species. Changes in temperature will also alter the timing of diurnal activity patterns of different groups of insects (Young 1982), and changes in interspecific interactions could also alter the effectiveness of natural enemies for pest management (Hill and Dymock 1989). Quantifying the effect of climate change on the activity and effectiveness of natural enemies for pest management will be a major concern in future pest management programs. The majority of insects are benign to agro-ecosystems, and there is considerable evidence to suggest that this is due to population control through interspecific interactions among insect pests and their natural enemies—pathogens, parasites, and predators (Price 1987). Oriental armyworm, *Mythimna separata* (Walk.) populations increase during extended periods of drought (which is detrimental to the natural enemies), followed by heavy rainfall because of the adverse effects of drought on the activity and abundance of the natural enemies of this pest (Sharma 2002).

Aphid abundance increases with an increase in CO_2 and temperature. However, the parasitism rates remain unchanged in elevated CO_2. Temperatures up to 25 °C will enhance the control of aphids by coccinellids (Freier and Triltsch 1996). Temperature not only affects the rate of insect development, but also has a profound effect on fecundity and sex ratio of parasitoids (Dhillon and Sharma 2008, 2009). The interactions between insect pests and their natural enemies need to be studied carefully to devise appropriate methods for using natural enemies in pest management. In contrast, to other insect groups such as leaf chewers, populations of most phloem-feeders like aphids may not be negatively affected by increased CO_2 concentrations in the future. The reasons for this difference include the possibility that aphids may be able to compensate for changes in host plant quality by altering feeding behaviour or by synthesizing amino acids (Hughes and Bazzaz 2001).

Rise in temperature may have a negative effect on the delicate natural enemies and pest relationships such as hymenopteran parasitoids and small predators. It has been estimated that with a 2 °C increase, insects might experience to give additional life cycles per season, especially species like Brown planthopper. Brown planthopper is 17 times more tolerant to 40 °C than its predator *Cyrtorrhynus lividipepennis* Reuter. But not wolf spider *Paradosa pseudoannulata* (Boesenberg and Strand) (Ramanjaneyulu and Raghunath 2009), which is tolerant to 40 °C.

Satpathi (2011) reported that the average atmospheric temperature was 2 °C higher in rainy season of 2010 than the previous years. The larvae of ephemeropteran insects and mosquitoes cannot build up population in hot climate. So, indirectly it affects the growth and development ofthere insects. Dabhi et al. (2011) reported that the correlation coefficient between the activity of *Bracon hebetor* Say and weather parameters was significant. There was negative association between the maximum temperature and adult activity during 2008 ($r = -0.310^*$) and 2009 (-0.337^*).

Impact of climate change on plant pollinators is sparse but more critical from ecological and economic standpoints. There is a general paucity of long term climatic data and its impact on pollinators in developing countries especially India (Inoue 1993). However, some insight into the pollinator system in apple orchards of western Himalayas is available. Regarding the decline of apple production, they emphasized technical solutions. For instance, it was iterated time and again that one of the driving forces behind the present crisis was the lack of pollinizers. The official recommendation is that pollinizers should cover about 20 % of any orchard. Scientists said that most of the trees which serve as pollinizers, such as Golden Delicious, had been chopped down and replaced with commercially lucrative varieties like Red Golden. However, the typical farmer responded to us in interviews that the number of pollinizers had decreased prior to the decline in apple performance. Scientists and local farmers were clearly not looking at the problem equivalently (Neeraj and Robert 2001).

In April, late cold can delay blossoming and reduce the pollination activity of bees (Abbott 1984). Also if it rains in this period, there is a risk that pollen will be washed away from plants. In addition, late snow affects the process of pollination indirectly; a relative immobilization of bees is triggered due to low temperatures brought about by late snowfall. Increasing incidence of pest and disease comprises a ecology and different climate change has played a vital role. Himalayan honeybee *Apis cerana*, endemic to the area, starts foraging at temperatures as low as 7 °C, where as *Apis mellifera*, which has been introduced over the last 10 years, begins at around 13 °C.

In tropical forests an overwhelming majority of tropical forest trees are animal-pollinated, and many, if not most, species are bee-pollinated. The effects of increased level of CO_2, elevated temperature, or changes in the length of dry season on pollinating insects are not well documented. Increased drought, however, is known to lower population densities of bees that use moist habitat as nesting sites. Decline in the number of nests associated with El Nino years has also been reported for stingless bees in Southeast Asia. Thus drought may reduce floral resources as well as nesting sites for insect- pollinators, further decreasing the reproductive output (Bawa and Dayanandan 1998; Frankie et al. 1993; Howe 1993; Feinsinger 1983).

3.2.6 Biopesticides and Synthetic Insecticides

There will be an increase in variability in insect damage as a result of climate change. Higher temperatures will make dry seasons drier, and conversely, may increase the amount and intensity of rainfall, making wet seasons wetter than at present. Natural plant products, entomopathogenic viruses, fungi, bacteria, and nematodes, and synthetic pesticides are highly sensitive to the environment. Increase in temperatures and UV radiation, and a decrease in relative humidity may render many of these control tactics less effective. Such an effect will be more pronounced on natural plant products and the biopesticides (Isman 1997). Rapid dissipation of insecticide residues due to increases in temperature and precipitation will require more frequent application of insecticides. Therefore, there is a need to develop appropriate strategies for pest management.

3.2.7 Pest Management Practices

The relationship between crop protection costs and the resulting benefits will change as a result of climate change. This will have a major bearing on economic thresholds, as greater variability in climate will result in variable impact of pest damage on crop yields. Increased temperatures and UV radiation, and low relative humidity may render many of these control tactics to be less effective and therefore, there is a need to:

- Predict and map trends of potential changes in geographical distribution. Study how climatic changes will affect development, incidence, and population dynamics of insect pests.
- Understand the influence of climate change on species diversity and cropping patterns, their influence on abundance of insect pests and their natural enemies.

- Understand the changes in expression of resistance to insect pests. Identify stable sources of resistance and pyramid the resistance genes in commercial cultivars.
- Study the effect of climate change on the efficacy of transgenic crops.

Assess the efficacy of various pest management technologies under diverse environmental conditions. A number of cultural practices used by farmers could be affected by changes in climate—although it is not clear whether these practices would be helped, hindered or not affected by the anticipated changes. Using crop rotation as an insect management strategy could be less effective with earlier insect arrival or increased overwintering of insects. However, this could be balanced by changes in the earliness of crop planting times, development and harvest. Row covers for insect exclusion might have to be removed earlier to prevent crop damage by excessive temperatures under the covers—would the targeted early insects also complete their damaging periods earlier or be ready to attack when the row covers were removed?

3.2.8 What Farmers Can Do?

Farmers should keep in mind that climate change is likely to be a gradual process that will give them some opportunity to adapt. It is not precisely understood how climate changes will affect crops, insects, diseases, and the relationships among them. If climate is warmer, increases in crop yields offset losses to pests, or will losses to pests outweigh yield advantages from warmer temperatures? It is likely that new pests will become established in more areas and be able to attack plants in new regions. Farmers who closely monitor the occurrence of pests in their fields and keep records of the severity, frequency and cost of managing pests over time will be in a better position to make decisions about whether it remains economical to continue to grow a particular crop or use a certain pest management technique. If more insecticide applications are required to grow a particular crop, farmers will need to carefully evaluate whether growing that crop remains economical. Those farmers who make the best use of the basics of integrated pest management (IPM) such as field monitoring, pest forecasting, record keeping and choosing economically and environmentally sound control measures will be most likely to be successful in dealing with the effects of climate change. The most effective way to address climate change is to adopt a sustainable development pathway by shifting to environmentally sustainable technologies such as promotion of energy efficiency, renewable energy, forest conservation, reforestation, water conservation and organic farming. The issue of highest importance to developing countries is to reduce the vulnerability of natural and socio-economic systems to the projected climate change (Satheye et al. 2006).

Building farmers knowledge and skills in making best use of local resources and natural processes and community action are urgently required. Natural ecological balance mould ensure that pests do not reach a critical numbers in the field that endangers the yield. Nature can restore such a balance if it is not meddled with too much. In India in many states such initiative implemented through Federations of Women Self Groups across the states in may districts in more than thousands villages covering lakhs of acres in the name of 'Non Pesticidal Management' has shown that such eco-approaches can bring in both ecological and economic benefits to farmers. This program was started in 2004–2005 with technical support from Centre for Sustainable Agriculture and Financial and Administrative support from Society for Elimination of Rural Poverty (SERP). The learning from this program are now considered by the 'National Mission on Sustainable Agriculture' as part of National Action Plan on Climate Change to be implemented across the country during the 11th and 12th five year plans.

4 Conclusions

Studies on climate change in general are at infant stage in the Indian subcontinent and Southeast Asia as a whole. The Indian subcontinent embraces countries that share similar natural resources, climatogeographic conditions (tropical/subtropical), socioeconomic conditions, agrobiodiversity and are close by. Therefore climatic studies in India would likely to impact in almost same way as for other countries in the continent. A coordinated network on climate change to study the issue in its entirety is mooted in continent as well as in Asia. In South Karnataka Brown Planthopper, hispa beetle, long brown scale, pegionpea podborers and sucking insect pest viz, whitefly, leafhoppers and thrips seemed to have impacted by climate change. The lepidopterous borer *H.armigera* is going to be more severe on crops in North India. Suggestions are advanced to mitigate the impacts of climate change on pest management in cultivated ecosystems and on biodiversity in general in India. The initiatives of Government of India and private sector in this direction are urgently warranted.

Acknowledgments The Authors are thankful to the authorities of the University of Agricultural Sciences, Bangalore.

References

Abbott DL (1984) The apple tree: physiology and management. Grower Books, London

Adamczyk JJ Jr, Adams LC, Hardee DD (2001) Field efficacy and seasonal expression profiles for terminal leaves of single and double *Bacillus thuringiensis* toxin cotton genotypes. J of Econ Ento 94:1589–1593

Altieri MA (1994) Biodiversity and pest management in agroecosystems. Haworth Press, New York, p 185

Arora R, Dhawan AK (2011) Climate change and insect pest management: recent trends in integrated pest management. In: Dhawan AK, Singh B, Arora R, Bhullar MB (eds) pp 77–88

Arora R, Dhawan AK (2011) Climate change and insect pest management, recent trends in integrated pest management, 3rd insect science congress, 20th April 2011, PAU, Ludhiana, India, pp 77–88

Bale JS, Masters GJ, Hodkinson ID, Awmack C, Bezemer TM, Brown VK, Butterfield J, Buse A, Coulson JC, Farrar J, Good JE, Harrington GR, Hartley S, Jones TH, Lindroth RL, Press MC, Symrnioudis I, Watt AD, Whittaker JB (2002) Herbivory in global climate change research: direct effects of rising temperatures on insect herbivores. Glob Change Biol 8:1–16

Bawa KS, Dayanandan S (1998) Global Climate Change And Tropical Forest Genetic Resources, ClimaticChange 39: 473–485.

Coley PD, Markham A (1998) Possible effects of climate change on plant/herbivore interactions in moist tropical forests. Climatic Change 39:455–472

Collier RH, Finch S, Phelps K, Thompson AR (1991) Possible impact of global warming on cabbage root fly (*Delia radicum*) activity in the UK. Ann Appl Biol 118:261–271

Coviella C, Trumble J (1999) Effects of elevated atmospheric carbon dioxide on insect plant interactions. Conserv Biol 13:700–712

Dabhi MR, Korat DM, Borad PK (2011) Seasonal abundance of *Bracon hebetor* Say in relation to temperature and relative humidity. Insect Environ 16(4):149–150

Dhaliwal GS, Arora R, Dhawan AK (2004) Crop losses due to insect pests in Indian agriculture: an update. Indian J Ecology 31:1–7

Dhaliwal GS, Jindal V, Dhawan AK (2010) Insect pest problems and crop losses: changing trends. Indian J Ecol 37:1–7

Dhillon MK, Sharam HC (2007) Influence of temperature and Helicoverpa armigera food on survival and development of the parasitoid, Campoletis chlorideae. ICRISAT, Patencheru, A.P

Dhillon MK, Sharma HC (2008) Temperature and *Helicoverpa armigera* food influence survival and development of the ichneumonid parasitoid, *Campoletis chlorideae*. Indian J Plant Prot 36:240–244

Dhillon MK, Sharma HC (2009) Temperature influences the performance and effectiveness of field and laboratory strains of the ichneumonid parasitoid, *Campoletis chlorideae*. Biocontrol 54:743–750

Earn DJ, Levin SA, Rohani P (2000) Coherence and conservation. Science 290:1360–1364

Elphinstone J, Toth IK (2008) *Erwinia chrysanthemi* (*Dikeya* spp.)—the facts. Oxford, UK, Potato Council

Environment Protection Agency (EPA) (1989) The potential effects of global climate change on the United States. National studies, vol 2. Review of the report to congress, US Environmental Protection Agency, Washington, p 261

Feinsinger P (1983) Coevolution and pollination. In: Futuyama DJ, Slatkin M (eds) Coevolution. Sinauer Associates, Sunderland, pp 282–310

Fitter AH, Fitter RS (2002) Rapid changes in flowering time in British plants. Science 296:1689–1691

Frankie GW, Newstorm L, Vinson SB, Barthell JF (1993) Nesting habitat preferences of selected *Centris* bee species in Costa Rican dry forest. Biotropica 25:322–333

Freier B, Triltsch H (1996) Climate chamber experiments and computer simulations on the influence of increasing temperature on wheat-aphid-predator interactions. Aspects Appl Biol 45:293–298

Gore A (2006) An inconvenient truth: the planetary emergency of global warming and what we can do about it. Rodale Publisher, Emmaus

Greenplate JT, Penn SR, Shappley Z, Oppenhuizen M, Mann J, Reich B, Osborn J (2000) Bollgard II efficacy: quantification of total lepidopteran activity in a 2-gene product. In: Dugger P, Richter D (eds) Proceedings of Beltwide cotton conference. Memphis, Tennesse, USA, National Cotton Council of America. pp 1041–1043

Gregory PJ, Johnson SN, Newton AC, Ingram JSI (2009) Integrating pests and pathogens into the climate change/food security debate. J Exp Bot 60:2827–2838

Hamilton JG, Dermody O, Aldea M, Zangerl AR, Rogers A, Berenbaum MR, Delucia E (2005) Anthropogenic changes in troposphereic composition increase susceptibility of soybean to insect herbivory. Environ Entom 34(2):479–485

Hilder VA, Boulter D (1999) Genetic engineering of crop plants for insect resistance—a critical review. Crop Prote 18:177–191

Hill MG, Dymock JJ (1989) Impact of climate change: agricultural/horticultural systems. DSIR entomology division submission to the New Zealand climate change program. Auckland, New Zealand: Department of Scientific and Industrial Research. pp 16

Howe HF (1993) Specialized and generalized dispersal systems: where does "the paradigm" stand? Vegetatio 107(108):3–13

Hughes L, Bazzaz FA (2001) Effects of elevated CO_2 on five plant-aphid interactions. Entomol Exp Appl 99:87–96

Hunter MD (2001) Effects of elevated atmospheric carbon dioxide on insect-plant interactions. Agric Forest Entomol 3: 153–159. http://www.reuters.com/article

Inoue K (1993) Evolution of mutualism in plantpollinator interactions on Islands. J Biosci 18:525–536

IPCC (2001) Climate change 2001: the scientific basis. In: Houghton JT et al (eds) Contribution of working group I to the third assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Isman MB (1997) Neem and other botanical pesticides: barriers to commercialization. Phytoparasitica 25:339–344

Jagadish KS, Nagaraju, N, Shadakshari, YG, Puttarangaswamy KT (2005) Faunal composition of thrips infesting sunflower, Insect Environ 11(3): 114–115

Kaiser J (1996) Pests overwhelm Bt cotton crop. Nature 273:423

Kannan R, James DA (2009) Effects of climate change on global diversity: a review of key literature. Tropical Ecology 50:31–39

Kiritani K (2006) Predicting impacts of global warming on population dynamics and distribution of arthropods in Japan. Popul Ecol 48:5–12

Kogan M, Herzog DC (eds) (1980) Sampling methods in soybean entomology. Springer, New York, p 587

Kranthi KR, Naidu S, Dhawad CS, Tatwawadi A, Mate K, Patil E, Bharose AA, Behere GT, Wadaskar RM, Kranthi S (2005) Temporal and intra-plant variability of Cry1Ac expression in Bt-cotton and its influence on the survival of the cotton bollworm, *Helicoverpa armigera* (Hubner) (Noctuidae: Lepidoptera). Curr Sci 89:291–298

Maffei ME, Mithofer A, Boland W (2007) Insects feeding on plants: rapid signals and responses proceeding induction of phytochemical release. Phytochemistry 68:2946–2959

Maiorano A, Blandino M, Reyneri A, Vanara F (2008) Effects of maize residues on the *Fusarium* spp. infection and deoxynivalenol (DON) contamination of wheat grain. Crop Protection 27:182–188

Mooney HA, Hobbs RJ (2000) Invasive species in a changing world. Island press, Washington

Morgan D (1996) Temperature changes and insect pests: a simulation study. Aspects of Applied Biology 45:277–283

Myers N, Mittermeier RA, Mittermeier C, Da Fonseca GAB, Kent J (2000) Biodiversity hotspotes for conservation priorities. Nature 403:853–858

Narasimhamurthy TN, Doddabasappa B, Shashank PR, Chakravarthy AK (2011) Incidence of long brown scale, *Coccus longulus* (Douglas) (Hemiptera: Coccidae) on pigeonpea. Current Biotica 4(4):478–481

Neeraj V, Robert ER (2001) Climate change in the Western Himalayas of India: a study of local perception and response. Clim Res 19:109–117

Newton AC, Begg G, Swanston JS (2009) Deployment of diversity for enhanced crop function. Ann Appl Biol 154:309–322

Pandher S, Singh S, Gill JS (2011) Whitefly and mealybug outbreaks in cotton: climate threat or changing host patterns. Insect Environ 17(1):10–12

Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37–42
Parry ML, Carter TR (1989) An assessment of the effects of climatic change on agriculture. Climatic Change 15:95–116
Peters RL, Lovejoy TE (1992) Global warming and biological diversity. Yala University Press, London
Petzoldt C, Seaman A (2007) Climate change effects on insects and pathogens. Climate change and agriculture: promoting practical and profitable responses, pp 11
Porter JH, Parry ML, Carter TR (1991) The potential effects of climate change on agricultural insect pests. Agric For Meteorol 57:221–240
Price PW (1987) The role of natural enemies in insect populations. In: Barbosa P, Schultz JC (eds) Insect outbreaks. Academic Press, San Diego, pp 287–312
Ramanjaneyulu GV, Raghunath TAVS (2009) Pest shifts are observed with changes in the ecological balance. The Hindu survey of Indian agriculture. pp 115–118
Ramaraj AP (2009) Regional climate models (PRECIS) for downscaling of climate change scenarios for crop simulations. M.Sc. Thesis, Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore
Rhoades DF (1985) Offensive-defensive interactions between herbivores and plants: their relevance in herbivore population dynamics and ecological theory. American Naturalist 125:205–238
Rupa Kumar K, Sahai AK, Krishna Kumar K, Patwardhan SK, Mishra PK, Revadekar JV, Kamala K, Pant GB (2006) High-resolution climate change scenarios for India for the 21st century. Curr Sci 90(3):334–345
Sachs ES, Benedict JH, Stelly DM, Taylor JF, Altman DW, Berberich SA, Davis SK (1998) Expression and segregation of genes encoding Cry1A insecticidal proteins in cotton. Crop Sci 38:1–11
Sathaye J, Shukla PR, Ravindranath NH (2006) Climate change, sustainable development and India: global and national concerns. Curr Sci 90(3):314–325
Satpathi CR (2011) Probable effect of global warming on the dragonfly, *Orthetrum Sabina Sabina* (Drury) in Eastern India. Insect Environ 16(4):158–159
Scherm H, Sutherst RW, Harrington R, Ingram JSI (2000) Global networking for assessment of impacts of global change on plant pests. Environ Pollut 108:333–341
Sharma HC (2002) Host plant resistance to insects: principles and practices. In: Sarath Babu B, Varaprasad KS, Anitha K, Prasada Rao RDVJ, Chandurkar PS (eds) Resources management in plant protection, vol 1. Plant Protection Association of India, Hyderabad, Andhra Pradesh, India, p 37–63
Sharma HC (ed) (2005) *Helicoverpa* management: emerging trends and strategies for future research. New Delhi, India: Oxford & IBH, and Science Publishers, USA, pp 469
Sharma HC (2010) Effect of climate change on IPM in grain legumes. In: 5th international food legumes research conference (IFLRC V), and the 7th European conference on grain legumes (AEP VII), Anatalaya, Turkey, 26–30 April 2010
Sharma HC, Ortiz R (2000) Transgenics, pest management and the environment. Curr Sci 79:421–437
Sharma HC, Waliyar F (2003) Vegetational diversity, arthropod response, and pest management. In: Waliyar F, Collette L, Kenmore PE (eds) Beyond the gene horizon: sustaining agricultural productivity and enhancing livelihoods through optimization of crop and crop-associated diversity with emphasis on semi-arid tropical agroecosystems. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, pp 66–88
Sharma HC, Mukuru SZ, Manyasa E, Were J (1999) Breakdown of resistance to sorghum midge, *Stenodiplosis sorghicola*. Euphytica 109:131–140
Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BFN, de Siqueira MF, Grainger A, Hannah L, Hughes L, Huntley B, van Jaarsveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Peterson AT, Phillips OL, Williams SE (2004) Extinction risk from climate change. Nature 427:145–148

White TCR (1984) The abundance of invertebrate herbivores in relation to the availability of nitrogen in stressed food plants. Oecologia 63:90–105

Willis CG, Ruhfel B, Primack RB, Miller, Rushing AJ, Davis CC (2008) Phylogenetic patterns of species loss in Thoreau's woods are driven by climate change. Proc Natl Acad Sci 105: 17029–17033 (USA)

Yamamura K, Kiritani K (1998) A simple method to estimate the potential increase in the number of generations under global warming in temperate zones. Appl Ent Zool 33:289–298

Yelshetty S, Sidde Gowda DK, Lingappa S, Patil BV (2003) Thogari kayi korakada bhadheya maleyadharitha munsuchne, Krishika Bhandhu 1(3): 38

Young AM (1982) Population biology of tropical insects. Plenum Press, New York, p 511

Arsenic Groundwater Contamination Related Socio-Economic Problems in India: Issues and Challenges

Barun Kumar Thakur, Vijaya Gupta and Utpal Chattopadhyay

1 Introduction

Water is increasingly becoming a scarce resource, both in terms of quantity as well as quality. Due to increasing population growth, urbanization and rapid industrialization, surface water and groundwater in many places have become scarce resources. Over the years, excess exploitation of both groundwater and surface water resources has caused serious problems in water pollution, as almost 70 per cent of total surface water resources and growing percentages of groundwater are contaminated by biological, toxic, organic and inorganic pollutants (MOWR 2000). Agriculture and allied activities still dominate the overall impact on water quality but higher incidence of severe contamination in urban area is more than rural area due to industrial and domestic sector water uses. The rapid depletion of groundwater, due to excess extraction for various uses, leads to groundwater contamination problem which affects more than 500 million people spread across 200 districts and 23 states of India (MOWR 2010a). Contaminations are caused by geogenic, biogenic and anthropogenic sources. The geogenic contaminants include salinity, iron, fluoride and arsenic which have long term impact on health and cause severe diseases. Arsenic contaminated drinking water causes skin pigmentation and skin cancer, and long-term use of fluoride in drinking water leads to

B. K. Thakur (✉)
Research Scholar, National Institute of Industrial Engineering (NITIE),
Mumbai 400087, India
e-mail: barunsandilya@gmail.com

V. Gupta
Associate Professor, National Institute of Industrial Engineering (NITIE),
Mumbai 400087, India
e-mail: Vijaya298@gmail.com

U. Chattopadhyay
Assistant Professor, National Institute of Industrial Engineering (NITIE),
Mumbai 400087, India
e-mail: utuchat@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_10, © Springer-Verlag Berlin Heidelberg 2013

tooth decay and crippled bones. Therefore, the degraded water quality can contribute to water scarcity as it limits its availability for both human use and the ecosystem (MOEF 2009).

Arsenic contamination in groundwater is a global problem. The delinquent of arsenic in drinking water is well recognized globally and measures have been taken to mitigate it (Roy 2007, 2008; Ghosh et al. 2007; Rahman et al. 1999). More than 150 million people are affected worldwide by arsenic contamination which constitutes 70 countries, out of which 50 million people in Bangladesh and 30 million people in India are at risk[1] (Ravenscroft et al. 2008). Arsenic in water can cause serious skin problems in the form of Melanosis and Keratosis at the initial stage and if left untreated it leads to skin cancer at the advanced stage.

A large number of studies are available on arsenic in drinking water and its affect on human health.[2] Studies show that arsenic in drinking water can cause cancer (Canter 1997; Chakraborti et al. 2006; Chakraborti and Saha 1987). Arsenic can cause problems in the reproductive system, birth defects and harm the central and peripheral nervous system (Canter 1997). Arsenic acquaintance during pregnancy can adversely affect several reproductive endpoints (Mukherjee 2006; Roy et al. 2004). Some of the studies also estimated the economic costs imposed by arsenic health problems. Study carried out by Roy (2008) and Khan (2007) was based on the economic cost imposed on households due to the arsenic contamination in water. The studies found that poor households incurred the largest number of sick days and suggest that children and women are more prone to diseases caused by long term exposure to arsenic. The fertilizers used for agricultural purpose also cause arsenic contamination. A study by Brammer (2008) found that arsenic-polluted water used for agriculture is a health hazard for the people eating food from the crops irrigated in the areas of India, Bangladesh and Nepal.

This study tries to emphasize on the preliminary understanding of socio-economic problems due to arsenic contaminated groundwater and is organized in the following way. Section 2 deals with causes and sources of water pollution and arsenic contamination. Section 3 presents the global and Indian arsenic scenario. Section 4 tries to link the depletion of natural resources and its levels, and how it has led to the current status over the years. In this section, we will also try to identify why inhabitants of Bihar and West Bengal are facing drinking water problems, irrespective of abundant availability of fresh water resources in the

[1] World Health Organization (WHO) study in 2010, estimates 130 million people are globally affected by arsenic contamination in groundwater. In 2008, a study by Ravenscroft et al. suggested that more than 150 million people worldwide are affected by arsenic contamination of ground water. More than 60 per cent of the people globally affected by groundwater arsenic contamination reside in India (mainly West Bengal, Bihar, Jharkhand and some parts of Uttar Pradesh and north eastern states) and Bangladesh, while Nepal accounted for around 2.5 million people. The real number will be more in the future as the effect of arsenic contamination can be seen in the long run. In recent times, arsenic related health concerns have been seen in Bihar.

[2] Some of the studies have been carried out on arsenic contaminated water are Chakraborti and Saha (1987), Canter (1997), Jain and Ali (2000), Saxena et al. (2004), Chakraborti et al. (2006), Ghosh et al. (2007), Roy Joyshree (2007, 2008), Khan (2007), and Khan and Haque (2011).

states. Section 5 is on the socio-economic problems arising due to the groundwater arsenic contamination. Health problems due to contaminated drinking water and agricultural productivity due to irrigated contamination water have been covered in details. Section 6 comprises of concluding remarks.

2 Causes and Sources of Water Pollution and Arsenic Contamination

Pollution and contamination of the environment is becoming a common occurrence and it is difficult to make the distinction between pollution and contamination. Egboka et al. (1989) makes an attempt to differentiate between pollution and contamination, and defined it as *Pollution is regarded as occurring in such high dosages or concentrations that it renders the polluted medium very hazardous or highly deleterious to biota. Contamination may occur to a lesser magnitude when compared to pollution, but it also may render the contaminated medium unusable or make it slightly hazardous to life. Many urban and rural areas of the developed or industrialized world have been adversely affected by large-scale pollution and contamination, resulting in losses of human, material and financial resources* (Egboka et al. 1989).

2.1 Water Pollution

Two main sources of water pollution and contamination are point and non-point (distributed) sources. Non-point source of pollution is one where determining the source of pollution is difficult to identify. Organic and inorganic chemicals also lead towards pollution and contamination. Distributed sources of pollution have a more widespread effect than the point sources. Agriculture, silviculture, terrestrial, mining, construction and some other are known as distributed sources of pollution. Cropland, pasture and rangeland, irrigated land and wood land, surface and underground, floods and snowmelt, rainfall, snowfall, etc., are some of the examples of distributed or non-point source of pollution and contamination. Sewage disposal systems, surface and underground waste disposal sites, spills washings and other intrusions, mining and natural mining, and ore deposits are some of primary causes which lead to point source of pollution. Sewage lagoons, septic systems, cesspools, barnyards or feed lots, landfills or garbage dumps, surface waste dumps, storage tanks, pit latrines, tunnels, trenches, caves waste subsurface injections, oil/gas/waste spills, auto workshop washings, seawater/saltwater intrusions, acid mine drainages, gas explosions/seepages, mine dumps and gangue deposits, tunnels/excavations outflows, saline ponds/lakes, hot springs/mineralized waters, anhydrite/pyrite deposits/evaporates are some of the examples of point sources of pollution and contamination. Point and distributed sources of pollution and contamination are listed in Table 1 in detail.

Table 1 Point and distributed sources of pollution and contamination

Point sources of pollution		Distributed sources of pollution	
Type of pollution	Examples	Source	Examples
Sewage disposal systems	Sewage lagoons, septic systems, cesspools, and barnyards/feed lots	Agriculture	Cropland, pasture and rangeland, irrigate land and wood land
Surface waste disposal sites	Landfills/garbage dumps, surface waste dumps	Silviculture	Feed lots, growing stock, logging
Underground waste disposal sites	Storage tanks, pit latrines, tunnels, trenches, caves Waste subsurface injections	Construction	Road building, urban development, highway construction
Spills, washings, and intrusions	Oil/gas/waste spills, auto workshop washings, seawater/ saltwater intrusions	Mining	Surface and underground
Mining sources	Acid mine drainages, Gas explosions/seepages, Mine dumps and gangue deposits, tunnels/excavations outflows	Terrestrial	Landfills and dumps
Natural mineral/ore deposits	Saline ponds/lakes, hot springs/mineralized waters Anhydrite/pyrite deposits/evaporates	Utility maintenance	Highways and streets DE icing
		Urban run-off precipitation	Floods and snowmelt, rainfall, snowfall, etc
		Background sources	Native forests, Prairie land, etc

Source Egboka et al. (1989)

2.1.1 Arsenic Contamination: Causes and Sources

Arsenic is found in the natural environment in plenty in the earth's crust and in small magnitudes in rock, soil, water, and air, and is always present as compounds with oxygen, chlorine, sulphur, carbon and hydrogen, on the one hand, and with lead, gold and iron on the other (MOWR 2010b). It can exist in both organic and inorganic form, but inorganic arsenic is more toxic than organic arsenic. Inorganic arsenic compounds are known to be more carcinogenic for humans. Arsenic, in the element form, is insoluble in water but soluble in its oxidized form. Countries including Argentina, Bangladesh, Chile, Ghana, Mexico, Mongolia, India, Taiwan, Vietnam, and United States are exposed to arsenic problems because the sources of arsenic are primarily natural rather than anthropogenic or geothermal. Inorganic arsenic of geological origin has been recognised as the main form of arsenic in groundwater.

The average concentration of arsenic in the continental crust is around 1–2 mg/l and in igneous rocks 1.5–3 mg/l, whereas, in sedimentary rocks it is in the range of 1.7–400 mg/l. Volcanic action has arsenic containing vapour which contributes about one third of the natural source of arsenic and two third comes from man-made sources. Therefore, arsenic sources can be categorised into three categories which are routed through geogenic, biogenic and anthropogenic routes. Geogenic sources for arsenic accrue through geothermal or volcanic activities or through weathering of rocks and minerals. Biogenic sources of arsenic appear through plants and agricultural organisms or micro-aquatic biota. Scientific research mainly concentrates on arsenic found from biogenic and geogenic sources, while social sciences and other research is mostly on the anthropogenic source.

The anthropogenic sources of arsenic occur due to human activities. The main source of anthropogenic can be further classified in three categories, viz., agricultural, industrial and others. Agricultural sources of arsenic can be mainly from pesticides, herbicides, seed treatment, cattle deep and fertilizer, while industrial sources are from timber treatment, tannery, electro plastic, and paints and chemicals. Other anthropogenic sources are from sewage and smelting. Figure 1 shows a schematic diagram of major sources and routes of arsenic in soil and aquatic ecosystems.

3 Arsenic Scenario

More than 70 countries, are affected directly or indirectly with arsenic contamination in drinking water which affects more than 150 million people across the globe. Around middle of the 20th century, arsenic poisoning surfaced in those areas where people ingested arsenic contaminated water. The major affected countries from arsenic poisoning were Argentina, Chile, Mexico, Taiwan, and some part of the United States. In the global arsenic contamination scenario, 38 countries are affected more severely at present. In the last quarter of 20th century,

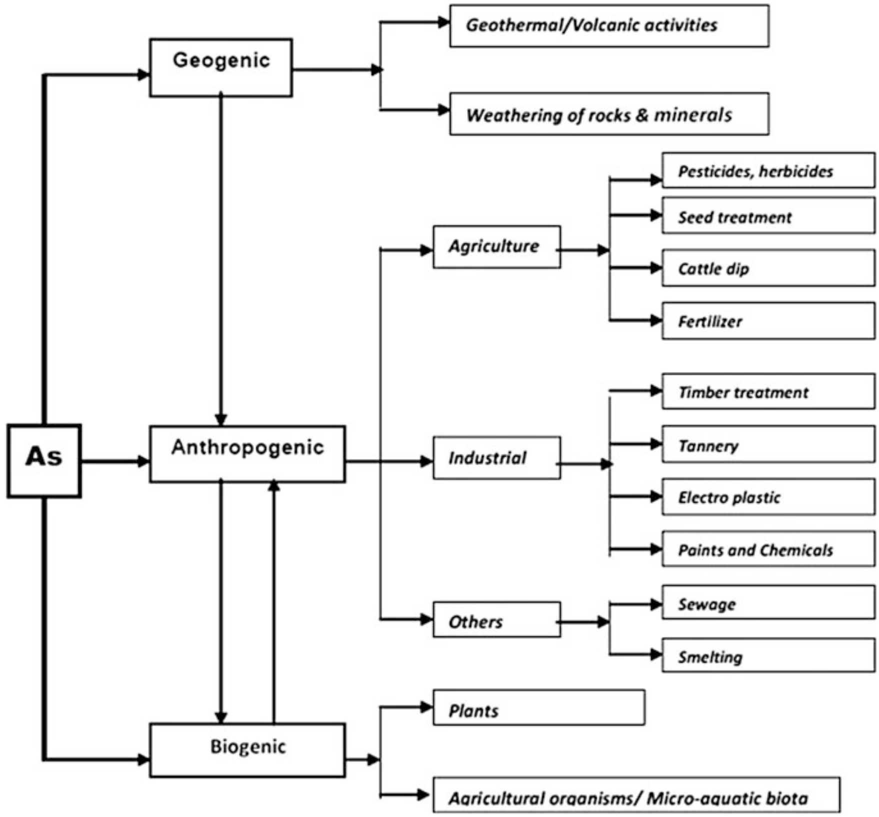


Fig. 1 Major sources and routes of arsenic in soil and aquatic ecosystem (*Source* Sparks 2005)

three Asian countries (Bangladesh, China, and India) came into lime light due to their suffering from groundwater arsenic contamination. The major source of arsenic contamination was contaminated hand tube-wells. As of September 2010, 13 Asian countries are arsenic affected and the level of arsenic contamination in Asian countries is more severe than the rest of the world. Bangladesh is the worst affected country, as 60 of its total 64 districts have arsenic groundwater contamination above (WHO 2010) guidelines of 10 mg/l for safe drinking water. In India, flood plains of all the states in the Ganga and Brahmaputra river basin are arsenic affected.

3.1 Arsenic Contamination in India

Arsenic contamination of groundwater in India is reportedly increasing at an alarming rate after each new survey is done. Seven states of India have reported arsenic contamination in groundwater. Out of reported states, Bihar and West

Bengal have severe impact on the livelihoods of the stakeholders due to the arsenic menace. Arsenic has been regarded as a toxic element and excess dosage of arsenic in drinking water is considered as a human health hazard and can lead to an end of human life.

After the industrial revolution and during the middle of the 20th century South Asian countries (mainly India and Bangladesh) went through two major problems. The first problem was providing food to a large population and second was insulating the population from water borne or diseases attributed to water contamination. In the decade of 1960s, excess extraction and exploitation of groundwater for agricultural irrigation was responsible for groundwater contamination in different forms in Andhra Pradesh, western Uttar Pradesh, Punjab, Haryana, and Tamil Nadu.

The first case of arsenic in India was reported in 1976 from Chandigarh, where some patients were suffering from noncirrhotic portal hypertension (NCPH) and later it was found that the water used by the patients who suffered from NCPH came from arsenic contaminated tube wells (MOWR 2010b). In 1982, a patient from North 24 Parganas district of West Bengal, whose skin lesions were not like any usual skin diseases, and later many patient from the same village were found suffering from similar such problems in the soles of their feet and palms of their hands, ulcer in hands and bodies, and it was found that this due to the excess availability of arsenic in drinking water from tube wells (MOWR 2010a). Soon after this incident, four districts of West Bengal (North 24 Parganas, South 24 Parganas, Nadia, and Murshidabad) were found to have arsenic contamination in ground water. In 1983, 33 villages of 4 districts were identified as having arsenic contamination. By the end of 2004, 3,200 villages of 85 blocks from 9 districts were identified having arsenic contaminated water and, by the end of 2008, more than 3,417 villages of 111 blocks from 9 districts have reported arsenic contaminated groundwater (MOWR 2010b).

In 1999, some villages of Rajnandgaon district of Chhattisgarh and in 2003, 25 villages of Balia district in Uttar Pradesh were reported having arsenic groundwater contamination and its ill effects on human health and skin lesions (MOEF 2009, 2010). In 2004, arsenic concentration above 50 mg/l from 17 villages of the Sahibgunj district of Jharkhand and Dhemaji district of Assam were also reported. In 2007, arsenic groundwater contamination came into the limelight from Manipur. Earlier, north eastern states were safe from water contamination and very few cases had been found there.

In 2002, two villages (Barisban and Semaria Ojhapatti) from the Bhojpur district of Bihar, in the middle Ganga plain, reported excess of arsenic contamination, exceeding 50 mg/l (Chakraborti et al. 2003). As of 2009, out of 38 districts of Bihar, 57 blocks from 15 districts having total population more than 10 million have been reported to have arsenic groundwater contamination above 50 mg/l (MOWR 2010a, 2010b, MOEF 2009). Due to the excess arsenic contaminated drinking water, 18 babies were born blind in the Bhojpur district. The demographic survey done by many organizations, mainly in Bihar and West Bengal, estimated that more than 13.85 million people could be under the threat of contamination level of above 10 mg/l, in which more than 6.96 million people could be above 50 mg/l, against the total population of those areas of the order of 50 million (MOWR 2010b). Live-stock in large numbers has also been exposed to arsenic contaminated groundwater. In the arsenic affected areas, arsenic contaminated groundwater is also used for agricultural irrigation. This leads to the possibility of arsenic exposure through the food chain not only in contaminated areas, but also in areas with no groundwater contamination due to open market sale of food products.

In Table 2, occurrence of high arsenic content in groundwater is given. From the table it can be seen clearly that seven states of India are affected by the presence of high arsenic contents in groundwater. More details can be seen from the table.

In Table 3, the status of the contamination in groundwater is given. Arsenic, chloride, fluoride, iron and nitrate are the most common pollutants found in the groundwater. Among all the 5 contaminants, nitrate is the most common contaminant of ground water and generally originates from non-point sources. It is difficult to identify natural and man-made sources of nitrogen in groundwater. The concentration of iron in ground water is very common in India. It is found in most of the states. Fluoride is also a very common contaminant and excess of it in drinking water leads to tooth decay problem.

Out of seven states, two states of India, namely Bihar and West Bengal, are the worst affected by arsenic contamination in groundwater. Altogether, more than 40 per cent of the people from Bihar and West Bengal are affected by arsenic contamination in groundwater, which causes serious threats to the people of the state

Table 2 Occurrence of high arsenic (>0.05 mg/l) in groundwater in India

Sl. No.	State	Districts having contamination of As >0.05 mg/l	Number of people affected from groundwater arsenic contamination
1.	Assam (1)	Dhemaji	5,71,944
2.	Bihar* (15)	Begusarai, Bhagalpur, Bhojpur, Buxar, Darbhanga, Katihar, Khagaria, Kishanganj, Lakhisarai, Munger, Patna, Purnea, Samastipur, Saran, and Vaishali	1,04,71,869
3.	Chhattisgarh (1)	Rajnandgaon	NA
4.	Jharkhand (1)	Sahibgunj	NA
5.	Manipur (1)		NA
6.	Uttar Pradesh (9)	Agra, Aligam, Balia, Balrampur, Gonda, Gorakhpur, Lakhimpur Kheri*, Mathura, and Muradabad	60,00,000
7.	West Bengal* (9)	Bardhaman, Hooghly, Howrah, Malda, Murshidabad, Nadia, North 24 Pragannas, South 24 Pragannas, and south Calcutta	2,60,00,000

Source Compiled from MOWR (2010a, b), MOEF (2009)

Table 3 Different groundwater contamination in India

Contamination	Permissible limit	Location and status
1. Arsenic	>0.05 mg/l is toxic and has human health hazard	7 states of India are affected with arsenic contamination in ground water. West Bengal and Bihar are highly affected by arsenic where around more than 40 per cent population is directly or indirectly affected with arsenic contamination in drinking water. Arsenic is toxic in nature and excess use of it can lead to death. It also hampers the socio-economic condition among the stakeholders
2. Chloride	>1,000 mg/l is not good for drinking	94 districts in 13 states are having chloride concentration of more than 1000 mg/l in groundwater drinking water in India. Andhra Pradesh, Gujarat, Rajasthan and Tamil Nadu are the most affected states in India and 13, 19, 23 and 16 districts, respectively, are reporting high toxicity
3. Fluoride	>1.5 mg/l is harmful <1 mg/l is beneficial	19 states with 225 districts are showing localized occurrence of fluoride in India. Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Rajasthan and Tamil Nadu are the worse affected by fluoride in groundwater and 123 districts of these six districts are affected by fluoride contamination in groundwater
4. Iron	>1 mg/l is harmful	The concentration of iron in groundwater is very common in India. It occurs in most of the states and 23 states with more than 274 districts have concentration of iron in groundwater. Bihar, Karnataka, Maharashtra, Madhya Pradesh, Orissa, and Rajasthan are some of the state where more than half of the districts of the state have high iron concentration in groundwater
5. Nitrate	>45 mg/l is harmful for infants	It is difficult to identify natural and man-made sources of nitrogen in groundwater. It generally originates from non-point sources and is the most common contaminant of groundwater. The excess dosage of nitrate in water is harmful for infants. 370 districts from 21 states show localized occurrence of nitrate in groundwater. The districts of Andhra Pradesh, Gujarat, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Orissa, Rajasthan, Tamil Nadu and Uttar Pradesh have high nitrogen content in groundwater

Source Authors' own compilation from various sources MOWR (2006, 2007, 2008, 2010a and 2010b; MOEF 2009)

in health and other hazards which threaten the socio-economic status of the affected people. In Table 4, summary of groundwater arsenic contamination status in these two states have been given in detail.

Table 4 Summary of groundwater arsenic contamination status in Bihar and West Bengal, India

Parameters	Bihar	West Bengal
Area in square kilometre	94,163	88,750
Population in million (2001 census)	82	80.2
Total no. of districts	38	19(19)
Total no. of water sample analysed	19,961	1,40,150
Per cent of samples having arsenic >10 mg/l	32.70	48.1
Per cent of samples having arsenic >50 mg/l	17.75	23.8
Maximum arsenic concentration so far analysed (mg/l)	2,100	3,700
No. of severely arsenic affected districts	5	9
No. of mildly arsenic affected districts	10	5
No. of arsenic safe districts	23	5
Total population of severely arsenic affected districts in million	130	50.4
Total area of severely arsenic affected districts in sq. km	42,173	38,861
Total no. of blocks/PS	243	341
Total no. of blocks/PS surveyed	57	241
Number of blocks having arsenic >50 mg/l	36	111
Number of blocks having arsenic >10 mg/l	57	148
Total number of village	NA	37,910
Total no. of village surveyed	NA	7,823
Number of villages having arsenic above 50 mg/l	NA	3,417
People drinking arsenic contaminated water >10 mg/l (in millions)	10.11	9.5
People drinking arsenic contaminated water >50 mg/l (in millions)	6.96	4.6
Population potentially at risk from arsenic contamination >10 mg/l (in millions)	30	26
No. of districts surveyed for arsenic patients	NA	9
No. of districts where arsenic patients found	NA	7
Villages surveyed for arsenic patients	NA	602
No. of villages with arsenical skin lesions	NA	488

Source Compiled from Chakraborti et al. (2008), MOWR (2010b)

4 Resource Depletion and Groundwater Contamination Problem

Major environmental problems currently existing in India are pollution (mainly air and water), depletion of non-renewable resources, and degradation of renewable resources (Sankar 2000). Resources are economic goods (in some cases sinks into which pollutants are discharged), while pollutants (the degrader of resources) are economic bads. Pollutants are the reverse of the resources (Dasgupta 2010) and pollution is, thus, the reverse of conservation (Dasgupta 1993, 2007). Pollution can be thought of as a pure public bad and, hence, pollution reduction as a public good (Baliga and Maskin 2005). Pollution is treated as negative externalities[3] in

[3] When certain actions of producers or consumers have unintended effects on other producers or consumers, externality arises. Externality is of two kinds positive and negative. In the case of

economics literature (Pigou 1920; Sankar 2005). Externalities may be global public bads (emissions of greenhouse gases, climate change, depletion of ozone layer, loss of bio-diversity and extinction of endangered species and other are some of the examples of global public bads) which have a global effect and local public bads (problem of groundwater or surface water in a region, land degradation, air and vehicular pollutions and others are some of the examples of the local public bads) which have a local or regional effect.

Natural resources are categorised as renewable and non renewable resources. A renewable resource is defined on the basis of significant rate of growth or renewal on a relevant time scale (Conrad 1999). Water (surface or groundwater) are the examples of renewable resources because over a relevant time scale it can be regenerated. A non renewable resource is not based on the exhibition of significant growth or renewal over an economic time scale (Conrad 1999). Over the economic time scale, with excess extraction of groundwater for the use of irrigation and other activities, the groundwater resources are depleting. The earliest explanation of the resource depletion was proposed by (Hotelling 1931) and he remarks on resource depletion as *Contemplation of the world's disappearing supplies of minerals, forests, and other exhaustible assets has led to demands for regulation of their exploitation. The feeling that these products are now too cheap for the good of future generations, that they are being selfishly exploited at too rapid a rate, and that in consequence of their excessive cheapness they are being produced and consumed wastefully has given rise to the conservation movement* (Hotelling 1931).

The World oceans[4] cover about 3/4th of earth's surface. But fresh water constitutes a small proportion. About 2.7 per cent of the total water available on the earth is fresh water, of which about 75.2 per cent lies frozen in the Polar Regions and another 22.6 per cent is present as groundwater (MOWR 2007; UN 2005). A small proportion (about 2 per cent) of total fresh water is available in lakes, rivers, atmosphere, moisture, soil and vegetation.

Water resources of a country constitute one of its most significant economic assets, and the different forms of water resource development differ for various uses and fluctuate from country to country depending on its climatic, physiographic, and socio-economic conditions and development (Jain 1977). India is rich in both surface water and groundwater resources. India has total annual replenishable groundwater resources of 433 billion cubic meters (BCM) and a net annual groundwater availability of 399 BCM. Annual ground water draft for irrigation, domestic and industrial use is around 233 BCM, and stage of groundwater development is around 58 per cent. Annual precipitation (includes snowfall) in

(Footnote 3 continued)
positive externality social benefit is higher than the private benefit, but in negative externality social cost is higher than private costs. Therefore, in the presence of externalities–positive or negative–social costs (benefits) and private costs (benefits) differ from each other.

[4] United Nations reports estimates that the total amount of water available on earth is about 1,400 million km^3 which is enough to cover the earth with a layer of 3,000 m depth.

India is 4,000 cubic kilometres, while average annual availability of water resources is around 1,869 cubic kilometres. Per capita water availability is 1,820 cubic meters according to 2001 MOWR sources. Estimated utilized water resources are 1,122 Km^3 in which the surface water resources share is 690 Km^3 and groundwater resource share is 431 Km^3.

Both the states of Bihar and West Bengal are rich in groundwater resources. In Bihar, annual replenishable groundwater resources, net annual groundwater availability and annual groundwater draft are 29 BCM, 27.42 BCM, 10.77 and for West Bengal 30.36 BCM, 27.46 BCM and 11.65 BCM, respectively. The stage of groundwater development in Bihar and West Bengal are 39 per cent and 42 per cent, respectively. The annual rainfalls (in mm) are 1,232 and 2,074 for Bihar and West Bengal. The per capita water availability is decreasing in both Bihar and West Bengal. In 2001, per capita availability of water (in cu m) was 844 and 1950 for West Bengal and Bihar. The decline in availability of groundwater in Bihar is due to the uncontrolled population growth, excess dependence on groundwater (85 per cent), over extraction of groundwater for irrigation, and uncontrolled deforestation. This leads to overall water quality problems. The state of West Bengal covers 2.7 percent of the area and is home to 8 per cent of the Indian population. West Bengal is endowed with 7.5 percent of the water resources of the country. But water is becoming increasingly scarce over the years. Uncontrolled growth of population, expansion of irrigation channels and developmental activity are responsible for the decline in water availability problems. It also leads to problems in water quality which affects the health and other problems.

5 Socio-Economic Problems

Access to safe water supply is the most important determinants of health and socio-economic development (Cvjetanovic 1986). The seventh Millennium Development Goal (MDG) is on 'ensure environmental sustainability'. One of targets of the seventh MDG is …*by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation* (UN 2009, 2010).

The arsenic problem has a major effect on the socio-economic structure. People often mistake symptoms of arsenic poisoning for leprosy or other contagious skin diseases and, thus, marriage, employment, and even the simplest social interaction become impossible for the victims. More often, a patient afflicted with arsenic poisoning repeatedly becomes depressed and sometimes even tries to commit suicide. It has been found from the surveys and studies that most of the population suffering from arsenic skin lesions is from a poor socio-economic background. From various researches it has been seen that more than one third of the populace is economically poor and living below the poverty line. Women are more prone to illness compared to men, and infants and children are more adversely affected than the adults. The adverse impact of arsenic contamination has both primary and secondary effects. Different diseases through arsenic contaminated drinking water

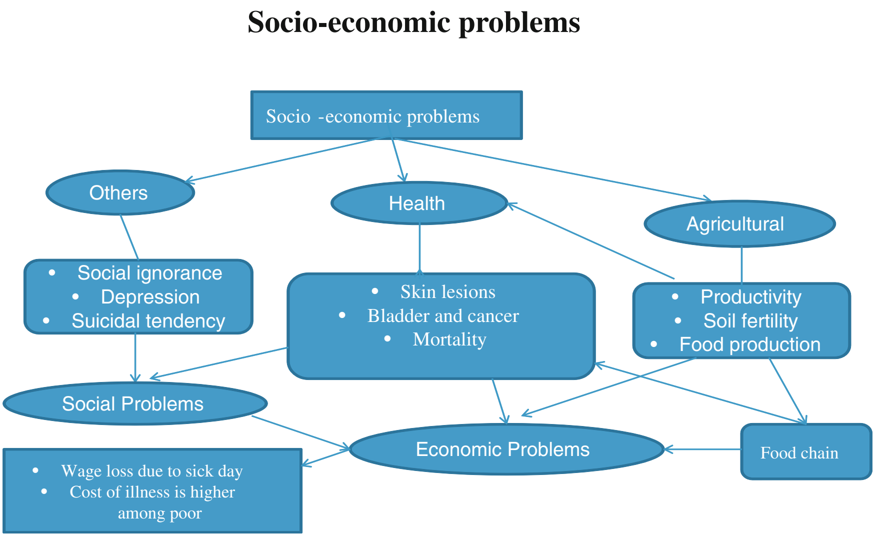


Fig. 2 Socio-economic problems of groundwater arsenic contamination (*Source* Authors' own compilation)

can be categorised into primary effects while secondary effects are the outcome of primary impacts and lead to inability to do productive works. It also leads to social exclusion due to the arsenic menace and finally to the socio-economic impacts of the affected population.

The socio-economic problems can be mainly categorised into three classes as agricultural problems, health problems and others. Excess contamination of water leads to decrease in agricultural productivity, soil fertility, and also creates health problems with contaminants entering the food chain. Brammer (2008) suggested that in India, Nepal and Bangladesh, arsenic contaminated water used for irrigation enter into the food chain. Skin lesions, bladder and cancer, and mortality are few of the health problems due to this. Social ignorance, depression and suicidal tendency are a few of the social problems. More socio-economic problems can be seen in Fig. 2.

5.1 Social Problems Due to Arsenic Contamination

Arsenic contamination has widespread social problems among the affected households. Social problems are linked with the health and the economic problems. Some of the common social problems are:

- Affected wives are sent back, sometimes even with their children to their parents because people believe that the disease will spread from one to another.
- Marriage of people of either sex from the affected village is difficult.

- Often jobs or services are denied to the arsenic affected persons.
- When a husband or wife is singled out as an arsenic patient, the social problems crop up and they may destroy their social life.
- Due to ignorance, the villagers sometimes view it as a case of leprosy and force the arsenic patients to follow an isolated life, which sometimes leads to suicide.
- Arsenic patients are socially excluded.

Possible Options

Arsenic related diseases are not spreadable disease. It is a common myth among the households in rural areas that it is a spreadable disease. The following are the options for alleviating the social problems due to arsenic contamination:

- To initiate awareness programme by the government at the community or grassroots level.
- Implement the awareness programme by large level and make sure that the participation of the women participants must participate in the awareness programme at larger level.
- Take the help of councillors to those patients who follow an isolated life due to social exclusion which leads to depression.

5.2 Economic Problems Due to Arsenic Contamination

Arsenic groundwater contamination has severe economic effect on the people residing in the areas where the menace is found. The study found that poor people are more prone to suffer from such problems. There is dearth of studies on economic aspects of arsenic problems (Roy 2008) estimated the economic costs imposed by arsenic-related health problems by using the household health production function model and household demand function for mitigating and averting activities to estimate the benefits from a decline in arsenic concentration in groundwater. Primary survey of 473 households (Midnapore and 24 Parganas districts of West Bengal) on three equation system (averting actions, medical expenditures and a sickness function) carried out and found that if arsenic concentration was reduced to the safe limit of 50 mg/l, the monthly and annual gains per household would be Rs. 297 and Rs. 3,573, respectively, and if the arsenic contamination was reduced by half of the present level, economic benefits would be Rs. 161 and Rs. 1,934 monthly and annually per household, respectively. Poor households incurred the largest number of sick days and person suffering from arsenic disease worked only 2.73 h per day compared to 8 h work per day. Khan (2007) studied health impacts and costs associated with arsenic groundwater contamination using primary data from Bangladesh, where arsenic problem is considered as a major public health concern. The study follows the household production function on 900 tube-wells and 878 households and estimates that 7 to 12 million man-days per year are lost as a result of arsenic exposure and the sick spend between US $3.5 to $6.25 million per year for medical help. The total cost of illness from arsenic was found to be US $9 to US $17 million per annum which was nearly 0.6 per cent annual income of the affected households. The study finds that the threat of Melanosis[5] and Keratosis[6] is high when there is cumulative exposure, and it is more commonly found in the poorer class rather than richer class because richer households are taking mitigation measures to reduce the risk of health threat. This study also suggests that children and women are more likely to get affected by inflammation of the respiratory tracts which is caused by long term exposure to arsenic. Therefore, economic costs are involved in the arsenic contamination and poor suffer most from that Ahmad et al. (2002) estimated WTP for piped water supply projects. They estimated that WTP for community water stand post in Bangladesh Taka (BDT) 51 per month plus an additional BDT 960 towards capital costs. For domestic connections, the mean estimate is BDT 87 per month plus BDT 1787 for capital expenses. For poor households, the costs are BDT 68 per month and BDT 1,401 in capital costs for a home connection. Khan and Haque (2011) measured the private cost of arsenic exposure in Bangladesh. They found that households spend BDT 1,057 per year for arsenic related ailments, which is nearly 0.73 per cent of the income of the household. This is big amount for poor household, considering that most of the population live with less than $2 a day.

5.3 Health Issues and Problems

A large number of studies have shown that arsenic in drinking water can cause bladder, lung, kidney, liver and skin cancer (Canter 1997; Chakraborti et al. 2006; Chakraborti and Saha 1987). Arsenic can harm the central and peripheral nervous systems as well as heart and blood vessels, and can cause serious skin problems. It may also cause birth defects and problems in the reproductive system (Canter 1997). In a developing country, attribution of medical expenditure to arsenic-related diseases imposes an extra burden on the already overburdened public provision of medical care. While other parts of India also have arsenic contamination, but such contamination is acute in West Bengal and Bihar (MOEF 2009). 500 million people residing in the Ganga-Meghna-Brahmaputra belt are on the verge of drinking arsenic contaminated water which spreads in the area of 569,749 square kilometre (Saha 2009, MOWR 2010b).

Arsenic contamination of groundwater is a global problem (Kondo et al. 1999; Jain and Ali 2000; Smedley and Kinniburgh 2002; Saxena et al. 2004; Ghosh et al. 2007). Arsenic exposure from contaminated drinking water of more 50 mg/l is a

[5] Melanosis is a disease in which black spots are found on the body.

[6] In Keratosis, the commonly found symptom is roughness in palms and soles.

significant cancer risk (Canter 1997). Drinking water rich in arsenic over a long period lead to arsenic poisoning or arsenicosis[7] (WHO 2010).

Arsenic is toxic in nature and the excess quantity of its use in drinking water leads to several health hazards. Drinking arsenic rich water over a long period results in various health effects including skin problems such as colour changes on the skin, and hard patches on the palms and soles of the feet, skin cancer, cancer of the bladders, kidney and lung, and diseases of the blood vessels of the legs and feet, and possibly also diabetes, high blood pressure and reproductive disorders (WHO 2010). Skin lesions such as hyper pigmentation and black foot disease, respiratory symptoms, such as cough and bronchitis and cancer are a few diseases accruing due to excess of arsenic in drinking water.

Arsenic acquaintance during pregnancy can adversely affect several reproductive endpoints (Mukherjee 2006; Roy et al. 2004) and the relationship between arsenic exposure and adverse pregnancy outcome, including spontaneous abortion, preterm birth, still-births, low birth weight and neonatal and prenatal mortality have been identified in West Bengal, Bihar and other states of India.

The chronic effects of inorganic arsenic exposure via drinking water include skin lesions, such as hyper pigmentation and black foot disease, and respiratory symptoms, such as cough and bronchitis. Besides, there is sufficient evidence to link bladder and lung cancers with ingestion of inorganic arsenic (NRC Report 2006). Some more health aspects have been found by repeated epidemiological investigations and some of the examples of disease are as: (a) dermal effects; (b) cardiovascular effects; (c) respiratory effects; (d) gastrointestinal effects; (e) endocrinological effects (diabetes mellitus); (f) neurological effects; (g) reproductive and developmental effects; (h) cancer effects; and (i) other effects. Symptoms of arsenicosis are primarily manifested in the form of different types of skin disorders such as skin lesions, hyper Keratosis and Melanosis. Long term exposure to arsenic in drinking water has variety of health concerns including several types of cancers, cardiovascular diseases, diabetes, and neurological effects which also affect the socio economics of concerned people. The short term and long term effects of arsenic on health are given in Table 5.

5.4 Agricultural Productivity Issues

Arsenic contaminated groundwater used for agricultural irrigation results in excessive amount of available arsenic in the crops in that area. It has been reported that second to the ingestion of arsenic, after the direct consumption as drinking arsenic contaminated water, is through the food chain, particularly use of contaminated rice followed by vegetables. This eventually indicates that the effects of

[7] Arsenicosis is the effect of arsenic poisoning usually over a long period such as from 5 to 20 years.

Table 5 Short terms and long term health effect of arsenic

Short term effect	Long[a] term effect
Abdominal pain	Skin, Kidney, Prostate, Bladder, and lung cancer
Changing in skin colour	Limb loss
Vomiting	Immunological disorders
Dryness/tightness in throat	Diabetes
Thirst	Reproductive problems
Convulsions	Developmental problems
Cramps	
Clammy sweat	

[a] Arsenic intake causes allosteric inhibition, restricting metabolic enzymes, causing organ failure, left untreated. This is responsible for human death in some cases

this occurrence are far-reaching. The sooner that we search sustainable solutions to resolve this problem, lesser will be its future environmental, health, socio-economic and socio-cultural hazards (MOWR 2010b). The fertilizers and pesticides used for agricultural purpose also cause arsenic contamination. Rice and vegetables are more effected by arsenic contaminated water. Brammer (2008) in his study suggested that arsenic-polluted water used for agriculture irrigation is a health hazard for the people eating food from the crops irrigated in the areas of India, Bangladesh and Nepal in recent times. Arsenic contaminated water used for irrigation can adversely affect the soil quality and, hence, reduce food production. Arsenic contaminated groundwater used for irrigation in the countries of south and south-east Asia is adding arsenic to soils and rice. This poses a serious risk to sustainable agricultural production and also the livelihoods and health of the affected population of those countries (Brammer 2009). The possible mitigation strategy or measures should be needed. Two possible options can be possible. The first is to provide the alternative irrigation sources and the second will be removing the contaminated soil by using appropriate technology.

6 Concluding Remarks

Arsenic contamination in groundwater has significant socio-economic impact on the population worldwide. More than 70 countries are directly or indirectly affected by arsenic contamination in drinking water, which affects more than 150 million people across the globe. Worldwide, 38 countries are acutely suffering from arsenic contamination in groundwater. Due to the arsenic menace in groundwater, a large number of people from India, Bangladesh and Nepal are suffering which hampers the socio-economic conditions of the affected people. The effect of arsenic in drinking water can be known in long run. The actual damage caused by arsenic in drinking and irrigated water could be much more than the current known level.

To provide safe drinking water to the households is one of the most emerging challenges. In the rural areas, alternative safe sources of both drinking water and water for irrigation need to be determined. As more than 70 per cent households are still depend on the groundwater sources for their drinking water. The second emerging challenges are in the form of contaminated irrigation water which leads to soil contamination. Soil contamination causes arsenic poisoning in food and finally affects the food chain due to the open market. It causes several health problems, decline in the soil fertility and food productivity.

Most of the affected households suffering from the diseases caused by arsenic contaminated drinking water are from the poor socio-economic sections. As the poor are more prone to health problems, there is a need for strategy to tackle the problems on groundwater arsenic contamination. The mitigation strategy and plans have been implemented but they do not reach to the downtrodden people and due to poor economic status the alternative safe source of clean water is out of their reach.

Attempts have been made so far to combat the menace of groundwater arsenic contamination, include identifying the causes of contamination, providing arsenic free drinking water to the affected people who depend on the groundwater resources. To reduce the socio-economic problems and to develop cost effective technology for eradication of arsenic contamination have proven inadequate, fragmented and less responsive, as evident from the rise in number of arsenic affected areas with every new survey. There is an urgent need to create awareness among people and educate the villagers for the dangers of arsenic toxicity and importance of using arsenic free water. This can be only achieved by active community participation among the affected stakeholders (more concentrate on the women) and full support from the government. Also, more research is needed on the arsenic menace of groundwater (including research on household and inter-disciplinary). Otherwise, the Indian states which are currently having arsenic problems may face severe problems as faced in Bangladesh.

References

Ahmad J, Goldar BN, Misra S, Jakariya M (2002) Fighting arsenic, listening to rural communities: willingness to pay for arsenic-free, safe drinking water in Bangladesh. Available online at www.wsp.org/publications/sa_arsenic_learning.pdf. Accessed 27 July 2011

Baliga S, Maskin E (2005) Mechanism design for environment. In: K-G Maller, JR Vincent (eds.) Handbook of environmental economics: valuing environmental changes, Elsevier, North-Holland 1, 305–324

Brammer H (2008) Threat of arsenic to agriculture in India, Bangladesh and Nepal. Economic and political weekly, 22 Nov 2008

Brammer H (2009) Mitigation of arsenic contamination in irrigated paddy soils in south and south-east Asia. Environ Int 35:856–863

Canter KP (1997) Drinking water and cancer. Cancer Causes and Control 8(3):292–308 The Harvard-Teikyo special issue

Chakraborti AK, Saha KC (1987) Arsenic dermatoses from tube-well water in West Bengal. Indian J Med Res 85:326–34

Chakraborti D, Mukherjee SC, Pati S, Sengupta MK, Rahman MM, Chowdhury UK, Lodh D, Chanda CR, Chakraborti AK, Basu GK (2003) Arsenic groundwater contamination in middle Ganga plain, Bihar India: a future danger. Environ Health Perspect 119(9):1194–1201

Chakraborti D, Sengupta MK, Ahamed S, Mukherjee SC, Pati S, Mukherjee A, Rahman MM, Hossain MA, Das B, Nayak B, Pal A, Zafar A, Kabir S, Banu SA, Morshed S, Islam T, Quamruzzaman Q (2006) An eight-year study report on arsenic contamination in groundwater and health effects in Eruani village, Bangladesh and an approach for its mitigation. J Health Popul Nutr 24(2):129–141

Chakraborti D, Sengupta MK, Rahman MM, Ahamed S, Chowdhury UK, Hossain MA, Mukherjee SC, Pati S, Saha KC, Dutta RN, Quamruzzaman Q (2008) Groundwater arsenic contamination and its adverse health effects in the Ganga-Meghna-Brahmaputra plain. In: Roy K (ed) Arsenic calamity of groundwater in Bangladesh: contamination in water, soil and plants. Nihan University, Japan

Conrad Jon M (1999) Resource economics. Cambridge University Press, New York

Cvjetanovic B (1986) Health effects and impacts of water supply and sanitation. World Health Stat Q 39(1):105–117

Dasgupta P (1993) An enquiry into well-being destitution. Oxford University Press, New York

Dasgupta P (2007) Economics: a very short introduction, Oxford University Press, New York

Dasgupta P (2010) The concept of natural capital. Lecture delivered at royal society on inter panel academy biodiversity conference on Jan 12–13

Egboka BCE, Nwankwor GI, Orajaka IP, Ejiofor AO (1989) Principles and problems of environmental pollution of groundwater resources with case examples from developing countries. Environ Health Perspect 83:39–68

Ghosh AK, Singh SK, Bose N, Chaudhary S (2007) Arsenic contaminated aquifers: a study of the Ganga levee zones in Bihar, India, symposium on arsenic: the geography of a global problem. Royal geographical society, London Available online at http://www.geo.cam.ac.uk/research/projects/arsenic/symposium/S3.5_A_Ghosh.pdf.Accessed. 12 Dec 2010

Hotelling H (1931) The economics of exhaustible resources. J Polit Econ 39(2):137–75

Jain JK (1977) India: underground water resources and discussion, philosophical transactions of the royal society of London, Series B. Biol Sci 278(962):507–524

Jain CK, Ali I (2000) Arsenic: occurrence, toxicity and speciation techniques. Water Resour 34(17):4304–4312

Khan MZH (2007) Managing the disaster in water supply: risk measurement, costs of illness and policy choices for Bangladesh. SANDEE working paper No. 27-07, Kathmandu, Nepal

Khan, M Z Hossain, Haque AKE (2011) Red wells, green wells and the costs of arsenic contamination in Bangladesh. In: Haque, Murty and Shyamsundar (eds) Environmental valuation in South Asia, Cambridge University Press, New Delhi

Kondo H, Ishiguro Y, Ohno K, Nagase M, Toba M, Takagi M (1999) Naturally occurring arsenic in the groundwater's in the southern region of Fukuoka prefecture. Japan Water Res 33(8):967–1972

Ministry of environment and forests (2009) State of environment report 2009. MoEF Government of India, New Delhi

Ministry of environment and forests (2010) Report to the people on environment and forests 2009–2010. MoEF Government of India, New Delhi

Ministry of water resources (2000) Annual report 1999–2000, MoWR, Government of India, New Delhi

Ministry of water resources (2006) Dynamic groundwater resources of India, Central Ground Water Board, New Delhi

Ministry of water resources (2007) Annual report 2006–2007, Government of India, New Delhi

Ministry of water resources (2008) Annual report 2007–2008. Government of India, New Delhi

Ministry of water resources (2010a) Groundwater quality in shallow aquifers of India, Central Groundwater Board, Faridabad

Ministry of water resources (2010b) Mitigation and remedy of groundwater arsenic menace in India: a vision document. National Institute of Hydrology, Roorkee and Central Ground Water Board, New Delhi
Mukherjee A (2006) Arsenic contamination in groundwater: a global perspective with emphasis on the Asian scenario. International centre for diarrheal research centre, Bangladesh
National research council (2003–2006) Fluoride in drinking water: a scientific review of EPA's standards, New Zealand
Pigou AC (1920) Economics of welfare. Macmillan and Company, London
Rahman M, Tondel M, Chowdhury IA, Ol Axelson (1999) Relations between exposure to arsenic, skin lesions, and glycosuria. Occup Environ Med 56(4):277–281
Ravenscroft P, Burgess WG, Ahmed KM, Burren M, Perrin J (2008) Arsenic in groundwater of the Bengal Basin Bangladesh: distribution, field relations and hydrological setting. Hydrol J 13:727–51
Roy J (2007) Estimating the economic benefits of arsenic removal in India: a case study from West Bengal. SANDEE working paper No. 21-07, Kathmandu, Nepal
Roy (2008) Economic benefits of arsenic removal from ground water–a case study from West Bengal, India. Science Total Environ 397: 1–12
Roy J, Chattopadhyay S, Mukherjee S, Kanjilal M, Samajpati S, Roy S (2004) An economic analysis of demand for water quality: A case study from Kolkata city. Econ Polit Wkly 39(2):186–192
Saha D (2009) Arsenic groundwater contamination in parts of middle Ganga plain, Bihar. Curr Sci 96(6):1–3
Sankar U (2000) Environmental economics, reader in economics, Oxford University Press, Oxford India paperback 4th impression 2004
Sankar U (2005) Environmental externalities Dissemination Paper-1, Madras School of Economics
Saxena VK, Kumar S, Singh VS (2004) Occurrence, behaviour and speciation of arsenic in groundwater. Curr Sci 86(2):281–284
Smedley PL, Kinniburgh DG (2002) A review of the source, behaviour and distribution of arsenic in natural waters. Appl Geochem 17(3):517–568
Sparks DL (2005) Advances in Agronomy. Elsevier Academy 86:440
UN Millennium project task force on environmental sustainability (2005) Environment and human well-being: a practical strategy. EARTHSCAN, London
United Nations (2009) The millennium development goals report 2009
United Nations (2010) The millennium development goals report 2010
World Health Organization (2010) Water for health: WHO guidelines for drinking-water quality. WHO 1:1–6

Climate Change and Tomography

Manish Kumar Bajpai, Brajesh Pande, Phalguni Gupta and Prabhat Munshi

1 Introduction

Ocean acoustic tomography was first developed by Munk and Wunsch (1979), Munk et al. (1995) and who used it to generate temperature profile of sea water using acoustics. Cornuelle et al. (1985, 2008) have used tomographic methods to generate temperature profiles. It has been already reported in literature that a temperature difference of 1 °C in sea water results in a difference of 4 m/s in speed of acoustic waves passing through it. This indicates that waves passing through different temperatures will have different time of flight to reach the same distance. This phenomenon can be used to regenerate the temperature profile of the path traversed by the wave (ray) from projection data. Sea water acts as a good medium for sound waves to travel long distances. These waves get destructed by many ways such as noise produced by naval ships, noise produced by sea mammals and other similar sounds. The projection data thus obtained gets noisy and the quality of the reconstructed image from this projection data gets reduced. The region of interest (area to be covered for the reconstruction) in ocean acoustic tomography is huge and it is almost impossible to cover it from all directions. It, thus, results in the domain of 'limited view tomography' with noisy projection data. It has been shown earlier that algebraic reconstruction methods (ART) perform better (than any other reconstruction method) in such noisy cases (Jain et al. 2011; Gordon et al. 1970; Kak and Slaney 1987; Gilbert 1972).

These methods (a) depend on the scanning geometry, (b) are slow in nature and (c) are computer intensive. They take a huge time if we want higher resolution reconstructed images. This fact indicated a strong need of parallel implementation of these algorithms. The present work focuses on graphical processing units (GPU) based parallel implementation of an ART-type method, Multiplicative Algebraic

M. K. Bajpai · B. Pande · P. Gupta · P. Munshi (✉)
Indian Institute of Technology Kanpur, Kanpur 208016, India
e-mail: pmunshi@iitk.ac.in

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_11,

Reconstruction Technique (MART) that has been used successfully in temperature profile generation of sea water and can be used for weather prediction.

2 Algebraic Method

Algebraic model for image reconstruction is defined as solving system of linear equations stated as:

$$Ax = b \tag{1}$$

Here, **A** is a weight matrix, **x** is vector of unknown parameters and b is projection data obtained through experiment. Implementation of these methods can be divided into the following parts: (1) weight matrix generation, (2) calculation of correction, (3) updation of each pixel and (4) check for convergence.

These steps are now grouped in two categories for GPU implementation: (a) Weight generation and (b) Pixel updation.

2.1 Weight Generation for a Test Case

Weight generation is geometry dependent and exact position of the transducers (used in the experiments) is required for accurate results. This step involves ray tracing methodology. Figure 1 shows a typical geometry (for ocean tomography application) in which transducers are placed at particular positions in a specified area. This area has been discretized into pixels. It has been assumed that:

$$A_{ij} = \begin{cases} 1 & \text{if ray passes through pixel} \\ 0 & \text{otherwise} \end{cases}. \tag{2}$$

A is order of $M \times N$ where M is total number of rays from all source positions taken into account to send acoustic signals and N is total number of pixels in discretized grid.

2.2 Pixel Updation

ART has been discussed in detail in Gordon et al. (1970) and Jain et al. (2011). Let $b_{i\theta}$ be projection data due to *ith* ray in (θ) source position, x_j be initial guess of pixel grid field value. The value of λ, relaxation factor, lies between 0 and 2 and e is a suitable stopping criterion. We now obtain $\bar{b}_{i\theta}$ by the following equation

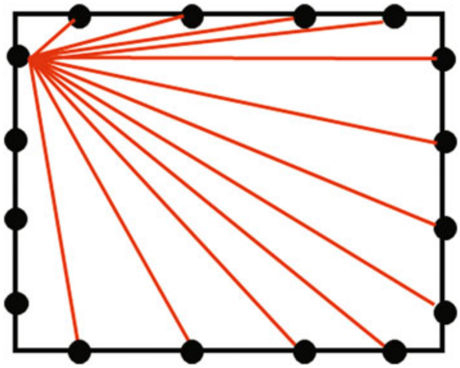


Fig. 1 Transducers position for weight generation

$$\bar{b}_{i\theta} = \sum_{j=1}^{N} A_{ij} x_j \tag{3}$$

Major steps of serial version of MART algorithm are as follows:
Step 1: k = 1
Step 2: For each source position (θ)
For each ray $(i\theta)$ Compute the numerical projection

$$\bar{b}_{i\theta} = \sum_{j=1}^{N} A_{ij} x_j$$

Calculate the correction as

$$\Delta b_{i\theta} = \frac{b_{i\theta}}{\bar{b}_{i\theta}}$$

For each cell (j)
If $A_{i\theta,j}$ is nonzero then:

MART1

$$x_j^{new} = x_j^{old} \times (1.0 - \lambda \times (1 - \Delta b_{i\theta}))$$

MART2

$$x_j^{new} = x_j^{old} \times \left(1.0 - \lambda \times \frac{A_{i\theta,j}}{(A_{i\theta,j})_{\max}} (1 - \Delta b_{i\theta})\right)$$

MART3

$$x_j^{new} = x_j^{old} \times (\Delta b_{i\theta})^{\left(\frac{\lambda A_{i\theta,j}}{(A_{i\theta,j})_{\max}}\right)}$$

If,

$$abs\left[\frac{x^{k+1} - x^k}{x^{k+1}}\right] \times 100 \le e$$

Then, Stop, else k = k+1 and go to Step 2

3 GPU Implementation

A GPU based code of MART algorithm (PdMART) has been developed. We have tested this on the Nvidia GTX-275 graphics card. This card has been installed in a Windows based work station having 3.2 GB RAM and 2.66 GHz core 2 Duo processors.

4 Results

Figure 2 shows reconstruction of a numerical phantom having different density profile (equivalent to temperature profile) along the area under consideration. Area average of original image is 0.73616 while it is 0.74792 in case of reconstructed image, hence, there is a global error in reconstruction less than 2 %. Weight matrix generation has been performed in 0.516 s for 256 × 256 pixel grid and for 90 source positions. Pixel updation takes less than a minute for 30 iterations.

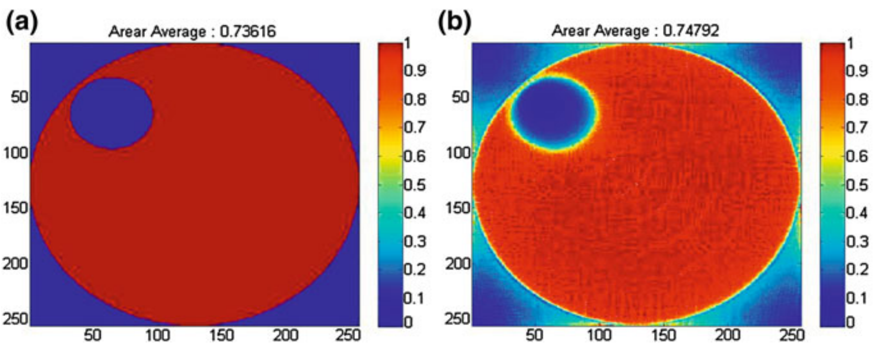


Fig. 2 Reconstruction of a numerical phantom. **a** Original image **b** Reconstructed image by PdMART

5 Conclusion

Major findings of this work are:

- Results indicate that reconstruction from PdMART algorithm is of good quality as the error is less than 2 per cent. The area covered under this experiment is of 256 $\times$ 256 km. PdMART requires only 90 view points (projections); hence, it reduces the cost of the experiment in comparison to other methods.
- GPU implementation has reduced the reconstruction time by an order of magnitude. It enables us to have online temperature profile of sea water.
- The geometry chosen in this validation exercise lays the foundation of future work that will involve a different type of geometry applicable to real life ocean acoustic experiments.

References

Cornuelle BD (1985) Tomographic maps of ocean Mesoscale part I: pure acoustic. J Phys Oceanogr 15:133–152

Cornuelle BD, Worcester PF, Dzieciuch MA (2008) Ocean acoustic tomography. In: 8746555 Proceedings of the second HELAS international conference, journal of physics: conference series 118: 0120–02

Gilbert P (1972) Iterative methods for the three-dimensional reconstruction of an object from projection. J Theor Biol 36:105–117

Gordon R, Bender R, Herman GT (1970) Algebraic reconstruction technique (ART) for three-dimensional electron microscopy and X-ray photography. J Theor Biol 29:471–481

Jain N, Raj A, Kalra MS, Munshi P, Ravindran VR (2011) MART algorithms for circular and helical cone-beam tomography. Res Nondestr Eval 22(3):147–168

Kak AC, Slaney M (1987) Principles of computerized tomographic imaging. IEEE Press, New York

Kirk DB, Mei W, Hwu W (2010) Programming massively parallel processors. Morgan Kaufmann Press, Burlington

Munk W, Wunsch C (1979) Ocean acoustic tomography: a scheme for large scale monitoring. Deep-Sea Res 26A:123–161

Munk W, Worcester PF, Wunsch C (1995) Ocean acoustic tomography. Cambridge University Press, Cambridge, New York

Nvidia CUDA programming guide

Rethinking Sustainable Development in the Context of Climate Change: Self-Development, Social Transformations and Planetary Realizations

Ananta Kumar Giri

> …What is managed under the policy of sustainable development is not the path towards a more sustainable future, but rather the inability and unwillingness to become sustainable.
>
> [We must] avoid essentializing the term [sustainability] by locking it into a recipe or an absolute state. Instead it is something to be embodied, as a state of being, as an orientation to life.
>
> Bussey (2008) p. 140.
>
> Harmony with nature should become a non-negotiable ethic. The rise and fall of great civilizations in the past have been related to the use and abuse of land, water and other natural resources.
>
> Swaminathan (2011a), p. 116.
>
> We need to balance the advances of science with the wisdom of indigeneity. We need education that encourages us to integrate the many aspects of our being. Through meditation and art, we can connect with our mother earth and reaffirm our cooperative nature, recognize the environment as part of ourselves. Planting seeds of peace, turning inward towards ourselves, we can heal ourselves and heal our planet.
>
> Sivaraksha (2009), p. 44.

1 Introduction and Invitation

Sustainable development is a key challenge of our times, but the discourse on it is many a time locked in an existing status quo without foundational interrogation of the dominant and dominating frameworks of economy, polity, self and society. We need to rethink and interrogate such a status-quoist understanding and practice of sustainable development and realize it as a multi-dimensional process of self and social transformations leading towards planetary realizations. In this, sustainable development goes beyond the prisons of nation-state centered rationality,

A. K. Giri (✉)
Madras Institute Development Studies, 79, Second Main Road,
Gandhi Nagar, Adyar, Chennai 600020, India
e-mail: aumkrishna@yahoo.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_12,

productivist profit-maiximization, and anthropocentrism, and contributes towards planetary realizations. Planetary realizations challenge us to understand that all of us, including non-human beings, plants and species are children of Mother Earth. Anthropogenic presence in the life of earth has created tremendous pressures on other life forms and matter. We need to conduct ourselves in a responsible way so that we nurture our Mother Earth as an abode of flourishing for all of us (Novacek 2011).[1] So, sustainable development involves responsibility, in fact a process of responsibilization. Sustainable development is also not just a noun, it is also a verb; in fact it is a manifold verb of action, meditation and transformation of self and society. Our engagement with sustainable development challenges us to move towards sustainable flourishing Jones (2010).

Fortunately for us, in the shifting discourses of sustainable development, we have some initiatives in new thinking and movements which present us sustainable development as a transformative process. We see this in the works of movements such as the degrowth movement, transition town movements, and visions and practices of scholars, such as Marcus Bussey, and scientists such as MS Swaminathan. In this chapter, I present a glimpse of their work and then discuss the challenges for transformation of self and society that realizing transformative sustainable development presents for us.

2 Sustainable Development as Transformative Quest in the Context of Climate Change

The current discourse on sustainable development owes its origin to initiatives such as the classic *Limits to Growth* and the United Nations Conference on Environment and Development in the 1970s (Meadows 1972). But sustainable development did not really challenge the growth paradigm of modernist development as a result of which we have witnessed the rise of a degrowth movement in vision and practice in European societies. While becoming mainstream, 'sustainability has been washed out of its more radical questioning of economic models' (Fournier 2008: 530). The degrowth movement challenges the growth paradigm of contemporary development and argues that unless we put a halt to economic

[1] In this context, what Yusoff and Gabrys (2011): 529 write deserve our careful consideration:

> […] there is a concurrent geographic imaginary that gestures towards the universal and the epic, that of the Anthropo scene: The Geological Age of Humans. The framing of human activity as a geomorphologic force summons up to the imagination what might be termed, after the French philosopher Michel Serres, 'the plates of humanity.' The destructive nature of these 'plates of humanity' to other forms of life raises questions about how we imagine and understand the collective human condition, the longevity and sustainability of Homo Sapiens, and the impact of humans on nonhuman [..] worlds.

growth we cannot realize sustainable development. 'The de-growth movement vigorously supports the 'post-development' critique' (Martinez-Allier 2010: 1745) and 'socially sustainable economic de-growth is a concept that is finding its way into social ecology, human ecology and ecological economics' (ibid). The de-growth movement has also been accompanied by the rise of transition town movements in Europe. In transition towns and ecological villages, inhabitants try to live in an ecologically sustainable way. They try to live with solar energy and other renewable sources of energy. As Anthony Giddens tells us: 'Part of the logic of ecotowns is to break dependence on the motor car […] For instance, local authorities have introduced congestion charges and traffic calming, and have banned cars altogether from some areas, thereby, encouraging people to put a positive value on walking or cycling' (Giddens 2009: 160). Cities like Malmo in Sweden are building energy-saving dwellings 'which cost no more to build than conventional homes, but use only a third of the energy required' (ibid: 159).

Alternatives emerging in degrowth and transition town movements can be read together with some other important contemporary visions and practices. Marcus Bussey, in his work on sustainability, presents us a layered concept of sustainability. Sustainable development here is not confined to the field of economic development only, and it embraces many fields and aspirations of our lives in self and society. Bussey presents us five categories of sustainability—physical, intellectual, emotional, ethical and spiritual. Bussey links moves towards sustainable development intimately connected with self-transformation as he writes: 'The only response is to take sustainability personally, to begin the slow process of remembering who we are and achieving the multi-layered strands that underpin an integrated sustainability that can generate transformative educational practice' (Bussey 2008: 144).

Adaptation is much talked about in the discourse of climate change and it has implications for our vision and practice of sustainability. But like sustainable development, adaptation is not a noun but a verb; it needs to be a meditative as well as transformative verb (Giri 2012). This resonates with what Giddens talks about as pro-active adaptation which is about 'designing and responding to vulnerabilities' in creative ways. Bussey et al. (2012: 387) also talk about the need to develop adaptive capacity and for them, 'Understanding adaptive capacity as the dynamic potential inherent in context can stimulate thinking about context that is free from habit and conditioning […].' Adaptive capacity is also a process of creative capacitation in which leadership, technology, imagination and institutions play an important role.[2] For Bussey and his colleagues, authoritarian leadership is likely to 'foster short-term maladaptive responses to climate change. Such leadership tends to reduce creativity and the sense of agency in its citizens, communities and institutions' (ibid: 391).

[2] We can link this to the vision and practice of capacitation initiated by Clodomoir de Santos in the field of education.

M.S. Swaminathan is a creative leader in science and institution building who has offered us new pathways of sustainable development. It may be noted that Swaminathan was the pioneer of green revolution in India, but now he pleads for an evergreen revolution which is sustainable and makes a transformative balance between economy and ecology. He now works for preservation of biological diversity and organic agriculture. In the context of climate change, he now works for a new kind of agriculture such as rice intensification (Swaminathan and Kesavan 2012).[3] Swaminthan argues for a new sustainability science which resonates with Bussey's outline for a new layered sustainable education. For Swaminathan, 'Sustainability science involves both anticipatory research, as for example, in the case of meeting the challenges of climate change, as well as participatory research and knowledge management with rural and tribal communities in order to ensure that the recommended practices are socially compatible and economically feasible' (Swaminathan 2011b: 116).

Swaminathan pleads for restoration of soil and making it fertile. He also pleads for a new climate care movement involving all the stake holders in the process. This climate care movement involves '…gene care conservation, climate literacy, appointment of local-level Community Climate Risk Managers and promotion appropriate mitigation and adaptation measures' (ibid: 17). From his research foundation, the M.S. Swaminathan Research Foundation (MSSRF), he adopts a community-based approach to sustainable development and creative responses to climate change. MSSRF works on community management and nurturance of mangrove forests in the coastal areas such as Pichavaram in Tamil Nadu. Here, in Pichavaram, along with saving of mangrove forests he works on building schools for the children. Thus, he writes: 'I told my colleagues that saving mangrove forest without saving children for whose well-being their forest were saved made no sense' (ibid: xi). He argues passionately for involving farmers in adopting creative responses to climate change.

> Farmers can help build soil carbon banks and at the same time improve soil fertility through fertilizer trees. Mangrove forests are very efficient in carbon sequestration. Biogas plants can help convert methane emissions into energy for the household. Hence, a movement should be started at global, national and local levels for enabling all farmers

[3] Swaminathan and Kesavan write about it:

> Since rice cultivation makes a large contribution to the release of green house gases, the adoption of a system of rice cultivation that does not require huge amounts of water and chemical fertilizers, with a proven track-record of much higher yields would be an effective solution. This is referred to as the System of Rice Intensification (SRI) which holds good for the most of the cultivated rice varieties. Above all, SRI greatly benefits small and marginal farmers with limited/little resources for chemical inputs such as fertilizers, pesticides, etc. Mitigation of methane emission from rice cultivation could also be by altering water management, particularly promoting mid-season aeration by promoting nerobic degradation through composting or incorporating it into soil during off season drained period, etc. (Swaminathan and Kesavan 2012: 4–5).

> with small holdings and a few farm animals to develop a water-harvesting pond, plant a few fertilizer trees and establish a biogas plant in their farms. I reiterate just these three—a farm pond, some fertilizer trees and a biogas plant—will make every small farm contribute to climate change mitigation, soil health enhancement, and water for a crop life-saving irrigation (ibid: 11).

In his work on sustainable development and climate change, Swaminathan pleads for a 'do ecology' which may also be called practical ecology in which we all practice an ecological way of doing, living, and production and consumption. This practical ecology may also be realized as part of what can be called practical spirituality (Giri 2011). Practical ecology, as part of practical spirituality, can give us what Swaminathan calls an ecology of hope in place of current regimes of destruction and despair (see Ikeda and Swaminathan 2005). Ecology of hope calls for transformation of poverty, on the one side, and greed and unsustainable consumption, on the other. Swaminathan also challenges us to realize biohappiness in place of conventional happiness which leads to unsustainable and uncreative lives which are helplessly bound to contemporary regimes of production and consumption. What Swaminathan writes here deserves our careful consideration.

> How can we define biohappiness? I would say it is the sustainable and equitable use of biodiversity leading to the creation of more jobs and income. When the use of biodiversity leads to sustainable livelihood security, the local population develops an economic stake in conservation. It means that growth and progress must be reliable and dependable and maintained at an even and steady pace. In farming it is the production of high yields in *perpetuity*, without associated social and ecological harm. Sustainable development must be firmly rooted in the principles of ecology, social and gender equity, employment generation, and economic advance (Swaminathan 2011a, b: ix).

In their different ways, both Swaminathan and Bussey plead for cultivation of a new language and new identity for sustainable development. For example, Swaminathan points out that crops like millet and bajra are called coarse cereals. But these crops can grow in many environments and with less consumption of water. In addition, they provide us more nutrition compared to rice and wheat. For Swaminathan, we should call these not coarse cereals but nutritious cereals (ibid). Resonating with this change of language, Bussey pleads for change of identity from one-dimensional productivist and consumption-trapped self to a layered self with an ecology of consciousness (Bussey 2008: 141).

Self-Development From the above the discourses and practices of a transformative sustainable development, we can realize that sustainable development is linked to creative self-development. It calls for transformation of self and its mode of production, consumption and living. In my related works, I have offered a multidimensional conception of self-development consisting of development of all the three overlapping dimensions of self—unconscious, techno-practitioner and transcendental (Giri 2006). Sustainable development calls for new imaginations and practices at the levels of all these dimensions. In sustainable development, the techno-practitioner self becomes a spiritually pragmatic self, trying to realize a deeper meaning of life in technology of self, society and science (Giri 2011).

Self-development also calls for the cultivation of a creative self and society. This is expressed in production, consumption, institutional matrix and intersubjective relations. In place of a short-term approach to production and consumption, we need to cultivate a long-term perspective. It is through creative technology of self and science that we transform our existing modes of production and consumption. Our creativity helps us overcome our bondage to the existing gods of consumption and find meaning in creative interpersonal relationships and social services. Such relationships help us overcome the tragedy and sufferings of isolated individualism and attendant narcissistic consumption. They constitute the bedrock of what Illich (1973) long ago called convivial society. Such creativity is linked to the nurturance, recovery and creation of the commons which create commons which is constituted of a plurality of communications that 'illuminates the worlds that are generative conditions of personhood—including ecological matrices' (Reid and Taylor 2010: 13). Furthermore, 'The commons need to be protected and preserved not only for the humans but also for the plants and birds, and yes, even the rocks and streams' (Cheri and Chhungi 2011: 484).

One important aspect of this creativity for sustainability is a new realization of time. In our present epoch, time has been made a servant to the production of capital and profit maximization which creates suffering in self and society. We have become slaves of time in which we do not have any time for creative conviviality for each other and society. But for sustainable development we need a new realization of pregnant temporality where time is not our anxiety-creating master as it is in the present systems of life but our mother. Our society and self nurture time in such a way that we are able to be creatively with time and, thus, give birth to the self and the other in new ways.[4] Pregnant temporality can create pregnant spatiality in which we can generate spaces of conviviality and togetherness for sustainable development. This is accompanied by a new poetics and music of sustainable self, societies, communities and cosmos. Furthermore, sustainable development also calls for a new ethics and aesthetics of self and society which may be called an aesthetic ethics of participation (Quarles van Ufford and Kumar Giri 2003).

[4] Making the link between a new temporality and sustainable education, Busssey also writes:

> I try to teach across time and beyond time. I, like the French philosopher Rousseau, have thrown away my watch. [….] The only response is to take sustainability personally, to begin the slow process of remembering who we are and activating the multilayered strands that underpin an integrated sustainability that can generate transformative educational practice (Bussey 2008: 143–144).

3 Social Transformations

Initiatives in multi-dimensional self-development find a resonance in appropriate social transformations for sustainable development. Linking to the earlier discussion on community and commons, Prafulla Samantara writes: 'Sustainable development is dependent on and, therefore, should promote service-based commons like food production and consumption, common school education and health. Developing physical natural commons together with reform social organizations and structure of communities is a prerequisite' (Samantara 2011: 124). Samantara is involved with struggles for land rights and dignity of tribals and the marginalized in Odisha, India. Preserving and transforming commons for sustainable development calls for transformation in the very language of commons and our contemporary discourse and organization of property.[5]

M.P. Parameswaran is the founder of Kerala Sastra Sahitya Parishada (KSSP) in Kerala, India. He is an inspiring example of a creative leader that Bussey would consider crucial for sustainable development (see Giri 1998). KSSP started its work in popularizing science and creating a people's science movement in Kerala. It had struggled to save the Silent Valley in Kerala, a storehouse of biodiversity, which was to be destroyed by the building of a large dam in the area. KSSP had protested against this and Dr MS Swaminathan, whose work we had discussed briefly above, was the Secretary of the Department of Agriculture of Government of India. From within the Government Dr Swaminathan lent crucial support to the struggle of KSSP and, as a result, the Government decided not to build the big dam and the Silent Valley was saved. Recently, KSSP has been focusing on sustainable development and organic agriculture. Parameswaran (2012: 93) writes about it.

> A decade and half ago, the KSSP carried out an experiment: a *sangha swapna* or collective dreaming exercise. About sixty leading activists of one panchayat—Madakkathara village

[5] As Cheri and Edwin tell us:

> An appropriate vocabulary and language of the commons are essential for the health of the surviving commons. At present the dominant paradigm is so pervasive that the language of property is used to describe and regulate the commons. In many cases, there is no vocabulary to describe and, therefore, the language of property is imported and deployed. Even those with legitimate constitutional backing term restoration of commons as encroachment or, in the case of MST Brazil, as 'invasions.' These should instead be seen and named as land restoration and liberation. It is only then that the legitimacy of retrieving the commons for commonness is affirmed with the empowering knowledge of legitimacy. This is the required 'vocabulary of commoning' needed for the active process of returning the resources to the commons and the commons to the community of commoners (2011: 515).

Cheri and Edwin use the term communing which challenges us to realize commons as a verb and it is in tune with what social theorist Laurent Thevenot calls '…composition of commonality: which further challenge us to go beyond the all-embracing liberal grammar and other grammars of commonality' (Thevenot 2012: 19).

> panchayat in Thrissur district—sat together to articulate their hopes and aspirations about the nature of their panchyat 25 years thence. At the end of the dreaming conclave they came up with a written report on their development perspective. They shared this dream with about 2000 citizens, took inputs from them and, finally, prepared a 25-year perspective plan. This perspective plan envisaged the following [among others: here I am presenting only some aspects of the plan which pertain to sustainable development].

1. Full utilization of all cultivable land to yield maximum possible production in a sustainable manner.
2. Recycle all the locally generated organic waste
3. To procure all the biodegradable waste from the neighboring municipal corporation and convert it into organic manure to improve soil nutrients
4. To have complete and scientific management of water as part of the command area of Peechi irrigation system
5. To go for large scale precision agriculture and, thereby, increase the efficiency of utilization of organic fertilizers and waters
6. To develop integrated animal husbandry of milk and meat animals like cow and goat; waste to food converters like pigs, poultry and fish and, thus, become self-sufficient in milk, meat, eggs and fish to ensure food self-sufficiency.
7. To ensure opportunities for economic activities (self as well as wage employment) for all those willing to work, so that livelihood related long distance travel is reduced to a minimum and as also transportation for goods of consumption.
8. To set up industries to manufacture as many items of daily use as possible within the panchayat, as well as to share with neighboring panchayat items requiring large-scale production.
9. To boycott all transnational, corporate products, wherever a near equivalent 'local' product can be produced.
10. To stop consuming goods which have only vanity value or destructive value

[…]

11. To provide pedestrian walkways and cycle paths

[…]

12. To reduce their [people's] carbon footprint continuously to zero by embarking upon an ambitious programme for carbon sequestration.

The above pathways towards sustainable development emerged out of a project of collective dreaming which reiterates the significance of new collective imagination. But this new imagination calls for transformation of existing systems of production, consumption, economy and polity. These proposals resonate with some of the earlier proposals towards sustainable life presented by Gandhi as well the noted Gandhian economist JC Kumarappa, who had challenged us to create an economy of permanence (see Bandhu 2011). These proposals also resonate with contemporary articulations for transformations coming from many quarters. Nadia Johanisova and Stephan Wolf argue, for instance, for the co-operative organization of economy and economic democracy as crucial to realizing sustainable development (Johanisova and Wolf 2012: 564). They also challenge us to realize the need to nurture diversity of scales and plurality of production modes. They also reiterate the significance of ecological tax reform: 'Ecological tax reform (which entails higher taxation of material and energy capital consumption and lower taxation of work) could help internalize the environmental externalities of large corporations as well as consumer behaviour' (ibid).

4 Planetary Realizations

Sustainable development calls for a new relationship with our Mother Earth, a new mode of living with our Mother Earth. It challenges us to realize, as Thomas Berry had invited us to, realize the dreams of our mother Earth (Berry 1990). For Berry, all our modern knowledge systems are deployed to exploit the resources of Mother Earth for our own narrow goals rather than for nurturing and taking care of our Mother Earth. Planetary realizations challenge us to transform such an exploitative relationship and embody a relationship of responsibility and care. This calls for a new way of life what Indian thinker Subash Sharma calls a New Earth Sastra (Sharma 2012). For Sharma, a new Earth Sastra brings Higher Consciousness to the world of economics to create inclusive and sustainable development. It also challenges us to nurture our soil and soul in a creative manner so that it creates sustainable flourishing of self and society. But our soil and soul also meet in a tired and wounded sole where feet, with which we walk with our Mother Earth, are wounded and poisoned by the forces of unsustainable development.[6] So we would have to heal our wounded soles, restore our soil and souls as part of a new trigonometry of regeneration of sole, soil and soul for transforming acquiescent sustainable development to a manifold art and mode of sustainable flourishing of life, self and society.

---

[6] The Hindu carried a photograph under the title 'Sole of the Nation' on 12 September 2012 depicting the water wounded feet of the people doing *satyagraha* by standing under water and protesting against the rise of the height of Narmada dam in Madhya Pradesh, India.

References

Bandhu P (ed) (2011) Back to the basics: A J.C. Kumarappa Reader. Odyssey, Udhgamandalam
Berry T (1990) The dream of the earth. Sierra Club Books, San Francisco
Bussey M (2008) Embodied education: reflections on sustainable education. Int J Environ Cult Econ Soc Sustain 4:139–147
Bussey M et al (2012) Framing adaptive capacity through a history-future lens: lessons from the south east Queensland climate adaptation research initiative. Futures 44:385–397
Cheri A, Chhungi H (2011) The sacred commons: the use, misuse and abuse of religion and spirituality. Found Ecol Secur, pp 475–490
Cheri A, Edwin X (2011) Challenges of modernity. Found Ecol Secur 2011:515–583
Fournier V (2008) Escaping from the economy: the politics of 'Degrowth'. Int. J. Sociol. Soc. Policy, vol 28
Jones P (ed) (2010) Sustainability education: perspectives and practices across higher education. EarthScan, London
Johanisova N, Wolf S (2012) Economic democracy: a path for the future? Futures, vol 44, issue 6
Giddens A (2009) The politics of climate change. Polity Press, Cambridge
Giri AK (1998) The portrait of a discursive formation: science as social activism in contemporary India. In: Idem, global transformations: post modernity and beyond. Rawat Publications, Jaipur
Giri AK (2006) Creative social research: rethinking theories and methods and the calling of an ontological epistemology of participation. Dialect Anthropol
Giri AK (2011) Practical spirituality and human development. Special issue, IBA J Manag, Bangalore
Giri AK (2012) Beyond adaptation and meditative verbs of co-realizations—in idem, sociology and beyond: windows and horizons. Rawat Publications, Jaipur
Ikeda D, Swaminathan MS (2005) Revolutions: to green the environment, to grow the human heart. East West Books Chennai
Illich I (1973) Tools for conviviality. Fontana/Collins, New York
Martinez-Allier J (2010) Sustainable de-growth. Ecol Econ
Novacek P (2011) Sustainable development. Palacky University of Olomouc Press, Olomouc
Meadows DH (1972) Limits to growth. Signet, London
Parameswaran MP (2012) Musings of a people's science activist. Seminar 637:88–93
Quarles van Ufford P, Kumar Giri A (eds) (2003) A moral critique of development: in search of global responsibilities. Routledge, London
Reid H, Taylor B (2010) Recovering the commons: democracy, place and global justice. University of Illinois Press, Urbana
Samantara P (2011) "Rural commons: a source of livelihood and sustainability." In: vocabularies of the commons (eds) Foundation for Ecological Security 2011, Anand, Foundation for Ecological Security, pp 107–126
Sharma S (2012) New Earth Sastra: Towards Holistic Development and Management (HDM). IBA Publications, Bangalore
Sivaraksha S (2009) The wisdom of sustainability: Buddhist economics for the 21st century. Silkworm Books, Bangkok
Swaminathan MS (2011a) In search of biohappiness: biodiversity and food health and livelihood security. World Scientific, Singapore
Swaminathan MS (2011b) Sarvodaya or Sarvanasha. Ahimsa Nonviolence VII 4:221–223
Swaminathan MS (2012) To the hungry, god is bread. Tapasya Summer
Swaminathan MS, Kesavan PC (2012) Agricultural research in an era of climate change. Agric Res 1(1):3–11
Thevenot L (2012) Bounded justifiability: making commonality on the basis of binding engagement. Manuscript
Yusoff K, J Gabrys (2011) Climate change and the imagination. Wiley Interdisc Rev Clim Change 2(4):516–534

Biofuels Utilisation: An Attempt to Reduce GHG's and Mitigate Climate Change

Ashwani Kumar

1 Introduction

Use of biomass for energy and industry allows a significant quantity of hydrocarbons to be consumed without increasing the CO_2 content of the atmosphere and, thus, makes a positive contribution to the Greenhouse effect and to the problems of 'global change' as it occurs in both industrialized and developing countries (Kumar 2008, 2011a). Climate change is any long-term significant change in average temperature, precipitation and wind patterns. It takes place due to emissions of greenhouse gases. Carbon dioxide (CO_2) is the most important greenhouse gas and increasing the use of biomass for energy is an important option for reducing CO_2 emissions. Carbon dioxide emission is projected to grow from 5.8 billion tonnes carbon equivalent in 1990 to 7.8 billion tonnes in 2010 and 9.8 billion tonnes by 2020 (Fig. 1).

The Kyoto conference agreement indicates the role clean energy sources will play in future. Biomass is renewable, non pollutant and available worldwide as agricultural residues, short rotation forests and crops. Thermochemical conversion using low temperature processes are among the suitable technologies to promote a sustainable and environmentally friendly development. Biomass can play a dual role in greenhouse gas mitigation related to the objectives of the United Nations Framework Convention on Climate Change (UNFCC), i.e., as an energy source to substitute for fossil fuels and as a carbon store. The fact that nearly 90 per cent of the world's population will reside in developing countries by 2050, probably, implies that local solutions for energy needs will have to be found to cope up with the local energy needs, on the one hand, and environment protection, on the other hand (Table 1). Biomass should be used instead of fossil energy carriers in order to

A. Kumar (✉)
Energy Plantation Demonstration Project Centre, Department of Botany,
University of Rajasthan, Jaipur 302004, India
e-mail: ashwanikumar214@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_13,

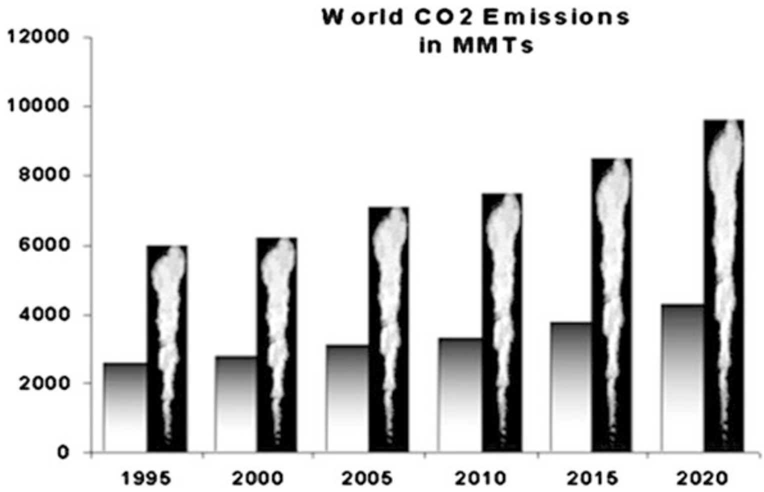


Fig. 1 Increasing levels of carbon dioxide in million metric tonnes (*Source* Kumar 2001a)

Table 1 Future trends of population growth (in billion people)

	1990	2020
World	5.2	7.9
EU	0.36	0.38
DCs	4	6.4

reduce (1) CO_2 emissions (2) the anticipated resource scarcity of fossil fuels and (3) need to import fuels from abroad (Kumar 2001b).

1.1 Global Land Availability and Biomass Production

Global land availability estimates for energy crop production vary widely between 350 and 950 million hectares (Alexandratos 1995). Biomass resources are potentially the world's largest and sustainable energy source, a renewable resource comprising 220 billion oven dry tones (about 4500 EJ) of annual primary production. The annual bio-energy potential is about 2,900 EJ though only 270 EJ could be considered available on a sustainable basis and at competitive prices. Current commercial and non-commercial biomass use for energy is estimated at between 20 and 60 EJ/annum representing about 6–17 % of the world's primary energy. Most of the biomass is used in developing countries, where it is likely to account for roughly one third of primary energy. As a comparison, the share of primary energy provided by biomass in industrialized countries is small and is estimated at about 3 % or less (Fig. 2). Agriculture and allied sectors contribute nearly 22 % of the Gross Domestic Product (GDP) of India, while about 65–70 %

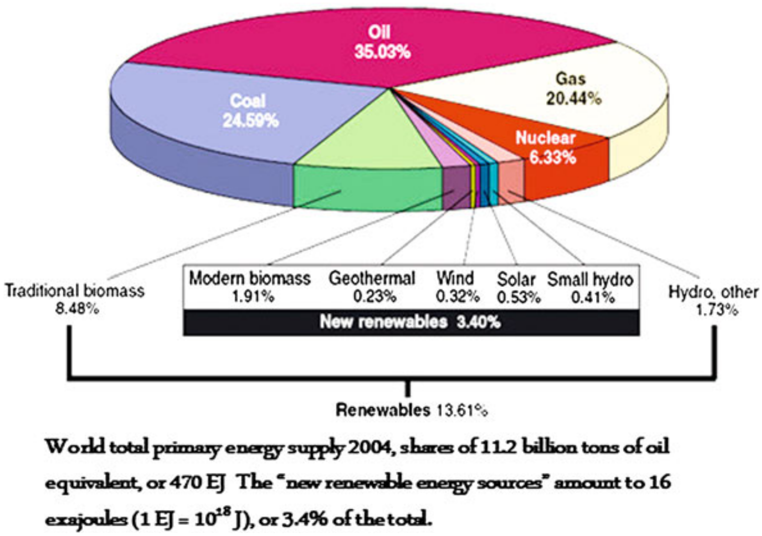


Fig. 2 World's total primary energy supply

of the population is dependent on agriculture for their livelihood. The agricultural output, however, depends on the monsoon as nearly 60 % of area sown is dependent on rainfall. Most of the population dependent on agriculture in India uses biomass for fuel in open *chulhas* (fire stoves) with poor fuel efficiency and lot of smoke generation causing serious asthmatic problems in rural women and children.

1.2 Advantages of Using Biofuels

There are several advantages of using biofuels: biodiesel burns up to 75 % cleaner than petroleum diesel fuel. Biodiesel reduces unburned hydrocarbons (93 % less), carbon monoxide (50 % less) and particulate matter (30 % less) in exhaust fumes, as well as cancer causing PAH (80 % less) and nitrited PAH (90 % less) compounds (US Environmental Protection Agency), and Sulphur dioxide emissions are eliminated (biodiesel contains no sulphur). Biodiesel is plant-based and using it adds no extra CO_2 greenhouse gas to the atmosphere. Nitrogen oxide (NO_2) emissions may increase or decrease with biodiesel but can be reduced to well below petro-diesel fuel levels. Biodiesel exhaust is not offensive and doesn't cause eye irritation.

Biodiesel can be used in any diesel engine without modification. Biodiesel can be mixed with petro-diesel in any proportion, with no need for a mixing additive. Biodiesel has a higher **cetane** number than petroleum diesel because of its oxygen content. The higher the **cetane** number the more efficient the fuel—the engine starts more easily, runs better and burns cleaner. With slight variations depending on the vehicle, performance and fuel economy with biodiesel is the same as with petro-diesel. Biodiesel is a much better lubricant than petro-diesel and extends engine life—even a small amount of biodiesel means cleaner emissions and better engine lubrication: 1 % biodiesel added to petro-diesel will increase lubricity by 65 %. The ozone-forming (smog) potential of biodiesel emissions is nearly 50 % less than petro-diesel emissions.

1.3 EU Mandate

Worldwide production of biodiesel increased by 60 % in 2005, and ethanol by 19 % over the previous year's production, as per World watch Institute, USA. The EU mandated that three times more than the current level of 2 % of the total energy content of petrol and diesel needs to come from renewable fuels. Countries like Thailand are aiming for a 10 % renewable mix in the next five years; India 20 % by 2020. Sweden has stated that it aims to become 100 % independent by 2020; most of this independence will come through its own nuclear power, but renewable fuels will likely make up the balance.

1.4 Hypothesis

1. Photosynthetic organisms use solar energy to generate reducing equivalents and incorporate atmospheric CO_2 into organic molecules.
2. Different plant species can provide biomass and biofuel in a three tier system developed by us (Kumar 2001a):
   a. Tree species of fast growing nature can be used as uppermost tier of biomass.
   b. Hydrocarbon yielding plants can make the lowest tier and hydrocarbons from plants can be converted to bio-diesel.
   c. Non edible oil yielding plants can be used to obtain biodiesel and they make the middle level of biomass production.
3. Conversion of lignocellulose plant material and waste for production of biomass.
   a. Carbon captured in cellulosic biofuels.
   b. Algal biodiesels are prominent biological approaches to sequester and convert CO_2.
   c. Lipid productivity of many algae greatly exceeds that of the best cellulosic ethanol production and can be used for biomass production.
4. Genetic engineering approach.
5. Direct conversion of CO_2 to fuels or chemicals.

1.5 Biofuels Available

Bioethanol, Biobutanol, Biodiesel, Vegetable oils, Biomethanol, Pyrolysis oils, Biogas, Biohydrogen.

Biodiesel: Technically, *Mono-alkyl esters of long chain fatty acids* derived from renewable lipid feedstock such as vegetable oils and animal fats *for use in Compression Ignition engines*. The definition eliminates pure vegetable oils.

Depending on the feed stock it may be referred as:

- Soybean methyl ester—SME or SOME
- Rape methyl ester—RME
- Fatty acid methyl ester—FAME (a collective term including both of the above).
- Vegetable oil methyl ester—VOME yielding plants provide bio-diesel.

1.6 Present Status and Future Prospects

A. Wood, wood chips agriculture waste to Briquetting, Gassifier, Vacuum pyrolysis or Bio-gas, heat and electricity generation.
B. Oil to trans-esterification to obtain Fatty acid methyl ester (FAME), e.g., Rape seed methyl ester (RME).
C. Liquid hydrocarbons to hydro-cracking—cracking of tri-terpenoid chain and adding of hydrogen using zeolite catalyst in bio-refinery.

1.7 Next Generation Biofuels

- Lignocellulosic biofuels made from the lignin and cellulose in the cell walls of plants.
- The feedstocks for these biofuels—trees, grasses, or leftover plant materials—have several potential advantages.
- Require less intensive agriculture and may be grown on 'marginal' land, reducing competition for resources.
- Could be made from agricultural or forestry residues such as rice husks and corn stover.
- UN report estimated:
- Biofuels commercialized by 2015.
- Competitive with petroleum-based fuels by 2025–2030.

Second and third generation biofuels: Altering host material and/or developing new enzyme systems.

a. Metabolic engineering for entire product

b. Industrial application of biofuel inclusive of related bio products of commercial value from fourth generation products.

Fourth generation biofuels: Direct conversion into biofuel from air or genetic engineered systems or from water through hydrogen production etc.

1.8 Objectives of Study

a. First generation biofuels: Developing first generation biofuel crops to be grown in semi arid regions on wasteland.
b. Laticiferous crops: Euphorbiaceae, Asclepiadaceae, Compositae, family members containing latex as biofuel crops. Strategy to develop their agro-technology. Biomass conversion studies in collaboration with IIP, Dehradun.
c. Collection and evaluation of high yielding *Jatropha curcas* from different locations in Rajasthan—Germ plasm collection, evaluation in collaboration at TERI, New Delhi, raising stock material in nursery from elite samples.
d. Agronomical and multi-locational trial of selected genotypes.
e. To standardize nursery techniques for large scale planting material *in vivo* and *in vitro*.
f. To demonstrate the agro-forestry practices for cultivation of *Jatropha curcas* in wastelands and standardization of the growth parameters for improvements.
g. To generate information on economics of production costs for different regions.
h. To establish pilot plant for extraction of biodiesel.

2 Methodology

2.1 Growth and Cultivation of Biofuel Plants

Certain potential plants were selected and attempts were made to develop agro-technology for their large scale cultivation (Kumar 1984, 1994, 1995, l996, 1998; Kumar et al. 1995; Roy and Kumar 1998). A 50 ha bio-energy plantation demonstration project centre has been established on the campus of the University of Rajasthan to conduct the experiments on large scale cultivation of selected plants with the objective of developing optimal conditions for their growth and productivity, besides conserving the biodiversity.

Next generation bio-fuels shall involve technical components:

a. Biological sciences: Plant biotechnology, Cellular and molecular biology, microbial/industrial biotechnology.
b. Chemical technology sciences: catalysis, reaction engineering and separations.

2.2 Bioethanol Production

- The acid pre-treatment of lignocellulosic biomass for biofuel ethanol production not only enables the release of monosaccharides, but also generates several types of compounds, which are inhibitory to yeast.
- Furans, like 5-hydroxymethylfurfural (HMF) and furfural, are known to inhibit yeast growth and viability and to reduce ethanol productivity.
- Thus, faster conversion rates of HMF and furfural are desirable.
- Yeast strains are naturally able to slowly reduce HMF and furfural to less toxic compounds, however the rate of inhibitor conversion and cofactor utilization are strain dependent (*NADPH-dependent)*.
- Dehydrogenase responsible for HMF conversion in *S. cerevisiae*.

3 Results

3.1 Development of Biofuel Resources

During the last 30 years we have carried out significant investigations on biofuels which are summarized here only in brief. Some of the important findings of the research work carried out by contemporary researchers and future projects are also reviewed. This chapter presents original results as well as review of research work being carried out in the field.

The selection of biofuel material is of utmost importance. Initial studies of Calvin (1979) concentrated on laticiferous plants. Melvin Calvin in 1980 suggested to me that to try the laticiferous plants in Rajasthan, where the climate is broadly similar to Arizona desert in several respects. We commenced work on laticifers in 1980 itself and at that time Department of Non-conventional energy sources (DNES) which was later on elevated to Ministry of Non-Conventional Energy Sources supported research projects to us to carry out researches on biofuels in 5 ha area to begin with which was raised to 50 ha energy demonstration project center (EPDPC). *Euphorbia lathyris* and *Euphorbia anitsyphilitica*, *Pedilanthus tithymaloides*, *Calotropis procera, Euphorbia* royleana, and *Euphorbia caducifolia* were investigated in detail. During this period (1970–1990) active research was carried out in India, USA, Australia and Japan (Kumar 1984, 2001a, 2008 and 2011).

Out of 600 plants screened, around 12 plants were selected for intensive studies. Two plants, viz., *Calotropis procera*, *Euphorbia antisyphilitica* were selected for detailed investigations. *Calotropis procera* grows wild while *Euphorbia antisyphilitica* has been introduced from Mexico. Detailed studies have been conducted on the growth and cultivation and improvement of hydrocarbon contents of *Calotropis procera* and *Euphorbia antisyphilitica*. 12 accessions of *Calotropis* *procera* were analysed and their growth parameters studied at the Energy Plantation Demonstration Centre, University of Rajasthan, Jaipur, under the Department of Biotechnology project Agrotechnology for their improved growth and hydrocarbon yield potential has been documented by Department of Biotechnology in their report (Kumar 2007).

3.2 Hydrocarbons from Plants

Some of the laticiferous plants identified by Bhatia et al. (1983) were investigated in detail at Jaipur (Kumar 1995, 2000, 2001b; Kumar et al. 1995). Certain potential plants were selected and attempts were made to develop proper agro-technology for their large scale cultivation. Initially, work was initiated on 5 ha and subsequently extended to the 50 ha EPDPC. In this paper a review of work done is presented in brief.

The work done included

1. Hydrocarbon yielding plants,
2. High molecular weight hydrocarbon yielding plants,
3. Non edible oil yielding plants.

Hydrocarbon yielding plants include: (1) *Euphorbia lathyris* Linn., (2) *Euphorbia tirucalli*. Linn., (3) *Euphorbia antisyphilitica,* Zucc., (4) Euphorbia caducifolia Haines., (5) *Euphorbia neriifolia* Linn, (6) *Pedilanthus tithymaloides* Linn, (7) *Calotropis procera* (Ait.) R.Br., (8) *Calotropis gigantea* Condensed by (Linn) R.Br.

High Molecular Weight Hydrocarbon Yielding Plants: *Parthenium argentatum* Linn.

Non edible oil yielding plants include: (1) *Jatropha curcas*. (2) *Simmondsia chinensis*.

Considerable work has been carried out on these plants (Kumar and Roy 1996; Roy and Kumar 1990, 1998; Kumar 1994, 1995). Investigations on several plant species have been carried out at our centre including *Euphorbia lathyris* (Garg and Kumar 1989a, b, 1990, 1987a, b, c) *Euphorbia tirucalli, Euphorbia antisyphilitica* (Johari et al. 1990, 1991) *Pedilanthus tithymaloides* (Rani and Kumar 1994; Rani et al. 1991); *Calotropis procera* (Rani et al. 1990); *Euphorbia neriifolia* and *E. caducifolia* (Kumar 1994, 1990); *Jatropha curcas* (Roy 1996; Roy and Kumar 1990) and *Simmondsia chinensis.* The following aspects have been studied in detail:

Propagation

Regarding environmental variations, the March to October period was best suitable for *E. antisyphilitica* because a linear increase in growth was recorded in this period (Kumar 1990). During these months, maximum sprouting was observed in *Pedilanthus tithymaloides, E.antisyphilitica* and *E.tirucalli*. Cuttings measuring around 15 cm in length and 1 cm in diameter gave optimal growth. Seeds of *Jatropha curcas* and *E. lathyris* also showed maximum germination during these months. Overall growth and productivity was lowest in the winter months from November to February. Higher accumulation of hexane extractables corresponded with higher temperatures of the summer season (Johari and Kumar 1992).

Edaphic factors

Among different soil types sand was best for the growth of *E. lathyris* (Garg and Kumar 1990) and *P. tithymaloides* (Rani et al. 1991) while red loam soil was best for *E. antisyphilitica.* However, for *E. lathyris* latex contents were maximum on sand gravel. Red soil was rich in nitrate, sodium, potassium and phosphorus pentaoxide (Johari and Kumar 1992). *E. antisyphilitica* plants were relatively tall in sandy soil and less branched as compared to red soil. Plants grown in red soil branched more instead of increasing much in height. When different combinations of these soil types were made, biomass of *E.antisyphilitica* was maximum in red loam+sand+gravel (Johari et al. 1990). While the red loam+sand combination in equal amounts was best for *P.tithymaloides* (Rani et al. 1990). A mixture of gravel+sand favored maximum increase in plant height fresh weight and dry weight in *E. lathyris* (Garg and Kumar 1990; Kumar and Garg 1995). Environmental factors influenced the growth and yield of *Calotropis procera* (Rani et al. 1990).

Fertilizer application

Application of NPK singly or in various combinations improved growth of all the selected plants. In general, NP combination gave better growth which was only slightly improved by the addition of K for *E. tirucalli.* When best doses of NPK were applied in different combinations like NP, NK, KP and NPK, the last combination gave best results in the form of biomass, latex yield, sugars and chlorophyll in *E.lathyris* (Garg and Kumar 1990) and *P. tithymaloides* (Rani and Kumar 1994). In *E. antisyphilitica*, however, NP combination gave best results, followed by NPK for biomass production. Chlorophyll, sugars and latex yield was best in combination (Johri and Kumar 1993).

Addition of farm yard manure (FYM) alone and in combination with urea improved the growth and productivity of *E. antisyphilitica*, E. lathyris (Kumar and Garg 1995), FYM+Urea application improved the productivity in comparison with FYM application alone. In *E.lathyris* addition of FYM increased the plant height fresh weight and dry weight to varying degrees. Hexane and methanol extractables also increased (Garg and Kumar 1986, 1987c). Salinity stress studies were also made on *Euphorbia tirucalli.* Salinity was applied in the form of irrigation water. Lower concentrations of salinity improved plant growth of *E. antisyphilitica* (Johari et al. 1990) but higher concentrations inhibited further increase in growth. Sugars, however, did not increase in any saline irrigation. A slightly higher level of salinity also impaired chlorophyll synthesis. At higher level of salinity, leaves of *E. antisyphilitica* became yellow and fell down but the stem did not show any visible adverse effects. *E. lathyris* could also tolerate lower salinity levels but its tolerance was lower than *E. antisyphilitica*. In *E. lathyris* salinity adversely affected root growth (Johari et al. 1990). *P. tithymaloides* also exhibited increases in biomass and yield at lower salinity levels and higher concentrations adversely affected the plant. Its underground part could tolerate slightly higher salinity concentration (Rani et al. 1991). Saline irrigation was also given with different percentage of FYM added in the soil. Both *E. antisyphilitica* and *P. tithymaloides* exhibited tolerance of higher salinity levels with increasing percentage of FYM in the soil, biomass sugars, bio-crude and chlorophyll all increased in proportion with increasing FYM levels in the soil and along with saline irrigation. It was found in *Euphorbia lathyris* that up to a certain level FYM causes increase in overall growth and yield along with different concentrations of saline irrigation. Beyond a certain level, increased FYM did not improve growth and productivity. *P. tithymaloides* required still higher percentage of FYM in the soil for best yield and biomass. Lower salinity levels increased the sugar contents in sand. Higher saline concentrations adversely affected the chlorophyll contents but with increase in manure supply the chlorophyll accumulation was promoted in *P. tithymaloides.* Above ground plant biomass improved significantly with increasing percentages of Field Capacity, maximum being 100 % FC irrigation. In *E. antisyphilitica* as well as in *P. tithymaloides* plant height also increased linearly with increasing soil water status. However, underground length was found to increase up to a certain level only. Irrigation beyond an optimum level tended to reduce bio-crude, sugar and chlorophyll in *E. antisyphilitica.* In *P. tithymaloides* lowest FC gave maximum yield of HE and chlorophyll. Sugar, however, increased with increasing levels of field capacity irrigation. Per cent dry matter yield also decreased with increasing the quantity of irrigation water to the soil in *E. antisyphilitica* and *P. titymaloides* (Rani and Kumar 1994).

Application of growth regulators

Exogenous application of growth regulators has been reported for several horticultural and ornamental plants and sugarcane. In *Euphorbia antisyphilitica*, in the present experiment, maximum plant height was observed with GA3, followed by CCC, NAA, 2, 4, 5-T and IAA treatment. Spray of growth regulators resulted in enhanced fresh and dry weight production (Johari and Kumar 1994). However, bio-crude synthesis occurred more with the auxins NAA and IAA in *E. antisyphilitica*. Out of all the growth regulators employed on *P. tithymaloides*, IAA supported maximum plant growth in terms of fresh weight and dry weight of above ground and underground plant parts.

2, 4, 5-T showed minimum plant growth, and certain nodular structures were observed on the stem of the plants. Bio-crude yield was best in IAA, followed by 2, 4, 5-T, GA3, CCC, NAA, and control. Application of growth regulators on *P. tithymaloides* resulted in a slight decrease in chlorophyll, whereas, on *E. lathyris* they induced favourable results regarding chlorophyll (Garg and Kumar 1987d). In *E. lathyris* IBA caused maximum fresh weight productivity followed by IAA, GA3 and NAA. NAA sprayed plants exhibited more production of HE. A favourable influence of growth regulators was also observed in sugar yield maximum with NAA followed by IBA, GA3 and IAA (Garg and Kumar 1987c). The cultivation of these plants suffers from plant pathogenic diseases affecting at the root level. Investigations on pathogenicity and control aspects of Charcoal rot of *E. lathyris* (Garg and Kumar 1987c); *E. antisyphilitica* (Johri and Kumar 1993) were also carried out.

Micropropagation

Plant tissue culture has been successfully employed to achieve rapid clonal propagation of *E. lathyris* (Garg and Kumar 1987b); *Pedilanthus tithymaloides* (Rani and Kumar 1994) and *E. antisyphilitica* (Johari and Kumar 1994). Likewise, propagation of jojoba has also been carried out. *Jatropha curcas* L. is potential diesel fuel yielding plant and details about this are given in Roy and Kumar 1998.

Development of wasteland

A protocol was set up for developing the wasteland following the three tier system in which small shrubs, shrubs and trees were used at a close spacing and this yielded a dry matter production of over 40 dry tonnes in a three year rotation. The *Euphorbia antisyphilitica* in the lower tier, *Jatropha curcas* in the middle tier and *Acacia tortilis* in the upper tier were used to colonize the EPDPC. The picture below represents the area as seen originally in Figs. 3 and 4 which has been developed at EPDPC as Greenland from the wasteland (Figs. 5, 6, 7, 8, 9, 10, 11, 12, 13, 14).

The possibility of conversion of biomass into liquid fuels and electricity will make it possible to supply part of the increasing demand for primary energy and, thus, reduce crude petroleum imports which entail heavy expenditure on foreign exchange. The families Euphorbiaceae (*Euphorbia antisyphilitica, E.tithymaloides,*

Fig. 3 Energy Plantation Demonstration Project Centre (EPDPC), University of Rajasthan, Jaipur, 1984. Barren land with only one tree (*Holoptelia integrifolia*)

Fig. 4 Another view of wasteland at EPDPC. Pitting was done at 1 × 1 m for plantation

Fig. 5 *Euphorbia antisyphilitica* nursery stage, with close spacing

Fig. 6 *Calotropis procera* a hydrocarbon plant used to colonizes

E. caducifolia E. royleana E. neerifolia etc. and Ascelpiadaceae (*Calotropis gigantea* and *C. procera)* which have been worked out in previous years (Kumar 2000) will form the basis for further studies.

Fig. 7 *Euphorbia tirucalli*

Fig. 8 *Euphorbia caducifolia*

Fast pyrolysis is a promising pre-treatment technology that converts solid biomass into an easier to transport and to process liquid energy carrier. One of the advantages of the fast pyrolysis process is that it produces a liquid fuel with a high energy density of ca. 22 GJ/m^3 compared to ca. 6 GJ/m^3 for wood chips. This is beneficial, especially when biomass resources are remote from where the energy is required: the liquid can be readily stored and transported. Another pro of pyrolysis is that the liquid product is cleaner than the original feedstock. Minerals and metals

Fig. 9 *Euphorbia neriifolia*

Fig. 10 *Jatropha curcas* and *Calotropis procera* in background

Fig. 11 *Euphorbia antisyphilitica* and *Calotropis procera*

Fig. 12 *Euphorbia antisyphilitica* and *Jatropha curcas* in background

Fig. 13 Three tier system with *E.antisyphilitica* in foreground and *Acacia tortilis* in background

Fig. 14 A well developed EPDPC following the three tier system

in the feedstock become concentrated in the solid by-product (char), because of the relatively low process temperature (ca. 500 °C).

Biofuels hold out the promise of a win-win solution

- Biofuels will reduce greenhouse gas emissions, promote energy independence, and encourage rural development.

- This enthusiasm translates into significant government support. Annual global subsidies for biofuel production were $11 billion in 2006 and could rise to $50 billion by 2020.
- Many governments have enacted new pro-biofuel policies in recent years. Developed country governments like the UK and EU have set consumption targets for biofuels

Next generation biofuels can reduce negative impacts.

- The first to arrive will be lignocellulosic biofuels made from the lignin and cellulose in the cell walls of plants.
- The feedstocks for these biofuels—trees, grasses, or leftover plant materials—have several potential advantages.
- They require less intensive agriculture and may be grown on 'marginal' land, reducing competition for resources.
- Lignocellulosic biofuels could be made from agricultural or forestry residues such as rice husks and corn stover.
- A 2007 UN report estimated that these biofuels would be commercialized by 2015 and become competitive with petroleum-based fuels in the next 10–15 years.

3.3 *Jatropha curcas*

Jatropha grows wild in south east Rajasthan which lies on the south east side of Aravalli hill range which roughly divides the state into semi-arid and arid regions. *Jatropha curcas* is now being extensively grown in India under the Department of Biotechnology supported micro mission projects with an object to identify, characterize and multiply high yielding strains and study their growth and productivity under different agro climatic conditions. The districts of Banswara, Bhilwara, Udaipur, Pali, Rajsamand, and Sirohi have huge strands of Jatropha growing under natural conditions. A detailed survey was carried out in these areas. 98 accessions were collected and analyzed for their oil contents. Four accessions having oil contents more than 35 % were selected for multiplication at the Energy Plantation Demonstration Centre, University of Rajasthan, Jaipur, under a Department of Biotechnology supported micro mission programme(Kumar 2011b).

Nursery techniques for large scale plantation of elite strains have been developed. An area of 35 ha has been planted with *Jatropha curcas* with the high yielding strains identified during the course of investigation. The plants have shown great degree of genetic diversity. The morphological parameters have been employed to characterize initial growth of the plants in the nursery stage. Some of the plants, in their second year of growth, have shown flowering and fruiting during the months of September to January. Application of fertilizers and proper irrigation schedule has improved the growth and productivity of plants. A detailed survey was carried out in Udaipur district. Several trees have attained a height of

4–10 m and a girth of 0.5–1 m. Such trees have a yield potential of 5–15 kg of seeds in extended seed bearing season (Kumar 2011b).

3.4 Possible Alternatives

Oil yielding crops: Europe has concentrated oil yielding crops like raps (*Brassica rapa*) in Germany, and soybean oil is used in USA for biofuel. The author himself witnessed buses in the campus of University of Illinois, Urbana Chamapaign Campus, and USA (Figs. 15, 16, 17 and 18).

4 Future of Bioenergy

In a number of scenarios of the global food and agriculture system in 2030, we examine to what extent increases in livestock and crop productivity, and changes in human diets, may expand the bio-energy potential. The results from the scenarios indicate that if the recent projections of global agriculture made by the FAO come true, the prospects for bio-energy plantations will be less favourable. In our scenario depicting the FAO projections, it is estimated that total agricultural land area globally will expand from the current 5.1 billion ha to approximately 5.4 billion ha in 2030, leaving little room for a major expansion of bio-energy plantations (Wirsenius 2003).

4.1 Lignocellulosic Biofuels

Currently, cellulosic biofuels and algal biodiesels are prominent biological approaches to sequester and convert CO_2. Ethanol and biodiesel are predominantly produced from corn kernels, sugarcane or soybean oil and create the food versus fuel

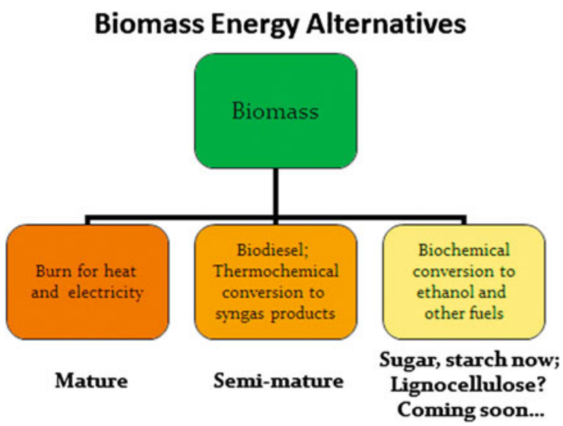


Fig. 15 There are three alternatives for mature biomass bioethanol from corn

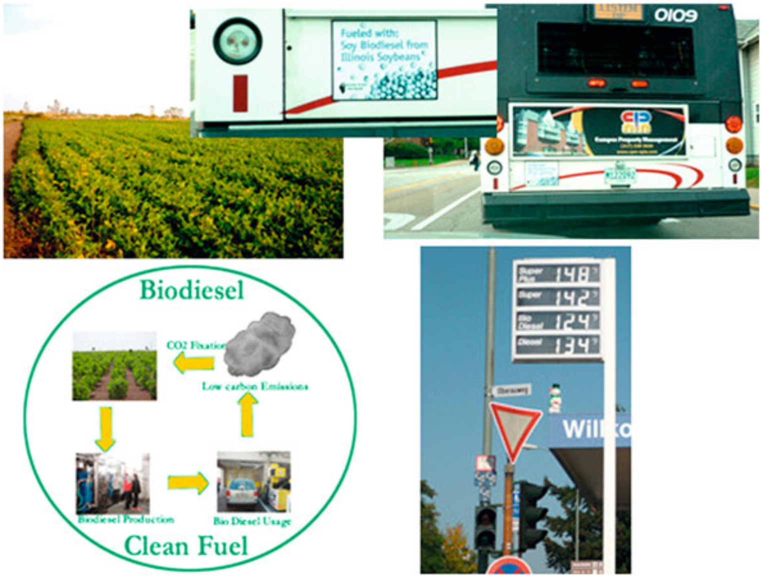


Fig. 16 Soybean cultivation in USA in a private farm, a bus being run on soybean diesel. Biofuels have a closed cycle and do not add carbon to atmosphere; a petrol pump selling bio-diesel based on raps oil in Germany

Fig. 17 Morrow plots of maize author with Professor Dr Jack Widholm.

competition and destabilize land use pattern for agriculture. In order to avoid this, another biofuel feedstock, lignocelluloses—the most abundant biological material on earth is being explored. Lignocelluloses is everywhere—wheat straw, corn husks, prairie grass, discarded rice hulls or trees. The race is on to optimize the technology that can produce biofuels from lignocelluloses sources more efficiently—and bio-tech companies are in the running. There is campaign, which advocates that 25 % of US energy come from arable land by 2025. The EU had called for a threefold increase in biofuel use by 2010, to 5.75 % of transportation fuel.

Fig. 18 Corn ethanol at petrol pumps in USA

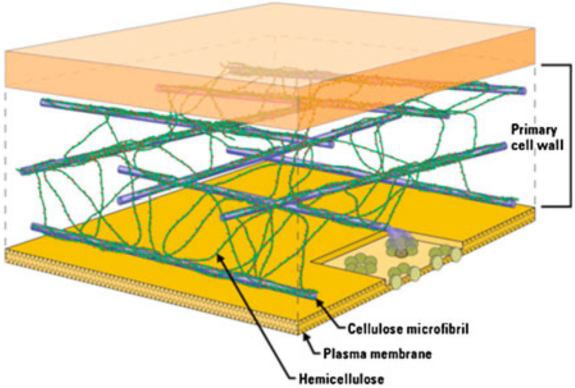


Fig. 19 Composition of cell wall

Whereas, starch is soft, lignocelluloses, the main component of the plant cell wall, has evolved to resist degradation. It consists of mostly hemicelluloses and cellulose—glucose chains stacked into crystalline fibrils, largely impenetrable to water or enzymes. Lignin, a more complex macromolecule, makes up much of the rest. Wood, one potential source of lignocelluloses, for example, typically consists of 40–50 % cellulose, 25 % hemicelluloses and 25–30 % lignins; the rest is made up of cell wall proteins and pectins. One approach to extract fuel from lignocelluloses borrows technology from the coal and oil industry to convert plant material into 'syngas,' mainly carbon monoxide and hydrogen. Syngas is then converted into ethanol or biodiesel by the Fischer–Tropsch process, invented in Germany in the early 1900s, usually using iron or cobalt catalysts. Another approach, popular in the United States, relies on enzymes and fermentation to produce cellulosic ethanol (Fig. 19).

4.2 *Why is Cellulose So Difficult to Turn into Fermentable Sugars?*

- Starch is a storage polysaccharide designed by nature as a food reservoir,

- Cellulose is part of a lignocellulosic composite designed by nature to resist degradation.

4.3 Synthetic Biology for Biofuels

- Synthetic biology has rapidly grown out of genetic engineering into a new science with new risks.
- Genetic engineers merely modify existing organisms by splicing a few genes from one organism into another.
- Synthetic biologists have far greater ambitions. They aim to design entirely new life forms with pre-selected functions, like the microbes which will digest trees and grasses and ferment them into biofuels, or the algae which will harvest solar energy to produce oil.

4.4 Synthetic Biology

- Still others aim to construct synthetic life forms entirely from scratch, using DNA synthesisers, ‘the biological equivalent of word processors’.
- The world’s first self-replicating synthetic genome, announced by the J. Craig Venter Institute on 20 May 2010, was constructed in this way.
- Venter described it as ‘the first self-replicating species we’ve had on the planet whose parent is a computer.’
- Source: Nicholas Wade, ‘Researchers Say They Created a ‘Synthetic Cell’’ *The New York Times* (New York 20 May 2010) <http://www.nytimes.com/2010/05/21/science/21cell.html> accessed 5 August 2011.

Recombinant DNA technology is being employed for modification of plant cell wall components to increase biofuel yields. The model describes the outline of recombinant expression of cell wall-targeted enzymes or proteins in transgenic plants (Figs. 20 and 21).

5 Metabolic Engineering

Recent advances in synthetic biology and metabolic engineering suggest that rather than limiting ourselves to fuel molecules provided by nature, we should engineer microorganisms to produce new fossil-fuel replacements (Keasling 2008a, b). Such products may include short-chain, branched-chain and cyclic alcohols, as well as alkanes, alkenes, esters and aromatics. To produce longer-chain alcohols and alkanes, it should be possible to tap into the fatty acid pools of nearly any organism. Sequential reduction, decarboxylation or decarbonylation

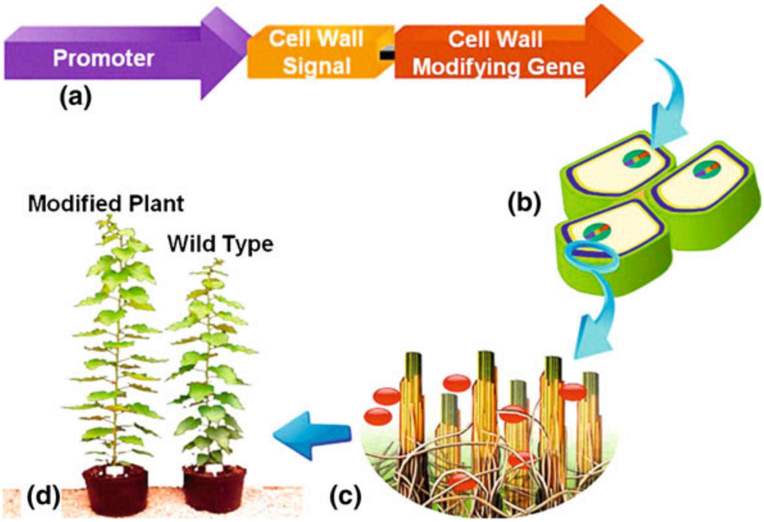


Fig. 20 Modification of plant cell wall components to increase biofuel yields. The model describes the outline of recombinant expression of cell wall-targeted enzymes or proteins in transgenic plants

Fig. 21 The interest of end users is increasing in use of biofuels globally

followed by reduction of fatty acids to alcohols and alkanes could yield valuable fuel candidates. It is also possible to esterify fatty acids with alcohols from any number of sources to produce candidate biodiesels. Isoprenoid biosynthesis offers an even richer source of next-generation biofuels. With the ability to produce branched-chain and cyclic alkanes, alkenes and alcohols of different sizes with diverse structural and chemical properties, this pathway could produce fuels or precursors to gasoline, diesel and jet fuel additives or substitutes. Efficient production of isoprenoid precursors has been engineered in *E. coli* and *Saccharomyces cerevisiae*, and many different isoprenoids have been produced using these engineered hosts (Atsumi et al. 2008).

Biofuels produced from Algae and Cyanobacteria:

- Further down the pipeline are biofuels produced from photosynthetic algae and cyanobacteria.
- This involves growing, harvesting, and then heating or chemically treating algae to recover the oil inside their cells.
- Algae that continuously secrete oil through their cell walls are in development.

6 Discussion

Biomass resources are potentially the world's largest renewable energy source—at an annual terrestrial biomass yield of 220 billion oven dry tonnes. Biomass conversion to fuel and chemicals is once again becoming an important alternative to replace oil and coal. Biodiesel from the rape seed oil, methylester (RME), produced by farmer cooperatives is about 2000 t RME per year. A large facility of 15,000 t RME per year is located at the oil mill at Bruck/Leitha in Austria. RME is excellent substitute for diesel. Already, European countries, mainly France, Italy, Germany and Austria are leading in biodiesel production, nearing 500,000 t, in 1997, out of which 250,000 was produced in France. The production capacity of biodiesel in Germany was fully utilized in1997, the sold quantity amounting to roughly 100,000 t.

World production of biofuel was about 68 billion L in 2007. The primary feedstocks of bioethanol are sugarcane and corn. Bioethanol is a gasoline additive/substitute. Bioethanol is by far the most widely used biofuel for transportation worldwide. About 60 % of global bioethanol production comes from sugarcane and 40 % from other crops. Biodiesel refers to a diesel-equivalent mono alkyl ester based oxygenated fuel.

Where we stand today:

- First generation biofuels—bioethanol from cereal,
- Crops and biodiesel from oilseeds increase greenhouse gas emissions—Land use change, deforestation for plantations.

- These biofuels are fertilizer-intensive—Drives soil erosion and eutrophication of aquatic ecosystems.
- They compete for agricultural land—Pressure on food availability.
- Challenges in Ensuring poor retain access to land and receive a fair share of the benefits from biofuels.
- Several candidate species for future biofuel production show the traits of invasive species.
- Brazilian sugarcane-to-ethanol producer Cosan announces a $12 billion joint venture with joint venture with Oil giant Royal Dutch Shell.
- Synthetic microorganisms released into the environment, accidentally or intentionally, could share genes with other microorganisms through horizontal gene transfer or evolve beyond their functionality.
- Production of advanced biofuels.
- Shell will contribute to the venture its equity interests in two advanced biofuel developers: Codexis and Iogen, in which the oil giant has 14.7 and 50 % stakes, respectively.
- Codexis, based in Redwood City, California, is developing enzyme products to use as biocatalysts to convert biomass into fuels.
- Ottawa, Ontario, Canada–based Iogen is developing a cellulosic biomass-to-ethanol conversion process that combines thermal, chemical and biochemical techniques

One hypothetical, worst-case scenario is a newly engineered type of high-yielding blue-green algae cultivated for biofuel production unintentionally leaking from outdoor ponds and out-competing native algal growth. A durable synthetic biology-derived organism might then spread to natural waterways, where it may thrive, displace other species, and rob the ecosystem of vital nutrients, with negative consequences for the environment.

Hydrocarbons from plants

Some of the laticiferous plants identified by (Bhatia et al. 1983) were investigated in detail at Jaipur for review see (Kumar 1995, 2000, 2001a).

Certain potential plants were selected and attempts were made to develop proper agro- technology for their large scale cultivation. Initially, work was initiated at 5 ha and subsequently extended to the 50 ha EPDPC.

Growing Interest by End Users

- Pratt & Whitney Canada: investigating biofuels from algae and Jatropha.
- Boeing: algae will be 1st feedstock for aviation biofuels within 10–15 years.
- Air France-KLM: agreement with Algae-Link to procure algae oil to be blended with conventional jet fuel.
- JetBlue, Airbus, Honeywell and the International Aero Engines partnership: replace up to 30 % of jet fuel with biofuels produced from algae and other non-food vegetable oils.

- Air New Zealand: test Jatropha as a fuel

Targets now promoted by the US Department of Energy (DOE) call for 30 % of today's fuel use to be supplanted by 2030 with ethanol—60 billion gallons of it each year. Triglycerides from oil seed crops can't come close to meeting US diesel demand (60 billion gal/yr) as agricultural productivity can't be diverted from the food supply.

Under that scenario, much of the fuel is slated to come from lignocelluloses, which the DOE expects will become cheaper to make as the technology improves. Researchers at the US National Renewable Energy Lab (NREL, Golden, Colorado) estimate the capital cost of a cellulosic biomass-converting facility, which would yield 50 million gallons of ethanol per year, at $215 million—about three-to four times more expensive than a corn grain ethanol plant with the same yield.

According to the US Renewable Fuels Association, a trade association for the US ethanol industry, annual production totalled 3.9 billion gallons last year, up 15 % from 2004. But estimates indicate that new plants to produce another 1.9 billion gallons a year are under construction and will come online by 2007. However, at present, less than 1 % of the United States' fuel stations sell ethanol. Targets now promoted by the US Department of Energy (DOE) call for 30 % of today's fuel use to be supplanted by 2030 with ethanol—60-billion gallons of it each year.

Despite the fact that biomass represents about one-third of energy consumption in developing countries, it has not been taken into account in energy studies. A set of factors explain the slow growth on the biomass utilization. They include:

1. High costs of production
2. Limited potential for production
3. Lack of sufficient data on energy transformations coefficients.
4. Low energy efficiency
5. Health hazard in producing and using biomass.

In the large scale use of biomass for energy, risks are insecurity in raw material supply and prices, doubts about adequate quality assurance and hesitance for a wider acceptance by the diesel engine manufacturers, missing marketing strategies for targeting biodiesel differential advantages into specific market niches and, last but not least, missing legal frame conditions similar to the clean air act in the USA.

Acknowledgments The constant encouragement of Professor Dr K.H. Neumann is gratefully acknowledged. His frequent visits witnessed the development of the wasteland into a green land. The support from Professor Dr. Sven Schubert Institut fur Pflanzenernaehrung der Justus Liebig Universitat Giessen, Germany, and research grant by Alexander von Humboldt Foundation is gratefully acknowledged. Financial Support from Department of Biotechnology, Government of India toProfessor Ashwani Kumar and guidance from Professor A.K. Sharma, Kolkatta and Dr Renu Swarup and Dr Meenakshi Munshi , DBT is gratefully acknowledged.

References

Alexandratos N (1995) World agriculture: towards 2010: an FAO study. Food Agric Organ, Rome

Atsumi S, Hanai T, Liao JC (2008) Non-fermentative pathways for synthesis of branched-chain higher alcohols as biofuels. Nature 451:86–89

Bhatia VK, Srivastava GS, Garg VK, Gupta YK, Rawat SS, Singh J (1983) Study of laticiferous (latex-bearing) plants as potential petro-crops. Fuel 62:953–955

Calvin M (1979) Petroleum plantations for fuel and materials. Bioscience 29:533–538

Garg J, Kumar A (1986) Studies on biomass production and improvement in biocrude content. Workshop on Petrocrops, New Delhi

Garg J, Kumar A (1987a) Effect of growth regulators on the growth, chlorophyll development and productivity of *Euphorbia lathyris* L, a hydrocarbon yielding plant. In: Biggins J (ed) Progress in photosynthesis research. Martinus Nijhoff Publishers, The Netherlands

Garg J, Kumar A (1987b) Effect of growth regulators on the growth, chlorophyll development and productivity of Euphorbia lathyris L A hydrocarbon yielding plant. Progress in Photosynthesis Research, J Biggins 4:403–406

Garg J, Kumar A (1987c) Improving growth and hydrocarbon yield of *Euphorbia lathyris L*. In: Sharma RN, Vimal OP, Mathur AN (eds) Bioenergy society fourth convention and symposium, vol 87, New Delhi

Garg J, Kumar A (1987d) Some studies on charcoal rot of *Euphorbia lathyris* caused by Macrophomina phaseolina. Indian Phytopathol 41:257–260

Garg J, Kumar A (1989a) Influence of salinity on growth and hydrocarbon yield of *Euphorbia lathyris*. J Indian Bot Soc 68:201–204

Garg J, Kumar A (1989b) Potential petro crops for Rajasthan. J Indian Bot Soc 68:199–200

Garg J, Kumar A (1990) Improving the growth and hydrocarbon yield of *Euphorbia lathyris* L in semi-arid regions of Rajasthan. In: Grassi G, Gosse G, Santos G (eds) Biomass for energy and industry. Elsevier, London, pp 1.527–1.531

Johari S, Kumar A (1992) Effect of N, P and K on growth and biocrude yield of *Euphorbia antisyphilitica*. Ann Arid Zone 31:313–314

Johari S, Kumar A (1994) Influence of growth regulators on biomas and hydrocarbon yield from *Euphorbia antisyphilitica* (Zucc). J Phytol Res 7:65–68

Johari S, Roy S, Kumar A (1990) Influence of edaphic and nutritional factors on growth and hydrocarbon yield of *Euphorbia antisyphilitica* Zucc. In: Grassi G, Gosse G, Santos G (eds) Biomass for energy and industry, vol 1. Elsevier, London, pp 522–526

Johari S, Roy S, Kumar A (1991) Influence of growth regulators on biomass and hydrocarbon yield from *Euphorbia antisyphilitica* Zucc. In: Sharma HL, Sharma RN (eds) Bioenergy for humid and semi-humid regions. Bioenergy Society of India, New Delhi

Johri S, Kumar A (1993) 'Charcoal rot of Candelilla (*Euphorbia antisyphilitica* Zucc) caused by *Macrophomina phaseolina* (Tassi) Goid. Indian J Mycol Plant Pathol 23:317

Keasling JD (2008) Synthetic biology for synthetic chemistry. ACS Chem Biol 3:64–76

Keasling JD, Chou H (2008) Metabolic engineering delivers next-generation biofuels. Nat Biotechnol 26:298–299

Kumar A (1984) Economics of bioenergy in developing countries. Bioenergy 84(14):172

Kumar A (1990) Prospects of raising latex bearing plants in semi-arid and arid regions of Rajasthan. In: Grassi G, Gosse G, Dos Santos G (eds) Biomass for energy and industry. Elsevier, London

Kumar A (1994) Laticifers as potential bioremedients for wasteland restoration. J Environ Pollut 1:101–104

Kumar A (1995) Cultivation of hydrocarbon yielding plants in Rajasthan as an alternative energy source. J Environ Pollut 2:67–70

Kumar A (1996) Bioenergy plantations: a model system for restoration of semi arid regions. In: Chartier P, Ferrero GL, Henius UM, Hultberg S, Sachau J, Wiinblad M (eds) Biomass for energy and environment. Elsevier, UK

Kumar A (1998) Biomass energy crops of semi arid regions of India and their energy potential. In: Kopetz H et al (eds) Biomass for energy and industry. Carmen, Germany

Kumar A (2001a) Bioengineering of crops for biofuels and bioenergy. In: Bender L, Kumar A (eds) From soil to cell: a broad approach to plant life. Giessen Electron Library (GEB), Giessen, pp 1–16 (http://gebuni-giessende/geb/volltexte/2006/3039/pdf/FestschriftNeumann)

Kumar A (2001b) Conservation and utilization of Herbal drugs to protect them from extinction: an urgent need. In: Proceedings of international forum for traditional medicine, Toyama, Japan, pp 281–284

Kumar A (2007) *Calotropis procera* (Ait) f (Akra Sodom Apple): agrotechnology package for bioenergy crops. In: Swarup R, Munshi M (eds) DBT, Govt. of India, New Delhi, pp 24–26

Kumar A (2008a) Hydrocarbon yielding plants and future prospects of biotechnological approach. Recent advances in biotechnology. Panima Publisher, New Delhi

Kumar A (2008b) Bioengineering of crops for biofuels and bioenergy. In: Kumar A, Sopory S (eds) Recent advances in plant biotechnology. IK International, New Delhi

Kumar A (2011a) Biofuel resources for green house gas mitigation and environment protection. In: P.C. Trivedi (ed) Agriculture biotechnology. Avishkar Publishers, Jaipur

Kumar A (2011b). Production and demonstration of high quality plant material of Jatropha curcas. In:Grassi J et. al (eds) Proceeding at 19th European Biomass Conference and exhibition, Berlin, Germany.June. 2011, 682–683.

Kumar A, Garg J (1995) Effect of organic manures on growth and hydrocarbon yield of *Euphorbia lathyris* L. J Environ Pollut 2:207–210

Kumar A, Johari S, Roy S (1995) Production and improvement of bioenergy sources. J Indian Bot Soc 74A:233–234

Kumar A, Roy S (1996) Biomass resources of semi arid regions: production and improvement of wood energy source. In: Chartier P, Ferrero GL, Henius UM, Hultberg S, Sachau J, Wiinblad M (eds) Biomass for energy and environment. Elsevier, UK, pp 721–724

Rani A, Kumar A (1994a) Effect of edaphic factors on the growth and physiology of *Pedilanthus tithymaloides* var green. J Environ Pollut 2:5–8

Rani A, Kumar A (1994b) Micropropagation of *Pedilanthus tithymaloides* var green, a hydrocarbon yielding plant. J Phytol Res 7:107–110

Rani A, Roy S, Kumar A (1990) Influence of morphological and environmental factors on growth and hydrocarbon yield in *Calotropis procera*. In: Grassi G, Gosse G, Santos G (eds) Biomass for energy and industry. Elsevier, London

Rani A, Roy S, Kumar A (1991) Effect of salinity stress or growth and hydrocarbon yield of *Pedilanthus tithymaloides* variety green (Linn) point. In: Sharma HL, Sharma RN (eds) Proceedings of bio-energy for humid and semi-humid regions, Bioenergy Society of India, New Delhi

Roy S (1996) Growth and productivity of non conventional energy sources: *J curcas*. In: Chartier P, Ferrero GL, Henius UM, Hultberg S, Sachau J, Wiinblad M (eds) Biomass for energy and environment. Elsevier, U K

Roy S, Kumar A (1990) Prospects of wood energy production in semi-arid and arid regions of Rajasthan. In: Grassi G, Gosse G, Santos G (eds) Proceedings of biomass for energy and industry, vol 2. Elsevier, London, pp 1153–1156

Roy S, Kumar A (1998) Non edible oil and seed plants as source of energy and biodiesel. In: Kopetz H et al (eds) Biomass for energy and Industry. Carmen, Germany

Wirsenius S (2003) The biomass metabolism of the food system: a model-based survey of the global and regional turnover of food biomass. J Ind Ecol 7:4

Impact of Forestry Products on Climate Change Mitigation in India

C. N. Pandey, S. K. Nath and D. Sujatha

1 Introduction

Climate change is a global environmental problem that has been associated with increasing concentrations of greenhouse gases (GHGs). Our modern lifestyles, the products we choose, the emissions of carbon dioxide from industry, society, transport and from our homes, have increased the concentration of CO_2 in the atmosphere. Forestry products definitely play a significant role in mitigating the adverse effects of climate change, by increasing the level of carbon removals from the atmosphere. Different corporate governance systems impact the ability of industries to adopt and transform their activities to meet issues associated with climate change. Until recently, relatively little has been done to measure the contribution made by forest based industries to mitigate the climate change.

The build-up of greenhouse gases (GHGs) in the atmosphere, much of it driven by human activity, is already affecting the global climate. Under current projections, concentrations of GHGs will continue to increase into the indefinite future, entailing a process of continued global warming. Between 1850 and 1998, some 270 billion tonnes of carbon were released into the atmosphere in the form of CO_2, mainly through the combustion of fossil fuels, resulting in a 30 % increase of CO_2 in the atmosphere and that concentration is currently increasing by a net accumulation of 3.3 billion tonnes of carbon a year. World GHG emissions have roughly doubled since the early 1970s and on current policies could rise by over 70 % during 2008–2050. Historically, energy related GHG emissions were predominantly from the richer developed countries so that the rise in GHG concentration from the industrial revolution to today is largely accounted for by economic activity in these countries. Today, however, two-thirds of the flow of new emissions into the atmosphere is accounted for by developing countries and, without new policies, this share is set to rise further to 2050.

C. N. Pandey · S. K. Nath · D. Sujatha (✉)
IPIRTI, Tumkur Road, P. B. No. 2273Bengaluru 560022, India
e-mail: sujathad1@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_14,

Any basic component used in the construction of a house needs to be fabricated from raw material. Fabrication needs energy. The extent of energy consumed to produce unit quantity of a product is not the same for all products. Energy in any form, either in the form of heat or electricity, comes from material of natural origin. Natural source may be coal, mineral oil, wood, solar energy, hydal energy, wind power, etc. Whatever may be the basic source of energy, it is heat and electrical energy which are predominantly used by the industry.

Both electricity and thermal power comes from burning of fossil fuel, coal or other lignocellulosic materials including wood. Burning of such fuels not only releases CO_2 in the air but also releases effluents which pollute the environment. Thus, a product made with high energy consumption is more harmful to the environment than a product needing less energy for production. In addition, manufacturers are also concerned with the cost of production which increases with the increase in consumption of energy. Generation of heat, due to burning of fuels, releases of CO_2 and other acid forming gasses, releases harmful effluents from the factories continually polluting the nature. Global warming, or the green house effect, melting of polar ice, desertification of soil have become a global concern.

Studies (Kaul et al. 2010) reveal that for short rotation species, the amount of carbon offset increases linearly with time since biomass is continuously harvested and replanted and used. On forest lands, the carbon balance is negative in the beginning (due to enhanced decomposition) but it turns positive after 14 and 3 years, respectively, for long rotation *sal* forests and short rotation poplar species. On non-forests lands, at 6 years, the carbon sink attains a maximum value of 11 Mg.C Ha^{-1} $year^{-1}$ for short rotation poplar plantation. The carbon benefit at any time is highest for short rotation poplar plantation. This may be attributed to the high carbon sequestration rate and high energy conversion efficiencies. At year 100, a total of 216 Mg C ha^{-1} $year^{-1}$ is sequestered for afforestation/reforestation using long rotation *sal* species, as opposed to offset of 412 Mg C ha^{-1} $year^{-1}$ for carbon storage for short rotation poplar plantations. Using short rotation plantations for electric power generation gives a mitigation potential in the range of 227–303 Tg C $year^{-1}$ from carbon storage and fossil fuel substitution. The energy generation potential of plantation generating 758 Tg wood annually would be 11,370 Pj. Thus, plantation of biomass could supply about 43 % of the total projected energy consumption in India by 2015.

Materials like plastic, metal and concrete all require a lot of energy for extraction of raw materials and manufacture. These materials all have negative carbon footprints. Wood has a positive footprint because of the carbon dioxide from air fixed by the original living tree. The emissions associated with harvesting, transporting and processing of wood products are small compared to the total amount of carbon stored in the wood. This means that even when energy used for harvesting, transport and processing are taken into account, wood still has a positive footprint.

Emphasis is being given to ‘Green Product’ made of renewable fibre coming out of nature. The green products are meant to replace conventional materials like cement, steel, etc., in building construction, to replace metal and plastic in household products and so on. Wood is being used as replacement of metal and plastic, and is undoubtedly carbon neutral, consumes lesser energy in conversion to users' products, and least polluting. However, for a country like India, wood has become a scarce commodity and depletion of forest areas, due to over exploitation, has been observed long back. A search has been made to find an alternative to wood among renewable natural source. Bamboo has been found a suitable alternative to wood and products made of bamboo can suitably replace wood products.

Although bamboo has been in use for centuries in India and elsewhere in the world, such uses were limited to art and crafts, and among the poorer sections of the society. Technical intervention has shown that bamboo can be suitably used to manufacture durable products similar to wood and wood products. Like any wood product, bamboo products are low energy consuming and eco-friendly. A variety of products, which have been made, for example: Bamboo Mat Board (BMB), Bamboo Mat Veneer Composite (BMVC), Bamboo Mat Corrugated Sheets (BMCS), and Laminates all form components for house construction. Most of these products are now made commercially in India and are getting popular among the consumers.

Any production unit of building component releases CO_2 due to burning of various types of fuel. Bamboo products, on the other hand, store a net amount of carbon in end products. Thus growing and use of bamboo and products from bamboo, a net amount of CO_2 is being removed from the air and stored in the bamboo products. IPIRTI has undertaken a study on the flow of carbon from raw material to finished products that indicates how environment friendly will be practice of using Forestry products.

2 Scope and Aim

For our daily needs, we burn fossil fuel, coal obtained from a reserve on the earth. Burning of these energy sources produces CO_2 along with other acidic gases like CO, SO_2 which get added to the atmosphere. Millions of tons of CO_2 (3.3 billion tons per year) are, thus, added to the atmosphere. The effect of accumulation of these in the air and global warming are inter related.

Secondly, these energy sources are limited. The present rate of use of petroleum and its reserve on the earth indicates that supply of petroleum may be another 150 years. The use of wood and bamboo can serve distinctly two purposes, viz., an alternate to high energy and polluting material like cement, steel, plastic and as a source of energy alternate to coal and petroleum.

Wood and bamboo are renewable material and grow by absorbing CO_2 from air and water from soil using solar energy. It is the most efficient way of storing solar energy by nature.

The Indian forest-based industry has a reasonable potential to sequester. However, domestic manufacturing is highly fragmented and unorganized, generally inefficiently managed, has low product quality, and lacks standardization.

Nonetheless, there are various ways to positively influence the carbon balance, including sink enhancements and increasing the market share of existing wooden products. Globally, forest market is undergoing dramatic changes. The natural advantage in the forestry sector is gradually shifting away from countries with the highest levels of forest resources to countries where trees grow to commercial maturity at the fastest rate and where the cost of converting them into products is the lowest. It is, thus, obvious that many foreign companies view India as a country with a strong commercial appeal, both as an emerging market and as an economic partner in possible collaboration of Indian forest industries and its livelihood impact. Developing carbon credit markets that motivate true reductions in carbon emissions must address all carbon pools and their GHG emissions. We shall have to master this natural science if human civilization has to go thousands of years ahead.

The aim of the study are:

- Calculation of energy required for production of Plywood and Bamboo Mat Corrugated Sheet (BMCS) and Bamboo Mat Ridge Cap (BMRC);
- Determination of release of CO_2 during processing of plywood, BMCS and BMRC;
- Determination of net carbon storage in plywood BMCS and BMRC;
- Comparative study on the energy requirement and net CO_2 released due to production of various structural material;
- Analysis of comparative benefit in using renewable material and their contribution in carbon mitigation.

3 Literature Survey

Forests and forest products can actually prevent GHG emissions through wood substitution, biomass substitution, and avoided land-use change. Substituting wood products obtained from sustainably managed forests addresses climate change in several ways, including fixing the carbon in store. The carbon in lumber and furniture, for example, may not be released for decades. Storage of carbon in harvested wood products is gaining recognition in climate change mitigation programmes. The climate change benefits of wood products lie in the combination of long-term carbon storage with substitution for other materials with higher emissions. As wood can substitute for fossil fuel intensive products, the reduction in carbon emissions to the atmosphere is comparatively larger than even the benefit of the carbon stored in wood products. This effect—displacement of fossil fuel sources—could make wood products the most important carbon pool of all (Malmsheimer et al. 2008).

The current political momentum behind reducing emissions from deforestation initiative in conjunction with the dynamic negotiations for a post-2012 climate regime could link tropical forest conservation with carbon markets. Carbon markets alone cannot be expected to overcome all hurdles; it may require significant non-carbon based support (Ebeling and Yasue 2008).

Wood harvest is a part of an important economic cluster as it provides livelihood to the forest-dependent communities. Thus, there is a trade-off between sequestration in forests and in the pool of forest products that may persist for decades. An appropriately designed community-based forest management policy can provide the means to sustain and strengthen community livelihoods and at the same time avoid deforestation, restore forest cover and density, provide carbon mitigation, and create rural assets (Singh 2008).

Carbon sequestration in wood products requires cooperation of multiple parties from the forest owner and product manufacturer to the product user, and perhaps others. Credit for sequestering carbon away from the atmosphere could go to the contributions of these multiple parties (Tonn and Marland 2007). Wood products contribute 15–22 % of the total emissions to the atmosphere. Carbon sequestration potentials are much greater for shorter periods than over longer periods (Karjalainen and Kellomaki 1995). Policy instruments that internalize the external costs of carbon emission should encourage a structural change towards the increased use of sustainably produced wood products (Sathre and Gustavsson 2009).

Simplified methods for estimating the fate of carbon in wood products need to be developed to allow estimation at the national level. Economists argue that if the cost of carbon emission was bid in the market, consumers would effectively make purchases that would reduce emissions. Almost every change in product design, product selection, or management results in changed levels of carbon emission across different stages of processing.

The United Nations Framework Convention on Climate Change (UNFCCC), which was adopted in 1992 at the United Nations Conference on Environment and Development (UNCED), aims at stabilizing the concentration of greenhouse gases in the atmosphere so as to prevent dangerous human-induced changes to the global climate system. Parties to the UNFCCC committed themselves to carrying out national inventories of greenhouse gas emissions and carbon sinks. Industrialized countries and the economies in transition (Annex I) committed themselves to working towards voluntary goals in the reduction of emissions. These obligations were intensified and specified in the Kyoto Protocol, which was adopted at the Conference of the Parties (COP) of the UNFCCC, held in Kyoto, Japan in December 1997. By June 2007, a total of 175 states had joined the Kyoto Protocol, accounting for 61.6 % of CO_2 emissions of all Parties. The Protocol came into force on February 16, 2005. There are mechanisms under the Kyoto Protocol which allow for some flexibility in how countries make and measure their emission reductions. These include the Joint Implementation (JI) and the Clean Development Mechanism (CDM) which include forestry projects.

Carbon mitigation options include reducing emissions from deforestation and forest degradation, enhancing the sequestration rate in existing and new forests providing wood fuels as a substitute for fossil fuels, and providing wood products for more energy-intensive material. One of the measures that is receiving increased attention is land management to protect and reforest forest land, either by direct forest management or be establishment of fast growing plantations that can be substituted for fossil fuels in energy production. A recent FAO study has indicated that potential industrial wood production from planted forests in 2005 was 1.2 billion cubic meter or two-thirds of the overall industrial wood production in that year. Establishment of plantations on degraded and waste lands is one of the best and the most promising options for halting deforestation and increasing carbon storage in trees.

In India, trees outside forests have a major contribution in meeting timber and fuel wood needs. It is estimated that the amount incurred for total import of timber, including paper and pulp, into the country is of the order of Rs. 12,000 crores per year. A realistic harmonization of various projections indicates a demand for wood for panel products in the range of 30.53 million cubic meter annually.

4 Methodology

Life Cycle Analysis (LCA) is an important tool to find out energy requirement for different stages of production of a product from raw material procurement to final products, during its useful life and also when the material is dumped into soil, reused or burnt after the useful life is over.

LCA has been taken up at IPIRTI for the study of two products:

1. Plywood—a wood veneer based panel product, and,
2. Bamboo Mat Corrugated Sheet and Bamboo Mat Ridge Cap—Bamboo mat based products.

The LCA study has been limited to raw material procurement to final usable product (gate to gate study). Two aspects have been taken up during the study, i.e., energy required for production and conversion ratio from raw material to final products. This study results in magnitude of carbon storage in final products. Both electrical energy and heat energy as required for production were calculated separately. As production of heat requires burning of coal/agro based fuel/wood, the emission of CO_2 during the process was also calculated.

Data were collected from manufacturing units of plywood and bamboo based industry:

1. For consumption of electrical energy, each machine was taken separately for study and total consumption during working hours in a day was added. Total electrical energy required for a day was multiplied by the total working days in a month to find out total electricity consumption by the machinery in the factory. This data was then added with general electricity consumption for lighting to find out the total electricity consumption in the factory. Finally, the consumption thus calculated was compared with the monthly consumption of electricity shown by the electric meters in different sections of the factory.

2. Records of fuel consumed for generating heat energy in the boiler was collected from the factories to calculate (1) heat energy requirement (2) emission of CO_2 due to burning of different types of fuel.
3. For calculation of conversion ratio of raw material to final products, the raw material input per day to the factory was found out. Conversion at each stage of production and losses occurred was calculated. Finally, volume/weight of the final products was taken. In this way conversion ratio in a month for a particular product was found out. The data, thus generated, was compared with the monthly raw material input and final production from the records of the factory.

4.1 Bamboo Mat Corrugated Sheet (BMCS) and Bamboo Mat Ridge Cap (BMRC)

Raw material for manufacture of Bamboo Mat Corrugated Sheet (BMCS) and Bamboo Mat Ridge Cap (BMRC): Woven bamboo mat, synthetic resin as binder.

Process:

Bamboo mats are dried to moisture content of 6–8 % and dipped into adhesive solution. Adhesive coated mats are wet and need to be dried to 10–12 % moisture content. These are laid one above another and hot pressed under high temperature and pressure.

A. Carbon footing in the manufacture of BMCS and BMRC:

Bamboo mats which arrive at the factory for secondary processing into BMCS or BMRC contain about 16–18 % of moisture. There is no transit loss of bio-mass. The mats, as they arrive to the factory, need drying to a moisture content of 6–8 %. During further processing of mats till hot pressing, there is no loss of solid biomass in the mats.

Finally, the BMCS and BMRC are trimmed to custom size. In this process loss of material to the tune of 10 % takes place:

$$\begin{array}{c}\text{Bamboo Mat (at 18 \% MC)}\\ \text{Dried and hot pressed}\\ \downarrow\end{array}$$

BMCS/BMRC (MC loss 8 %)

$$\begin{array}{l}\text{Average MC} - 10\ \%\\ \text{Material Content} - 28.31\end{array}$$

Trimming—loss 10 % material

↓
BMCS/BMRC (at 10 % MC)
Bio-mass content – 25.48
Loss of carbon – 2.83
Equivalent CO_2 = 10.38

The final product contains 25.4 % of the biomass which contains 13 08 % of C. Thus, by processing 100 parts of green bamboo with an average 58 % MC, an amount of 13.08 parts of C is being stored in the BMCS and BMRC.

B. Carbon balance:

Starting with green bamboo, with average material content of 42.00 %, the final products (BMCS and BMRC) contains 25.48 %. The carbon balance in the whole process can be summarized as follows:

Green bamboo (100 %)	Bio-mass content	42.00
	Moisture content	58.00
	Carbon content	21.63
CO_2 removed from air in the process growth		79.31
BMCS/BMRC	Biomass content	25.4
Carbon content		13.08
Equivalent CO_2		**47.95**

Thus, by processing 100 parts of green bamboo into BMCS/BMRC 13.08 parts of carbon is stored in the products which is equivalent to 47.96 parts of CO_2

C. Carbon stored in BMCS and BMRC:

A corrugated sheet is made up of four bamboo mats. A bamboo mat of size 2.44 × 1.22 with weight of about 2.4 kg. (average) at 10–12 % Moisture Content will be used.
Weight of four mats = 9.6 kg.
After the BMCS is being formed, the product is trimmed to 2.44 × 1.07 M. Trimming margin is 10 % on an average.
Hence, Actual weight of mats in the BMCS = 8.64 kg.
Average M.C in the product = 10 %.
Actual biomass content = 7.78 kg/one BMCS.
Carbon content = 4.01 kg/BMCS.

From the calculation, it has been found that 13.08 kg of carbon is stored in BMCS using 100 kg of green bamboo at average MC of 58 %. Hence, for making one BMCS 30.65 kg of green bamboo, at 42 % biomass, is required. Biomass content in 30.65 kg of bamboo = 12.87 kg.

Carbon content = 6.63 kg
CO_2 Equivalent = 24.31 kg.

Out of 6.63 kg of carbon removed from the atmosphere, only 4.01 kg are stored in BMCS and rest 2.62 kg of carbon is burnt to CO_2 and gets back into the atmosphere.

Diesel consumed/BMCS = 0.94 l = 2.82 kg CO_2
Fuel wood consumed/BMCS = 16.95 kg (approx. 20 % MC)
Oven dry biomass = 13.56 kg
Carbon content = 6.98 kg
Equivalent CO_2 = 25.61 kg
Total CO_2 emitted due to burning of fuel = (2.82 + 25.61) kg = 28.43 kg
Carbon stored in one BMCS = 4.01 kg. Equivalent CO_2 = 14.70 kg.
Net release of CO_2 due to manufacture of one BMCS = (28.43 − 14.70) = 13.73 kg
Net release of CO_2 in 1 ton of BMCS manufacture = 1.3076 tons
[Weight of one BMCS of size 2.44 × 1.07 m = weight of 4 mat with 10 % mc + 1.8 kg of resin = (8.64 + 1.8) kg = 10.44 kg ~10.5 kg.]

The Net CO_2 released during production of 1 Ton of different products and the energy required per tons of different roofing sheets is given in Tables 1 and 2 respectively.

4.2 *Plywood*

Raw material for plywood manufacture: Thin slices of wood called veneer obtained by rotary cutting or slicing from round logs and synthetic adhesive.

Process of manufacture:

Round logs in green condition are cut into thin slices called Veneers. Veneers are dried to 6–8 % moisture content and laid in definite manner into sheet having

Table 1 Net CO_2 released during production of 1 ton of different products

Sl. No.	Name of the products	CO_2 released (tons)
1	Stainless steel	3.8
2	Cement	1.0
3	Aluminium	1.5
4	Plastic	3.0
5	Bamboo mat corrugated sheets	1.308

Table 2 Energy requirement for roofing/corrugated sheets

Sl. No.	Name of the products	Net energy required (MJ/t)	Net energy required (Kw-h/m^2)
1	Aluminium	89,408	38.0
2	Galvanized iron	32,541.7	36.6
3	Asbestos	300	1.0
4	Fibre reinforced plastics (FRP)	77,190	–
5	Bamboo mat corrugated sheets	23382.4	26.61

Source ACPMA (2010) http://www.acpma.com/fact-asbestos.html

glued and non-glued veneer placed alternately in the assembly. The assembly is then pressed under high temperature and pressure into an integrated composite.

A. Carbon Footprint in manufacture of plywood (log input to finished plywood):

Total quantity of CO_2 produced for supply of electricity, thermal power and fuel for miscellaneous uses for production of one ton of plywood is given in Tables 3 and 4:

B. **Carbon Balance:** The final product in the manufacture of plywood from log (gate) to plywood (gate) can be described as:

Total wood input = 161.36 m^3
Total plywood output = 103.43 m^3

Sample analysis of raw material (log in green stage) has revealed that at 12 % MC has density 0.6 and weight 600.00 kg/m^3. The corresponding mass of biomaterial is 528 kg/m^3. Hence, total content of biomass in 161.36 m^3 = 85.20 ton. Carbon content and corresponding CO_2 equivalent are 43.878 and 160.87 ton, respectively.

The conversion from log (green) to finished plywood is 64 % by volume. An amount of 103.43 m^3 of panel product having density 0.65 is produced. The product contains, beside wood, 6 % by weight of resin polymer with other additives and 10 % by weight of moisture. Actual weight of wood biomass contained

Table 3 Total quantity of CO_2 produced for production of one ton of plywood

Quantity of plywood produces	Type of fuel	Quantity consumed	CO_2 produced (kg)	Total CO_2 (kg)
1 ton (1.538 m^3)	Diesel	23.37 l	62.16	
	Coal	9.91 kg	29.04	
	Wood	0.331 ton	625.03	716.23
1 m^3				465.69

Table 4 Comparative energy requirement for structural and housing component

Sl. No	Commodity	Net energy required [million kcal (oil equivalent) per ovendry ton]	Net energy required (MJ)
1	Lumber	0.73	3056.36
2	Wood fence post	1.00	4186.80
3	Plywood	1.50	6280.20
4	MDF	2.14	8959.75
5	Concrete slab	2.15	9001.62
6	Concrete block	2.21	9252.83
7	Clay brick	2.28	9545.90
8	Steel stud	12.68	53088.62
9	Steel fence post	12.68	53088.62
10	Aluminium siding	50.51	211475.27
11	Carpet and pad	9.37	39230.32

Source Koch (1992)

in 103.43 m^3 of panel product is: wt. of plywood—wt. of water in plywood—wt. of resin and additives.

Wt. of plywood = 103.43 × 0.65 = 67.23 ton
Wt. of water = 6.723 ton
Wt. of resin + additives = 4.034 ton
Wt. of wood biomass = 56.473 ton
Carbon content in plywood = 29.084 ton
CO_2 equivalent = 106.641 ton

Hence, 1 m^3 of finished product stores 281.195 kg of carbon which is equivalent to 1.031 ton of CO_2.

For producing 1 m^3 of plywood 465.69 kg of CO_2 is being produced in the process burning of various types of fuel. Included in this is 406.39 kg of CO_2 generated due to burning of waste wood accumulated during production of plywood. Hence net CO_2 produced due to burning of fossil fuel (465.69 − 406.39) kg = 59.3 kg/m^3 of plywood or 16.17 kg of carbon.

Net carbon gain = (281.195 − 16.17) kg or 264.83 kg of carbon/m^3 of plywood produced.

5 Results and Discussions

Wood based panel products like plywood, particle board, medium density fibre board, oriented strand board, hard board are examples of structural material widely used in housing and making of various utilities, household, etc. Studies have been undertaken by IPIRTI to evaluate the energy requirement to manufacture unit quantity of plywood and to find out the amount of carbon stored in the final products under manufacturing practices and use pattern in India. Data generated from the study and given below clearly indicates that substantial amount of energy is been saved in the manufacture of panel from wood compared to conventional structural/material from raw materials excavated from soil and non-recyclable in nature. More important is the net storage of carbon in making and use of wood panel product for a period from 25 to 100 years.

The use of biodegradable bamboo as raw material for manufacture of durable roofing sheet is unique by itself. The present study has conclusively shown that it is low energy consuming compared to conventional roofing sheet like GI, plastic, aluminium etc. Although the energy consumption in the manufacture of BMCS is higher than ACC sheet, BMCS is eco-friendly while ACC sheet is unhygienic/carcinogenic in nature. Moreover, using bamboo in making roofing sheet, a substantial amount of CO_2 is removed from air and stored in BMCS as lignocellulose material. Polluting effect of environment due to effluent or emission during manufacture of BMCS is very low.

The Net Carbon dioxide released during the production of BMCS & BMRC (Table 1) per ton is found to be 1.308 ton and that of steel being 3.8 ton and for Aluminium and plastic is 1.5 and 3.0 ton respectively. The carbon dioxide released during the production of BMCS & BMRC is less by 14–190 % when compared to the other existing roofing materials.

The energy audits determined that the combined total energy consumption was 22784 MJ for the manufacture of one ton of BMCS (Table 2), while for Aluminium, Galvanized iron and fibre reinforced plastic corrugated sheets energy consumption is 32,541.7 MJ, 89,408 and 77,190 MJ, respectively, which are very high compared to BMCS & BMRC, while for Asbestos roofing sheet the energy consumption is 430 MJ which is very less compared to all the existing roofing materials. However, during the processing of Asbestos roofing sheet, the health hazards (carcinogenic) is higher and asbestos is banned in most of the countries.

Wood and plywood have conventionally been used as structural material. Metal, concrete, plastic have replaced wood products in substantial quantity. The use of wood alternatives cannot go on for an indefinite period as their supply is restricted till their availability on the earth. Further, their extraction and conversion into usable form requires high energy and is associated with emission of green house gases and other pollutants.

Use of wood and plywood can be supported because these are renewable material and their supply can be made sustainable. The growth of trees removes CO_2 from air and stores it in the body of the wood. Even burning of wood does not add up additional CO_2 into air, it only returns the carbon that gets removed from air during its growth. Thus, burning of wood is carbon neutral.

Energy required for processing of plywood is very low which can be generated by burning of wood waste itself. Thus, processing will not add additional CO_2 to air as it happens during processing of steel, cement, plastic.

Plywood and bamboo products are very useful carbon storage as the amount of carbon stored in these products is several times bigger than what is released during manufacturing.

6 Conclusions

The manufacture of plywood and BMCS, thus, has an edge over the other competitive existing material with respect to energy efficiency, green house effect, storage of carbon and effect on environment.

In the early days of development of plywood and panel industries, environmental issues represented a very small component of any decision to build and operate a wood composite plant. However, in today's highly sensitive environmental climate, these issues have come to represent a significant initial and operating investment.

The most suitable option for a developing country like India lies in the use of non forest lands for fast growing short rotation plantations. Short rotation plantations with higher growth rates result in greater net carbon benefit at the end of 100 year as compared to long rotation forests used for permanent carbon storage. An understanding of promising new environmental friendly technologies and their application will go a long way in sustainable development of these industries.

R&D work done at IPIRTI in the last couple of years in the field of development of bio-adhesives, wood alternatives based on fast growing agro forestry timber species, and other renewable fibres like bamboo and agro residues, and use of eco-friendly preservatives as glue line additive, have significantly contributed to the development of *greener* engineered panel products.

It is, therefore, envisaged that more use of fast growing plantation wood by the plywood and panel industries and application of green technologies will go a long way in tackling the problems of global warming and climate change mitigation. The inclusion of wood and wood-based products into carbon accounting will constitute a positive step to increase wood consumption and carbon removals from the atmosphere by wood products.

References

Asbestos Cement Products Manufacturers' Association (ACPMA) (2010) (1) ACPMA Ltd. http://www.acpma.com/fact-asbestos.html

Ebeling J, Yasue M (2008) Generating carbon finance through avoided deforestation and its potential to create climatic, conservation and human development benefits. Phil Trans R Soc B 363:1917–1924

Karjalainen T, Kellomäki S (1995) Simulation of forest and wood product carbon budget under a changing climate in Finland Springer Online Journal Archives 1860–2000

Kaul M, Mohren GMJ, Dadhwal VK (2010) Carbon storage versus fossil fuel substitution: a climate change mitigation option for two different land use categories based on short and long rotation forestry in India. Mitig Adapt Strat Glob Change 15:395–409. doi:10.1007/s11027-010-9226-1

Koch P (1992) Wood versus non-wood materials in U.S. residential construction: some energy related global implication. Forest. Prod J 42(5):31–42

Malmsheimer RW et al (2008) Forest management solutions for mitigating climate change in the United States. J Forest 106:115

Sathre R, Gustavsson L (2009) Using wood products to mitigate climate change: external costs and structural change. Appl Energy 86(2):251

Singh PP (2008) Exploring biodiversity and climate change benefits of community-based forest management. Global Environ Change 18(3):468–478

Tonna B, Marland G (2007) Carbon sequestration in wood products: a method for attribution to multiple parties. Environ Sci Policy 10:162–168

Climate Change Impact in Cold Arid Desert of North–Western Himalaya: Community Based Adaptations and Mitigations

F. A. Shaheen, M. H. Wani, S. A. Wani and Chewang Norphel

1 Introduction

Situated in the northern extremity of India, Ladakh occupies a unique niche—physiographically, climatically and culturally. A cold desert, the region is characterized by lofty ranges, mountain rock-walls, bare ridges, glaciers and snow fields. Geographically, the Ladakh region in Jammu and Kashmir state lies in the high altitude ranges of northern most tip of the Asian sub-continent, between Karakoram and greater Himalayan ranges, interwoven with nude and rugged mountains extending from 32°–15′ to 36°–0′ N latitude and 75°–15′ to 80°–10′ E longitude, covering an area of 96,701 km^2 of which 27,555 km^2 is with Pakistan and China (Annexure 1). Meteorologically, it comes under cold arid zone. The cold arid occupies 16 % of earths land mass which are usually confined to high altitude and circumpolar region (Singh and Ahmed 2005). India accounts for 3.87 lakh km^2 arid zone of which 27.8 % lies in cold region of Western Himalaya and rest is under hot arid of Western Gangetic plains and Peninsular India (Dauley 1987; Directorate of Economics and Statistics, J&K Govt. 2008). Ladakh region, consisting of Leh and Kargil districts, lies in the high altitude range of North-Western Himalaya. Western Himalaya exhibit diverse topographic and climatic features and amongst these cold arid is almost fragile, inaccessible and marginalized with unique socio-economic and cultural issues. The aridity and extreme coldness are coupled in the region in such a manner that it gives rise to new environment that requires specific treatment with a different approach. The region has highest average elevation dotted with deep gorges, deserts and plateaus.

F. A. Shaheen (✉) · M. H. Wani · S. A. Wani
Division of Agricultural Economics and Marketing, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar Campus, Srinagar 191 121 Jammu and Kashmir, India
e-mail: fashaheen@rediffmail.com

C. Norphel
Leh Nutrition Project (LNP-NGO), Leh, Ladakh, Jammu and Kashmir, India

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_15,

Elevation ranges from more than 2,400–8,500 m. Soils of the Ladakh region are coarse textured, shallow and sandy, with high permeability and low water holding capacity. The region is snow-clad for almost 7–8 months, the remaining being the only productive months in the year. Lying north of the Himalayan watershed, Ladakh does not receive any summer monsoon and the annual rainfall is less than 7 cm, making it one of the world's highest cold deserts. Temperatures drop to minus 45 °C in winters and hover within the range of 10–20 °C during summer.

Despite hostile conditions, the region is inhabited for centuries and its people have learnt to survive there by establishing a synergistic relationship with their environment. However, life is never easy for the hard working people of Ladakh region and is severely constrained by the perpetual shortage of water. At the altitudes of more than 4,267 m, the severe climate and inhospitable terrain means Ladakh's peasants are able to plant and harvest only a single crop each year—wheat, barley or vegetables. It seldom rains in the area, so farmers rely heavily on natural glacier melt to irrigate the crops. Hundreds of glacier melt streams make three great rivers, the Indus, the Zanskar, and the Shayok in Ladakh that finally make their way into the ocean before passing through the Pakistan. Only 10–15 % agriculture farming is benefited out of Indus and Shayok in Ladakh, with the rest 85 % of farming irrigation entirely dependent on snow-melt streams and traditional water management system of all the watershed areas in the cold arid desert of Ladakh that are prevalent and practiced for centuries by the farmers. This system of water distribution during the farming season is strictly followed by the peasants at their respective villages and is recorded very minutely in revenue records popularly known as *Rewaj-e-Abpashi* (customs of irrigation) recorded in between 1909 and 1911 having time table for each and every distribution channel in every village. A strict implementation of the system is ensured through a group of *Churpon* (Mir-Abs/water-man), elected amongst the farmers by turn each year and these *Churpons* are highly empowered to penalize those who violate the system. Therefore, there has been least opportunity for extension of land holdings as there is no scope to share the water for new areas to bring under plantation or vegetation.

2 Climate Change and its Impact in the Region

In the face of global warming, most Himalayan glaciers have been retreating at a rate that ranges from a few metres to several tens of metres per year (Hasnain 2002). Glacier and ice cover some 17 % of the greater Himalayan region, a total area of nearly 1,13,000 km^2, the largest area covered by glaciers and permafrost outside the polar region. With glacier coverage of 33,000 km^2, the region is aptly called the 'Water Tower of Asia' as it provides around 8.6×10^6 million cubic meters of water annually (Dyurgerov and Meier 1997, 2000). It is the source of nine largest rivers in Asia, whose basins are home to over 1.3 billion people. Climate change has impacted the glacial ecosystem tremendously. Sixty seven per cent of glaciers are retreating at a startling rate in the Himalaya and major causal factor has been identified as climate change (Ageta and Kadota 1992; Yamada et al. 1996; Fujita et al. 1997, 2001; Kaul 1999; Ageta et al. 2001). Glacial melt will affect freshwater flows with dramatic adverse effects on drinking water supply, biodiversity, hydropower, industry, agriculture and others with far reaching implications on the people of region.

In order to validate the stark reality of climate change happenings in the region, the meteorological data was studied over a period of time. Data obtained from the meteorological department (Field Research Laboratory, Leh) for 36 years (1973–2008) was analysed to ascertain the trend over the period in temperature and precipitation. The temperature trend was analysed for peak winter and summer months. Analysis clearly indicates rising trend of minimum temperature of the order of nearly 1 °C for all the winter months at Leh (Fig. 1). Likewise, the maximum temperature for summer months showed rising trend of nearly 0.7 °C in the last 36 years (Fig. 2). One degree increase in winter temperature has serious implications on glacial formation and water security of the Ladakh region, in particular, and the Indus basin, in general. The snowfall which accounts for 70 % of total precipitation shows a declining trend by about 4 mm (Fig. 3) and rainfall in the summer season which contributes 30 per cent to total precipitation has declined by 3 mm over the time period (Fig. 4).

Glaciers and snow melt water play a very important role in the sustenance of life as they are the only source of water, be it for irrigating the fields or for any other domestic purpose. The most critical factors for extension of glaciers are extremely low temperatures complimented by heavy snowfall during peak winters, which in earlier days was favourable. However, over the past 36 years, due to changing temperature and precipitation, small glaciers in the region are retreating at a much faster pace than imagined, especially since the rising temperature trend is sharper in min temp of winter months and the declining trend in precipitation is sharper for the winter months. The winter precipitation is of utmost importance as 70 % of the total precipitation (in the form of snowfall) over the entire year takes place in the winter months.

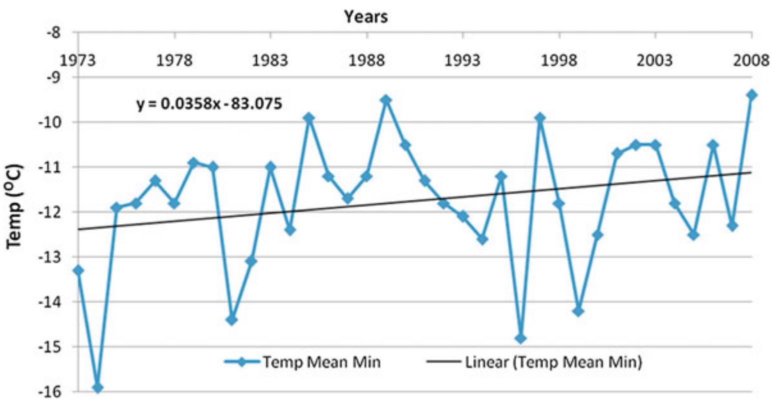


Fig. 1 Mean minimum temperature and trend, Leh–Ladakh (December 1973–2008)

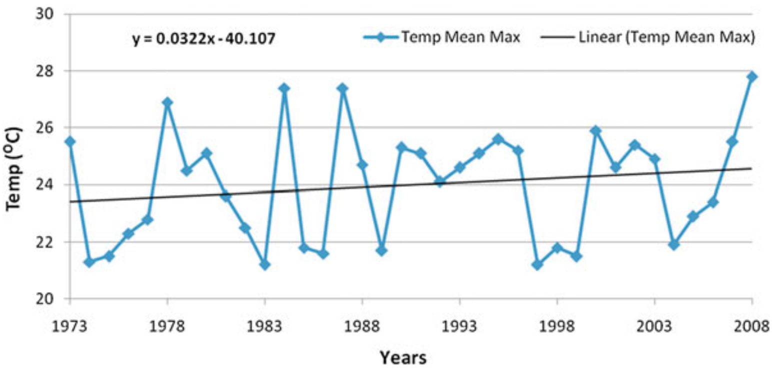


Fig. 2 Mean maximum temperature and trend, Leh–Ladakh (June 1973–2008)

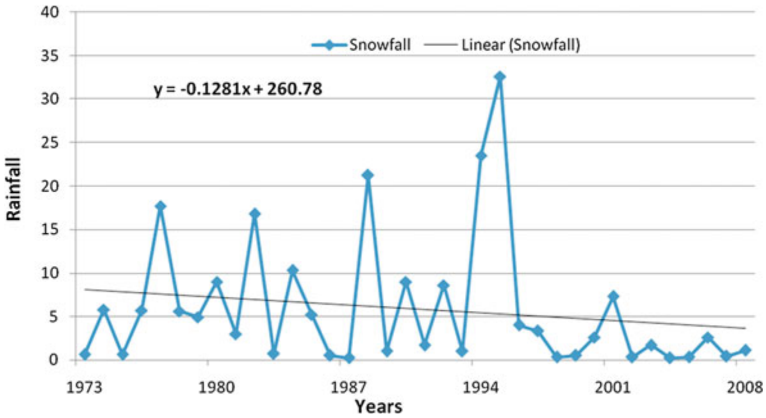


Fig. 3 Snowfall and trend, Leh–Ladakh (December 1973–2008)

Results from a survey of 17 villages and 180 individuals over 55 years of age also corroborated with the meteorological data analysis. People were asked about their perception in the change of temperature and precipitation over their life period, the results of which are depicted in Tables 1 and 2, respectively. Most people interviewed in villages said that winter temperatures have been increasing (2008 being an exception) and that the duration of the cold period (winter) has been decreasing. Likewise, the warm period, i.e., summer is getting longer; hot temperatures are perceived even in April. This was validated by the climatic data analysis for Leh. People's perception about less snowfall during winter months was more (93 %) as compared to low rainfall in summer (54 %) months. The people also perceived the erratic and untimely behaviour of summer rainfall which adversely affects the crop yield.

Ladakh is known as the land of mountain passes and majestic glaciers—glaciers that feed some of Asia's largest rivers and, thereby, sustaining the livelihoods of millions of people. There is a famous Ladakhi folk song 'a glacier on your right, a

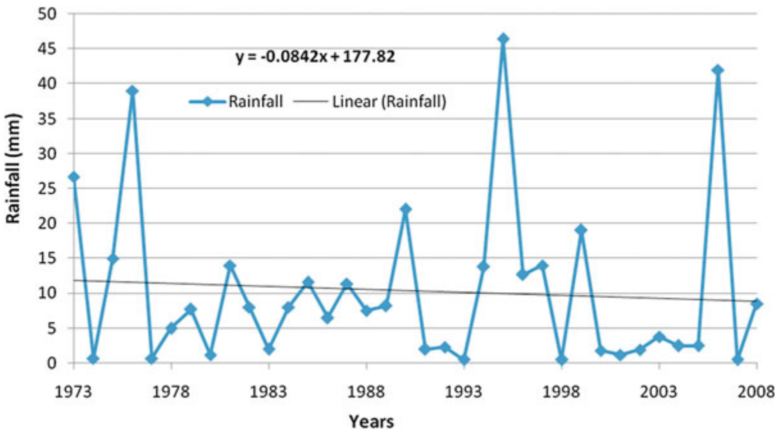


Fig. 4 Rainfall and trend, Leh–Ladakh (August 1973–2008)

Table 1 Perceptions of people regarding change in temperature

Perception	Percentage of farmers	
	Summer temperature	Winter temperature
Warmer	84	93
Colder	15	6
No change	1	1

Table 2 Perceptions of people regarding change in precipitation

Perception	Percentage of farmers	
	Change in rainfall	Change in snowfall
Less	54	87
More	30	6
No change	16	7

glacier on your left—a glacier as white as conch, the whiter the glacier….the better it is: the better it is for us all'. However, the need of concern is that for how long the people of region will be able to chant this song with fast retreating of glaciers, as Ladakh is no exception for the adversities of climate change. The signs of climate change are visible all over the region and they are disturbing to say the least. Over the years, winters are getting shorter, there is less snowfall and what virtual snow there is melts away rapidly leaving the region long before it can be put to use in the sowing season. Over the last few years, impacts of global climate change have been increasingly visible in the Ladakh region. Rainfall and snowfall patterns have been changing; small glaciers and permanent snow fields are melting, affecting water runoff in the rivers/streams, and rise in temperature and humidity inducing favourable conditions for the invasion of insects and pest aggression. The impacts of climate change are being felt most seriously in such extreme regions because, on one hand, they belong to one of the most vulnerable ecosystems and, on the other hand, people living in these regions often lack the possibility to adapt to the changing conditions.

The changing temperatures have already begun impacting the region’s biodiversity and its communities. Some changes in migration patterns of birds have been noticed in villages and also at Tsomoriri lake (as reported by WWF and wildlife warden). Migratory birds like Red-Shelldock used to leave Ladakh long before the harsh winters of this cold desert, now some of them have become residents. However, some other migratory birds like the geese, Brahmini duck have stopped migrating outside; they are found in the region throughout the year. Likewise, the breeding of bar-headed goose and black-necked crane is not on schedule in recent years and migration routes of communities on Tsokar lake (who rear the changthangi goats from which the famous pashmina shawls are woven) have become more frequented as these pastoral communities migrate due to degrading pastures (WWF 2006).

Chadar trek is getting shorter (January–February instead of December–March) and Tsokar Lake starts melting in beginning of March instead of mid-April which makes it difficult for the pastoral nomads to cross it with their cattle. Likewise, the Tsomoriri and Pangong Lakes are rising due to increased melting of glaciers and this is evident from the fact that the roads close to it are completely submerged under water and construction of newer roads along these lakes at higher elevations are on full swing. These lakes are unique and famous over the world and designated as Ramsar sites. The impact of climate change unfolded a human crisis in March, 2006, on the banks of river Zanskar. The people used to walk on the frozen river as late as March to their homes upstream at the other side of the river. Elders recall that during their teen age, the river used to remain frozen for a good three months and one could easily walk over to the village. Now, the ice sheet does not form thick enough to walk over it and gets melted early and people remain stranded in Leh. As sowing season approaches, they are unable to reach their village for necessary agricultural operations.

3 The Issue

Ladakh is a highly elevated, cold arid desert where people live at altitudes exceeding 4,000 m above mean sea level. Spread over an area of about 9.9 million hectares, the region has a population of about 2,36,539 (2001 census) of which nearly 85 % depends on agriculture. Situated in the rain shadow region of the upper Himalayas, Ladakh receives an annual average rainfall of 50 mm between May and July. Subsistence farming on very small holdings (average land holdings 0.72 ha with 80 % holdings smaller than one ha) with nominal animal husbandry and a limited trading activity (Annexure 1), is still the mainstay of a major chunk of the population, relying on hard work and scarce local natural resources, to meet their everyday need. Hardly anything grows in Ladakh naturally; everything has to be cultivated using irrigation techniques. The key to cultivation in Ladakh is the intelligent use of water. Ladakh has abundant sunlight and good soil but without water it is a vast barren desert. Nearly 68 % of the total land lies 5,000 m above mean sea level and is virtually unfit for vegetation and human life. Agricultural operations are confined to areas below 4,500 m in altitudes with the growing season restricted to less than 6 months a year.

Dry land cultivation is not possible in Ladakh. The entire 19,967 ha of cultivable land depends on assured irrigation from the glacial melt water through long, rocky, sandy and winding streams from the upper mountain reaches. There is habitation and vegetation where there is a stream. Beyond that there is no trace of vegetation and/or habitation for miles, only long unending stretches of desert plains until another patch of greenery and human dwelling surrounding the streak of a small stream. It is really water from melted snow that sustains life and most people live along glaciers and snow-melt water courses. The agriculture season in Ladakh begins in April with the melting of snow in fields. The melting of snow is often late, delaying the availability of water for irrigation and the sowing of crops, thereby, adversely affecting the production. The summer season in the region is of short span and mono-cultured. The farmers need to cultivate the crops like wheat, barley, peas, potatoes, alfa alfa, etc., at the proper time to allow it to mature within limited short summer season. The agriculture season commences in the month of April–May, while the process of snow and glacier melting at high altitude begins around end-June. During the rest of the year, from August to April, very little water comes down the streams, as temperatures at the high mountain peaks do not allow snow to melt. This delays the process of seed sowing, which affects the crop productivity adversely. So, spring is the most crucial season for farmers to begin the sowing process. Very little water comes down through streams during the spring as the temperature at the high mountain peaks, where snow/natural glaciers are inhabited, is not adequate enough to facilitate the snow/glacier melting process. The potential for improving agricultural production is, thus, restricted to the traditional turn of water sharing and distribution system prevalent throughout the year.

4 Community Based Adaptations and Mitigations

Adaptation is the processes through which societies make themselves better able to cope with an uncertain future. Adapting to climate change entails taking the right measures to reduce the negative effects of climate change (or exploit the positive ones) by making the appropriate adjustments and changes. There are many options and opportunities to adapt. These range from technological options to behaviour change at the individual level. The adaptation and mitigation measures taken by the community to combat the externalities of climate change were identified and assessed for broader implications. Water storage and water use efficiency has a great role to play in the adaptation in the ecologically harsh cold arid desert where nothing grows naturally without proper application of water. Furthermore, the communities of such regions have also developed livelihood assets to reduce vulnerability against the natural extremities. The creation of artificial glaciers to combat the receding of natural glaciers, thereby, increasing water storage and its availability in summer and production of vegetables in the peak of winter, through improved solar greenhouses which mitigate the effects of CO_2 emissions, were identified as the major climate change adaptation and mitigation strategies.

4.1 Water Management

The traditional ponds, reservoirs and khuls existing in many villages are in a dilapidated condition, which cannot store the melting water for long time. A lot of efforts were put up by different agencies to find out the possibilities to make these reservoir/ponds more spacious, efficient and strong. The khul and distributaries were also repaired to improve the efficiency, however, the main problem of making water available to farmers during the spring season still persist. The need was, therefore, felt to develop a technique that will ensure the water availability to farmers during the critical stage of seed sowing period (April–May). Chewang Norphel (one of the co-authors), a retired civil engineer and National Prize Award winner, known to his men as the 'ice man', came with a solution with an innovative technique of creating artificial glaciers in the region. Norphel's big idea came from a small observation of water rushing out of pipe in the lane near his house. At the centre of the torrent, water rushed out and flowed on while at its sides, it slowed down and froze. The water was freezing in stages as it lost the momentum. This inspired Norphel to make the artificial glacier. The first artificial glacier was experimented in 1987 at Poktse Pho village in Leh district and was spread to other villages after establishing its successful performance. Till now, ten artificial glaciers have been created purely on a community based approach, keeping in view the farmers demand with a bottom up approach and peoples cooperation. A detailed study was made to know better about this technique of water management in the context of climate change in the cold arid desert and how to replicate this model in similar regions across the globe. It was in this backdrop that an in-depth study was conducted to explore various facets of this innovative technology of creating 'artificial glaciers' for irrigation in the highest cold arid desert of the world.

4.2 Purpose of Creating Artificial Glaciers

Ladakh, known as the land of mountain passes and majestic glaciers—glaciers that feed some of Asia's largest rivers, thereby, sustaining the livelihoods of millions of people. However, glaciers are now retreating by some 50 ft every year and Ladakh is no exception. There are visible marks of climate change impact on the region. Over the years, winters are getting shorter, there is less snowfall, and whatever snow is there melts rapidly leaving the region before it can be used in the sowing season. The main purpose and need felt for creating of artificial glaciers was to make water available at the beginning of sowing time in the month of April when there is no water. The artificial glaciers are created at the top of the villages below the foothills on shady side. These glaciers are created with the objectives to ensure the availability of water during early spring season for cultivation; to enhance the crop productivity by making water available in adequate quantity and in time; to bring waste lands, uncultivated land under productive activities; to improve the cropping pattern of the farmers; to prevent the wastage of scarce water and to mobilize farmers participation in the management of artificial glacier formation and components of the irrigation system.

4.3 Design and Components of Artificial Glacier

The technology for creating artificial glaciers consists of three main components, i.e., headworks or diversion channels, main artificial glacier structure and distribution network/channels. The mainstream water is diverted towards a shady area by constructing a long channel created with the help of dry stonewall across the hill slopes to the artificial glacier site. The length, breadth and depth of channel vary with the slope of the hill as well as an estimated discharge of the stream. The channel is protected by dry stone retaining and breast wall and suitable bed grade to smoothen the flow of water to a canal. The stone wall is erected with the help of locally available stone and chassed with organic manure mixed with soft soil. The organic manure and soil help to establish the stone wall with the help of naturally mixed shrubs and plant materials to strengthen the wall. No other concreting or cementing material is used to strengthen the wall. This minimizes the cost of construction so also there is minimum danger of it getting washed away as there is no torrential rain.

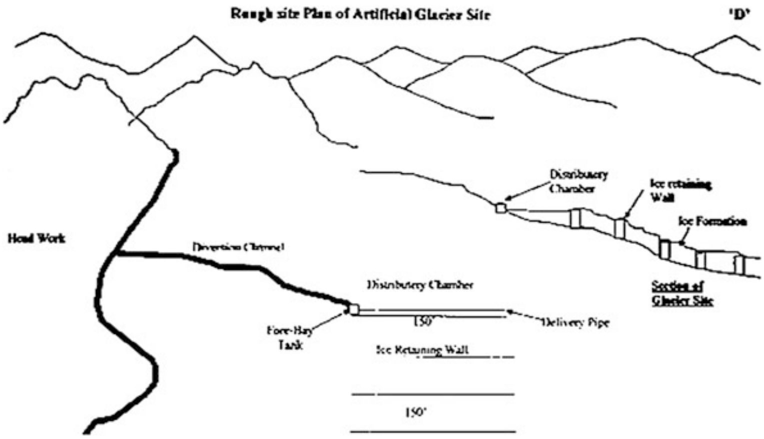
The process of artificial glacier formation and site selection envisages some basic pre-requisites. First, the collection of discharge data from the main stream is done to ascertain where water remains throughout the winter. After this, the selection of site for formation of the artificial glacier is based on that it should be on the north side of the hill under shade which prevent/minimize the effect of direct exposure of the glacier to sun shine as well as smoothening the process of glacier formation. Secondly, it should not be located on a steep slope but preferably in plain area with 20–30 slope gradients so that along with losing momentum, water gets frozen into ice sheets. Thirdly, it should be at a lower altitude to facilitate the process of early melting, preferably at 3,962–4,267 m; and, finally, it should be near to a village so as to make ice melt water available within shortest distances from the cultivated fields and minimize seepage losses and delivery time.

The diversion channel is constructed across the hill slopes to the site of artificial glacier formation. Construction of snow barrier bund/ice retaining bund is built of dry stone masonry in crate wire on the lower side of diversion channel at the glacier formation site. Length of proposed glacier and number of barrier bunds depends upon the slope at the site. Lesser the slope more will be the length and less number of bunds, with more inter-bund intervals and vice versa. If the section of the stream is very wide with a mild slope, then the dry stone masonry bund in crate wire across the stream are constructed in a series parallel to each other. The number and dimension of ice retaining bunds depends upon the water discharge available in the main stream during peak winter. In the month of November, when winter starts, some wild grasses locally available are needed to be put on the base of the dry bund to plug the void which helps in freezing the water instantly (Map 1).

If the section of stream is narrow with a steep grade, then it needs to be diverted to a shady area by constructing a gravitational channel with a bed grade 1 in 30. When it reaches at the glacier site, the bed grade should be gradually reduced, say up to 1 in 50, so that water can flow through various small outlets. The water flowing through these small outlets being in very small quantity freezes instantly. Dry stone masonry in crate wire needs to be constructed parallel to the channel in series at a distance of 10–30 m according to the nature of slope of terrain. Steeper the terrain, lesser the distance and lesser the slope more is the distance between the bunds. The process of ice formation continues for 3–4 months and a huge reserve of ice accumulates on the mountain slope, aptly termed as 'artificial glacier'.

4.4 Operational Aspects

The work for creation of the structure is taken up in between May and October. Water collection at the glacier site begins in mid-November at a slow pace. Freezing of water begins at zero degrees Celsius. Stabilization of ice occurs within



Map 1 Rough site plan of artificial glacier site

24 h and, thus, gets converted into a glacier or ice block. The glacier remains in place till end of March when the process of melting begins with the rise in temperature. Artificial glaciers start melting earlier compared to natural glaciers as the former are located at lower altitudes and exposed to rising temperature early. There is almost 1,219–1,524 m altitudinal difference between the locations of natural and artificial glaciers. In the beginning of April, the temperature in the Leh plains is in the range of 9–10 °C, whereas, at high altitudes where natural glaciers are located, temperature remains confined to −10 °C.

The melting of the glacier depends upon the size and temperature; however, the benefit is that when the artificial glacier melts completely and flows in full swing, the process of high altitude snow melting starts, which slowly streams into the reservoir. Melting water from glacier is stored in the reservoir ponds located at different sites in the village. Water distribution is regulated by the volunteers appointed by the village community through existing network of khuls and channels. The active life of an artificial glacier is usually about 4 months (mid-November to mid-April), however, it will depend upon the length of winter and prevailing temperature. During cloudy weather, when the snow melting process gets slowed or stopped completely, then the water in the village reservoir ponds is used for irrigation.

4.5 Impact of Technology

For any technology to sustain, it should be socially, environmentally and economically viable. An impact assessment of the technology was undertaken to examine the change on the agrarian economy of the beneficiaries besides knowing its social and environmental impact. Usually, for impact assessment studies in case of irrigation projects are done by adopting with and without and ex-ante and ex-post scenarios. In this case, the impact of artificial glacier technology was assessed by applying ex-ante and ex-post (before-after) method. In order to estimate the additional benefits accrued due to technology, four artificial glaciers were selected for complete assessment. The particulars of these four created artificial glaciers are depicted in Table 3.

The positioning of these artificial glaciers is in the range of 3,810–4,389 m amsl. These glaciers have augmented the household economy of almost 450 families with a population of 2,315. The cost for creation of these glaciers usually range from 3 to 10 lakhs and were funded under the government's watershed development programmes as well as under Indian Army's Sadhbavna Project. Due to difficult terrain and high altitude compounded with non-availability of labour, the cost of transporting the materials is very high.

The artificial glacier has been operating in the area for the past so many years and is performing with great success. Farmers, in particular, are extremely happy with the positive results of the technology. Water from the artificial glacier melts much earlier in the year than the natural glacier. The process is able to take place

Table 3 Particulars of selected artificial glaciers

Particulars	Name of artificial glacier sites			
	Saboo	Nang	Phuktse	Stakmo
Altitude (m)	4,389	3,810	4,114	3,931
Year of creation	2001	2000	1987	2000
Volume of glacier created (cubic m)	2,53,710	2,93,589	2,34,152	3,74,523
No. of villages catered	2	1	4	1
No. of families benefited	58	70	176	147
Population	340	385	890	700
Cultivable area including plantation (ha)	75	105	87	120
Cost in Lakh Rs.	5.94	7.80	1.35	9.35
Funding agency	WSDP	WSDP	WSDP	Sadhbavna

in spring, whereas, with the natural glacier water melting, cultivation would take place 20–30 days later, thereby, adversely affecting the crop yield. The wastage of water from the winter can later be used for irrigation. In this region, only one crop can be taken, after which the water goes to waste. With an adequate quantity of water available at this earlier stage, more areas can benefit from the production of food crops, vegetables, fodder crops, trees, willows, poplars, etc.

As is evident from the Table 4, there has been shift in area from traditionally grown crops to more remunerative crops as well as in the yield of these crops. Both of these changes (area shift as well as increased yield) have resulted in 3–4 times increase in the income of the farmers of these villages getting benefited out of this technology. Moreover, they are also generating more income from the livestock rearing through milk and other products due to more acreage as well as increased number of cuttings from alfa alfa fodder crop. It has also helped in developing pastures for cattle rearing, which is an important livelihood asset of the region.

There is environmental and social impact of this technology too in the positive direction. It has helped to increase the ground water recharging in the area as the existing springs in the village produce more water. The artificial glacier can be used despite low snowfall, as water produced at the spring can be frozen at lower altitudes and converted to ice within the vicinity of the village. With the artificial glacier being so near to the villages, people save time accessing water and there is a decrease in loss of water due to seepage. The summer season now gets extended

Table 4 Change in cropping pattern and crop yield

Name of crop	Before		After		Percentage change	
	Area (ha)	Yield (q/h)	Area (ha)	Yield (q/h)	Area	Yield
Barley	28	19.20	20	21	−28.57	9.37
Wheat	238	10	174	12.5	−26.89	25.0
Potato	34	180	53	217	55.88	20.55
Peas	17	30	35	37.5	105.88	25.0
Other vegetables	9	37	25	43	177.77	16.22
Alfa alfa	18	1–2 cuttings	37	3–4 cuttings		

since water is available from April which has enabled farmers to grow additional crops like potatoes and green peas in addition to other vegetables, which fetch them good income. There is increase in availability of labour man-days as farmers now get relatively more employment on their fields and has, thereby, checked the emigration of people from these villages. Furthermore, due to adequate and timely availability of water, it has reduced the water sharing disputes among the farmers and has brought social cohesion in the project villages.

4.6 Constraints in Operation of Technology

No technology is without limitations and constrains. Likewise, this technology has experienced some constraints in its operation which are as follows:

1. Availability of appropriate site is the primary constraint as the location has to be on the northern side of hill which makes, at most times, a long diversion channel to bring water to the glacier formation site necessary, thereby, exacerbating the cost.
2. Flow of water at reduced pace into the glacier sites cannot be ensured every time due to temperature variation as increased flows affects the process of freezing.
3. The feeder channel/dimension channels get blocked due to falling stones from hills, ice block, soil and other debris, which reduce the smooth flow of water into the glacier site.
4. Continuous monitoring of flow channel is required to ensure the sustained water flow and such supervision may not be forth coming from villagers.
5. Occasional maintenance of diversion channel and ice retaining bunds is needed to keep the structures in working condition.
6. Labour availability and shorter working season is also a constraint in doing the groundwork. Sometimes Nepali labourers are to be employed for construction of diversion channels at high altitude and at higher wages.
7. Due to uneven terrain and high altitude as well as non-availability of proper road infrastructure, the cost of transporting the material goes up exorbitantly.
8. The availability of funds is also a major constraint as it takes a long time to get finances for creation of artificial glaciers. Many of the artificial glacier structures have been implemented under the watershed development programme. Due to non-receipt of full instalment of project funds, many projects had to be left incomplete.

4.7 Relevance of Artificial Glaciers with Climate Change

The creation of artificial glaciers is a high altitude water conservation technique in the wake of climate change. As the glaciers are receding rapidly and winters are getting shorter and warmer, whatever little snowfall is received melts away quickly. The snow and glacier melt water drains into the rivers without any use to the farmers for most part of the year and farmers are unable to find any water when it is needed during the sowing season. So the construction of artificial glaciers is a means for harvesting glacial melt water for the irrigational needs of farmers, which otherwise goes waste and is of no use. Natural glaciers are way up in the mountains and melt slowly in summer reaching the villages in June, whereas, artificial glaciers start melting in spring right when the first irrigation requirement called '*Thachus*' (in Ladakhi which means 'germinating water') is most needed.

The history of glacier growing goes back to 13th century when the news of Genghis Khan and his marauding Mongol hordes reached what is now the northern Pakistan. The people there came up with an unlikely means of keeping them out by simply growing glaciers across the countryside according to local legends (Douglas 2008). Whether or not these stories are true, the art of glacier growing also known as 'glacial grafting' has been practised for centuries in the mountains of Hindu Kush and Karakoram ranges (Tveiten 2007). It was developed as a way to improve water supplies to villages in the valleys where glacial melt water tended to run out before the growing season (Inayatullah 2007). The Aga Khan Rural Support Program (AKRSP), an NGO based in Baltistan, is actively engaged in funding for grafting of new glaciers in the region in order to improve the water supplies to villages with limited access (Khan 2005). Can artificial glaciers help compensate for the disappearance of naturally forming ones? Now, as these remote mountain communities come under pressure from population growth and climate change, researchers and development agencies need to take a serious look for improving the art of glacier growing to address the water problems of such regions. The technique of creating artificial glacier need to be replicated in similar geo-climatic regions such as Lahaul and Spiti in Himachal Pradesh, India; Hindu Kush Himalayan range of Pakistan and Afghanistan; and some central Asian countries like Kazakhstan and Kyrgyzstan. The technology can be replicated in areas with features of 4,666–5,333 m altitude range; temperature as low as −15 to −20 °C during peak winters; and longer winter periods of 4–5 months to ensure longer expansion and formation of glaciers.

4.8 Low Carbon Solar Greenhouse Vegetable Production

The small-scale agriculture, with an average holding size of 0.72 ha, coupled with monoculture of limited growing season limits the options of household food security of the region which remains cut off from rest of country most of the time. During summer, most of fresh vegetables are imported by truck from the Indian plains. But from November on to May, the two main access roads (from Manali and Srinagar) are closed and the capital city, Leh, is the only place to get fresh supplies, sent by air. Villages benefiting from a small economic centre (such as Nyoma) can have access to basic commodities, fresh vegetables being rarely available. Market prices are tripled compared to summer prices and few products are available. During this period, most of the families do not have access to fresh vegetables, either because they live in remote areas or because the prices are too high, which makes them more vulnerable to disease and prevents them from having a balanced and nutritious diet.

The issues of food security and nutrition are at the very core of sustainable mountain development, and yet they tend not to be given due consideration. Socially and economically marginalised, mountain people are more vulnerable to food shortages and chronic malnutrition due to a variety of factors, such as their isolation, the harshness of the climate to which they are exposed, and the difficulty to grow nutritious crops on a difficult terrain. The implementation of solar greenhouse project by a local NGO based on passive solar concept: solar gain, heat storage, heat release, insulation and ventilation, offers a valuable experience as to the possibilities of supporting small-scale farmers living in cold arid regions to improve their livelihood. The greenhouses, heated entirely by sunlight to keep the inner temperature high enough to grow vegetables, even when outside temperatures drop to –25 °C, support the development of seasonal and off-seasonal vegetables (such as spinach, coriander, onions or garlic) that improves: (1) the dietary intake of populations living in remote areas; and (2) the access of vulnerable farming communities to an increased amount of basic services through income generation. Simple to build, using cheap locally sourced material and labour, each greenhouse constitutes a relatively minimal investment, to which the owner contributes the largest part, mostly in kind. From an improved solar greenhouse with dimension of 16 × 19 m costing Rs 30,000 in which Rs 10,000 are invested in cash and the rest is in form of labour component or locally available material at the farmstead. A farmer grows on an average 500 kg of vegetables and earns Rs 15,000 per year. The payback period of the total cost is less than 3 years. The increase in household income of the beneficiaries has been by 20–50 % (Table 5). The income is generated during the off winter period when there are no other opportunities. Usually, women have been found active in this enterprise.

The impact of solar greenhouse has been remarkable, particularly on health, by an improved diet, as vegetable consumption has been multiplied by more than 8 times for each family. A total of 586 improved solar greenhouses along with compost pits covering 163 villages with an equal number of households have been benefited with this technology. In addition, the development of solar greenhouses has not only contributed to reinforce men and women's self esteem and confidence but also helped them to move beyond subsistence livelihoods in integrating the market economy and, therefore, made them able to play a more active role in society.

Passive solar greenhouse relies on solar energy only and does not require any additional heating to guarantee vegetable production, even during peak winter. Hence, it ensures a low-carbon vegetable production that replaces imports which were previously brought by truck during summer or by air-transport during winter. Thus, the project contributes to reducing greenhouse gas (GHG) emissions. The local NGO promoting the solar greenhouse project in cooperation with MyClimate, a Swiss based organisation, developed a baseline scenario in order to estimate reductions of GHG emissions. It was assumed that without the project,

Table 5 Features, production and income from solar greenhouse low carbon vegetable production

S. No.	Particulars	No./Units
1.	No. of solar greenhouse constructed	586
2.	No. of villages covered	163
3.	No. of beneficiaries benefited	586
4.	No. of compost pits constructed	144
5.	Standard size of IGH	16 × 19 ft
6.	Average cost of IGH	Rs. 30,000
7.	Average Production of vegetables from IGHs	300 tonnes
8.	Increase in income of beneficiaries	20–50 %
9.	Increase in consumption of fresh vegetables in winter	8 times
10.	Additional quantity of vegetables produced in year	500 kg
11.	Payback period	3 years
12.	Average reduction in CO_2 emissions by one IGH	835 kg per year

vegetables would be imported during winter and would lead to GHG emissions due to air transportation. It has been estimated that the additional quantity of vegetables produced annually by one greenhouse (500 kg in average) contributed to the reduction of CO_2 emissions of 835 kg per year. Since the beginning of the project up to 2008, the solar green house project allowed the reduction of 1,343 t CO_2 equivalent (Triquet 2009).

4.9 Conclusions and Policy Suggestions

Water links the climate system with our human ecosystem and should be central to the debate over how to most effectively tackle the climate crisis. Because the climate impacts on water are so widespread, much climate change adaptation translates into water adaptation. By 2025, almost half of the global population is projected to live in water stressed areas (Smith 2009). In general, arid and semi-arid regions are predicted to experience significant temperature increases and reduced precipitation. Under these circumstances, it becomes highly important to capture and store the water so that it can be used for food production. Taking the right steps now, to implement effective water governance that maintains well functioning watersheds, can increase the resilience of both communities and economies. The need of the hour is to scale up the technologies for mitigation of climate change impacts like that of the artificial glacier technology and solar greenhouse low carbon vegetable production in ecological harsh and fragile environs. It is important to strengthen local knowledge, innovations, and practices within social and ecological systems as well as strengthening the functioning of institutions relevant for adaptation. Sound science together with credible, salient, legitimate knowledge is important to support the development and implementation of sound policies. Researchers and developmental agencies need to further improve such adaptive technologies and funding should come forth from the donor agencies for implementing of such technology on wider scale.

Annexure 1: Demography, Land Use and Agriculture Scenario of the Region

S. No.	Particulars	Leh	Kargil	Ladakh region
(A)	*Demographical features*			
1.	Population (2011census)	82,665*	14,036	96,701
2.	Geographical area (sq.km)	147104	143388	290492
3.	Literacy rate (%)	80.46	74.49	62.4
4.	BPL population (%)	22.07	31.9	27.3
(B)	*Land use classification*			
1.	Total area according to village papers	45,167	19,459	64,626
2.	Area under forests	–	64	64
3.	Land put to non-agricultural uses	2,908	1,176	4,084
4.	Barren and uncultivable land	25,163	4,578	29,741
5.	Permanent pastures & grazing lands	1,092	–	1,092
6.	Land under miscellaneous tree crops	1,147	392	1,539
7.	Culturable waste land	4,410	3,022	7,432
8.	Fallow lands	198	134	332
9.	Current fallow	146	229	375
10.	Net area sown	10,103	9,864	19,967
11.	Average holding size	0.75	0.69	0.72
(C)	*Area under different crops*			
1.	Wheat	2,634	1,764	4,398
2.	Barley	76	3,029	3,105
3.	Millets	303	571	874
4.	Pulses	306	547	853
5.	Condiments and spices	5	–	5
6.	Fruits and vegetables	439	359	798
7.	Other food crops	4,639	895	5,534
8.	Total food crops	8,402	7,165	15,567
9.	Oilseeds	86	–	86
10.	Fodder crops	2084	–	2084
11.	Total area sown	10,516	10,732	21,248
12.	Area sown more than once	413	868	1281
13.	Net area sown	10,103	9,864	19,967
14.	Cropping intensity (%)	104	109	106
15.	Total Irrigated area	10,516	10,732	21,248
16.	Net irrigated area	10,103	9,864	19,967
17.	Irrigation intensity (%)	104	109	106
(D)	*Livestock*			
1.	Total Livestock population	4,75,300	2,88,500	7,64,400
2.	Sheep	1,33,700	1,01,500	2,35,200
3.	Goat	2,62,700	85,600	3,48,300
4.	Others	78,900	1,01,400	1,80,900

Source Statistical Digest 2011-2012

* Out of 82,665 sq.km. area, only 45,110 sq. km. is in possession with India and rest (37,555 sq. km. is under illegal occupation of China in Leh (Ladakh) district

References

Ageta Y, Kadota T (1992) Predictions of changes of glacier mass balance in the Nepal Himalaya and Tibetan Plateau: a case study of air temperature increase for three glaciers. Ann Glaciol 16:84–94

Ageta Y, Naito N, Nakawo M, Fujita K, Shankar K, Pokhrel AP, Wangda D (2001) Study project on the recent rapid shrinkage of summer accumulation type glaciers in Himalayas, 1997–1999. Bull Glaciol Res 18:45–49

Dauley HS (1987) Technologies for integrated development of agriculture in arid areas. In: Shafi M, Raza M (eds) Dry land agriculture in India. Rawat Publications, Jaipur, pp 71–78

Digest of Statistics (1991–1992, 2008–2009, 2011-2012) Planning and Development Department, Jammu and Kashmir Government, Srinagar, J&K

Douglas E (2008) How to grow a glacier. New Scientist Magazine 197 (2461):1–2 (http://www.newscientist.com/article.mg19726412.000-how-to-grow-a-glacier.html?page1-2)

Dyurgerov MB, Meier MF (1997) Mass balance of mountain and sub-polar glaciers: a new global assessment for 1961–1990. Arct Alp Res 29(4):379–391

Dyurgerov MB, Meier MF (2000) Twentieth century climate change: evidence from small glaciers. Proc Nat Acad Sci 97(4):1406–1411

Fujita K, Nakawo M, Fujii Y, Paudyal P (1997) Changes in glaciers in Hidden Valley, Mukut Himal, Nepal Himalayas, from 1974 to 1994. J Glaciol 43:583–588

Fujita K, Kadota T, Rana B, Shreshta RB, Ageta Y (2001) Shrinkage of glacier AX010 in Shorong Region, Nepal Himalayas in 1990s. Bull Glaciol Res 18:51–54

Hasnain SI (2002) Himalayan glaciers meltdown: impact on South Asian Rivers. IAHS Publication 274:1–7

Inayatullah F (2007) Artificial Glacier Grafting: Indigenous knowledge of the Mountain People of Chitral. Asia Pac Mt Netw (APMN) Vol 8(1):6–7

Kaul MK (1999) Inventory of Himalayan glaciers. Geological Survey of India, Calcutta (Special Publication No. 34)

Khan S (2005) Glacier grafting. In: The Aga Khan rural support programme, vol 16, Skardu, Pakistan

Singh N, Ahmad Z (2005) Solar green house technology for vegetable production in high altitude cold arid regions. Field Research Laboratory, DRDO, Leh, Ladakh

Smith M (2009) Two for the price of one. In: World conservation, the magazine of the International Union for Conservation of Nature, IUCN, 21 Oct 2009

Triquet M (2009) Passive solar greenhouse in Ladakh: a path to income generation and livelihood improvement. GERES Report

Tveiten I (2007) Glacier growing—a local response to water scarcity in Baltistan and Gilgit. Master of Science Thesis, the Norwegian University of Life Sciences

WWF (2006) Report on impact of global warming on biodiversity in Ladakh region

Yamada T, Shiraiwa T, Kadota T, Watanabe T, Rana B, Ageta Y, Fushimi H (1996) Fluctuation of glaciers from the 1970s to 1989 in the Khambu, Shorong and Langtang regions, Nepal Himalayas. Bull Glacier Res 10:11–19

Conservation of Multipurpose Tree Species to Ensure Ecosystem Sustainability and Farmers Livelihood in Indian Arid Zone

S. K. Malik, D. C. Bhandari, Susheel Kumar and O. P. Dhariwal

1 Introduction

Arid and semi-arid areas in India cover 1.27 million sq km accounting for 38 % of the country's geographical area. The Great Indian Desert, also known as 'Thar Desert', has an area of 0.32 million sq km, which is approximately 10 % of the total geographic area. The Indian desert happens to be the smallest desert of the world, however, exhibiting a wide range of habitats and rich in biodiversity comprising Palaearctic, Oriental and Saharan elements. There are around 30 plant species in the arid zone known for their edible use and of these around 20 species are known for their edible fruits, either raw or use as vegetables. The genetic resources of these species are of great significance because of their adaptability to harsh environmental conditions as well as in sustaining the fragile ecosystems and supporting livelihood of the inhabitants. Despite the vast genetic diversity of fruit crops, only important fruits like mango, banana, citrus and guava have gained in the productivity and acceptability by the people in the tropical part of the World. Many of the indigenous tropical and temperate fruits have still remained under-exploited due to the lack of awareness of their potential, market demand, and low and erratic bearing in many cases. Many of these species have multipurpose uses as fruits, vegetables and also have therapeutic and medicinal properties. Genetic resources of such fruits are facing a great threat of extinction due to climate change, large-scale urbanization and developmental activities. To safeguard the existing diversity of underutilized fruits and to achieve sustainable development based on use of available genetic wealth, promotion and conservation of these species is of immense importance. Organized production and processing for value addition of products would enhance income of small and marginal farmers and also help in on-farm *in situ* conservation of valuable germplasm. At the National

S. K. Malik (✉) · D. C. Bhandari · S. Kumar · O. P. Dhariwal
National Bureau of Plant Genetic Resources (NBPGR), Pusa Campus,
New Delhi 110 012, India
e-mail: skm1909@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_16,

Bureau of Genetic Resources (NBPGR), an extensive collection, characterization and conservation programme has been undertaken for identification of promising germplasm and to support the improvement programmers of these fruit species.

Southeast Asia is home to 500 species of fruits, while the Hindustani region of diversity represent 344 species of fruits having vast potential as new crops, most of which are still growing in the wild or semi-wild state (Arora 1998). About 90 % of the world food comes from 20 plant species. Lack of awareness of their potential, market demand, and low and erratic bearing in many cases has led to their under exploitation. Genetic resources of tropical underutilized fruits (UUF) have not been given desired attention due to their comparatively less commercial importance and limited research on genetic improvement of cultivars. Opening of the world markets and development of new biotechnological methods of genetic modifications in high value commercial fruits would further keep the attention away from these traditional underutilized fruits leading to great loss in genetic diversity of these fruits. Several other factors such as change in climatic conditions, introduction of new irrigation methods and canals, large scale developmental activities taking place in developing economies, like India, is leading to an alarming loss of genetic resources of these species. These genetic resources are well adapted to the stressed, arid and semi-arid ecosystems having high potential for mitigating inevitable climate change scenario, and hence need immediate attention. Besides their importance for ecosystem sustainability, these underutilized fruit species provide substantial livelihood support to small, marginal and landless farmers. In view of the great importance of these underutilized fruit species and urgent need to strengthen the genetic resources and improvement work, Indian Council of Agricultural Research launched a "National Network Project on Underutilized Fruits" to collect, introduce, characterize, evaluate, conserve and utilize the genetic resources of these species. There is a need to further evaluate these identified genotypes and release the cultivars for respective areas.

The present paper deals with the current status of distribution, role in ecosystem sustainability, socio-economic status and conservation strategies of several tree and shrub species of underutilized fruits namely *Aegle marmelos, Buchanania lanzan*, *Capparis decidua*, *Carissa congesta*, *Cordia myxa*, *Emblica officinalis, Garcinia indica, Grewia asiatica, Madhuca indica*, *Manilkara hexandra*, *Pithecellobium dulce*, *Prosopis cineraria*, *Salvadora oleoides, S. persica, Tecomella indica* and *Ziziphus nummularia, Syzygium cuminii* in Indian arid zone.

2 Materials and Methods

For this study, several survey and exploration trips were conducted in arid and semi-arid regions of India, mainly Rajasthan, Gujarat, Madhya Pradesh and Haryana. Survey studies included recording of numbers of species, area, status of natural population, indigenous technical knowledge on importance and use of species, market demand, biological status and cultivation practices. Data on livelihood support of species was collected based on production, harvesting and market value of the produce. Survey was also made to various field genebanks maintaining these multipurpose tree species germplasm in India. Ethno-botanical information regarding importance and use of these underutilized fruit species like *Capparis decidua*, *Cordia myxa*, *Manilkara hexandra*, *Salvadora oleoides, S. persica, Pithecellobium dulce*, *Prosopis cineraria*, *Tecomella undulata* and *Ziziphus nummularia* were collected by interacting with local people. Specifically, senior-most persons and local traditional healers were interviewed to collect information on religious, medicinal and dietary uses of these species. Collections were made following selective sampling strategy in which plant material, especially fruits, were collected from a single plant and sample was treated as individual accession. Passport data of each collected accession was recorded individually.

3 Results and Discussion

3.1 Extent of the Arid Zone

Arid zones account for about 19 % of the land area of the world on all continents: of this area, Africa has about 46 %, and Asia 36 %. Arid and semi-arid areas are defined as areas falling within the rainfall zones of 0–300 mm and 300–600 mm, respectively (FAO 1987). Drylands cover more than 60 % of the earth's surface. Arid zones are described as a part of the drylands, and have the most severe edapho-climatic conditions. This makes a great difference in terms of the nature of the ecosystem, the socio-economic environment and the challenges for sustainability. Vegetation is sparse, and there are few perennial woody tree species making an important component of the green cover. Indian arid zone, popularly known as Thar, is the most vegetated arid zone in the world, and farmers grow arable crops in association with trees. The drought-resistant trees provide fuel, fodder, fruits and many other products, and are an important component of the life support system of this region. Because the Thar Desert has been inhabited for a very long time, it is one of the most studied and best understood arid zones in the world.

Thar is classified as a tropical thorn forest, where the hostile environment does not support much natural regeneration and growth of native plants. Of the 682 plant species, only 9.4 % are endemic. There are relatively few tree species (forty-nine), mostly introduced from other arid zones in the world. Most of these are multipurpose species, providing numerous livelihood support products to local inhabitants. They are often grown in association with other crop plants, as part of vegetation complexes in the form of agro-forestry species. Tree species in these areas are grown for several reasons. They can utilize incoming solar radiation throughout the year; enrich micro-sites by depositing litter in the top soil, which can then be utilized by shallow-rooted agricultural crops, modify the microclimate, and generally bring about favourable effects on the soil and associated plant species.

3.2 Special Habitats

The vegetation is mainly dry open and interspersed grasslands consisting mainly of stunted, thorny or prickly shrubs and perennial herbs which are mostly drought resistant. The ephemerals come up during the rainy season, complete their life cycle before the advent of summer and the bulk of area is once more transformed into open sandy plains, desolate and barren. Desert vegetation is mainly categorized on the basis of its habitat (Shetty and Singh 1987). In arid zones, vegetation is typically sparse, and is comprised of perennial and annual grasses, other herbaceous plants, shrubs and small trees.

The number of tree species is very limited in arid zones and, in general, they are very slow growing due to limitations of environmental conditions, but nowhere in the world they are so intricately associated with the life of human beings. To evade or minimize the adverse affects of frequent droughts, the native people in arid zones have often developed production systems in which woody perennials have a very important role, both from a productivity as well as a resource conservation point of view (Tewari et al. 2000). When arid zones have been looked at from the perspective of forestry development, the focus has been on the management of trees and shrubs that are either native to a particular arid zone, or have been introduced, especially for conservation purposes. However, concern for trees and forests has increased in arid zones as it has in many other regions in recent years. In India, traditional animal husbandry and agroforestry practices have been used to manage parklands, rangelands, reserved silvipastures near holy places, lay farming, and run-off farming (traditional watershed management). Trees are managed mainly for their non-wood forest products (NWFP) and their environmental services. Animals are an essential part of the production system. The whole system has been traditionally developed to spread the risk of drought in diversified components and efficient utilization of scarcely available natural resources.

Several important multipurpose tree species like *Aegle marmelos, Buchanania lanzan*, *Capparis decidua*, *Carissa congesta*, *Cordia myxa*, *C. rothii*, *Emblica officinalis, Garcinia indica, Grewia asiatica, Madhuca indica*, *Manilkara hexandra*, *Pithecellobium dulce*, *Prosopis cineraria*, *Salvadora oleoides, S. persica, Tecomella indica* and *Ziziphus nummularia, Syzygium cuminii* are growing in arid and semi-arid regions of the country, which have tremendous potential for livelihood security and as life support species (Table 1).

3.3 Arid Ecosystem and Climate Change

There is now a strong consensus that climate change presents a fundamental challenge to the well-being of all countries, with the potential of being most harsh on countries already suffering from water scarcity. A recent IPCC report (Bates et al. 2008) predicts that climate change over the next century will affect rainfall

Table 1 Regions of diversity and distribution of minor fruits

Species	Common name	Family	Region of diversity/origin	Distribution in India	Economic importance
Aegle marmelos (L) Correa.	Bengal Quince, Bael	Rutaceae	Northern India	Sub-Himalayan tract, dry and deciduous forests of central and southern India	Pulp used for making sharbat, squash, murabba; to cure diarrhoea, dysentery and other stomach ailments
Buchanania lanzan Sperg. Syn. *B. latifolia* Roxb.	Chironji, Cuddapah almond, Piyal	Anacardiaceae	India	In drier parts of India	Bark used for tanning, dry fruits used for making sweet dishes
Capparis decidua (Forsk.) Edgew syn *C. aphylla* Roth.	Ker, Teet, Dela	Capparidaceae	India	Arid regions of Rajasthan, Punjab, Haryana, Gujarat states of India	Termite resistant timber, Root bark and stem used for treatment of asthma, inflammation and cough
Carissa congesta Wight syn *C. carandus* L.	Karonda	Apocynaceae	India	Western ghats, semi-arid regions	Fruits used for making pickle, jam, jelly and marmalade and also used for curing anaemia and as an astringent
Cordia myxa L. syn. *C. dichotoma* Forst. F.	Lasora, Indian cherry,	Boraginaceae	Northwestern India	Throughout country especially in warmer regions.	Fruits used for making vegetables and pickles, used in cough mixture in diseases of chest and is given in bilious infections as a laxative
Diospyros melanoxylon Roxb. Ex A. DC. Syn. *D. tupru* Buch.-Ham	Tendu, Coromandel ebony persimmon	Ebenaceae	India	Peninsular dry forest tracts.	Bark used for curing small-pox, Dried powdered fruit used as carminative and astringent, leaves used for making 'Bidi' (Indian cheap smoke)
Emblica officinalis Gaertn syn *Phyllanthus emblica* L.	Indian gooseberry, Aonla, Myrobalan	Euphorbiaceae	Peninsular India, South Asia	All over India	Rich source of vitamin C, used for preparation of Murabba, chawanparash and trifala, fruit powder is also used in preparation of toiletries and cosmetics

(continued)

Table 1 (continued)

Species	Common name	Family	Region of diversity/origin	Distribution in India	Economic importance
Garcinia indica Choisy	Kokum	Clusiaceae	South India	Western ghats	The seeds yield a valuable edible fat known in commerce as 'kokum butter', fruit rind used for making anti-obesity drug
Grewia asiatica Mast. Syn *G. subinequalis* DC	Phalsa	Tiliaceae	Western India	Semi-arid regions	Edible sweet and sour fruits, Fruit possess astringent properties and used for several stomach ailments
Madhuca indica J. F. Gmel. Syn. *M. latifolia* (Roxb.) Macb.	Mahua, Butter tree	Sapotaceae	India	Penninsular and Central India	The bark is used to cure leprosy and to heal wounds, dried flowers used for distillation of 'Mahua Liquor', Kernel oil used for skin care and for manufacture of soaps and detergents
Manilkara hexandra (Roxb) Dub syn *Mimusops hexandra* Roxb.	Khirni	Sapotaceae	India	North central India and Deccan plateau to North east	Fruit rich in vitamin A, fresh fruits are very sweet and eaten raw as well as after drying and bark used for several medicinal purposes
Pithecellobium dulce (Roxb.) Benth. Syn. *Inga dulcis* Willd, syn. *Prosopis dulcis* Kunth.	Manila Tamarind, Jangel Jalebi	Leguminosae	Mexico		Pulp consumed raw by tribals and local people and extracted oil is edible and also used for the manufacture of soap
Prosopis cineraria (L.) druce	Khejri/Jant/ Janti	Fabaceae	Western and south Asia	Arabian peninsula, western Asia, Indian sub-continent	Khejri produces a brown shining gum just like arabic gum the dried pods locally called Kho–Kho eaten by local people
Salvadora oleoides Decne.	Pilu	Salvadoraceae	Tropical Africa	Arid and semi-arid regions	Seeds used in production of soaps, cosmetics, paints, varnishes and lubricants, has medicinal properties to cure piles, rheumatism, skin diseases, etc

(continued)

Table 1 (continued)

Species	Common name	Family	Region of diversity/origin	Distribution in India	Economic importance
S. persica L.	Miswak	Salvadoraceae	Tropical Africa	Arid and semi-arid regions	Seeds used in production of soaps, cosmetics, paints, varnishes and lubricants, has medicinal properties
Tamarindus indica L.	Tamarind	Leguminosae	Tropical Africa	Throughout tropics	Fruit pulp rich source of calcium, phosphorous, riboflavin, niacin and thiamine, used in the preparations of chutney, tamarind powder, puree, juice concentrate, jam, jelly, candies and pickles
Tecomella undulata G. Don	Rohida (Desert Teak)	Bignoniaceae	Indian subcontinent	Thar Desert regions of northwest and western India	Wood used as a source of Timber. Bark used as a remedy for syphilis and in curing urinary disorders, seeds used against abscess
Zizyphus mauritiana Lam. syn *Z. jujuba* Lam. non Mill.	Ber, Indian jujube	Rhamnaceae	Indian subco ntinent	All over India	Fruit rich source of calcium, phosphorous, protein, minerals, vitamin C and vitamin A, and fruit used as laxative and aphrodisiac
Z. nummularia (Burm. F.) Wt. et Arn.	Jharber	Rhamnaceae	Indian subcon tinent	All over India	Fruit is rich source of calcium, phosphorous, protein, minerals, vitamin C and vitamin A
Syzygium cuminii	Jamun	Myrtaceae	India, Burma, Ceylon	Throughout Indian plains	Fruits are processed for squash, sharbat, syrup, jam, jelly, wine, vinegar and juice; fruits used for curing diabetes, heart and liver problems

patterns, river flows and sea levels all over the world. For many parts of the arid and semi-arid regions there is an expected precipitation decrease over the next century of 20 % or more. Even if efforts to reduce greenhouse gas emissions are successful, it is no longer possible to avoid some degree of global warming and climate change. Arid and semi-arid regions will suffer the maximum precipitation decrease worldwide. Throughout Asia, one billion people could face water shortage leading to drought and land degradation by the 2050s (Christensen et al. 2007). In spite of harsh conditions in arid and semi-arid regions, a number of multipurpose tree (MPT) species grow as populations unattended in forest, community lands and also in agricultural fields as isolated trees. Trees are managed mainly for their non-wood forest products and their environmental services. The number of tree species is very limited in arid zones and, in general, they are very slow growing due to limitations of environmental conditions. However, these are intricately associated with the life of human beings in these regions. To evade or minimize the adverse affects of frequent droughts, the native peoples in arid zones have often developed production systems in which woody perennials have a very important role, both from a productivity as well as a resource conservation point of view (Tewari et al. 2000). Additionally, fruit tree diversity in farms, orchards, home gardens and natural forests contributes to the provision of valuable ecosystem services and may provide buffers against the effects of climate change.

3.4 Conservation Strategies

Conservation of plant genetic resources is attempted using two basic approaches, *in situ* and *ex situ*, ensuring conservation in the natural habitat and in manmade genebanks, respectively (Fig. 1). Plant genetic resources, comprising a wide range of useful plant species, possess diverse mechanisms of reproduction and

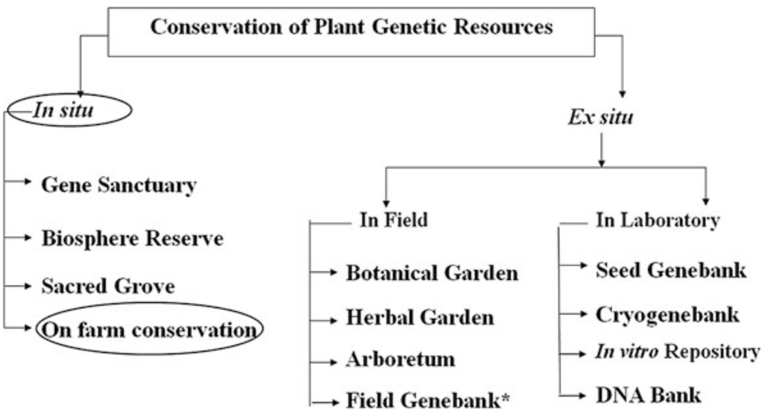


Fig. 1 Outline of PGR conservation strategies

regeneration. Selection of suitable conservation strategies depends upon reproductive and breeding mechanism and physiology of seeds and plant propagules. These factors determine the sample size of the propagules to be stored, and the appropriate conservation technologies to be applied. Accordingly, different conservation strategies have been suggested and utilized by conservation biologists for achieving successful conservation of targeted species.

Conservation of horticulture genetic resources (HGR) and specifically the MPT species which still grow as naturally wild and in semi-wild conditions, would require adoption of complementary conservation strategies where suitable *in situ* and *ex situ* conservation methods are be employed to achieve successful conservation. Within this group of underutilized fruit crops, specific conservation strategy is to be developed and adopted based on extent of genetic diversity available, mechanism of propagation, reproductive biology and present biological status of the species. *In situ* conservation involves promoting growth of plant species in their natural habitats where evolutionary processes continue to operate, making it a dynamic system. Majority of the underutilized fruits grow in the diverse climatic and edaphic conditions and are adapted to arid and semi-arid conditions. Horticulture genetic resources of underutilized fruits may be conserved based on their biological status and propagation method using following *in situ* conservation approaches:

3.4.1 *In Situ*/on Farm *Conservation*

In situ conservation is important for underutilized fruit species still occurring as natural wild or in the semi-domesticated conditions using the following two approaches:

1. In natural habitats like protected areas and national reserves: Fruit species specific area based on presence of natural diversity are to be identified for species found as only natural wild namely *Buchanania lanzan, Capparis decidua*, *Diospyros melanoxylon*, *Manilkara hexandra, Salvadora oleodis*, *S. persica*, *Tamarindus indica, Pithecellobium dulce*. For species where both natural wild and cultivated genotypes are available, wild populations are to be protected immediately. Such species are *Aegle marmelos*, *Emblica officinalis, Grewia* species*, Carissa* species, *Cordia* species, *Madhuca* species and *Ziziphus* species. Fruit species and possible protected area for *in situ* conservation is to be finalized based on diversity maps and policy of respective state government.
2. On-farm conservation for local natural selections/cultivars/farmer's varieties. In some of underutilized fruits local selections or farmers varieties have been developed or identified since time immemorial. These local selections are being grown as isolated plants or in small numbers in the homestead gardens, farmers' fields, backyards or in the common panchayat lands in villages. Such selections need urgent attention for further characterization, evaluation and

on-farm conservation. Underutilized fruits where such selections are indentified and available are *Syzygium cumini*, *Cordia myxa*, *Tamarindus indica, Aegle marmelos, Embelica officinalis* and *Ziziphus* species.

3.4.2 Natural *In Situ* Conservation Sites Proposed for UUF Species

Fruit species and possible protected area for *in situ* conservation is to be finalized based on diversity maps and policy of respective state government for on-farm conservation of local natural selections/cultivars/farmer's varieties. In some of underutilized fruits local selections or farmers varieties have been developed or identified, these local selections are being grown as isolated plants or in small numbers in the homestead gardens, farmers' fields or backyards, or in the common panchayat lands in villages. Such selections need urgent attention for further characterization, evaluation and on-farm conservation. Underutilized fruits where such selections are indentified and available are *Syzygium cumini*, *Cordia myxa*, *Tamarindus indica, Aegle marmelos, Embelica officinalis* and *Ziziphus* species. For conservation of these multipurpose tree species, various natural sites have been identified for in situ on farm conservation (Fig. 2).

3.5 Nutritional Value, Market Demand and Indigenous Technical Knowledge

Fruits and vegetables are the main source of various vitamins, minerals, antioxidants and soluble fibres for human beings. Humans, since their evolution, depended heavily on the natural food and diversity of plants growing around. Such plant species were, therefore, domesticated first. As far as fruits are concerned, these were the last to be domesticated and still several wild fruit species are under domestication as soon as local people recognize their importance for their use and commercial value (Malik et al. 2010). People prefer to have fruits with good taste and having less unpleasant tannins and glycosides which are amply available in the wild fruits. Another preference is for the larger fleshy or edible part and no or negligible seediness in fruits.

Many of these fruits are highly perishable and difficult to store in the fresh form. Some of them are not easy to eat out of hand. A few are not acceptable as a fresh fruit, because of high acidity and/or strong astringent taste. However, all these fruits have unlimited potential in the world trade in their processed form. Presently various value added products such as jams, pickles, chutneys, squashes, dried form of fruits, pulp, etc. are being exported to targeted Indian populations living in other countries, for example, Malabar tamarind is being exported to countries wherever Malayalies are settled in the World as this makes an important ingredient of their

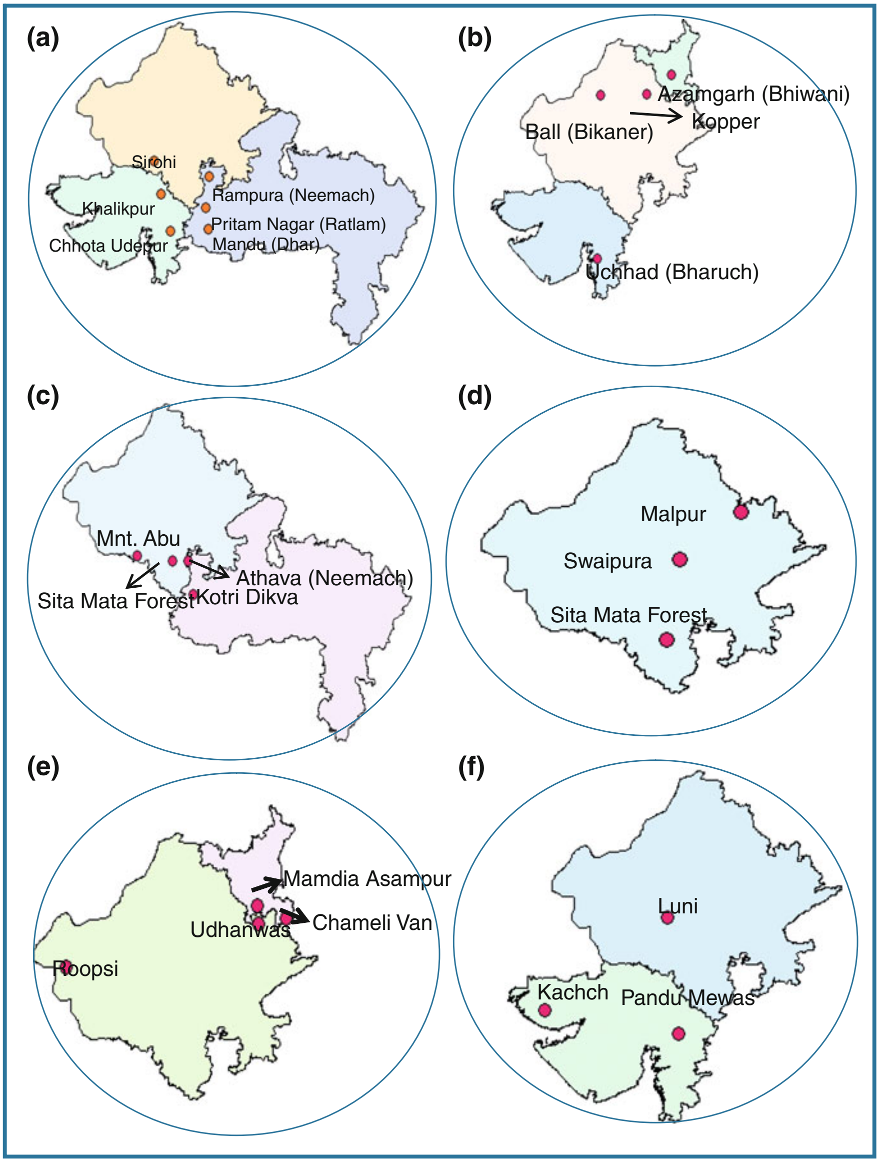


Fig. 2 On farm conservation sites of some underutilized tree species in Rajasthan, Gujarat and Madhya Pradesh in India, **a** *Manilkara hexandra*, **b** *Capparis decidua*, **c** *Carissa carandas*, **d** *Cordia myxa*, **e** *Salvadora oleoides*, **f** *Salvadora persica*

food preparations. Similarly, other products prepared under small scale industry are processed and exported to the USA, Europe and to several other countries as per demand. These products have found place in supermarkets along with other Indian products. This will provide an opportunity to consumers all over the world to enjoy these minor tropical fruits in the form of processed products. Apart from processing, market potential and strong campaigning is necessary to create awareness and consciousness among the producers and consumers of underutilized tropical fruits.

Most of the tropical underutilized fruits are often available only in the local markets and are rarely known in other parts of the country. These fruit species have the ability to grow under stressed and adverse conditions and are also known for their medicinal, therapeutic and nutritive values. Because of their curative and nutritional properties, these fruits have been used by local people for nutrition and curing diseases. Many of these species have been used as traditional medicinal plants and some of them have found an important place in the Indian Systems of Medicine and in Unani, since time immemorial. Tribal populations, particularly children and women of these localities, are fulfilling their nutritional requirements by consuming these fruits available freely in their vicinity. In addition, some of these fruits have excellent flavour, juiciness and have very attractive appearance. There is always a good market demand all over the world for new food products, especially which are highly nutritious and delicately flavoured. Urban consumers today are becoming increasingly conscious and aware of the health and nutritional aspects of their food due to prosperity and awareness. Demand for natural, herbal and non-synthetic food products is increasing among the urban middle and upper middle class of developing and developed countries. There is an increased emphasis by the government and non-government agencies to popularise the traditional and natural products. In India the Department of Ayurveda, Yoga and Naturopathy, Unani, Siddha and Homoeopathy (AYUSH), Ministry of Health and Family Welfare, Government of India, has been effectively taking up the cause of protecting and popularising the Indian Systems of Medicines for the benefit of large population and also its being nature friendly and affordable. Several private organisations and non-governmental organizations have established naturopathy and herbal clinics based on the natural products extracted from these underutilized fruits to increase immunity and also to cure various ailments. In view of all these recent developments in the traditional health sector, underutilized fruit plants rich in vitamins, minerals, anti-oxidants and with other medicinal properties have bright market future. The underutilized tropical fruits discussed in this publication have an important role to play in satisfying the present day market demands. Nutritional status of fruits being discussed in this publication is given in the Table 2.

3.6 Livelihood Support: Importance and Issues

Small and marginal farmers—few trees in own and common land; landless farmers – common lands such as Panchayat and forest land; and tribals—non-wood forest products (NWFP) provide additional income to these farmers for livelihood support. Survey indicated that 20–30 % of their income come from these multipurpose tree species.

Table 2 Nutritional value of some of the underutilized fruits (*Source* of data: Rathore 2009)

Species	Protein (%)	Carbohydrate (%)	Fat (%)	Fiber (%)	Vit. A (mg/100 g)	Vit.B2 (mg/100 g)	Vit.C (mg/100 g)	Ca (mg/100 g)	P (mg/100 g)	Fe (mg/100 g)	Energy (Kcal/gm)
Balanites aegyptiaca	4.9	69.9	0.1	3.5	–	0.07	46	147	58	4	300.1
Capparis decidua	8.6	1.8	–	12.3	–	–	7.81	55	57	–	41.6
Cordia dichotoma	2.0	92.0	2.0	2.0	–	–	–	55.0	275.0	6.0	394.0
Prosopis cineraria	23.2	56.0	2.0	20	–	–	523.0	414.0	400.0	19.0	334.8
Salvadora oleoides	6.0	76.0	2.0	2.0	–	–	–	6.0	76.0	8.0	346.0
Ziziphus mauritiana	0.8	17.0	0.3	–	0.02	0.02	76.0	4.0	9.0	1.8	73.9
Aegle marmelos	1.8	31.8	0.3	2.9	0.055	1.2	–	85.0	31.8	0.6	137
Feronia limonia	7.3(7)	15.5(17)	0.6	5.2	–	0.170	2.0	0.13(4)	0.11(9)	0.6(0.5)	96.6

Most of these under utilized fruit species play an important role in the social economy and livelihood of tribals, small, marginal and landless farmers. Survey of targeted areas revealed that these trees growing in the community lands, panchayat lands, forest lands and marginal lands provide access to the local inhabitants. Produce of the trees provides additional income to these farmers and substantial livelihood support in addition to the nutritional security to the children and women. Survey undertaken for some fruits species like *Manilkara hexandra, Buchanania lanzan, Capparis decuidua,* and *Cordia myxa* revealed that these species provide substantial additional income to the farmers. Most of these species generally fruit in summer months and whole farming family, including children and women, get involved in the plucking, grading and marketing of these fruits. Organized production and processing for value addition of products would further enhance income of small and marginal farmers and also help in on-farm conservation of valuable germplasm.

References

Arora RK (1998) Genetic resources of native tropical fruits in Asia: diversity, distribution and IPGRI's emphasis on their conservation and use. In: Arora RK, Rao V Ramanatha (eds).Tropical fruits in Asia: diversity, maintenance, conservation and use, Proceedings of the IPGRI-ICAR-UTFANET regional training course on the conservation and use of germplasm of tropical fruits in Asia held at Indian institute of horticultural research, 18–31 May 1997, Bangalore pp 42–53

Bates BC, Kundzewicz WZ, Wu S, Palutikof (eds) (2008) Climate change and water. Technical paper of the intergovernmental panel on climate change, IPCC secretariat, Geneva: 210

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon W-T, Laprise R, Magaña Rueda V, Mearns L, Menéndez CG, Räisänen J, Rinke A, Sarr A, Whetton P (2007) Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt K B, Tignor M, Miller HL (eds) Climate change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change, Cambridge University Press. Cambridge

FAO (1987) Improving productivity of dryland areas. FAO, Committee on Agriculture (Ninth session), Rome

Malik SK, Chaudhury R, Dhariwal OP, Bhandari DC (2010) Genetic resources of tropical underutilized fruits in India. NBPGR, New Delhi, pp 25–37

Rathore M (2009) Nutrient content of important fruit trees from arid zone of Rajasthan. J Hortic For 1(7):103–108

Shetty BV, Singh V (1987) Flora of Rajasthan. Vols. I-III, Botanical Survey of India, Calcutta

Tewari JC, Bohra MD, Harsh LN (2000) Structure and production function of traditional extensive agrofrestry systems and scope of intensive agroforestry in the Thar desert. Indian J Agrofor 1(1):81–94

Exploring the Impacts of Climate Variability on Traditional Agricultural Practices in the Villages of THAR

Aditi Phansalkar

1 Introduction

The biggest threat that human kind is facing today, is of the changing climate and its relative impacts. Sufficient evidences from a variety of different studies indicate that, changes of climate would have an important effect on agriculture and livestock. Studies have not yet conclusively determined whether, on average, global agricultural potential will increase or decrease but, negative impacts could be felt at the regional level as a result of changes in weather.

Moisture stress from prolonged dry spells or thermal stress resulting from heatwave conditions are some of the critical factors that affect the agricultural productivity, increasing the pressures on the farmers. Natural atrocities like desertification or increase in the area of non-cultivable land, incurs further pressures on the agricultural productivity. These impacts replicate themselves on the livelihoods of the marginal farmers and eventually on the economies of the society at large. A significant loss of traditional knowledge system, that was observed, is leading to unsustainable practices. The study also explores the social dimensions for the change. With the advancement of technology and increase in family sizes, continuous cropping on smaller patches of land is largely leading to the deterioration of the productive capacity of the land.

Considering all these, it is essential to formulate the tailor made crop management practices, revive the traditional knowledge, and disseminate it across the regions. Apart from this, adaptive measures need to be undertaken to ensure food security, which has been threatened due to increasing climate variability and other socio-economic pressures. The paper attempts to focus on the changes in the agriculture practices in Thar, documents them, and further analyse the drivers of change.

A. Phansalkar (✉)
M. Tech in Climate change and Sustainable Development, Centre for Environment and Planning (CEPT University), Ahmedabad, India
e-mail: araditiphansalkar@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_17,

2 The Great Indian Desert

Spread over an area of about 0.32 million square kilometers, the Great Indian Desert forms 10 % of the total geographical area of India. More than 60 % of the desert lies in the state of Rajasthan, followed by 20 % in Gujarat. Almost 58 % of western Rajasthan, the Thar, is made up of sand dunes, low infertile hills, and land rich in mineral content. It is believed that the name for the Thar Desert in the local dialect of western Rajasthan is Marwar, whose Sanskrit root, Maru Desa, means the land of death. And yet, millions of people call this land their home. The Thar has a population of 22.5 million (2001 Census) 110 persons per sq km of which 61 % were cultivators and 10 % were agricultural labourers. Harsh climatic conditions, less vegetation, erratic rainfall add to the tedious conditions of the community here. The Great Indian Desert is one of the most populated deserts. The extensive agricultural practice with a very high dependency on ground water has resulted in the depletion of the ground water aquifers. Rajasthan has always been in the forefront of excellent rainwater harvesting techniques. The traditional *Nadis*, *Johads*, *Beris* and many more, stand tall as epitomes of the best water storage techniques in the country. Over a period of time, negligence, the dying importance of these traditional systems and knowledge has altogether resulted in the defunctness of these systems. The desert in all aspects is confronting stress from the increasing population in the region, making the region more and more vulnerable to the impacts of climate change.

3 Materials and Methods

In order to study the scenarios relating to agriculture in the Thar, a study was undertaken for 10 villages, in each of the Barmer and Jodhpur districts of western Rajasthan respectively. The study involved intensive Focused Group Discussions (FGD) with the socially excluded Dalit Community. Minimum three FGDs were undertaken in each of the villages. The focused groups were mostly mixed groups. The groups were divided into 3 sets on the basis of age and sex (Table 1).

Hands on participatory mapping techniques like resource mapping that included the common property resources like, *Nadis, Beris* and *Johads* were undertaken. Apart from this, questionnaire surveys with the key stakeholders like the marginal farmers, the Sarpanch and others added to the portfolio of information. The other important objective behind the discussions with the community was also to

Table 1 Showing the distribution of the focused groups

Groups	Composition of the groups
1. Group A	Middle aged men and youth
2. Group A	Women
3. Group A	Women and youth

understand the changing stakes over these resources and to identify the possible social dimensions behind the same.

Different age groups were targeted in order to explore the transitions across the generations. This was done with an objective of testing the transfer of traditional knowledge and its application in the present conditions. Extensive visual documentation in the form of live sketches were produced simultaneously Figs. 1 and 2.

4 Role of Climate in Agriculture

Climate has always been a pivotal factor for the communities involved in agricultural sector irrespective of its location in the world. The Thar desert receives between 100 to 500 mm of rainfall annually and consistently faces issues like recurrent droughts and prolonged monsoons. Almost 80 % of the agriculture in Thar is rainfed. Over 80 % of the annual rainfall occurs during the short southwest monsoon season from July to September, hence, the nine remaining months are dry. The meagre rainfall makes groundwater hard to replenish, which means groundwater cannot serve as a long-term supply for drinking and irrigation purposes. Dusty storms, scorching summer, chilly winter, high diurnal temperature differences and huge shifting and rolling sand dunes are some of the characteristics that give identity of the Great Indian Desert. Recurrence of droughts compels the

Fig. 1 Map showing the areas studied in the Rajasthan state. (*Source* http://en.wikipedia.org/wiki/File:Rajasthan_locator_map.svg accessed on 23 August 2011). *Barmer District, Sindhri Block*. Dhanne ki dhani, Taku beri, Shivnagar, Trishulia, Dandali, Sanpa, Godara sara, Aakal, Dabad batiya, Kardali. *Jodhpur District, Phalodi Block*. Bhopeji ki dhani, Bhomnagar- Moriya, Raamsagar, Fatehsagar, Shivsagar Kolu pabuji, Babanagar, Dayakor *Note* The villages largely inhibited the socially excluded Dalit communities and were settled outside the revenue villages in the *Dhanis*

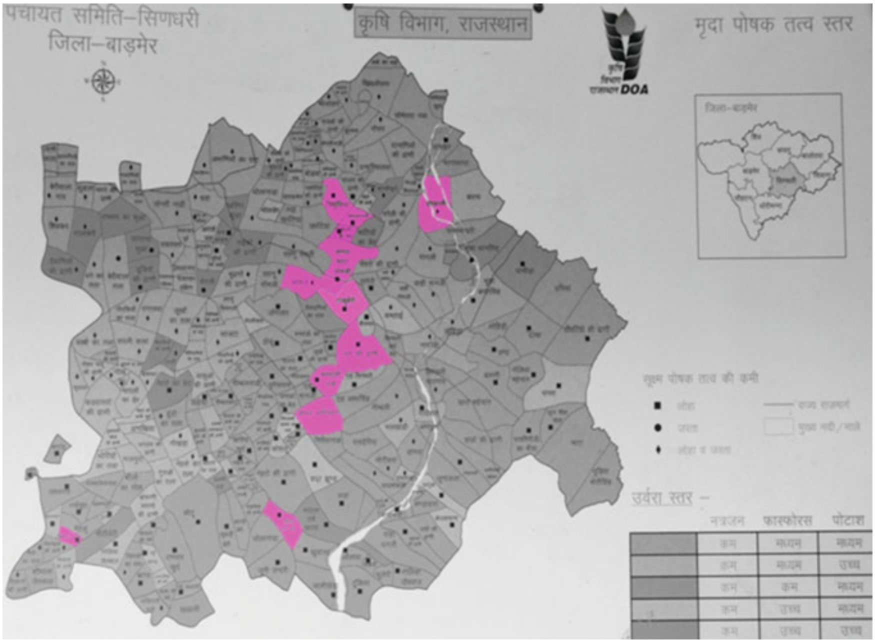


Fig. 2 Map of the Sindhri block in Barmer District highlighting the villages visited for the study (*Source* Jodhpur, Prayas Organisation). *Note* The selection of the blocks was done on the basis of the organization's requirement as well as accessibility limitations

communities to migrate to the nearby cities in search of employment. These conditions make agriculture an altogether tedious business for the localites. Analysis of the rainfall pattern over a period of 20 years (Figs. 3 and 4) shows, the prevalent erratic nature of rainfall in the region. Prolonged monsoons directly affect the quantity of the produce, incurring financial stress on the farmers. This generates food insecurity among the community.

5 Agriculture Scenario in Thar Desert

Agriculture is the primary occupation for over 82 % of the population in rural areas. Agricultural lands are dominantly sandy, with 60–90 % fine sand and 2–10 % of silt–clay in the topsoil and are poor in nutrient status (Joshi et al. 2009). The main crops grown here are, BAJRA (pearl millet), Jowar (Coarse millet), MOONG (pigeon pea) MOTH (Local legume), TIL (Lentil seeds) and MATIRA (local variety of melon). Mixed cropping exists in larger parts of Rajasthan due to unpredictability of climate. With the advent of tube wells, the communities have a sense of security towards water and hence the produce. With this, they also manage to grow commercial crops like, coriander, wheat to some extent and also

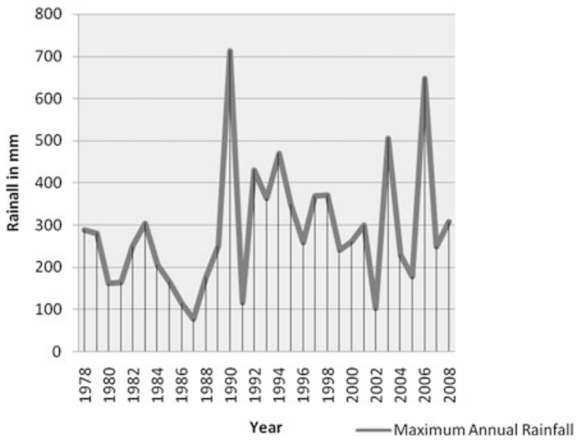


Fig. 3 Graph showing the erratic nature of rainfall over 30 years in Barmer districts of Western Rajasthan

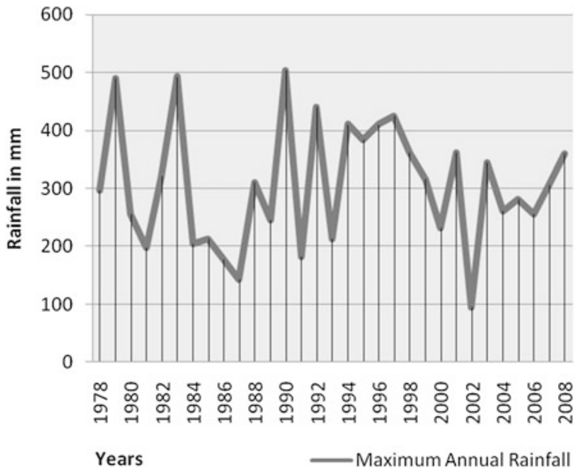


Fig. 4 Graph showing the erratic nature of rainfall Over 30 years in Jodhpur districts of Western Rajasthan (*Source* India water portal)

jeera which add to their income. Only 20 % of the agriculture is irrigated as of today. The dependency on rainfall thus only exacerbates the stress among the farmers. Traditionally rainfed kharif crops are grown in the region, but irrigation through canals and groundwater has made vast changes in land use and agricultural production. Though, as a matter of fact, the tube wells are still owned by handful number of farmers, other without it, are in the same state of adversities.

6 Impacts of Human Interventions on Agriculture

Apart from the natural hindrances to the agricultural productions, there are other human interventions that are adding to these hostile conditions. The textile and dying industries located upstream in Barmer and Jodhpur districts are forming a threat to the fresh water source of Luni River. Unmonitored discharges from these industries are adding to the change in the morphology of the local soil conditions, degrading the quality of surface and ground water. All these factors put together, have begun to affect the quality of the produce. Discussions with community in the village of Barmer revealed a gradual decrease in the nutritional value of some of the crops. These discharges are also responsible in changing the mineral contents of the soil.

6.1 Community Perception

When discussed with the communities, it was observed that, there was a conspicuous decline in the nutritional value of Bajra (pearl millet). The heat produced while churning the Bajra was unbearable some 25 years back. Today it is the other way round. Bajra no more possesses the same nutritional value as it did before. As described by the community, also the quantity of produce has been considerably showing a decreasing trend since past 25 years. Bajra produce used to be good 8–12 quintals per season, while today it has reduced to 2–3 quintals precisely (Primary Survey 2011).

7 Impact of Climate on Livestock and Agriculture

Livestock rearing or animals husbandry was of the primary occupation of people in Thar till late 1970's after agriculture. Animals like camels, buffaloes, and cows were reared for agricultural practices and dairy business respectively. In the time of drought, these animals also served as a source of income. Since fodder was easily available in the adjacent agricultural lands, maintaining large number of animals was never a problem with the advent of tractors, increase in drought, and lack of vegetation, livestock rearing has taken a backseat. Tractors are largely responsible for the up root of the indigenous species and hence the reason for lack of fodder availability. With high maintenance of animals like camel and cows, there is an observed decline in the rearing of the livestock and thus, resulting in the decline of animal husbandry. The current trend is the fodder is bought from the nearby market at the cost of Rs 200 or 300 per kg and can be retained for not more than 2 months. This adds to the total expenditure of the farmers. Camels were reared some 15–20 years back, for their dual role i.e., as an animal power for ploughing in the fields and for dairy purposes. But with the increase in the unpredictability of the weather conditions coupled with the advancement of tractors on the fields, the indigenous species (used as fodder) is facing extinction.

8 Climate Responsive Traditional Agriculture Practices

Agriculture practices in the Thar were highly climate responsive and well managed. It included timely land preparation and field management practices. Agriculture being completely rainfed, good land preparation formed the base for the further operations. With the encroachment of monsoons, the land was prepared for sowing. Practices like SOOD—removing unwanted weeds, JHOOR—cutting of the wild shrubs into pieces and using them as manure again, KANABANDI—barricading the field for protecting the field from harsh wind storms, required complete engagement of the farmers in the field. Figures 5 and 6 show the traditional agricultural practices, methods and seasonal calendar of annual agricultural operations, etc. The other field management practices like, BAAD-fencing of the field with the help of available local species like Khejri, Ankh, Jaal, and Bordi were used to protect the field from the animals. However, it also protected the seeds from wind storms. Traditional operations like these demanded time on the fields and human labour as well.

Rotational farming was largely prevalent with the rain-fed agricultural practice. The land was rotated with respect to the smaller patches as well as the crops to increase the fertility of both land and soil. The indigenous species grown in the non-cultivated patch of land was used further as fodder for animals. But with the decrease in the amount of average land holding size there is a repetitive cultivation in the smaller size of land affecting the productivity of the land (Tables 2 and 3).

9 Changing Face of Agriculture in Thar

Agricultural practices have seen a radical shift from animal driven to mechanization. The introduction of mechanization has contributed considerably to these changes. There are many drivers which can be held responsible for this change. Some of the drivers identified from our study are as follows: (1) Climate variability; (2) Technological advent–role of tractor; 3. Increase in family sizes.

9.1 Climate Variability and Increasing Unpredictability

Agriculture in Thar always revolved around the climatic conditions. Climatic variability have laid several implications on these practices. Climate change is expected to only exacerbate these situations making them all the more worse and tedious to deal with. The impacts of climate variability on the produce can be explained through the figure below, (Fig. 5) that highlights the interdependencies of various factors in agriculture. Warming around the world is resulting in increasing heat waves in different parts of the world. These heat waves increase the

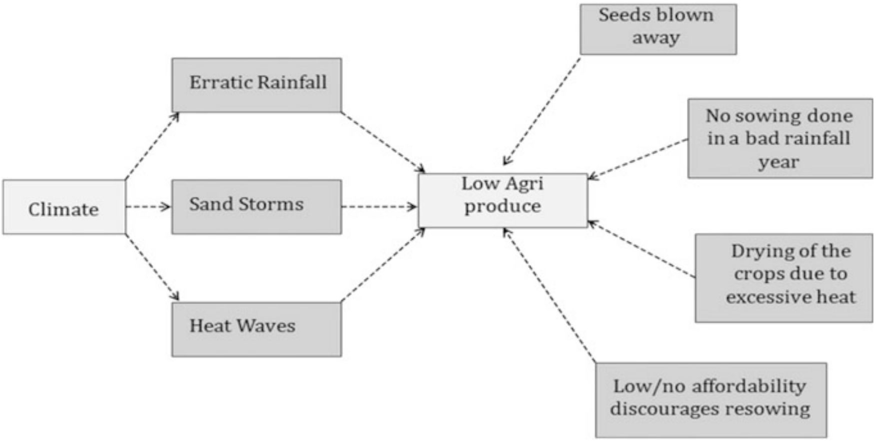


Fig. 5 Role of climate in agricultural practice. *Note* The chart is based on the understanding of the issues and participatory mapping with the communities

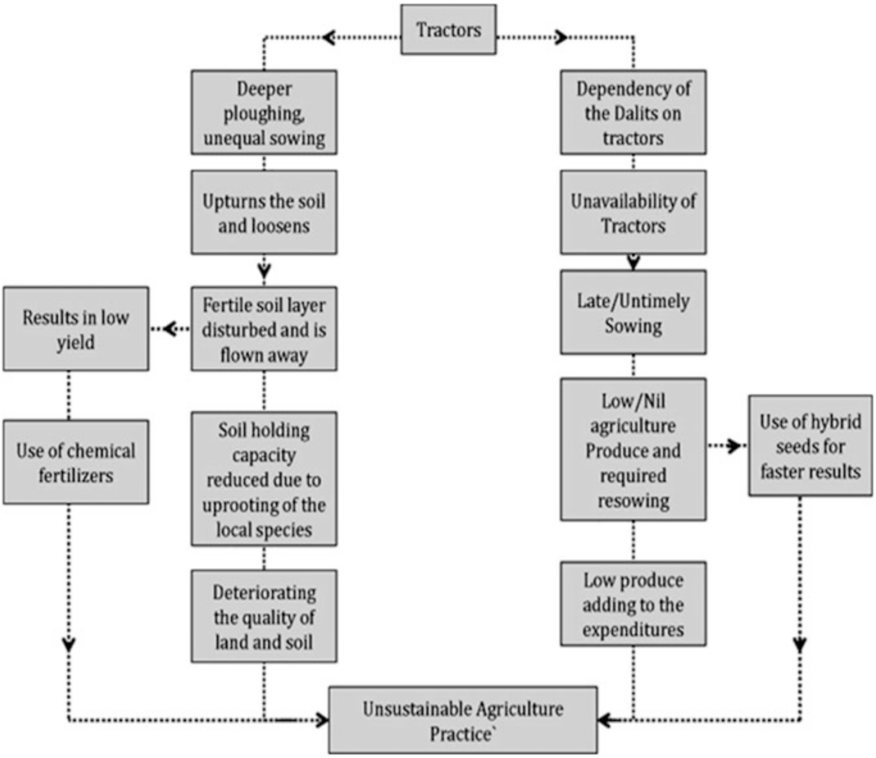


Fig. 6 Chart showing the impact of tractor as a technology leading to unsustainable practice in Thar. *Note* The chart is based on the field understanding of the issues and participatory mapping with the communities

Table 2 Matrix documenting the traditional agricultural operations

Traditional agricultural operations	Function	Practice methods
Sood, Jhoor, Kanabandi	To remove extra weeds and unwanted growth before sowing	Was done using basic home-made tools
Nidaan	Trimming of the existing trees in the field (if any)	Done using basic home-made tools
Ploughing	Upturning of the soil by making furrows	Was done using animal power
Sowing	Sowing of mixed seeds	Was done using man power by spreading the seeds all over
Harvesting/ Threshing	Done to cut the grown yield and separation of grains	Using a winnower/Manually
Storage	To preserve the seeds of the produce for following monsoon year	Stored in Kinharas/Potlis etc

Source Participatory mapping, Bharat Jhunjhunwala, traditional agricultural and water management practices of Thar (2008)

Table 3 Calendar showing the calendar of annual activities in the villages

Seasonal Agricultural Calender highlighting the major operations (Participatory mapping : Barmer and Jodhpur)												
	Baisakh (April-May)	Jeth (May - June)	Ashad/ Asar (June - July)	Savan /Shrawan (July - August)	Bhadar (August - Sepetember)	Kuwar (september October)	Kartik (October - November)	Aghrayan (November-December)	Poos (Dec-Jan)	Megh (January-February)	Phalgun (Feb-March)	Chait (March to April)
Agriculture Operations												
Sood/Jhoor/ Land preparation		■										
Ploughing	■	■										
Sowing/ Resowing			■	■			■	■				
Nidaan/Katai				■	■							
Harvesting/ Threshing					■	■	■					
Pruning/Katai							■					
Livelihood												
Out Migration									■	■	■	■

Note The seasonal calendar of agricultural operations is entirely based on participatory mapping and focused group discussions with the communities of Barmer and Jodhpur districts, respectively

thermal stress, while the sand storms result in blowing away of the seeds sown. This calls for re-sowing, which becomes a costly affair for the poor and marginal farmers, shooting up their annual expenditures and increasing financial insecurities. Low affordability and poor knowledge on the field management/protection systems is making the poor farmer's life full of stress and atrocities. It is believed that global warming is actually causing the western storms, which are in turn pushing the moisture laden monsoon winds, further delaying the monsoon and thus generating tedious situations for the farmers. The immense stretches of sand dunes and sand storms actually make agricultural practice a costly as well as a difficult affair altogether (NASA, Central Arid Zone Research Institute, CAZRI).

9.1.1 Impacts of Recurrent Droughts

The Thar desert has always been confronted with recurrent droughts. These conditions add to the challenges faced by the people. There is drought every three to five years in this region. With the advancement of drought, the villagers are forced to both, walk very long distances to fetch water, and to purchase water from expensive private water carriers (Rs 300–500 for 500 L). This amount can only last a family of five for about 15 days, so this cost quickly becomes a burden on the poor families. Recurrent drought like conditions result in crop failure and re-sowing is not possible for all the farmers given the fact that it adds to their expenditures, they are thus forced to migrate to other areas, abandoning their fields.

9.2 Technological Advent and Market Dependency-Coping Mechanisms by the Communities

9.2.1 Tractor

With the increase in the mechanization in the agriculture, tractor is becoming increasingly an integral part of the practice. Larger patches of land are ploughed as well as sowed in few hours as against more number of days consumed by animal power. Due to unpredictability of climate, agriculture is no more the only income generating occupation of the community. Out-migration is prevalent here and since most of the males in the Thar migrated out in search of better livelihood opportunities, the time allotted for agriculture (as it was before) is considerably less. This demands technology, which is fast and produces the same quality and quantity of yield, and, hence, tractor proves to be the only answer to the situation today.

Deeper ploughing, unequal sowing: The discussions in the fields revealed that the larger sections of the Dalits as well as clean caste community operate tractor in their fields. The TAWI done by tractor, due to mechanized pressure results in deeper ploughing. This results in better and faster yields, against the animal driven agriculture, where the ploughing and sowing traditionally was done manually. This allowed equal sowing of seeds even on the larger patches of lands. But today, with tractors, the case is not the same. The sowing is done unequally with tractors; also many patches of land remain unsown disturbing the monotony of the produce.

Threat to the native environment: With the deeper tillage, tractor sometimes upturns the soil to a larger extent resulting in pushing down the fertile layer, loosens the layers of soils, further resulting in soil erosion. Deeper tillage not only loosens the soil but also uproots the existing vegetation in the field. With the advent of tractors, many of the indigenous species of the desert are becoming extinct. Tractor uproots the species, on its way resulting in the gradual extinction of the same. Many species like, Aankh, Bordi, Jaal are becoming extinct in the region.

Decrease in land association: Tractor is also responsible for gradual decrease in the land association that persisted in the farmers. Traditional agricultural operations undertaken by the farmers demanded a prolonged engagement in the fields. The total time spent by any average farmer was over 2–3 days to plough 5 bigha (2 ha) land before onset on monsoons. But today, the scenario has changed. With the advent of tractors the same patch of land can be ploughed in 5 h time. Thus reducing the time spent on the fields also encouraging repetitive ploughing that results in the deterioration of the quality of soil and land.

Towards inorganic Agriculture: There is an observed increase in the use of pesticides, especially in the irrigated produce. In case of Jodhpur, where the agriculture has undergone transition from Rainfed Agriculture to Irrigated ones, the use of pesticides in at its peak, as irrigated crops are easily affected by insects. As the increase in family sizes is resulting in the shrinking of land, it is imparting additional pressure on the land for cultivation. With the traditional agriculture practices, the production is very low, given the size of the family. Moreover, since the farmers prefer hybrid seeds to be sown, only the modern insecticides/medicines are effective on those crops, thus, moving towards unsustainable agriculture practices. With the recurrence of droughts in past 15 years, dependency on the fast and reliable solutions has increased. Easy availability of the pesticides in the market, has threatened practice of home based solutions.DDT is popularly used by the farmers. Use of DDT is increasingly damaging the quality of the soil.

9.3 Increase in Family Size

The population is increasing at an alarming rate in Rajasthan adding further pressures on the land. The increase in population has led to decrease in the size of land holding from 14.6 ha in 1961 to about 6 ha at present, and is likely to decrease further to less that 4 ha by 2020 (Joshi et al. 2009). Absolute absence of a sense of family planning is leading to population explosion the villages of Thar. The distribution of land into smaller sizes is putting pressure on the available cultivable area due to repetitive ploughing on the same patches of land. Continuous cropping and decline of rotational farming practices has reduced the productivity of the land. Especially in the case of Bajra (pearl millet), the nutrient value of the soil is observed to be reducing over a period of time affecting the production. This transition is putting a question on the sustainability of such agricultural practices. This also calls for urgent coping strategies in order to modify the ill practices and internalize smart agriculture practices (World Bank).

10 Results and Discussions

In the study of the 20 villages, a few things became very conspicuous. It was observed that agriculture is undergoing radical shift from animal driven to tractor driven, today. Focussed discussions revealed that climate variability is largely responsible for the changes in the agricultural practices in Thar. Climate change has been observed to be having cross sectoral impacts. From livestock to livelihoods, every sector is seen to be affected directly or indirectly by the impacts of climate variability and this is expected to increase in the future years, without the desired coping mechanisms. The increase in desertification is another ever increasing threat to the agricultural practices. With the increase in the non cultivable area, the crop yield will be affected in larger parts of Thar. Thus, probability of the decrease in crop yield is exacerbated by these climate and human induced impacts. The community adapted coping mechanisms like migration, tractor and tube wells are short term interventions, and tend to forecast an ambiguous picture when it comes to sustainability. With the population growing exponentially, the stresses on the land as a resource ought to increase, without appropriate natural resource management, community based adaptation practices can be enhanced in order to encourage sustainable practices within the region. Government and civil society require to work in tandem with each other as far as dissemination these strategies are concerned. Since climate change is expected to lay uneven impacts on the society at large, the economically and socially backward community in the Thar is highly vulnerable to this impact, owing to their low capacity to adapt.

Every study has a limitation. Our study, too, was limited to the socially excluded Dalit community and some other key stake holders from the cleaner castes. So a cross sectoral perspective could not be achieved.

11 Conclusions and Recommendations

Agriculture has undergone a radical shift in the past 30 years. Mechanization in agriculture and high market dependency has nearly brought the traditional organic agro practice to an end. Extreme and unreliable weather and erratic rainfall patterns force the communities to migrate outside the village in search of livelihood, as agriculture no more acts as one. This prevents them from spending the required time on the farm, thus, affecting the quality of the yield. Migration extracts most of their time and, thus, to save time, the traditional techniques are sidelined and are taken over by the market products due to their fast and effective outputs. Thus, hybrid seed, insecticides, are preferred by the community for their effectiveness over traditional practices. Use of tractor over animal power is increasingly posing a threat to the quality of the land. Apart from the insecticides and other chemical fertilizers, tractors are leading to loosening of the soil more than required, as against the use of animal power. The fertile top soil layer is thus under a severe threat of erosion in monsoons. Traditional practices to protect the crop, like home made insecticides and other techniques, and their knowledge was lost over generations. These are no more known to the communities and, thus, agriculture is turning from organic to an inorganic practice.

Thus, Climate Smart Agricultural practices can help better the situation and support the production required with sustainable farming practices. Traditional agricultural field management techniques can be integrated together with the modern techniques for better productivity and combat the impacts of climate variability. Income generating options, to provide a sense of financial security at the time of crisis, are essential, keeping in mind the multiplying effects projected due to climate change. Community adaptation practices need to be strengthened in the vulnerable sections in conjuncture with the other planned adaptation strategies. Other promising approaches like changes in agricultural land management, conservation tillage, agro forestry, and reviewing the waste lands for fodder, can substantially add to the sustainability of these practices. Thus, it becomes the prime responsibility of the civil society organisations as well as the government to work out an appropriate tailor made adaptation strategies for the region of Thar to build in resilience against climate impacts. Also, mainstreaming climate change in the broader economic agenda, rather than taking a narrow agricultural perspective, will be crucial in implementing those plans.

Acknowledgments I would like to extend my gratitude to Dr Minal Pathak, Professor, Faculty of climate change and sustainable development, CEPT University, Ahmadabad, for her excellent insights, without which this paper would have not been possible. I would also like to thank Mr Binoy Acharya, Director Unnati Organisation, for development education for giving us this wonderful opportunity to explore this area of Rajasthan and issues of climate change and for his excellent guidance. Special mention for Swapni mam for her consistent inputs and, last but not the least, Dr Shrawan Kumar Acharya, Dean, Faculty of Climate Change and Sustainable Development, CEPT University, Ahmadabad, for always encouraging and motivating us to give our best.

Reference

Joshi NL, Saxena A, Kumar P (2009) Cropping systems in the Indian Thar desert and long-term effects of continuous cropping. Trends in Arid Zone Research in India, CAZRI, Jodhpur 493:296

Bt Cotton Cultivation in Gujarat: Emerging Issues and Environmental Challenges

N. Lalitha and P. K. Viswanathan

1 Introduction

India was first exposed to the use of insecticides way back in 1948. Between 1950 and 1970, which were the heydays of Green Revolution, Indian agriculture witnessed a surge in the use of organochlorines, organophosphates and carbamytes, which are in use even today. During the green revolution, high yielding varieties of different crops were introduced, which were susceptible to pests and diseases and there was substantial increase in the use of pesticides over time from 2,330 tons during 1950–1951 to 54,773 ton in 1990–1991. Pesticide use in India is generally reported to be higher in irrigated areas and among the commercial crops in particular. Among the states, Uttar Pradesh, Punjab, Haryana, Tamil Nadu, Rajasthan, Maharashtra and Gujarat together account for a larger share (almost 72 %) in pesticide use as compared to others. Among the crops, cotton and rice together account for the largest share (65 %) in the total pesticide use in India (Bag 2000; Shetty 2004; Abhilash and Singh 2009).

However, the commercial release of Bt cotton in India in 2002 has been considered to be an important departure in Indian agriculture as the Bt technology is anticipated to contain the increased pesticide use by way of reducing the pesticide application by farmers for bollworm control and, thereby, minimizing the problems related to health and environment. It has been reported that subsequent to the introduction of Bt cotton in India, cotton consumed only 18 % of the total pesticides market in 2006 compared to a much higher share of 30 % in 1998. Similarly, the market share of cotton insecticides, as percentage of total insecticides,[1] also declined from 42 % in 1998 to 26 % in 2006 (Choudhary and Gaur

[1] Insecticides are an integral part of agro-chemicals. In this chapter, terms insecticides and pesticides are used interchangeably.

N. Lalitha (✉) · P. K. Viswanathan
Gujarat Institute of Development Research, Gota, Ahmedabad 380 060, India
e-mail: lalithanarayanan@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_18,

2010). At the same time, it is also important to examine how far the macro level data reflects the micro level trends in the use of chemical insecticides at the farm level, as the farmers often tend to be highly concerned about protecting the crop against all possible risks. Moreover, even if the technology becomes effective in reducing the use of pesticides and, thereby, avoid the loss of crops due to pest infestation, farmers often tend to be indiscriminate in using the pesticides. Given this, pesticide use and its impacts on the environment and health are subjects of societal concern (Jacquet et al. 2011) and intense debates the world over.

Set in the specific context of the wider diffusion of Bt technology in the major cotton growing states in India, this chapter examines the critical aspects of farmers' use of seeds and plant protection technologies in the case of Gujarat. The chapter specifically deals with the: (a) emerging trends in the choice of Bt technology (Bt seed varieties); (b) the resultant changes in pesticide use pattern; and (c) the probable implications of the pesticide use practices on health and the environment.

1.1 Data and Methodology

To understand the persistent technology impact, we have conducted three rounds of farm household surveys, in 2003–2004, 2007–2008 and 2010–2011, covering a random sample of 200 cotton farmers in Gujarat state. However, the analysis in this chapter is restricted to a subset, covering a panel of 66 farmers drawn from Rajkot, Bhavnagar and Vadodara districts of Gujarat. The farm level information pertaining to use of seeds and other inputs, including pesticides have been gathered for the three sub-periods. The use of panel data, though small in number, might provide a holistic perspective of the pesticide use practices of the farmers in Gujarat in the wake of commercialisation of Bt technology.

The chapter is organized into five sections including introduction and conclusion. Sect. 2 briefly describes the pest incidence in cotton in India in terms of the various insects affecting the crop, the stage of their occurrence, damage symptoms and the temporal dimension of pest activity. The section then examines the diffusion of Bt cotton in India with particular reference to Gujarat. Section 3 discusses the pesticide use pattern among the panel farmers, the type, chemical combinations as well as the hazardous nature of insecticides used by the Bt cotton farmers. Section 4 explores the potential environmental and health related impacts arising from the insecticide use practices followed by the Bt cotton farmers.

2 Pest Incidence in Cotton

Cotton cultivation has been affected by different types of pests worldwide (Showalter et al. 2009). Table 1 presents the various pests that affect cotton cultivation in India. As evident, most of the insects that affect cotton are active

Table 1 Details of insects affecting cotton cultivation

Insects	Stage of occurrence	Symptom of damage	Time duration of pest activity
1. American bollworm	All stages	The larvae feed on leaf. Also bores into square flowers and bolls	Active throughout the year
2. Pink bollworm	Crop mid stage to End of the crop	Affected flowers do not grow fully. Show characteristic resetting i.e. buds shed	Active in August-November
3. Spotted bollworm	Boll formation stage	Larvae bore into the terminal shoot of young plant leading to its death. Also bore into flower buds and young bolls. Damages buds and flowers. Bolls shed	Active throughout the year
4. Tobacco caterpillar	Throughout the crop period	Early larvae feed on under surface of leaf. Also feed on flowers, buds, flowers, calyx and bolls	Throughout the year
5. Whitefly	Throughout the crop growth	Sucks plant sap by feeding on under surface of leaf-chlorotic spots on leaves. Leads to premature leaf fall	December-February
6. Aphids	Early growth stages	Sucks leaf sap. Leaves curl and drop quickly. Sticky honey dew and sooty growth on leaves	May–November
7. Jassids	Seed mostly at seedling stage or throughout the year	Insect feeds on underside of the leaf causing curling of edges. Leaf turns red and brown, dries up and sheds	Almost throughout the year
8. Spider mite	Throughout crop growth period	Punctures the leaves, feeds on the sap. Leaf turns red, whittle and falls	Almost throughout the year
9. Thrips	Vegetative stage	Nymphs and adults lacerate leaf surface and feed on sap. Upper side of older leaf turns brown. Lower side silvery white	May–September

Source www.ikisan.com, accessed on Feb 7, 2007 throughout the plant life which necessitates spraying of pesticides to protect the crop.

Incidentally, not all varieties of cotton are susceptible to pests. The conventional varieties of cotton, which have been traditionally cultivated in both rainfed and irrigated conditions, do not require any pesticides. In the context of Gujarat (Table 2, Fig. 1) we find that cotton cultivation can be grouped into three distinct phases. The first phase was when desi cotton varieties were the most popular varieties that were cultivated widely. This phase that ended with the early '1990s when hybrid cotton varieties became the most preferred verities and this trend lasted till the introduction of Bt cotton in 2002. Interestingly, though the third phase witnessed tremendous transition in seed use towards Bt varieties, the desi and hybrid varieties continue to be grown by the farmers in Gujarat on a significant scale.

It is important to note that with increased adoption of hybrid varieties, the use of pesticides also started increasing in Gujarat. For instance, massive bollworm infestations were widely reported during 1977, 1983, 1987 and 1997 which increased the use of pesticides heavily in cotton cultivation. The puzzle that: 'why the use of pesticides had increased despite the technological shift in cotton?' needs an explanation here. Pesticide is defined as 'any substance or mixture of substances, intended for preventing, destroying or controlling any pest including vectors of human or animal diseases, unwanted species of plants and animals. It includes substances intended for use as a plant growth regulator, defoliant, desiccant or fruit thinning agent, for preventing the premature fall of fruit and substances applied to crops to protect the commodity from deterioration' (Bag 2000).

Table 2 Distribution of area under cotton in Gujarat (%)

Variety of cotton	1991–1992	1995–1996	2003–2004	2004–2005	2007–2008
1. Desi	52.5	47.8	43.7	39.9	26.5
2. Hybrids other than BT	47.5	52.2	56.3	47.8	21.9
3. Bt hybrids	0.0	0.0	0.0	12.3	51.7
Total area (Lakh ha)	15.02 (100)	20.46 (100)	16.47 (100)	19.06 (100)	25.16 (100)

Source From 2003–2004, obtained from GOG, earlier data Season and crop reports of different years

Fig. 1 Technological shift in cotton cultivation in Gujarat

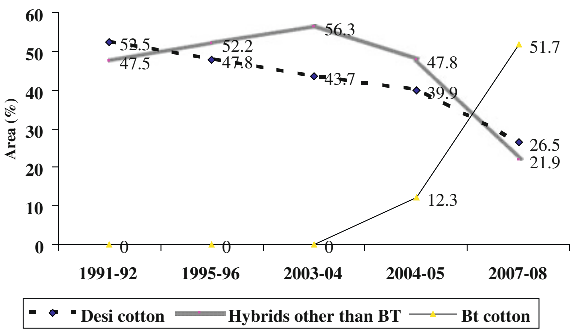


Table 3 Pesticide use and consumption in Gujarat and India (MT)

Year	Gujarat	India	Gujarat (% share)
1989–1990	5,500	71,894	7.65
1990–1991	4,100	75,033	5.46
1995–1996	4,560	61,260	7.44
2000–2001	2,822	43,584	6.47
2005–2006	2,700	39,773	6.79
2009–2010	2,750	41,822	6.58
Annual Change (%)	−1.95	−2.51	−0.73

Source Compendium of Environmental Statistics, 2008–2009, Ministry of Statistics and Programme Implementation, Government of India

This being so, even if the pest pressure is low and the atmospheric conditions are against pest infestation, cotton farmers continue with pesticide sprays for different purposes.

While climatic conditions and erratic rainfall could cause pest outbreaks, continuous monocropping also lead to the bollworm manifestation in cotton and the crop loss due to bollworm was estimated to be 50–60 % (Shetty 2004). It has to be mentioned that in India, crop specific use of pesticides is hard to come by. However, the overall consumption of pesticides across states is available (Table 3), from which it cannot be conclusively said anything about the pesticide consumption in cotton except reminding us of the fact that is cited by many studies that cotton accounts for the largest share in pesticide consumption (Abhilash and Singh 2009).

Nevertheless, a broad trend emerges from Table 3, which shows that pesticide consumption has been on the decline both at the national and state levels. While there was an annual decline of 2.51 % in pesticide consumption at the national level, in Gujarat the annual decline has been 1.95 %, posting a decline of about 50 % in absolute terms between 1989–1990 and 2009–2010. The decline in pesticide consumption, both at the national and state levels, could be due to several reasons including that of positive effect of the technology such as GM cotton.

2.1 The Diffusion of Bt Cotton in India

India’s cotton production, which was 4.85 lakh bales in 1961–1962, increased to only 9.71 lakh bales in 1991–1992 (Appendix Table A.1). However, this situation changed remarkably ever since the commercialization of Bt cotton in India in 2002 leading to a phenomenal increase in production thereafter. Production has more than doubled from 10 lakh bales in 2001–2002 to 24.35 lakh bales in 2007–2008 (Barik and Gautam 2009). When Bt cotton was commercially launched in India in 2002, the area under Bt cotton was only 0.3 million ha (hardly 4.3 %) against the total cotton area of 7.3 million hectares. But, the latest estimates indicate that the area under

Table 4 Adoption of single and multiple gene Bt cotton hybrids in India (Million Hectares)

Number of gene	2005	2006	2007	2008	2009
Single	1.3 (100)	3.65 (96)	5.74 (92)	5.56 (73)	3.58 (43)
Multiple	–	0.15 (4)	0.46 (8)	2.04 (27)	4.82 (57)
Total	1.3 (100)	3.8 0(100)	6.20 (100)	7.60 (100)	8.40 (100)

Note Figures in parentheses indicate the percentages
Source Table 4, Choudhury and Gaur (2010)

Bt cotton has reached 10.5 million hectares during 2011–2012, which is more than 90 % of the total area under cotton (11.5 million hectares) in India (Barik 2011). Further, there has also been a major shift from single gene (Bollgard 1) Bt to double gene Bt or Bollgard 2,[2] the share of which became 57 % in 2009 (Table 4).

Most of the studies that have looked at the use of pesticide in Bt cotton have drawn attention to the reduction in the use of pesticides (a) in general (Pray et al. 2001; Julie et al. 2001; Qaim 2001; Indira et al. 2005; Qaim and Janvry 2005; Narayanamoorthy and Kalamkar 2006; Dev and Rao 2007; Peshin et al. 2008; Lalitha et al. 2009); (b) on bollworms (Bennett et al. 2006; Lalitha and Ramaswamy 2007; Huang et al. 2009); and (c) the income savings due to the reduced pesticide expenditure (Qaim et al. 2005; Gandhi and Namboodiri 2006). In Colombia, however, use of Bt cotton is not associated with a significant reduction in insecticide use. As boll-weevil is the major pest in cotton in Colombia, Bt growers spend more on insecticide than farmers growing conventional varieties (Zambrano et al. 2009). Kranthi et al. (2005) found that the commercial Bt cotton hybrids introduced in India express less than the critical levels of Cry1Ac gene required for full protection against bollworms late in the season and in some plant parts. Hence, they observed that the 'Bt cotton hybrids in India may require more supplemental insecticide sprays than being used in Bt cotton varieties elsewhere in the world.'

There are a few studies (Rupa et al. 1991; Mancini et al. 2005; Kouser and Qaim 2011) that analyse the health and environmental impacts of pesticide use and highlight the positive as well as negative externalities of pesticide applications. For instance, Rupa et al. (1991) bring out the startling evidence on the impact of pesticide use among cotton farmers. Comparing a large group of couples (1016), in which the males were exposed to pesticide spraying for 1–20 years with another group of couples (1020), identical in terms of socio-economic background but who were not spraying pesticides, this study reports the stark health problems encountered by the sprayers compared to the non-sprayers. While the sprayers themselves had eye and skin irritation, giddiness and nervous disorders, the wives of the sprayers experienced abortions, still births and neonatal deaths. Mancini et al. 2005 analyses the acute poisoning due to pesticide use among the cotton

[2] Recently, Bollgard 2, based on the pyramid technology, has been introduced which protects against bollworm and *Spodoptera*. Hence, because of the in-built protection against these pests in cotton, it is expected that the pesticide use in Bt cotton farms would decline due to wider adoption of Bollgard 2.

Table 5 Bt Cotton adoption trend among the panel farmers

Years	Panel farmers (n = 66)	
	Total cotton land (Ha)	Proportion of Bt
2003–2004	194.6	0.54
2007–2008	296.6	1.00
2010–2011	285.8	1.00

Source Farm Household Survey, GIDR

growers in India. This study observes that there are no significant differences in the health effects experienced by women workers who were involved in pesticide mixing and refilling of the containers, while the men did the actual pesticide spraying. Analysing the self reported health events of the cotton workers, this study points out while the 16 % of the events were asymptomatic, 39 and 38 % led to mild and moderate poisoning and 6 % reported severe poisoning. A similar result is observed in a study on cotton growers and farm workers in Gujarat (Lalitha and Ramaswamy 2007). Kouser and Qaim (2011) note that while Bt cotton adoption resulted in 50 % reduction in pesticide use, 70 % of the reduction happened in most toxic chemicals and has reduced the incidence of acute poisoning cases among the cotton workers, leading to significant savings in health costs.

Apparently, almost all the studies are based on analysis of single year data and none[3] analyse the long term and repeated exposure to pesticides in the context of wide-scale diffusion of Bt technology, which warrants more systematic analysis.

3 Pesticide Use Pattern Among the Bt Cotton Growers

Before we discuss the pesticide use pattern among the cotton growers, a little background information about the study farmers is provided here. The panel farmers share some commonalities across districts in terms of age and education status. With a mean age of 47 years, at the aggregate level, farmers in Rajkot show an average of 44 years against 50 years in Vadodara. The education status shows a mean of 10 years of schooling (ranging from 9.5 to 11.4 years).

There was a dramatic increase in the adoption of Bt seeds among the sample farmers over a period of less than a decade. For instance, Bt adoption ratio which was 0.54 % of the total cotton area in 2003–2004 increased to 1 in 2007–2008 and remained so in 2010–2011 as well (Table 5). In 2003–2004, farmers had used both unapproved and approved Bt varieties. It also needs to be mentioned that in 2010–2011, there had been a marked shift from Bollgard 1 towards growing Bollgard II varieties that offers protection against bollworm and *spodeptora*.

[3] Though the study by Rupa et al. (1991) is an exception, it was not addressing the pesticide use behaviour in the context of technology shift towards Bt cotton.

Table 6 Trends in cotton yield and pesticide sprays reported in Bt cotton farms 2003–2004 to 2010–2011

Years	Average yield (Kg/ha)	Std. Dev.	C.V (%)	Sprays per ha (No.)
2003–2004	2,676	876	32.7	5.4
2007–08	1,854	979	52.8	3.9
2010–11	1,947	689	35.4	3.7

Source Farm Household Survey, GIDR

Though initial years of Bt adoption had witnessed significant rise in cotton yield across states and regions, the recent farm level data indicate that Bt cotton yield declined steeply in 2007–2008 (1,854 kg/ha) compared to 2003–2004 (2,676 kg/ha), and picked up, at a slower rate, in 2010–2011(1,947 kg/ha) (Table 6). Variation in the yield in 2007–2008 (with a CV of 53 %) has been particularly high, which could be attributed to the reason that farmers had more number of varieties (of course with varying yield levels) to choose in that year along with a reduction in the prices of Bt seeds. Further, variability in yield in 2010–2011 is almost comparable with that of 2003–2004, which perhaps indicate the suitability of the double gene variety in Gujarat soil conditions in 2010–2011.

In 2003–2004, the average number of sprays per hectare was 5.4 which had subsequently gone down to 3.7 during 2010–2011. It may be noted that in 2003–2004, cultivation of unapproved Bt varieties were more than the approved Bt varieties. However, the average number of sprays used in the farms growing unapproved Bt varieties (4.59) was lower than the number of sprays in the farms with approved Bt (6.3) seeds (Lalitha and Ramaswamy 2007). In 2007–2008, the area under the approved Bt cotton increased as farmers started taking advantage of the seed choices available to them. It is evident that the average number of sprays has reduced to 3.9 by 2007–2008. In 2010–2011, the average number of sprays has only marginally declined to 3.7. In fact, the reduction in the pesticide had gone beyond the Bt adoption effect in the sense that even the non-Bt adopters had experienced reduction in the pesticide sprays in the post 2006 years (Kouser and Qaim 2011).

It should also be noted that in this period, though there had been a shift from cultivation of single gene Bt to double gene Bt, which offer protection against bollworms and spodeptora, the need to spray against sucking pests which remained high and, hence, there has not been a significant reduction in 2010–2011.

A closer look at the pattern of pesticide use as shown in Fig. 2 reveals that a major chunk of pesticide sprays take place between 31 and 90 days after sowing, which is quite contradictory to the scientific prescriptions that Bt cotton does not require sprays between 45 and 120 days. However, the sprays could have been intended not for controlling the pests but to boost the growth of the plant and boll formation also. The largest number of sprays takes place between 60 and 90 days of crop growth and the trend has remained the same during the three time points under consideration.

One possible explanation for the deviation from the scientific recommendations could be the new pest complexities that emerge with the increasing infestation of

Fig. 2 Pesticide spraying pattern among Bt cotton farmers (*Source* Farm Household Survey, GIDR)

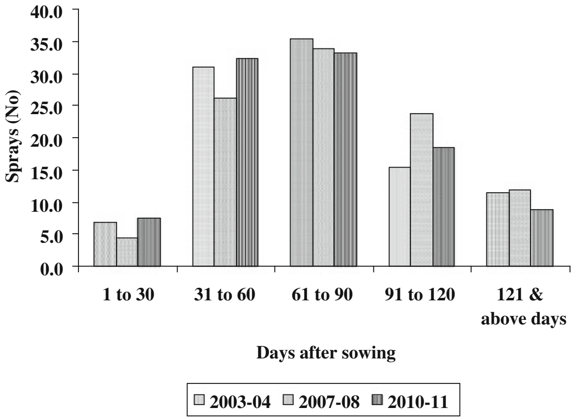
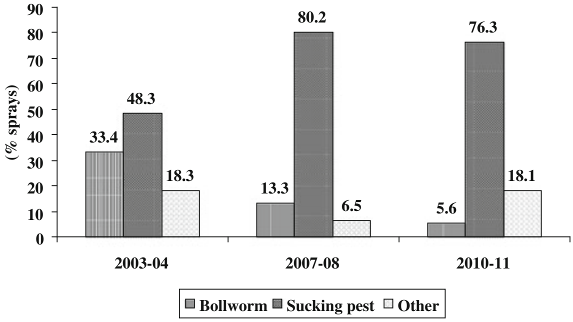


Fig. 3 Pesticide use on targeted pests by Bt cotton farmers (*Source* Farm Household Survey, GIDR)



sucking pests. This is further evident from the specific pest targeted sprays undertaken by the farmers as presented in Fig. 3. It was observed that the sprays intended for the control of bollworms had significantly and consistently declined over time.

However, the sprays for control of sucking pests have increased from 48 % in 2003–2004 to 76 % in 2010–2011, which coincides with the farmers' observation that with increased Bt adoption, the sucking pests' pressure was more than the bollworm and other pests. It could be that while bollworms are under control, the sucking pests have emerged as the major pests. More importantly, the trend in sprays against control of sucking pests has been almost the same during the three time points.

Now, the sucking pests could have increased because of three reasons. First, an increase in the sucking pests' population could be due to the reduction in the sprays intended at bollworms. Second, the atmospheric changes were such that bollworms declined giving rise to the sucking pests. Third, the pest management strategy as adopted by the farmers in the post Bt scenario perhaps had not been effective, giving rise to the increased incidence of sucking pests.

Table 7 highlights a disquieting practice of pesticide use that prevails among the farmers. It seems that perhaps the increasing incidence of sucking pests had

Table 7 Number of chemicals mixed in each spray in 2003–2011

Number of chemicals	2003–2004		2007–2008		2010–2011	
	Sprays (No.)	%	Sprays (No.)	%	Sprays (No.)	%
1	228	21.8	209	18.16	140	13.1
2	550	52.5	620	53.87	722	67.5
3	258	24.6	278	24.15	155	14.5
4	12	1.1	38	3.301	52	4.9
5	0	0.0	6	0.521	1	0.1
Total	1,048	100.0	1,151	100	1,070	100.0

Source Farm Household Survey, GIDR

prompted the farmers to evolve a strategy of pest management by deliberately choosing to use more than one chemical in sprays, a practice discouraged by entomologists. The proportion of sprays involving 3 chemicals has been more than 24 % in the first two periods, though it declined to 15 % during the latest period. While the sprays involving two chemicals had increased to 67.5 %, pesticide sprays involving 4 chemicals also made a significant rise over time from 3.3 % (2007–2008) to 5 % (2010–2011).

During field surveys, it was quite common to find the combinations of two or more than two pesticides widely being used, such as acephate (moderately hazardous), monocrotophos (highly hazardous), imidia choloroprid (highly hazardous) and Karbendenzim (slightly hazardous) (Table 8). 'When two or more pesticides are used simultaneously, then they may interact and become more toxic and hazardous. However, no study has been done on various health hazards due to the combined effects of various pesticides including their treatment and antidote' (Mukhopadhyay 2003). In fact, combinations other than those suggested by the Central Insecticide Board and Registration Committee (CIBRC) could be detrimental to the soil and the crop which is perhaps reflected in the declining trend in yield along with high variability as also presented in Table 6.

Table 8 Pesticide combination used by farmers

Major pesticide	Combinations used
Monocrotophos	Endosulfan,[a] Confidor, Tatamida, Acephate, Acetamypride, Prophanophos, DDVP, Imidaclorópride, Compute, Simbus, Admire, actara, Quinalphos, Astafpowder, Cyper, Ethion, Hostathion, Phenyl, Media, Sarfen, Tarthin, Proclaim, Nokil powder, Remon, Ekza, Ektachambal, Veshisuper, Reject, Agromil, Airgone, Stop, Ozone, Curaphone, Hamla
Acephate	Monocrotophos, Endosulfan, confidor, Tatamida, Prophenophos, computer, actara, Ethion,Hostathion, Saf, Confidor
Starthion	Monocrotophos, Confidor, Prophenophos, Media, Dhantron

[a] Many civil society organizations have been actively demanding a ban on endosulfan at the national level in India due to its adverse impacts, as reported from few states, viz., Kerala and Karnataka. In early June 2011, the Government of Gujarsat had banned the use, production and sale of endosulfan

Note A few of the local names as reported by farmers have also been mentioned

Source Farm Household Survey, GIDR

Table 9 Pesticides that are commonly used by the Bt cotton farmers*

Pesticide Name	WHO category	2003–2004		2007–2008		2010–2011	
		No. of times reported	%	No. of times reported	%	No. of times reported	%
Acephate	Slightly hazardous (Class III)	52	6.6	333	18.1	383	23.1
Computer	Moderately hazardous (Class II)			99	5.3	27	1.6
Confidor	Moderately hazardous (Class II)	182	23.3	245	13.3	171	10.3
Endosulfan	Moderately hazardous (Class II)	81	10.3	165	8.9	91	5.5
Ethion	Moderately hazardous (Class II)	–		35	1.9	–	–
Fenval	Moderately hazardous (Class II)	30	3.8	–	–	–	–
Imidacloprid	Moderately hazardous (Class II)	–	–	76	4.1	–	–
Larvin (powder)	Moderately hazardous (Class II)	23	2.9	–	–	–	–
Monocotophos	Highly hazardous (Class IB)	265	33.9	421	22.8	567	34.2
Profenophose	Moderately hazardous (Class II)	–		32	1.7	131	7.9
Quinalphos	Moderately hazardous (Class II)	24	3.1	–	–	–	–
Tarthin	Slightly hazardous (Class III)	–	–	–	–	42	2.53
Tatamida	Moderately hazardous (Class II)	–	–	44	2.3	–	–

Source Farm Household Survey, GIDR
Note *This is not a very exhaustive list. We have provided those chemicals, which could be classified in the WHO hazardous classification (2005)

A careful look at the types of popular pesticides being used reveals that monocrotophos is the all time favourite among the farmers, followed by acephate (Table 9). Except for monocrotophos which is an extremely hazardous pesticide, all other names reported either belongs to moderately hazardous or slightly hazardous pesticide categories as per (WHO 2005) norms.

Does this suggest that except for monocrotophos the farmers are shifting from organochlorines to newer neonicotinoids? Is this a trend to rejoice? The answer could be both yes and no. This is because, though there is a decline in the average number of sprays per hectare, yet the chemicals and chemical combinations have been used in an unscientific manner (Tables 7 and 8). The apprehension here is that when costly neonicotinoids are used with an extremely toxic organochlorine or organophosphate, it could end up with the fate of pyrethroids for which all the major cotton pests have developed resistance.

4 Pesticide Use in Bt Cotton and Potential Environmental and Health Impacts

Pesticides are useful technology to increase productivity. However, continuous use of pesticides causes irreversible damage to the environment and soil productivity. Besides, contamination and deterioration in the quality of groundwater sources are also reported as the casualties caused by increased use of pesticides, which indiscriminately kill insects and micro-organisms (Mukhopadyay 2003; Shetty 2004). Both organochlorines and organophosphates have their own adverse effects. 'Organochloric pesticides are more persistent in soil due to their lower biodegradability than organophosphates. The absorptive capacity of soil to chemicals is highest in organo rich soil and is least in sandy soils. Leaching to groundwater sources in permeable soil is about 1 % of the chemical application, depending upon the type of soil and the characteristics of the groundwater aquifers. Thus, contaminated groundwater by the chemical residues in soil can kill valuable microorganisms which contribute to crop growth and can form a potential hazard to the source of safe drinking water' (Bag 2000: 3383).

Similarly, there are serious health impacts due to indiscriminate use of pesticides on farmers and farm workers who mix and spray chemicals and work in the sprayed fields without any protective clothing/gear. Besides the pesticide residues in food is a potential hazard.

It remains a fact that the effects on health and the environment due to pesticide sprays could not be effectively captured in our study due to paucity of information and the level of understanding of the Bt cotton farmers. Hence, it is a limitation of the study as we stopped with asking the farmers about the 'observed' immediate environmental impacts like hardening of the land, reduction in the beneficial insects, etc. More importantly, we feel that a period of 10 years may not be sufficient enough to reflect upon the health and environmental impacts of intensive use of pesticide applications on Bt cotton. None of the farmers reported any visible adverse impact on the environment or health due to continued pesticide use. Depending on the phenotype and plant density, it is estimated that 35–50 % of the pesticide sprayed is deposited immediately in the soil after spraying. Further, applied pesticides reach the ground water in three ways, viz: (a) run-off where the applied pesticides are physically transported due to rain water; (b) inflows where physical pollutants are directly absorbed in the rain water; and (c) leaching, i.e., movement of pollutants through rain or irrigation water (Jayasree and Vasudevan 2006). This over a period of time would render the soil unproductive and the pesticide totally ineffective.

A study in the US found that Bt cotton adopters use less insecticides and proportionately less pyrethroids and, thus, may have a impact in preserving the remaining efficacy of pyrethroid insecticides (Hubbell et al. 2000). But resistance build-up happens when a particular group of pesticides is heavily relied upon. The various combinations of pesticides that the farmers use (Table 8) could also lead to the chemicals losing their efficacy and will, in turn, lead to farmers using more pesticides. The outcome would be the further loss of beneficial insects and increase in pest levels which are widely observed in the form of increased sprays as observed above.

The poison information centre of the National Institute of Occupational Health in Ahmadabad, India, reported that organophosphorous pesticides were responsible for the maximum number of poisonings (73 %) of all agricultural chemicals (cited in Gupta 2004). The severity of any adverse effects of exposure to pesticides on humans depends on the dosage, the route of exposure and how easily the pesticide is absorbed, its accumulation and persistence in the body (Mukhopadhyay 2003). In contrast, it was revealed by the farmers that none of them had serious health problems after spraying. However, a majority of the farmers reported the mild poisoning effect like eye and skin irritation, nausea and loss of appetite, and, according to the farmers, the symptoms reported were not serious to get medical attention immediately in all the three time periods. Hence, there was no medical expense reported or man days lost due to sickness. There could be two explanations for this contradiction. Either the farmers are so immune to the pesticides or, perhaps, the way the different chemicals are combined, their toxicity is totally lost and they are ineffective, which again forces the farmers to use more pesticides. However, we cannot totally rule out the possibility of pesticide residues on the soil and water, and their potential damage to the environment and soil productivity in the long run.

Also, all the farmers in our panel have been cultivating cotton for long years. Hence, they have been exposed to pesticide applications for long. This being so, separating out the effects of pesticide sprays due to Bt cotton would call for a totally different scientific enquiry at the farm level. Essentially, the potential environmental implications emerging from the use of pesticides should need more empirical investigations based on information/data generated from micro level monitoring and surveillance, which are virtually lacking in the current context. The empirical reality reveals that farmers are pursuing an unsustainable method of cultivation, without paying attention to the fast depleting and degrading natural resources, particularly, land and water.

There are also systemic issues emerging from the very approach being adopted by the farmers in growing Bt cotton as a monocrop. This is evident from the fact that out of the panel of 66 farmers, only 23 % mentioned growing other food or vegetable crops as intercrops in the cotton field, though Bt is essentially a short duration crop. Various reasons like inadequate water and resources are cited as reasons for not going for another crop after growing Bt cotton. Hence, the continuous mono-cropping could also lead to declining land productivity along with the erosion of soil fertility contributed by the leaching of the pesticides.

4.1 The Need for Environmentally Sound Farm Management Practices

The need for environmentally sustainable farm management practices are the need of the time, as Gujarat has already started recording a declining trend in cotton yield. As per the latest official statistics of Government of Gujarat, (www.agri.gujarat.gov.in, accessed on 31 January, 2011), cotton yield at the state level has reduced from 581 kg per hectare in 2007–2008 to 507 kg per hectare in 2008–2009. Variety of reasons like inadequate rain, resistance build-up in cotton, monocropping, increasing sucking pests including mealy bug, etc., have been attributed to this. This also highlights the need for sustainable farm management practices in Bt cotton on a wider scale to ensure stability in yield along with judicious use of insecticides and, thereby, strengthening the livelihoods and food security of the farmers. Moreover, the state has to come out with suitable regulatory controls on pesticide use practices in order to ensure the safety of the farm workers and to protect the quality of the drinking water as well as the soil.

It is also important to consider the potential of devising crop or region-specific pest/insect management practices. It may be observed that Bt cotton might work as a useful technology and if it is complemented with IRM and IPM programmes, it would lead to more benefits. In all the three time points, our questions about farmers awareness about the IRM and IPM programme got very few responses in the affirmative.

In this regard, it may be relevant to give a glimpse of the IRM programme that was introduced in 2006 for cotton in Wardha and Yavatmal districts of Maharashtra at the instance of the Central Institute of Cotton Research, Nagpur, Maharashtra. The IRM intervention is knowledge intensive and creates awareness among the farmers about the importance of looking for threshold limits of pests before undertaking spraying and be aware of the loss of beneficial insects that could be wiped out due to indiscriminate spraying. More importantly, the IRM strategy is to inform the farmers of the rational and the required level of combining chemicals and spray. At the time of introducing this program, it was learnt that the farmers were mostly influenced by the decision of the progressive farmers and considered more number of sprays of expensive chemicals as means of better plant protection.

In 2006–2007 when the program was evaluated, it was realized that the IPM interventions helped reduce both the number of sprays and the number of chemicals that were used in each spray. For instance, in Warul village in Yavatmal, the average number of sprays was 10 per hectare in 2005–2006. This consisted of chemicals such as endosulfan, imidacloprid, acephate, methomyl and dimethoate. After the IRM intervention, the average number of sprays was reduced to 1 per hectare and only endosulfan was used. In Lonawali in Wardha district, the average number of sprays before the intervention was 7.66. It consisted of endosulfan, monocrotophos, metasystox, methomyl, indaxacarb, cypermethrin, NSKE, dimethoate, profenophos. Following IRM intervention, the number of sprays was reduced to 0.17 and only endosulfan and quinalphos were used. The results also indicate considerable savings in cost of spraying along with increase in profitability. For instance, the reduction in sprays due to IRM practices has been 85 % in Wardha and 72 % in Yavatmal districts, leading to a significant saving in spraying costs (78 and 61 %, respectively) along with gains in profits (Rs. 2961/ha and Rs. 1,312/ha, respectively) (Sharma 2007).

Nevertheless, though the success of IRM can be replicated at all the cotton growing regions of India, especially, Gujarat, the program is knowledge intensive and continuous monitoring is required to motivate and support the farmer in the transition to achieve desired outcomes. In this regard, the once active extension services of the public sector (State Agriculture Departments and the Agricultural Universities) needs to be revived again to promote the IPM and the IRM programmes among the farmers, in general, and cotton farmers, in particular.

5 Conclusion

With increasing yield, it is only expected that in the future, Bt cotton cultivation will occupy more space leaving a very small elbow space for organic and desi cotton. An outright ban on use of pesticides is not possible without assessing the substitutability, cost and trade impact of the alternate pesticides. For instance, presently, farmers are using the easily available generic versions of chemicals. If these become ineffective then the farmers will have to shift to newer costlier chemicals (even imported pesticides) which are under patent protection and are not yet produced in India. Hence, in the present situation, if the chemicals that are popularly used become ineffective due to unscientific practices, the yield advantage of Bt technology would be lost. Hence, to derive maximum benefit out of the available seed technology, the chemical inputs need to be used more diligently by adopting suitable IPM and IRM strategies. As these are knowledge intensive and require frequent guidance, it is essential that the extension services need to be revived so that the available agricultural technologies benefit the farmers.

Appendix

Table A.1 Share of India in global cotton area and production

Years	Area (Million ha)		India's share (%)	Production (Lakh bales)		India's share (%)
	World	India		World	India	
1961–1962	32.77	7.98	24	57.75	4.85	8
1971–1972	32.98	7.80	24	76.59	6.95	9
1981–1982	33.84	8.06	24	88.53	7.88	9
1991–1992	33.03	7.66	23	111.84	9.71	9
2001–2002	33.38	9.13	27	126.41	10.00	8
2005–2006	34.19	8.68	25	145.64	18.50	13
2007–08	33.60	9.55	28	152.35	24.35	16
				CAB	31.50	21

Note CAB stands for Cotton Advisory Board
Source Barik and Gautam 2009

References

Abhilash PC, Singh N (2009) Pesticide use and application: an Indian Scenario. J Hazard Mater 165(1–3):1–12

Bag D (2000) Pesticides and health risks. Econ Political Wkly 35(38):3381–3383

Barik A (2011) Overview of cotton production in India with special reference to Bt cotton. Presentation made at the National seminar on Tryst with Bt Cotton in India: experiences and challenges, organized and held at Gujarat Institute of Development Research, May 3 and 4, 2011

Barik A, Gautam HC (2009) Revolution in Indian cotton. Directorate of cotton development, Government of India, Mumbai and National Centre of Integrated pest management, Indian Council of agriculture research, Pusa campus, New Delhi

Bennett R, Morse S, Ismael Y (2006) The economic impact of genetically modified cotton on South African small holders: yield, profit and health effects. J Dev Stud 42(4):662–677

Choudhary B, Gaur K (2010) Bt cotton in India-A country profile. ISAAA series of biotech crop profiles. Available at www.isaaa.org. Accessed on 20 Aug 2010

Dev MS, Rao NC (2007) Socio economic impact of Bt cotton. CESS Monograph No. 3, Centre for Economic and Social Studies, Hyderabad

Gandhi VP, Namboodiri NV (2006) The adoption and economics of Bt cotton in India—preliminary results from a study, WP2006-09-04, Indian Institute of Management, Ahmedabad

Gupta PK (2004) Pesticide exposure—Indian scene. Toxicology 198(1–3):83–90

Huang J, Ruijian C, Jianwei M, Ruifa H, Ellie O (2009) Farmer's seed and pest control management for Bt cotton in China. In: Robert T (ed) Biotechnology and agricultural development transgenic cotton, rural institutions and resource-poor farmers, Routledge, Oxon/New York, pp 105–134

Hubbell B, Marra MC, Carlson GA (2000) Estimating the demand for a new technology: Bt cotton and insecticide policies. Am J Agric Econ 82(1):118–132

Indira A, Bhagwan MR, Virgin I (2005) Agricultural biotechnology and biosafety in India: expectations, outcomes and lessons. Stockholm Environment Research Institute, Stockholm

Jacquet F, Pierre J, Laurence B, Guichard (2011) An economic analysis of the possibility of reducing pesticides in French field crops. Ecological Economics, xx 2011 xxx–xxx (11 pages). doi:10.1016/j.ecolecon.2011.04.003

Julie E, Benedict H, John J, Carroll P, Reding HK (2001) Bollgard cotton: an assessment of global economic, environmental and social benefits. J Cotton Sci 5(2):121–136

Kouser S, Qaim M (2011) Impact of Bt cotton on pesticide poisoning on small holder agriculture: a panel data analysis. Ecol Econ. doi:10.1016/jiecolecon.2011.06.008,1-9

Kranthi KR, Naidu S, Dhawad CS, Tatwawadi A, Patil EM, Bharose AA, Behere GT, Wadaskar RM, Kranthi S (2005) Temporal and intra-plant variability of cry1Ac expression in Bt cotton and its influence on the survival of the cotton bollworm, Helicoverpa, Armigena (Hubner) (Noctuidae;Lepidoptera). Curr Sci 89(2):291–298

Lalitha N, Ramaswami B (2007) Pesticides use pattern among cotton cultivators in Gujarat. In: Dholakia R (ed) Frontiers of agricultural development in Gujarat. Centre for Management in Agriculture. Indian Institute of Management, Ahmedabad, pp 77–98

Lalitha N, Ramaswami B, Viswanathan PK (2009) India's experience with Bt cotton: case studies from Gujarat and Maharashtra. In: Robert T (ed) Biotechnology and agricultural development transgenic cotton, Rural Institutions and resource-poor Farmers. Routledge, Oxon/New York, pp 135–167

Mancini F, Van Bruggen AHC, Jiggins JLS, Ambatipudi AC, Murphy H (2005) Acute pesticide poisoning among female and male cotton growers in India. Int J Occup Environ Health 11(3):221–232

Mukhopadhyay AN (2003) Pesticide usage scenario in India and viable alternatives. Voluntary Health Association of India, New Delhi

Narayanamoorthy A, Kalamkar SS (2006) Is Bt cotton cultivation economically viable for Indian farmers? An empirical analysis. Econ Political Wkly 41(26):2716–2724

Peshin R, Dhawan AK, Vatta K, Singh K (2008) Attributes and socio-economic dynamics of adopting Bt cotton. Econ Political Wkly 42(52):73–80

Pray C, Danmeng M, Jikun H, Fangbin Q (2001) Impact of Bt cotton in China. World Dev 29(5):813–825

Qaim M (2001) Transgenic crops in developing countries. Econ Political Wkly 36(32):3064–3070

Qaim M, Janvry DA (2005) Bt cotton and pesticide use in Argentina: economic and environmental effects. Environ Dev Econ 10(2):179–200

Qaim M, Naik G, Subramanian A, Zilberman D (2005) Bt cotton controversy: some paradoxes explained. Econ Political Wkly 40(10):1514–1517

Rupa DS, Reddy DP, Reddi OS (1991) Reproductive performance in population exposed to pesticides in cotton fields in India. Environ Res 55:123–128

Sharma A (2007) Insecticide resistance management for cotton: dissemination of IRM technologies in cotton. Wardha and Yavatmal districts of Maharashtra: A report submitted to CICR. Nagpur, Maharashtra

Shetty PK (2004) Socio-ecological implications of pesticide use in India. Econ Political Wkly 39(39):261–267

Showalter AM, Heuberger S, Tabashnik BE, Carriere Y (2009) Development, agronomic performance and sustainability of transgenic cotton for insect control. In: Robert T (ed) Biotechnology and agricultural development: transgenic cotton. Rural Institutions and Resource-poor Farmers. Routledge, Oxon/New York, pp 49–71

World Health Organization (2005) The WHO recommended classification of pesticides by hazard and guidelines to classification 2004. WHO, Geneva

Zambrano P, Fonseca AL, Cardona I, Magalhaes E (2009) The socio-economic impact of transgenic cotton in Colombia. In: Robert T (ed) Biotechnology and agricultural development: transgenic cotton. Rural Institutions and Resource-poor Farmers. Routledge, Oxon/New York, pp 168–199

Water Conservation in Urban Areas: A Case Study of Rain Water Harvesting Initiative in Bangalore City

S. Manasi and K. S. Umamani

1 Introduction

Urbanization and its consequences are challenging to manage as they increase the demands on the infrastructure specifically for meeting the key services like water, sanitation, transportation and housing. At the 2000 UN Millennium Summit, the experts came up with certain important resolutions in order to hasten the development process which led to the formulation of the Millennium Development Goals (MDGs), of which, Goal 7 in particular is related to environment and water; and its aim was to reduce the proportion of population having no sustainable access to safe drinking water and basic sanitation to half, by 2015. In the context of water, it means the provision of potable water for drinking and hygiene. Although the fact that the water requirements for drinking and hygiene purposes, as compared to the other sectors, are low rainwater could be a relatively good source for meeting such requirements. It is considered useful to adopt technologies to suit the changing scenarios to help the society by making it decentralized and economical (Konig and Uberlingen 2009).

Water harvesting can be advantageous in several respects given the crisis of water. Rain water could be collected and used for drinking purpose, but adequate precautions must be taken to avoid water pollution. Rain water harvesting (RWH) improves access and availability of water. RWH also helps reduce floods in addition to increasing the availability and quality of ground water. It reduces the dependency on regular water supply, prevents soil erosion and improves its quality and rejuvenates defunct wells/bore wells through recharging of ground water. Although there

S. Manasi (✉)
Centre for Ecological Economics and Natural Resources, Institute for Social and Economic Change, Bangalore, India
e-mail: manasi@isec.ac.in

K. S. Umamani
Centre for Human Resource Development, Institute for Social and Economic Change, Bangalore, India

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_19,

are no disadvantages associated with RWH, it can be detrimental if not installed as per the prescribed design. In such cases, the disadvantages could be in the form of contamination of water quality if rooftops are not clean, water logging if ground water is not recharged properly and flooding of roofs, if filters are not properly designed and cleaned frequently. Rainwater stagnates on the surface of earth if ground water is not reused properly. Further, improper care leads to the leakage of under drainage water, toilet pits nearby and wastes discharged by industrial units lead to the pollution of ground water. RWH of varied types has been popular and being practiced in several countries at levels and across users. While some of them have adopted it in urban areas on a large scale, there are others where there are individual initiatives taken up at buildings, airports, hotels etc.

The present paper is based on the study that focused on the emerging trends in respect of RWH implementation and management in Bangalore based on field views in response to the initiatives taken by the Bangalore Water Supply and Sewerage Board in making RWH installations compulsory for households. The study tries to explore issues and constraints facing users with regard to RWH implementation and also looks into the institutional initiatives taken and interventions made in respect of RWH. The findings are presented with key messages and recommendations.

RWH in India

Practices of RWH systems are to be found throughout history across civilizations in India. Water has been harvested traditionally since pre-historic times. Ancient civilizations emerged and developed near water sources. During the Harappan civilization, (around 6,000 years ago) rain water was collected directly in the open wells. Designs of traditional structures varied from state to state and even from region to region depending on the monsoon patterns. As per the Archeological and historical records, Indians were adapt at constructing dams, lakes and irrigation systems during the reign of Chandra Gupta Maurya [392-297BC]. The largest artificial lake in India in the 11th century AD was constructed by the king Bhoja of Bhopal. It covered an area of over 65,000 hectares and was fed by 365 streams and springs. Indians had developed indigenous techniques for diverting the river water into artificial channels for agriculture through simple engineering structures.

In view of the absence of a river source near by, Bangalore was always heavily dependent on lakes and tanks. Bangalore had evolved on an intricate system of RWH during 1860s itself. Then the commissioner of Bangalore, Sir Lewing Bentham Bowring, in 1866, had laid storm water drains to the rainwater to out lying tanks. A very little rainwater was wasted in this process (Dying Wisdom by Agarwal and Narain 1997). Thus, water harvesting has been part of our civilization.

Rain water harvesting is a simple process in which rainwater is collected and stored for regular use. Rainwater is harvested through other water sources, either naturally or artificially, directly or indirectly. RWH is an old practice of collecting rainwater from a building rooftop and filling it in large tanks. This water is useful for all purposes except drinking; however, it could be treated to potable standards as well.

2 Rainwater Harvesting Techniques

Broadly, there are two main techniques of rain water harvesting (1) Storage of rainwater on surface (2) Ground water recharge

2.1 Storage of Rainwater on Surface

The structures used include underground tanks, ponds, check dams, weirs etc., i.e., which receives direct rainfall viz. footpaths, roads and rooftops. However, ideal among them for catchment is rooftop as a large coefficient of runoff is generated from it and also contamination of water is less as compared to the other two options (http://www.ecoindia.com/education/rainwater-harvesting.html).

2.1.1 Rooftop RWH

Rooftop RWH is suitable for either flat or inclined roofs for the collection of water. The roof area determines the quantum of water that could be collected. Down water pipes made out of PVC, HDPE, cement pipes or half cut horizontal plastic pipes (for inclined roofs) are fixed to the rooftop and connected to a storage sump or syntax tank with specially designed filter, mesh etc. The stored water can be used for secondary purposes and, if treated through boiling, aqua guard and other purification methods, it could be used for drinking. To avoid contamination, precaution should be taken to protect stored water by covering it properly and ensure that either sunlight or dust does not enter the sump/tank. It is also important to manually maintain the storing system like cleaning of filters, removing of leaves and twigs and other wastes from the mesh etc., for obtaining good results Plate 1.

Plate 1 RWH models displayed at Theme Park, *Photo*: Manasi S

2.1.2 Rooftop Rain Water for Recharging of Open Wells and Bore Wells

Rainwater collected from rooftops may be filtered using suitable filters and recharge groundwater from an existing open well or a bore well. The filtered rainwater may be directly let into an open well through a pipe from any side of the well. Precautions are to be taken not to allow the filtered rainwater into a bore well, functioning or defunct as the filter may not hold fine silt or dust from the rooftops, hence infiltration gallery is to be installed.

2.1.3 RWH on Roads

Rainwater falling on roads can be guided into side drains, as roads are built sloping towards the sides. Water collected in the side walk areas flows into storm water drains. The existing system could be used for gaining some benefits by building infiltration trenches by the side of drains all along the roads. There are technical specifications regarding the way infiltration trenches are laid. During rains, water from roads flows into infiltration trenches leading to water percolation into the ground. Similarly, during heavy down pours, excess water spills over to the storm water drains and the infiltration trenches store water for a temporary period and for later infiltration. These infiltration trenches can also serve as walkways (Kumar 2005).

2.1.4 RWH in Parks and Open Spaces

RWH in parks and open spaces involve micro-watershed management methods that facilitate rainwater infiltration and percolation into the ground. Rainwater run offs need to be minimized through building of a sufficient number of percolation pits and dispersion trenches. In large parks, ponds could be built for storage of rainwater and integrated with the surrounding landscapes of park. The other aspects include mapping of the contours, planning for rainwater outflow in consonance with natural drainage patterns, identifying appropriate areas for percolation pits or dispersion trenches (Kumar 2005).

2.2 Groundwater Recharge Technique

The percolation of excess rain water through an infiltration system to the subsurface is called 'Artificial Ground water Recharge'. In the floor area, water recharge would be about 1 L/m^2, where as in the pavement area i.e., through pavers with gaps, it would be about 10 L/m^2. Another estimate indicates that when

Plate 2 Model of Ground water recharge pit, RWH Theme Park, *Photo* Manasi S

the breadth of a footpath is 3 m, 3,00,000 L of rainwater flows for 1 mile, more will be the flow of rainwater if more is the breadth of the footpath (BBMP brochure) Plate 2.

3 RWH in Bangalore

Bangalore's urbanization process has been alarmingly unprecedented making it a challenge for the State government to provide the much needed infrastructure facilities. Bangalore, the capital city of Karnataka, is India's sixth most populous city and fifth most populous urban agglomeration. Bangalore, with its strategic location as well as congenial climate, and the establishment of the IT industry attracts people from all over the country. Of the many challenges that urban Bangalore faces, water scarcity remains one of the critical issues. Availability, Accessibility, Equity and Quality have been the serious challenges, while environmental concerns are on the increase in view of ground water depletion and contamination. Bangalore has lost many of its water bodies making the ecosystem fragile with the increasing need for space to meet the demands of housing and business establishments.

Bangalore gets water from river Cauvery, about 100 km away and 500 m below Bangalore, incurring huge financial costs. Water flows against gravitational force from Cauvery, and is pumped at various stages before reaching Bangalore. Thus, Cauvery travels a distance of 100 km to a height of 500 m against gravity using 71 mw of electricity. A huge amount of Rs. 25 crore is being paid as power charges every month, but Bangalore still faces an acute shortage of water supply against the total demand. Hence, Bangalore Water Supply and Sewerage Board (BWSSB) has taken the initiative to drill bore wells for supplying water; besides the citizens also drill private bore wells in order to overcome the water shortage problem. This has resulted not only in the rapid increase of bore wells throughout Bangalore, but also overexploitation of ground water. It is estimated that the number of bore wells total around 2 lakhs. The ground water level has declined by about 10 m in between 1978 and 2003 (Kumar 2005). Many defunct wells and failed (dry) bore wells are also seen throughout Bangalore. Another relevant issue that adds to groundwater depletion is the closure of tanks. Bangalore has an advantage of having nearly 70 rainy days spread over the year. However, Bangalore drainage system can handle only 30 mm of rainfall in one hour. So whenever there is a heavy down pour, the city faces problems. There were about 370 tanks in Bangalore, but have declined over time due to improper management giving way to construction of the Stadiums, Parks, Bus stops and Buildings. Major lakes in the city have been occupied by buildings, parks, bus stands, Stadiums etc., and tar/cement roads have been increased leaving no place for rain water run offs to reach underground. The rainwater infiltration has also declined as the soil exposed to this purpose has gradually decreased over time.

Further, the storm water drains were designed about 20 years ago and the carrying capacity remains the same even though the city has expanded enormously. Although BBMP has got the technical expertise to re-design the drainage network, the process is time consuming; besides, it involves huge costs (Times of India 26.04.2011). Storm water getting mixed with sewage is another issue that needs serious attention. Besides, the sewage system of Bangalore is 80 years old; and does not have the capacity to control large quantity of water which causes flooding. Even as BWSSB has a plan to make zero sewage storm water drains so that they are free of wastes that block rainwater flow.

In view of this, Bangalore Water Supply and Sewerage Board (BWSSB) have been adopting various initiatives to improve its services with conservation being one of its focus areas of late. RWH would play a dual role by way of solving water crisis on the one hand and handling the havoc caused by heavy rains, on the other (DH News Service 04-10-2010). It is possible to collect 4 crore liters of water in a year if RWH is adopted on one acre of land. Totally if RWH is carried out spread across an area of 9,300 acres of land, about 1,500 crore liters of water could be collected in a year. This acts as a suitable solution to flooding (BBMP, Brochure).

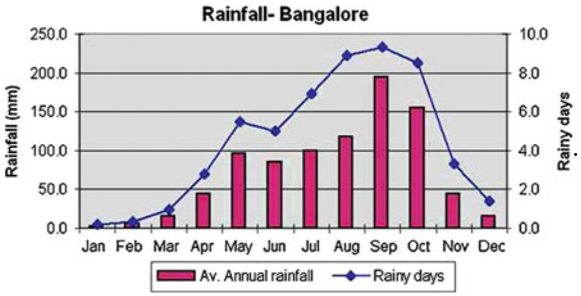
In this backdrop, RWH has been made mandatory for households in Bangalore city with a site dimension of 40/60 and above from 2009. Post BWSSB amendment act, there has been a gradual increase in the number of RWH installations. Currently, there are more than 25,000 households with RWH installations (see Annex 1). Several scientists and architects have worked on the methods to be adopted in respect of RWH. Theme park, the first information and research centre in respect of RWH established in co-ordination with BWSSB and KSCST at 5th block, Jayanagar, is a well established awareness creation centre.

Table 1 Rainwater potential in Bangalore (1985–2005)

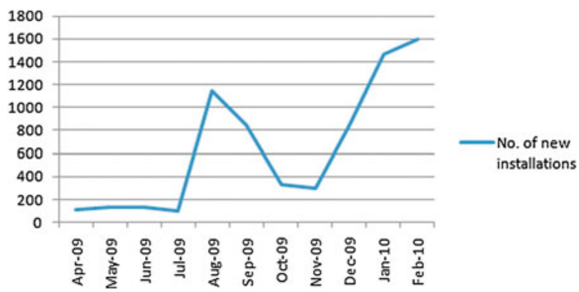
Months	Rainfall in mm	Rainy days
January	2.3	0.2
February	6.4	0.3
March	16.0	1.0
April	44.5	2.8
May	96.0	5.5
June	85.7	5.0
July	100.3	6.9
August	117.8	8.9
September	194.6	9.3
October	154.5	8.5
November	43.9	3.3
December	15.8	1.4
Total	877.8	53.2

Source BBMP Documents

Currently, per capita water demand in Bangalore works out to about 150–200 L per day, while the actual supply comes to about 100–125 L per day, amounting to about 40 % of water shortage Table 1



Growth in the number of buildings with RWH facilities April 2009 to Feb 2010



Against this backdrop, this study provide insights into the emerging trends in respect of RWH implementation and management in Bangalore based on field views in response to the initiatives taken. The study also tries to explore issues and constraints facing various users with regard to RWH implementation. The study covers two areas where RWH is being largely implemented. The study also looks into the institutional initiatives taken and interventions made in respect of RWH. Key issues are identified and recommendations provided.

The objectives are mainly to

(i) to understand the institutions involved and their role in RWH implementation.
(ii) to understand the actual implementation of RWH in Bangalore city.
(iii) to suggest strategies for improved RWH implementation and management.

4 Methodology

We have used both primary and secondary data for the study: primary data from the households, and the secondary data from institutions—BWSSB, BCC, BDA and the KSCST. The study was conducted in Bangalore from April 2011 to July 2011. Based on discussions with the officials of the BWSSB, the area for the survey was identified. RWH adopted across Bangalore has been divided into Central, North, South, East, West and South East zones. There was no data available on the number of households that had adopted RWH across areas within these zones. Hence, among the zones, we identified the South Zone and two areas within the zone (Girinagar and Katriguppe) where majority of the households have adopted RWH. A questionnaire covering various aspects on perceptions, usage, problems, cost incurred on installing RWH was designed. Although the study could not cover all zones in Bangalore, the field situation largely reflects the situation in other areas as well.

5 Role of Institutions

The role of institutions has been admirable in promoting RWH. Bangalore Water Supply and Sewerage Board, Karnataka State Council for Science and Technology (KSCST), Brihat Bangalore Mahanagara Palike (BBMP), Bangalore Development Authority (BDA), are involved in promoting RWH. In the following section the role of each of these institutions are looked into.

5.1 BWSSB

The most important initiative taken by the BWSSB has been developing the RWH Regulations in 2009 specific to Bangalore. 'Rainwater Harvesting Regulations, 2009' *for Bangalore,* every owner or occupier in the building in the site area 2,400 sq ft and above and who construct the building in the site area 1,200 sq ft and above have to install RWH structures. Besides this, any new building construction plan is approved only with a RWH system in place.

BWSSB is engaged in various activities in promoting RWH viz., publishing materials pertaining to RWH, conducting the training programmes for the plumbers and organizing awareness programmes for the public besides implementing RWH in their own offices. BWSSB has also taken up installation of RWH in 40 of its buildings throughout Bangalore. BWSSB is also responsible to monitor the proper installation of RWH structures and BWSSB officials regularly check the water meter along with RWH storage tanks.

BWSSB in collaboration with the KSCST has built a Theme park in Jayanagar, a resource centre to disseminate information about RWH and is India's First Rain Water Information Centre. The Theme Park visually displays 27 models of RWH in the theme park making it convenient for visitors to choose in terms of design and costs. Interestingly every aspect of conserving rain effectively displayed and designated staff explains the models, its usage and benefits. 'Help desk' adds to the convenience with resource persons giving additional information and clarifications about RWH to the public. The officials have seen a positive response from the visitors and remarkable progress with increase in the number of RWH installations each year. As the theory and practical aspects are exhibited well, it has led to positive awareness creation Plate 3.

Plate 3 Theme Park, *Photo* Umamani

BWSSB has conducted 21 RWH Abhiyana Programmes. A complete model of RWH has been designed in a vehicle which is a means of publicity. BWSSB has conducted RWH programs besides Jathas are held involving students. RWH awareness programs were held in schools as well.

362 Slums in Bangalore are surveyed and are proposed to approve RWH on group basis, which in future ease the water burden of BWSSB by 15–20 %.

5.2 Karnataka State Council for Science and Technology

KSCST has directly been involved in RWH promotion and besides practically displaying its promotion through implementation. RWH in twenty landmark buildings and four exhibition plots for demonstration of cost and groundwater recharge technologies are displayed at Bangalore and Tumkur. KSCST is also involved in conducting various training programmes for Engineers, Architects, Planners, Contractors, Plumbers, Masons etc. In different wards of Bangalore and Tumkur several awareness camps were also organized. KSCST has established RWH resource and training centers for Southern states at Mahatma Gandhi Regional Institute for Rural Energy Development in Bangalore and District RWH Nodal Centre at 27 districts in the state. Technical support is provided in establishing RWH system in 176 villages (one each in every taluk of Karnataka) and 23,680 rural schools in the state. About 10,000 people from Bangalore and other parts of Karnataka have availed a technical support on RWH from council (Karnataka State Council for Science and Technology, 2005).

5.3 Bruhat Bengaluru Mahanagara Palike

BBMP has taken up several initiatives to promote RWH. They have identified two main types of RWH (1) Rainwater harvesting in surface water bodies such as lakes, ponds, rivers, dams etc. for the direct use. (2) Ground water recharge in a scientific manner to increase the underground water recharge, by constructing recharge pits and by adding life to the defunct well and bore wells. BBMP aims to reduce the pressure on major valleys which come under BBMP besides using rain water to improve flora and fauna growth.

BBMP has identified specific sites with defined guidelines to adopt RWH (1) All the apartments and other properties with the area of 1 acre (2) Properties with a very large area. e.g., palace ground (3) Parks and playgrounds of BBMP (4) Houses above 30 × 40 sizes have to implement RWH (5) RWH done on roads and redesign the shoulder drains and adopt catch pits to store the water which over flows.

Awareness Creation—As the necessity of RWH is being brought to the notice of the Government, it was interesting to note that the political representatives personally involved in promoting RWH. The honorable Chief Minister, Home

Minister, Transport Minister and other ministers, Mayor and Deputy Mayor of Bangalore, the members of Vidhana Sabha and Vidhana Parishat and all the members of BBMP have supported the campaign. BBMP has provided simple and clear information to the public by distributing pamphlets and advertisements in the newspaper and other media. Promotion through Personal Appeals is also an interesting aspect. BBMP has requested all the citizens, private, government and non government offices and environmental organizations to support the RWH for the welfare of the society. The BBMP Commissioner personally visited the Chief Officers of all the departments of Central Government and requested to adopt RWH installations. The large properties which come under the area of four major valleys Vrishabhavathi, Challaghatta, Koramangala and Hebbal area were identified by BBMP and requested the owners of those properties through personal letters to adopt RWH structures. The results have been positive and more than 500 households are adopting RWH almost every month.

Implementation—All the properties either Government (both Central and State) or private of area above 1 acre are recognized area wise. RWH is to be implemented some government properties. Another interesting initiative has been to install RWH structures in BBMP parks, playgrounds, offices, open spaces and drains on the road sides. BBMP has taken up 3 major programmes in the year 2010–2011 viz. (1) Rainwater harvesting (2) Planting saplings and (3) Preservation of trees. 'Bridge an Edge' is the vital programme which RWH is adopted through percolation rainwater through the trees. Percolation through trees is a simple method wherein they build a small structure around the tree for the water to infiltrate which aids in collection of rainwater and protection of trees simultaneously. Besides, the long term effect could be to improve the healthy water cycle. If care is taken to conserve trees all the rainwater that flows on the footpath should

Plate 4 Initiating recharge around trees—before and after scenario, *Photo*: BBMP

reach the RWH structure in complete, quantity of water stored is estimated to be 877.8 mm. So if RWH structures are adopted for 20 lakh trees which come under BBMP the rainwater collected will be 874.30 crore liter Plate 4.

5.4 Role of BDA, BBMP and Karnataka Forest Department—Restoring lakes through RWH

Bangalore has been gifted with large number of lakes and tanks which acted as the system of flood control as well as water supply. Over time, numbers of lakes have declined. In the year 1985, the state government constituted an expert committee headed by Sri N. Lakshman Rau to examine all the aspects of the preservation and restoration of the existing tanks in Bangalore. The main objective of BDA is the rejuvenation of the dying lakes coming under its jurisdiction and protection of the lakes from getting contaminated in order to recharge the depleting ground water and improve the atmosphere of the surroundings and conditions of the local sanitary system with the help of community participation.[1] In order to restore lakes, the state government established the Lake Development Authority to formulate policies and implementation of projects for the purpose of development of lakes. The LDA has given the responsibility of 11 lakes to BDA for the rejuvenation at a cost of Rs. 104 crores (BDA Documents 2011).

5.4.1 Role of BBMP in the Revival of Lakes

183 live lakes have been identified by BBMP and has taken up the various tasks viz. surveying, fencing and development of 132 lakes in its limits. Desilting, waste water diversion, formation of bunds pathways, improvements of storm water inlet and outlet, construction of watchmen shed, toilets, sewage treatment plant or wetland bund for treating rainwater mixed with sewage are other specific features included into their developmental works. So far, fencing of 50 lakes is complete while 63 lakes are in the process of being fenced. Encroachment is another serious issue and work in this direction is under progress and is taken up by BBMP with the assistance of the task force. There are complex issues as in many places encroachment is seen by other departments like for instance, the slums/ashraya houses have come up to an extent of 40 acres 12 guntas in 6 lakes, it becomes

[1] BDA has handed over the preparation of Detailed Project Report (DPR) to the expert agencies. The main objective is to develop the lakes for both recreation and education. The agencies studied the history of each lake in detail, the reason for deterioration of lakes, extent of encroachment, the flora and faunal situation and the necessary steps to be taken to restore the lake to its previous condition. There after BDA constituted the Lake Development Advisory Committee headed by the famous environmentalist Dr. A. N. Yellappa Reddy to study the details of DPR's and to suggest improvements.

necessary to consult and take necessary measures by the concerned department for rehabilitation. (Progress report w.r.t WP No.817/2008 and others). Totally there are 189 lakes in the BBMP area.

5.4.2 Role of Lake Development Authority (LDA)

The Lake Development Authority is an autonomous regulatory, planning and policy body that aims to protect, conserve, reclaim, restore, regenerate and work towards Integrated Development of Lakes, both natural and man-made in the State. The LDA also intends to coordinate with other organizations to achieve its aim. The LDA is also responsible for preparing database about lakes using satellite imageries, topo sheets from the Survey of India, and ground verification. The LDA would also focus on monitoring of lakes besides taking up actual implementation of various State and Centrally sponsored schemes for lake development. An expert committee formed with the leadership of Shri. N.Lakshman Rau on lake restoration and protection suggested remedies for the same. Public filed Public Interest Litigation in the High Court as writ petitions based on which the High Court ordered towards taking immediate steps for implementing the recommendations of the expert committee and the Government is acting on the order and has initiated restoration of water bodies in the State.

5.4.3 Role of Karnataka Forest Department (KFD)

KFD also works on rejuvenation of lakes and had taken up the survey works of 5 lakes for the current year and is completed for the year 2011–2012.[2] They also carry out other related works like desilting, deepening of tank bed, providing feeder channel to allow storm water to store into tank, sewage water diversion, total station survey and demarcation, fencing etc.

5.4.4 Incentives by the Government

- There is a proposal to introduce 2 % property tax rebate for 5 years for households with the installation of RWH.
- BWSSB has coordinated with Banks to provide loans to install RWH. The loan amount provided will be 75 % of the estimated cost and with a provision of repayment in 60 installments.

---

2 Madivala lake, Puttenahalli lake, J. B. Kaval lake, Hennur lake, Mylasandra lake.

6 Results

Two sets of questionnaire were prepared specifically for the survey, for collecting information from (1) households with RWH structures and (2) households without RWH structures.

6.1 Households with Rain Water Harvesting Structures

One hundred and twenty households with RWH structures have been surveyed. The site dimension of these households works out to 40 × 60 and above. The built area varied from 1,0000–35,000 sq ft.

Nearly 99 % of households surveyed have BWSSB connection with more than 93 % of the families using it for all purposes. Only 7 % of the households owning bore wells use bore well water also. Residents of this area do not experience water shortage even though such situations do occur rarely, mostly during the summer, forcing people to postpone some of the household chores for a day or two. Dependency on Tankers is found insignificant; only two families have informed that they get water from a tanker during such emergencies.

Respondents who have installed RWH structures (79 %) have done so mainly because of the force exerted by the BWSSB (Table 2) rather than on their own interest. As opined by the respondents, they were issued notices and were compelled to do so by the BWSSB officials; in fact, they felt helpless that water connection would be suspended if they did not oblige. This has resulted in the installation of RWH structures, just to avoid water supply suspension. They feel that the RWH, if made mandatory during the time of construction and would be less cumbersome and not at a later stage. Maximum numbers of people have adopted underground recharge method. Moreover, water scarcity was not an issue in this area and only 5 % of the households encountered scarcity during summer occasionally.

Out of 120 households with RWH structures, 86.6 % have adopted groundwater recharging method, while 19.16 % roof top harvesting method. The remaining 20 % of the households are found to have directed the roof top rain water directly either to bore well or open well without filtering or treating water. This approach has mainly been adopted because of the fact that wells dried up or they are not in use. Residents feel that water collected could possibly be used for washing or

Table 2 Reasons for installing RWH

Reasons	Number	Percent
Compulsion from Govt/BWSSB	95	79.2
Self interest	25	20.8
Total	120	100.0

Source HH Survey Data

Table 3 Method of RWH adopted across households

Type of RWH Installed	Number	Percent
Roof top	23	19.16
Underground recharge	104	86.6
Directly to bore well	4	4.2
Directly to open well	20	17.5

Source HH Survey Data
Note Figures do not add up to total since in few houses both roof top and underground recharge methods are adopted

gardening. There are technical specifications that need to be adopted for roof top rain water harvesting and reusing rainwater, which were not to most of the limits. Majorities of the people are found unwilling to take up roof top RWH as it is more expensive, and also for the fact that one has to fix and maintain filters; besides, most of them face the space problem. Owing to these problems, many of them do not seem very keen on using harvested rain water, rather for them; ground water recharging seems a more convenient option, practically Table 3.

Deviations in terms of design are found common among the households who have adopted RWH technique. Scientists have suggested specific designs where in an infiltration gallery be designed to recharge a bore well irrespective of its working condition, i.e., live or failed. Mere filtering of rainwater for letting into the bore well directly would cause damage not only to their bore wells, but also the surrounding bore wells besides polluting ground water. In practice, many households have not followed this design due to the lack of awareness of the harmful effects. Another deviation observed relates to the construction of recharge pits in close proximity to the bore wells leading to the pollution of ground water.

6.1.1 Usage of Harvested Rainwater

Among the families who have adopted roof top rain water harvesting, two families were found using water for cooking and drinking. They direct rooftop water directly to their overhead tanks and use that water for all purposes. However, they have installed Aquaguard's in their kitchens for filtering water. They were convinced of using harvested rainwater as they are skeptical about using BWSSB water which could also be contaminated because of sewage leakages. The remaining households use water for cleaning toilets, gardening and bathing (Table 4). It is interesting here to note that only 9 families opine that the quality of harvested rainwater is good. The rest of the respondents are not sure about the quality of harvested rain water because it gets mixed with water received from BWSSB or their own bore well water.

Table 4 Usage of harvested rainwater

Purpose	No	Percent
Only for ground water recharge	52	43.3
Only for cleaning	22	18.3
Only for gardening	18	15
Only for bathing	5	4.2
For cooking and drinking	2	1.6
All purposes	6	5
No response	15	12.5
Total	120	100

Source HH Survey Data

6.1.2 Problems Encountered After the Installation of RWH Structures

Only one household adopting roof top harvesting has encountered problems with respect to the maintenance of filter, while others could not specify any problems as it is was too early to encounter some problems. Three respondents, opined that there were practical problems in maintenance of roof tops Table 5.

Table 5 Problems encountered following the installation of RWH structures

	Disadvantages of RWH	
If yes	Yes	Percent
Maintenance of filter is difficult	1	0.83
RWH is not recharging our bore well/open well	1	0.83
Others specify (physical strain and no use)	3	2.5
Total	5	4.16

Source HH Survey Data

6.1.3 Source of Knowledge on RWH

Table 6 clearly indicates that BWSSB and BBMP have played a major role in creating awareness with respect to RWH. People opine that pamphlets are

Table 6 Sources of information on RWH[a]

Source of knowledge	Number	Percent	Knowledge gained through awareness programmes	
BWSSB	92	76.7	12	10.0
BBMP	31	25.8	0	0
KSCST	0	0	0	0
Theme park	0	0	0	0
NGOs	0	0	0	0
Newspaper/TV/magazine/internet	36	30.0	0	0
Others	3	0	0	0

Source HH Survey Data

[a] *Note* Figures do not total up to 100 due to multiple responses

distributed and line men or meter readers inform them to install RWH structures. Next in the order comes media like news papers, magazines and TV play a major role. About 12 households (families—one member each) mention that they have attended awareness programmes conducted by BWSSB.

6.1.4 Advantages of RWH

As shown in Table 7, a majority of people (84 %) opine that RWH increases ground water level and thus helps overcome water scarcity. Only 13 % of them say it is eco-friendly, 5 % feel it helps in reducing water bills, 4 % reduction in electricity bills, while nearly 3 % feel it checks soil erosion and 3 % express that water will be stored for future use. All this indicates that people are by and large aware of the advantages associated with rainwater harvesting and also that they are positive about RWH, as a technique. A majority of the respondents (94 %) report that they would recommend RWH to others, an encouraging sign of RWH awareness and its popularity.

Table 7 Advantages of RWH

Advantages of RWH	No	Percent
Increase in ground water level	101	84.2
No water scarcity	42	35.0
Reduction in water bills	6	5.0
Reduction in electricity bills	5	4.2
Eco-friendly	16	13.3
Checks soil erosion	3	2.5
Stored water for future use	4	3.3

Source HH Survey Data

6.1.5 Expenditure Incurred on Installing RWH Structures

Table 8 shows that none of them have taken bank loans for the installation of RWH structures; however, a substantial variation is observed in the expenditure incurred on the installation of RWH structures; which is understandable given the building structure and the type of RWH that the households have adopted. However, people feel that guidance and authentication of these figures in terms of costs by the BWSSB would have been more useful. A majority of respondents (46 %) are found to have spent less than Rs. 15,000, while 23 % of them are found to have incurred expenditure between Rs. 16,000 and Rs. 25,000, and only 3 % of them have incurred expenditure of Rs. 26,000 and above. However, 28 % of the respondents are found unable to specify the costs incurred by the heads of their families.

Table 8 Expenditure incurred towards installation of RWH structures

Total expenditure	Number	Percent
Rs <15,000	55	45.8
Rs 16,000 = 25,000	27	22.5
Rs >26,000	4	3.3
Don't Know	34	28.3

Source HH Survey Data

6.1.6 Problems Encountered with RWH Installation

As can be seen from Table 9, 98 % of the households say they did not encounter any problems during the installation of RWH structures, is a positive sign. Only two families have reported problems.

Table 9 Problems encountered with RWH installation

Problems encountered	Number	Percent
Yes	2	1.7
No	118	98.3
Total	120	100.0

Source HH Survey Data

6.2 Households Without Rain Water Harvesting Installations

Households who have not adopted RWH have been identified as a control group, the aim being to understand the reasons and perceptions for not adopting RWH. These households (105) were chosen from the same area where interviews were conducted for households with RWH installations. Similar to the households with RWH structures households which were built on the site dimension of 40/60 and above were selected for the survey. Here again, the built area varied from 15,000–35,000 sq ft. A separate questionnaire was prepared for collecting information from these households.

BWSSB was the main source of water supply for majority (89 %) of the these families, and its water is used for cooking, drinking and other secondary purposes; 45 % depended on both BWSSB and Bore well supply and none purchased water from any other source like water tankers or packaged drinking water. None of the households faced water shortage, as reported by a majority of the households (104 families).

6.2.1 Awareness About RWH

It is interesting to know that 94 % of them are aware of RWH. As can be seen from Table 10, the major sources of knowledge regarding RWH are BWSSB and Media (57.6 %), while rest of the respondents mention news paper/TV and other sources like internet, magazines and the like indicating the significance of BWSSB and Media role in this respect. Participation in Awareness programmes conducted by BWSSB was minimal (6 %).

Table 10 Awareness about RWH

Aware about RWH	Number	Percent
Yes	99	94.3
No	6	5.7
	105	100.0
Awareness source		
BWSSB and media	57	57.6
News papers/TV/other media	42	42.4
Total	99	100

Source HH Survey

7 Reasons for not Installing RWH Structures

Nearly 18 % of the respondents have stated four major reasons for not installing RWH structures such as, (1) not being aware of it (2) nobody insisted on it (3) financial problems and (4) lack of space for carrying it out. Among the people who

Table 11 Reasons for not installing RWH structures

	Number	Percent
Not aware of it	4	3.8
Nobody insisted	5	4.8
Financial problem	5	4.8
Lack of space	5	4.8
Not Necessary reasons	13	12.4
•No water scarcity		
•Excess water in the bore well		
•Undergone RWH indirectly		
•Waste of money		
Other reasons specified	56	53.3
•Lack of education		
•Hectic schedule		
•Not workable throughout the year		
•Health problem		
Not willing to respond	17	16.2
Total	105	100.0

Source HH Survey Data

are not aware of RWH, respondents around 12 % feel it is of no use and is a waste of money. More than half of the respondents (53.3 %) mention that they have become old and that they are not keeping good health and also there is no other responsible person at home to carry out this task; the fact is that most of these households harbour retired people and their children are staying elsewhere. About 16 % of the families are found reluctant to express their views regarding the non-installation of RWH structures Table 11.

7.1 Installation of RWH Structures in Future

Families were also asked about their intentions to install RWH structures in future. Most of the respondents (44.4 %) are found to be not interested in installing. These residents did not experience water scarcity and hence did not feel the need for it while others had no space. Rest of them opposed RWH as it is thrust upon them. Few experienced overflow of bore well water hence, recharging was inappropriate. About 15 % of them are yet to explore the possibilities and hence are not in a position to specify the methods they can adopt. Among those who are found sure to install RWH structures in future, 8 % prefer roof top harvesting, while 25 % underground recharge Table 12.

Table 12 Perceptions on Future Plans for installation of RWH structures

	Number	Percent
Interested	29	27.6
Not Interested	21	20.0
Yet to explore	15	12.2
Roof top RWH	8	7.6
Recharge ground water	25	23.8
Not willing to respond	7	6.6
Total	105	100

Source HH Survey Data

8 Conclusions

RWH is an essential and welcome initiative taken up by the BWSSB in particular besides the various institutions involved in RWH. General awareness about RWH is good. However, it is important that the process of implementation of RWH is strengthened at all levels. It is also important that the initiatives taken in respect of RWH across various institutions are coordinated to ensure expected results.

However, among the households that have not installed RWH, it is important to understand the problems and work towards addressing them.

Integration of Institutional Initiatives

As discussed earlier, there are several organizations (BWSSB, BBMP, BDA, KFD, LDA) that take up varied initiatives with respect to rain water harvesting. The overall goal is the same though the focus areas differ. It is important that these institutions are integrated for having a common vision towards obtaining effective results.

Promoting RWH in Water Scarce Areas—RWH should be popularized in water scarce areas and later be promoted in relatively less scarce areas to make RWH implementation more effective. Few experienced overflow of bore well water hence, recharging was inappropriate. Aquifer mapping is another important requirement to assess the ground water status and initiatives taken up accordingly. As can be seen in areas where water scarcity is not an issue, the citizens considered RWH as a burden which is unnecessary.

Ground Water Mapping to be Made Compulsory Before the Implementation—*BWSSB* with the coordination of CGWB should come up with the task of studying the depth of ground water level before sending the NOTICE and also before the construction of recharge pits in low lying areas to avoid the contamination of sewage and flooding. Thus the ground water mapping and RWH would be holistic to conserve water appropriately.

Involvement of RWH Experts and Scientists is Necessary

Deviation in terms of scientific methods adopted in the construction of recharge pits are found in few places. So it is necessary for BWSSB and BBMP to take the initiative to construct the RWH pits as per the suggestions given by the RWH experts. This enhances the water flow to the pits and results in the conservation of water scientifically.

Awareness Creation Initiatives

RWH- a 'Compulsion' must be Transformed as RWH—a 'Necessity'

Providing a context in which RWH becomes important would play a crucial role in terms of its implementation; and further it is also desirable that BWSSB urge the citizens to understand the need for adopting RWH by way of making it a necessity rather than compulsion. A communication expert may be hired to ensure effective communication.

Need for More Popularization Through Books and Pamphlets

There is a gap in distribution of the published material. The BWSSB and BBMP should take charge of distributing booklets in a more systematic manner. There are a few individuals eager to work as volunteers for promoting RWH whose services can be effectively utilized.

Promotion of Awareness Creation Programs

- The programmes related to RWH must be aired on T.V., Radio and published in newspapers repeatedly. The benefits of rainwater should be emphasized with examples like its role in growth of healthier plants, groundwater recharge, and purified rainwater as a better alternative than bore well water, reduction in water bills and electricity bills and negatives if not implemented like urban flooding and traffic congestion.
- Increasing the number of awareness camps conducted by BWSSB besides intimating the residents of a particular colony, in advance.
- Involvement of resource persons is necessary for promoting RWH.
- Other popular and effective modes of communication like street plays, flash mobs could be tried for promoting RWH concept.
- Theme park is one of the best resource centers for promoting RWH. However, it can be made more popular through advertisements. Special trips for the various institutions/residents to the Theme Park could be organized.

On Technical Aspects and Costs

People are not aware of the technical details associated with RWH and also the related costs of installation of RWH structures. For instance, lack of awareness among the people as to how harvested rainwater could be connected to bore wells. Access to proper information will aid in avoidance of deviation from the design and safeguard ground water quality. Another important aspect is making a provision for providing help desk on cost aspects and streamline transparency and accountability. This would help citizens take informed decisions. This aspect assumes significance because variations in prices quoted by plumbers could make residents skeptical towards the adopting RWH.

Initiatives Through NGOs/CBOs and Other Institutions

- The motto "Catch water wherever it falls" must be made practical. This work could be shared by the NGO's, RWA, social- service clubs, Institutions etc., for harvesting rainwater in certain areas through a network of separate pipes and tanks, so that it could be supplied to houses whenever necessary. This could act as a model for others.
- All the Schools, Colleges, (Government/Private) must install RWH structures by way of promoting RWH besides acting as models of change. RWH as a concept must be included in the school syllabus during early years in order to educate children.
- A special task force should be initiated by the Forest Department for the maintenance of vegetation where ever necessary, so as to increase ground water level.

- The Central Ground Water Board can come up with a programme for demonstrating how underground water gets recharged following RWH adoption in urban areas.
- Awards could be given to the specific wards where RWH is promoted and also for successful implementation and effective management.

Need for Being Sensitive to Consumer Preferences and Providing Better Support Services

Help Desk—The complete process of implementing RWH should be provided at one point help desk where the citizens are not left to themselves to decide on various stages of implementation. The help desk should be able to take complete responsibility of ensuring access to information on technical guidance, costs and personnel to be contacted. Special assistance may be provided to senior citizens, disabled, single women during implementation for ensuring convenience, security and quality. It is important that there is a further strengthening of the process in terms of services provided so as to make it more user-friendly. A blanket insistence of adoption of RWH without understanding the practical constraints involved could lead to process defaults.

Package Services—It has been observed that many senior citizens living in ancestral houses are financially weak (pensioners) and physically dependent. It is important to be sensitive to the needs of such residents by way of providing a package of RWH services through the BWSSB or an authentic source and charging them in installments. The package services could be extended to people who are willing to pay an extra charge as a few of them have complained about the lack of time to install RWH structures. People have no time to purchase things needed for RWH adoption. BWSSB can introduce subsidized packages for the economically weaker sections. There are households with single women managing household expenditure being over burdened with loans. Incentives/subsidies should be made effective at the earliest for those who install RWH structures as in the case of solar water heater installation.

Access to Expert Opinion**—**Group discussions should organized with people for understanding scientific facts and clarifications. Arrangements must be made by the Departments concerned for the common people for contacting Geologists, Technical experts, Engineers, Scientists etc., in order to clear their doubts, such as—(1) Ground water recharge may cause damage to the foundation (2) Earthquakes may occur (3) Acid rains may happen and the harvested rain water may be harmful (4) Animal and bird excreta mixed with rain water is toxic (5) Uncertainty about lifespan of RWH structures.

Annexure 1

Details of the rain water harvesting

Div	Sub Div	*Total* up to Mar-2010	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	As on 26/4/11	*Total*
Central	C-1	28	2	0	20	20	6	15	7	3	3	0	6	8	9	127
	C-2	115	9	9	39	21	10	15	4	8	74	9	8	10	9	340
	C-3	72	9	6	26	8	7	42	10	5	16	15	11	9	11	247
	Total	215	20	15	85	49	23	72	21	16	93	24	25	27	29	714
North	N-1	502	28	57	124	245	42	38	24	48	84	118	12	17	14	1353
	N-2	151	3	4	6	12	1	2	34	3	44	0	2	11	6	279
	N-3	1241	35	169	187	134	45	93	32	60	61	51	56	42	38	2244
	N-4	162	40	74	91	174	108	161	39	21	113	60	29	113	56	1241
	Total	2056	106	304	408	565	196	294	129	132	302	229	99	183	114	5117
West	W-1	716	41	39	61	106	53	59	32	42	37	22	19	27	15	1269
	W-2	303	9	8	37	9	28	7	197	31	132	19	8	13	1	802
	W-3	65	3	4	2	3	12	12	4	18	2	8	5	7	4	149
	W-4	374	2	100	12	103	90	1	11	37	6	10	46	91	3	886
	W-5	535	46	56	343	205	92	244	63	38	29	57	60	48	16	1832
	W-6	374	2	10	65	43	27	12	40	11	13	27	47	44	0	715
	Total	2367	103	217	520	469	302	335	347	177	219	143	185	230	39	5653
East	E-1	193	34	18	26	13	16	36	47	32	53	48	50	52	15	633
	E-2	393	33	131	335	5	57	8	3	19	38	0	0	34	2	1058
	E-3	299	6	12	9	14	2	11	9	18	15	14	13	10	3	435
	E-4	95	9	8	42	174	18	24	11	5	3	9	7	82	0	487
	E-5	113	1	1	17	1	4	1	7	2	2	4	2	1	2	158
	Total	1093	83	170	429	207	97	80	77	76	111	75	72	179	22	2771

(continued)

(continued)

Details of the rain water harvesting																
South	S-1	1318	112	195	44	120	140	160	78	51	80	70	10	32	5	2415
	S-2	1131	83	127	82	62	48	99	59	70	259	54	35	49	55	2213
	S-3	226	21	42	167	160	47	28	37	23	38	23	39	21	15	887
	S-4	284	21	85	63	87	44	28	17	23	24	21	14	17	12	740
	S-5	646	21	172	69	29	33	67	19	24	47	38	23	40	40	1268
	Total	3605	258	621	425	458	312	382	210	191	448	206	121	159	127	7523
South East	SE-1	484	29	67	87	149	61	41	33	34	25	19	18	28	2	1077
	SE-2	317	19	45	193	148	101	69	47	52	23	18	34	18	21	1105
	SE-3	504	36	179	101	104	85	69	54	40	95	41	34	42	26	1410
	Total	1305	84	291	381	401	247	179	134	126	143	78	86	88	49	3592
Grand total		10641	654	1618	2248	2149	1177	1342	918	718	1316	755	588	866	380	25370

Source BWSSB

References

Agarwal A, Narain S (1997) Dying Wisdom: Rise, fall, and potential of India's traditional water harvesting systems centre for science and environment, New Delhi, India

BBMP, Brochure BDA Documents (2011) BDA's initiative to conserve a great heritage DH News Service, 4 October 2010

Karnataka State Council for Science and Technology: rain water harvesting (2005) http://kscst.iisc.ernet.in/rwh_files/rwh_initiate.html. Accessed on 4 July 2011

Kumar AR (2005) Amruthavarshini—a guide for rainwater harvesting. Karnataka State Council for Science and Technology

Model Rainwater Harvesting Projects of CSE (2013) http://www.rainwaterharvesting.org/Uraban/Mode-Projects.html Accessed on 15 July 2011 Popular Mechanics

Preservation of lake in Bangalore city rainwater harvesting KSCST (2011) http://www.slideshare.net/mynk/rain-water-harvesting-kscst Accessed on 19 July 2011

Mining-Induced Desiccation of Water Bodies and Consequent Impact on Traditional Economic Livelihood: An Analytical Framework

Lekha Mukhopadhyay and Bhaskar Ghosh

1 Introduction

Mining induced desiccation of water sources has made a significant negative impact on economic livelihood of indigenous communities all over the world (Hilson 2002; Shiva 1991). Liberalization in mine licensing policy due to globalization and increasing demand from industrial economies bring about rampant mining activities (MA) which, in some cases, are severe threats to the survival of traditional economic livelihood. Lack of irrigation water, coupled with pollution from manganese mining, sharply reduced the rice yields of 60 %of the farmers in and around Gaodong, China (Jigang and Chuhua 2008). At Nahi-Kala and Thano villages in Doon Valley, India, limestone mining caused siltation and obstruction to some first order stream flows like Bhitarli, Kiarkuli, Arnigad and Baldi, in addition to huge soil erosion and landslides (Kumar 2000); which led to a water crisis and consequent fall in agricultural productivity. In Meghalaya, a north-eastern state of India, huge quantity of mine spoils or overburden (consolidated and unconsolidated materials overlying the coal seam) in the form of gravels, rocks, sand, soil, etc., have been responsible for depletion of ground water resources for a period of 5–6 years up to a depth of ranging from 500 m to 1 km (Sahu and Goel 2004).

Resolving the conflict of interest between a modern growing industrial economy and long-term sustainable traditional economy is a challenge to the government in many developing countries today (Sahu 2008). Mining activity cannot fully compensate the loss to traditional economic livelihood (Singh 2007). People from

L. Mukhopadhyay (✉)
Department of Economics, Jogamaya Devi College, 92 S.P Mukherjee Road, Kolkata 700026, India
e-mail: lekha.mukhopadhyay@gmail.com

B. Ghosh
Department of Geology, Jogamaya Devi College, 92 S.P Mukherjee Road, Kolkata 700026, India
e-mail: bghosh2006@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_20, © Springer-Verlag Berlin Heidelberg 2013

traditional communities dependent on the mine lose their livelihood after mining stops, and they cannot go back to their traditional livelihood as mining activity changes the local biogeochemical environment. Hence, there arises a question of trade-off: how much should a society sacrifice of the traditional production, which have been sustaining for hundreds of years, to gain benefit from mining operations in the economy? Can one think of development inclusive of the sustainability of traditional economic livelihood?

With this ground reality at the backdrop, this chapter contains some theoretical exercises in the arena of natural resource management and environmental planning. Traditional economic activities largely depend on the surface water bodies (streams, lakes, ponds, etc.); direct use of groundwater is rare, with a few exceptions of natural or dug wells. Both the quality and quantity of water of the surface water bodies are affected by mining activities. The impact of mining activities on water quality and concomitant effects on traditional economic livelihood are described in Mukhopadhyay and Ghosh (2010). The present work describes the change in the quantity of water in a particular surface water body (PSWB) caused by anthropogenic disturbances (mining induced) to exhibit how it may change the economically determined social extraction path of exhaustible resource (mine resources) under different sustainability criteria.

Quantity of water in a PSWB is determined by various factors like annual precipitation, evaporation, capacity of soil to absorb moisture, permeability of layers in the vadose zone that facilitate downward and lateral flow of infiltrated water, surface runoffs, depth of water table determining the flow of water to or from groundwater reservoir (aquifers) etc. (Fetter 1988; Nagabhushaniah 2001). Any natural and anthropogenic change in one or more of these factors may cause disruption in the inflow and outflow of water in the surface water bodies (Younger 2004). This, in turn, affects the availability of water for traditional economic livelihood. Limnological effects of anthropogenic desiccation and their consequent impact on aquatic species, and possible abatement measures have been studied with various physical hydrological, hydro geochemical and environmental science perspectives.

Long term control of exhaustible resources, in general, (Dasgupta 2001; Dasgupta and Heal 1979; Gray 1914; Hotelling 1931) and of mine resource, in particular, has been separately addressed in the context of different market structures, discoveries of new reserves, availability of substitutes, and different kinds of uncertainty (Dixit and Pindyck 1994; Stiglitz 1974). The sustainable path, i.e., path of intergenerational and intertemporal equity in consumption has also been devised for an economy with exhaustible resources (Farzin 2006; Martinet 2008; Martinet and Doyen 2007). But the formulation of long term control of exhaustible resources (which may cause anthropogenic desiccation of PSWB) by internalizing the externally induced cost of desiccation is yet to be done.

This chapter attempts to incorporate the hydrological explanation of desiccation of PSWB in economic methodologies in deriving social extraction path of mine resource, thereby, narrow down the existing knowledge gaps mentioned above. These theoretical exercises are pre-requisites for any future empirical research and policy formulations in this context.

2 Mining Induced Changes in Quantity of Water in Surface Water Bodies

When meteoric water (rain or snow) falls on the land surface, some amount of it is intercepted by the vegetation which may later be evaporated. The remaining part of precipitation reaches the land surface and enters the soil by infiltration. When the precipitation rate exceeds the infiltration capacity of the soil, the excess water flows across the land surface. This is known as surface runoff or Horton's overland flow. A part of infiltrated water is absorbed and retained in the soil as soil moisture, and the remaining part moves downward through the vadose zone. If the vadose zone is uniformly permeable, most of the infiltrated water moves vertically downward to reach the saturated zone, leading to groundwater recharge and raising of the water table. If there are less permeable layers, at least locally, in the vadose zone, then a part of infiltrated water moves laterally. If that lateral flow emerges on the surface at the foot of a slope as a seepage or spring and, thus, adding to surface runoff, it is called throughflow. If, alternatively, it enters directly into a surface water body (SWB), it is called interflow.

A PSWB gains water by (1) direct precipitation falling into it (P), (2) the part of surface runoff reaching it (S), (3) interflow coming into it (I), (4) the part of throughflow reaching it (f) and (5) base flow coming into it from a groundwater reservoir connected to it. On the other hand, it loses water by (1) direct evaporation from its surface (E) and (2) flow of water from it to the groundwater reservoir, leading to groundwater recharge (r). b and r depend on the water level of PSWB relative to the water table. When the surrounding water table is higher than the water level of the connected PSWB, water flows into the latter from the aquifer as base flow. In that case, $b > 0$, $r = 0$ and the PSWB is *effluent*. Conversely, when the water level of PSWB is higher than the surrounding water table, water flows from PSWB to the aquifer and recharge the groundwater. In that case $b = 0$ $r > 0$ and the PSWB is *influent*.

Taking all these factors into account, the annual change in the quantity of water in the tth year in a PSWB (η_t) can be expressed in terms of the water balance equation at tth year:

$$\eta_t = P_t - E_t + S_t + f_t + I_t + b_t - r_t \tag{1}$$

2.1 *Mining Induced Impact on* S_t, f_t, I_t, b_t *and* r_t

Mining activities (MA) can bring about significant changes in S_t, f_t, I_t, b_t and r_t. As MA starts, mine wastes are produced along with the desired material, and the quantity of wastes (W) increases with increase in the production of the desired material (Y). Waste materials absorb and retain a considerable amount of precipitated water (μ) causing less amount of water flowing overland, thus decreasing

S_t. If $W = k_{WY}Y$, with k_{WY} being the strip ratio, i.e., quantity of waste material produced per unit production of Y, the marginal impact of Y on S through μ can be derived by:

$$S = S(\mu(W)) = S(\mu(k_{WY}Y)) = k_{WY}S(\mu(Y))$$

$$\frac{\partial S}{\partial \mu}\frac{\partial \mu}{\partial Y} = k_{WY}S_Y < 0 \quad \text{since } \frac{\partial S}{\partial \mu} < 0 \tag{2}$$

Water absorbed and retained by waste materials also decreases infiltration, thus, very little or no infiltration can take place in the areas covered by waste dump. Moreover, fine waste materials blown from the waste dump settle in the soil pore spaces, decreasing infiltration in the surrounding regions as well. Consequently, throughflow and interflow decrease in the area, and the amount of water reaching the PSWB through them, i.e. f and I also decrease. Larger is the area covered by waste dump (A_W), less will be the total amount of infiltration and, consequently, less will be f and I.

Furthermore, throughflow or interflow sometimes intersects the excavated area of the mine and discharges water into the mine. That water is pumped out from the mine, and most of it, instead of reaching a SWB, is wasted. Larger is the volume of excavated area (V_E), greater amount of water will be wasted in this way and less will be f and I. f and I, therefore, can be considered as:

$$f = f(A_w + V_E), \text{ and } I = I(A_w + V_E) \tag{3}$$

If we assume the waste dump to be conical with slope θ, and the average density of the waste material being ρ_W

$$A_W = \left(\frac{3\sqrt{\pi}W}{\tan\theta\rho_W}\right)^{\frac{2}{3}} = \left(\frac{3\sqrt{\pi}k_{WY}}{\tan\theta\rho_W}\right)^{\frac{2}{3}} Y^{\frac{2}{3}} \tag{4}$$

(See Appendix A2.1) If we further assume that the volume of excavated area is cubic and the respective average densities of the desired and waste material being ρ_Y and ρ_W:

$$V_E = \left(\frac{Y}{\rho_Y} + \frac{W}{\rho_W}\right) = \left(\frac{1}{\rho_Y} + \frac{k_{WY}}{\rho_W}\right)Y \tag{5}$$

(See Appendix A2.2) Then,

$$\begin{aligned} f &= f\left[\left(\frac{3\sqrt{\pi}k_{WY}}{\tan\theta\rho_W}\right)^{\frac{2}{3}} Y^{2/3} + \left(\frac{1}{\rho_Y} + \frac{k_{WY}}{\rho_W}\right)Y\right] \\ &= f\left(k_1.Y^{2/3} + k_2.Y\right) \end{aligned} \tag{6}$$

where, $k_1 = \left(\frac{3\sqrt{\pi}k_{WY}}{\tan\theta\rho_W}\right)^{\frac{2}{3}}$ and $k_2 = \left(\frac{1}{\rho_Y} + \frac{k_{WY}}{\rho_W}\right)$ Similarly,

$$I = I\left[\left(\frac{3\sqrt{\pi}k_{WY}}{\tan\theta\rho_W}\right)^{\frac{2}{3}}Y^{2/3} + \left(\frac{1}{\rho_Y} + \frac{k_{WY}}{\rho_W}\right)Y\right]$$
$$= I\left(k_1.Y^{2/3} + k_2.Y\right) \quad (7)$$

In the above expressions (6) and (7) the common factors are k_1 and k_2 which contains a set of parameters related to MA. f as a function states about the pathway: how the mining induced source factors A_W and V_E (determined by Y, given the geological parameters k_1 and k_2) changes the water level of a PSWB through the mining induced change in throughflow. This pathway depends upon many factors like soil permeability, dip of the less permeable layer/zone on which lateral flow takes place, surface slope where water seepage occurs, loss of water on the way from zone of emergence to SWB (by evaporation, absorption etc.) and so on. Similarly, I as a function states about the pathway: how the mining induced source factors A_W, V_E (determined by Y, given the geological parameters k_1 and k_2) changes the water level of a PSWB through the mining induced change in interflow. Here also, the pathway depends upon soil permeability, dip of the less permeable layer/zone on which lateral flow takes place, distance of the SWB and so on. If we assume $Z = k_1.Y^{2/3} + k_2.Y$, then $f = f(Z(Y))$ and $I = I(Z(Y))$. Thus $f_Y = \frac{\partial f}{\partial Z}\cdot\frac{\partial Z}{\partial Y} = \left(\frac{2}{3}k_1.Y^{-1/3} + k_2\right).f_Z$. Similarly, $I_Y = \frac{\partial I}{\partial Z}\cdot\frac{\partial Z}{\partial Y} = \left(\frac{2}{3}k_1.Y^{-1/3} + k_2\right).I_Z$. Thus adding the marginal impact of Y on throughflow and interflow we get:

$$f_Y + I_Y = \left(\frac{2}{3}k_1.Y^{-1/3} + k_2\right).f_Z + \left(\frac{2}{3}k_1.Y^{-1/3} + k_2\right).I_Z$$
$$= \left(\frac{2}{3}k_1.Y^{-1/3} + k_2\right).(f_Z + I_Z) \quad (8)$$

Groundwater in many cases seeps into the excavation site. That water is pumped out and mostly wasted by evaporation and absorption in the soil. Also, a considerable quantity of groundwater is withdrawn by the mining community for MA as well as for domestic purposes. In both the cases, the mining-induced loss of groundwater lowers the water table and, consequently, b decreases (for effluent SWB) or r increases (for influent SWB), attributing to the desiccation of PSWB. Since mining induced change in $(b-r)$, i.e. net change of water in PSWB from groundwater-surface water interaction, occurs by $Y + W = (1 + k_{WY})Y$; at the marginal level of MA, mining induced change is to be considered as: $(1 + k_{WY})(b_y - r_Y)$

Now let the change in water quantity be expressed as:

$$\dot{\eta} = \eta - \eta_Y Y \quad (9)$$

i.e., change in quantity of water in a PSWB over time is equal to the natural quantity of water (determined by P_t, E_t, S_t, f_t, I_t b_t and r_t) minus the quantity of water decreased by mining induced desiccation. From the above discussion it follows that, for each marginal unit of mining production Y, the change in water quantity in PSWB is given by:

$$\eta_Y = k_{WY}S_Y + (f_Y + I_Y) + (1 + k_{WY})\left(b_Y - r_Y\right) \quad (10)$$

3 Social Optimal Mining Plan Under the Circumstance of MID: A Model

There exists a hypothetical community of individuals who share a land with water and mineral resources. A subset of the communities comprises aboriginal people dependent alone on traditional economic activity namely hunting/fishing a species from surface water bodies (a common pool resource). Their economic livelihood and water consumption are assumed to be dependent on availability of water in SWB. The rest of the individuals are settled after launching of mining activities. Their primary interest lies in mining production from the exhaustible mineral resources of the area. Thus, there is a conflict of interest between the people dependent on mining production and those eking out their livelihood from traditional production. There is a 'social planner' whose role is to co-ordinate between the interests of private economic agents to maximize the social welfare.

3.1 Social Optimal Mining Plan (SOMP)

In our community model, we assume that change in the quantity of water in PSWB is mining induced. MA produces desired material Y along with some mine wastes $W = k_{WY}Y$. In Gray's (1914) framework, marginal cost of extraction of an individual mine $C_Y > 0$ and $C_{YY} > 0$. C_Y is assumed to be an increasing function of extraction flow, i.e., $Y(t) + W(t) = (1 + k_{WY})Y_t$ (which of course, is a little deviation from Gray (ibid) as W was not taken into account separately). Now, given the competitive price p (assuming that the miner is a price taker, which is quite plausible for a miner in developing country) and given the stock of mine resources $R(t)$, extraction of $Y(t)$ creates profit $(= pY(t) - (1 + k_{WY})C(Y(t); R(t))$ to the private miner but at the cost of decrease in traditional production Ω due to mining induced desiccation. The social planner's objective is to control $Y(t)$, i.e., the optimal rate of extraction from a given mine resource stock in such a way that would (1) maximize total discounted social welfare comprising the welfare of the miner and traditional producer, and (2) ensure a minimum socially acceptable level of $\Omega(t)$, possible by a minimum amount of water quantity say η_b where $\eta \geq \eta_b$.

3.2 Production Function of Traditional Community (Ω) *and Impact of MID on it*

Traditional production $\Omega(a;\eta)$ depends upon a, the labour employed, and η, the quantity of water, here treated as 'natural capital'. $\Omega(a;\eta)$ declines over time as mining induced desiccation occurs.

The relation between a and η is very important to determine the potential sustainability of Ω. We use the most popular form used in the literature in this context. It is the Cobb- Douglas production function presuming the substitutability of η by a up to a certain extent (say $\eta = \bar{\eta}$). Let,

$$\Omega(a(t);\ \eta(t)) = \eta^{\theta} a^{\beta};\ \text{where},\ \theta < \beta < 1;\ \eta \geq \bar{\eta} > 0 \tag{11}$$

$\Omega_a > 0,\ \Omega_\eta > 0;\ \Omega_{aa} < 0,\ \Omega_{\eta\eta} < 0$

As mining induced desiccation occurs for each unit, decrease in η, Ω decreases. We assume the possibility that as mining induced desiccation occurs, traditional production starts declining; the traditional community strives to maintain the same level of output by forced substitution (imperfect) of η by a i.e. deploying more a to compensate the loss attributed by decrease in η. This case is similar to the case with η as a 'weak essential' resource in the sense of Dasgupta and Heal (1979). η is needed in production but with an unbounded potential production up to a certain limit of $\eta \geq \bar{\eta}$. This concept will be used in the following sections.

3.3 Social Optimal Rate of Mine Resource Extraction as MID Occurs

The composite welfare of the society, that a social planner aims to maximize, is constituted by miner's utility i.e. $U_1(Y(t);p(t))$ plus the utility of traditional community i.e. their production $\Omega(a,\eta)$, weighted by σ, where $0 \leq \sigma \leq 1$. σ is a matter of choice of social planner, i.e., how much weight or importance he would give to the loss of traditional production due to MID is the matter of his decision. In dynamic optimal control theory frame work, social planner in her optimization problem has now one control variable Y_t with two state variables: (1) R_t the stock of mined resource and (2) η_t the state of volume of water available in a PSWB at time t. The trajectory path of η_t that evolves over time is determined by MID dynamics, i.e. $\dot{\eta} = \eta - \eta_Y Y$ as it is modelled in (Sect. 2.1). In addition to those, now the social planner has another constraint, i.e., not allowing η to decrease below η_b, the minimum volume of η that ensure sustainable level of production Ω_b. Her optimization problem therefore is:

$$\max_Y \int_0^T U(Y,\ \Omega,\ t)e^{-\delta t}dt = \max_Y \int_0^T \left[\bar{p}Y_t - (1 + k_{WY})C(Y_t,\ R_t) + \sigma a_t^{\beta}\eta_t^{\theta}\right]e^{-\delta t}dt, \tag{12}$$

subject to

$$\dot{R}_t = -(1 + k_{WY})Y_t;\ R_{t=0} = R_0,\ \text{and } R_t \geq 0\ \forall 0 < t \leq T;\ R_T \geq 0 \tag{13}$$

$$\dot{\eta} = \eta - \eta_Y Y \tag{14}$$

$$\eta \geq \eta_b > 0 \tag{15}$$

In the present context, (12) taking together (13) and (14) constitutes the Hamiltonian H, the objective function, which we need to maximize subject to the constraint (15). The augmented Hamiltonian in present value term therefore is:

$$\begin{aligned} \mathrm{H} &= \mathrm{H} + \varphi(\eta_b - \eta_t) \\ &= e^{-\delta t}U(Y, \Omega(); t, \sigma) - \lambda_R(1 + k_{WY_i})Y + \lambda_\eta(\eta - \eta_Y Y) + \varphi(\eta_b - \eta_t) \end{aligned} \tag{16}$$

Assuming that everything is continuously differentiable and those concavity assumptions hold, the first order conditions of this problem are:

$$\frac{\partial \mathrm{H}}{\partial Y} = 0 \Rightarrow \left[\bar{p} - (1 + k_{WY})C'_Y + \sigma\theta a^{\beta}\eta^{\theta-1}\eta_{Y}\right]e^{-\delta t} = \lambda_R(1 + k_{WY}) + \lambda_\eta \eta_Y \tag{17}$$

$$\frac{\partial \mathrm{H}}{\partial R} = -\dot{\lambda}_R :\ \dot{\lambda}_R = 0 \Rightarrow \lambda_R = \text{Constant} \tag{18}$$

$$\begin{aligned} \frac{\partial \mathrm{H}}{\partial \eta} = -\dot{\lambda}_\eta &\Rightarrow \sigma\theta a^{\beta}\eta^{\theta-1}e^{-\delta t} + \lambda_\eta - \varphi = -\dot{\lambda}_\eta \\ &Or, \dot{\lambda}_\eta + \lambda_\eta = \varphi - \sigma\omega_\eta e^{-\delta t} \end{aligned} \tag{19}$$

since $\theta a^{\beta}Q^{\theta-1} = \Omega_\eta\ \frac{\partial \mathrm{H}}{\partial \varphi} \geq 0 \Rightarrow \eta_t \geq \eta_b$ with the complementary slackness condition $\varphi \geq 0$ and

$$\varphi \frac{\partial \mathrm{H}}{\partial \varphi} = 0 \Rightarrow \eta = \eta_b \tag{20}$$

Now re-consider (17) with (20). The last term in RHS of (17) $\lambda_\eta \eta_Y$ is the cost to the discounted social benefit (from *Y*) of the mining induced desiccation. LHS of the Eq. (17) on the other hand, is the discounted value of marginal social benefit from mining production (after taking into account its impact on traditional production), after meeting the sustainability constraint $\eta \geq \eta_b$ equalized with RHS showing the cost to future benefits of a marginal increase in *Y*. Discounted value of marginal social benefit from mining decreases as the social planner ascribes greater value on σ. This is because after desiccation $\eta_{Y} < 0$ and the value of the second component of LHS of (17) is negative.

Again in (17), let $\bar{p} - (1 + \sum k_{WY})C'_Y = \tilde{p}$, the net price of Y which is assumed to take the functional form of inverse demand with γ as demand parameter $\tilde{p} = e^{-\gamma Y}$. $\tilde{p}$ is the social price that internalizes the marginal benefit (or cost) of traditional production Ω. The transversality condition on R i.e. $R_T \geq 0$(Eq. 14) indicates the possibility that some resource may be left in the ground if at T, $\tilde{p}$ is equal to minimum average social cost (mine extraction cost + cost on traditional production due to mining induced water pollution). $\lambda_T = 0$. Beyond T, $\tilde{p} <$ average social cost (Lasserre 1991). Equation (17) now becomes:

$$e^{-\gamma Y} = \left[\lambda_R(1 + k_{WY}) + \lambda_\eta \eta_Y\right]e^{\delta t} - \sigma\theta\Omega_\eta \eta_Y$$

Taking log on both sides, with $\lambda_R(1 + k_{WY})$ being a constant, $\ln[\lambda_R(1 + k_{WY})] = \bar{\lambda}_R$ we get:

$$-\gamma Y = \delta t + \bar{\lambda}_R + \left(\log \lambda_\eta - \sigma \log \Omega_\eta\right)\eta_Y = \delta t + \bar{\lambda}_R + \eta_Y \log\left(\lambda_\eta / \sigma\Omega_\eta\right) \tag{21}$$

$$Y^{SOC} = -\frac{1}{\gamma}\left[\delta t + \bar{\lambda}_R + \eta_Y\left(\lambda_\eta / \sigma\Omega_\eta\right)\right] \tag{22}$$

3.3.1 Shadow Cost Path of WQI and Social Optimal Mine Extraction Path

Given the discount factor δ, demand parameter γ, η_Y, $\bar{\lambda}_R$ and, Ω_η Eq. (22) shows that Y_t^{SO} the social optimal rate of extraction at t depends upon λ_η the shadow cost path to social benefit due to MID. Until we solve them we cannot determine Y_t^{SO}. We re-consider Eq. (19): $\dot{\lambda}_\eta + \lambda_\eta = \varphi - \sigma\Omega_\eta e^{-\delta t}$

This is a first order differential equation with the variable term $e^{-\delta t}$. Solving it in terms of initial value condition $\lambda_\eta = \lambda_{\eta_0}$ we get the time path of λ_η as:

$$\lambda_\eta = (1 - e^{-t})\varphi - \sigma(1 - \delta)\Omega_\eta\left(e^{-\delta t} - e^{-t}\right) - \lambda_{\eta_0}e^{-t} \tag{23}$$

(Appendix A3). A numerical simulation with $\delta = 0.6$ for $0 \leq t \leq 20$; $\Omega_\eta = 0.5$; $\varphi = 0.1$, $\lambda_{\eta_0} = 0.3$ and $\sigma = 0.2$ shows that path of shadow cost λ is a concave curve which over the time increases at the decreasing rate (Fig. 1). With increasing the weight σ on the loss of traditional production the λ_η curve will be lower.

Incorporating the value of λ_η from (23) into (22) we get the social optimal rate of extraction Y^{SOC}. Numerically simulating with $\delta = 0.6\,\Omega_\eta = 0.5$, $\varphi = 0.1$, $\lambda_{\eta_0} = 0.2$, $\eta_Y = -0.6$ and $\sigma = 0.2$ we get

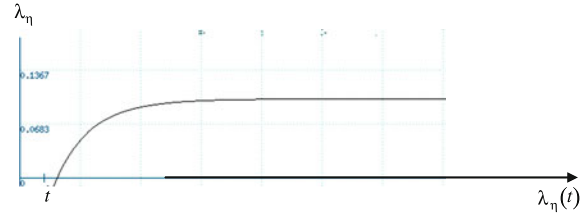


Fig. 1 Numerical simulation of time path of $\lambda_\eta(t)$

$$Y^{SOC} = -\frac{1}{\gamma}\left[\delta t + \bar{\lambda}_R + \eta_Y \log\left(\lambda_\eta/\sigma\Omega_\eta\right)\right] = -0.67t - 2.03$$

If the social planner targets to deplete mine reserve up to R_0 and $R_0 = 100$ then

$$R_0 = \int Y^{SOC} dt = -0.67 \int t dt - 2.03 \int dt$$

Numerically plotting this for $0 \le t \le 20$ the social optimal mine extraction path (Fig. 2)

This path is concave downward indicating that social optimal rate of mine resource extraction (which is $\dot{R}_t$, the slope of the curve) should be diminishing at the increasing rate.

3.3.2 Importance of the Relative Weight Given to the Loss of Traditional Fish Production in Social Welfare

We found above that for both shadow cost path of desiccation λ_η and social optimal mine extraction Y^{SOC}, the relative weight that social planner gives to the mining induced loss in traditional production is important. In the composite welfare $U(Y, \Omega; t, \sigma)$, the first one $\bar{p}Y_t - (1 + k_{WY})C(Y_t, R_t)$ is the profit component of the miner say π_M and if we assume that cost of traditional production is nil, in the second component $a_t^\beta \eta_t^\theta$ at the normalized price can also be considered as the profit of traditional community say π_e. Then $U = \pi_M(Y(t); p(t)) + \sigma\pi_e(\eta)$ along a social indifference curve $U(\pi_M, \pi_e) = \bar{U}$; $\sigma = -d\pi_M/d\pi_e$ i.e. σ is nothing but how much sacrifice in the benefit (vis-à-vis, profit) from traditional production a social

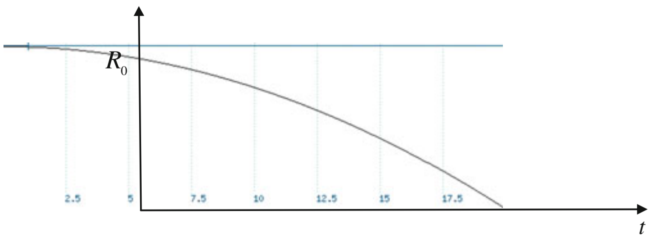


Fig. 2 Social optimal mine resource extraction path (numerically simulated)

planner will allow for each unit benefit (vis-à-vis, profit) from mine production in the society. In our given construct $\pi_e = \Omega$. Therefore, after rearrangement we can express $\sigma = -\frac{d\pi_M/dY}{(d\Omega/d\eta).(d\eta/dY)}$. It is already shown in Sect. 2.1 that $d\eta/dY$i.e., $\eta_Y = k_{WY}S_{_Y} + (f_Y + I_Y) + (1 + k_{WY})\left(b_{_Y} - r_{_Y}\right)$. This indicates that for each additional unit of profit from mining production, how much loss in traditional production a social planner will allow, i.e., what value of σ he will assign given $d\Omega/d\eta$i.e. Ω_η (which is a technology parameter) is to be determined by η_Y i.e. by the hydro-geological parameters k_{WY}, k, $f_{_Y}$, $I_{_Y}S_{_Y}$, $b_{_Y}$ and $r_{_Y}$. Therefore, if society allows to sacrifice some amount of traditional output in order to get more benefit from mine production and set the maxi-min rule for traditional community (i.e., maximum of minimum acceptable quantity of traditional production which is possible at $\eta > \eta_b$ what should be the value of σ is a matter of choice by the social planner.

4 Sustainable Development Path of the Society as a Whole and Sustainability of Traditional Production Under Mining Induced Desiccation

4.1 Brundtland Sustainability

The sustainability criterion as reported by the Brundtland Commission 1987, after the name of its chairperson is the 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' In economic theory analytically, the approach to the sustainability issue has been made by deriving the 'stationary equivalent' of the utilitarian optimal welfare path. Some constraints on social objectives, i.e., optimization of social utility or welfare are set so that two important components of sustainability (Stavins et al. 2003), viz., inter generational equity and efficiency, can be assured. As proposed by Solow (1974) it is obtained in terms of non-decreasing utility over time and optimizing the discounted value of utility (economic well-being).

In our present context if MID starts at time $t > 0$ and the social planner wants to maximize the social utility: $U(t) = \int_t^\infty U(Y(s) + \Omega(a, Q(Y(s)))e^{-\delta(s-t)}ds$, the Brundtland condition of sustainability requires that, inter temporal social utility U would not decrease over time t, i.e. $U'(t) \geq 0$. This is obtained by differentiating the above expression:

$$\begin{aligned} U'(t) &= -\,U(Y(t) + \Omega(a(t), \eta(Y(t))) + \delta U(t) \geq 0 \\ &= -\,\bar{p}Y(t) + (1 + k_{WY})C(Y(t)) - \sigma\Omega + \delta U(t) \end{aligned}$$

This yield, $U(T_1) \geq \frac{\bar{p}Y_t - C[(1+k_{WY})Y_t] + \sigma a_t^{\beta}\eta_t^{\theta}}{\delta}$

The condition for an optimal sustainable utility path (when it exists) is obtained in two stages: first, by adopting the usual utilitarian approach to optimize a general utilitarian social welfare function in an infinite time horizon: $\int_{T_1}^{\infty} [\bar{p}Y_t - C[(1+k_{WY}) Y_t + \sigma a_t^{\beta}\eta_t^{\theta}]e^{-\delta t}dt$ and, second, obtaining the condition under which this optimal path is constant over time (Farzin 2006). The optimal control problem and the solution are almost same as that we found in Sect. 3. The condition (16) i.e. $\eta \geq \eta_b$ takes the form $\lim_{t\to T} \lambda_\eta(t)[\eta(t) - \eta_b]e^{-\delta t} = 0$. Solving it we obtain$(Y^*(t), [R^*(t), \eta^*(t)], \left[\lambda_R^*, \lambda_\eta^*\right])$, the maximized current-value Hamiltonian along the optimal paths. This maximized current-value Hamiltonian, is the 'stationary equivalent' of the utilitarian optimal welfare path (Weitzman 1976), i.e.

$$\int_{T_1}^{\infty} e^{-\delta(s-t)}H(t)ds = \int_{T_1}^{\infty} e^{-\delta(s-t)}[\bar{p}Y^*(s) - (1+k_{WY})C(Y^*(s)) + \sigma\Omega(\eta(Y^*(s)))]ds \quad \forall t \geq T_1$$

In this approach, the necessary and sufficient condition for permanently sustaining the highest consumption path (i.e., the maxi-min path) is that the maximized current-value Hamiltonian remains constant over time, i.e. that $\frac{\partial H}{\partial t} = 0$ (Farzin, ibid). This implies:

$$\frac{dH}{dt} = \frac{\partial H}{\partial t} + \delta\left[\lambda_R\dot{R} + \lambda_\eta\dot{\eta}\right] = 0 \tag{24}$$

For simplicity, if we heuristically assume that direct and exogenous effects of time on the economy, i.e., net 'pure time effect' is nil, i.e., the economy is time-autonomous, the maximin sustainability cum optimality criterion (which also leads to Rawlsian criterion of intergenerational justice) that follows from Eq. (24) simply leads to:

$$\frac{\partial H}{\partial t} = \left[p - (1+k_{WY})C'_Y + \sigma\Omega'_Y\right]\frac{\partial Y}{\partial t} = \delta\left[\lambda_R\dot{R} + \lambda_\eta\dot{\eta}\right] = 0 \tag{25}$$

This condition is none but the generalized version of the Solow-Hartwick's sustainability rule. It shows that well being of the society depends not only on Y^*but also on the depletion of the stock of natural capital. If the sustainability condition (25) is satisfied, from right hand side of this equation we get:

$$-\lambda_R\dot{R} = \lambda_\eta\dot{\eta} \tag{26}$$

In our present context, λ_R is the shadow cost of depletion of mine resource stock and $(-\lambda_R)$ is the shadow price of keeping the mined resource conserved at time t. λ_η is the shadow cost of MID in PSWB. From (26), $-\dot{R} = \frac{\lambda_\eta}{\lambda_R}\dot{\eta}$. From this we reach a conclusion that in order to achieve sustainable path of development by reducing desiccation, mined resource R has to be conserved. At what rate R has to be conserved (i.e. mine production has to be sacrificed) depends upon the shadow cost of MID and shadow benefit (of mine production) path over time.

As it is further envisaged above, $-\dot{R}(t) = Y(t) + W(Y(t)) = (1 + k_{YW})Y(t)$, and, therefore, along the sustainable path,

$$Y^* = \frac{\lambda_\eta}{\lambda_R(1 + k_{YW})}\dot{\eta} \tag{27}$$

This (27), in other words, explains that the domain of MID $\dot{\eta}$ along with λ_η and λ_R determines what should be the highest sustainable extraction path $Y^*(t)$ for the economy, which is also the 'stationary equivalent' of the utilitarian optimal welfare path $U(Y*(t), \Omega(Y*(t)))$. This condition also determines a minimum critical stock of mine resource (threshold) that ought to be preserved to ensure at least Ω_b for the rest of the time concerned. Mining induced change in quantity of water over time $\dot{\eta} = \eta_Y \frac{\partial Y}{\partial t}$. From Sect. 2 we got $\eta_Y = k_{WY}S_{_Y} + (f_Y + I_Y) + (1 + k_{WY})\left(b_{_Y} - r_{_Y}\right)$. Therefore,

$$\dot{\eta} = \left[k_{WY}S_{_Y} + \left(f_{_Y} + I_{_Y}\right) + (1 + k_{WY})\left(b_{_Y} - r_{_Y}\right)\right]\frac{\partial Y}{\partial t}$$

Thus, $-\dot{R} = \frac{\lambda_Q}{\lambda_R}\left[k_{WY}S_{_Y} + (f_Y + I_Y) + (1 + k_{WY})\left(b_{_Y} - r_{_Y}\right)\right]\frac{\partial Y}{\partial t}$. This further indicates that as MID occurs, in order to achieve the sustainable path of development at what rate R has to be conserved (vis-à-vis at what rate mine resource has to be depleted), will have to be determined by at what rate mine production reduces surface runoff S and reduces base flow b after increasing the groundwater recharge g. As we discussed in Sect. 2, these factors again are determined by the hydro geological parameters in the area concerned.

Whether the society will be able to meet the sustainability condition (25) or not also depends on the choice of the value of σ by the social planner. From condition (25) we can determine the required value of θ:

$p - (1 + k_{WY})C'_Y - \sigma\left(-\Omega'_Y\right) = 0$; since $-\Omega'_Y > 0$, and the net marginal profit $p - (1 + k_{WY})b'_Y = \tilde{p}$, then

$$\sigma^* = \frac{\tilde{p}}{(-Q'_Y)} \tag{28}$$

Thus, the required σ^* will be the marginal net benefit from the mine production $(\tilde{\pi})$ over the marginal net loss of traditional output due to desiccation. Since both numerator and denominator of (28) are functions of time σ^* will also be time-variant.

4.2 Sustainable Development and Management of Mine Production by Means of Taxation

For a developing country with no control on market price (determined in the international market), to reach the goal of sustainable development inclusive the sustainability of traditional production, the social planner can introduce the social management of mine extraction by means of taxation. If her objective is to satisfy the Brundtland sustainability condition (26), she can set the tax structure principally in two ways. (1) Tax can be imposed on the rate of depletion of mine reserve $\left(-\dot{R}\right)$ that causes desiccation in PSWB, and (2) it can be imposed on the amount of loss that MA makes in traditional output $\left(-\Omega'_Y\right)$ due to desiccation. In the first case the tax rate τ as a function of time will be derived directly from (26), i.e., $\lambda_R\left(-\dot{R}\right) = \lambda_\eta \dot{\eta}$. Replacing $-\dot{R}$ by τ we get:

$$\tau = \frac{\lambda_\eta}{\lambda_R}\dot{\eta} = \frac{\lambda_\eta}{\lambda_R}\left[k_{WY}S_{_Y} + k.(f_Y + I_Y) + (1 + k_{WY})\left(b_{_Y} - r_{_Y}\right)\right]\dot{Y}$$

In the second case re-arranging LHS of (25), $\left[p - (1 + k_{WY})C'_Y - \left(-\Omega'_Y\right)\right] = 0$. Replacing $-\Omega'_Y$ by τ we get:

$$Or, \tau = p - (1 + k_{WY})C'_Y = \tilde{p}_\tau = e^{-\gamma Y_\tau}$$

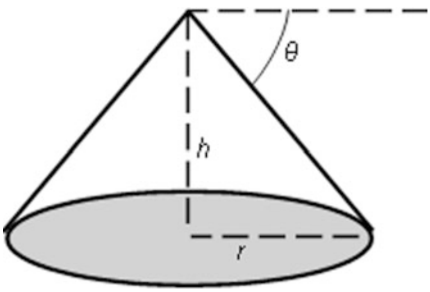
In both the cases τ will be increasing exponentially along the sustainable path of development. In the former situation given λ_R, it increases with λ_η and rate of mine production $\left(\dot{Y}_t\right)$, given the hydro geological factors viz., k_{WY}, k_1, k_2, $S_{_Y}$, $f_{_Y}$, $I_{_Y}$, $b_{_Y}$ and $r_{_Y}$. In the latter case it increases with the rate of depletion $(-Y_\tau)$, given the demand parameter γ. In the first case, tax rate is constrained by $\eta \geq \eta_b$, where from the production function of traditional output $\eta_b \geq \left(a^{-\beta}\Omega_b\right)^{1/\theta} \geq \bar{\eta}$ and $\Omega_b > 0$. In the latter case, the tax rate is constrained by $R \geq R_b > 0$. In the former case evolution of tax rate is directly sensitive to the hydro geological condition of the study area concerned, while in the latter case, tax rate is determined by the degree of sensitivity of Ωto the mining induced desiccation.

5 Summary of Results and Conclusions

In the context of environmental planning with mining and long term sustainable traditional economy, the proposed analytical model shows how optimal mine extraction path, depending on the shadow cost path of mining induced desiccation, can be derived. This shadow cost path of desiccation increases at a decreasing rate. The social optimal rate of depletion of mine reserves becomes gradually faster over time. The stationary equivalent of the utilitarian optimal welfare path has been derived for a hypothetical society, from which we obtain a generalized version of the Solow-Hartwick's sustainability rule, which further corroborates the Brundtland condition of sustainability. The sustainability condition shows that to ensure the minimum quantity of water for survival of production of the traditional community, a certain amount of mined resource has to be conserved. The rate of conservation in that context is to be determined by shadow cost path of water desiccation and that of depletion of mine reserve. The sustainable development path inclusive of sustainability of traditional production adds some constraint on stationary equivalent of the utilitarian optimal welfare path. If society allows sacrificing some amount of traditional output in order to get more benefit from mine production and set the maxi-min rule for traditional community (i.e., maximum of minimum acceptable traditional output) then the required target for minimum availability of water in PSWB will be determined by the production technology of the traditional community. Finally, if the social planner wants to introduce taxation as a means of achieving economic development inclusive of sustainability of traditional production, our analytical results suggest that tax rate should evolve dynamically incorporating various hydro geological parameters and the sensitivity of traditional production to MID.

Appendix

A2.1: The waste dump is assumed to have conical shape. If its height is h, basal radius is r and slope is θ, (i.e. sub vertical angle is $90^\circ - \theta$),



Then its volume (V_W) is:

$V_W = \frac{1}{3}\pi r^2 h = \frac{1}{3}\pi r^2 . r . \tan\theta = \frac{1}{3}A_W\left(\sqrt{\frac{A_W}{\pi}}\right)\tan\theta = \frac{1}{3\sqrt{\pi}}(A_W)^{\frac{3}{2}}\tan\theta$ Here A_W is the area covered by waste dump.

The volume of the waste dump can be expressed as the ratio of its mass and average density, i.e. $V_W = \frac{W}{\rho_W}$

Therefore

$$A_W = \left[\frac{3\sqrt{\pi}}{\tan\theta}(V_W)\right]^{\frac{2}{3}} = \left(\frac{3\sqrt{\pi}W}{\tan\theta\rho_W}\right)^{\frac{2}{3}} = \left(\frac{3\sqrt{\pi}k_{WY}}{\tan\theta\rho_W}\right)^{\frac{2}{3}} Y^{\frac{2}{3}} \tag{A2.1}$$

A2.2: The materials dug out from the mine comprise the desired material (Y) and the waste material (W). Volume of a material is equal to its mass divided by its average density. Therefore, the volume of desired material and waste material are $\frac{Y}{\rho_Y}$ and $\frac{W}{\rho_W}$ respectively. Therefore the total volume of the excavation:

$$V_E = \left(\frac{Y}{\rho_Y} + \frac{W}{\rho_W}\right) = \left(\frac{1}{\rho_Y} + \frac{k_{WY}}{\rho_W}\right) Y$$

A3: The shadow cost path of desiccation can be obtained by $\dot{\lambda}_\eta + \lambda_\eta = \varphi - \sigma\Omega_\eta e^{-\delta t}$

Here, the integrating factor is $\int e^{dt} = e^t$. Multiplying both sides by e^t we get:

$$\lambda'_\eta e^t + \lambda_\eta e^t = \varphi e^t - \sigma\Omega_\eta e^{-\delta t + t} \ or, \ \left(\lambda_\eta e^t\right)' = \varphi e^t - \sigma\Omega_\eta e^{(1-\delta)t}$$

Integrating both sides we get:

$$\begin{aligned}\lambda_\eta e^t &= \varphi \int e^t dt - \int \sigma\Omega_\eta e^{(1-\delta)t} dt \\ &= \varphi e^t - \sigma(1-\delta)\Omega_\eta e^{(1-\delta)t} + K\end{aligned}$$

At $t = 0$, $\lambda_\eta = \lambda_{\eta_0}$ and thus, $K = \sigma(1-\delta)\Omega_\eta - \varphi - \lambda_{\eta_0}$. Plugging this value into the above equation, we get:

The shadow cost path of desiccation can be obtained by $\dot{\lambda}_\eta + \lambda_\eta = \varphi - \sigma\Omega_\eta e^{-\delta t}$

Here, the integrating factor is $\int e^{dt} = e^t$. Multiplying both sides by e^t we get:

$$\lambda'_\eta e^t + \lambda_\eta e^t = \varphi e^t - \sigma\Omega_\eta e^{-\delta t + t} \ or, \ \left(\lambda_\eta e^t\right)' = \varphi e^t - \sigma\Omega_\eta e^{(1-\delta)t}$$

Integrating both sides we get:

$$\begin{aligned}\lambda_\eta e^t &= \varphi \int e^t dt - \int \sigma\Omega_\eta e^{(1-\delta)t} dt \\ &= \varphi e^t - \sigma(1-\delta)\Omega_\eta e^{(1-\delta)t} + K\end{aligned}$$

At $t = 0$, $\lambda_\eta = \lambda_{\eta_0}$ and thus, $K = \sigma(1-\delta)\Omega_\eta - \varphi - \lambda_{\eta_0}$. Plugging this value into the above equation, we get:

$$\begin{aligned}\lambda_\eta &= \varphi - e^{-\delta t}\sigma(1-\delta)\Omega_\eta - \left(\varphi - (1-\delta)\sigma\Omega_\eta + \lambda_{\eta_0}\right)e^{-t} \\ &= (1 - e^{-t})\varphi - \sigma(1-\delta)\Omega_\eta\left(e^{-\delta t} - e^{-t}\right) - \lambda_{\eta_0} e^{-t}\end{aligned}$$

References

Dasgupta P (2001) Human well-being and the natural environment. Oxford University Press, New Delhi
Dasgupta P, Heal G (1979) Economic theory and exhaustible resources. Cambridge University Press, Cambridge
Dixit AK, Pindyck RS (1994) Investment under uncertainty. Princeton University Press, New Jersey
Farzin YH (2006) Conditions for sustainable optimal economic development. Rev Dev Eco 10(3):518–534
Fetter CW (1988) Applied hydrogeology, 2nd edn. Merrill publishing company
Gray L (1914) rent under the assumption of exhaustibility. Q J E 28:466–489
Grüne L, Kato M, Semmler W (2005) Solving ecological management problems using dynamic programming. J Econ Behav Organiz 57:448–473
Hartwick JM (1990) Natural resources, national accounting and economic depreciation. J Pub Eco 43:291–304
Hilson G (2002) An overview of land use conflicts in mining communities. Land Use Policy 19(1):65–73
Hotelling H (1931) The economics of exhaustible resources. JPE 39:137–175
Kumar P (2000) Estimation and economic evaluation of soil erosion: a case study of Doon valley in India. Paper presented at the Beijer Institute of ecological economics, Stockholm, Sweden
Lasserre P (1991) Long term control of exhaustible resources. Series on fundamental of pure and applied economics 49, Harwood academic publishers, Luxembourg
Martinet V (2008) The viability framework: a new way to address the sustainability issue. In: Lopez RA (ed) Progress in sustainable development research. Nova Science Publishers, New York, 143–167
Martinet V, Doyen L (2007) Sustainability of an economy with an exhaustible resource: A viable control approach. Res Eng Econ 29:17–39
Mukhopadhyay L, Ghosh B (2010) Mining induced water pollution—impact on traditional economic livelihood: an analytical framework. 4th world congress of environment and resource economics, Montréal, Canada (Published in conference website and abstract volume)
Nagabhushaniah HS (2001) Groundwater in hydrosphere. CBS Publishers & Distributors, New Delhi
Perrings C (1999) Comment on ecological and social dynamics in simple models of eco-system management. In: Carpenter SR, Brock WA, Hanson P (eds) Conserv Ecology 3(2):10
Perrings C (1999b) Comment on ecological and social dynamics in simple models of eco-system management. Conserv Ecology 3(2):10
Sahu G (2008) Mining in the niyamgiri hills and tribal rights. EPW April 12, 19–21
Sahu BP, Goel NG (2004) Social and environmental impact assessment of opencast mining in Meghalaya. In: Husain Z, Barik SK (eds) Environment and development. Regency publications, New Delhi, pp 273–289
Shiva B (1991) Ecology and the politics of survival: conflicts over natural resources in India. Sage Publications, California
Singh G (2007) Minenvis: a newsletter of the ENVIS centre on environmental problems of mining areas 54. 2007 centre of mining environment/Department of environmental science and engineering, Indian schools of mines, Dhanbad
Solow RM (1974) Intergenerational equity and exhaustible resources. Rev of Econ Studies 41:29–45
Stavins R, Wagner A, Wagner G (2003) Interpreting sustainability in economic terms: dynamic efficiency plus intergenerational equity. Econ Letters 79:339–343
Stiglitz JE (1974) Growth with exhaustible natural resources: efficient and optimal growth paths. Rev Econ Studies 41:123–137

Weitzman ML (1976) Optimal revenue functions for economic regulation. Working papers 193, Massachusetts institute of technology, department of economics, Massachusetts

Younger PL (2004) Impacts of mining on physical hydrogeology. In: Younger PL (ed) Groundwater management in mining areas. In: Proceedings of the 2nd IMAGE-TRAIN advanced study course, 8–16

Web References

Jigang Z, Chuhua Z (2008) In China's mining region, villagers stand up to pollution. Yale Environment 360, Yale School of Environment Studies. Available at http://e360.yale.edu/author/Zhou_Jiganang_and_Zhu_Chuhua/59/. Accessed on 22. 12. 2010

Mathematical Equation Plotting Software. Available at http://www.wessa.net/math.wasp. Accessed on 5.1.2011

Water Pollution Impacts on Livelihoods: A Case Study of Fishing Communities in Tungabhadra Sub Basin

S. Manasi

1 Introduction

Aquatic ecosystem is one of the most productive ecosystems as the large proportion of the earth's biodiversity resides in it. They provide many critical services such as assimilation of waste products, food production, transport, water supply and supports terrestrial ecosystems and wildlife. On the other hand, increasing pollution loads have degraded the water quality of many rivers across the world. The situation is no different in the Tungabhadra river sub basin (TBSB), where agricultural activities, urbanization and industrialization have significant impacts on water quality, surface water as well as ground water. Knowledge of the water quality has become important because of its implications to human and aquatic health and significant costs associated with decisions involving water management, conservation, and regulation. The present paper is based on the EC-funded STRIVER project, "Strategy and methodology for improved IWRM—An integrated interdisciplinary assessment in four twinning river basins", "2006–2009"[1] of which TBSB represents the Indian case. IWRM intends to understand and integrate various disciplines related to water issues. IWRM also entails to develop plans by involving the assessment of the current conditions and the evaluation of future options. The paper is an attempt to understand the extent of water-quality

[1] The study is a part of an international collaborative research project (STRIVER) funded by the European Union under FP7 research program between 2006-09. The team for this part of the study included Prof. K. V. Raju, Nagothu, Dr. Udaya Sekhar, Dr. Manasi. S, Latha N and Dr. Lenin Babu. More information on the IWRM assessment can be found in the STRIVER report (2008) which is based on individual basin reports prepared by researchers from the respective river basins.

S. Manasi (✉)
Centre for Ecological Economics and Natural Resources,
Institute for Social and Economic Change, Bangalore, India
e-mail: manasi@isec.ac.in

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_21, © Springer-Verlag Berlin Heidelberg 2013

problems and its impact on livelihoods with specific reference to fishing communities and associated key issues and constraints.

2 Tungabhadra Sub Basin

River Tungabhadra is the largest tributary of the river Krishna, contributing an annual discharge of 14,700 million m^3 at its confluence point to the main river. TBSB is a transboundary river, stretches over an area of 48,827 km^2 in both the riparian states of Karnataka (38,790 km^2) and Andhra Pradesh (9,037 km^2) and finally joins Krishna that flows into the Bay of Bengal. Tungabhadra covers seven districts[2] in Karnataka and four districts in Andhra Pradesh,[3] the sub-basin is mostly rainfed, dominated by red soils with an average annual rainfall of 1,200 mm. The upper basin of Tungabhadra is characterized by undulating terrain with high rainfall while the lower portion of the basin is characterized by much lower rainfall, drought conditions and mainly plain terrain. Agriculture is the major occupation across the basin. The major crops grown are paddy, jowar, sugarcane, cotton and Ragi (finger millet). The river catchment includes a number of large and small-scale units supporting industrial activities. Fishing is next major activity that supports more than 10,000 families. Brick making, potters etc. are other livelihood options practiced along the basin.

Reservoir water storage capacity of the Tungabhadra reservoir is reducing due to siltation from mining activities, dust, soil erosion etc. During the last two decades there has been an increase in the number of small towns and industrial areas, which has enthused the competing demands for water, making the situation more difficult. While increased industrialization and growing urban areas have made it possible to improve the economy, it has also led to negative externalities like pollution and land degradation. Pollution affecting human health, agriculture and fish production is prominent. There has been a disparity between maintaining the tempo with development activities and providing sanitation and water supply infrastructure while population stresses have added on. The TBSB is a politically sensitive basin as negotiations between the states concerning water allocation are presently going on. Conflicts within and across sectors are widespread, besides interstate disputes, as it is an interstate river.

3 Methodology

Both primary and secondary data was collected for the study. Primary data was collected from key informants and direct and indirect dependents. Secondary data was collected from different National and Regional institutions—Karnataka State

[2] Shimoga, Chikamaglur, Davanagere, Haveri, Bellary, Koppal and Raichur.

[3] Karnool, Cudappa, Ananthpur and Mahaboobnagar.

Pollution Control Board (KSPCB), Department of Mines and Geology, Central Ground water Board, State Fisheries Department, Karnataka State Fisheries Development Corporation and Fishermen co-operative societies (FCS) within the TBSB. Data included were chemical and biological quality of available water resources (actual situation, seasonal changes, trends); water allocation and priorities, water resources needs and quality constraints for optimum performance in the different sectors and expected future needs; data on political priorities and plans. Primary sources mainly included focus group discussions and surveys. Stakeholder workshops were another main source of information. Household survey of fishermen households (direct dependents), labourers hired by fishermen (direct dependents), middleman—traders (Regional, contractors, agents, local traders, petty traders—women selling fish (indirect dependents) were carried out.

The study was conducted in TBSB from January 2008 to April 2008. The data was gathered through household survey of 106 fisher folk (in 16 villages) selected through stratified random sampling based on two criteria—water sources and their socio-economic status. Information was also collected through interviews and focus group discussions with 30 traders who were indirectly dependent on fishing for their livelihoods. Due to time and resource constraints, a larger sample survey was not possible in this study. The survey was more extensive in nature to get a broader idea of fisheries across the sub basin. The sampling ensured representation of informants from different fishing sources across the basin—Reservoirs—Major and Minor, Tanks—Major and Minor, Private Ponds, River Stretch leased out by the Department and Canals. Women and men together contribute to the household economy through fishing; hence to understand livelihoods, both men and women were interviewed. Information related to variables such as income from fishing, incomes from other sources, type of fishing, nature of work, water quality related, marketing problems etc., were collected.

4 Results

Irrigated agricultural lands suffer from water logging and salinity problems apart from the extensive use of fertilizers in crop production. In particular runoffs of phosphorus is a problem, leading to eutrophication of water bodies causing taste and odour in the water supplied to the public; and excess algae growth leads to deoxygenation of water and fish kills. In fact, across the TBSB, fertilizer consumption increased to 700 tonnes in 2001–2005 from 510 tonnes in 1995–1996 indicating nutrient loss in the soil systems. The problems related to irrigated agriculture are mainly seen in the downstream of the river basin (Koppal, Raichur and Bellary districts) due to intensive cultivation and excessive use of fertilizers. Bellary district accounts for 19,170 Ha affected by salinity. Water logging is also observed high in Raichur, Bellary and Koppal. The excessive use of fertilizers has also affected ground water quality with high Nitrate concentrations in the ground water. However, there have been no systematic studies carried out with respect to these non-point pollution sources.

Industries are another key source of pollution in Tungabhadra and there are about 77 large-scale industries (27 functioning and 50 under implementation). Major types of industries include iron and steel, paper and pulp, chemical and sugar. Major industries permitted to discharge treated effluents into the river as per the law are: Vishweshvaraiah Iron and Steel Industries, Harihara Polyfibres, Gwalior Rayon Silk Manufacturing Industry, two sugar and two distillery units. Following the public protests regarding the discharge of 6,000 tonnes of molasses into the river that led to fish kills on a large scale in 1984, the government instructed the distillery unit to discharge only treated effluents into the river. Apart from large-scale industrial units, there are 2,543 small-scale industrial units operating (as of 2006–2007). The water consumption by industrial units in the TB Basin works out to 172.733 Mm^3 per day (Tungabhadra—129.125 Mm^3 and Bhadra—43.608 Mm^3).

Also two major iron mining areas, i.e., Kudremukh and Hospet, exist in the river basin; however, there are no proper mining standards followed in iron ore extraction. The mining of iron ore at Kudremukh and Manganese in Sandur has seriously affected the stability of the catchments in the form of soil erosion and silting of several small reservoirs, traditional tanks and the Tungabhadra reservoir, and thus conflicting with irrigation needs of the region. Further, these mining activities have adversely affected water tables besides causing iron contamination of water (Patel 2005). Air pollution due to the transportation of iron ore in open trucks and truck movements cause dust nuisance. Agriculture in the region is also affected because of mining induced dust pollution as the dust gets deposited on crops. Polluted water affects river basin ecosystems while downstream fish kill which is frequent, affects the livelihood of fishing families. The number of fish species has reduced over the years with several local varieties of fish becoming extinct. According to fishermen, around 50 % of the local breeds have disappeared or decreased over time (Sekhar et al. 2008b). During the field study of the STRIVER project, many fishermen expressed concern over increased use of chemical fertilizers in agriculture; 47 % of the fishermen believed polluted water killed fish stock (Sekhar et al. 2008b).

With regard to urban settlements, a majority of the “Urban local bodies” and Town municipalities do not have underground drainage system and treatment facilities in place for collecting and treating the municipal sewage (Fazi and Porto 2009), and as a result, the sewage directly enters the river system or agricultural fields. In the rest of these settlements such treatment is only partial, impacting around 75 villages. Domestic and industrial pollution, combined with deforestation, use of pesticides and fertilizers have affected water quality extensively making it unfit for consumption (Raju and Manasi 2007).

The Karnataka and Andhra Pradesh State Pollution Control Boards being responsible for monitoring water quality, have initiated action plans to prevent river pollution in 4 towns under the National River Action Plan, introduced by the National River Conservation Directorate of the Ministry of Environment and Forests, Government of India. There are various standards set up for allowable concentrations of and parameters related to pollution, of which the most relevant is the drinking water standards specified by IS 10500:1991. In spite of these regulatory measures, implementation has not been very effective in controlling pollution levels. The role of the state pollution control boards is limited to sample testing, warning polluters and issuing show–cause notices indicating institutional constraints. What is important to keep in view, however, is that such issues cannot be the responsibility of the regulatory authorities alone as a strong political will is also required to bring in the required changes.

4.1 Pollution Sources and Impacts

Largely the sources of pollution in the TBSB are from the following categories (a) Agricultural runoff (b) Industrial effluents (c) Sewage from urban settlements (d) Mining activities and (e) Over exploitation of ground water.

4.2 Agriculture Activities and Pollution

Agriculture is the major activity in the TBSB and 80 % of the population is dependent for their livelihoods. Though the area is designed for semi-arid crops, paddy and sugarcane are the major crops grown. The area under these crops is increasing indicating growing demand on water. Dependency on ground water for irrigation has been increasing over time, as the canal water supply is not meeting the demand.

As agriculture is the main occupation in the TBSB, the use of fertilizer has been increasing over a period of time. The data indicates the increase in fertilizer consumption to 700 tons in 2001–2005 from 510 tons in 1995–1996 (Table 1) indicating nutrient loss in the soil. Manure spreading carried out as a fertilizer activity; pesticide usage, spreading on frozen ground results in high levels of contamination of receiving waters by pathogens, metals, phosphorus and nitrogen leading to eutrophication and potential contamination.

Runoff from agricultural fields has resulted in water logging and salinization problems in the basin affecting the irrigated areas and water quality. The total area affected by salinity, alkalinity and water logging in the Tungabhadra command

Table 1 Fertilizer consumption in the river basin

Years	Fertilizer consumption in tons			Total
	Nitrogen (N)	Phosphorous (P)	Potash (K)	
1991–1992	305.18	192.9	102.14	600.22
1995–1996	272.65	145.28	92.08	510.01
2001–2002	369.88	200.36	129.77	700.01
2004–2005	353.98	199.31	146.73	700.02

Source District at a Glance, Karnataka

Table 2 Areas affected with salinity, alkalinity and water logging in the TBSB

District/Taluk	Area affected (Area in hectares)			
	Salinity	Alkalinity	Water logging	Total
Tungabhadra command area				
Koppal	6,916.51	1,028.88	4014.59	11,959.98
Raichur	25,931.57	4,546.76	23,838.88	54,317.21
Bellary	19,170.51	2,770.2	7,997.39	29,938.1
Total	52,018.59	8,345.84	35,850.86	96,215.29
Bhadra command area	3,826	1,643	29,219	

Source Tungabhadra Command Area Development Authority and Bhadra Command Area Development Authority

area is 52,000, 8,345 and 35,850 ha respectively. These problems are prevalent mainly in the downstream of the basin—in Koppal, Raichur and Bellary districts (Table 2).

Application of chemicals and pesticides in the agriculture area, especially on paddy crop, is another source of water pollution. The fishing communities expressed anxiety over the increasing use of chemical fertilizers in agriculture. There is lack of data and no scientific studies about the impacts of non-point pollution sources. Specific incident of intensive spraying of pesticides for paddy crop in 2006 affected water quality in the river resulting in foul smell in the area and the local people were cautioned not to drink the water until dilution.

4.3 Industrial Activities and Implications

Industries pollution is another major source of water pollution across the basin. Major types of industries include Iron and steel, paper and pulp, chemical and sugar etc. There are 27 large-scale industries in the basin, while 50 are under various stages of implementation. In addition, there are 2,543 small-scale industries, which are showing an increasing trend since 2003–2004 (refer Table 3). Across the river Bhadra, the two major industries viz., Mysore Paper Mills (MPM) and Vishweshvaraiah Iron and Steel Industries (VSIL) are located at Bhadravathi. Harihara Polyfibres, GRASIM, two sugar industries and two distilleries are the major industries located across Tungabhadra River (Raju and Manasi 2007).

Table 3 Number of small scale industries in the Tungabhadra basin

Years	Number	Investment in Rs. Lakhs
2003–2004	2,425	6,620
2004–2005	2,374	7,773
2005–2006	2,494	7,525
2006–2007	2,543	7,974

Source Department of Industries and Commerce, H.O Bangalore

The sources of supply are both surface and ground water with majority of the water supply from ground water sources. Water demand for industrial usage has not been estimated. Based on the water availability, water is distributed to the industries. For instance, with the case of Harihar Polyfibres, the local people objected their fresh demand for expansion, as it would mean reduced water flows and more effluent discharge. The intensity of pollution from the industries is seen near Bhadravathi, Haveri, Harihara and Ranebennur area due to discharge of untreated or partially treated industrial effluents.

4.3.1 Health Impacts

Observations in the field revealed that the industrial sewage inflow from major industries have affected the nearby villages in the basin. For instance, Harihara Polyfibres had affected around 45 surrounding villages. People are exposed to foul smell and several other health implications. Washer-men and fishermen who spent long hours in the river had experienced skin diseases and other ailments. Free skin disease detection and treatment camps held at villages located at a distance of 20 km from HPF effluent discharge point revealed that around 13 fishermen were suffering from skin diseases 'Superficial folliculitis', an inflammation of the hair follicles. Health department received several complaints and the health supervisor found most of the residents suffering from skin diseases and stomach ailments. Discussion with the Doctor at Chennagiri town confirmed the negative health implications of poor quality water with increased number of Gastroenteritis cases reported. Similar situations were observed at the downstream of the basin (Harihar, Ranebennur and surrounding areas). There are no scientific studies on the implications and extent of pollution on health conducted so far.

In the upper reach of the basin, the villages located in the surroundings of VISL and MPM encounter pollution related health issues. Around 11 villages located in the stretch between Bhadravathi town and Kudli, (confluence point of river, Tunga and Bhadra), are affected. The river Bhadra is highly polluted at Holehonnur town as the effluents from MPM and VSIL joins the river. The residents of Holehonnur town are supplied with poor quality drinking water and several protests by the public was observed demanding safe drinking water. The Public filed their initial complaint in 2001–2002 to water authorities but was not effective. Hence, the people protested and continued their demands by registering complaints continuously (up to 15 times) after which the treatment plant was installed to purify the water before the supply (Raju and Manasi 2007).

On the contrary, the water quality monitoring results of Pollution Control Boards have indicated that the industries are meeting the discharge standards. But the discussions with the people living in the surroundings of these industries indicate that the industries violate norms during some days and the discharge of effluents without treatment which may not be documented by the PCB. There were several instances of protests by the local people to impede the effluents discharge.

As a result of this, Tungabhadra Environment Monitoring Committee—was formed to curb and monitor the pollution.

4.4 Fish Kills

One of the important indicators of water quality is the impact on fish and other aquatic life. Fish kills are a serious issue resulting from pollution, more so industrial pollution. Fish kills occur more during summer season due to minimum water flows and least dilution. The effects of pollution were felt 40 km downstream during the summers. In TBSB fish kills occurred for 3–4 times annually as opined by the department officials. In 1984, major fish kill was observed in the Tungabhadra River downstream of the Birla industries. KSPCB pointed out uncontrolled discharge of industrial effluents as the cause and issued a notice to the industry to stop releasing effluents. Another occurrence was in March 1994 in the downstream of Tungabhadra to a stretch of 25–30 km affecting more than 30 villages. This was one of the colossal fish kill ever observed where an estimated 2.5 tonnes of fishes were dead. The study showed that the BOD levels in the raw effluents released into the river were 1,000 mg/l.

During discussions, fishermen expressed concern over the increasing use of chemical fertilizers in agriculture besides industrial effluents. Several stretches of the river are polluted affecting around 75 villages. 47 % of fishermen indicated that water was polluted due to pollution and fish kills had negative impacts in terms of health and reduced income −26 %, while some had a combination of health, reduced income and also witnessed fish kills—9 %. 44 % of the fishermen felt that it was the responsibility of the government to clean the river while 20 % felt it should be the responsibility of the polluters. There are no systematic data regarding the extent of fish kills and its damage on the species (Sekhar et al. 2008b).

4.4.1 Decline in Fish Species

Decline in fish species is another serious issue. According to Mr. Gireesha, Assistant Director of Fisheries, Shimoga, there were nearly 120 species of fishes in the river, among them 28 species are threatened due to over exploitation and pollution. He also stated that the fish yield decreased by 50 % over 10 years (1,200 tonnes to 650 tonnes annually). Another important impact has been on the fish species especially due to impounding of water in large reservoirs. The issue of water quality and the availability of fish have added significance as they are directly related to the livelihoods of a large number of families in the basin where 10,000 fishing families reside.

5 Implications of Blasting

Stretches of the river encounter threat from explosives blasts occurrence carried out by some illegal groups. The Indian Fisheries Act 1897 empowers the state governments to make rules for the introduction of conservancy measures and licensing system. The Mysore Game and Fish Preservation Regulation 1901 applicable to old Mysore districts empowers the government to prohibit poisoning or use of explosives in any stream or lake and declare closed seasons. The district forest officer with the approval of the district commissioner is authorized to declare any river stream, pond, lake, tank or other water body to be closed to fishing during any year or during the spawning season. The regulation also prohibits the use of dynamite or deleterious substances and the use of nets having mesh of less than two inches in perennial streams. Irrespective of the Fisheries Acts placing a ban on such activities, the problem is not resolved.

Blasting is practiced with the purpose to catch fish at one go (20–30 kg). Blasting kills all the fish, particularly the small ones and the fingerlings. In the process, fish can be collected partially leaving the remaining fish to decompose. This results in bad stench and pollution of the river ecosystems. There have been many conflicts between the fishing communities and the illegally operating groups but to no avail. The fishing communities have also lodged complaints to the Department of Fisheries but the problem remains. There is no data or information on number of blasts and areas of blasts that occur along the basin. Based on discussions with the officials at the Department of Fisheries, it was opined that blasts occur 2–3 times in a week in 10 locations across the TBSB (Raju and Manasi 2007).

5.1 Urban Settlements and Pollution

Karnataka Urban Water Supply and Drainage Board is responsible for providing water supply and sewerage facilities to all 28 Urban Local Bodies (ULBs) in the basin. During the study, twelve towns were visited to understand the drinking water supply status and pollution problems. River Tunga, Bhadra and Tungabhadra are the main sources of drinking water supply. In addition, during scarcity, water is supplied through other alternative sources—ground water and surface water tanks to meet the demand. The total volume of water supplied is 344.5 MLD, out of which 4.32 TMC (331.4 MLD) constitutes surface water and 13.09 MLD is from ground water. The domestic sewage generated is estimated, as 267.4 MLD from these urban bodies.

Table 4 Prevalence of UGD and treatment plants

Towns	UGD system	Treatment plant	Waste water disposal
Partial	7 towns	1	7 into the river
Not prevalent	20 towns	21	20 into agricultural fields/valleys

Source Discussions with Officials, 2009

5.1.1 Lack of STPs

Majority (around 20 out of 27) of the ULBs do not have underground drainage system and treatment facilities to collect and treat the municipal sewage. In the rest of ULBs though UGD is present, it is partial. Eleven towns across the basin discharge waste water into the river while the rest of the towns' discharge waste water into agricultural fields, open tanks or low-lying areas (Table 4).

There is lack of coordination and cooperation across the Departments. During discussions, the officials of State Pollution Control Board expressed constraints and pressures from the local politicians curtailing them to take action against the Urban Local Bodies who are to take responsibility for effectively implementing safe disposal of sewage.

5.2 Mining and Pollution

Two major iron-mining areas (Kudremukh and Hospet), exist in the river basin. Mining industries are affecting the water quality (Patel 2005). There are no proper mining standards for iron ore extraction as open cast mining is practiced. The earlier practice of mining was restricted to mine heads, but now it is practiced at the foothills too adding to pollution. Impact on water quality due to the silt from mines is prominent and contamination of surface water from iron is observed in Bellary district. Mining also causes air pollution caused during transportation of ore using open trucks besides dust pollution is prominent with its prominent deposits on trees and crops. There seems to be no scientific study conducted to assess crop losses and damage caused by air pollution due to mine dust, although officials mention about negative impacts. It exists as qualitative information, observed problems in research studies and NGOs reports but no quantification has been done.

Several research studies are conducted, however, confine only to certain parts of the basin. For example—A study by Krishnaswamy et al. (2006) on the 'Impact of iron ore mining on suspended sediment response in a tropical catchment in Kudremukh', highlights that more than 50 % of the suspended sediment load in both the Bhadra River and Bhadra Reservoir comes from mining-affected lands that occupy less than one per cent of the total catchment area. During the 2002 and 2003 monsoons, the suspended sediments discharge rates had increased to about

1.99 and 7.89 Mg km_2 day_1 for upstream and downstream sites respectively and sediment concentration downstream was significantly higher than upstream for all conditions. The current annual suspended sediment load below the mine ranges from 100,000 to over 150,000 Mg, depending on the size and frequency of large rain events. Comparison of historic data and another study in 1994, with recent measurements confirm that mining and associated activities in Kudremukh National Park are the greatest sources of sediment entering the Bhadra River; and the Bhadra river carries considerably more sediment now than before mining started damaging riverine ecosystems and disrupting downstream water resources.

A study on the impact of Kudremukh mining activity on the environment of the western-ghats region has revealed the sedimentation in the Bhadra river (Chikamagalur) between 2002 and 2004. The study highlighted that the mining and other related activities have altered the water quality. The water leached from mine waste/tailing and dumps in the Kudremukh area are joining the river Bhadra with high BOD concentration, iron content, and manganese in the upstream of the basin. The concentrate sediment analysis revealed that it was rich in ferrous and ferric iron ore magnetite, haematite and consisted of 59 % of magnetic concentrate of iron ore tailings and other additional metallic compounds (Patel 2005). Besides these, sand mining from the riverbed where mechanized boats are used is also causing affecting water quality.

5.3 Ground Water Contamination

Ground water is the main source of drinking water for several villages located on the river bank. Seepage of domestic, industrial sewage and agricultural runoff has contaminated the ground water quality in the basin. In addition, over-exploitation of ground water for irrigation has also added on. There are around 6 lakhs wells in TBSB and is increasing over a period of time. The extraction levels are high in the downstream of the river (Davanagere, Raichur and Bellary districts) and irrigation is the key sector contributing to extraction.

The Department of Mines and Geology monitor ground water quality regularly in the state. Based on the extent of contamination, the area is classified into four categories—most critical, critical, less critical and non-critically affected. Table 5 indicates the area with affected ground water quality in TBSB as on March 2004. Around 150 villages have been affected with poor ground water quality. The major pollutants are Nitrate, Flouride, Hardness and Iron. The most affected districts are Raichur and Bellary.

5.3.1 Ground Water Depletion

Over exploitation of ground water and increased use of fertilizers and pesticides have lead to ground water quality degradation in the TBSB. The data from the

Table 5 Area with affected ground water quality (in Hectares) (2004)

Status	Area with affected ground water in Ha			
	Tunga		Bhadra	
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Most critical			Nil	125.48
Critically affected	732.59	3,875.62	2	11,715.86
Less critically affected	3,233.95	3,550.79	2,093.43	17,117.13
Non-critically affected	13,087.69	9,627.82	54,365.54	27,502.51
Total	17,054.23	17,054.23	56,460.97	56,460.97

Source Department of Mines and Geology, 2009

Table 6 Ground water Levels in meteres

Districts	Years		
	1978	1987	1997
Bellary	7.37	7.40	10.91
Chikkamagalur	8.95	9.22	9.95
Raichur	5.96	7.03	6.58
Shimoga	9.23	9.03	9.76

Source Department of Mines and Geology, 2009

Department of Mines and Geology revealed that the ground water levels were depleting over a period of three decades as shown in Table 6.

6 Regulatory Institutions

KSPCB has an important role in the river water quality maintenance of the TBSB. The *Central Pollution Control Board (CPCB)* and the *Karnataka State Pollution Control Boards (KSPCB)* are the only bodies responsible for the monitoring and controlling of pollution. They were first set up under the 1974 Water Act. At present they are responsible for implementation of a number of pollution related Acts, their various amendments and Rules framed under them. The Board is enforcing the various Acts and Rules, out of which the ones related to water, are

- The Water (Prevention and Control of Pollution) Cess Act, 1977, and as amended in 1991.
- The Water (Prevention and Control of Pollution) Cess Rules, 1978.
- The Environment (Protection) Act, 1986.
- Rules framed under the Environment (Protection) Act, 1986.

6.1 Regulatory Mechanism

Regulatory institutions prevail to curtail water pollution. The Central Office of the KSPCB is responsible for making general policies relating to enforcement of various environmental legislations. KSPCB monitors water quality through carrying out sample testing across the river Basin. The Regional Pollution Control Boards located at five districts (Shimoga, Chikamaglur, Davangere, Bellary, Raichur and Koppal) in TBSB carries out frequent river water quality monitoring under Global Environmental Monitoring System Program (GEMS), Monitoring of National Aquatic Resources Programme (MINARS) and Board Programmes by collecting 74 samples (5 under GEMS, 40 under MINARS and 19 under Board Programmes)—(see Fig. 1). In addition, the Board has initiated action plans to prevent river pollution in four towns under the National River Action Plan (NRAP), initiated by the National River Conservation Directorate of the Ministry of Environment and Forest, Government of India.

The water quality status of the river was analyzed based on the quality analysis data collected from the KSPCB and Central Pollution Control Board (CPCB). It was difficult to get data from the Andhra Pradesh Pollution Control Board (AP-PCB) hence most of the description of water quality deals mainly with the stretch of the river in Karnataka state, which forms a major portion of the basin. However, there is considerable variation in the number of parameters monitored at the different stations over the years. After 2001, the KSPCB decided to restrict the number of parameters monitored and this creates a hiatus in the data. Inspection of the data provided by the KSPCB showed that at most five parameters at ten locations could be traced over a sufficiently long time period (from 1986 to 2005).

6.2 Prescribed Standards

There are various standards set up for allowable concentrations of parameters related to pollution. The most relevant are the drinking water standards specified by IS 10500:1991. More detailed standards are also recommended by the CPCB for different classes of surface waters and by the Bureau of Indian Standards (BIS) for Drinking Water.

Department of Mines and Geology (DMG) Ground water wing analyses ground water/surface water samples at the main laboratory at Bangalore, and also in the divisional laboratories at Mysore, Chitradurga, Dharwar, Belgaum, Bellary and Gulbarga. Ground water investigation also forms one of the functions of the Department where monitoring of quality is undertaken. However, linkages with other institutions and sharing the information on further curtailing pollution is not under its purview.

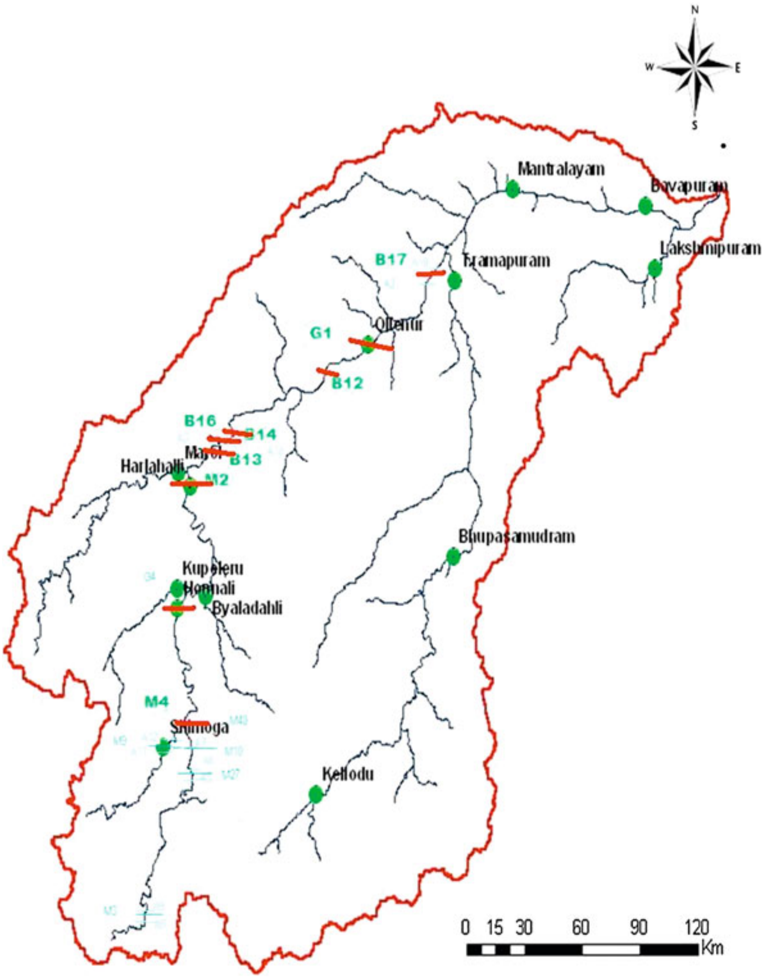


Fig. 1 Tungabhadra basin KSPCB water sampling stations *Source* Fazi et al. Deliverable 7.1

7 Fishing Communities

Fishing communities, located throughout the basin are either restricted to a few households spread out in a village or living in a locality together in groups, or ‘camps’ and range between 4 and 200 households. The fishing population is concentrated more in the Tungabhadra river stretch (5,000 families) compared to Tunga (3,000 families) and Bhadra stretch (2,000 families). Total fishermen population was 133,987 out of which 34,028 were full time fishermen. Difference in economic status across small scale fishermen was evident. Few households were totally dependant on fishing and others had complementary income from varied sources.

7.1 Large-Scale Fishermen

Large-scale fishermen fish in larger groups by hiring 15 to 20 labourers and were confined only to TB reservoir (400 groups) representing about 30 % of the total fishermen population. Nearly 66 % of the fishermen were engaged in fishing activity throughout the year and the rest between 6 and 10 months. During the lean period, they were engaged in agriculture and construction etc. These fishermen are paid members of Fishermen Cooperative Societies and obtain licenses. The larger groups are headed by a fisherman who would invest approximately around INR 3 lakhs. Each labourer is paid between INR 1800 and 2500 per month along with allowance for food, medical expenses, etc. The group spends the whole night (up to 10 h) in casting the nets and fishing till early hours. Fish catch ranges between 10 and 100 kg, which is highly dependent on the weather conditions, fingerlings released and season.

7.2 Small-Scale Fishermen

Small-scale fishermen work in a team of two or three persons representing 60 % of the fishermen population in the basin. Payments made to the society[4] varied between INR 200 (riverine, tank) to INR 4,000 (reservoir) based on type of net and fishing location. They were using gill nets of various sizes. 53 % of fishermen invested about INR 2,000 on boats and nets, annually. Small-scale fishermen who are members obtained licenses from the FCS and the period varied between 3 months and 1 year. However, whenever there were instances where some fishing communities paid the Fisheries department for canal fishing in Saibabanagar. Small-scale fishermen were economically poor and most vulnerable as the income level is low due to minimum fish catch. The quantity of fish catch per day during the lean season was as low as ½ kg at times, however, majority up to 55 % caught between 3 and 5 kg. 76 % of the fishermen were able to harvest 10–20 kg during peak season. Average income level varied between INR 2,000 and INR 6,000 per month. Poverty among the small-scale fishermen in particular was prominent as fish catch depended on external factors beyond their control hence migration was inevitable to sustain livelihoods. Poverty levels varied across locations even among the small-scale fishermen. 26 % fishing camps were located in areas that had very poor access to the main city, isolating women and children for most part of the year. During lean periods, women had to walk long distances in search of odd jobs while men migrated for months. With no transportation facilities, children were confined to these camps and had no access to schooling and basic medical care.

---

[4] Payments have to be made to the FCS that would have got the bid.

7.3 Women and Fishing in TBSB

The role of the women largely depended on the socio-economic conditions of the households. Overall, the conditions and quality of life for women were poor across different fishing groups. This included long working hours, poor wages as compared to men and in addition the burden of household maintenance. There were no special programs targeting women in the fishing sector. For instance, women in Hale Ayodhya, village confined themselves mainly to weaving of the nets. However, women in this village did not go out to sell fish unlike in some villages where they were responsible for selling fish. Women were involved mostly in processing and marketing of fish. In Thambrahalli, about 40 women worked as labourers sorting fish for the large contractors. On an average they sorted 30 kg of fish per day and were paid about INR 45 per day. Women also worked as agricultural labourers to substitute income from fishing (Sekhar et al. 2008a).

7.4 Formal Fishing Rights

Fishing rights were given through open tenders in reservoirs and rivers, whereas in case of tanks it was through open auctioning. As we see in the following sections, these varied forms of allocating fishing rights favour/disfavour the fishing communities. For example, licensing favours the fishermen in the place of tender systems, similarly, in the tank systems, open auctioning has no restrictions on bidding (initially bidding was done only by local fishing communities) for the tank and promote aquaculture as an entrepreneur, which is acting against the interests of the fishing communities. With respect to obtaining fishing rights, Department of Fisheries decides minimum reserve price.

7.5 Licensing

The legal fishing rights across sources were granted by the Department of Fisheries through licensing process. Members had to register by paying the prescribed fee annually, which varied based on location, duration of contract, types of nets, and number of boats. The members were given license to fish for a prescribed period, usually 6 months or one year. However, they were not eligible to get any credit facilities except fishing rights. Licensing system was preferred as the fee was minimal in TB basin where initially, leasing of the reservoir, was given to the small-scale fishermen by obtaining license from the TB Board. However, this practice was changed in 2001. The Board calls for a tender notification and the societies bid and the highest bidder benefits. However, in certain areas, fee varied and fishermen found it difficult to pay the license amount forcing them to depend on middlemen. Thus, the system worked against the welfare of the fishermen.

7.6 Open Auctioning

Open auctioning was another common practice to allot fishing rights across water bodies except in the Tungabhadra reservoir. In case of village tanks, *Grama-panchayats* were empowered to allot fishing rights through open auctioning that is not confined to the fishing communities within the village. Such a practice is usually to the disadvantage of the small fishermen in the village as outsiders/middlemen get involved in bidding and often tend to get the fishing rights. These middlemen in turn employed the local fishermen as labourers for fishing, in the process the local fishermen not only lose the rights to fish in the local water bodies but were forced to work for low wages. Although there was a regulation in the Department of Fisheries that the local fishermen should be given priority, the local councils and government agencies do not follow it. The government should support the local fishermen through loans or subsidies in order to help them get the fishing rights in these water bodies.

7.7 Open Tender

Allotting fishing rights through open tenders is practiced only in the Tungabhadra Reservoir since 2000. Tungabhadra Board, an autonomous body is responsible for inviting tenders. Main reason for inviting tenders was to cut down on illegal users. Information on call for tender is intimated to the FCS. The highest bidder gets the tender and they in turn sub lease the fishing rights to other fishermen. In reality, it is the private contractors/middlemen who enter the process and bid using the support of FCS, as the fishermen are not economically competent to invest the tender amount. Thus the open tender remains in the name of the FCS but invested and dictated by the middlemen. Presence of middlemen has led to more competition and an increase in the tender amount each year—from INR 300,000 in 2000 to INR 450,000 in 2007. Middlemen play an important role in the TBSB fisheries influencing fishing activities from the net to the market stage. Middlemen provide advance loans to fishermen who in turn are expected to sell their fish to him. The prices were decided by the middlemen and often lower than the market price. It was often the case that middlemen from the neighbouring districts Vijayawada and Kolkata paid advances to individuals and promoted them to compete for the tender. These individuals in turn sub-contract the licenses to middle level fishermen.

Although the system benefits the Board, it has led to disadvantages to the fishing community. All categories—small/large-scale fishermen and small-scale traders were against the tendering system. Irrespective of the harvest, the fishing groups have to pay, which may not be in the interest of the fishing groups. Apart from this, fishermen have no other skills to bank upon. Tender system has led to creation of more societies, dependency on middlemen, debt traps and conflicts.

8 Discussion and Conclusion

Pollution from various sources contaminates the river causing immense damage to the river ecosystems and livelihoods. Irrespective of various regulatory measures, implementation has not been as effective. Initiatives towards pollution control are not integrated across institutions and sectors. For instance, the role of the Karnataka State Pollution Control Board is limited to collecting water samples and sending reminders and issuing show–cause notices to the polluters. Monitoring and accountability systems are not in place. Similarly, in the case of ULBs, efforts towards establishing sewage treatment plants are constrained due to several reasons, finances, lack of political will and so on. Pollution from agriculture was obvious throughout the basin with impacts on land use changes. Current institutions have fewer roles to play with respect to non-point sources. Few studies conducted along the basin indicate the intensity and implications of pollution at specific points. Several water quality assessment models like SWAT and TEOTIL, AQUA MONITOR are popularly implemented in the developed countries to forecast future trends, however are not suitable due to data constraints both in terms of adequacy, access (costs and sharing) and quality and compatibility of data.

There is now greater awareness of water quality issues amongst the public in the area, although it is sometimes only narrowly focused on the two major activities of industry and mining. This awareness needs to be extended to agricultural diffuse pollution and urban wastewaters besides associated changes. There is a need for continued monitoring, and vigilance, on the part of civil society groups and concerned stakeholders. It is important that the roles of institutions are redefined to work towards restricting pollution. So, far, none of the organizations work in unison regarding the water quality issue but have a segmented approach in understanding water quality.

The study also showed that there were linkages between water quality and implications on livelihoods, besides fisheries in TBSB supported the livelihoods of a significant percent of population. Other issues on fishing communities were also discussed showing the need for interventions. The State Water Policy and water management plans in TBSB do not consider fisheries as a priority, though it does mention that water should be ensured for various sectors and to support livelihoods. Development initiatives by the Department of Fisheries are not integrated with the water management plans or other development activities of the water resources department or the Agriculture Department.

A number of policies and institutions already exist in TBSB that can facilitate improvement, what is needed is an integrated framework where the relevant polices; departments (state and local agencies) and programs can be pulled together to facilitate the access of the poor to fisheries and addressing the concerns discussed. Besides pollution, a number of measures can be imitated at the local level, for example, improving the water bodies, issuing licenses only to small scale and traditional fishermen and prioritizing the poor, developing local co-operative insurance schemes to include poor, legitimizing community networks, increasing training programs etc. Security of tenure is an important issue and fishermen are concerned about the rights to access and use common waters. The contexts of the poor are diverse and need to be addressed in a holistically in development programs.

References

Fazi S, Porto L (eds) Inputs by Line Barkved J, Porto AL, Fazi S, Raju KV, Latha N, Manasi S, Deelstra J, Thaulow H, Paranjape S, Joy KJ (2009) Scientific report on pollution source assessment, including source apportionment results, and pollution prevention measures. STRIVER Report No.D7.1, Part 1

Krishnaswamy J et al (2006) Impact of iron ore mining on suspended sediment response in a tropical catchment in Kudremukh, Western Ghats, India. For ecol manage 224(1):187–198

Patel AN (2005) Studies on the impact of Kudremukh mining activity on the environment of the western-ghats region

Raju KV, Manasi S (2007) (eds) Integrated water resources management in tungabhadra sub basin: issues and constraints, CEENR Report, Institute for Social and Economic Change, Bangalore

Sekhar NU, Raju KV, Manasi S, Latha N, Babu L (2008a) Fisheries and Livelihoods, STRIVER Deliverable 9.4

Sekhar NU, Raju KV, Manasi S, Latha N, Babu LK (2008b) Current status and future possibilities to improve the livelihoods of marginal communities. STRIVER Deliverable 9.5

Pollution Caused by Agricultural Waste Burning and Possible Alternate Uses of Crop Stubble: A Case Study of Punjab

Parmod Kumar and Laxmi Joshi

1 Introduction

With the adoption of photo-period non sensitive short duration varieties of wheat and rice in Punjab, rice-wheat crop rotation is practiced in areas which formerly produced only wheat or rice but not both in the same field in any one farming year. The major constraint in the rice-wheat cropping system is the available short time between rice harvesting and plantation of wheat and any delay in planting adversely affects the wheat crop. Preparation of the field also involved removal or utilization of rice straw left in the field. Every year almost 15 million tonnes of rice straw is generated in Punjab, due to the rice-wheat cropping pattern being followed in the region. Out of this, according to various estimates, on an average almost 7–8 million tonnes of rice residue is set on fire in the open fields. The reasons for this are manifold. According to a widely perceived notion, farmers find it the easiest and the most economical way of getting rid of the rice stubble. Also, the shortage of time for sowing the wheat crop, after the rice crop harvest, leaves farmers with no other option but to burn it.

One of the recognized threats to the rice-wheat cropping system sustainability is the loss of soil organic matter as a result of burning. The straw collected from the fields is of great economic value as livestock feed, fuel and industrial raw material. In northern India, wheat straw is preferred while in South India rice straw is fed to livestock. The residue generated from the rice-wheat cropping system can be put to many uses, but this is possible if the residue is separated from the grain and carried out of the field. Burning reduces the availability of straw to livestock, which is

P. Kumar (✉)
Professor and Head, ADRTC, Institute for Social and Economic Change (ISEC),
Nagarbhavi PO, Bangalore 560072, India
e-mail: pkumar@isec.ac.in

L. Joshi
Associate Fellow, National Council of Applied Economic Research,
New Delhi 110002, India

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_22,

already in short supply by more than 40 %. However, in the case of combine harvesting, most of the residue is left in the field for burning adversely affecting overall sustainability of the rice-wheat cropping system (Thakur 2003). Zero tillage after stubble burning is now being adopted by many farmers. In 2005–2006, around 10 % of the total area sown under wheat was by using zero till machines. Apparently less than one percent of farmers incorporate the rice straw because in the case of incorporation more tillage operations are required than after burning (Department of Agriculture, Punjab, 2005). The options for crop residue management may include developing systems to plant residue into bailing and removal for use as animal feed or for industry. Enhanced decomposition of machine-harvested straw to improve nutrients in the soil can be useful. The use of microbial sprays that can speed decomposition of residue is also an option. The option of planting into residue needs further investigation of inorganic N and its adverse effect due to N deficiency.

Burning of farm waste causes severe pollution of land and water on local as well as regional scale. It is estimated that burning of paddy straw results in nutrient losses, viz., 3.85 million tonnes of organic carbon, 59,000 tonnes of nitrogen, 20,000 tonnes of phosphorus and 34,000 tonnes of potassium. This also adversely affects the nutrient budget in the soil. Straw carbon, nitrogen and sulphur are completely burnt and lost to the atmosphere in the process of burning. It results in the emission of smoke which when added to the gases present in the air like methane, nitrogen oxide and ammonia can cause severe atmospheric pollution. These gaseous emissions can result in health risk, aggravating asthma, chronic bronchitis and decrease lung function. Burning of crop residue also contributes indirectly to the increased ozone pollution. It has adverse consequences on the quality of soil. As the crop residue is burnt the existing minerals present in the soil get destroyed which adversely hampers the cultivation of the next crop.

The problem of pollution caused by rice and wheat crop stubble burning has not received much attention by the policymakers and the various pollution authorities till recently. This could be partially due to the fact that the rice burning (the major source agri waste burning pollution) takes place only during selected months of October, November and December and it is mostly prevalent in Punjab and Haryana. The pollution is restricted only during harvesting months but even during these months there is considerable loss to human health and environment degradation. This paper makes an attempt to measure the extent of pollution generated by agriculture waste burning, especially that of crop stubble burning. The paper presents various estimates available in the literature on the volume of agriculture crop stubble being generated and out of that how much is being burnt. The paper also looks into the possible alternate uses of crop stubble that if become effective can save the environment on the pollution front. The information is compiled from various published and unpublished documents and by visiting offices of various departments of Punjab Government. The paper is divided into 5 Sections. Next section presents various estimates of crop stubble generation. Section 3 presents amount of pollution caused by crop stubble burning. Section 4 is devoted on the possible alternate uses of crop stubble. The alternate uses include various options like use of stubble for fodder, its use in paper industry, mushroom production, biogas, ethanol production etc., but the most important is its use in energy generation. Finally paper is concluded in the Sect. 5.

2 The Proportion of Crop Stubble Produced

Various studies have brought to the forefront the quantity of crop stubble generated in Punjab and the proportion of wheat and rice stubble in the total. As per different studies, the residues of rice and wheat crops are major contributors in the total stubble loads. One such study by Garg (2008) estimates the contribution of rice and wheat stubble loads in the total stubble as 36 and 41 % in India, respectively, while the contribution of Punjab in the total burnt stubble of rice and wheat to be 11 and 36 %, respectively. According to Gupta et al. (2004), the total crop residue produced in India is approximately 347 million tonnes of which rice and wheat crop residues together constituted more than 200 million tonnes. According to Sidhu and Beri (2005), total production of paddy stubble in Punjab in 2004–2005 reached 18.8 million tonnes of which 15 million tonnes was burnt in the open fields. The study further quotes that 80 % of the rice harvested using combined harvester is burnt in the open fields. According to Singh et al. (2008), around 17 million tonnes of rice straw is produced every year in Punjab of which 90 % is burnt in the open fields. Another study by Punia et al. (2008) attempts to estimate district-wise burnt area of agricultural residue by using remote sensing data. The total burnt area in Punjab was found to be around 4315.35 km^2 in 2005. Among these, Amritsar had more area burnt (673.99 km^2) followed by Jhalandar, Ludhiana, Firozpur and Patiala districts while Roopnagar had the least burnt area (41.36 km^2).

3 Studies on the Amount of Pollution Caused by Crop Stubble Burning

Open field burning of crop stubble results in the emission of many harmful gases in the atmosphere, like Carbon Monoxide, N_2O, NO_2, SO_2, CH_4 along with particulate matter and hydro carbons. These trace gases have adverse implications not only on the atmosphere but also on human and animal health, Gupta and Sahai (2005), Lal (2006), Agrawal et al. (2006) and Canadian Lung Association (2007). The burning also results in the loss of plant nutrients and thus adversely affects the soil properties. It has been estimated that for the year 2000 the emission of CH_4, CO, N_2O and NO_2 was 110, 2,306, 2 and 84 Gg respectively, from the field-burning of rice and wheat straw, Mandal et al. (2004). A study conducted by National Remote Sensing Agency in Punjab reported that wheat crop residue burning contributed about 113 Gg (Giga gram = 10 billion gram) of CO, 8.6 Gg of NO_2, 1.33 Gg of CH_4, 13 Gg of PM_{10} and 12 Gg of $PM_{2.5}$ during May 2005 and paddy straw/stubble burning was estimated to contribute 261 Gg of CO, 19.8 Gg of NO_2, 3 Gh of CH_4, 30 Gg of PM_{10} and 28.3 Gg of $PM_{2.5}$ during October, 2005 (Badarinath and Chand Kiran 2006).

The information provided by Punjab Agricultural University to the State Environmental Council also estimated that the crop residues contained about 6.0 million tonnes of Carbon that on burning could produce about 22.0 million tonnes of Carbon Dioxide in a short span of 15–20 days. Additionally, the smoke plumes contained particulates of partially combusted materials as soot, which became airborne and were transported downwind especially during winters when inversion sets in. Studies conducted by Punjab Pollution Control Board (PPCB) in 2006 in villages namely, Dhanouri, Simbro and Ajnouda kalan in district Patiala also indicated that CO and pollutant particulates were of major concern. CO appeared to be the most critical as concentrations of 114.5 mg/m^3 or more were observed at 30 m distance from burning fields and 20.6 mg/m^3 CO was recorded at residences which were even 150 m away. Since the permissible limit of CO in ambient air is 4.0 Ug/m^3, this was a major health hazard for residents and road travelers in the area. Further, particulates were also being released in large quantities. $PM_{2.5}$ ranged between 146 and 221 μg/m^3 in critically affected areas and average PM_{10} values were found 300 μg/m^3, against a permissible limit of 60 μg/m^3 for residential rural areas. Significant amounts (40–50 μg/m^3) of NO_2 and NH_3 were also recorded during burning, at residences located 200–4,000 m away from burning site, though concentration of SO_2 was less. Further, concentrations of organic pollutants were also found to be significantly high. The smoke was also found to be toxic due to presence of heavy metals, especially iron and Zinc. Iron concentrations were in the range of 6,778–13,240 μg/m^3 whereas zinc concentrations were in the range of 1,021–4,854 μg/m^3.

Burning of crop stubble has severe adverse implications especially for those people suffering from respiratory disease, cardiovascular disease. Pregnant women and small children are also likely to suffer from the smoke produced due to stubble burning. Inhaling of fine particulate matter of less than $PM_{2.5}\mu$ triggers asthma and can even aggravate symptoms of bronchial attack. According to Singh et al. (2008), more than 60 % of the population in Punjab live in the rice growing areas and is exposed to air pollution due to burning of rice stubbles. As per the same study, medical records of the civil hospital of Jira, in the rice-wheat belt showed a 10 % increase in the number of patients within 20–25 days of the burning period every season.

According to Gadde et al. (2009), open burning of crop stubble results in the emissions of harmful chemicals like polychlorinated dibenzo-p-dioxins, polycyclic aromatic hydrocarbons (PAH's) and polychlorinated dibenzofurans (PCDFs) referred to as dioxins. These air pollutants have toxicological properties and are potential carcinogens. Furthermore, the release of Carbon dioxide in the atmosphere due to crop stubble burning results in the depletion of the oxygen layer in the natural environment causing green house effect. Burning of crop waste also has adverse implications on the health of milk producing animals. Air pollution can result in the death of animals, as the high levels of CO_2 and CO in the blood can convert normal hemoglobin into deadly hemoglobin. There can also be a potential decrease in the yield of the milk producing animals. Burning also results in the loss of important nutrients present in the crop stubble. About 25 % of N and P, 50 % of S and 75 % of K uptake by cereal crops are retained in crop residues making them viable nutrient sources. According to Singh et al. (2008) the nutrients loss due to burning of rice residues in Punjab in 2001–2002 was 2,400 kg of C, 35 kg of N, 3.2 kg of P, 21 kg of K and 2.7 kg of S in one hectare. While loss of C and N was almost full, the loss of P, K and S was partial (around 20–60 %).

As per a study by Gupta et al. (2004) one tonne of straw on burning releases 3 kg of particulate matter, 60 kg of CO, 1,460 kg of CO_2, 199 kg of ash and 2 kg of SO_2. Further, in the year 2000, around 78 million tonnes of rice and 85 million tonnes of wheat straw were generated in India of which around 17–18 million tonnes ended up being burnt in the field (Table1). According to Singh et al. (2008), the major pollutants that are emitted during crop residue burning are given in Table 2. According to Venkataraman et al. (2006) open burning contributed to 25 % of black carbon, organic matter and carbon monoxide emissions, 9–13 % to $PM_{2.5}$ and CO_2 emissions and 1 % to SO_2 emissions. The crop waste burned in the fields range from 18 to 30 % and has strong regional variations Table 3 provides details of crop wise biomass burned and emissions of aerosols and trace gases as estimated by Venkataraman et al (2006). (Table 3).

Study by Gupta et al. (2004) indicated that burning of straw also emits large amount of particulates that are composed of a wide variety of organic and inorganic species. One tonne straw on burning releases 3 particulate matter, 60 kg CO, 1,460 kg CO_2, 199 kg ash and 2 kg SO_2. These gases and aerosols consisting of carbonaceous matter have an important role to play in the atmospheric chemistry and can affect regional environment that also has linkages with global climate change. Gupta et al. (2004) in their study estimated that burning of straw raises the soil temperature up to 33.8–42.2 °C (1 cm depth). About 23–73 % of nitrogen is lost and the fungal and bacterial population are decreased immediately (2.5 cm depth of soil). According to a study conducted by Department of Soils, PAU 2006, Punjab produces around 23 million tonnes of rice straw and 17 million tonnes of wheat straw, annually. The burning of straw raises the temperature of the soil in the top 3 inches to such a high degree that Carbon-Nitrogen equilibrium in soil changes rapidly. The carbon as CO_2 is lost to atmosphere, while nitrogen is converted to nitrate. This leads to a loss of about 0.824 million tonnes of NPK from soil.

The above data clearly establishes that mass agricultural residue burning in the fields is seriously damaging the environment. Further, open burning of residue in the fields also leads to death of soil micro flora and funa and may also damage nearby trees in addition to adjoining standing crops. Further, the ash left after burning is a very good absorbent and if not fixed properly, absorbs the applied weedicides, which results in decreased efficacy of herbicides.

Table 1 Various studies reporting the quantity of rice residue burnt in open fields in Punjab

Literature and year of study	Percentage of rice and wheat crop harvested using a combined harvester in Punjab	Dry fodder yield of		Quantity of rice residue burnt in open fields in Punjab
		Rice	Wheat	
Badarinath and Chand Kiran (2006)	75–80 %	6.2–11.8 t ha^{-1}	3.2–5.6 t ha^{-1}	70–80 million tonnes
Mandal et al. (2004)	More than 75 %	Data not available	Data not available	10 t ha^{-1}
Sidhu et al.(1998)	88.6 % for rice, 56.6 % for wheat	Data not available	Data not available	Varies according to different districts. Highest being for Bhatinda where all the rice stubble is burnt, followed by Faridkot at 97.6 %, Ludhiana and Sangrur at 95 % each
Gupta et al.(2004)	75 %	78 million tonnes (2000)	85 million tonnes (2000)	17 million tonnes of rice 19 million tonnes of wheat
Sidhu and Beri (2005)	More than 75 %	Data not available	Data not available	80 % of the total harvested using combined harvesters
Badve (1991)	Data not available	134.35 million tonnes (1983–1984)	67.71 million tonnes (1983–1984)	Data not available
Venkataraman et al. (2006)	Data not available			30–40 % straw burnt (IGP)
Sarkar et al. (1999)	75 % combine harvested			100 % burnt

Source Different studies in the literature

Table 2 Major pollutants emitted during crop residue burning

Category	Pollutants	Source
Particulars	SPM (PM_{100})	Incomplete combustion of in organic material, particle on burnt soil
	RPM (PM_{10}) FPM ($PM_{2.5}$)	Condensation after combustion of gases and incomplete combustion of organic matter
Gases	CO	Incomplete combustion of organic matter
	NO_2 and N_2O	Oxidation of N_2 in air at high temperature
	O_3	Secondary pollutant, form due to Nitrogen Oxide and Hydrocarbon
	CH_4/Benzen	Incomplete combustion of organic matter
	PAH_S	Incomplete combustion of organic matter

SPM Small particulate matter; *PM* Particulate matter; *FPM* Fine particulate matter
Source Singh et al. (2008)

Table 3 National estimates of biomass burned and emission of Aerosols and Trace gases for crop waste open burning

Pollutants	Crop waste burning (Emission factors Gg yr^{-1})				
	Cereals	Sugarcane	Others	Total crop waste	Total open burning
Biomass burned Tg yr^{-1}	67–189	32–70	17–30	116–289	148–350
BC	55–292	19–49	12–31	86–372	102–409
OC	134–770	48–122	39–79	211–970	399–1529
OM	287–1,250	97–247	60–143	444–1,639	663–2,303
$PM_{2.5}$	369–1,913	125–289	78–191	572–2,393	851–3,317
CO_2 Tg yr^{-1}	102–353	48–131	25–55	175–539	224–638
CO, Tg yr^{-1}	6–49	3–18	2–8	10–74	13–81
SO_2	27–113	13–42	7–18	46–172	66–238
NO_X	168–845	80–313	42–132	289–1,290	393–1,540
CH_4	181–762	86–283	45–119	313–1,164	420–1,486
NMVOC	1,055–4,430	500–1,644	263–693	1,818–6,767	2,039–7,406
NH_3	87–367	41–136	22–57	151–560	189–661

Source Venkataraman et al. (2006)

Thus, the on-site impact of burning includes removal of a large portion of the organic material, denying the soil an opportunity to enhance its organic matter and incorporate important chemicals such as nitrogen and phosphorus, as well as, loss of useful micro flora and funa. The off-site impacts are health related due to general air quality degradation of the region resulting in aggravation of respiratory (like cough, asthma, bronchitis), eye and skin diseases. Fine particles also can aggravate chronic heart and lung diseases and have been linked to premature deaths in people already suffering from these diseases. The black soot generated during burning also results in poor visibility which could lead to increased road side incidence of accidents. It is thus essential to mitigate impacts due to the burning of agricultural waste in the open fields and its consequent effects on soil, ambient air and living organisms.

Table 4 End use of paddy straw

S No.	Author	Disposal pattern
1	Badarinath and Chand Kiran (2006)	75–80 % area is machine harvested ¾ or 75 % of straw is burnt
2	Venkataraman et al. (2006)	30–40 % straw burnt (IGP)
3	Sarkar et al. (1999)	75 % combine harvested and 100 % burnt
4	Gupta et al. (2004)	Industrial/domestic fuel, fodder, packaging, feeding, wall construction, in situ incorporation, green manuring, thatching etc
Average		75 % of paddy is burnt

The disposal pattern of paddy straw by the farmers depends on the market value of the by-product. Table 4 presents the methods adopted by the farmers for disposal of by-product as mentioned in various studies. From the table it is clear that on average, three fourth or 75 % of the paddy straw is burnt openly in the fields. The above ratio implies that during 2007–2008, around 11,930–15,858 thousand tonnes of paddy straw was burnt in the open field in Punjab. The state produces around 23 million tonnes of rice straw and 17 million tonnes of wheat straw annually. More than 80 % of paddy straw (18.4 million tonnes) and almost 50 % wheat straw (8.5 million tonnes) produced in the state is being burnt in fields. Almost whole of paddy straw, except Basmati paddy is burnt in the field to enable early sowing of next crop. Lately, the farmers have extended this practice to wheat crop also. Though part of the wheat straw is used as dry fodder for the milch cattle, but the remaining straw is usually burnt for quick disposal. Burning in Punjab involves partial and full burning. Partial burning entails running of combine harvester followed by burning of small stalks while complete burning entails setting the entire field on fire. The latter practice is mostly followed by the farmers in Punjab. Both the practices cause pollution but the impact is more severe in the case of complete burning. The farmers in the region are resorting to burning of straw because they don't have other equal or more remunerative alternatives available to them.

4 Management of Agricultural Waste for Alternate Uses

There are many environmental risks associated with stubble burning. If followed continuously burning can reduce soil quality and make land more susceptible to erosion. Moreover, continuous burning is not a sustainable agricultural practice. Smoke from burning straw also contributes to increased carbon dioxide levels in the atmosphere which may affect greenhouse gas build-up.

The Department of Science, Technology and Environment and Non Conventional Sources of Energy, Government of Punjab, constituted a task force in September, 2006 for formulation of policy to mitigate the problem due to the severity of burning of agricultural waste in the open fields after harvest and its consequent effects on soil, ambient air and health effects on living organism. The task force has suggested promotion of agronomic practices and technological measures for better utilization of agricultural wastes. These include use of happy seeder, developed by Punjab Agricultural University (PAU) in collaboration with Australian Centre for International Agriculture Research (ACIAR) and use of paddy straw for power generation.

Agricultural waste includes paddy and wheat straw, cotton sticks, bagasse and animal waste. Keeping in view the increasing problems associated with crop stubble burning several initiatives for its proper management have been taken up. Various departments and institutions are promoting alternative uses of straw instead of burning. These include:

4.1 Use of Rice Residue as Fodder for Animals

The rice residue as fodder for animals is not a very popular practice among farmers in Punjab. This is mainly because of the high silica content in the rice residue. It is believed that almost 40 % of the wheat straw produced in Punjab is used as dry fodder for animals. However to encourage the use of rice residue as fodder for animals, a pilot project was taken up by Punjab State Council for Science and Technology (PSCST) at PAU under which trials on natural fermentation of paddy straw for use as protein enriched livestock feed were conducted. The cattle fed with this feed showed improvement in health and milk production. The technology was demonstrated in district Gurdaspur, Ludhiana, Hoshiarpur and Bathinda. The department of Animal Husbandry, Punjab has propagated the technology in the state.

In India, total production of residue of paddy is almost 30 million tonnes for the total livestock of 464,472 thousands. Thus the consumption of paddy residue per livestock stands at 0.06 tonnes per animal. Highest imbalance of livestock and consumption is in Rajasthan with zero consumption per animal. Other such low ranked states with least consumption rate are Madhya Pradesh, Himachal Pradesh, Maharashtra and Sikkim. Punjab has the highest ratio of consumption, followed by Kerala and North Eastern states viz., Tripura and Manipur. Uttar Pradesh has highest concentration of livestock which is followed by Rajasthan, Madhya Pradesh and Maharashtra. The residue is found highest in West Bengal and Arunachal Pradesh.

The availability of crop residue in India is 253.26 million tonnes whereas the requirement is 415.83 million tonnes. Thus there is a shortfall of almost 40 %. On the other hand, the availability of green fodder is 142.82 million tonnes and requirement is 221.63 million tonnes with a short fall of almost 36 %. Only Punjab and Mizoram have surplus residues. Excepting Assam almost all the north Eastern States and Kerala have least availability of crop residue. States like Punjab, Haryana and Bihar has higher per animal availability as compared to other states of India. It makes a perfect case if Punjab rather than burning surplus residue on the field exports it to the deficit neighbouring states like Rajasthan and Gujarat. However, for that to happen there is need for developing technology to plant residue into bailing and removal from the field its compressing the same for easy transportation to other places.

4.2 Use of Rice Residue as Bedding Material for Cattle

The farmers of the Punjab have been advised to use paddy straw as bedding material for cross bred cows during winters as per results of a study conducted by the Department of Livestock Production and Management, College of Veterinary Sciences, Punjab Agricultural University. It has been found that the use of paddy straw bedding during winter helped in improving the quality and quantity of milk as it contributed to animals' comfort, under health and leg health. Paddy straw bedding helped the animals keep themselves warm and maintain reasonable rates of heat loss from the body. It also provides clean, hygienic, dry, comfortable and non-slippery environment, which prevents the chances of injury and lameness. Healthy legs and hooves ensure enhancement of milk production and reproductive efficiency of animals. The paddy straw used for bedding could be subsequently used in biogas plants. The use of paddy straw was also found to result in increased net profit of Rs 188 to Rs 971 per animal per month from the sale of additional amount of milk produced by cows provided with bedding. The PAU has been demonstrating this technology to farmers through training courses, radio/TV talks and by distributing leaflets.

4.3 Use of Crop Residue for Mushroom Cultivation:

Paddy straw can be used for the cultivation of Agaricus bisporus, Volveriella volvacea and Pleurotus spp. One kg of paddy straw yields 300, 120–150 and 600 gm of respective quantity of mushrooms. At present, about 20,000 metric tonnes of straw is being used for cultivation of mushrooms in the state. Paddy Straw Mushrooms (Volvariella Volvacea) also known as grass mushrooms are so named for their cultivation on rice straw used in South Asia. Paddy Straw is high temperature mushroom grown largely in tropical and subtropical regions of Asia, e.g. China, Taiwan, Thailand, Indonesia, India, and Madagascar. In Indonesia and Malaysia, mushroom growers just leave thoroughly moistened paddy straw under trees and wait for harvest. This mushroom can be grown on a variety of agricultural wastes (the cultivation method of this mushroom is similar to that of Agaricus bisporus) for preparation of the substrate such as water hyacinth, oil palm bunch waste, dried banana leaves, cotton or wood waste, though with lower yield than with paddy straw, which is most successful. Paddy straw mushroom accounts for 16 % of total production of cultivated mushroom in the world.

4.4 Use of Rice Residue in Paper Production

The rice straw is also being used in conjunction with wheat straw in 40:60 ratio for paper production. The sludge can be subjected to bio-methanization for energy production. The technology is already operational in some paper mills, which are meeting 60 % of their energy requirement through this method. Rice straw is also used as an ideal raw material for paper and pulp board manufacturing. As per information provided by Punjab Agricultural University more than 50 % pulp board mills are using paddy straw as their raw material.

4.5 Use of Rice Residue for Making Bio Gas

The PSFC has been coordinating a project for processing of farm residue into biogas based on the technology developed by Sardar Patel Renewable Energy Research Institute (SPRERI). A power plant of 1 MW is proposed to be set up at Ladhowal on pilot basis on land provided by PAU. The new technology will generate 300 cubic metre of biogas from one tonne of paddy straw.

4.6 In Situ/Incorporation of Paddy Straw in Soil

The other technical measures of disposing off crop stubble are 'straw incorporation' and straw mulching'. In both these measures, the residue is incorporated in the field itself and is thus used to increase the nutrient value or fertility of the soil. In the first measure, the residue is allowed to decompose in the field itself through a chemically developed process and in the second measure incorporation is done with the help of a properly designed machine along with seeding. The second measure is more useful as there is no weeding in this process and it is less expensive.

The incorporation of the straw in the soil has a favorable effect on the soil's physical, chemical and biological properties such as pH, Organic carbon, water holding capacity and bulk density of the soil. On a long-term basis it has been seen to increase the availability of zinc, copper, iron and manganese content in the soil and it also prevents the leaching of nitrates. By increasing organic carbon it increases bacteria and fungi in the soil. In a rice-wheat rotation, Beri et al. (1992) and Sidhu et al. (1995) observed that soil treated with crop residues held 5–10 times more aerobic bacteria and 1.5–11 times more fungi than soil where residues were either burnt or removed. Due to increase in microbial population, the activity of soil enzymes responsible for conversion of unavailable to available form of nutrients also increases. Mulching with rice straw has been shown to have a favorable effect on the yield of maize, soybean and sugarcane crops. It also results in substantial savings in irrigation and fertilizers.

4.7 Production of Bio-Oil from Straw and Other Agricultural Wastes

Bio-oil is a high density liquid obtained from biomass through rapid pyrolysis technology. It has a heating value of approximately 55 % as compared to diesel. It can be stored, pumped and transported like petroleum based product and can be combusted directly in boilers, gas turbines and slow and medium speed diesels for heat and power applications, including transportation. Further, bio-oil is free from SO_2 emissions and produces low NO_2. Certain Canadian companies (like Dyna Motive Canada Inc.) have patented technologies to produce bio-oil from biomass including agricultural waste. Though their major experience is with bagasse, wheat straw and rice hulls, feasibility of this technology with rice straw needs to be assessed.

4.8 Use of Crop Residue in Bio Thermal Power Plants

Rice straw is a major field-based residue that is produced in large amounts in Asia. In fact the total amount of 668 tonnes could produce theoretically 187 gallons of bio-ethanol if the technology were available (Kim and Dale 2004). Biomass, such as agricultural residue, bagasse, cotton stalks, rice stubble etc., is emerging as a viable source of power. Direct burning of such waste is inefficient and leads to pollution. When combusted in a gasifier at low oxygen and high temperature, biomass can be converted into a gaseous fuel known as producer gas. This gas has a lower calorific value compared to natural gas or liquefied petroleum gas, but can be burnt with high efficiency and without emitting smoke. The advantages of utilizing crop residue over and above conventional resources are that the residue is renewable, readily available and can be used successfully by burning in boilers with an efficiency of 99 %. Further, they are available at low cost relative to coal and their ash contents are also much less (as compared to 36 % ash content of coal). The calorific value of both coal and paddy straw are comparable, i.e., 4,200 and 3,590 kcal/Kg, respectively. Additional income to the farmers from the sale of straw is an added advantage. At the same time, state agencies involved could also take advantage of carbon credit policy set up under the United Nation Framework Convention on Climate Change (UNFCCC). The policy involves the allocation of credits to programs which help in curbing global warming. Indian government should encourage private parties/agencies to take advantage of this carbon credit policy of UNFCCC.

Bio-mass-based power plants of 10–20 megawatts capacity set up in a group of villages or every *Taluka* can meet energy needs of villagers and employ thousands of people. Kirangatevalu village in Karnataka is a prime example in this regard. In Punjab in the 1980s Punjab State Electricity Board (PSEB) had set up a 10 MW power plant based on rice straw at Village Jalkheri, District Fatehgarh Sahib in which 250–3,000 tons per day (TPD) of fuel is burnt in a boiler furnace of steam generation capacity of 50 tons per hour (TPH). The plant earlier used rice straw but due to clinkerisation of boiler, rice straw was replaced with rice husk, cow dung and other agro wastes. This plant has since been leased out by PSEB to M/S Jalkheri Power Private Limited. Now these plants will be using improved technology and M/S Punjab Biomass Power Limited has signed two agreements with PSEB for setting up 12 MW rice straw based power plants at Baghaura in Rajpura Tehsil and Sawai Singh village in Patiala Tehsil. A total amount of 0.1 million tones of paddy straw would be collected from a command area of 25 km^2 around each unit and a barter system of providing electricity will be worked out with the farmers. The units will be run on Build Own Operate (BOO)[1] basis. Detailed project reports (DPR) have been prepared and land is being purchased.

Transportation costs of straw are a major constraint to its use as an energy source. As a rule of thumb, transportation distances beyond a 25–50 km radius (depending on local infrastructure) are uneconomical. For longer distances, straw could be compressed as bales or briquettes in the field, rendering transport to the site of use a viable option. Nevertheless, the logistics of a supply chain is more complicated in the case of straw. Although five different energy conversion technologies seem to be applicable for rice straw in principle, only combustion technology is currently commercialized and the other technologies are at different stages of development. As a general rule for energy use, each step in the chain consumes a certain amount of energy and thus reduces the net energy supplied at the final stage.

The National Biomass Assessment Project of Ministry of New and Renewable Energy, Government of India, conducted a biomass study in which 29 Tehsil were surveyed from 1995 to 2001. A total of 36 Talukas were included from different districts. The power generating potential was estimated at 342 MW. Following these developments, Punjab Energy Development Agency (PEDA) facilitated setting up of a 6 MW biomass power project at village Gullabewala in district Mukatsar. This was undertaken as a joint project with M/s Malwa Power Pvt. Ltd., at a cost of Rs 21.50 crore. The project was completed and commissioned in May 2005 and is operating satisfactorily.

Encouraged by the success of Gullabewala, PEDA is now collaborating with the private sector for the establishment of power projects based on agricultural residues. A total of 20 projects with a total installed capacity of 320 MW have

[1] In a BOO project ownership of the project remains usually with the Project Company. Therefore the private company gets the benefits of any residual value of the project. This framework is used when the physical life of the project coincides with the concession period. A BOO scheme involves large amounts of finance and long payback period.

Table 5 Detailed status of biomass based power projects

Sr. No	Name of the company	Site	Capacity (MW)	Date of commence-ment
Phase I				
1	M/s Turbo Atom TPS Projects Pvt Ltd	Vill. Booh Patti (Amritsar)	10	Dec 2011
2	-do-	Vill. Choran Wali Batala (Gurdaspur)	10	Dec 2011
3	-do-	Vill. Burj Baghel Singh Wala Malerkotla (Sangrur)	20	March 2012
4	-do-	Vill. Jhok Tehal Singh, (Ferozepur)	10	March 2012
5	M/s Green Field Energen Pvt. Ltd	Talwandi Sabo	6	Dec 2011
Phase II				
6	M/s Dee Development Engineers Pvt. Ltd	Village Gadda Dhob, Tehsil Abohar, District Ferozepur	8	Commenced
7	M/s Sea Sky Cargo and Travels Pvt. Ltd.	Vill. Ajnala (Amritsar)	10	Canceled
8	M/s Meenakshi Infrastructure Pvt Ltd	Sunam (Sangrur)	31	Canceled
Phase III				
9	M/s Green Planet Energy Pvt. Ltd	Vill. Manuke Gill, Tehsil Nihal Singh Wala & Bagha Purana (Moga)	5	Oct 2011
10	-do-	Vill. Bir Pind, Tehsil Nakodar (Jalandhar)	10	June 2011
11	-do-	Vill. Deep Singh Wala, (Faridkot)	9	Dec 2011
12	-do-	Vill. Ramiana, Tehsil Jaito (Faridkot)	13	Dec 2011
13	-do-	Vill. Binjon, Tehsil Garhshankar (Hoshiarpur)	10	June 2011
14	-do-	Vill. Talwandi Rai, Tehsil Raikot (Ludhiana)	14	March 2012
15	-do-	Vill. Handiyan, Tehsil & District Barnala	10	Cancelled
16	-do-	Phillour, District Jalandhar	10	Cancelled
17	-do-	Shahkot, District Jalandhar	10	Cancelled
18	-do-	Vill. Kalyan Sukha, Tehsil & District Bathinda	13.5	March 2012
19	-do-	Vill. Dhanasoo, Telsil & District Ludhiana	15	Dec 2011
20	-do-	Vill. Challaiwala, Tehsil Sultanpur Lodhi (Kapurthala)	9	Dec 2011
21	-do-	Vill. Boran, Tehsil and District Fatehgarh Sahib	11	Dec 2011

(continued)

Table 5 (continued)

Sr. No	Name of the company	Site	Capacity (MW)	Date of commence-ment
22	-do-	Vill. Kanhari, Tehsil Amloh and District Fatehgarh Sahib	6	Cancelled
23	M/s. P and R Engineering Services Ltd.	Anandpur Sahib	5	March 2012
24	-do-	Ropar	10	March 2012
25	-do-	Nawanshahr	10	March 2012
26	M/s Orient Green Power Pvt. Ltd	Amritsar	10	March 2012
27	-do-	Patiala	10	Cancelled
28	M/s Food Fats and Fertilizers Pvt. Ltd.	Mansa	20	Feb 2012
29	M/s Universal Biomass Energy Ltd.	Malout (Near Mandi Dabwali)	14.5	Commissioned
	Gross Total		330	

Source Punjab Energy Development Agency (PEDA); www.peda.gov.in been allotted on BOO basis to private developers. These projects are being setup by the private developers with the state of the art technologies such as Biomethanation, Combustion etc. The plants will be designed to receive mixed waste such as paddy straw, cotton stalks and other agro residues available in the state. Two projects of 8 and 14.5 MW were expected to be commissioned by 2009. Land has already been allocated to the developers for another 5 plants and work was scheduled to commence by March–April 2009. According to information provided by PEDA, biomass power projects are planned to be allocated in the following phases:

- Phase I—agreements reached with two companies—M/s Turbo Atom TPS and M/s Green Field Energen Pvt. Ltd., in New Delhi and Chandigarh, respectively for two Tehsils, Ferozepur and Patti with a total capacity of 56 MW (For details see Table 5).
- Phase II—three companies were there for Abohar, Sunam and Ajnala, respectively. The two companies of Sunam and Ajnala are cancelled having 41 MW. With the capacity of 8 MW the company M/s Dee Development in Abohar Tehsil is commissioned (see Table 5 for details) .
- Phase III—six companies with different feed stocks. The M/s Green Plant of Chandigarh is based on paddy straw which is planned in 14 Tehsils with total 146.5 MW of capacity. Out of which Garhshankar with 10 MW capacity is likely to begin. M/s Univeral Biomass of Mukatsar which is mostly based on cotton stock with 14.5 MW in Malout Tehsil is commissioned. The Malwa Power Ltd., in the village Gulabevala in the district of Muketsar was started before PEDA took over with 6 MW. Other three companies have total capacity of 65 MW (for details see Table 5).

PEDA has so far allocated 30 sites/tehsils for setting up plants with a total generation capacity of 337 MW. Table 5 gives detailed status of biomass based power projects.

5 Conclusions and Policy Implications

Crop residue burning is one among the many sources of air pollution. Nature has always had the ability to absorb the entire residue being generated by farming since the beginning of time. However due to technological advancements in the agricultural sector, waste concentration goes beyond certain limits thereby distorting the balance. Burning of farm waste causes severe pollution of land and water on local as well as regional scale. It is estimated that burning of paddy straw results in nutrient losses viz., 3.85 million tons of organic carbon, 59,000 tons of nitrogen, 20,000 tons of phosphorus and 34,000 tons of potassium. This also adversely affects the nutrient budget in the soil. Straw carbon, nitrogen and sulphur are completely burnt and lost to the atmosphere in the process of burning. It results in the emission of smoke which if added to the gases present in the air like methane, nitrogen oxide and ammonia, can cause severe atmospheric pollution. These gaseous emissions can result in health risk, aggravating asthma, chronic bronchitis and decrease lung function. Burning of crop residue also contributes indirectly to the increased ozone pollution. It has adverse consequences on the quality of soil. When the crop residue is burnt the existing minerals present in the soil get destroyed which adversely hampers the cultivation of the next crop. Open field burning of crop stubble results in the emission of many harmful gases in the atmosphere, like Carbon Monoxide, N_2O, NO_2, SO_2, CH_4 along with particulate matter and hydro carbons.

The on field impact of burning includes removal of a large portion of the organic material, denying the soil an opportunity to enhance its organic matter and incorporate important chemicals such as nitrogen and phosphorus, as well as, loss of useful micro flora and fauna. The off field impacts are related to human health due to general air quality degradation resulting in aggravation of respiratory (like cough, asthma, bronchitis), eye and skin diseases. Fine particles also can aggravate chronic heart and lung diseases and have been linked to premature deaths in people already suffering from these diseases. The black soot generated during burning also results in poor visibility which could lead to increased road side incidences of accident. It is thus essential to mitigate impacts due to the burning of agricultural waste in the open fields and its consequent effects on soil, ambient air and living organisms.

Management of agricultural waste for alternate uses is being practiced and promoted. Agricultural waste includes paddy and wheat straw, cotton sticks, bagasse and animal waste. Keeping in view the increasing problems associated with crop stubble burning several initiatives for its proper management have been taken up. Various departments and institutions of Punjab Government are promoting alternative uses of straw instead of burning. These include use of rice residue as fodder, crop residue in Bio thermal power plants and mushroom cultivation, rice residue used as bedding material for cattle, production of bio-oil, paper production, bio-gas and in situ. Other uses include incorporation of paddy straw in soil, energy technologies and thermal combustion.

It is believed that Punjab Government regularly publishes the adverse impacts of crop stubble burning in local newspapers. Punjab Government, its various Departments and other institutions like Punjab Agricultural University, Punjab Farmers Commission are all making efforts to devise alternate economic uses of rice stubble. Punjab government is also providing subsidy to the farmers to promote the use of equipments which help in checking the burning of crop residues, like rotavators, happy seeders, zero–till-drills and straw reapers. While on the one hand, there is an urgent need to revitalize the research in agriculture and related activities, on the other hand, to tackle the problem of soil degradation and water depletion, a dedicated programme for promoting resource conservation technologies, such as zero tillage, deep ploughing, raised bed planting, laser land leveling etc., should be undertaken. Heavy investments are required to be made for rejuvenation of these resources. The Rashtriya Krishi Vikas Yojana (RKVY) is a welcome initiative in that direction. An eco friendly technology will be beneficial to the farmer community and the state by providing them a tool for improving soil health and environment for sustainable agriculture.

References

Agrawal S, Trivedi C, Sengupta R (2006) Air pollution due to burning of residues. In: Proceeding of the workshop on air pollution problems due to burning of agricultural residues, held at PAU, Ludhiana organized by the Indian Association for Air Pollution Control in collaboration with the Punjab State Pollution Control Board, Patiala and the Central Pollution Control Board, New Delhi

Badarinath KVS, Chand Kiran TR (2006) Agriculture crop residue burning in the Indo-gangetic plains: a study using IRSP6 WiFS satellite data. Curr Sci 91(8):1085–1089

Badve VC (1991) Feeding systems and problems in the Indo-Ganges plain: case study. In: Speedy A, Sansoucy R (ed) Feeding dairy cows in the tropics. Proceedings of the FAO Expert Consultation held in Bangkok, Thailand, 7–11 July 1989

Beri V, Sidhu BS, Bhat AK, Singh BP (1992) Nutrient balance and soil properties as affected by management of crop residues. In: Bajwa et al MS (eds) Nutrient management for sustained productivity. pp 133–135, Proc Int Symp Vol.II, Department of Soil, Punjab Agricultural University, Ludhiana, India

Canadian Lung Association (2007) Pollution and air quality: http://www.lung.ca/protect-protegez/pollution-pollution_e.php

Department of Agriculutre (2005) Report on Dynamic Ground Water Resources of Punjab, Government of Punjab

Gadde B, Bonnet S, Menke C, Garivait S (2009) Air pollutant emissions from rice straw open field burning in India Thailand and the Philippines. Environ Pollut 157(5):1554–1558

Garg SC (2008) Traces gases emission from field burning of crop residues. Indian J Air Pollut Control viii(1):76–86

Gupta PK, Sahai S (2005) Residues open burning in rice-wheat cropping system in India: an agenda for conservation of environment and agricultural conservation. In: Abrol IP, Gupta RK, Malik RK (eds) Conservation agriculture: status and prospects. Centre for Advancement of Sustainable Agriculture, National Agriculture Science Centre, New Delhi, pp 50–54

Gupta PK, Sahai S, Singh N, Dixit CK, Singh DP, Sharma C, Tiwari MK, Gupta RK, Garg SC (2004) Residue burning in rice-wheat cropping system: causes and implications. Curr Sci 87(12):1713–1715 25 December

Kim S, Dale BE (2004) Cumulative energy and global warming impact associated with producing biomass for bio based industrial products. J Ind Ecol 7:147–162

Lal MM (2006) An overview to agricultural burning. In: Proceeding of the workshop on air pollution problems due to burning of agricultural residues, held at PAU, Ludhiana organized by the Indian Association for Air Pollution Control in collaboration with the Punjab State Pollution Control Board, Patiala and the Central Pollution Control Board, New Delhi

Mandal KG, Misra AK, Hati KM, Bandyopadhyay KK, Ghosh PK, Mohanty M (2004) Rice residue management options and effects on soil properties and crop productivity. J Food Agric Environ 2:224–231

Punia M, Nautiyal VP, Kant Y (2008) Identifying biomass burned patches of agriculture residue using satellite remote sensing data. Centre for the Study of Regional Development, School of Social Sciences, Jawaharlal Nehru University, New Delhi 110 067, India and Indian Institute of Remote Sensing, 4 Kalidas Road, Dehradun 248 001, India

Sarkar A, Yadav RL, Gangwar B, Bhatia PC (1999) Crop residues in India. Project Directorate for Cropping System Research, Modipuram

Sidhu BS, Beri V (2005) Experience with managing rice residues in intensive rice-wheat cropping system in Punjab. In: Abrol IP, Gupta RK, Malik RK (eds) Conservation agriculture: status and prospects, Centre for Advancement of Sustainable Agriculture, National Agriculture Science Centre, New Delhi, pp 55–63

Sidhu BS, Rupela OP, Beri V, Joshi PK (1998) Sustainability Implications of Burning Rice and Wheat Straw in Punjab. Econ polit wkly 33(39):A163–A168

Sidhu BS, Beri V, Gosal SK (1995) Soil microbial health as affected by crop residue management. In: Proceedings of National Symposium on Developments in Soil Science, Ludhiana, India, 2–5 November, 1995. Indian Society of Soil Science, New Delhi, India, pp 45–46

Singh RP, Dhaliwal HS, Sidhu HS (2008) Singh Manpreet, Singh, Yadvinder and Blackwell, John, 2008. Economic assessment of the Happy Seeder for rice-wheat systems in Punjab, India. Conference Paper, AARES 52nd Annual conference, Canberra, ACT, Australia

Thakur TC (2003) Crop residue as animal feed. addressing resource conservation issues in rice–wheat systems of south asia, A Resource Book. Rice Wheat Consortium for Indo-Gangetic Plains (CIMMYT), March

Venkataraman C, Habib G, Kadamba D, Shrivastava M, Leon JF, Crouzille B, Boucher O, Streets DG (2006) Emissions from open biomass burning in India: Integrating the inventory approach with high-resolution Moderate Resolution Imaging Spectroradiometer (MODIS) active-fire and land cover data. Global Biogeochemical Cycles, Vol 20

Bioremediation of Hexachlorocyclohexane (HCH) Pollution at HCH Dump Sites

Shailly Anand, Jaya Malhotra, Neha Niharika, Devi Lal, Swati Jindal, Jaspreet Kaur, Aeshna Nigam, Nidhi Garg, Pushp Lata, Jasvinder Kaur, Naseer Sangwan, Amit Kumar Singh, Ankita Dua, Anjali Saxena, Vatsala Dwivedi, Udita Mukherjee and Rup Lal

1 Introduction

1.1 Dirty Secret of HCH Contamination

Globally, the period from the early 1950s to late 1980s has shown an increased use of primarily three pesticides namely DDT (dichlorodiphenyltrichloroethane), endosulfan, and HCH (hexachlorocyclohexane ⇔ lindane) for the control of agricultural pests in almost all health programs (Prakash et al. 2004). The extensive use of these pesticides during this time span brought enormous benefits round the world, particularly in tropical countries by protecting crops from insects (Ware 1989) and by eradicating vector borne diseases (Lal et al. 2008). Lindane formulations were also used medically on the skin to control head lice and scabies (ATSDR 1997). Due to the low production cost, the worldwide use of lindane reached about 10 million tons during this period. However, the indiscriminate use and unregulated production of HCH over the years have now created a serious problem of environmental pollution and has raised human health risks. The residues of HCH have been reported from different components of the ecosystem; predominantly from soil (Concha-Graña et al. 2006; Kumari et al. 2007; Prakash et al. 2004; Raina et al. 2008a, b), water (Bakore et al. 2004; Kumari et al. 2007: Prakash et al. 2004) and air (Lammel et al. 2007; Li et al. 2006; Popp et al. 2000). There have been reports of the presence of HCH traces even in food products like oil (Bajpai et al. 2007), honey (Blasco et al. 2004), rice grains (Toteja et al. 2003), fish (Malik et al. 2007), mammals (Gangwar et al. 1979) and also in human blood samples (Bhatnagar et al. 2004), breast milk (Sanghi et al. 2003; Zhao et al. 2007)

S. Anand · J. Malhotra · N. Niharika · D. Lal · S. Jindal · J. Kaur · A. Nigam · N. Garg · P. Lata · J. Kaur · N. Sangwan · A. K. Singh · A. Dua · A. Saxena · V. Dwivedi · U. Mukherjee · R. Lal (✉)
Molecular Biology Laboratory, Department of Zoology, University of Delhi, New Delhi 110007, India
e-mail: ruplal@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_23, © Springer-Verlag Berlin Heidelberg 2013

and fat tissues (Ben-Michael et al. 1999). More acutely toxic than DDT, lindane has been shown to interfere with the cat-ion flux across nerve cells during synaptic transmission and axonal conduction (White and Larrabee 1973) that results in mental impairment, convulsions, and violent seizures. As a result, by late 1970s, the deleterious effects of HCH isomers was realized worldwide. In perspective of the persistent nature and carcinogenic properties of the HCH isomers posing a serious threat to the environment, it became a global issue. The nascent step towards preventing its further addition to the vast pool of environmental contaminants was to halt its production and consumption. Consequently, most of the nations banned the production of lindane by industrial units involved in the manufacturing of HCH (technical as well as lindane) and its usage was brought to a standstill (Li 1999).

1.2 HCH: Production and Problem

Commercially, HCH is synthesized by photochemical chlorination of benzene resulting in principally five isomers *α*-, *β*-, *γ*-, *δ*- and *ε*- produced in different proportion of 70: 14: 8: 6 and 2 respectively (Fig. 1). This mixture is also known as 'technical HCH' of which only *γ*-HCH, commonly known as lindane, has the insecticidal property. The spatial arrangement of the chlorine atoms on the cyclohexane ring of these isomers is responsible for the differences in their physio-chemical and biological properties, which, in turn, affects their environmental fate and distribution (Phillips et al. 2005). While *α*-, *γ*-, *δ*-, *ε*-HCH isomers have 4, 3, 1 and 2 chlorine atoms in the axial position, respectively, *β*-HCH has all in equatorial position (Fig. 1). The positioning of the chlorine atoms in the *β*-isomer reduces its susceptibility to bio-chemical transformation to a greater extent.

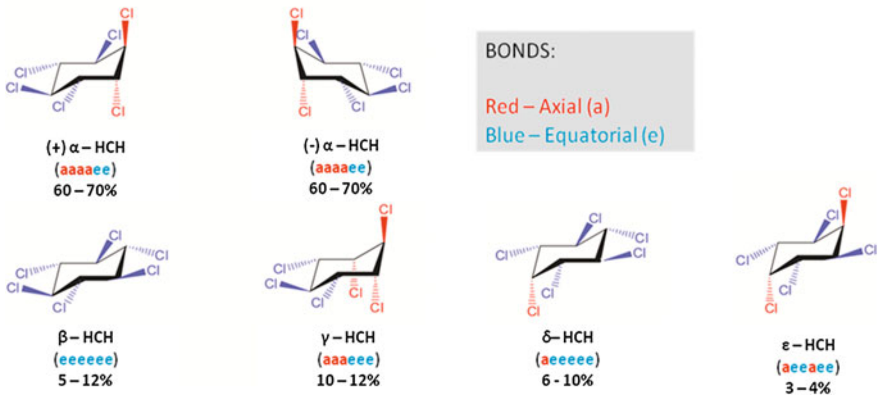


Fig. 1 Axial versus equatorial arrangement of chlorine atoms in the five major isomers of HCH *α*-, *β*-, *γ*-, *δ*- and *ε*-HCH

Additionally, due to structural symmetry of β-HCH (unlike in other isomers) and greater crystal lattice energy, this isomer has a very high melting point and a lower water solubility creating a reason good enough for its increased stability (Heinisch et al. 2005) and, thus, its persistence in the environment.

Interestingly, only γ-HCH with insecticidal property is comparatively safer due to low stability in nature (Kumari et al. 2002). However, concentration and purification of γ- isomer from the technical mix involved multiple steps which increased its production cost by several folds. On one side, while the developed nations could afford the heavy purification cost; due to economical constraints, developing countries, including India, continued using technical HCH in place of the purified γ-HCH (Lal et al. 2010). Technical production or processing of HCH has led to deposition of ballast isomers with a predominance of α-, β-, δ- and ε-HCH in contrast to lindane. Consequently, though the latter has resulted in hazardous effects because of the direct release and spread of the HCH waste into the environment, the former has led to creation of stockpiles of residual isomers. It has been estimated that purification of one ton of γ-HCH generates around 9–10 tons of HCH waste consisting of α-, β- and δ-HCH together constituting the so called 'HCH muck' (Vijgen 2006). This muck for long has been either dumped in the open by the side of the industrial units engaged with lindane production or pyrolysed in closed vessels to trichlorobenzene and hydrochloric acid (Huisman and Smit 1955). We still do not have the exact estimate of HCH waste scattered around the world, but it is certain that the total production of lindane during a time span of nearly 4 decades between 1950 and 1990 had been 600,000 tons (agricultural purpose = 450,000 tons + use of lindane on livestock, forestry, human health and other purposes = 150,000 tons: Lal et al. 2010) and, consequently, between 4–7 million tons of toxic, persistent and bio-accumulative HCH muck should have been dumped. Sites heavily contaminated with HCH (i.e., more than 50,000 tons) have been reported from Netherlands (van Liere et al. 2003), Brazil (Osterreicher-Cunha et al. 2003), Germany (Jürgen and Roth 1989), Spain (Concha-Graña et al. 2006; Rubinos et al. 2007), Greece (Golfinopoulos et al. 2003), Canada (Phillips et al. 2006), United States (Phillips et al. 2006), Japan (Nagata and Tsuda 2005), South Africa, India (Lal et al. 2010; Prakash et al. 2004; Singh et al. 2007) and even in pristine locations like arctic (Hinckley et al. 1992; Jantunen and Bidleman 1996; Li et al. 1998) and pacific ocean (Baek et al. 2011). It is this waste that is a cause of concern today, especially the more problematic β-isomer, which has very low water solubility and reduced vapour pressure leading to an increased potential for its accumulation.

From the outlook of environmental toxicology, the alarming threat that HCH poses is chiefly due to the problematic α-, β- and δ- isomers, predominantly at the dumpsite. α-HCH being the most carcinogenic of all the isomers was classified as technical grade HCH as Group B2—probable human carcinogen by US EPA (UNEP 2009). Based on the magnitude of contamination, toxicity and persistence of these HCH isomers, they were listed as the Persistent Organic Pollutants (POPs) by the Stockholm convention in 2009 (UNEP 2009).

1.3 Ban on HCH: How Far Could it Solve the Problem

By the late 1970s, the deleterious effects of HCH isomers were realized worldwide. In perspective of the persistent nature and carcinogenic properties of the HCH isomers posing a serious threat to the environment, it became a global issue. The nascent step towards preventing its further addition to the vast pool of environmental contaminants was to halt its production and consumption. Consequently, most of the nations banned the production of lindane by industrial units involved in the manufacturing of HCH (technical, as well as lindane) and its usage was brought to a standstill (Lal et al. 2008). To our knowledge, only India continues producing lindane. In India, technical HCH was used until 1995 and its use peaked to 25,000 tons during the 1990s. During the past 10 years, around 7,000–8,000 tons of lindane has been produced that should have led to stockpiles of HCH muck weighing nearly 90,000 million tons that still awaits clearance.

While new dumpsites are being created in India, the extensive production of dirty HCH muck in the past has resulted in a severe issue of environmental contamination that has been broadly categorized as High and Low—dose point HCH contamination, based on the degree of pollution at these sites. There are many such dumpsites located in and around the production units that have been discovered now. Most of them have been traced but, it is difficult to detect all of them as HCH issue is politically very sensitive. As a result, neither the general public nor the government bodies seem to be completely aware of this major problem that still continues to spread under a veil. HCH residues from these open muck sites are continually escaping to the environment, either through leaching into the nearby water bodies or to places far off from the dump site by the blowing wind. This dirty play of HCH contamination will continue spreading unless these dump sites are cleared. It is the call of the hour to initiate urgent steps to explore the possible solutions to remediate HCH—the problem!

1.4 Possible Solutions

Looking back at the vast amount of lindane production during the past many decades, one can estimate the millions of tons of waste that has been generated and scattered round the world (Lal et al. 2010). The seriousness of the problem demands concrete steps be taken to devise strategies for the remediation of these toxic HCH isomers. Environmental activists, government and several organizations, including International HCH and Pesticide Association (IHPA), have all raised concern for the potential hazards of HCH. Efforts have been intensified to locate these HCH contaminated sites for remediation of HCH waste and to implement adequate regulatory oversight, especially by the government. A number of strategies for remediation, such as incineration, landfills, chemical oxidation and photo-degradation, are being used for several pollutants (Phillips et al. 2005) but these techniques are neither cost-effective nor easy to implement for HCH. Thus, the greener alternative for HCH decontamination is bioremediation—exploiting the catabolic abilities of microorganisms against this problematic pollutant. It will be pertinent to say here that developing bioremediation technology for a particular pollutant that is scattered round the world in such a huge amount is difficult but the account given below will justify the statement that, at least for HCH decontamination, bioremediation is nearly possible.

1.4.1 Bioremediation: A Greener Solution to the Problem!

The richness of microbial diversity in nature offers a vast reservoir of resources that can be explored for our benefit. Bacterial species for long have shown to play a significant role in harnessing their biogeochemical processes for both the cycling of the elements and mitigating the toxic effects of many compounds. The reason behind this is the ongoing, continuous process of evolution, which in the long run has enabled the microbial communities to adapt to the compounds to which they were exposed (van der Meer et al. 1992). However, little is known about the intricacies of the molecular events that have led to such major changes in the organisms, enabling them to utilize hazardous chemicals. Although it is rather difficult to delve with the evolution of catabolic genes in bacteria under the selecting pressure of xenobiotics, HCH pressure is offering a very good example of bacteria acquiring catabolic genes in a span of not more than 50 years. The first bacterium, now called *Sphingobium japonicum* UT26, that degraded γ-HCH was reported from Japan followed by the discovery of yet another strain *Sphingobium indicum* B90 from India in the same year (Sahu et al. 1990). Though these two strains could degrade γ-HCH, the latter was also reported to degrade β-HCH (HCH isomer that was once thought not to be degraded by any biological system). For nearly more than 15 years, these two bacterial strains remained the only strains with the ability to degrade HCH isomers. However, in 2005 (Boltner et al. 2005) a large number of bacteria were reported that could degrade HCH isomers from the dumpsites. During the next half a decade, the literature was flooded with novel HCH degrading bacterial strains chiefly *sphingomonads* that were isolated from many such HCH dumpsites. Now it is almost clear that wherever HCH dumpsites have been created, microbes get evolved to face the challenge and start degrading HCH isomers. It is this aspect that compels us to believe that there is a greener hope to remediate this toxic waste.

Over the years, the possibility of remediating HCH residues by way of microorganisms has proved to be feasible with the availability of a large number of *Sphingomonads* capable of degrading all the HCH isomers to a varying degree from dumpsites, especially reported from India (Bala et al. 2010; Dadhwal et al. 2009; Garg et al. 2011; Jit et al. 2008; Kaur et al. 2011; Kumar et al. 2008, 2009, 2011; Nigam et al. 2010; Sharma et al. 2010; Singh and Lal 2009; Verma et al. 2009), Germany (Jürgen and Roth 1989), Spain (Concha-Graña et al. 2006), The Netherlands (van Liere et al. 2003), Portugal (Osterreicher-Cunha et al. 2003), Greece (Golfinopoulos et al. 2003), Canada (Phillips et al. 2006), The United States (Popp et al. 2000), Eastern Europe (Vijgen et al. 2011) and South Africa (Vijgen et al. 2011). These bacterial strains have not only paved the way for remediating HCH by biological means but have also given a deeper understanding of the biochemistry and genetics of degradation of HCH isomers. In contrast, there are reports of no organisms available that can degrade DDT and endosulfan and, thus, these pollutants still remain a cause of serious concern.

1.5 Unique Example of Rapid Evolution of Genes

Until the discovery of the first bacterial strain capable of eating HCH, nothing was known about the degradation of α-, β- and δ-HCH. However, the pathways of degradation of these isomers now seem to have been partly deciphered. It is very interesting to see that within a span of a few years, new pathways of degradation of HCH isomers got established in *Sphingomonads*. In addition to this, the genes involved in the degradation pathway too are gradually undergoing mutations resulting in either a wider scope to act on multiple isomers, pressing the reaction at a faster pace or taking the pathway to an extended step. Of all the genes (*lin* genes) of the pathway, two enzyme coding genes linA (HCH dehydrochlorinase) and linB (Haloalkane dehalogenase) seem to be central to the degradation of HCH isomers. These two enzymes compete with each other for different substrates, either HCH isomers or their intermediates for degradation. The dynamism of these genes is increasingly making it interesting to investigate their evolution in such a short span of time.

Yet another captivating aspect is the acquisition of *lin* genes, specifically by *Sphingomonads*. Of the total 30 bacteria that have been so far reported to degrade HCH isomers, 90 % are *Sphingomonads*. Surprisingly, their *lin* genes also appear to be associated with IS*6100* elements indicating the possible role of horizontal gene transfer of these genes across diverse organisms.

Apart from acting as a model to study the rapid evolution of catabolic genes and associated pathways, the existing data indicate that there is everything available in this system that can lead to the development of bioremediation as a tool for decontamination of HCH muck. If developed, this will be the first example of microbial system being exploited for bioremediating HCH isomers. The approaches that are currently being worked out include (1) Bioaugmentation, (2) Biostimulation and (3) Enzymatic Bioremediation. Bioaugmentation seems to be feasible as there are a large number of *Sphingomonads* that are available now that can be either alone or in combination be used for this purpose. These organisms seem to be the suitable starting material. The feasibility of the second approach—biostimulation is also quite emerging. It is interesting to note that *Sphingomonads* survive and, hence, degrade HCH isomers even at dumpsites where HCH levels are as high as 450 mg/g of soil. Perhaps these two approaches can be combined together to develop a bioremediation technology. But, historically, microbial bioremediation is limited by factors such as mass transfer, aeration, nutrient level at contaminated site and problems with thermal conditions (Fantroussi and Agathos 2005). Thus, the third approach of enzymatic remediation that relies on the use of enzymes catalyzing substantive detoxification of the pollutant(s) in question can be brought in use to address the above issues. In recent years, enzyme-based decontamination has become an attractive alternative to augment the bio treatment techniques due to its advantage over the traditional approaches by being rapid and bypassing the requirement of the effective growth of the microbial culture.

2 Results and Discussion

Our studies on the degradation of HCH isomers by *Sphingomonas paucimobilis* strain B90 began in 2002 when we characterized the *lin* genes encoding enzymes that were responsible for the degradation of HCH isomers. Two non-identical copies of the *linA* gene encoding HCH dehydrochlorinase, which were designated *linA1* and *linA2*, were found in *S. paucimobilis* B90. The *linA1* and *linA2* genes that were expressed in *Escherichia coli*, lead to dehydrochlorination of α-, γ-, and δ-HCH but not of β-HCH, suggesting that *S. paucimobilis* B90 contained another pathway for the initial steps of β-HCH degradation. The cloning and characterization of the halidohydrolase (*linB*), dehydrogenase (*linC* and *linX*), and reductive dechlorinase (*linD*) genes from *S. paucimobilis* B90 revealed that they shared 96–99 % identical nucleotides with the corresponding genes of *S. paucimobilis* UT26. No evidence was found for the presence of a *linE*-like gene, coding for a ring cleavage dioxygenase, in strain B90. The gene structures around the *linA1* and *linA2*genes of strain B90, compared to those in strain UT26, suggested of a recombination between *linA1* and *linA2*, which formed *linA* of strain UT26 (Kumari et al. 2002). Two years later, by 2004, studies on the organization of *lin* genes and IS*6100* in the three strains of *Sphingomonas paucimobilis* (B90A, Sp+, and UT26) which degraded hexachlorocyclohexane (HCH) isomers but which had been isolated at different geographical locations gave an insight on the possible role of horizontal gene transfer as a potential evolutionary force in the evolution of these organisms (Dogra et al. 2004). The *lin* genes in these strains were found to be associated with IS*6100*, an insertion sequence classified in the IS*6* family. Eleven, six, and five copies of IS*6100* were detected in B90A, Sp+, and UT26, respectively. IS*6100* elements in B90A were sequenced from five, one, and one region of the genomes of B90A, Sp+, and UT26, respectively, and were found to be identical. DNA–DNA hybridization and DNA sequencing of cosmid clones also revealed that *S. paucimobilis* B90A contained three and two copies of *linX* and *linA*, respectively, compared to only one copy of these genes in strains Sp+ and UT26. Although the copy number and the sequence of the remaining genes of the HCH degradative pathway (*linB*, *linC*, *linD*, and *linE*) were nearly the same in all strains, there were striking differences in the organization of the *linA* genes as a result of replacement of portions of DNA sequences by IS*6100*, which gave them a strange mosaic configuration. Spontaneous deletion of *linD* and *linE* from B90A and of *linA* from Sp+ occurred and was associated either with deletion of a copy of IS*6100* or changes in IS*6100* profiles. This when coupled with the observation that the G + C contents of the *linA* genes were lower than that of the remaining DNA sequence of *S. paucimobilis*, strongly suggested that all these strains acquired the *linA* gene through horizontal gene transfer mediated by IS*6100*. The association of IS*6100* with the rest of the *lin* genes further suggested that IS*6100* played a role in shaping the current *lin* gene organization (Dogra et al. 2004). In addition, the overall organization of catabolic genes involved in the degradation of HCH isomers revealed that *lin* genes are not organized in co-ordinately regulated operons. Instead, at least six different transcriptional units forming the γ-HCH degradation pathway in *S. indicum* B90A (linX1X2A1, linX3A2, *linB, linC, linDE* and *linR*) were proposed and it was also revealed that *lin* genes were not uniformly distributed on the chromosome but were also present on plasmids in *S. indicum* B90A, *S. japonicum* UT26 and *S. francense* Sp+ (Malhotra et al. 2007). Thus, IS*6100* and plasmids (probably conjugative) appeared to have a significant role in HGT of *lin* genes among *sphingomonads*.

During the same year, *Sphingomonas paucimobilis* B90A was investigated to degrade α-, β-, γ-, and δ-isomers of HCH. The strain was found to contain the genes *linA*, *linB*, *linC*, *linD*, *linE*, and *linR*, which had been implicated in HCH degradation. Subsequently, dynamic expression of the *lin* genes was measured in chemostat-grown *S. paucimobilis* B90A by RNA dot blot hybridization and real-time reverse transcriptase PCR upon exposure to a pulse of different HCH isomers. Irrespective of the addition of HCH, *linA*, *linB*, and *linC* were all expressed constitutively. In contrast, *linD* and *linE* were induced with α-HCH (2 mg/l) and γ-HCH (7 mg/l). The addition of β-HCH (5 mg/l) or δ-HCH (20 mg/l) did not lead to *linE* and *linD* induction, despite the fact that 50 % of the compounds were degraded. This led us to implicate that the degradation of β- and δ-HCH proceeded by a pathway different from that of α- and γ-HCH (Suar et al. 2004) (Fig. 2).

These HCH degrading bacterial strains isolated from India, Japan, France, Germany and Spain were not only analyzed for the presence of *lin* genes but were also subjected to phylogenetic analysis. The taxonomical positions of *S. indicum* B90A, *S. japonicum* UT26 and *S. francense* Sp+, initially thought to be three strains of *Sphingomonas paucimobilis*, were classified as three distinct species (i.e., *Sphingobium indicum* sp. nov, *Sphingobium japonicum* sp. nov and *Sphingobium francense* sp. nov, respectively) (Pal et al. 2005) by way of the polyphasic approach. In parallel to this, in the same year, it was revealed that *Sphingomonas paucimobilis* B90A contained two variants of dehydrochlorinase, LinA1 and LinA2 that catalyzed the first and second steps in the metabolism of hexachlorocyclohexanes. Comparison at the amino acid level showed that LinA1 and LinA2 were 88 % identical to each other, whereas, LinA2 was 100 % identical to LinA of *S. paucimobilis* UT26. Incubation of chiral α-HCH with *Escherichia coli* BL21 expressing functional LinA1 and LinA2 *S*-glutathione transferase fusion proteins confirmed that LinA1 preferentially converted the (+) enantiomer, whereas LinA2 preferred the (−) enantiomer. Concomitant formation and

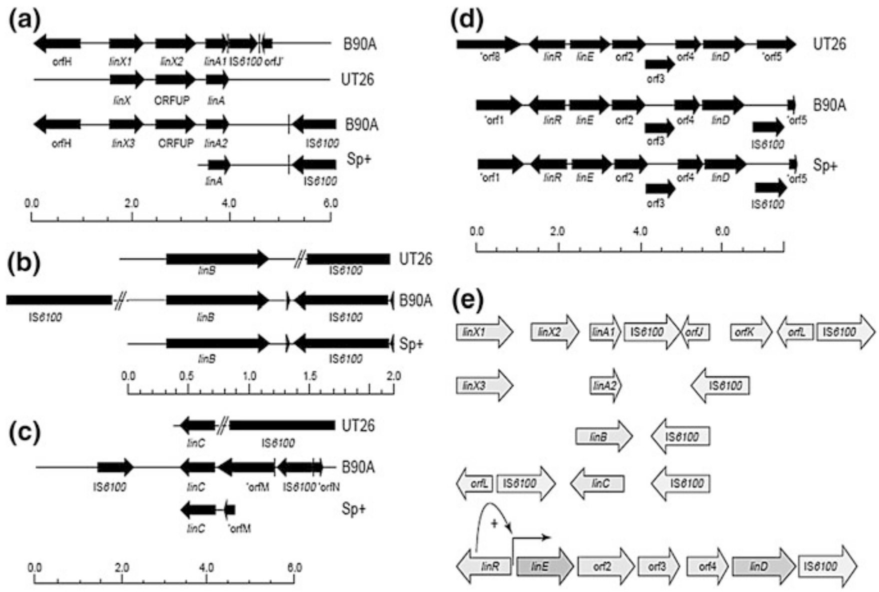


Fig. 2 **a** 'Mosaic' organization of *linA* gene in *Sphingobium indicum* B90A (*linA*1 and *linA*2), *Sphingobium japonicum* UT26 (linA) and *S. francense* SpC (linA). **b** Comparison of the organization of *linB* gene in *S. japonicum* UT26, *S. indicum* B90A and *S. francense* SpC. **c** Organization of *linC* gene in *S. japonicum* UT26, *S. indicum* B90A and *S. francense* SpC. **d** Organization of linDER gene in *S. japonicum* UT26, *S. indicum* B90A and *S. francense* SpC. **e** Six transcriptional units (linX1X2A1, linX3A2, linB, linC, linDE and linR) encoding the g-HCH degradation pathway in *S. indicum* B90A. linA (combination of linA1 and linA2), linB, linC and linX are constitutively expressed. The only known regulatable promoter among the lin genes is in front of linE and is activated by LinR. The function of linX gene is not known but, based on sequence homology, it was predicted to be a dehydrogenase, perhaps similar in function to LinC. Arrows denote the direction of transcription. Where IS*6100* is depicted by a box, direction of transcription is not known (Lal et al. 2006)

subsequent dissipation of *β*-pentachlorocyclohexene enantiomers was also observed in these experiments, indicating that there was enantioselective formation and/or dissipation of these enantiomers. Because enantioselectivity was not observed in incubations with whole cells of *S. paucimobilis* B90A, we concluded that LinA1 and LinA2 were equally active in this organism. The enantioselective transformation of chiral α-HCH by LinA1 and LinA2 thus provided us the first evidence of the molecular basis for the changed enantiomer composition of α-HCH in many natural environments (Suar et al. 2005). Additionally, we also investigated the competition between SN2 and E2 mechanisms for the dechlorination of hexachlorocyclohexane isomers which revealed that the specificity of the enzymes was a direct result of the intrinsic reactivity of the various isomers. The two key enzymes that catalyse HCH degradation via distinct pathways: LinA which catalyses the degradation of α- and γ-HCH (not *β*-HCH) used an E2 mechanism while LinB catalysed the degradation of β-HCH (not α- and γ-HCH) using an SN2 mechanism (Brittain et al. 2011).

So far, the majority of our work was focused on studying the role, organization and characterization of *lin* genes involved in the degradation of HCH. But in later years, our attention drifted to the revelation of the degradation pathways for different isomeric forms of HCH and the possible role of *lin* genes associated with them. In 2006 (Sharma et al. 2006), resting cell experiments showed that LinB of B90A, UT26 and Sp+ were able to transform β- and δ-HCH, the most recalcitrant hexachlorocyclohexane isomers, to pentachlorocyclohexanols (PCCH). Though the three LinB enzymes differed only marginally with respect to amino acid sequence, they showed interesting differences with respect to substrate specificity. In contrast to the LinB proteins from strains UT26 and Sp+, which could not catalyze to further steps during the degradation reaction, B90A could remarkably take the reaction to still lower intermediates. By 2007, these hydroxyl metabolites that were formed during incubation of β- and δ-HCH with *Sphingobium indicum* B90A were isolated, characterized, and stereochemically identified by gas chromatography-mass spectrometry (GC–MS) and nuclear magnetic resonance spectroscopy (NMR) (Raina et al. 2007). The metabolites were identified as isomeric pentachlorocyclohexanols (B1, D1) and tetrachlorocyclohexane-1,4-diols (B2, D2); δ-HCH additionally formed a tetrachloro-2-cyclohexen-1-ol (D3) and a trichloro- 2- cyclohexene-1,4-diol (D4), most likely by hydroxylation of δ-pentachlorocyclohexene (δ-PCCH), initially formed by dehydrochlorination. The dehydrochlorinase LinA was responsible for conversion of δ-HCH into δ-PCCH, and the haloalkane dehalogenase LinB was responsible for the transformation of β-HCH and δ-HCH into B1 and D1, respectively, and subsequently into B2 and D2, respectively. LinB was also found to be responsible for transforming δ-PCCH into D3 and subsequently into D4. These hydroxylations proceeded in accordance with SN2 type reactions with initial substitution of equatorial Cls and formation of axially hydroxylated stereoisomers. Several of these metabolites were detected in contaminated sites which indicated that these reactions proceeded under natural environmental conditions and that the metabolites were of environmental relevance (Raina et al. 2007). Since we had by then found haloalkane dehalogenase LinB to be responsible for the hydroxylation of β-HCH, δ-HCH, and δ-pentachlorocyclohexene (δ-PCCH), we decided to examine whether β- and γ-PCCH, which can be formed by LinA from α- and γ-HCH, respectively, were also converted by LinB. For this we incubated such substrates with Escherichia coli BL21 expressing functional LinB originating from Sphingobium indicum B90A and observed that both β- PCCH and γ-PCCH were direct substrates of LinB. Furthermore, we identified the main metabolites as 3, 4, 5, 6-tetrachloro-2-cyclohexene-1-ols and 2, 5, 6-trichloro-2-cyclohexene-1, 4-diols by nuclear magnetic resonance spectroscopy and gas chromatography-mass spectrometry. In contrast to α-HCH, γ-HCH was not a substrate for LinB. On the basis of our data, we then proposed a modified γ-HCH degradation pathway in which γ-PCCH was converted to 2,5-cyclohexadiene-1,4-diol via 3,4,5,6- tetrachloro-2-cyclohexene-1-ol and 2,5,6-trichloro-2-cyclohexene-1,4-diol (Raina et al. 2008a, b).

We then moved here on to applying the bioaugmentation approach for bioremediation of HCH. For the targeted degradation of all HCH isomers *Sphingobium indicum* B90A, an aerobic bacterium was brought into use. In particular, we examined possibilities for large-scale cultivation of strain B90A, tested immobilization, storage and inoculation procedures, and determined the survival and HCH-degradation activity of inoculated cells in soil. We conducted experiments in small pits and at an HCH-contaminated agricultural site too. As expected, we observed 85–95 % HCH degradation by strain B90A applied via corncob, depending on the type of HCH isomer and even at residual HCH concentrations. These results indicated that on-site aerobic bioremediation of HCH exploiting the biodegradation activity of *S. indicum* B90A cells stored on corncob powder could stand out as a promising technology (Raina et al. 2008a, b).

In parallel to the bioaugmentation approach, we also implemented the biostimulation strategy and assayed its efficiency in decontamination of chronically HCH-contaminated sites. For this, we located a high-dose point hexachlorocyclohexane (HCH)-contaminated site and isolated bacteria from soil samples collected from areas near an HCH-manufacturing unit and its dumpsite in North India. After confirming the presence of indigenous HCH-degraders (seven of 24 strains), an *ex situ* biostimulation experiment was conducted by mixing contaminated soil with pristine garden soil and under proper aeration, moisture and nutrients, the soil was monitored for reduction in different HCH isomer levels and stimulation of HCH-degraders. Terminal restriction fragment length polymorphism (tRFLP) analysis reflected changes in microbial community structure during the course of experiment. We observed that biostimulation of indigenous HCH-degrading microbial population could serve as an effective method for decontamination of an HCH-contaminated sites (Dadhwal et al. 2009). Additionally, we also conducted a preliminary evaluation of HCH contamination levels in soil and water samples collected around the production area and the vicinity of this major dumpsite in Lucknow, India to inform the design of processes for an appropriate implementation of the Stockholm Convention 2009 (Jit et al. 2011). It was seen that all the soil samples taken at the lindane production facility, the dumpsite and in their vicinity were contaminated with an isomer pattern characteristic of HCH production waste. While the dumpsite surface samples contained up to 450 gkg − 1 of Σ HCH, the ground water in the vicinity and river water was found to be contaminated with 0.2–0.4 mgl − 1 of HCH waste isomers. The total quantity of deposited HCH wastes from the lindane production unit was estimated between 36,000 and 54,000 tons. The contamination levels in ground and river water, thus, suggested significant run-off from the dumped HCH wastes and contamination of drinking water resources (Jit et al. 2011).

Though bioaugmentation and biostimulation proved to be working well for decontamination of HCH polluted sites, we needed a more rapid and efficient way of getting, rid of this pollutant from the environment. Here came the role of enzymatic bioremediation i.e., employing enzymes (free or encapsulated) that could catalyze the substantive detoxification of the pollutant to be remediated. Unlike other technologies, this remediation process is not dependent on growth of intact bacterial population or soil health, and, rather, depends on catalytic efficiency and concentration of degradative enzyme used (Scott et al. 2008). Another advantageous aspect was the time frame required for remediation process: at most a few hours, perhaps as little as a few minutes in certain cases (Russell et al. 1998). Thus, paving our way for enzymatic bioremediation we first looked for LinA and LinB variants (i.e., from different organisms) in the public database and fished the sequences of seven LinA and sixteen LinB variants. On the basis of amino acid sequence alignment, these LinA and LinBs formed two and three different groups, respectively (Lal et al. 2010). The differences in the activities of known LinAs and LinBs were found to be apparent and recently their kinetic parameters were determined to indicate the efficiency of the enzyme activity. The kinetic observations suggested that LinA-γ1-7 is the best LinA variant (Sharma et al. 2011) and LinB SSO4-5 and LinB SSO4-3 (unpublished) possessed fastest dehalogenase activity for developing an enzyme-based bioremediation technology for HCH. However, in the case of HCH dehydrochlorinase, LinA, it was seen that a major amount of protein was captured into the insoluble fraction, forming Inclusion bodies, thus, decreasing the yield. Thus, our future work revolves around the recovery of this bioactive protein from inclusion bodies. Additionally, we are also working on ways to tap the unculturable diversity to analyze the community structure at the dumpsite for establishing in situ bioremediation strategies. Nevertheless, our genomic aspect on sequencing the genome of this unique *sphingomonad, Sphingobium indicum* B90A would also give a deeper insight on the biodegradation of this xenobiotic compound—the HCH.

3 Conclusion and Future Prospects

Because HCH is such a chemically refractory molecule, the evolution of an effective detoxification and utilization pathway has required the acquisition of qualitatively new functions for certain individual enzymes, plus the assembly of these and other enzymes into a coordinately regulated pathway. The isomer complexity of HCH adds a further degree of difficulty, with major differences between isomers in the reactions by which their breakdown can be catalyzed, at least under aerobic conditions. These have apparently necessitated the recruitment of alternative enzymes for different isomers in certain upstream steps in the aerobic pathway. Work to date indicates that several microbes, often but not always sphingomonads, are assembling the requisite capabilities, although the phenotype remains variable and probably not optimized in either its genetics or its biochemical efficacy (Lal et al. 2010).

One fundamental gap concerns the reactions in the upper pathway, where the most biochemically problematic detoxification steps occur. Two sets of observations indicate that certain key elements of the widely accepted scheme for this pathway may be incorrect. One disconcerting observation has been that the presumptive dehydrochlorination of the putative δ-HCH metabolite δ-PCCH by LinA is inexplicable in terms of the bimolecular elimination reaction characteristic of enzymes from the family in which LinA sits (Raina et al. 2008a, b). The second recent surprise has been the finding that heterologously expressed LinB (from B90A at least) has a wider substrate specificity across HCH and PCCH isomers in vitro (albeit with unknown kinetics) than the accepted pathway assumed and, moreover, it produces metabolites from some of these substrates that do not sit in the accepted pathway either (Raina et al. 2008a, b). There is now considerable doubt as to the validity of certain steps in the pathway that have hitherto been inferred rather than empirically demonstrated. The resolution of these uncertainties about the upper metabolic pathway clearly requires more detailed metabolite analyses of HCH degradation in HCH-degrading bacteria. Another important goal will be to better understand the biochemistry of the LinA and LinB enzymes. Particular priorities in the latter are detailed kinetic analyses of heterologously expressed LinA and LinB with a range of resolved isomers of putative substrates within the pathway. There are also other important aspects of the Lin pathway that we currently do not understand. One of these involves the mysterious LinX enzymes, which are distantly related to LinC and show some LinC function in vitro, but are apparently not essential for γ-HCH degradation, at least in vivo. One possibility is that LinX catalyzes the transformation of γ -hydroxymuconic-6-semialdehyde to maleylacetate in the downstream pathway. This, like the upstream step catalyzed by LinC, requires a dehydrogenation step. This step is not essential for HCH degradation in vivo because a bifurcation in the downstream pathway two steps prior to the production of γ-hydroxymuconic- 6-semialdehyde provides another option for the catabolic process (Lal et al. 2010).

Another major gap in our current knowledge of the system concerns the extent and biological significance of genetic variation both in the organization of the various *lin* genes and in the coding sequences of the key upstream *linA* and *linB* genes. Although some condensation of *lin* genes into operons has been reported, the complements and structures of the operons reported are still highly variable, and some *lin* genes remain apparently unlinked to the operons, either on plasmids or elsewhere in the various genomes. Such variation is unusual and suggests that the evolution of *lin* operons is still a work in progress. Several studies have found transposable elements, in particular IS*6100* elements, in the vicinity of the *lin* genes. This is not unusual for recently assembled catabolic operons, but it is certainly consistent with a dynamic, ongoing process of the organization of *lin* genes into arrangements suited to coordinate control. Time course studies of the genetics of HCH degradation in highly contaminated sites could prove very informative in this context. Evidence to date indicates high levels of polymorphism in the amino acid sequences of both the LinA and LinB enzymes, with convincing if indirect evidence that at least some of it affects function. The LinB proteins of UT26 and B90A, in particular, seem to differ qualitatively in their HCH isomer preferences. Similarly, profound differences appear to exist between the α-HCH enantiomer preferences of LinA1 and LinA2. However, there could well be many other qualitative and quantitative differences in the activities of other LinA and LinB variants. Further work is needed to elucidate the extent of the variation, the molecular basis of isomer-specific differences in the functions of some of the variants, and the role of these differences in generating the metabolic diversity needed to deal with the plethora of isomers involved in the first four steps of the upstream pathway (Lal et al. 2010).

We believe that there are good prospects for developing economically viable HCH bioremediation technologies based on the sphingomonad/Lin systems: soil bioremediation through various biostimulation/bioaugmentation approaches and stockpile and, as necessary, liquid remediation through direct enzymatic approaches. Significant work on enzyme characterization, particularly for LinA, and strain and enzyme improvement is still needed. However, the promise of the system evident thus far and the potential of modern microbial and enzyme research technologies to make radical improvements gives us confidence that the development of successful technologies for a most pernicious pollutant is quite achievable.

References

Agency for Toxic Substances and Disease Registry (ATSDR) (1997) Toxicological profile for alpha-, beta-, gamma- and delta- hexachlorocyclohexane; 205–93-0606. Research Triangle Institute, Research Triangle Park, pp 1–239

Baek SY, Choi SD, Chang YS (2011) Three-year atmospheric monitoring of organochlorine pesticides and polychlorinated biphenyls in polar regions and the South Pacific. Environ Sci Technol 45(10):4475–4482

Bajpai A, Shukla P, Dixit BS, Banerji R (2007) Concentrations of organochlorine insecticides in edible oils from different regions of India. Chemosphere 67:1403–1407

Bakore N, John PJ, Bhatnagar P (2004) Organochlorine pesticide residues in wheat and drinking water samples from Jaipur, Rajasthan, India. Environ Monit Assess 98:381–389

Bala K, Sharma P, Lal R (2010) Sphingobium quisquiliarum sp. nov., P25T a hexachlorocyclohexane (HCH) degrading bacterium isolated from HCH contaminated soil. Int J Syst Evol Microbiol 60:429–433

Ben-Michael E, Grauer F, Raphael C, Sahm Z, Richter ED (1999) Organochlorine insecticide and PCB residues in fat tissue of autopsied trauma victims in Israel 1984 to 1986. J Environ Pathol Toxicol Oncol 18:297–303

Bhatnagar VK, Kashyap R, Zaidi SS, Kulkarni PK, Saiyed HN (2004) Levels of DDT, HCH, and HCB residues in human blood in Ahmedabad, India. Bull Environ Contam Toxicol 72:261–265

Blasco C, Lino CM, Pico Y, Pena A, Font G, Silveira MI (2004) Determination of organochlorine pesticide residues in honey from the central zone of Portugal and the Valencian community of Spain. J Chromatogr A 1049:155–160

Boltner D, Moreno-Morillas S, Ramos JL (2005) 16S rDNA phylogeny and distribution of *lin* genes in novel hexachlorocyclohexane degrading Sphingomonas strains. Environ Microbiol 7:1329–1338

Brittain DR, Pandey R, Kumari K, Sharma P, Pandey G, Lal R, Coote ML, Oakeshott JG, Jackson CJ (2011) Competing S(N)2 and E2 reaction pathways for hexachlorocyclohexane degradation in the gas phase, solution and enzymes. Chem Commun (Camb) 47:976–978

Concha-Graña E, Turnes-Carou MI, Muniategui-Lorenzo S, Lo′pez- Mahia P, Prada-Rodriguez D, Ferna′ndez-Ferna′ndez E (2006) Evaluation of HCH isomers and metabolites in soils, leachates, river water and sediments of a highly contaminated area. Chemosphere 4:588–595

Dadhwal M, Jit S, Kumari H, Lal R (2009) *Sphingobium chinhatense* sp. nov., a hexachlorocyclohexane (HCH) degrading bacterium isolated from an HCH dump site. Int J Syst Evol Microbiol 59:3140–3144

Dogra C, Raina V, Pal R, Suar M, Lal S, Gartemann KH, Holliger C, van der Meer JR, Lal R (2004) Organization of *lin* genes and IS*6100* among different strains of hexachlorcyclohexane degrading *Sphingomonas paucimobilis* strains: Evidence of natural horizontal transfer. J Bacteriol 186:2225–2235

Fantroussi E, Agathos SN (2005) Is bioaugmentation a feasible strategy for pollutant removal and site remediation? Curr Opin Microbiol 8(3):268–275

Gangwar MP, Lakhchaura BD, Sud SC (1979) In vitro studies on the effect of certain pesticides on rumen microorganisms of the Buffalo. Indian Vet J 56:1001–1006

Garg N, Bala K, Lal R (2011) *Sphingobium lucknowense* sp. nov., a hexachlorocyclohexane (HCH) degrading bacterium isolated from HCH contaminated soil. Int J Syst Evol Microbiol 62:618–623

Golfinopoulos SK, Nikolaou AD, Kostopoulou MN, Xilourgidis NK, Vagi MC, Lekkas DT (2003) Organochlorine pesticides in the surface waters of Northern Greece. Chemosphere 50:507–516

Heinisch E, Kettrup A, Bergheim W, Martens D, Wenzel S (2005) Persistent chlorinated hydrocarbons (pchc), source oriented monitoring in aquatic media 3. The isomers of hexachlorocyclohexane. Fresen Environ Bull 14(6):444–462

Hinckley DA, Bidleman TF, Rice CP (1992) In results of the third joint US-USSR bering and Chukchi seas expedition (BERPAC), summer 1988. In: Nagel PA (ed) U.S. fish and wildlife service, Washington, DC

Huisman HO and Smit A (1955) A new synthesis of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). Recueil des Travaux Chimiques des Pays-Bas 74(2):155–160. http://onlinelibrary.wiley.com/doi/10.1002/recl.v74:2/issuetoc

Jantunen LM and Bidleman TF (1996) Air-water gas exchange of hexachlorocyclohexanes (HCHs) and the enantiomers of a-HCH in arctic regions. J Geophys Res 101:28,837–28,846; corrections 1997, Ibid. 102:19,279–19,282

Jit S, Dadhwal M, Prakash O, Lal R (2008) *Flavobacterium lindanitolerans* sp. nov., isolated from hexachlorocyclohexane-contaminated soil. Int J Syst Evol Microbiol 58:1665–1669

Jit S, Dadhwal M, Kumari H, Jindal S, Kaur J, Lata P, Niharika N, Lal D, Garg N, Gupta SK, Sharma P, Bala K, Singh A, Vijgen J, Weber R, Lal R (2011) Evaluation of hexachlorocyclohexane contamination from the last lindane production plant operating in India. Environ Sci Pollut Res 18:586–597

Jürgen HJ, Roth R (1989) Case study and proposed decontamination steps of the soil and groundwater beneath a closed herbicide plant in Germany. Chemosphere 18:1163–1169

Kaur J, Verma M, Lal R (2011) *Rhizobium rosettiformans* sp. nov., isolated from hexachlorocyclohexane (HCH) dump site in India, and reclassification of [*Blastobacter*] *aggregatus* Hirsch et al. [1985] as *Rhizobium aggregatum* comb. nov. Int J Syst Evol Microbiol 61:1218–1225

Kumar M, Verma M, Lal R (2008) *Devosia chinhatensis* sp. nov., isolated from hexachlorocyclohexane (HCH) dump site in India. Int J Syst Evol Microbiol 58:861–865

Kumari R, Subudhi S, Suar M, Dhingra G, Raina V, Dogra C, Lal S, van der Meer JR, Holliger C, Lal R (2002) Cloning and characterization of *lin* genes responsible for the degradation of Hexachlorocyclohexane isomers by *Sphingomonas paucimobilis* strain B90. Appl Environ Microbiol 68:6021–6028

Kumari B, Madan VK, Kathpal TS (2007) Status of insecticide contamination of soil and water in Haryana, India. Environ Monit Assess 136:239–244

Kumari H, Gupta SK, Jindal S, Katoch P, Lal R (2009) Description of *Sphingobium lactosutens* sp. nov., isolated from a hexachlorocyclohexane dump site and *Sphingobium abikonense* sp. nov. isolated from oil contaminated soil. Int J Syst Evol Microbiol 59:2291–2296

Kumari K, Sharma P, Tyagi K, Lal R (2011). *Pseudoxanthomonas indica* sp. nov., isolated from Hexachlorocyclohexane (HCH) dumpsite in North India. Int J Syst Evol Microbiol 61:2107–2111

Lal R, Dogra C, Malhotra S, Sharma P, Pal R (2006) Diversity, distribution, and divergence of *lin* genes in hexachlorocyclohexane degrading Sphingomonads. Trends Biotechnol 24:121–130

Lal R, Dadhwal M, Kumari K, Sharma P, Singh A, Kumari H, Jit S, Gupta SK, Nigam A, Lal D, Verma M, Kaur J, Bala K, Jindal S (2008) *Pseudomonas* sp. to *Sphingobium indicum*: a journey of microbial degradation and bioremediation of hexachlorocyclohexane. Indian J Microbiol 48:3–18

Lal R, Pandey G, Sharma P, Kumari K, Malhotra S, Pandey R, Raina V, Kohler HP-E, Holliger C, Jackson C, Oakeshott JG (2010) The biochemistry of microbial degradation of hexachlorocyclohexane (HCH) and prospects for bioremediation. Microbiol Mol Biol Rev 74:58–80

Lammel G, Ghimb YS, Gradosa A, Gaod H, Hühnerfussc H, Lohmann R (2007) Levels of persistent organic pollutants in air in China and over the Yellow Sea. Atmos Environ 41:452–464

Li YF (1999) Global technical hexachlorocyclohexane (HCH) usage and its contamination consequences in the environment: from 1948 to 1997. Sci Total Environ 232:121–158

Li YF, Bidleman TF, Barrie LA, McConnell LL (1998) Global hexachlorocyclohexane use trends and their impact on the Arctic atmospheric environment. Geophys Res Lett 25:39–41

Li J, Zhu T, Wang F, Qiu XH, Lin WL (2006) Observation of organochlorine pesticides in the air of the Mt. Everest region. Ecotoxicol Environ Saf 63:33–41

Malhotra S, Sharma P, Kumari H, Singh A, Lal R (2007) Localization of HCH catabolic genes (*lin* genes) in *Sphingobium indicum* B90A. Ind J Microbiol 47:271–275

Malik A, Singh KP, Ojha P (2007) Residues of organochlorine pesticides in fish from the Gomti River, India. Bull Environ Contam Toxicol 78:335–340

Nagata Y, Tsuda M (2005) Metabolic pathway, genes, and enzymes for the degradation of chlorinated pesticide, gamma-hexachlorocyclohexane. Tanpakushitsu Kakusan Koso 50(12):1511–1518

Nigam A, Jit S, Lal R (2010) *Sphingomonas histidinilytica* sp. nov. isolated from hexachlorocyclohexane (HCH)- dumpsite, India. Int J Syst Evol Microbiol 60:1038–1043

Osterreicher-Cunha P, Langenbach T, Torres JP, Lima AL, de Campos TM, Vargas EA Jr, Wagener AR (2003) HCH distribution and microbial parameters after liming of a heavily contaminated soil in Rio de Janeiro. Environ Res 93:316–327

Pal R, Bala S, Dhingra G, Prakash O, Dadhwal M, Kumar M, Prabagaran SR, Shivaji S, CullumJ, Holliger C, Lal R (2005)The hexachlorocyclohexane-degrading bacterial strains Sphingomonas paucimobilis B90A, UT26 and Sp+ having similar lin genes are three distinct species, Sphingobium indicum sp. nov; S. japonicum sp. nov; and S. francense sp. nov. and reclassification of [Sphingomonas] chungbukensis as Sphingobium chungbukense comb. nov. Int J Syst Evol Microbiol 55:1965–1972

Phillips TM, Seech AG, Lee H, Trevors JT (2005) Biodegradation of hexachlorocyclohexane (HCH) by microorganisms. Biodegradation 16:363–392

Phillips TM, Lee H, Trevors JT, Seech AG (2006) Full-scale in situ bioremediation of hexachlorocyclohexane-contaminated soil. J Chem Technol Biotechnol 81:289–298

Popp P, Bruggemann L, Keil P, Thuss U, Weiss H (2000) Chlorobenzenes and hexachlorocyclohexanes (HCHs) in the atmosphere of Bitterfeld and Leipzig (Germany). Chemosphere 41:849–855

Prakash O, Suar M, Raina V, Dogra C, Pal R, Lal R (2004) Residues of hexachlorocyclohexane (HCH) isomers from different soil and water samples in Delhi and adjoining areas. Curr Sci 87:73–77

Raina V, Hauser A, Buser HR, Rentsch D, Sharma P, Lal R, Holliger C, Poiger T, Müller MD, Kohler H-PE (2007) Hydroxylated metabolites of β- and δ-hexachlorocyclohexane: bacterial formation, stereochemical configuration, and occurrence in groundwater at a former production site. Environ Sci Technol 41:4292–4298

Raina V, Rentsch D, Geiger T, Sharma P, Buser HR, Holliger C, Lal R, Kohler HP (2008a) New metabolites in the degradation of α and γ- hexachlorocyclohexane (HCH): pentachlorocyclohexenes are hydroxylated to cyclohexenols and cyclohexenediols by the haloalkane dehalogenase LinB from *Sphingobium indicum* B90A. J Agric Food Chem 56:6594–6603

Raina V, Suar M, Singh A, Prakash O, Dadhwal M, Gupta SK, Dogra C, Lawlor K, Lal S, van der Meer JR, Holliger C, Lal R (2008b) Enhanced biodegradation of hexachlorocyclohexane (HCH) in contaminated soils via inoculation with *Sphingobium indicum* B90A. Biodegradation 19:27–40

Rubinos DA, Villasuso R, Muniategui S, Barral MT, Diaz Fierros F (2007) Using the landfarming technique to remediate soils contaminated with hexachlorocyclohexane isomers. Water Air Soil Pollut 181:385–399

Russell RJ, Harcourt RL, Oakeshott JG (1998) Bioremediation of pesticides using enzymes. ACIAR Proc 85:341–348

Sahu SK, Patnaik KK, Sharmila M, Sethunathan N (1990) Degradation of alpha-, beta-, and gamma- hexachlorocyclohexane by a soil bacterium under aerobic conditions. Appl Environ Microbiol 56:3620–3622

Sanghi R, Pillai MK, Jayalekshmi TR, Nair A (2003) Organochlorine and organophosphorus pesticide residues in breast milk from Bhopal, Madhya Pradesh, India. Hum Exp Toxicol 22:73–76

Scott C, Pandey G, Hartley CJ, Jackson CJ, Cheesman MJ, Taylor MC, Pandey R, Khurana JL, Teese M, Coppin CW, Weir KM, Jain RK, Lal R, Russell RJ, Oakeshott JG (2008) The enzymatic basis for pesticide bioremediation. Indian J Microbiol 48:65–79

Sharma P, Raina V, Kumari R, Malhotra S, Dogra D, Kumari H, Kohler H-PE, Buser HR, Holliger C, Lal R (2006) Haloalkane Dehalogenase LinB is responsible for β- and δ-Hexachlorocyclohexane in *Sphingobium indicum* B90A. Appl Environ Microbiol 72:5720–5727

Sharma P, Verma M, Bala K, Nigam A, Lal R (2010) Sphingopyxis ummariensis sp. nov., isolated from hexachlorocyclohexane (HCH)-dumpsite in north India. Int J Syst Evol Microbiol 60:780–784

Sharma P, Pandey R, Kumari K, Pandey G, Jackson CJ, Russell RJ, Oakeshott JG, Lal R (2011) Kinetic and sequence-structure-function analysis of known LinA variants with different hexachlorocyclohexane isomers. PLoS ONE 6(9):e25128. doi:10.1371/journal.pone.0025128

Singh A, Lal R (2009) A novel hexachlorocyclohexane degrading bacterium *Sphingobium ummariense* sp. nov. isolated from HCH contaminated soil. Int J Syst Evol Microbiol 59:162–166

Singh KP, Malik A, Sinha S (2007) A Persistent organochlorine pesticide residues in soil and surface water of northern indo-gangetic alluvial plains. Environ Monit Assess 125:147–155

Suar M, van der Meer JR, Lawlor K, Holliger C, Lal R (2004) Dynamics of multi *lin* gene expression in *Sphingomonas paucimobilis* B90A in response to different HCH isomers. Appl Environ Microbiol 70:6650–6656

Suar M, Hauser A, Poiger T, Buser HR, Müller MD, Dogra C, Raina V, Holliger C, van der Meer JR, Lal R, Kohler HP (2005) Enantioselective transformation of α-HCH by dehydrochlorinases LinA1 and LinA2 from soil bacterium *Sphingomonas paucimobilis* B90A. Appl Environ Microbiol 71:8514–8518

Toteja GS, Mukherjee A, Diwakar S, Singh P, Saxena BN (2003) Residues of DDT and HCH pesticides in rice samples from different geographical regions of India: a multicentre study. Food Addit Contam 20:933–939

UNEP (2009) Report of the conference of the parties of the Stockholm convention on persistent organic pollutants on the work of its fourth meeting. UNEP/POPS/COP.4/38.8 May 2009

Van der Meer JR, De Vos WM, Harayama S, Zehnder AJB (1992) Molecular mechanisms of genetic adaptation to xenobiotic compounds. Microbiol Rev 56:677–694

Van Liere H, Staps S, Pijls C, Zwiep G, Lassche R, Langenhoff A (2003) Full scale case: successful in situ bioremediation of a HCH contaminated industrial site in central Europe

(The Netherlands). In: J. Vijgen (ed) Forum book; 7th International HCH and Pesticides Forum: 128–132, Sustainable Development and Ecological Research Center, Kiev, Ukraine

Verma M, Kumar M, Dadhwal M, Kaur J, Lal R (2009) *Devosia albogilva* sp. nov. and *Devosia crocina* sp. nov., isolated from hexachlorocyclohexane (HCH) dump site. Int J Syst Evol Microbiol 59:795–799

Vijgen J (2006) The legacy of lindane HCH isomer production. A global overview of residue management, formulation and disposal. International HCH and Pesticide Association

Vijgen J, Abhilash PC, Li YF, Lal R, Forter M, Torres J, Singh N, Yunus M, Tian C, Schäffer A, Weber R (2011) Hexachlorocyclohexane (HCH) as new stockholm convention POPs—a global perspective on the management of lindane and its waste isomers. Environ Sci Pollut Res Int 18(2):152–162

Ware GW (1989) The pesticide book, 3rd edn. Thomson Publications, Fresno

White GL, Larrabee MG (1973) Phosphoinositides and other phospholipids in sympathetic ganglia and nerve trunks of rats.Effects of neuronal activity and inositol analogs (- and -hexachlorocyclohexane (lindane)) on (32 P)-labelling, synaptic transmission and axonal conduction. J Neurochem 20:783–798

Zhao G, Xu Y, Li W, Han G, Ling B (2007) PCBs and OCPs in human milk and selected foods from Luqiao and Pingqiao in Zhejiang, China. Sci Total Environ 378:281–292

Habitat Characteristics of the Critically Endangered Pigmy Hog (*Porcula salvania*) of Manas National Park and Rajiv Gandhi Orang National Park in Assam, Northeast India

P. P. Mary, Radha Raman Sinha, Awadhesh Kumar, Mintu Medhi, Gautam Narayan and Parag Deka

1 Introduction

The pygmy hog (*Porcula salvania*) is one of the endemic animals of northeast India and it is the smallest and the rarest wild Suid in the world. The animal was once distributed in tall, wet grasslands throughout the range of southern foothills of the Himalayas, occurring only in the Indian sub-continent (Oliver 1985). These habitats were known as "terai", which are essentially flat, thinly-forested and well-drained (Oliver 1980). Pygmy hog is an indicator species of "terai" ecosystem. Currently, however, it is restricted to small populations in a few pockets along Assam's border with Bhutan. These grasslands are characterized by the presence of tall thatch, or elephant grasses. This habitat is fringed on the south by similar looking lowland savannah, which gets waterlogged during monsoons. Most of this area has been taken over for paddy cultivation.

Pigmy hog was thought to be extinct from India, but in 1971 this species was rediscovered from Manas National Park (NP), Assam (Oliver 1980). In fact, the only viable population of the species exists in the Manas NP and nowhere else in the world (Narayan and Deka 2008). The International Union for Conservation of Nature (IUCN) has accorded the highest priority rating (Status Category 6—Critically Endangered) to the species putting it among the most endangered of all mammals. It is also listed in the Schedule I of the Indian Wildlife (Protection) Act, 1972. Thus the conservation of the species is important on priority basis for ensuring their survival.

P. P. Mary (✉) · R. R. Sinha · A. Kumar · M. Medhi
Forestry Department, North Eastern Regional Institute of Science and Technology(NERIST)-Deemed University, Nirjuli P.O., Papum Pare District, Arunachal Pradesh 791109, India
e-mail: purakat@yahoo.co.in

G. Narayan · P. Deka
Pigmy Hog Conservation Breeding Centre, Guwahati, Assam 781029, India

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_24, © Springer-Verlag Berlin Heidelberg 2013

The rural population surrounding pigmy hog habitat exert a tremendous pressure on natural resources to meet their basic needs of fuel wood, bush meat, livestock fodders, and other forest produces. Habitat destruction and alteration for agriculture and silviculture are regarded as some of the key causes of threat to pigmy hog's survival in India. Preservation of the grassland habitat within protected areas of such as Kaziranga National Park involves the process of annual dry-season burning. The burning is carried out to prevent re-forestation, to encourage fresh growth of grasses for ungulate grazers, and to prevent accidental fires. This practice and annual flooding of the parks have drastic negative effects on the pygmy hog. Illegal hunting and trapping is also observed as one of the major direct threat to this species. At present, Manas National Park, claimed to be the 'only or the best habitat for the continued survival of the pygmy hog'.

Research and conservation activities was started by the Pigmy Hog Conservation Programme (PHCP), launched in 1996, to save this species from extinction through conservation breeding, reintroduction in the wild, preservation of its original habitat, modifying the managment practices etc. to promote survival of natural population of pigmy hog (Narayan and Deka 2008). However, the quantitative information assessing the link between habitat variables and population size, is not available. This is crucial in not only understanding the ecology of this critically endangered species but also in developing future conservation and management plans. From the conservation and rehabilitation point of view, this paper presents information on the habitat characteristics of pigmy hogs in Manas National Park and proposed rehabilitation/release site Rajiv Gandhi Orang National Park with special reference to community structure (Frequency, Density, Dominance Index, Diversity Index and Importance Value Index) to examine the variables that are important in determining the suitable habitats to release and increase the population density of pigmy hog.

2 Materials and Methods

2.1 Study Animal

Adult pigmy hog measures about 65 cm (25 inches) in length, 25 cm (10 inches) in height and weighs 8–9 kg. Females are a little smaller than males and the newborn babies weigh only 150–200 g. A vestigial tail (2.5 cm) and only three pairs of mammae distinguish it from the wild boar (*Sus scrofa*). It is locally called *Nal Gahori* or *Takuri Borah* in Asamese, *Oma Thakri* in Bodo and *Sano Banel* in Nepali. Pigmy hogs are omnivorous in habit and their diet includes roots and tubers, grass, shoots, insects, fruits, seeds, earthworms, and probably even ground nesting birds, eggs and carrion. They are habitual foragers spending in the region of six to eight hours a day actively searching for food. Their foraging involves rooting with their snout, digging and turning up the litter and topsoil, leaving a characteristic forage mark, distinguishable from signs of other species (Oliver

1980). Searching for food is naturally the primary occupation of pigmy hog activity and in both food preference and feeding behaviour they again seem to be quite comparable to *Sus* sp.

They are non-seasonal nest builders. While nest building during the breeding season is quite widespread amongst suids, non-seasonal nest building behavior exhibited by this species is unusual and unique among suids. The nests, made with thatch and other soft plant material collected from the immediate vicinity, are well-concealed and very efficient at protecting against moisture (Oliver 1980). Nests are generally built by late-term sows as a prelude to furrowing for the protection of neonate infants. Though it was formerly classified under the genus, *Sus*, recent phylogenic analysis support its classification as a unique genus, *Porcula* (Funk et al. 2007). Pigmy hog belongs to the family Suiidae under sub-order Artiodactyla, order ungulata of class mammalia.

2.2 Study Area

Study was conducted in Manas National Park where pigmy hog naturally occurs and Rajiv Gandhi Orang National park where it is to be reintroduced (Fig. 1). Manas NP is the core of a tiger reserve, a biosphere reserve, and an elephant reserve apart from being a world heritage site. It is found at the foothills of the Himalayas, bordering Bhutan. Approximately 60 % of its area is covered by grasslands classified as the Eastern Wet Alluvial Grasslands (Champion and Seth 1968). It spans the Manas River and is bounded on the north by the Royal Manas National Park in Bhutan, on the south by the populous region of North Kamrup and on both east and west by forest reserves (26° 30′ N–27° 00′N by 90° 50′ E–92° 00′E). Several highly important threatened umbrella species of wildlife such as Royal Bengal Tiger (*Panthera tigris)* Indian elephant (*Elephas maximus*), Indian rhinoceros (*Rhinoceros unicornis*) occurs naturally in the park in addition to giant squirrel (*Ratufa indica*), Particolored flying squirrel (*Hylopetes alboniger*), Indian pangolin (*Manis crassicaudata*), Hispid hare (*Caprolagus hispidus*),Golden langur (*Trachypithecus geei*), Capped langur (*Tracopithecus pileatus)* Hoolock gibbon (*Bunopithecus hoolock*), Ganges dolphin (*Platanista gangeticus*), wild boar (*Sus scrofa*), Pygmy Hog (*Porcula salvania*) Swamp deer or Barasingha (*Cervus duvauceli*), sambar (*C. unicolor*), hog deer (*Axis porcinus*), cheetal (*A. axis*), barking deer (*Muntiacus muntjac*), Gaur (*Bos gaurus*), Asiatic wild water buffalo (*Bubalus bubalis*) etc. The Park lies within one of the world's Endemic Bird Areas where the endangered Bengal florican (*Eupodotis bengalensis*) is found.

The Rajiv Gandhi Orang National Park, located on the north bank of the Brahmaputra River in the Darrang and Sonitpur districts of Assam. It was established as a sanctuary in 1985 and declared a National Park on 13th of April 1999. It is also known as the mini Kaziranga National Park (IUCN site) since the two parks have a similar landscape made up of marshes, streams and grasslands and are inhabited by the Great Indian One-Horned Rhinoceros. The park encompasses an

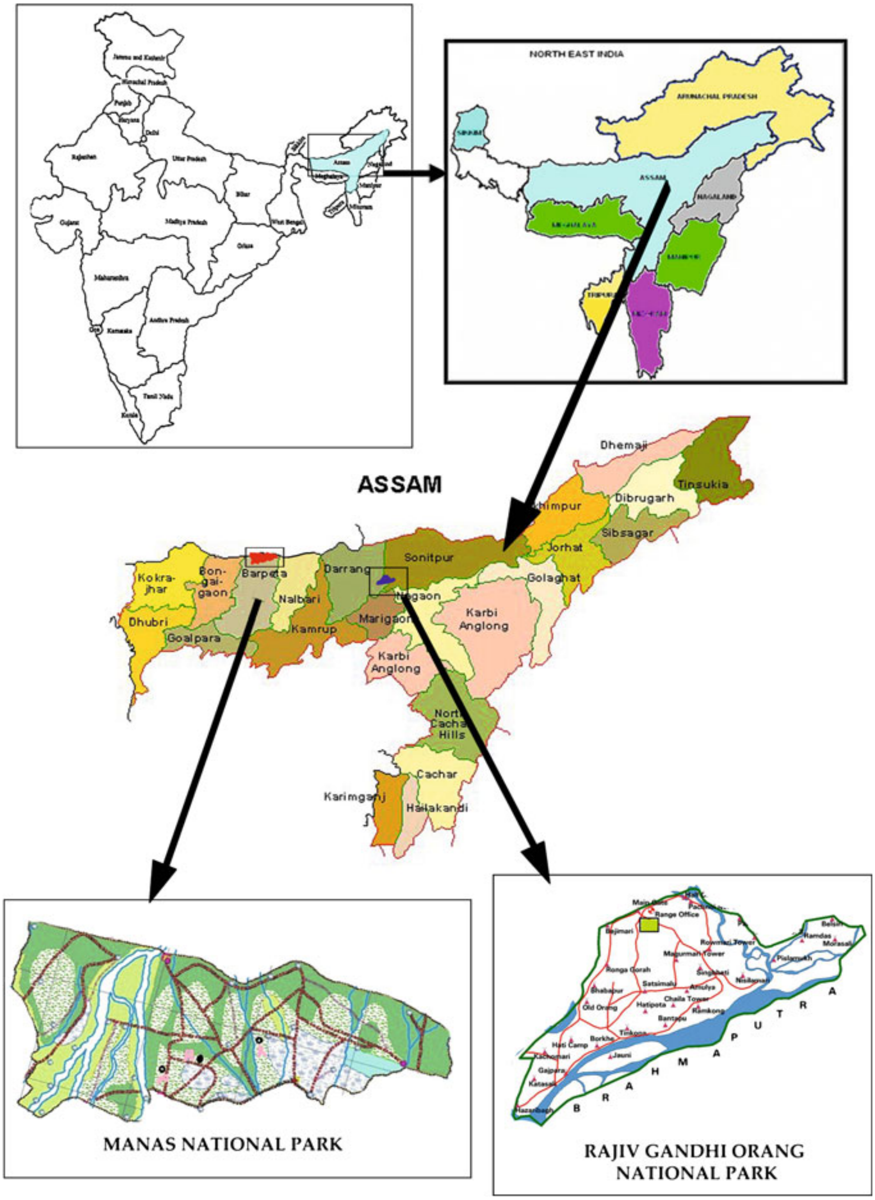


Fig. 1 Location of Manas NP and Orang NP in Assam state, North-East India

area of 78.81 km^2 (26°28′59″N–26°39′58″N by 92°15′58″E–92°27′00″E/26.483; 92.266). Pachnoi River, Belsiri River and Dhansiri River border the park and join the Brahmaputra River. Except the few species like golden langur, and pigmy hog etc., faunal characteristics of Orang is almost similar to that of Manas.

2.3 Methods

Rapid survey of vegetation was conducted from December 2009 to May 2010. Ten numbers of Belt transacts (size: 100 m $\times$ 1 m = 100 m^2) were laid randomly (Davis and Richards 1933) in activity-sites (natural habitats) of Pigmy hog with identifying marks like foraging marks, footprints, pellets, nests etc. in Manas and 10 belt transects in Orang in selected release sites of the park. All the plant species found within the transect were recorded, and their number counted and identified. If any species, recorded in any of transect, cannot be identified in the field, then herbarium was made for further identification by taxonomic experts. After identification of the species, quantitative analysis of vegetation was done (Mueller-Dombois and Ellenberg 1974 and Sharma 2006). Various community parameters were calculated such as Frequency, Frequency class, Density, Relative frequency, Relative density, IVI, Simpson Dominance Index (C), Shannon-Wiener Diversity Index (H) and Sorensen Similarity index. The comparison between the natural site (Manas NP) and proposed released site (Rajiv Gandhi Orang NP) was made by calculating similarity index of these habitats.

3 Quantitative Analytical Characters Determined

Frequency (%):

$$\text{Frequency }(\%) = \frac{\text{No.of sampling units in which the species occurred} \times 100}{\text{Total no. of sampling units studied}}$$

After determining the frequency (%) of each species, species are distributed among Raunkiaer's five classes as follows:

Frequency (%)	Frequency class
0–20	A
21–40	B
41–60	C
61–80	D
81–100	E

The value of each of the five frequency classes are found out to prepare the frequency diagram. Raunkiaer on the basis of frequency figures proposed the following law of frequency:- A > B > C <=> D < E The frequency diagram prepared for the study areas is then compared with normal frequency diagram proposed by Raunkiaer.

Density:

$$\text{Density} = \frac{\text{Total no. of individuals of the species in all the sampling units}}{\text{Total no. of sampling units studied}}$$

Relative Frequency:

$$\text{Relative Frequency} = (\text{Frequency of a species}) \times 100/\text{Total frequency of all the species}$$

Relative density:

$$\text{Relative density} = (\text{Density of the species}) \times 100/\text{Total density of all the species}$$

$$\textit{Importance Value Index (IVI)} = \text{Relative Frequency} + \text{Relative Density}$$
$$\textit{Simpson Dominance Index (C)}: \text{C} = \sum(\text{ni}/\text{N})^2 *$$

where,
n_i IVI of individual species
N Total IVI of all the species

$$\textit{Sorensen Similarity index} := [2\text{C}/(\text{A}+\text{B})]\times 100$$

where ‘A’ is the number of species at area A, ‘B’ is the number of species at area B and ‘C’ denotes the number of species common to area “A” and area “B”.

4 Results and Discussion

A total of 51 plant species were recorded from the selected both study sites. Of these, 21 plant species were found common to both sites. Photographs of these 51 plants are given in Plates 1, 2, 3, 4, and 5. 36 plant species were recorded and identified from each study site (Table 1). 30 plants were identified up to species level and 21 plants were identified up to only genus level.

4.1 IVI of Pigmy Hog Habitat in MANAS NP and ORANG NP

In Manas NP 36 species of plant were identified under 20 different families, out of which 7 species belong to grass habit and others belong to non-grass habit (Table 1). In Orang NP also, 36 species of plants were identified under 18 families out of which 8 species belong to grass habit and others belong to non-grass habit. Figures 2 and 3 represent bar diagrams of IVI of different species arranged in descending order for Manas and Orang, respectively.

It can be observed that in Manas, species with highest IVI is *Narenga porphyrocoma* (26.61) followed by *Cymbopogan martenii* (20.25), *Saccharum*

Plate 1 Plant species recorded in Pigmy hog's habitats of Manas and Orang NP.

spontaneum (19.06), *Imperata cylindrica* (17.98), *Commelina* sp.1 (17.63), *Arundinella bengalensis* (17.05), *Commelina bengalensis* (15.54) (Fig. 2). So, these are the dominant species in the surveyed Pigmy Hog natural habitat of Manas. *Narenga porphyrocoma* is mainly used by Pigmy hog for nest building purpose. It also feeds on the root of *Narenga porphyrocoma*, *Cymbopogan martenii*, *Saccharum spontaneum*, *Imperata cylindrica*, and *Arundinella bengalensis*. These dominant species are mainly grass in habit. Kaziranga National Park of Assam is reported to have similar types of dominant tall grass species of *Saccharum procerum*, *Sccharum spontanium* and *Imperata cylindrica* (Mary et al. 1998).

The highest IVI of *Narenga porphyrocoma* (27.43) followed by *Cymbopogan martenii* (20.69442), *Saccharum spontaneum* (16.68), *Arundinella bengalensis*

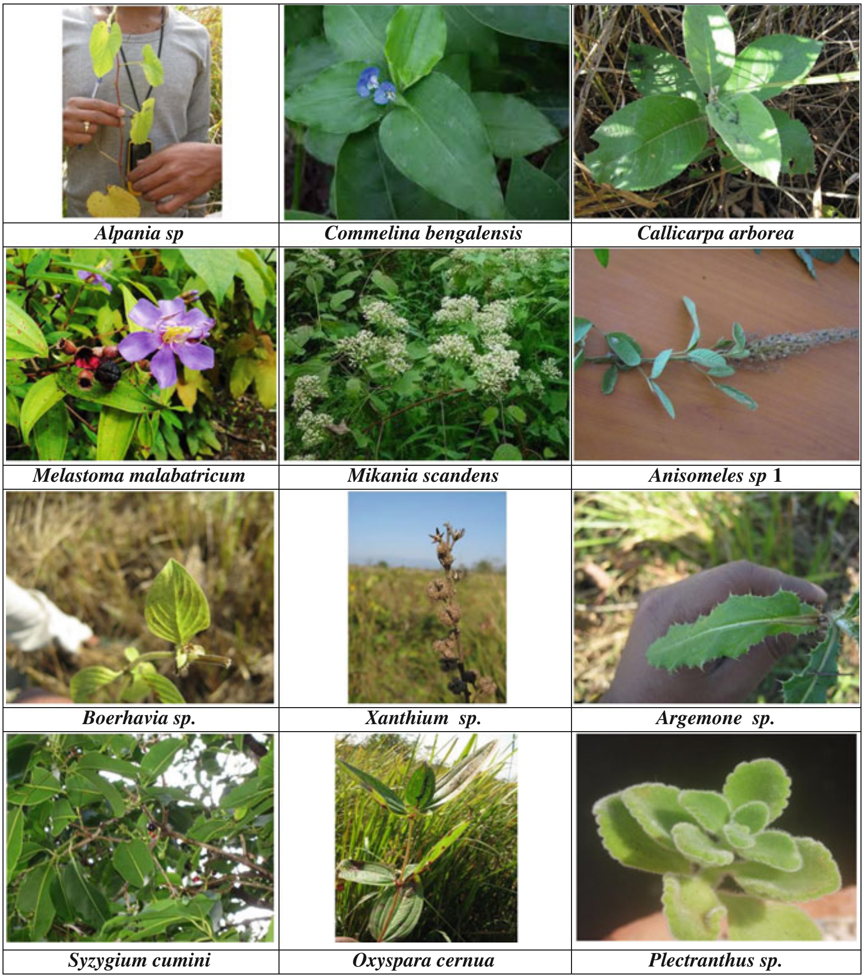


Plate 2 Plant species recorded in Pigmy hog's habitats of Manas and Orang NP.

(15.82), *Commelina* sp.1 (15.76), *Commelina bengalensis* (15.68) etc. were recorded in Orang NP. So, these are the dominant species in the surveyed habitat of Orang NP. *Imperata cylindrica* has important value index of only 5.05 in Orang National Park whereas it has IVI of 17.98 in Manas National Park (Fig. 3).

4.2 Relative Density of Pigmy Hog Habitat in MANAS NP and ORANG NP

Highest relative density of plant species in Pigmy Hog habitat of Manas was *Narenga porphyrocoma* (19.519 %) followed by *Cymbopogan marteni* (13.167 %),

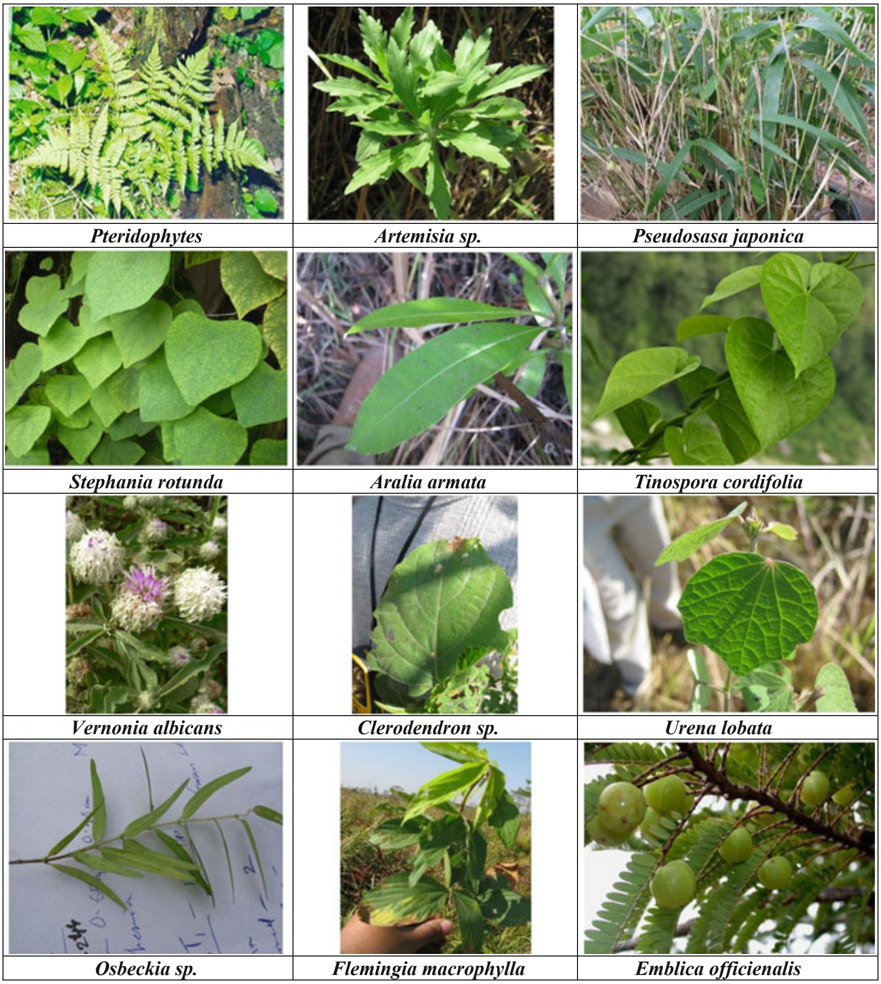


Plate 3 Plant species recorded in Pigmy hog's habitats of Manas and Orang NP.

Saccharum spontaneum (11.973 %), *Imperata cylindrica* (10.89 %) etc. (Table 1) while plant species with highest relative density in Orang NP were *Narenga porphyrocoma* (21.22 %) followed by *Cymbopogan marteni* (14.48 %) and *Saccharum spontaneum* (10.47 %). *Arundinella bengalensis* has almost same relative density in Orang (9.60 %) and Manas (9.96 %) (Table 1).

Plate 4 Plant species recorded in Pigmy hog's habitats of Manas and Orang NP.

Plate 5 Plant species recorded in Pigmy hog's habitats of Manas and Orang NP.

Table 1 Different values of vegetation analysis like frequency (*FR*), frequency class (*FRC*), density (*D*), relative frequency (*FR*), relative density (*RD*), importance value index (*IVI*), dominance index (*DI*) and diversity index (*Div*. I) of study sites

Sl. No.	Species	Family	Manas								Orang							
			FR	FRC	D	RF	RD	I V I	DI	Div I	FR	F.C	D	RF	RD	I V I	DI	Div I
1	*Narenga porphyrocoma*	Poaceae	100	E	12,260	7.09	19.51	26.61	0.11660	0.01773	100	E	12,280	6.21	21.22	27.43	0.018817	0.27
2	*Cymbopogan martenii*	Poaceae	100	E	8,270	7.09	13.16	20.25	0.10075	0.01027	100	E	8,380	6.21	14.48	20.69	0.010706	0.23
3	*Saccharum spontaneum*	Poaceae	100	E	7,520	7.09	11.97	19.06	0.09734	0.00910	100	E	6,060	6.21	10.47	16.68	0.00696	0.2
4	*Imperata cylindrica*	Poaceae	100	E	6,840	7.09	10.88	17.98	0.09410	0.00810	60	C	770	3.72	1.3	5.05	0.000639	0.09
5	*Commelina sp.1*	Commelinaceae	100	E	6,620	7.09	10.53	17.63	0.09303	0.00778	100	E	5,530	6.21	9.55	15.76	0.006216	0.20
6	*Arundinella bengalensis*	Poaceae	100	E	6,260	7.09	9.96	17.05	0.09120	0.00728	100	E	5,560	6.21	9.60	15.82	0.006257	0.20
7	*Commelina bengalensis*	Commelinaceae	100	E	5,310	7.09	8.45	15.54	0.08626	0.00605	100	E	5,480	6.21	9.47	15.68	0.006148	0.19
8	*Leea crispa*	Leeaceae	80	D	2,070	5.67	3.29	8.96	0.06046	0.00201	60	C	1,230	6.21	9.47	15.68	0.006148	0.19
9	*Mikania scandens*	Asteraceae	50	C	1,560	3.54	2.48	6.02	0.04582	0.00091	90	E	2,390	5.59	4.13	9.72	0.002362	0.14
10	*Gerwia sp*	Tiliaceae	70	D	520	4.96	0.82	5.79	0.04456	0.00084	10	A	60	0.62	0.10	0.72	1.31E−05	0.02
11	*Oxalis corniculata*	Oxalidaceae	50	C	1,370	3.54	2.18	5.72	0.04417	0.00082								
12	*Bombex ceiba*	Fabeceae	40	B	490	2.83	0.78	3.61	0.03149	0.00033	10	A	200	0.62	0.34	0.97	2.34E−05	0.02
13	Alpinia	Zingiberaceae	40	B	360	2.83	0.57	3.41	0.03017	0.00029								
14	*Pseudosasa japonica*	Poaceae	30	B	460	2.12	0.73	2.86	0.02640	0.00020	100	E	670	6.21	1.15	7.36	0.001358	0.12
15	*Callicarpa arborea*	Verbenaceae	30	B	240	2.12	0.38	2.50	0.02380	0.00016								
16	*Tinospora cordifolia*	Menispermaceae	30	B	160	2.12	0.25	2.38	0.02292	0.00014								
17	*Melastoma malabatricum*	Mealstomeaceae	20	A	380	1.41	0.60	2.02	0.02017	0.00010	80	D	480	4.96	0.82	5.79	0.000841	0.10
18	*Eupatorium sp.*	Asteraceae	20	A	300	1.41	0.47	1.89	0.01914	0.00009	30	B	530	1.86	0.91	2.77	0.000193	0.05
19	*Anisomeles sp1*	Lamiaceae	20	A	270	1.41	0.42	1.84	0.01875	0.00008								
20	*Boerhavia sp*	Nyctaginaceae	20	A	260	1.41	0.41	1.83	0.01867	0.00008								
21	*Xanthium sp.*	Asteraceae	20	A	100	1.41	0.15	1.57	0.01654	0.00006								
22	*Argemone sp*	Papaveraceae	20	A	90	1.41	0.14	1.56	0.01645	0.00006								
23	*Syzygium cumini*	Dipterocarpaceae	20	A	90	1.41	0.14	1.56	0.01645	0.00006								
24	*Oxyspara cernua*	Melastomaceae	20	A	50	1.41	0.07	1.49	0.01586	0.00006	10	A	250	0.62	0.43	1.05	2.77E−05	0.02
25	*Plantago sp.*	Plantaginaceae	20	A	40	1.41	0.06	1.48	0.01578	0.00005	10	A	90	0.62	0.34	0.96	2.34E−05	0.02
26	*Pteridophytes*	Pteridophyta	10	A	300	0.70	0.47	1.18	0.01316	0.00003	60	C	2,550	3.72	4.40	8.13	0.001654	0.13
27	*Artemisia sp*	Asteraceae	10	A	160	0.70	0.25	0.96	0.01114	0.00002								
28	*Clerodendron sp.*	Verbenaceae	10	A	140	0.70	0.22	0.93	0.01085	0.00002	10	A	150	0.62	0.25	0.88	1.94E−05	0.02

(continued)

Table 1 (continued)

Sl. No.	Species	Family	Manas								Orang							
			FR	FRC	D	RF	RD	I V I	DI	Div I	FR	F.C	D	RF	RD	I V I	DI	Div I
29	*Bidens pilosa*	Asteraceae	10	A	90	0.70	0.14	0.85	0.01009	0.00002								
30	*Aralia armata*	Araliaceae.	10	A	80	0.79	0.12	0.83	0.00989	0.00002								
31	*Anisomeles sp.2*	Lamiaceae	10	A	60	0.70	0.09	0.80	0.00960	0.00002	80	D	500	4.94	0.86	5.83	0.000851	0.10
32	*Commelina sp. 2*	Commelinaceae	10	A	30	0.70	0.04	0.75	0.00910	0.00001	10	A	90	0.62	0.15	0.77	1.51E−05	0.02
33	*Anisomeles sp 3*	Lamiaceae	10	A	20	0.70	0.03	0.74	0.00900	0.00001	10	A	120	0.62	0.20	0.82	1.72E−05	0.02
34	*Ficus hispida*	Moraceae	10	A	20	0.70	0.03	0.74	0.00900	0.00001								
35	*Vernonia cinerea*	Asteraceae	10	A	10	0.709	0.01	0.72	0.00880	0.00001								
36	*Crotalaria pallida*	Fabaceae	10	A	10	0.70	0.01	0.72	0.00880	0.00001								
37	*Hedychium sp.*	Zingiberaceae									40	B	950	2.48	1.64	4.12	0.000426	0.08
38	*Scoparia dulcis*	Scrophulariaceae									40	B	750	2.48	1.29	3.78	0.000357	0.07
39	*Ageratum conyzoides*	Asteraceae									30	B	305	1.86	1.31	3.17	0.000252	0.65
40	Osbeckia sp.	Melastomaceae									40	B	220	2.48	0.38	2.86	0.000205	0.06
41	*Emblica officinalis*	Euphoriaceae									30	B	430	1.84	0.74	2.60	0.00017	0.05
42	*Lygodium sp.*	Lycopodiaceae									30	B	70	1.86	0.12	1.98	9.84E−05	0.04
43	*Spilanthes paniculata*	Asteraceae									20	A	20	1.24	0.03	1.27	4.08E−05	0.032
44	*Plectranthus sp*	Lamiaceae									10	A	120	0.62	0.20	0.82	1.72E−05	0.02
45	*Urena lobata*	Malvaceae									10	A	110	0.62	0.19	0.81	1.65E−05	0.02
46	*Borreria hispida*	Rubiaceae									10	A	100	0.62	0.17	0.79	1.58E−05	0.02
47	*Vernonia albicans*	Asteraceae									10	A	50	0.62	0.08	0.70	1.25E−05	0.01
48	*Cajanus sp*	Fabaceae									10	A	50	0.62	0.08	0.70	1.25E−05	0.01
49	*Artocarpus sp*	Moraceae									10	A	30	0.62	0.05	0.67	1.13E−05	0.01
50	*Stephania rotunda*	Menispermaceae									10	A	10	0.62	0.07	0.63	1.02E−05	0.01
51	*Flemingia macrophylla*	Fabaceae									80	D	710	4.96	1.2	6.19	0.00096	0.10
Total									0.072	2.93							0.066603	3.01

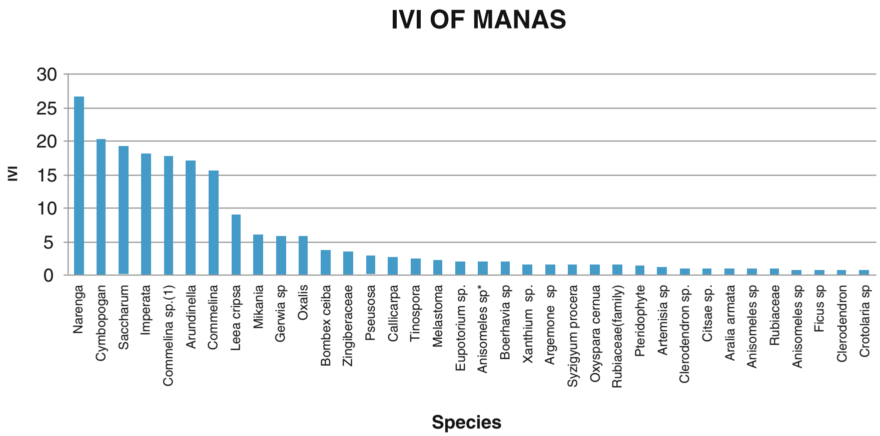


Fig. 2 IVI of plant species recorded in Manas NP

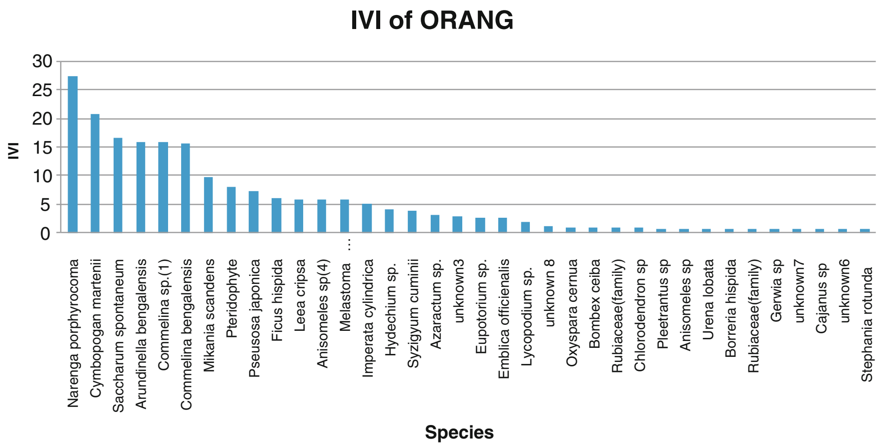


Fig. 3 IVI of plant species recorded in Orang NP

4.3 Frequency Class of Pigmy Hog Habitat in MANAS NP and ORANG NP

The data in Table 1 is used to calculate the frequency no. of frequency classes of Manas NP and Orang NP (Table 2) which is illustrated in Figs. 4 and 5 respectively. Based on which the frequency diagrams obtained for the Pigmy Hog habitat in Manas NP and Orang NP are as follows:- $A > B > C = D < E$—Manas and $A > B > C = D < E$—Orang.

The obtained frequency diagrams are similar with that given by Raunkiaer. Hence, it can be concluded that the habitat of Pigmy Hog in Manas NP and the proposed future release area of Orang NP belongs to Normal grassland habitat.

Table 2 Distribution of frequency class in Manas NP and Orang NP

	Manas NP			Orang NP	
Frequency class	Occurrence No	Frequency (%) of frequency class (observed)	Frequency (%) of frequency class (normal)	Occurrence No	Frequency (%) of frequency class (observed)
A	20	55.56	53	15	41.66
B	5	13.89	14	7	19.44
C	2	5.56	9	3	8.33
D	2	5.56	8	3	8.33
E	7	19.44	18	8	22.22

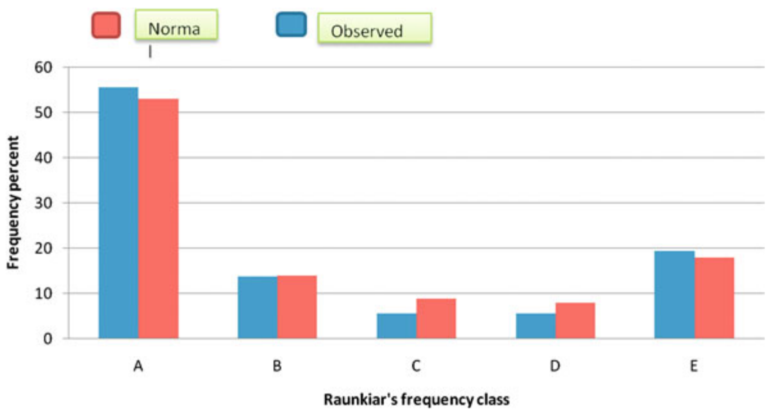


Fig. 4 Frequency distribution of plants species of Pigmy Hog habitat in Manas NP

4.4 Dominance Index and Diversity Index of Pigmy Hog Habitat in MANAS NP and ORANG NP

Using the IVI in Table 1, Simpson dominance index and Shannon-Wiener diversity index of individual species were calculated and their total was calculated as 0.072 and 2.93 respectively for Manas NP. In case of Orang NP the total of dominance indices and total of diversity indices were found to be 0.0666 and 3.01 respectively. These two values are used for comparing the two study areas. So, Diversity of Manas < Diversity Orang. It can be observed that the vegetation in Manas is less diverse than Orang (Table 3 and Fig. 6). Since diversity is less in Manas but higher in Orang, dominance index should be higher in Manas but lower in Orang which can be justified from Table 3 and Fig. 7.

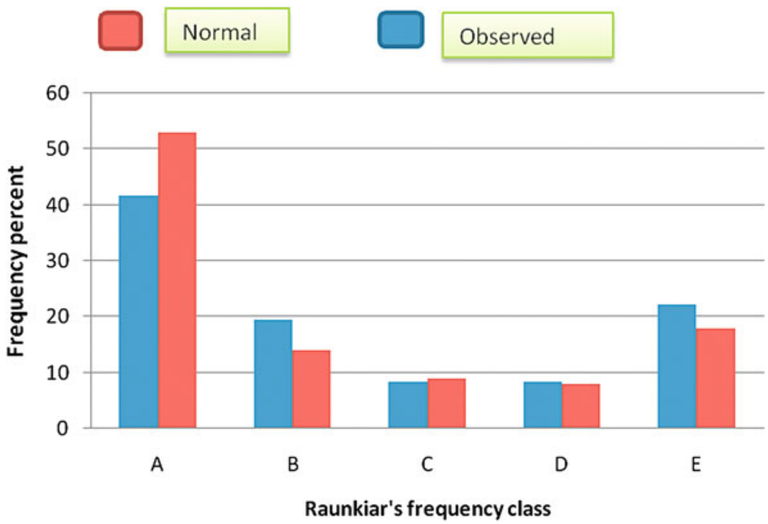


Fig. 5 Frequency distribution of plants species of proposed Pigmy Hog habitat in Orang NP

Table 3 Showing dominance index and diversity index for Manas NP and Orang NP

Sites	Dominance index	Diversity index
Manas	0.072	2.93
Orang	0.0666	3.01

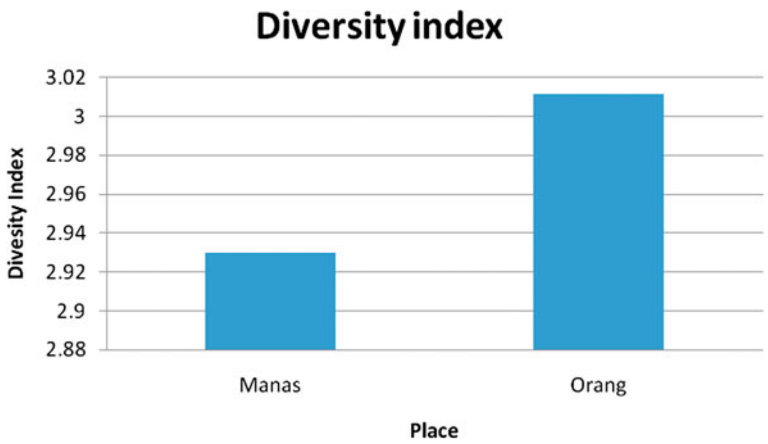


Fig. 6 Diversity index of Manas NP and Orang NP

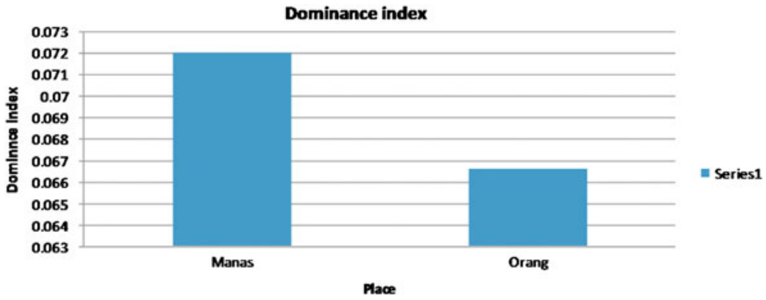


Fig. 7 Dominance index of Manas NP and Orang NP

4.5 Similarity Index of MANAS: ORANG Pigmy Hog Habitats

Sorensen similarity index for Manas-Orang was calculated as 58.33 %. Since it is more than 50 % it can be stated that Pigmy Hog habitat in Manas NP is similar to that of Orang NP.

5 Conclusion

Four species of grasses, *Narenga porphyrocoma, Cymbopogan martenii, Saccharum spontaneum* and *Arundinella bengalensis*, on which pigmy hog is mostly dependent for food and shelter, were found to be dominant in both habitats (Manas NP and Orang NP). Two species of *Commelina* sp. were also dominant in both parks. It can be concluded that Orang has almost similar vegetation as Manas. Hence, rehabilitation of Pigmy Hog in Orang NP would help in conservation of pigmy hog population. The proposed release site can be more improve by introduction of plant species like *Oxalis corniculata*, *Alpania sp.,Callicarpa arborea, Tinospora cordifolia* etc. which have good IVI values pigmy hog distributed area of Manas NP.

However, only based on vegetation suitability we cannot surely ascertain about the suitable habitat of pigmy hog, because suitability of habitat also depends on various other factors like seasonal vegetation composition, physico-chemical characters of soil, anthropogenic threat, prey-predator relationship, other locality factors etc. Further studies on impacts of the changing climate and global warming on pigmy hog are recommended. It is expected that these vegetation parameters of pigmy hog habitat will help in determining the other factors and will also help in establishing a foundation for suitable habitat of this species.

Acknowledgments The authors express their sincere gratitude to the Director and faculty members of NERIST forestry department for providing permission to carry out this work. We would also like to thank all forest officials of Manas NP and Rajiv Gandhi Orang NP for extending their valuable co-operation. We thank all people working in the Forestry department who directly or indirectly helped in successful completion of this work.

References

Champion HG, Seth SK (1968) A revised survey of forest types of India. The Manager of publications, Dehra Dun

Davis TAW, Richards PW (1933) The vegetation of Moraballi Creek, British Guiana. An ecological study of a limited area of tropical rain forest. I J Ecol 21:350–384

Funk SM, Verma SK, Larson G, Prasad K, Singh L, Narayan G, Fa JE (2007) The pigmy hog is a unique genus: 19th century taxonomists got it right first time round. Mol Phylogenet Evol 45:427–436

Mary PP, Solanki GS, Limboo D, Upadhaya K (1998) Observations on feeding and territorial behaviour of Indian rhino (Rhinoceros unicornis) in Kaziranga National Park, Assam, India. Tiger Paper 25(4)4: 25–28

Mueller-Dombois D, Ellenberg D (1974) Aims and methods of vegetation ecology. Wiley, USA

Narayan G, Deka PJ (2008) Conservation breeding programme for Pigmy Hogs (Porcula salvania). Zoos' Print XXIII(11)11:19–21

Oliver, WLR (1980) The Pigmy Hog: the Biology and conservation of the Pigmy Hog, Sus salvanius and the Hispid Hare, Caprolagus hispidus. Special scientific report 1980; No. 1, Jersey Wildlife Preservation Trust, Jersey, UK, p 120

Oliver WLR (1985) The distribution and status of the hispid hare (Caprolagus hispidus), with some additional notes on the pigmy hog (Sus salvania)—a report on the 1984 field survey. Unpublished. Rrep. to Wildlife Preservation Trust, p 94

Sharma PD (2006) Ecology and environment, vol 179, 7th edn. Rastogi publications, Meerut, New Delhi, p 191

Conservation, Restoration, and Management of Mangrove Wetlands Against Risks of Climate Change and Vulnerability of Coastal Livelihoods in Gujarat

P. K. Viswanathan

1 Introduction

In an estimation done by Rao and Datye (2003) it is found that globally 6 % of the land surface is wetland and it is distributed in all climatic zones of the earth except Antarctica. According to Mitsch and Gosselink (2000) wetlands have been identified as one of the most important ecosystems on the earth and as much as 13 % has been proposed for protection (WWF 2001). Despite their global recognition wetlands have been disappearing at alarming rates (Mitsch and Gosselink 2000). Wetlands form an integral part of the natural environment of Trinidad and with proper management could contribute to Trinidad's ecological wealth and economic development as they provide a wide range of resources. Specifically, wetlands provide income via directly exploitable resources such as timber, tannins, charcoal, fish, collection of snails, and small-scale rice farming for the cash-poor people living under traditional subsistence economies and in village communities. Wetlands also provide many ecological services such as providing nursery habitat for juvenile marine species and coastal protection from tropical storms.

India has a long coastal line of over 7,500 km supporting vast habitats such as lagoons, backwaters, estuaries, coral reefs and mangrove swamps. Among them, the mangrove ecosystem commands the highest importance because of its biological productivity and specialized diversity. After coral reefs, mangrove forests have the highest productivity among the coastal wetlands (Sandilyan et al. 2010). Mangrove wetlands of India account for about 3 % of the global mangrove vegetation and are spread over an area of 4,661.56 km^2 along the coastal areas of the country.

As per the inventory of wetland resources of India during 1990 as prepared by the Ministry of Environment and Forests (MoEF), the wetland area of India was assessed at about 4.1 million ha including both natural (36 %) and manmade (64 %) wetlands

P. K. Viswanathan (✉)
Gujarat Institute of Development Research, Ahmedabad, Gujarat, India
e-mail: pkviswam@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_25,

(Rao and Datye 2003). However, this assessment seemed to be an underestimate as the MoEF assessment included only wetlands less than 100 ha in area.

A much more realistic and more recent assessment of the wetlands in India (national and state-wise) is being made available by the MoEF using Remote Sensing and GIS data compiled by the Space Application Centre (SAC), ISRO Ahmedabad, published as the *National Wetland Atlas, 2011*. According to this, the wetlands of India have been assessed at 15.26 million ha, of which, 69 % is inland wetlands (natural and man-made) with coastal wetlands forming 27 % (GoI 2011). As per the assessment, wetlands constitute about 5 % of the total geographical area of India and mangrove wetlands constitutes about 3 % of the wetland area as evident from Table 1.

Notably, Gujarat has the largest share in the total wetland area in India (23 %), followed by Andhra Pradesh (9.5 %), West Bengal (7.3 %), Maharashtra (6.65 %), and Tamil Nadu (5.9 %). Though the seven states together account for only 57 % of the total wetland area, they occupy almost 85 % of the mangrove area in the country. Gujarat has the largest proportion of wetland area (17.56 %) in the total geographical area, followed by West Bengal (12.5 %). Along the Gulf of Kutch, Gujarat has the second-largest mangrove cover (19.2 %) after Sundarbans in West Bengal (44 %), followed by Andhra Pradesh (8.8 %) and Orissa (5 %) in the third and fourth positions.

The ecological profile of Gujarat is unique in that the state has a long coastal belt of 1,600 km (approximately 21 % of the national coastline) falling into four distinct geographical regions with physical and oceanographic formations, viz., (1) Gulf of Kutch, (2) Saurashtra Coast, (3) Gulf of Khambhat, and (4) South Gujarat Coast. Ironically, most of these coastal formations and their ecosystems have become highly vulnerable to various anthropogenic activities including rapid industrialization and coastal infrastructure development projects (like ports, oils refineries), jeopardizing both the ecological and livelihood securities along the regions (GEC 2011).

Table 1 State-wise distribution of wetland and mangrove area in India, 2010

State	Wetland area (million Ha)	(%) Share	Mangrove area (Ha)	(%) Share	Wetland as % of TGA[a]	Mangrove as % of total wetland area
Andhra Pradesh	1.45	9.48	41,486	8.80	5.26	2.87
Gujarat	3.47	22.77	90,475	19.19	17.56	2.60
Kerala	0.16	1.05	Na	0.00	4.13	0.00
Maharashtra	1.01	6.65	30,238	6.41	3.30	2.98
Orissa	0.69	4.53	23,395	4.96	4.49	3.39
Tamil Nadu	0.90	5.91	7,315	1.55	6.92	0.81
West Bengal	1.11	7.26	209,330	44.41	12.48	18.89
Sub total	8.80	57.66	402,239	85.33	6.51	3.63
All India	15.26	100.00	471,407	100.00	4.63	3.09

[a] *TGA* total geographical area

Source Estimated from GoI (2011): National Wetland Atlas, 2011

Though the state is predominately an arid and semi-arid region, the topographical variations make it quite rich in ecological wealth, ranging from grasslands, forests (thorny scrub to canopy forests), wetlands, saline deserts, and the coastal systems. As at the national level, the wetland ecosystem of Gujarat has also been classified into two major types, viz.: (a) inland wetlands (natural & man-made); and (b) coastal wetlands (natural & man-made), as presented in Table 2.

From Table 2, it may be observed that the coastline of Gujarat is the longest and rich in terms of dominance of coastal wetlands, both natural and man-made, which together account for almost 81 % of the total wetland area in the state.

Given this backdrop, this paper makes an illustrative case for conservation, restoration, and sustainable management of mangrove wetland-based ecosystems in Gujarat amidst the growing crisis of livelihoods facing the coastal communities in the event of climate change induced threats and livelihood security. The empirical analysis contained in the paper is based on the study of the impacts of mangrove restoration activities in the Gulf of Kutch undertaken by the Government of Gujarat under the initiatives of the India–Canada Environment Facility (ICEF) in the initial phase (2000–2005) and the Gujarat Ecology Commission, later on (since 2005).

Rest of the paper is organized into three sections. In Sect. 2, the paper discusses the importance of conservation and restoration of mangrove wetlands in the present context and the global and local initiatives thereon. Section 3 presents the empirical case of the socio-economic and ecological outcomes of the community-based mangrove restoration (CBMR) in Gujarat and its livelihood outcomes. Section 4 concludes the paper by underlying the major challenges facing the conservation and restoration of mangrove wetlands in the state and the imperatives of policy and institutional interventions in the emerging context of climate change risks and vulnerability of coastal livelihoods. It also brings out the imperative of a better understanding of the dynamics of the ongoing interventionist policies and programmes towards restoration and conservation of mangroves in rest of the Indian states, especially, West Bengal, Orissa, Tamil Nadu, and Andhra Pradesh, which are in the forefront of implementing mangrove restoration activities.

Table 2 Types of wetlands in Gujarat and their spread

Wetland category	Number of wetlands	Total wetland area	% of wetland area	Open water area		% change
				Post-monsoon	Pre-monsoon	
Inland wetlands	11,433	658,191	18.9	409,416	165,049	148.1
Coastal wetlands	2,750	2,807,051	8	741,339	567,432	30.6
Wetlands (<2.25 ha[a])	9,708	9,708	0.3	–	–	–
Total wetlands	23,891	3,474,950	100	1,150,755	732,481	57.1
Mangroves	746	90,475	3.2[b]	–	–	–

[a] Include mainly tanks; [b] Indicates the share of mangroves in total coastal wetland area
Source: GoI (2011)

2 Conservation and Restoration of Mangrove Wetlands: Policies and Interventions in India

The period since early 1990s in particular had witnessed the emergence of policies and interventions with increasing efforts by the national governments, NGOs, and local communities around the world to conserve, rehabilitate, and manage mangrove wetlands on a sustainable basis (World Bank 2003). Wetlands, including mangroves and the supported ecosystems, and other aquatic habitats in India have naturally been the victims, directly or indirectly, of various anthropogenic activities (Gopal 2001) especially, the growing industrial expansion along the coastlines of Gujarat (Viswanathan and Parikh 2010).

This was also the time around which the early signals of climate change had started receiving global attention. It was recognized that along with various anthropogenic factors, climate change posed additional threats to mangrove ecosystems as mangroves occupied marginal land areas that could shrink significantly under the projected sea level rise (UNEP-UNESCO 1992). The need for policies and interventions became imperative in many countries as they virtually had no policies for management of mangroves or failed in enforcing the conservation policies and protection measures.

There has been a rapid expansion of mangrove restoration programmes in the Indian Ocean region in the light of the 2004 tsunami, supported by the respective national governments and non-governmental organizations (NGOs) to replant and rehabilitate mangrove ecosystems as ‘‘natural barriers’’ to future tsunamis and other tropical storms. Post-tsunami disaster, increased emphasis has been placed on replanting degraded and deforested mangrove areas in Asia as a means to bolstering coastal protection. For instance, the Indonesian Minister for Forestry has announced plans to reforest 600,000 ha of depleted mangrove forest throughout the nation in 5 years (EJF 2005). The governments of Sri Lanka and Thailand have also initiated programmes for rehabilitation/replanting of mangrove areas (Barbier 2008). Thailand’s national policy has been to expand mangroves from 170,000 to 200,000 ha by 2006. Thailand has instituted the Office of Mangrove Conservation under the Department of Marine and Coastal Resources, which is a department under the new Ministry of Natural Resources and Environment (Sugunnasil and Sathirathai 2004).

More interestingly, a major thrust of the mangrove restoration programmes in these countries has been to motivate the local villagers to volunteer their labour to mangrove replanting schemes (Erftemeijer and Lewis 2000; Stevenson et al. 1999; Barbier 2008). The assumption is that since the mangrove areas impact directly the livelihoods and income of the mangrove-dependent communities, the household members (both male and female) would be willing to volunteer in the mangrove restoration programmes. In turn, the voluntary labour contributions made by the local communities are compensated with wage transfers.

In India, the early initiatives for development and restoration of mangroves have come from the MS Swaminathan Research Foundation (MSSRF) even before the encounter with the devastating tsunami. The MSSRF, Chennai launched a major programme in 1996 for the restoration of the mangrove wetlands of the east coast of India, with financial support under the India Canada Environment Facility (ICEF) and in collaboration with the Ministry of Environment and Forests and State Forest Departments of Tamil Nadu, Andhra Pradesh, Orissa, and West Bengal. In Gujarat, mangrove restoration programmes were implemented by the State Forest Department as well as the Gujarat Ecology Commission (GEC) during 2002–2007 with financial support from the ICEF. The project aims at development of mangrove plantations in the gulfs of Kutch and Khambhat, outside the protected forest areas, i.e., in the wastelands provided by the Government of Gujarat (Viswanathan et al. 2011).

As a result of the proactive interventions made by the major maritime states, there was significant increase in mangrove cover in India since 2001. Apparently, mangrove restoration programmes have gained a major impetus in the states of Gujarat, Tamil Nadu, Orissa, and Andhra Pradesh, in particular, especially after the 2004 Tsunami as well as the frequent cyclones.

As evident from Table 3, the area under mangroves in India had increased by more than 4 % from 4,482 km^2 in 2001 to 4,663 km^2 in 2010, with significant growth reported mainly from states, such as Maharashtra, Gujarat, West Bengal, and Orissa. Though West Bengal has the largest area under mangroves (46 %), the area expansion was most spectacular in Gujarat, as it increased by almost 15 % from 911 km^2 to 1,046 km^2 during the last 2 decades (Fig. 1).

It is important to note that the mangrove restoration programmes in these states have been promoted under the joint initiatives of the state and the local communities. Accordingly, the local communities were expected to have a potential stake in sustaining the restoration efforts by desilting the artificial canals dug in the resorted areas wherever needed and protecting the young plantations against grazing (Selvam et al. 2003).

Table 4 shows the concentration of mangrove restored areas in major states along with the major pressures causing degradation of mangroves that prompted the restoration activities in these states. It is also evident that the mangrove areas are largely concentrated in few districts across the six states.

Table 3 Growth in mangrove cover in India, 1991–2010 (km^2)

States	1991	1995	2001	2005	2007	2010	% share
Andhra Pradesh	399	383	333	354	353	352	7.6
Gujarat	397	689	911	991	1,046	1,058	22.7
Maharashtra	113	155	118	186	186	186	4.0
Orissa	195	195	219	217	221	222	4.7
West Bengal	2,119	2,119	2,081	2,136	2,152	2,155	46.2
A & N Islands	971	966	789	635	615	617	13.2
Total	4,244	4,533	4,482	4,581	4,639	4,663	100.0

Source Forest Survey of India (2011)

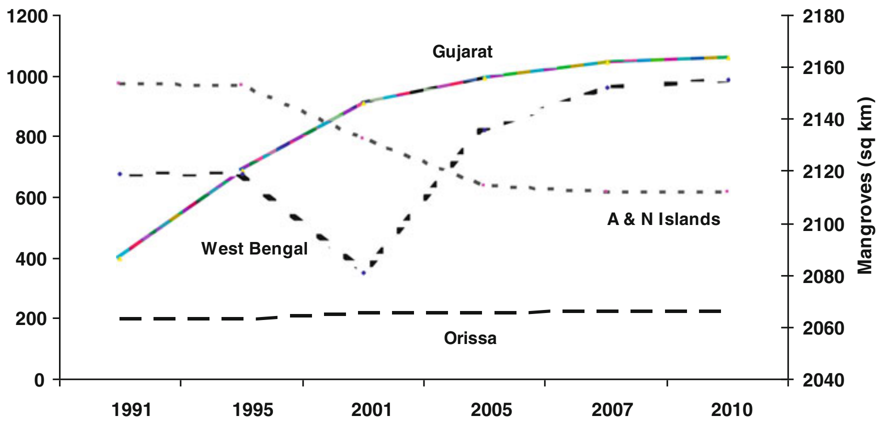


Fig. 1 Growth in mangrove cover in major States, 1991–2010 (*Source* Viswanathan et al. 2011)

There are several threats caused by both natural as well as anthropogenic interventions in these areas. The impacts of different economic sectors on coastal and marine biodiversity vary from region to region. In Gujarat for example, industrial development, urbanization port development, high maritime traffic, and mechanized fishing are particularly significant, while in Orissa, large-scale mechanized fishing, commercial aquaculture, and off-shore oil exploration are important issues.

The community driven interventionist policies and programmes adopted by the states, particularly, Andhra, Tamil Nadu, and Orissa under the ICEF-MSSRF project have been found to be quite successful in many respects in improving the status of mangrove plantations as well as in restoring the mangrove ecosystems with significant reduction in the indiscriminate exploitation of mangrove resources by the communities (MSSRF 2004). The project was reported to be quite successful in terms of creating awareness about conservation among the communities (particularly in Tamil Nadu and Andhra Pradesh) as well as in ensuring active participation (including financial contribution) among the State Forest Departments.

3 Socio-Economic and Ecological Outcomes of Community Based Mangrove Restoration in Gujarat

In Gujarat, as the original ICEF-MoEF Restoration of Mangroves (REMAG) project ended in 2007, the Gujarat Ecology Commission (GEC) has been entrusted with the task of carrying forward the mangrove restoration activities in the state in view of the potential benefits of mangroves to the coastal communities and in conserving the coastal ecosystems and marine biodiversity. It may be observed

Table 4 Distribution of mangrove areas and major causes of degradation in India

State	Mangrove area, 2011 (km^2)	Districts having mangrove cover	Biotic and other pressures causing degradation@
Andhra Pradesh	353 (−1)	East Godavari, Krishna, Guntur, Nellore, Prakasam	Erosion, land reclamation
Gujarat	1,058 (+12)	Kutch, Jamnagar, Bharuch, Valsad, Ahmedabad, Bhavnagar, Surat, Vadodara, Rajkot, Navsari, Amreli, Junagadh, Porbandar	*Gulf of Kutch*: Continuous grazing, timber and fuel wood harvest, erosion of shoreline, industrial impact, grazing pressure *Gulf of Khambhat*: Marine National Park activities, stunted growth, barren. In many areas stunted and sparse *Avicennia marina* *South Gujarat*: Coral reef degradation, conversion of high tidal mud-flats into agriculture and urbanisation
Maharashtra	186 (Nil)	Mumbai suburbs, Raigarh, Thane, Ratnagiri, Sindhudurg	Industrial pollution and domestic sewage, erosion
Orissa	222 (+1)	Kendrapara, Bhadrak, Jagatsinghpur, Puri, Baleshwar	Shoreline change, settlements, conversion for agriculture, aquaculture, etc
Tamil Nadu	39 (Nil)	Nagapattanam, Thanjavur, Cuddalore, Ramanathapuram, Thuthukudi	Erosion, illicit cutting for timber and fuelwood, grazing, aquaculture and agriculture effluents, accumulation of heavy metals
West Bengal	2,152 (+3)	South Parganas, 24 North Parganas, Medinipur	Huge exploitation of *Phoenix paludosa*, erosion and deposition, paper, and petro-chemical effluents
All India	4,662 (+23)		

Note Figures in parentheses indicate the change w.r.t. revised assessment of 2009 (km^2)
Source Forest Survey of India, *India State of Forest Report*, 2011; Upadhyay et al. (2002)

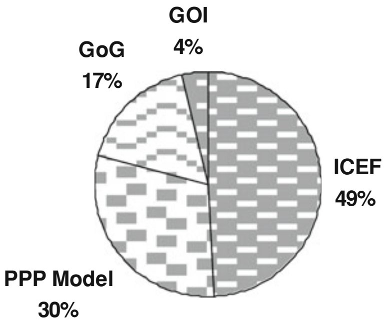


Fig. 2 Mangrove restoration in Gujarat, 2003–2004 to 2009–2010 (*Source* Gujarat Ecology Commission Gandhinagar, March 2010)

that the highest expansion in mangrove area as achieved by Gujarat has been mainly attributed to the 'community based restoration' model promoted under REMAG project.

In this backdrop, this section discusses the important outcomes of the community-based model of mangrove restoration adopted by Gujarat. The section largely draws from the preliminary evidences of community-based mangrove restoration (CBMR) underway in the coastal areas of Gujarat. The major thrust of extended REMAG programme has been on public–private partnership (PPP) based management/governance regime. Accordingly, investments by the state as well as private sector companies/industries have been encouraged with a commitment to cherish community participation in the mangrove development/restoration efforts. Figure 2 shows that the multiple stakeholder/community-based mangrove development and restoration model has gained popularity in Gujarat.

This model is being popularized in the state as the PPP model in which, mangrove development and restoration activities are promoted by the government involving the local communities, the private industries, and the NGOs. It is evident that the CBMR model currently occupies almost 30 % of the total mangrove planted area in the state. Geographically, 56 % of the mangroves plantations are in the gulfs of Kutch (27 %) and Khambhat (29 %), while the remaining mangrove plantations are in the coasts of South Gujarat and Saurashtra (44 %). Map 1 shows the district-wise locations in Gujarat where mangrove restoration/regeneration activities are underway.

Table 5 shows the development of mangrove plantations in Gujarat initiated by various states as well as non-state (private) agencies. It may be noted that the mangrove plantations by various private sector companies/industries is almost 26 %, which forms the second-largest category after the ICEF and the Government of Gujarat. Among the various private sector companies, the largest mangrove areas developed are by: Adani (28 %), followed by Pipapav Shipyard (23.4 %), Shell Hazira (14 %), and NIKO (12 %).

As per the CBMR model, the GEC acts as the Nodal Agency with key responsibility of preparation of project management plan, financial management, and imparting trainings on both technical and social aspects to the project implementation partners (PIPs) and the community-based organizations (CBOs)

Map 1 Location of mangrove restoration activities in Gujarat (*Source* GEC 2011)

Table 5 Mangrove plantation development by various agencies in Gujarat

Type of implementing agency	Area-ha	% share
A State sector agencies		
Gujarat Heavy Chemicals Limited (GHCL)	50	0.81
Gujarat Maritime Board (GMB)	120	1.95
Gujarat Mineral Development Corporation (GMDC)	170	2.76
GSPC Pipapav Power Company (GPPC)	10	0.16
India Canada Environment Facility (ICEF)	4,101	66.51
Ministry of Environment and Forests (MoEF)	300	4.87
Government of Gujarat (GoG)	1,415	22.95
Sub total	6,166 (74.1)	100.00
B Private sector agencies		
ADANI	600	27.78
Pipavav Shipyard	505	23.38
Shell Hazira	300	13.89
NIKO Resources India Ltd.	250	11.57
Essar	200	9.26
Ambuja Cement	150	6.94
Others[a]	155	7.17
Sub total	2,160 (25.9)	100.00
Grand total	8,326 (100.0)	

Note Figures in parentheses indicate the percentages in the total area
[a] Others include ABG Shipyard, Anjan Cement, Bayer, Petronet LNG and Ultatech
Source Estimated from data provided by Gujarat Ecology Commission (2010)

for smooth implementation of the project. The PIPs facilitate in community mobilization, formation, and registration of the CBOs, helping the community in micro-planning and implementation of the project activities. The physical implementation of the project at the grass-root level is carried out by the CBOs. This includes, activities like preparation of micro-plans, undertaking activities like seed collection, nursery development, plantation, land development etc., protection of the plantations through social fencing, formation and amendment of by-laws for the utilization of the corpus funds, benefit sharing, and conflict resolution (Viswanathan et al. 2011).

The mangrove development and restoration activities are being carried out by 22 CBOs spread across eight districts. Of the total mangrove planted area (8,326 ha) operated by the CBOs, Surat district has the largest share (40 %), followed by Kutch (16 %), Bhavnagar (15 %), Rajkot (10 %), Bharuch (8 %), and Ahmadabad (6 %).

3.1 Mangroves and Socio-Economic and Environmental Benefits

For empirical analysis of the socio-economic outcomes or community benefits of the mangrove restoration activities, a household survey was undertaken during 2010 in seven coastal villages, viz., Lakki, Ashira Vandh, Nada, Kantiyajal, Dandi, Karanj, and Tada Talav, spread over six talukas in four districts. A total of 227 households were covered under the survey. The villages selected were diverse in terms of growth of plantations and their beneficial outcomes. Also, villages were seen to be distinct in terms of concentration of communities with uniform activity status (like fisheries, agriculture, livestock, etc.) and the dependence on mangroves.

The development/restoration and conservation of mangroves call for integration of three crucial dimensions. First, the socio-economic outcomes of restoration which helps the communities build up and strengthen their livelihoods. Second, the ecological/environmental dimension that signifies the increasing importance of mangroves as a ‘bio-shield’ against the threats emerging from climate change and the potential environmental consequences. Third, governance dimension underlines the importance of policies and institutions for effective management of mangrove ecosystems. This dimension essentially sets out the way in which mangrove restoration practices are implemented at the grass-root level and the extent to which the restoration activities promote joint action as well as coordination between the various actors, like the state, the local communities, and the private sector (industries) in the specific context of the REMAG villages in Gujarat.

The empirical analysis as presented in Table 6 demonstrate significant socio-economic gains and environmental benefits as realized by the communities across villages that were studied within a short span of 6–7 years of the CBMR activities. Evidently, the household dependence on mangroves for various benefits has been quite significant across the villages (34 %). While fishermen communities are present in all the villages, the highest proportion of fisher households was found in

Table 6 Socio-economic and environmental benefits of community-based mangrove restoration in Gujarat, 2002–2007

Descriptives	Lakki	Ashirawandh	Karanj	Dandi	Nada	Kantiyajal	Tadatalav	All villages
Household dependence on mangroves (%)	27.6	25.2	35.2	54.8	28.4	35.1	33.6	34.1
Presence of fishermen communities (%)	29.4	16.7	66.7	40.4	41.5	18.0	10.3	29.5
Land close to mangrove sites (%)	25.0	42.9	0	0	66.7	80.0	36.4	52.5
Women household members get employment (%)	52.2	63.0	0	60.3	45.1	55.9	51.5	53.9
Annual average employment generated per household during 2002–2007 (No.)	188	243	0	67	103	85	185	134
Average earnings from mangroves work (Rs.)	12,577	14,820	0	4,728	6,822	3,954	10,327	8,735
Households extract mangroves for various uses (%)	88.2	94.4	0	21.3	56.1	22	71.8	45.8
Women extracting mangroves (%)	26.7	76.5	0	90.0	52.2	27.3	85.7	62.5
Mangroves extraction for fodder (%)	100.0	100.0	0	10.0	56.5	90.9	92.9	64.3
Mangroves extraction for fuel (%)		0	0	90.0	43.5	9.1	7.1	35.7
Percent gain in fishery income after mangroves	32.8	50.1	31.3	17.2	73.0	19.1	13.5	31.5
Households own livestock (%)	82.4	94.4	13.3	0.0	26.8	30.0	71.8	38.3
Mangroves reduce salinity ingress in crop lands (%)	58.8	44.4	0.0	68.1	68.3	76.9	71.4	55.4
Mangroves reduced crop damage due to winds (%)	82.4	55.6	0	19.1	53.7	68.0	71.8	50.1
Households reporting seriousness of cyclones (%)	94.1	100.0	73.3	51.1	87.8	72.0	97.4	78.9
Households reporting reduced effects of coastal cyclones after mangrove plantation	82.4	83.3	25.0	66.0	85.4	78.0	94.9	73.6

Source Viswanathan et al. (2011)

Karanj (67 %), Nada (41.5 %), and Dandi (40 %). Households also reported having farmed lands closer to the mangrove restoration cites (53 %) which could not be cultivated earlier due to coastal cyclones.

Another important benefit realized by the communities has been an increase in the employment and wage earnings. While all households were benefited by the employment opportunities created by development and maintenance of mangrove plantations, the percentage of women households getting such opportunities has been quite significant in all the villages, except Karanj. On an average, each household received wage employment for 134 days per annum during the seven year period, with notable differences across villages. The resultant gain in wage earnings has been as high as Rs. 14,820 per annum in Ashirawandh, followed by Rs. 12,577 in Lakki and Rs. 10,327 in Tadatalav.

Majority of the households extract mangroves for various uses (46 %), which ranged from 94 % in Ashirawandh to 88 % in Lakki, 72 in Tadatalav, and 56 % in Nada. Compared to male household members, more women had been engaged in mangrove extraction for various uses. Among the various uses for which mangroves are extracted, fodder and fuel uses are the prominent ones, with highest extraction of mangroves reported for fodder used for the cattle. Reportedly, this provided at least two immediate benefits to the communities, viz., (a) helping them avoid purchase of fodder from the market; (b) an increase in milk production as mangrove leaves were available in plenty to be fed upon to the livestock.

Besides, a reasonable number of households have also reported about the multiple benefits realized, in the form of extraction of mangrove leaves (49 %), fuel wood (24 %), collection of seeds (23 %), and wood planks (4 %) as shown in Fig. 3.

Similarly, mangroves have benefited fishermen communities in terms of an increase in fish catch from the mangrove beds, which resulted in an increase in income from fishery, as reported by 73 % of respondents in Nada and 50 % in Ashirawandh with other villagers also reporting significant income gains.

The environmental benefits realized by the households have been several. For instance, the villagers had been suffering from frequent coastal cyclones, which caused damage to their farm lands and in turn loss of crops. Salinity ingress in crop lands had also been a major problem that was mitigated by mangroves restoration.

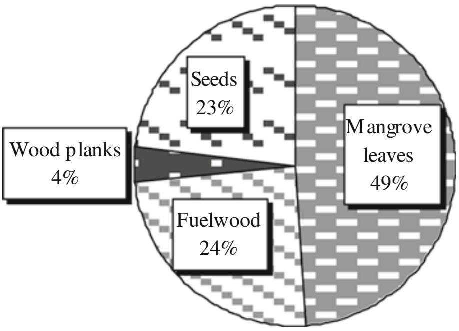


Fig. 3 Multiple benefits realized from mangroves by the communities (*Source* Viswanathan et al. 2011)

Majority of the communities reported that mangroves have been helping them in mitigating climate-induced risks to their farm lands as well as livelihoods *per se*. Further, the coastal cyclones always cause serious damages to the houses and other immovable properties of the households, which have now been protected by the mangrove belt.

3.2 Mangroves and Biodiversity Benefits

In this regard, it is important to observe here that mangroves also provide several intangible benefits, especially, protection of coastal ecosystems, including marine biodiversity. We undertook a detailed biological assessment to examine the vegetative growth and biodiversity dimensions of mangrove plantations in the villages studied, which brought about the diversity in terms of presence of invertebrates, mobile fauna, and other species. The mangrove areas have been found to be quite rich in terms of other species, such as mudskippers, crabs, bivalve, gastropods, fish, and habitat for other species. As mangroves areas have achieved good growth over the past few years, they also seem to be providing habitat for birds and marine reptiles, like snakes. An assessment of the biodiversity surrounding the mangrove plantations revealed interesting insights of the rich biodiversity as presented in Table 7.

4 Climate Change Risks and Conservation and Management Challenges of Mangroves in Gujarat

Based on the above analysis, one needs to consider the relevance and importance of CBMR as an effective strategy for conservation and restoration of mangroves in the face of the potential threats emerging from the climate change events. Based

Table 7 Status of biodiversity observed in the mangrove restoration villages

	Tadatalav	Lakki	Ashirawandh	Karanj	Dandi	Nada	Kantiyajal
Crustacean							
(a) Crabs	++	++++	+++	+++	++	++	++++
(b) Prawns	++	+++	++	++	+	+	++
Molluscan							
(a) Gastropods	++	++++	+++	+++	+++	+++	++++
(b) Bivalves	++	+++	++	++	+	+	+++
Snake	+	–	–	–	–	–	+
Birds	–	++	+	–	–	–	++
Mudskipper	+++	++++	++++	++++	+++	++++	+++
Other Fish	++	+++	++	++	++	++	+++

Note – Absent, + Satisfactory, ++ Good, +++ Excellent, ++++ Quite rich
Source Viswanathan et al. (2011)

on a critical assessment, Gujarat may try to explore the scope for scaling up of the CBMR model as part of evolving a long-term perspective on climate change adaptation and mitigation strategies. This becomes quite important in view of the persistent problem of salinity ingress in the coastal villages of the state (Fig. 4).

As shown in the figure, the severity of salinity ingress is very high in almost all the coastal villages with a large number of villages already suffering from salinity ingress in parts. This suggests that if climate change in terms of rise in sea level of even a smaller magnitude might lead to inundation of a large number of villages, affecting the livelihoods of the coastal communities. Hence, the state should develop long-term plans and strategies for development and restoration of mangrove ecosystems through active involvement of the local communities in the programme as developers as well as conservators.

Having said, there are several challenges that need to be overcome to make the model work better in all scenarios. Although the CBMR activities in Gujarat as well as other states, viz., Tamil Nadu, Andhra, and Orissa have been found to be quite significant in terms of the socio-economic and environmental outcomes as observed, there are several challenges to be addressed if the intervention has to be scaled up as a strategy for mitigating the climate change effects in the coastal regions of these states. First of all, the CBMR activities as being implemented in these states are yet to receive a wider acceptance among the local communities. As a result, the participation especially in the villages of Gujarat have been very

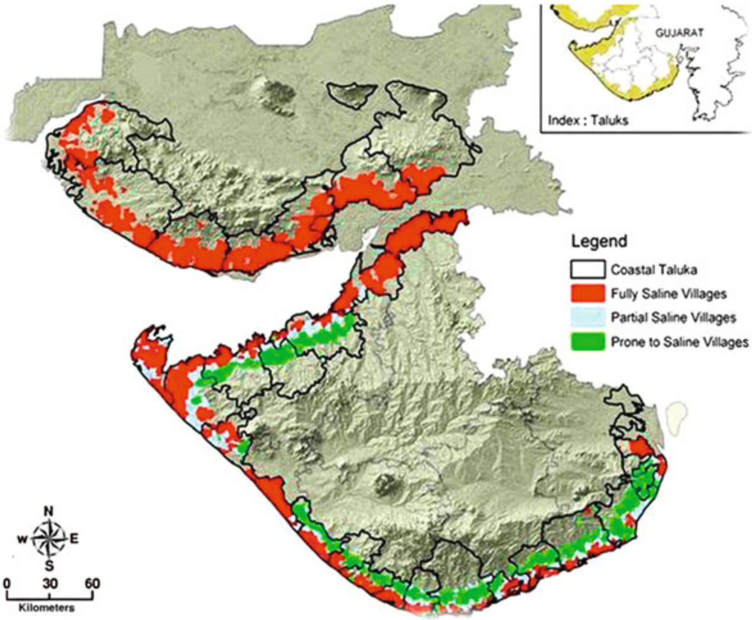


Fig. 4 Extent of salinity ingress in coastal villages of Gujarat (*Source* Gujarat Institute of Desert Ecology)

limited to the extent of taking benefits from the employment created as well as extraction of mangroves for various uses as reported above.

It emerges from the study that the local communities and the CBOs mostly lack the initiatives to consistently engage into the conservation of the mangrove ecosystems due to several operational constraints which are generic to management of CPRs in several contexts. It has been found that the communities and the CBOs need to be strengthened in terms of increased awareness about the importance of conserving mangroves and the supported ecosystems in the context of climate-change induced threats surfacing the coastal regions. It also requires skill development and capacity building among the coastal communities so as to enable them to conserve/restore the mangrove ecosystems for the future. Though majority of the communities (91 %) do feel that growing mangroves is important for protecting the coastal systems and livelihoods from the adverse effects of potential climate change threats, cyclones, soil erosion, etc., they still lack the motivation, incentives as well as resources to conserve the mangroves on a sustainable basis. This is an important challenge, which needs to be addressed through policies and interventions for achieving sustainable conservation and restoration goals against the unforeseen climate change threats.

As such, much of the benefits of mangrove restoration activities are in the form of immediate short-term benefits of employment, wage income and extraction of mangroves for fodder, fuel wood, etc. Given this, the community participation tends to be highly motivated by such short-term gains without much emphasis on restoring the mangrove systems for future benefits. For community participation to have more beneficial outcomes, in terms of mobilization and collective action for conservation of mangrove ecosystems, there should be continued support from the state or the private agencies engaged in mangrove restoration activities with action and financial support programmes. Since mangrove conservation requires long-term maintenance, the expectations of the local people in terms of both short-term and long-term economic benefits to be obtained from mangrove rehabilitation and conservation should be addressed. It has been reported that the participatory outcomes in the case of the ICEF-MSSRF project on Joint Forest Management (JFM) in restoration and conservation of mangrove wetlands in Tamil Nadu, Andhra Pradesh, and Orissa have been far from satisfactory.

Apparently, there are no institutional mechanisms in the mangrove restored villages (except the CBOs, which are less active) particularly in Gujarat, to protect the plantations from a future perspective as a buffer or shield against all contingencies, including climatic aberrations in the coastal areas. Strengthening the CBOs or mangrove dependent communities with clearly drawn ownership and access to rights would be necessary for sustained use, conservation, and management of mangroves, as has been the case in several state-driven mangrove conservation programmes in Indonesia. This calls for evolving long-term policies and institutional intermediations for carrying forward the development of new mangrove plantations as well as conservation/restoration of the existing plantations in the mangrove dependent states.

Another important challenge is determining the stakes and corporate social responsibilities of the private sector and industries that are also part of the mangrove development and restoration activities in Gujarat. In most cases, the private sector initiatives in mangrove plantation development could be merely motivated by the private gains that might bring to these actors in terms of carbon credits, increased access to global markets as a result of compliance with green belt development activities, etc. A major issue that needs addressing in this regard is whether these green belt development activities with a thrust on mangrove plantations by the private/corporate/industry stakeholders are leading to better conservation/restoration outcomes along with increased involvement of local communities in these initiatives?. This is a major challenge in Gujarat especially in the context when most of these private sector stakeholders also have their polluting industries established along the coastal regions, including the marine protected areas (MPAs), such as the Marine National Park and Marine Sanctuary in Jamnagar, are infamous for causing irreparable damages to the mangrove ecosystems and the marine biodiversity (Viswanathan and Parikh 2010). More interestingly, many of these industrial stakeholders have been quite successful in accessing/acquiring lands along the coastal regions in the pretext of developing green belts with mangrove plantations. Though these mangrove plantations are established involving the local communities, the question remains that how far the local communities will be able to have rights to access these pristine lands? This also raises some pertinent issues: (a) how can the private and state sector industrial entities be held primarily responsible for the serious casualties that have impaired the marine ecosystems and biodiversity?; and (b) how these private sector entities could join hands with the state as well as the CBOs in evolving long-term strategies and action plans for conserving the mangrove ecosystems and the biodiversity of the coastal regions, including the MPAs.

More importantly, the mangrove rich states have to evolve a coordinated approach and strategic action plans towards protection of mangrove ecosystems and the marine biodiversity under the international initiative called, the 'Mangroves for the Future (MFF)'. Under the MFF initiative, states should come out with concerted action plans and strategies in cognizance with the Directive Principles of State Policy of the Constitution of India.

Furthermore, sustainable CBMR activities essentially call for more efforts for creating opportunities for collective action among the multiple stakeholders, like line state departments under various government portfolios, the local communities, private firms, and industries who are increasingly investing in mangrove plantations, NGOs, local administration units, like the village Panchayats. This requires regular interactions among these stakeholders towards identifying more innovations and action plans for sustainable development and restoration of mangrove plantations in the coastal regions. Needless to say that all these innovations and action plans should be targeted towards strengthening the capabilities of the local communities and sustaining their livelihoods without compromising on the broader goals of sustainable management of mangrove ecosystems.

Finally, there exists a major knowledge gap about the vulnerability of climate change and its impacts on coastal regions of India. This necessitates the imperative of detailed investigations about the occurrence and intensity of various climate change induced events in the coastal regions and their possible impacts on the coastal communities, mangroves as well as other ecosystems, and biodiversity. Since the coastal regions are highly diverse in terms of ecosystems, habitat, biodiversity, and community livelihoods, these diversities need to be properly understood and captured through coastal surveillance systems and intensive field research using inter-disciplinary methodologies and analytical procedures in spatial and temporal dimensions. The information and data generated through this research should form the basis for appropriate policies and interventions in respect of adaptation towards and mitigation of climate change induced hazards in the coastal regions.

The conservation and management of wetlands and other natural resource requires a paradigmatic shift in terms of treating them as major entities with multitude of socio-economic, environmental and ecosystem functions, such as water regime management, groundwater recharge, nutrient recycling, wastewater treatment, etc. especially in the emerging context of climate change risks and food security challenges.

Interest in mangrove ecosystem conservation and management has risen in recent times among many stakeholders nationally and internationally. Globally, many organizations apart from ITTO carry out research, conservation, rehabilitation and management activities in mangrove ecosystems. Organizations such as ADB, CIDA, EU, FAO, International Society for Mangrove Ecosystems (ISME), IUCN (World Conservation Union), IUFRO, JICA, Ramsar Convention, UNDP, UNEP, UNESCO, USAID, Wetlands International as well as numerous national governmental, non-governmental, and educational organizations have sponsored programmes on mangrove ecosystem conservation and management. The experiences of many of these organizational initiatives in conservation, rehabilitation, and management of mangrove ecosystems are needed to be understood for streamlining appropriate conservation, restoration, and management strategies specific to the Indian context.

The complexity of the mangrove forest and the adaptability and vulnerability of mangrove species and of the entire ecosystem are the critical aspects to be considered for developing a national mangrove restoration plan in the Indian context. Experience from elsewhere suggests that knowledge acquired for the utilization of mangroves in one area cannot be directly transferred to other areas without prior adaptation to local environmental conditions. Detailed local conservation strategies that consider and include the interests and the traditional knowledge systems of local communities should always be developed on this basis. The value of mangrove forests varies widely from place to place as a function of species composition, local productivity of the system and of particular species, and the needs of the local population for livelihoods and trade.

Acknowledgments I wish to thank the Gujarat Ecology Commission, Government of Gujarat for supporting this study. Thanks are also due to Kinjal D. Pathak and Ila Mehta for their help and support in undertaking the field surveys. The usual disclaimers apply.

References

Barbier EB (2008) In the wake of tsunami: lessons learned from the household decision to replant mangroves in Thailand. Resour Energy Econ 30(2):229–249

EJF (2005) Did the loss of mangrove forests exacerbate the impact of the Tsunami?. Environmental Justice Foundation, London

Erftemeijer PLA, Lewis III RR (2000) Planting mangroves on intertidal mudflats: habitat restoration or habitat conversion? In: Sumantakul V et al (eds) Enhancing coastal ecosystem restoration for the 21st century. Proceedings of the regional seminar for East and Southeast Asian countries: ECOTONE VIII, Ranong and Phuket, Thailand, 23–28 May 1999. Royal Forestry Department, Bangkok, Thailand, pp 156–165

GEC (2011) Ecological profile of coastal talukas around gulf of Khambhat. Gujarat Ecology Commission, Government of Gujarat, Gandhinagar, p 131

Gopal B (2001) Overview of lakes and wetlands in India In: Bandhu D, Guha K (eds) Wetland conservation: community participation, awareness and education. Proceedings of the workshop on wetland conservation, 25–26 Sept 2000, Agra, Indian Environmental Society, Delhi, pp 67–92

Governmnet of India (GoI) (2011) National wetland Atlas. Ministry of Environment & Forests (MoEF), Space Applications Centre, ISRO, Ahmedabad, p 334

Mitsch WJ, Gosselink JG (2000) Wetlands. Wiley, New York

MSSRF (2004) Annual report, 2004. MS Swaminathan Research Foundation, Chennai. Available at www.mssrf.org

Rao YN, Datye H (2003) Overview of Indian wetlands. In: Parikh J, Datye H (eds) Sustainable management of wetlands: biodiversity and beyond. Sage Publications, New Delhi, pp 41–98

Sandilyan S, Thiyagesan K, Nagarajan R, Vencatesan J (2010) Salinity rise in Indian mangroves—a looming danger for coastal biodiversity. Curr Sci 98(6):754–756 (25 March)

Selvam V, Ravichandran KK, Gnanappazham L, Navamuniyammal M (2003) Assessment of community-based restoration of Pichavaram mangrove wetland using remote sensing data. Curr Sci 85(6):794–798

Stevenson NJ, Lewis RR III, Burbridge PR (1999) Disused shrimp ponds and mangrove rehabilitation. In: Streever W (ed) An international perspective on wetland rehabilitation. Kluwer Academic Publishers, Dordrecht, pp 277–297

Sugunnasil W, Sathirathai S (2004) Coastal communities, mangrove loss and shrimp farming: social and institutional perspectives. In: Barbier EB, Sathirathai S (eds) Shrimp farming and mangrove loss in Thailand. Edward Elgar, London, pp 191–209

UNEP-UNESCO (1992) Impact of expected climate change on mangroves. In: Report of the first meeting. Rio de Janeiro, 1–3 June 1992, UNEP-UNESCO Task Team, UNESCO Reports in Marine Science (UNESCO), no. 61. UNESCO, Paris (France). UNEP, Nairobi (Kenya), p 23

Upadhyay VP, Ranjan R, Singh JS (2002) Human–mangrove conflicts: the way out. Curr Sci 83(11):1328–1336 (10 December)

Viswanathan PK, Parikh J (2010) Impact of industrialisation and related activities on marine protected areas: a case study of Marine National Park, Jamnagar District in Gujarat, Report submitted to IRADe, New Delhi, vi, 103

Viswanathan PK, Pathak Kinjal D, Mehta I (2011) Socio-economic and ecological benefits of mangrove plantation: a study of community based mangrove restoration activities in Gujarat. Gujarat Ecology Commission (GEC), Government of Gujarat, Gandhinagar, Ahmedabad, p 164. Available at www.gec.gov.in/pdf/GIDR%2520Report.pdf

World Bank (2003) Draft code of conduct for the sustainable management of mangrove ecosystems. International Society for Mangrove Ecosystems (ISME), Centre for Tropical Ecosystem Research, Denmark, Center Aarhus, p 79

WWF (2001) World wildlife fund. Available at http://www.worldwildlife.org

Land Acquisition and Land Diversion for Mining Towards Industrial Growth: Interest Conflict and Negotiation Game for Sustainable Development

Lekha Mukhopadhyay and Bhaskar Ghosh

1 Introduction

Mining induced land acquisition is bringing forth interest conflict between the modern growing industrial economy and the long term sustainable traditional economy in most of the developing countries today (Sahu 2008). While leasing out community land for a given time period to the mining firm, the traditional community now-a-days, backed by land acquisition laws and social activist groups, often negotiates with mining company an appropriate rate of compensatory return. When the community sets some rules for negotiations, the compensatory return it may claim can take various forms. It may be a royalty payment, i.e., a percentage value of gross mining production. It may be surface rental, based upon the area of land taken on lease by the company for searching of ore, extraction, etc. It may also be the payment of rent, i.e., a percentage of net profit from selling the desired material. The Forest Policy of 1988 along with Forest Conservation Rule of 2003 in India have framed up a rule to determine the cost of compensatory afforestation to be paid to the forest department of the government. Many mining sectors like coal, aluminium and bauxite have framed out their rehabilitation resettlement and reclamation policies to acquire land from community. A multi-national limestone mine company had to settle royalty payment with the *durbar* (village council) of Nongtarai village Meghalaya, India as the payment of INR 5.00 per ton of limestone extracted from their leased out community land. For mining of aluminous laterite from Belgundi village in Karnataka the mine company had to settle

L. Mukhopadhyay (✉)
Department of Economics, Jogamaya Devi College, 92 SP Mukherjee Road, Kolkata 700026, India
e-mail: lekha.mukhopadhyay@gmail.com

B. Ghosh
Department of Geology, Jogamaya Devi College, 92 SP Mukherjee Road, Kolkata 700026, India
e-mail: bghosh2006@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_26, © Springer-Verlag Berlin Heidelberg 2013

collectively with the villagers for reclamation of agricultural and waste land leased for mining (Banerjee 2004). Balipara Tract & Frontier Foundation, an NGO of Assam (a north-eastern state of India), resolved that mine companies should pay rent (for land) and royalty (for minerals) to the host community (or family) where the value of land must be based on the value of ascertained minerals (Balipara Tract and Frontier Foundation, India 2010). Ministry of Environment and Forest (MoEF) and the National Mining policy of Government of India charge the cess and royalty from mining company at varying rates (e.g., INR 64.00 per tonne of bauxite) for different types of desired material (EPGORISSA 2011). These rent-royalty payments are expected to be used for reclamation and development of the host community. In spite of all these, unjust and forced encroachment of community lands by corporate mining is a recurrent phenomena in India. Miners, and sometimes also the state governments, are found to shirk the livelihood issues of local people, even the traditional rights of local institutions like community forest management (Kalpavriksh and Vasundhara 2008; Bhubaneswar, Orissa). In that context, the possibility and power of negotiation to settle the claims with mining company is extremely relevant.

The necessity of extraction of natural resources for development cannot be denied. But the problem is to find out the ways in which environmental devastation can be minimized and community can get a substantial benefit of mining not only for the present but also for its future generations. Resolving the interest conflict in the process of development has become the greatest challenge to most of the developing countries today.

The government of India, for resolving the interest conflict, for the last few years is concerned about designing the principle of benefit sharing of mining with the local community. It is about whether local people should get a share of royalty or share of profit, and in what proportion, and under what type of institutional arrangement. Very recently, a bill of sharing 26 % of profit in case of nationalized coal mining and 100 % royalty sharing in case of other mining with the local community through the district-level fund has got the approval of the Cabinet Ministry in India.

2 Mining Induced Land Acquisition, Negotiation Game Between Miner and Traditional Community: A Model

2.1 An Outline of the Model

There exists a hypothetical community of traditional producers who is going to lease out the community land (which is a common property resource) with a mine reserve. The community's traditional livelihood so far is derived from the community land out of traditional economic activities like cultivation, firewood collection, etc. Now, there is a miner firm seeking entry into that community land for exploration of some exhaustible mine resources. It is a profit maximizer facing a competitive market for the desired material. It starts negotiation with the traditional community to settle the compensatory return for land acquisition. While leasing out land to the miner firm, the community may get some compensatory return in terms of royalty and rent payment, but at the cost of losing some production values of their traditional economic activities. In the following subsections, we consider two possible negotiation games. In the first, each of the miner and traditional community is a 'Nash' player, i.e., each from their own private interest is trying to reach an agreement. It is a multi-stage game.

Given the productivity of land with respect to its traditional output, its price and amount of mine reserve (which is assumed to be known by the community), the community decides how much rent and share of mine-output it will claim. In the second stage after rent and share of mine-profit are determined, the community decides how much land it will retain for traditional production and how much it will lease out.

So far as the mining firm is concerned, at stage I, given price of the desired material, geological features of the mine resource, and stock of reserves and cost of extraction, it decides how much claim of rent (γ) and royalty (Ψ) (i.e., sharing of mine production by the community) it will accept. And then on the basis of that it decides how much community land will be taken on lease. In the final stage, given the area of land acquired, the miner decides how much acquired land it will explore and thereby produce the output.

Alternatively, we will consider a situation where there is a 'social planner' with the objective of maximizing the discounted composite social welfare. The composite welfare is constituted by the miner's net profit and the traditional community's net profit. Miner's net profit is calculated after deducting the cost of extraction and the cost of paying the rent and royalty to the community. Community's net profit from traditional production and their earning from rent is calculated after deducting the loss of traditional production due to leasing out land to the miner. In composite social welfare, the relative weight (or importance) given by the social planner to the loss of traditional production is also an important matter for policy decision.

2.2 NASH Settlement Game

2.2.1 Miner's Nash Strategy Game

With a history of choices on the rent on mine reserve, γ, and royalty Ψ, he bids at stage I. The miner decides how much area of community land A_c it will lease and how much Y, and the desired material it will extract from that. The compensatory return it will have to pay in terms of Y and value of reserve R is: $(\Psi.Y(A_c) + \gamma R)$. Analytically it's optimization problem is similar to that in the extended framework of Pindyck (1978):

$$Max_{Y,A} \int_0^\infty [pY - C(Y,R) - \Psi.Y(A_c) - \gamma R]e^{-\delta t}dt \tag{1}$$

subject to:

$$\dot{R} = \dot{x} - Y \tag{2}$$

$$\dot{x} = f(A_c, x) \tag{3}$$

$$Y \geq 0; \quad A \geq 0\, R \geq 0; \quad x \geq 0 \tag{4}$$

p is the market price of the desired material Y, exogenously determined. C is the cost of extraction which depends upon Y and the reserve level R. $C_Y > 0$, $C_{YY} > 0$, $C_R < 0$, $C_{RR} > 0$. These imply that marginal cost of extraction is positive and cost of extraction increases as reserves decline. x is the cumulative addition of reserves which over time increases by the production cum exploration function f. f given x depends upon A_c the area of land taken by lease for exploration. $f_A > 0$; $f_{AA} < 0$. These indicate that marginal product of exploration from the area of land acquired increases at the decreasing rate. $f_x < 0$, implying that exploration decreases with cumulative addition of reserve. $\Psi(A)$ is the cost of leasing land which is land rent. $\Psi_A > 0$. $\dot{R}$ is the net addition of reserve over time. γ is the effective rent on the reserve.

In the optimal control theory framework, the Hamiltonian function (Appendix 1) for this problem, with single control variable $Y(A_c)$ and two state variables R and x is:

$$H = (p - \Psi)Ye^{-\delta t} - C(Y,R)e^{-\delta t} - \gamma R(A_c)e^{-\delta t} + \lambda_1[f(A_c,x) - Y(A_c)] + \lambda_2[f(A_c,x)] \tag{5}$$

Solving (5) we get,

$$\lambda_1 = (p - C_Y - \Psi)e^{-\delta t} \tag{6}$$

$$\dot{\lambda}_1 = (C_R + \gamma)e^{-\delta t} \tag{7}$$

$$\begin{aligned}\dot{\lambda}_2 &= -f_x(\lambda_1 + \lambda_2) \\ &= -[C_R + \gamma]R_{A_c}\frac{f_x}{f_{A_c}}e^{-\delta t}\end{aligned} \tag{8}$$

(See: Appendix 1)

The above equation is of shadow cost path of exploration of new reserves to the miner. Since marginal cost of extraction from each additional unit of reserve $C_R < 0, R_{A_c} > 0, f_x > 0$ and $f_{A_c} > 0$, shadow cost of exploration will increase over time if $\gamma > -C_R$. The shadow cost decreases if $\gamma < -C_R$.

Again, plugging the value of λ_1 from Eqs. (6) into (8), we obtain the value of λ_2 from:

$$Or, \lambda_2 = \frac{1}{f_{A_c}}[(p - C_Y - \Psi)f_{A_c} - (C_R + \gamma)R_{A_c}]e^{-\delta t} \tag{9}$$

Differentiating Eq. (6) with respect to time and putting the value of $\dot{\lambda}_1$ from Eq. (7), we get the optimal mine extraction path:

$$\dot{Y} = \frac{-\delta(p - C_Y - \Psi) + \dot{p} - C_{YR}\dot{R} - (C_R + \gamma)}{C_{YY}} \tag{10}$$

Mine production will be declining in the present context if

$$\dot{p} < \delta(p - C_Y - \Psi) + C_{YR}\dot{R} + (C_R + \gamma)$$

$C_{YR}\dot{R}$ shows the impact on marginal cost of depletion of reserve over time. As the reserve depletes, cost of extraction increases. Thus, $C_{YR}\dot{R} < 0$. $\delta(p - C_Y - \Psi)$ indicates the discounted value of marginal profit which is greater than zero. $C_R < 0$ but $\gamma > 0$. Hence, the sign of $(C_R + \gamma)$ may be negative or positive depending upon the relative dominance of C_R and γ. If price rises at the rate of discount, i.e., $\dot{p} = \delta p$ mine production will be still declining if:

$$\gamma > \delta(C_Y - \Psi) - C_{YR}\dot{R} - C_R$$

i.e., rent on reserve is greater than the discounted value of net marginal cost of extraction + marginal extraction cost due to reserve depletion net of cost saving effect of having more reserve.

Now, differentiating Eq. (6) with respect to time (Appendix 2), we get the time path of land acquisition chosen by miner, which is also the demand path of land acquisition:

$$\begin{gathered}
[-\delta[(p - C_Y - \Psi)f_{A_c} - (C_R + \gamma)R_{A_c}] + [(p - C_Y - \Psi)f_{A_cA_c} - (C_R + \gamma)R_{A_cA_c}]\dot{A}_c]e^{-\delta t} + f_{A_cA_c}\dot{A}_c\lambda_2 + f_{A_c}\dot{\lambda}_2 = 0 \\
-\delta[(p - C_Y - \Psi)f_{A_c} - (1 + f_x)(C_R + \gamma)R_{A_c}] + \left(\frac{f_{A_cA_c}R_{A_c}}{f_{A_c}} - R_{A_cA_c}\right)(C_R + \gamma)\dot{A}_c = 0 \\
\dot{A}_c^{\mathrm{M}} = \delta[(p - C_Y - \Psi)f_{A_c} - (1 + f_x)(C_R + \gamma)R_{A_c}]\left(\frac{f_{A_cA_c}R_{A_c}}{f_{A_c}} - R_{A_cA_c}\right)(C_R + \gamma)
\end{gathered} \tag{11}$$

(See: Appendix 2)

In the above expression, the relative dominance or non-dominance of C_R, i.e., the cost saving effect of having reserve over γ the cost rising effect of rent again determines whether the demand path of land acquisition path by the miner will be rising or falling over time. To simplify the matter let $f_{A_cA_c} = 1$ and $R_{A_cA_c} = 1$, i.e., rate of exploration of new reserve and the rate of change of reserve both with respect to A_c increases at the same rate as that of the rate of increase of A_c . $\frac{R_{A_c}}{f_{A_c}} > 1$ i.e., rate of increase in reserve is greater than rate of exploration of reserve from each additional unit of land leased in. The first component in the numerator, i.e., $(p - C_Y - \Psi)f_{A_c}$ is the net marginal return from extraction from the new explored land. The second component $(1 + f_x)(C_R + \gamma)R_{A_c}$ is the net cost of having the reserve (both from the existing stock and that from the new explored area). The sign of the denominator is negative if $|C_R| > \gamma$. In that case, $\dot{A}_c < 0$. Since cost saving effect of having reserve dominates over cost on account of rent payment on reserve, over time the miner's urge to acquire more land will be declining. Opposite phenomenon will occur, i.e., demand path will be rising $\dot{A}_c > 0$ if $|C_R| < \gamma$.

Miner's choice of $(\dot{Y}, \dot{A}_c)$ at stage 2 of conflict resolution game depends upon history of choices of (Ψ_A, γ) at stage I, that miner offers to the traditional community, given the community's claim. Unless and until (Ψ_A, γ) are decided we cannot obtain the optimal $(\dot{Y}, \dot{A}_c)$.

2.2.2 Traditional Community's Nash Strategy Game

The community has a land based traditional production with the production function: $g(L; A_c)$. Traditional production increases with L, the area of land used for that purpose and decreases with increase in A_c, the area of land leased out to the mining firm. The total available land in the community: $\bar{L} \geq L + A_c$ i.e., L cannot exceed the total available land $\bar{L}$. The change in available land for traditional production is defined by an equation of motion: $\dot{L} = -A_c$.

The control problem of the traditional community is to choose a path for the land-leasing that maximizes the following objective function defined as discounted net return from traditional production plus rent and share of mining profit from mine company as compensatory return from land conversion.

$$Max_L \int_0^\infty [w.g(L) + \Psi.p.Y(A_c) + \gamma.R(A_c)]e^{-\theta t} dt; \tag{12}$$

subject to:

$$\dot{L} = -A_c \tag{13}$$

$$L(0) \in [\bar{L}, 0]$$

The present value Hamiltonian for this problem with the single control variable L is:

$$H = w.g(L)e^{-\theta t} + \Psi.p.Y(A_c)e^{-\theta t} + \gamma R(A_c)e^{-\theta t} - \xi_1 A_c \tag{14}$$

Differentiating H with respect to A_c and L we get:

$$H_{A_c} = (\Psi.p.Y_{A_c} + \gamma R_{A_c})e^{-\theta t} - \xi_1 = 0. \tag{15}$$

$$H_L = -\dot{\xi}_1 = w.g_L.e^{-\theta t}$$

The optimal path is found from the necessary conditions by substituting the equation of motion $\dot{L} = -A_c$ into (14) and taking the time derivative of the resulting equation (Appendix 3).

Finally, we get the land acquisition path chosen by the community which is to be considered as the supply path of land acquisition by the community as:

$$\dot{A}_c^{\mathrm{G}} = \frac{w.g_L - \theta(\Psi Y_{A_c} + \gamma R_{A_c})}{(\Psi Y_{A_c L} + \gamma R_{A_c L})} \tag{16}$$

(See: Appendix 3)

Rolling back from stage 2 to stage 1 game, i.e., solving the miner's demand path $\dot{A}_c^{\mathrm{M}}$ with traditional community's supply path $\dot{A}_c^{\mathrm{G}}$ finally, they reach the equilibrium rate of royalty Ψ^* and rent on in situ reserve γ^*.

$$\dot{A}_c^{\mathrm{G}} = \dot{A}_c^{\mathrm{M}} \rightarrow$$

$$\frac{w.g_L - \theta(\Psi Y_{A_c} + \gamma R_{A_c})}{(\Psi Y_{A_c A_c} + \gamma R_{A_c A_c})} = \frac{\delta[(p - C_Y - \Psi)f_{A_c} - (1 + f_x)(C_R + \gamma)R_{A_c}]}{\left(\frac{f_{A_c A_c} R_{A_c}}{f_{A_c}} - R_{A_c A_c}\right)(C_R + \gamma)} \tag{17}$$

For simplification let $\Psi = 0$, i.e., we assume that there is no compensation to be paid on the basis of the value of mine output but only on in situ reserve, and the rate of discount of miner and the community is the same, i.e., $\theta = \delta$. To illustrate the fact let us further assume, $Y_{A_c L} = 1, f_{A_c A_c} = 1, R_{A_c A_c} = 1$ and $C_R = 0$ i.e., marginal cost of extraction for having reserve is nil (say cost of mine production due to reserve is negative but constant, i.e., $C(R) = -\bar{C}$). Then from (17) we get:

$$\gamma^* = \frac{f_{A_c}^2(p - C_Y) - (R_{A_c} - f_{A_c})\frac{w.g_L}{\theta}}{R_{A_c}[R_{A_c} - f_{A_c} f_x]} \tag{18}$$

2.3 Negotiation Game Through Social Planner

Social planner has to choose socially desirable Y and A_c and thereby determine Ψ and γ in such a way that maximizes the aggregate welfare or benefit of the society. In our present context, one component of that social benefit is the net profit of the miner, i.e., $P.Y(A_c) - C(Y(A_c), R(A_c))$. A part of this goes back to the social planner in the form of rent and royalty payment which is $[\Psi.p.Y(A_c) + \gamma R(A_c)]$. A proportion of $[\Psi.p.Y(A_c) + \gamma R(A_c)]$ again goes back to the community say ρ to compensate the loss of traditional production. ρ is arbitrarily chosen by the social planner $\rho < 1$. It is the weight or importance given by the planner to the welfare loss of the traditional community (vis-à-vis the loss of production) due to leasing out land. Now the optimization dynamic problem of the social planner is:

$$Max \int_0^T e^{-\delta t}[P.Y(A_c) - C(Y(A_c), R(A_c)) + g(L) - [\Psi.p.Y(A_c) + \gamma R(A_c)](1-\rho)] \tag{19}$$

subject to :

$$\dot{R}(A_c) = \dot{x} - Y \tag{20}$$

$$\dot{x} = f(x, A_c) \tag{21}$$

The Hamiltonian function with the single control variable $Y(A_c)$ and two state variables R and x is:

$$\begin{aligned}\tilde{H} =& e^{-\delta t}[P.Y(A_c) - C(Y(A_c), R(A_c)) - [\Psi.p.Y(A_c) + \gamma R(A_c)](1-\rho.) + g(\bar{L} - A_c)] \\ &+ \mu_1[f(x, A_c) - Y] + \mu_2.f(x, A_c)\end{aligned} \tag{22}$$

Differentiating (22) with respect to A_c and Y we get the shadow cost of depletion of mine reserve:

$$\mu_1 = [p - C_Y - \Psi.p.(1-\rho)]e^{-\delta t} \tag{23}$$

(See: Appendix 4)compared to the shadow cost of depletion of mine reserve under Nash solution $\lambda_1 = (p - C_Y - \Psi)e^{-\delta t}$ (6).

The shadow cost of depletion of mine reserve in case of social planning will be higher than that determined through Nash equilibrium if $p.(1-\rho) < 1 \rightarrow \rho > 1 - \frac{1}{p}$.

Again, in the present context,

$$\frac{\partial \tilde{H}}{\partial R} = \dot{\mu}_1 = [C_R - \gamma(1-\rho)]e^{-\delta t} \tag{24}$$

As compared to $\dot{\lambda}_1 = (C_R + \gamma)e^{-\delta t}$ in the former case.

Since $\rho < 1$, $\dot{\mu}_1 < \dot{\lambda}_1$ which implies that under social planning the shadow cost of depletion of mine reserve declines at the rate slower than that under the Nash solution. Greater the value on ρ is attached by the social planner, greater will be the value of $\dot{\mu}_1$. Differentiating (22) with respect to x we have,

$$\dot{\mu}_2 = -f_x(\mu_1 + \mu_2) \tag{25}$$

Plugging the value from (25) into (23) we get:

$$\begin{aligned}\tilde{H}_{A_c} &= e^{-\delta t}[[P - C_Y - \Psi.p.(1-\rho)]Y_{A_c} - [C_R + \gamma(1-\rho)]R_{A_c} - g] \\ &\quad - [p - C_Y - \Psi.p.(1-\rho)]Y_{A_c}e^{-\delta t} - \dot{\mu}_2\frac{f_{A_c}}{f_x} \\ &= 0\end{aligned} \tag{26}$$

Since, $\mu_1 = [(p - C_Y + \Psi.p(1-\rho))]e^{-\delta t}$ from (23), plugging it into (25) we have:

$$\dot{\mu}_2 = -[(C_R + \gamma(1-\rho))R_{A_c} + g]\frac{f_x}{f_{A_c}}e^{-\delta t} \tag{27}$$

Compared to $\dot{\lambda}_2 = -[C_R + \gamma]R_{A_c}\frac{f_x}{f_{A_c}}e^{-\delta t}$

Since $\rho < 1, \dot{\mu}_2 > \dot{\lambda}_2$. Thus, the shadow benefit path of exploration of new reserve through the land acquisition under social planning will lie above the shadow benefit path of exploration by Nash solution. And there might be no differences between those two shadow cost paths if $\rho = 1$. After rearrangement (26) can be expressed as:

$$\begin{aligned}\tilde{H}_{A_c} &= e^{-\delta t}[[-[C_R + \gamma(1-\rho)]R_{A_c} - g] + [(p - C_Y + \Psi.p(1-\rho))]f_{A_c}] + \mu_2.f_{A_c} \\ &= 0\end{aligned} \tag{28}$$

Differentiating (28) with respect to time and plugging the values of $\dot{\mu}_2$ and μ_2 we get the land acquisition path under social planning:

$$\dot{A}_c^{SO} = \frac{f_{A_c}(\delta - f_x)[[C_R - \gamma(1-\rho)]R_{A_c} + g]}{(1-\rho)[\gamma R_{A_cA_c} + \Psi.p.f_{A_c}((1+\rho)-1)[[[C_R + \gamma(1-\rho)]R_{A_c} - g](p - C_Y)]]} \tag{29}$$

(See: Appendix 5).

From the results above, we can make a comparison of the shadow benefit of mining under social planning and that under Nash solution. The results are summarized in Table 1.

Table 1 Comparison of the shadow benefit of mining under social planning and that under Nash solution

Shadow benefit of	Under social planning	Under nash solution	Condition : social benefit nash benefit
Depletion of mine reserve	$[p - C_Y - \Psi.p.(1-\rho)]e^{-\delta t}$	$(p - C_Y - \Psi)e^{-\delta t}$	$p \leq \frac{1}{1-\rho}$
Exploration of new reserve by land acquisition	$-[(C_R + \gamma(1-\rho))R_{A_c} + g]\frac{f_x}{f_{A_c}}e^{-\delta t}$	$-[C_R + \gamma]R_{A_c}\frac{f_x}{f_{A_c}}e^{-\delta t}$	$\rho < 1$

Whether the social benefit (shadow) from depletion of mine reserve and exploration of new reserve by land acquisition will be greater under the socially planned mine extraction path than that under the Nash determined path, depends the value of ρ in relation to the market price p. It is already explained that ρ is the weight/importance (in terms of percentage) chosen to be given by the social planner on mining induced loss of traditional livelihood. It is the proportion of rent and royalty payment that the social planner will redistributed from himself to the community. $\rho < 1$ is the condition for lesser social cost (vis-à-vis greater social benefit) from exploration of new reserve under social planning than under Nash solution. But ρ must be such that $p \leq \frac{1}{1-\rho}$ i.e., $\rho \geq 1 - \frac{1}{p}$ for getting greater social benefit from depletion of mine reserve. For a miner of a developing country, p is determined exogenously by the market forces. From the above condition, it is clear that ρ has to be adjusted accordingly, i.e., to be increased with increase in price to get the positive social benefit from depletion of reserve.

3 How Much Land Does a Miner Need to Extract the Desired Material?

When a mining firm takes decision regarding how much land it will take on lease from the community and explore, it needs prior information about the mine reserve in the land concerned. In mining, area of excavation (A_E) and volume of waste materials (W) increase with the increase in extraction of the desired material (Y). How much A_E will increase with Y and W again depends on the shape of the excavation. In our hypothetical context, if we assume that there is a surface mining and the shape of the excavation is cubic, then:

$$A_E = \left(\frac{Y}{\rho_E} + \frac{W}{\rho_W}\right)^{\frac{2}{3}} \tag{30}$$

where ρ_E and ρ_W are the average densities of desired material and waste material respectively.

If the strip ratio (quantity of waste material produced per unit production of the desired material) is assumed to be constant (k_{WY}), then

$$W = k_{WY} Y \tag{31}$$

$$A_E = \left(\frac{Y}{\rho_E} + \frac{k_{WY} Y}{\rho_W}\right)^{\frac{2}{3}} \tag{32}$$

(Appendix 6).

Again, the area of land for waste dump (A_W) is functionally determined by the mining production (Y). Assuming that the waste dump is conical with its slope being θ,

$$A_W = \left(\frac{3\sqrt{\pi}k_{WY}Y}{\tan\theta\rho_W}\right)^{\frac{2}{3}} = \left(\frac{3\sqrt{\pi}k_{WY}}{\tan\theta\rho_W}\right)^{\frac{2}{3}} Y^{\frac{2}{3}} \tag{33}$$

Taking (32) and (33) together, we get the relation between the area of the land to be needed for excavation and waste dumping and mining output (Appendix A3) as:

$$A_E + A_W = \left[\left(\frac{1}{\rho_E} + \frac{k_{WY}}{\rho_W}\right)^{\frac{2}{3}} + \left(\frac{3\sqrt{\pi}k_{WY}}{\tan\theta\rho_W}\right)^{\frac{2}{3}}\right] Y^{\frac{2}{3}}. \tag{34}$$

From the above expression, we find that for a given amount of Y, the area of community land it needs:

$$A_c \geq \left[\left(\frac{1}{\rho_E} + \frac{k_{WY}}{\rho_W}\right)^{\frac{2}{3}} + \left(\frac{3\sqrt{\pi}k_{WY}}{\tan\theta\rho_W}\right)^{\frac{2}{3}}\right] Y^{\frac{2}{3}} \geq k.Y^{\frac{2}{3}}$$

where

$$k = \left[\left(\frac{1}{\rho_E} + \frac{k_{WY}}{\rho_W}\right)^{\frac{2}{3}} + \left(\frac{3\sqrt{\pi}k_{WY}}{\tan\theta\rho_W}\right)^{\frac{2}{3}}\right] \tag{35}$$

This is calculated with some simplified assumptions and may not be applicable in practical field, but may be used in our theoretical model. This is the information on the basis of which a miner or a 'social planner' can take decision on how much land it will lease from the community. (35) will be utilized in the next sub-section.

4 Sustenance of a Targeted Level of Traditional Production and Sustainability Issue in Social Planning of Land Acquisition

4.1 Land Acquisition with a Targeted Level of Traditional Production

In order to foster industrial growth in the economy the society has to make a trade-off: how much loss in traditional production they will allow for the expansion of mining sector. The social planner can target to assure a constant level of social welfare due to land acquisition: $\bar{U} = U^M(A_c) + U^G(A_c)$. It is constituted by the welfare of miner U^M and that of the traditional community U^G. As defined above in our present context,

$$U^M(A_c) = P.Y(A_c) - C(Y(A_c), R(A_c)) - [\Psi.p.Y(A_c) + \gamma R(A_c)] \text{ and}$$
$$U^G = g(L) + \rho.[\Psi.p.Y(A_c) + \gamma R(A_c)]$$

At the constant level of welfare,

$$\frac{d\bar{U}}{dA_c} = \frac{dU^M}{dA_c} + \frac{dU^G}{dA_c} = 0 \rightarrow \frac{dU^M}{dA_c} = -\frac{dU^G}{dA_c} \tag{36}$$

From the above expression $\frac{dU^M}{dA_c} = p(1 - \Psi - C_Y).\frac{\partial Y}{\partial A_c} - (C_R + \gamma)\frac{\partial R}{\partial A_c}$ and $\frac{\partial U^G}{\partial A_c} = g_L \frac{\partial L}{\partial A_c} + p.\left(\rho.\Psi.\frac{\partial Y}{\partial A_c} + \gamma.\frac{\partial R}{\partial A_c}\right)$. Adding them together we get the revised form of the Eq. (36) as:

$$\begin{aligned} &p(1 - \Psi - C_Y).\tfrac{\partial Y}{\partial A_c} - (C_R + \gamma)\tfrac{\partial R}{\partial A_c} = -g_L \tfrac{\partial L}{\partial A_c} - p.\left(\rho.\Psi.\tfrac{\partial Y}{\partial A_c} + \gamma.\tfrac{\partial R}{\partial A_c}\right) \\ &Or, \quad p(1 - C_Y - (1-\rho).\Psi).\tfrac{\partial Y}{\partial A_c} - (C_R + (1-p)\gamma)\tfrac{\partial R}{\partial A_c} = -g_L \tfrac{\partial L}{\partial A_c} \end{aligned} \tag{37}$$

The first component of the LHS of (37) is the marginal benefit to the society in terms of depletion of mine reserve Y (which is mine output) by land acquisition and the second component is the marginal cost of maintaining the reserve acquired by land acquisition. The LHS is, therefore, the net marginal benefit to the society due to land acquisition. Due to decrease in availability of land L, the loss of traditional production at the marginal level is $-g_L \frac{\partial L}{\partial A_c}$, which is the marginal cost to the society due to land acquisition. If social planner wants to fix this loss at some constant level K to assure sustainable level of production,

$$p(1 - C_Y - (1-\rho).\Psi).\frac{\partial Y}{\partial A_c} - (C_R + (1-p)\gamma)\frac{\partial R}{\partial A_c} = \mathrm{K} \tag{38}$$

This will occur (taking the second order derivative of the above equation with respect to A_c) if the rate of increase of depletion of mine reserve for each unit of rate of conservation of mine reserve due to acquisition of community land:

$$\cdot\frac{\partial^2 Y}{\partial A_c^2} \Big/ \frac{\partial^2 R}{\partial A_c^2} = \frac{(C_R + (1-p)\gamma)}{p(1 - C_Y - (1-\rho).\Psi)} \tag{39}$$

From Eq. 35, we can write $\frac{\partial Y}{\partial A_c} = \frac{3}{2}k.A_c^{1/3}$. Thus $\frac{\partial^2 Y}{\partial A_c^2} = \frac{k}{2A_c^{2/3}}$. Plugging this value into (38), we get $A_{c\,|\max}$, the maximum area of community land that can be leased out for mining after ensuring a minimum targeted level of traditional production, as:

$$A_{c\,|\max} = \left(\frac{k.p(1 - C_Y - (1-\rho).\Psi).\frac{\partial^2 R}{\partial A_c^2}}{2.(C_R + (1-p)\gamma)}\right)^{3/2} \tag{40}$$

4.2 Land Acquisition and Sustainable Path of Development

The sustainability criterion as reported by the Brundtland Commission 1987, after the name of its chairperson, is the 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' In economic theory, analytically, the approach to the sustainability issue has been made by deriving the 'stationary equivalent' of the utilitarian optimal welfare path. Some constraints on social objectives, i.e., optimization of social utility or welfare are set so that two important components of sustainability (Stavins et al. 2003), viz., inter generational equity and efficiency can be assured. As proposed by Solow (1974) it is obtained in terms of non-decreasing utility over time and optimizing the discounted value of utility (economic well-being).

In our present context, when acquisition of community land takes place to foster the growth of the mining sector at time $t = T_1 > 0$ and the social planner wants to maximize the social utility:

$$U(T_1) = \int_{T_1}^{\infty} [U^M(A_c) + U^G(A_c)]e^{-\delta(s-T_1)}ds,$$

$$= \int_{T_1}^{\infty} [P.Y(A_c) - C(Y(A_c), R(A_c)) - [\Psi.p.Y(A_c) + \gamma R(A_c)] + g(L)$$
$$+\rho.[\Psi.p.Y(A_c) + (A_c)]]e^{-\delta(s-T_1)}ds$$

Brundtland condition of sustainability requires that intertemporal social utility U would not decrease over time T_1, i.e., $U'(T_1) \geq 0$. This is obtained by differentiating the above expression with respect to time:

$$U'(T_1) = -\left[U_t^M + U_t^G\right] + \delta U(T_1) \geq 0$$

This yields,

$$U(T_1) \geq \frac{[p.Y_t - C(Y_t, R_t) + (1-\rho)[\Psi.p.Y_t + \gamma R_t] + g_t]}{\delta} \tag{41}$$

The condition for an optimal sustainable utility path (when it exists) is obtained in two stages: first, by adopting the usual utilitarian approach to optimize a general utilitarian social welfare function in an infinite time horizon: $\int_{T_1}^{\infty} [p.[1 + (1-\rho).\Psi]Y_t - C(Y_t, R_t) + (1-\rho)\gamma R_t + g_t]e^{-\delta t}dt$ and, second, obtaining the condition under which this optimal path is constant over time (Farzin 2006). Following Weitzman (1976), the maximized current-value Hamiltonian is the 'stationary equivalent' of the utilitarian optimal welfare path. And in this approach, the necessary and sufficient condition for permanently sustaining the highest consumption path (i.e., the maximin path) is that the maximized current-value Hamiltonian remains constant over time, i.e., that $\frac{\partial \tilde{H}}{\partial t} = 0$ (Farzin 2006).

This implies:

$$\frac{d\tilde{H}}{dt} = \frac{\partial\tilde{H}}{\partial t} - \delta\left[\mu_1\dot{R} + \mu_2\dot{x}\right] = 0 \tag{42}$$

For simplicity if we heuristically assume that direct and exogenous effects of time on the economy, i.e., net 'pure time effect' is nil, i.e., the economy is time-autonomous, the maximin sustainability cum optimality criterion (which also leads to Rawlsian criterion of intergenerational justice) that follows from Eq. (4.3) simply leads to:

$$\begin{aligned}
&[p.[1 + (1-\rho).\Psi + \delta\mu_1 - C_Y + C_R + (1-\rho)\gamma]Y_{A_c} + g_{A_c}]\tfrac{\partial A_c}{\partial t} \\
&= [\delta[\mu_1 + \mu_2] + [C_R + (1-\rho)\gamma]]\dot{x} = 0\frac{\partial\tilde{H}}{\partial t} \\
&= [p.[1 + (1-\rho).\Psi - C_Y]Y_{A_c} + g_{A_c}]\frac{\partial A_c}{\partial t} - [C_R + (1-\rho).\gamma]\frac{\partial R}{\partial t} \\
&= \delta\left[\mu_1\dot{R} + \mu_2\dot{x}\right] = 0
\end{aligned} \tag{43}$$

If the sustainability condition (43) is satisfied, from left hand side of this equation we get:

$$\frac{\partial R}{\partial A_c} = \frac{p.[1 + (1-\rho).\Psi - C_Y]Y_{A_c} + g_{A_c}}{C_R + (1-\rho).\gamma} \tag{44}$$

The RHS of the numerator of (44) is the net return at the marginal level from land acquisition $(g_{A_c} < 0)$ and the denominator is the net cost of maintaining reserve $(C_R < 0)$. From the condition given by (44) we reach a conclusion that in order to achieve the sustainable path of development change in mine reserve (∂R) (depletion or expansion) per unit change in the area of land acquired over time must be in proportion of net marginal return from land acquisition to net marginal cost of maintaining reserve. Utilizing (42) we can also find out the rent on mine reserve (γ_S) and royalty on mine output (Ψ_S) that the traditional community deserve along the path of sustainable development. To simplify the matter, let us again assume $\Psi = 0$. From (42) we get:

$$\gamma_S = \frac{1}{(1-\rho)}[p.[1 - C_Y]Y_{A_c} + g_{A_c}].\left(\frac{\dot{A}_c}{\dot{R}}\right)_S - C_R \tag{45}$$

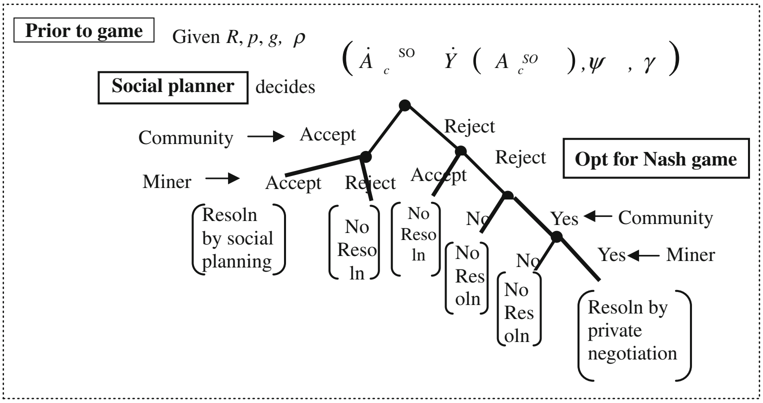
γ_s is the dynamic rent as it depends on $\left(\frac{\dot{A}_c}{\dot{R}}\right)_S$

4.3 Community-Miner Resolution Game Under Social Planning and Under Private Nash Solution

For miner-community conflict resolution, two possible types of economic institutions, viz., ‘private’ and ‘private’ but under socially planned way with their resulting impacts are analytically discussed. There are both advantages and disadvantages of each of these institutions. In case of privately resolved institution, i.e., by the Nash solution, miner and traditional community gets opportunity to interact directly with each other. There are at least two advantages of that. Since the community has greater interest for and better knowledge about local environment, by this resolution local environment may be better protected. Since the interaction is direct, the process of reaching the conflict resolution may be less time consuming. But there are so many disadvantages. Firstly, since there is no authority to monitor the process of miner-community negotiation, the terms and condition settled by them may not be followed by both parties. So there is every possibility to break the path of conflict resolution. Secondly, in the terms and conditions, the localized issues may get the highest priorities and those may not be conformable with the national and global objectives. Finally, in the whole process of negotiation, the relative bargaining power will determine who will get the maximum benefit. In that case, it may happen that traditional community with weaker bargaining power may not get the benefit at all. In the alternative institution, on the basis of socially desirable rate, of mine extraction and land acquisition determines and collects the rent and royalty from miner. It further decides how much of the collected rent and royalty they will redistribute to the miner. One of the advantages of this method is that it would be backed by the government’s rules and regulations it is easily implementable. Secondly, sharing o benefit from mining between miner community and government may be better entwined with national and global objectives. But among the disadvantages, a complaint is often raised by the miners and communities that government is much more interested with their own coffer rather than with the benefit of the miners and communities. Secondly, due to bureaucratic involvement, the process of resolving the conflict may be unnecessarily lengthy. Now, the most practical question is under what condition the conflict resolution in the recommended path of social panning will be acceptable to both miner and traditional community?

Given the mine reserve, prices, land productivity with respect to traditional output and the relative weight (or importance) on the net loss of traditional production, the social planner derives the socially desirable paths (taking into account the socially determined rule of sustainability) of land acquisition and mine extraction, rent, royalty and sharing the value of mine output with community. If it is an indicative planning the miner and community are free to accept and reject the solution indicated by social planner. The miner-community conflict is resolved in the socially planned path if both parties accept the socially planned solution. If either of them rejects it, no resolution occurs. If both of them reject, then the possibility of conflict resolution may occur by opting for Nash strategy game. Now

Table 2 Miner–community option for socially planned solution versus private Nash solution



in this particular context, whether the miner and traditional community will opt for resolution in the socially planned way (S^*) rather than that through Nash solution (N^*) depends on whether each of them is getting the payoff (i.e., benefit) from S^* given that its opponent option is greater than or equal to the payoff from opting for N^* or not (Table 2). It is, therefore, the vital task of the social planner to design the benefit sharing principle in such a way that neither of the miner and community will like to opt for Nash strategic solution or no solution to resolve the interest conflict.

5 Summaries and Conclusion

In the context of acquisition of community land for mining, two types of negotiation games to settle the compensation for traditional community's loss, area of acquired land, and quantity of mining production have been modelled. The first game results in a Nash solution. Given the rate of compensatory return the community claims, the miner individualistically chooses the paths of land leased-in and depletion of mine reserve. The traditional community as a single agent, also, given the land productivity and expected rate of compensatory return from miner, individualistically chooses the paths of land leased-out. The second game results in a solution through the intervention of social planner who assigns some weight or value to the loss of traditional production due to land acquisition. This weight plays a pivotal role in the second type model.

In the Nash settlement game, the traditional community's choice of the time path determining the rate of leasing out land to the miner to maximize the return from traditional production plus compensation for land conversion depends upon the history of choices of rent and royalty that the traditional community offers to the miner. Similarly miner's choice of time path of mine extraction through land acquisition depends upon history of choices of rent and royalty that miner bids to the traditional community.

The relative dominance or non-dominance of the cost saving effect of having reserve over cost rising effect of rent determines whether land acquisition path chosen by the miner will be rising or falling over time. If cost saving effect of having reserve dominates over cost on rent for reserve, miner's urge to acquire more land will be declining over time.

In the second type of game, where the miner-community settlement occurs through social planning, it is found that the shadow benefit of depletion of mine reserve declines at a rate slower than that under Nash settlement game. Shadow cost path of exploration of new reserve through land acquisition under social planning lies above the shadow cost path of exploration by Nash solution. At a particular point of time, whether the shadow benefit of depletion of mine reserve will be higher than that under Nash solution depends on the proportion of benefit from mining the planner chooses to redistribute to the community relative to the price of mine output.

A quantifiable relation in terms of the geological parameters has been derived to show how much land a miner needs to extract the desired material. This relation has been utilized to find out the maximum socially acceptable area of community land that can be leased out for mining that ensures a minimum targeted level of traditional production.

In order to achieve the sustainable path of development change in mine reserve (i.e., depletion or expansion) per unit change in the area of land acquired over time must be in proportion of net marginal return from land acquisition to net marginal cost of maintaining reserve.

A dynamic rent on mine reserve and royalty on mine output that the traditional community deserves to move the society along the path of sustainable development has been formulated. If indicative planning exists in the society where the miner and community have freedom to opt for conflict resolution through the social planning and that through private Nash solution, each of them will voluntarily opt for the first, if at least one of them get greater payoff (i.e., benefit) from this with no lesser payoff (benefit) for other.

The results of the analytical exercises identify four key factors that play an important role in designing the benefit sharing principle to resolve the interest conflict. They are: (1) relative dominance or non-dominance of cost saving effect of mine reserve over cost rising effect of rent on miner, (2) productivity of traditional output in the community land, (3) geological parameters determining the relation between the quantity of mine output and the area of land to be extracted and (4) social planner's choice of the proportion of benefit to be redistributed from mining to the traditional community. Examining these key factors, the policy makers can decide whether the government should promote mutual negotiation between miner and traditional community or a settlement through the social planner to settle the miner-community conflict in the process of development. One of the restrictive but simplifying assumptions, however, we have made throughout our analysis that price of mine and traditional output remains unchanged over time. It is competitive and stable. Price is such that miner always earns a positive profit throughout the whole period. The effect of change in price, particularly that of mine output, can play a significant role in determining the time path of mining induced land acquisition which will be taken into account in future research.

A.1 6 Appendix

A.1.1 Appendix 1

The Hamiltonian for this problem is:

$$H = (p - \Psi)Ye^{-\delta t} - C(Y, R)e^{-\delta t} - \gamma R(A_c)e^{-\delta t} + \lambda_1[f(A_c, x) - Y(A_c)] \\ + \lambda_2[f(A_c, x)]$$

Differentiating H with respect to Y, R, x and A_c we get:

$$pe^{-\delta t} - C_Y e^{-\delta t} - \Psi e^{-\delta t} - \lambda_1 = 0$$

Solving this, we get, $\lambda_1 = (p - C_Y - \Psi)e^{-\delta t}$

$$\dot{\lambda}_1 = (C_R + \gamma)e^{-\delta t}$$
$$\dot{\lambda}_2 = -f_x(\lambda_1 + \lambda_2)$$

Again differentiating H with respect to A_c we obtain:

$$[(p - C_Y - \Psi)Y_{A_c} - (C_R + \gamma)R_{A_c}]e^{-\delta t} + f_{A_c}(\lambda_1 + \lambda_2) - \lambda_1 Y_{A_c} = 0$$

Plugging the value of λ_1 in the above expression we get:

$$[(p - C_Y - \Psi)Y_{A_c} - (C_R + \gamma)R_{A_c}]e^{-\delta t} + f_{A_c}(\lambda_1 + \lambda_2) - (p - C_Y - \Psi)e^{-\delta t}Y_{A_c} = 0$$

$$[-(C_R + \gamma)R_{A_c}]e^{-\delta t} + f_{A_c}(\lambda_1 + \lambda_2) = 0$$
$$[-(C_R + \gamma)R_{A_c}]e^{-\delta t} - \frac{f_{A_c}}{f_x}\dot{\lambda}_2 = 0$$

$$\dot{\lambda}_2 = -[C_R + \gamma]R_{A_c}\frac{f_x}{f_{A_c}}e^{-\delta t}$$

A.1.2 Appendix 2

Now differentiating Eq. (6) with respect to time we get the time path of land acquisition chosen by miner:

$$\left[-\delta[(p-C_Y-\Psi)f_{A_c}-(C_R+\gamma)R_{A_c}]+[(p-C_Y-\Psi)f_{A_cA_c}-(C_R+\gamma)R_{A_cA_c}]\dot{A}_c\right]e^{-\delta t}$$
$$+f_{A_cA_c}\dot{A}_c\lambda_2+f_{A_c}\dot{\lambda}_2=0$$
$$-\delta[(p-C_Y-\Psi)f_{A_c}-(1+f_x)(C_R+\gamma)R_{A_c}]+\left(\frac{f_{A_cA_c}R_{A_c}}{f_{A_c}}-R_{A_cA_c}\right)(C_R+\gamma)\dot{A}_c=0$$

$$\dot{A}_c^{\mathrm{M}}=\frac{\delta[(p-C_Y-\Psi)f_{A_c}-(1+f_x)(C_R+\gamma)R_{A_c}]}{\left(\frac{f_{A_cA_c}R_{A_c}}{f_{A_c}}-R_{A_cA_c}\right)(C_R+\gamma)}$$

A.1.3 Appendix 3

The present value Hamiltonian for this problem with the single control variable L is:

$$H=w.g(L)e^{-\theta t}+\Psi.p.Y(A_c)e^{-\theta t}+\gamma R(A_c)e^{-\theta t}-\xi_1 A_c \tag{14}$$

Differentiating H with respect to A_c and L we get:

$$H_{A_c}=(\Psi.p.Y_{A_c}+\gamma R_{A_c})e^{-\theta t}-\xi_1=0\ H_L=-\dot{\xi}_1=w.g_L.e^{-\theta t}$$

The optimal path is found from the necessary conditions by substituting the equation of motion $\dot{L}=-A_c$ into (14) and taking the time derivative of the resulting equation.

$$\left(\Psi Y_{A_c}\left(-\dot{L}\right)-\gamma R_{A_c}\left(-\dot{L}\right)\right)e^{-\theta t}-\xi_1=0$$
$$\left(\Psi Y_{A_cL}\left(-\dot{L}\right)\ddot{L}+\gamma R_{A_cL}\left(-\dot{L}\right)\ddot{L}-\theta\left(-w.g_{A_c}+\Psi Y_{A_c}\left(-\dot{L}\right)+\gamma R_{A_c}\left(-\dot{L}\right)\right)\right)-w.g_L=0$$

$$(\Psi Y_{A_cL}+\gamma R_{A_cL})\ddot{L}=\theta(\Psi Y_{A_c}+\gamma R_{A_c})-w.g_L$$

As defined in (13), $\ddot{L}=-\dot{A}_c$, i.e., rate of change of available land for traditional production is the change of acquired land over time.

$$(\Psi Y_{A_cL}+\gamma R_{A_cL})\dot{A}_c=w.g_L-\theta(\Psi Y_{A_c}+\gamma R_{A_c})$$

A.1.4 Appendix 4

The Hamiltonian function with the single control variable $Y(A_c)$ and two state variables R and $x$is:

$$\tilde{H} = e^{-\delta t}[P.Y(A_c) - C(Y(A_c), R(A_c)) - [\Psi.p.Y(A_c) + \gamma R(A_c)](1-\rho.) + g(\bar{L} - A_c)] \\ + \mu_1[f(x, A_c) - Y] + \mu_2.f(x, A_c)$$

Differentiating it with respect to A_c and Y we get:

$$\tilde{H}_{A_c} = e^{-\delta t}[[P - C_Y - \Psi.p(1-\rho)]Y_{A_c} - [C_R + \gamma(1-\rho)]R_{A_c} - g] - \mu_1 Y_{A_c} + (\mu_1 + \mu_2).f_{A_c} = 0$$
$$\tilde{H}_Y = e^{-\delta t}[(p - C_Y - \Psi.p(1-\rho))] - \mu_1 = 0$$
$$Or,\ \mu_1 = [p - C_Y - \Psi.p.(1-\rho)]e^{-\delta t}$$

A.1.5 Appendix 5

Differentiating $\tilde{H}$ with respect to A_c, we get:

$$\tilde{H}_{A_c} = e^{-\delta t}[[-[C_R + \gamma(1-\rho)]R_{A_c} - g] + [(p - C_Y + \Psi.p(1-\rho))]f_{A_c}] + \mu_2.f_{A_c} \\ = 0$$

Again differentiating the above expression with respect to time we get:

$$e^{-\delta t}(1-\rho)[\gamma R_{A_cA_c} + \Psi.pf_{A_cA_c}.]\dot{A}_c + \delta[[C_R - \gamma(1-\rho)]R_{A_c} + g] + \mu_2.f_{A_cA_c}\dot{A}_c \\ + f_{A_c}\dot{\mu}_2 \\ = 0$$

Plugging the value of $\dot{\mu}_2 = -[[C_R + \gamma(1-\rho)]R_{A_c} + .g]\frac{f_x}{f_{A_c}}e^{-\delta t}$ and μ_2 into it we get the land acquisition path under social planning:

$$\dot{A}_c^{\mathrm{SO}} = \frac{(\delta - f_x)[[C_R - \gamma(1-\rho)]R_{A_c} + g]}{(1-\rho)\left[\gamma R_{A_cA_c} + \Psi.p\left(1 + \rho - \frac{1}{.f_{A_c}}\right) + \left[\frac{1}{f_{A_c}}[[C_R + \gamma(1-\rho)]R_{A_c} - g](p - C_Y)\right]\right]} \\ = \frac{f_{A_c}(\delta - f_x)[[C_R - \gamma(1-\rho)]R_{A_c} + g]}{(1-\rho)[\gamma R_{A_cA_c} + \Psi pf_{A_c}((1+\rho) - 1)[[[C_R + \gamma(1-\rho)]R_{A_c} - g](p - C_Y)]]}$$

A.1.6 Appendix 6

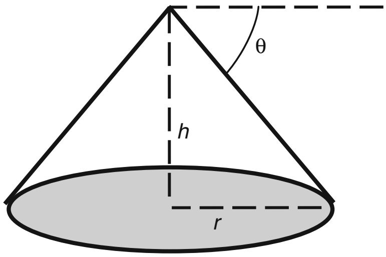
If the shape of the excavated material is cubic with sides a, V_E is the total volume of material excavated from the mine that includes the volumes of desired material and that of the waste material,

$$A_E = a^2 = \left(a^3\right)^{2/3} = (V_E)^{2/3}. \tag{46}$$

Expressing the volume as the ratio of mass and average density, the volume of the desired material and the waste materials are $\frac{Y}{\rho_Y}$ and $\frac{W}{\rho_W}$ respectively.

Therefore from (46) $A_E = (\frac{Y}{\rho_Y} + \frac{W}{\rho_W})^{\frac{2}{3}} = (\frac{1}{\rho_Y} + \frac{k_{WY}}{\rho_W})^{\frac{2}{3}} Y^{\frac{2}{3}}$, where k_{WY} is the strip ratio.

If the area of an waste dump is having conical shape, let the height and radius of conical waste dump be h and r respectively, and its slope is θ. (i.e., subvertical angle is $90° - \theta$).



Then its volume (V_W) is:

$$V_W = \frac{1}{3}\pi r^2 h = \frac{1}{3}\pi r^2 . r. \tan\theta = \frac{1}{3} A_W \left(\sqrt{\frac{A_W}{\pi}}\right) \tan\theta = \frac{1}{3\sqrt{\pi}} (A_W)^{\frac{3}{2}} \tan\theta$$

The volume of the waste dump can be expressed as the ratio of its mass and average density, i.e., $V_W = \frac{W}{\rho_W}$

Therefore $A_W = \left[\frac{3\sqrt{\pi}}{\tan\theta}(V_W)\right]^{\frac{2}{3}} = (\frac{3\sqrt{\pi}W}{\tan\theta \rho_W})^{\frac{2}{3}} = (\frac{3\sqrt{\pi}k_{WY}}{\tan\theta \rho_W})^{\frac{2}{3}} Y^{\frac{2}{3}}$

References

Balipara Tract and Frontier Foundation, India (2010) Optimizing biodiversity and social security in the indian mining areas, A two day consultation in Balipara, Assam, 2nd & 3rd December, 2010. From http://www.baliparafoundation.com/Balipara%20Consultation.pdf. Accessed on 24 May 2011

Banerjee SP (2004) Social dimensions of mining sector. Min eng 85:5–30

EPGORISSA (2011) Vedanta's aluminum refinery project and bauxite mining project on Niyamgiri: environmental and social costs of vis-à-vis benefits to Orissa and its people. Report by environmental protection group Orissa, 70. From http://www.freewebs.com/epgorissa/. Accessed on 26 April 2011

Farzin YH (2006) Conditions for sustainable optimal economic development. Rev of Dev Eco 10(3):518–534

Kalpavriksh and Vasundhara (2008) Halt destructive development to save forests and forest-dwellers! statement of the national workshop on underlying causes of deforestation and forest degradation in India, organized by Kalpavriksh and Vasundhara. India, Press Release, Bhubaneswar, 26–28th Jan 2008

Pindyck RS (1978) The optimal exploration and production of non-renewable resources. JPE 86:841–61

Sahu G (2008) Mining in the Niyamgiri Hills and tribal rights. EPW 19–21, 12 April 2008

Solow RM (1974) Intergenerational equity and exhaustible resources. Rev Econ Studies 41:29–45

Stavins R, Wagner A, Wagner G (2003) Interpreting sustainability in economic terms: dynamic efficiency plus intergenerational equity. Econ Letters 79:339–343

Weitzman ML (1976) Optimal revenue functions for economic regulation. Working papers 193, Massachusetts Institute of Technology, Department of Economics

Sustainable Land Use Planning Using Geospatial Technology

S. P. S. Kushwaha and Suchismita Mukhopadhyay

1 Introduction

Everyone in the world depends completely on Earth's ecosystems and the services they provide such as food, water, disease management, climate regulation, spiritual fulfilment, and aesthetic enjoyment. Over the past 50 years, humans have changed the ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet the rapidly growing demands for food, fresh water, timber, fibre, and fuel of an ever-expanding human population. This has resulted in a substantial, and largely irreversible, loss in the diversity of life on Earth. The changes that have been made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing costs in the form of the degradation of many ecosystem services, increased risks of non-linear changes, and the exacerbation of poverty for some groups of people. These problems, unless addressed, will substantially diminish the benefits that future generations may obtain from the ecosystems. The consumption of natural resources by humans is 1.6 times higher than their natural regeneration capacity (MEA 2005).

The scientists, planners and decision makers are slowly turning their attention towards sustainable development, a concept suggested by the World Commission on Environment and Development (WCED). Sustainable Development has been defined as the 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987a). The FAO definition-'sustainable development is the management and conservation of natural resources base and the orientation of technological and institutional changes in such a manner so as to ensure the attainment and continued

S. P. S. Kushwaha (✉) · S. Mukhopadhyay
Indian Institute of Remote Sensing, ISRO, Dehradun 248001 Uttarakhand, India
e-mail: spskushwaha@gmail.com

S. Mukhopadhyay
e-mail: suchismita.mukhopadhyay@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_27,

satisfaction of human needs for present and future generations' (FAO 1989) is considered to be the most comprehensive. The essence of sustainable development planning is to look for management practices in which the resources are handled and managed sustainably. Such a development emphasizes on the maintenance of the productivity of natural resources, especially land and water, while retaining the ecological equilibrium (WCED 1987b).

The sustainable development concept received a much-needed impetus after the Rio Conference in June 1992, mainly through 27 principles on sustainable development and the action plan called Agenda-21 (UNCED 1992). The approach was followed up in a big way during the World Summit on Sustainable Development in 2002 at Johannesburg. The Summit re-emphasized the need for strengthening the three pillars of sustainable development, viz., economy, society and the environment (WSSD 2002). Watershed forms an appropriate unit for analyzing the development-linked resource problems, designing the appropriate solutions of identified problems and eventually testing the efficacy of the prescribed solutions (Tejwani 1987). Since watersheds and their environments also have direct or indirect bearing on human lives, it becomes necessary to devise proper management of the resources in these areas. The watershed approach is a system-based approach that facilitates the holistic development of agriculture, forestry and allied activities in the watershed (Tideman 2000). Sustainable watershed development planning requires high resolution and accurate spatial data and knowledge of ecology and socio-economy.

Remote sensing provides effective support in terms of reliable and timely information (Marble et al. 1983; Gugan 1993). A number of studies, carried out worldwide, demonstrate the capability of remote sensing and GIS in development planning (Hellden et al. 1982; Kushwaha 1993; Beinat and Nijkamp 1998). Spatial analysis is vital to economic performance and GIS is important for planning from local to global scales. By interfacing remote sensing with GIS, different management scenarios could be generated. Latter could help the planners assess the feasibility of various alternatives before selecting the one that would be most suitable (Nellis et al. 1990). Kushwaha et al. (1996, 2010) have demonstrated the methodology for integrated sustainable rural development planning using remotely sensed data and GIS. The objective of this study was to generate an environmentally sound and sustainable land use plan for in Pathri rao sub-watershed in the Haridwar district of Uttarakhand.

2 Study Area

Pathri rao sub-watershed (29°55′–30°03′ N and 77°59′–78°07′ E), covering an area of ca. 44 km^2, is located at the foothills of Shivaliks in the Haridwar district of Uttarakhand (Fig. 1). The area is drained by the river Pathri rao (*rao* means a river locally) and its two tributaries, Chhirak rao and Harnaul rao. It experiences three distinct seasons—summer, winter and monsoon. The temperatures range

Fig. 1 The location of study area in India

from 2° in winter to more than 40°C in summer. The average elevation varies from 250 to 800 m above msl. The upper part of the sub-watershed, falling in the Rajaji National Park (RNP), has moderate to steep slopes. The RNP, a protected area, is the natural habitat of a large variety of wild flora and fauna, including elephants and tigers. The Park portion of the sub-watershed is dominated by dry deciduous forest. The downstream plains are characterized mainly by the agricultural fields, where both rabi and kharif crops, viz., wheat, sugarcane, groundnut and maize are grown. Besides, there are mango and guava orchards and forest plantations of eucalyptus, poplar, and the bamboo.

Water scarcity is a major problem and most of the agriculture is rain-fed. Riverbank erosion and consequent loss of productive agricultural land is common during the monsoon. The groundwater table has receded over time due to over-use of water for drinking and irrigation in the lower piedmont area. Local people have turned to other professions for sustenance in spite of the availability of agricultural land. The area is deficient in food grains as well as fodder. The situation was worsened after the relocation of the gujjars (erstwhile nomads engaged in animal husbandry, who now prefer to stay in forests) from RNP to Pathri rao sub-watershed. There are also large tracts of culturable wasteland. No major soil or water conservation measures are practiced in the area.

3 Materials and Methods

The Survey of India (SOI) topomaps on 1:25,000 scale (with Lambert Conformal Conic projection), IKONOS satellite image of November 2004 with 1 m spatial resolution (Fig. 2) and LISS-III + PAN merged data with 5.8 m spatial resolution were geo-referenced using WGS 84 Zone 44 N datum, Universal Transverse Mercator (UTM) projection and well-defined ground control points (GCPs). The scale of the study was 1:12,500. A watershed boundary, procured from the Uttarakhand Watershed Management Directorate at Dehradun, was used as the reference for delineation of the final sub-watershed boundary using the contours at 10 m interval from the digital topomap on 1:25,000 scale, specially provided by the SOI for the study. The boundary was then overlaid on the satellite image to extract the study area. Resource information extraction was done using remote sensing data and field surveys.

The land use/land cover map was prepared from IKONOS image using on-screen visual interpretation. The land use/land cover map was field-verified for assessing the classification accuracy. For soil mapping, the satellite image-derived physiographic units were field investigated. Horizon-wise soil samples were analysed for physical and chemical properties. The groundwater potential of the area was inferred from the hydro geomorphology map prepared using satellite data and field survey. Crop suitability map was prepared using the soil parameters such as pH, texture and erosion to derive criteria and rating for crop suitability following overlay analysis. The crop suitability map was compared to the present land use to determine the most appropriate recommendation for the conservation of soil and the increase in crop yield. Subsidiary information such as roads, drainage, settlement, village locations and slope were extracted from the SOI digital topomaps on 1:25,000 scale. The socio-economic data were collected by interviewing the local people and discussing with the block and district development officials. This exercise helped significantly in user needs assessment.

A composite layer was generated by intersecting spatial data layers on land use/cover, groundwater potential, crop suitability and slope in GIS domain, and a set of decision rules were applied for generation of sustainable land use plan. Soil texture, digital elevation model, slope, run-off potential, buffer map of settlements, and agriculture were integrated to generate water resources action plan, using decision rules/criteria (Table 1). The Integrated Mission for Sustainable Development guidelines (Rao et al. 1991) were followed for framing the decision rules for data integration. The socio-economic aspects, skills of local people, and available local infrastructure were also considered before recommending any land use. Site-specific strategies for identifying areas suitable for specific crops,

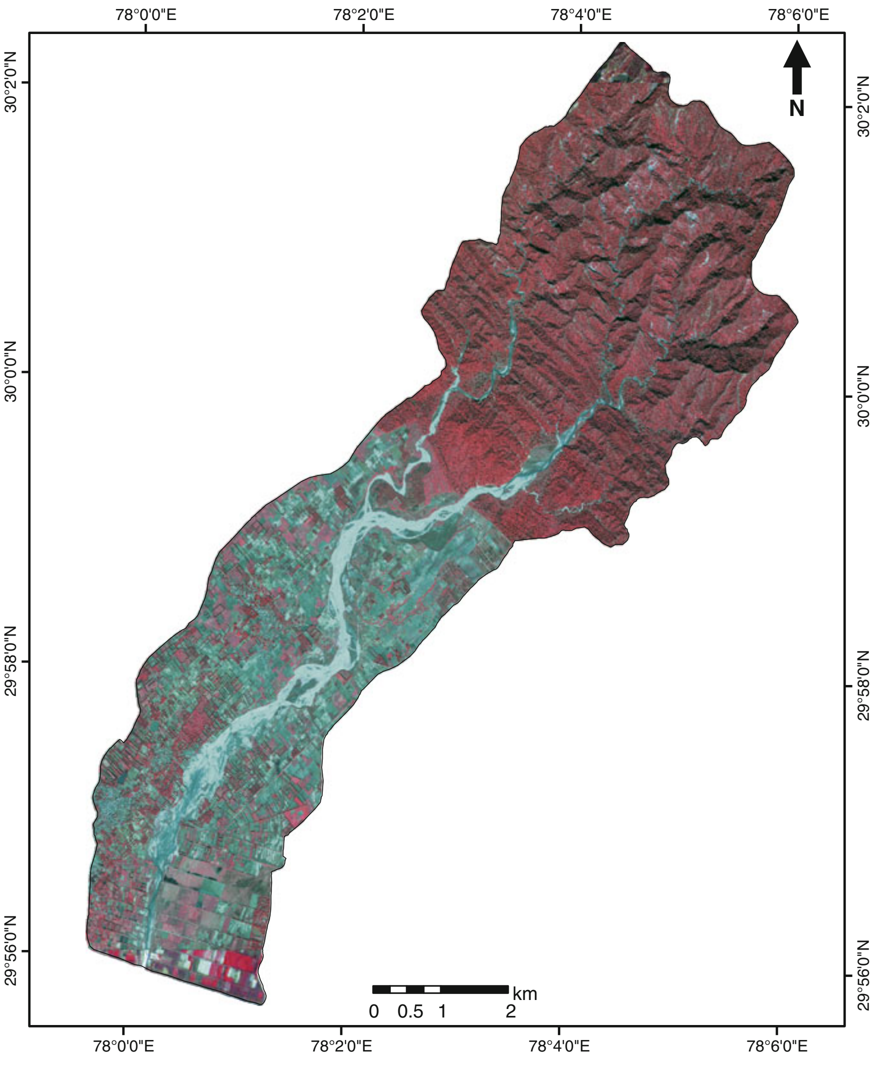


Fig. 2 The IKONOS image of the study area

horticultural plantations, agroforestry and fodder development were evolved. Current practices such as cropping pattern, crop rotation, cultural practices, irrigation methods, water harvesting structures, ground water exploration, soil and water conservation measures, were examined to arrive at a suitable locale-specific sustainable land use action plan. Figure 3 shows the overall methodology.

Table 1 Decision rules/criteria for generation of sustainable land use plan

S.No.	Slope (%)	Groundwater	Land use/cover	Suitability	Action recommended
1.	25–35	Very poor	Dry deciduous (< 10 %)	Forest	Reforestation
2.	>35	-do-	-do-	-do-	-do-
3.	10–25	-do-	-do-	-do-	-do-
4.	3–10	-do-	-do-	-do-	-do-
5.	1–3	-do-	-do-	-do-	-do-
6.	0–1	-do-	-do-	-do-	-do-
7.	0–1	-do-	Dense scrub	-do-	-do-
8.	3–10	-do-	-do-	-do-	-do-
9.	1–3	-do-	-do-	-do-	-do-
10.	10–25	-do-	-do-	-do-	-do-
11.	25–35	-do-	-do-	-do-	-do-
12.	>35	-do-	-do-	-do-	-do-
13.	10–25	-do-	Dry deciduous (40–70 %)	-do-	Gap filling
14.	25–35	-do-	-do-	-do-	-do-
15.	>35	-do-	-do-	-do-	-do-
16.	3–10	-do-	-do-	-do-	-do-
17.	1–3	-do-	-do-	-do-	-do-
18.	0–1	-do-	-do-	-do-	-do-
19.	>35	-do-	-do- (10–40 %)	-do-	-do-
20.	25–35	-do-	-do-	-do-	-do-
21.	0–1	Poor	Wasteland with scrub	Not suitable	Fuel and fodder plantations
22.	1–3	-do-	-do-	-do-	-do-
23.	1–3	-do-	-do-	-do-	-do-
24.	0–1	-do-	-do-	-do-	-do-
25.	0–1	-do-	Wasteland without scrub	-do-	-do-
26.	3–10	Very poor	Wheat/groundnut/ maize/mustard	-do-	Agro-forestry
27.	10–25	-do-	-do-	Not suitable	Agro-horticulture
28.	1–3	Moderate	Sugarcane	Highly suitable for mustard/maize	Mustard/maize
29.	3–10	-do-	-do-	-do-	-do-
30.	1–3	Poor	-do-	Highly suitable for wheat/maize	Wheat/maize

4 Results and Discussion

Nine villages, viz., Aneki Hetampur, Puranpur, Mirpur, Garh, Salempur Mahdud, Rajpur, Jhabarpur, Begumpur and Alipur are located in the sub-watershed. The Salempur Mahdud is area-wise the largest village and village Jhabarpur is uninhabited. The roads are mostly unmetalled. They get inundated during heavy rains,

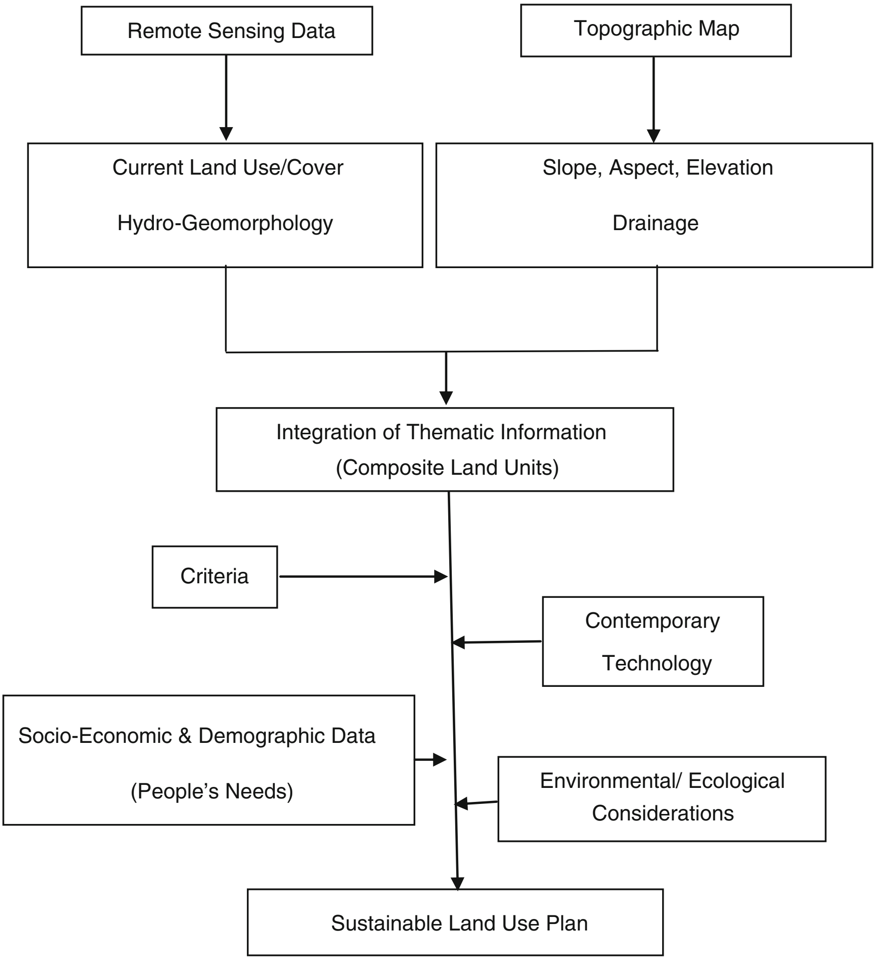


Fig. 3 The methodology (Kushwaha et al. 2010)

making connectivity a problem for the villages. The study area was divided into four major land forms based on the variations in the physiography: (1) Siwalik hills (SH): this unit comprises of moderately to steep slopes of southern Sivaliks, which are covered by trees and shrubs of different densities, (2) Piedmont (P): the piedmont plains having 3–7 % slope and with slight to moderate soil erosion, (3) Alluvial plain (AP): these soils, formed by the river Pathri rao and its tributaries, has very deep and well to poorly-drained soils, and (4) Flood plain (FP); the floods affect the flood plain during rainy season for a short time. These are used for cultivation of wheat, pea, groundnut, etc. The slope is less than 2 % with slight to moderate soil erosion. The physiographic units were further divided into sub-units based on soil types.

Twenty two land use/cover classes were identified through visual interpretation of IKONOS image. Table 2 shows the area under each land use/cover class. Forests were mapped into type and density classes (i.e., <10, 10–40, 40–70 and >70 % canopy cover). The categories mapped included dry deciduous forests (four densities) dense scrub, forest plantation, wasteland with and without scrub, orchards, permanent fallow, agricultural bunds, river and settlements. The land use/cover map is illustrated in Fig. 4. Major land cover in the sub-watershed is forest (46.73 %) followed by Agriculture (25.61 %), wasteland (8.28 %), and plantations (7.47 %). The mapping accuracy was estimated to be 93 %. The mapping accuracy of other input maps was also more than 90 %.

The field survey clearly indicated that there is over-exploitation of groundwater. There has been a steady decline of the groundwater table in the past few years. More than 50 % of the sub-watershed area had poor groundwater potential. Only about 5 % of the area had very good groundwater potential. The ground water situation the sub-watershed is, thus, grim. There is, however, ample scope for

Table 2 Land use/land cover in Pathri rao sub-watershed

S. No.	Land use/land cover	Area (ha)	(%)
1. Forests		2051.99	46.73
1.1	Mixed dry deciduous > 70 %	302.08	6.88
1.2	Mixed dry deciduous 40–70 %	1311.24	29.86
1.3	Mixed dry deciduous 10–40 %	249.37	5.68
1.4	Mixed dry deciduous < 10 %	189.30	4.31
2. Dense scrub		116.25	2.65
3. Forest blank		12.33	0.28
4. Plantations		328.09	7.47
4.1	Forest plantation	236.82	5.39
4.2	Bamboo Plantation	1.46	0.03
4.3	Orchards	89.81	2.05
5. Wastelands		363.81	8.28
5.1	Wasteland with scrub	103.82	2.36
5.2	Wasteland without scrub	259.99	5.92
6. Agricultural land		1124.78	25.61
6.1	Wheat/groundnut/maize/mustard	800.09	18.22
6.2	Sugarcane	275.88	6.28
6.3	Vegetables	2.92	0.07
6.4	Permanent fallow	30.05	0.68
6.5	Fodder	2.30	0.05
6.6	Agricultural bunds	13.54	0.31
7. Water bodies		279.87	6.37
7.1	River	276.77	6.30
7.2	Ponds	3.10	0.07
8. Built-up		102.05	2.32
8.1	Settlements	75.43	1.72
8.2	Mixed built-up land	26.62	0.61
9. Roads		12.38	0.28
Total		4391.54	100.00

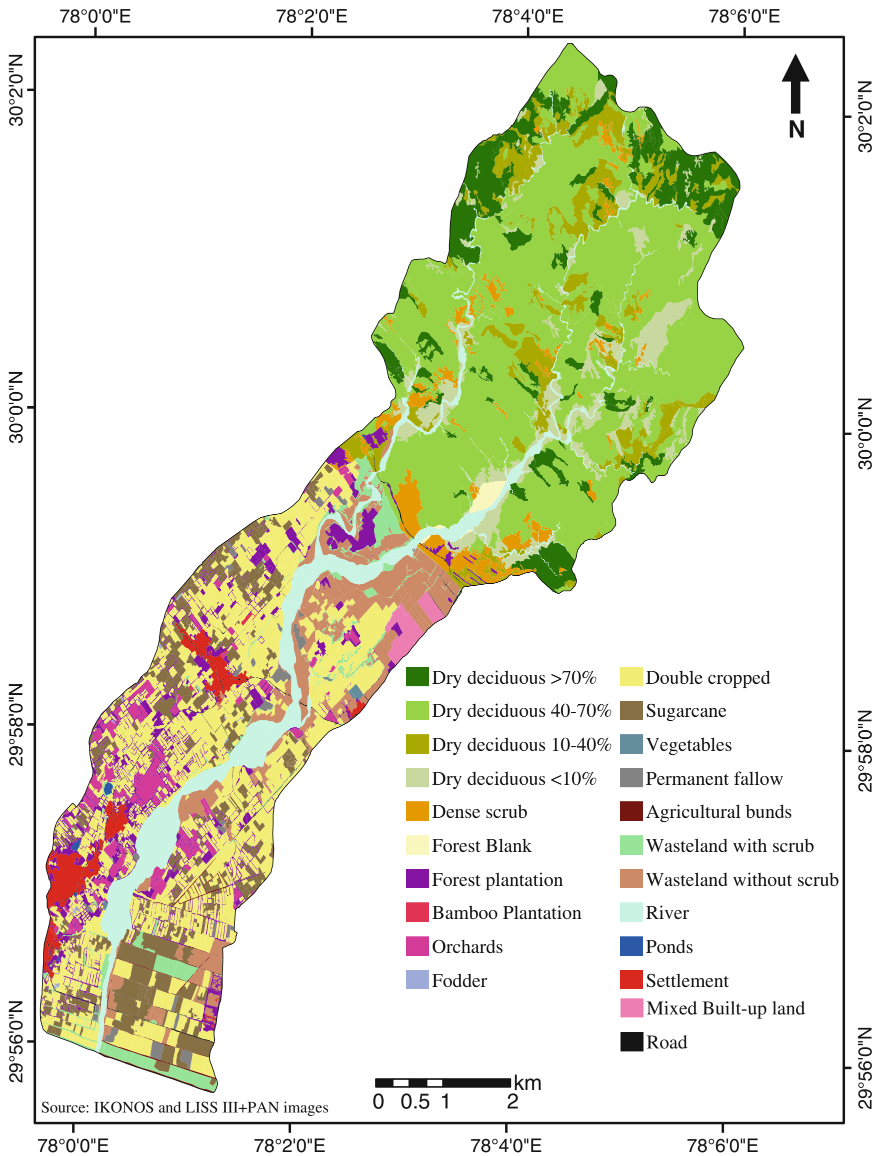


Fig. 4 The land use/land cover

artificial ground water recharge. About 50 % of the area in the sub-watershed is forested. In the remaining area, which comprises the agricultural land, most of the area was found to be highly suitable for mustard and maize. About 4 % of the total area was found unsuitable for growing crops and should, therefore, be put to production of fuel and fodder.

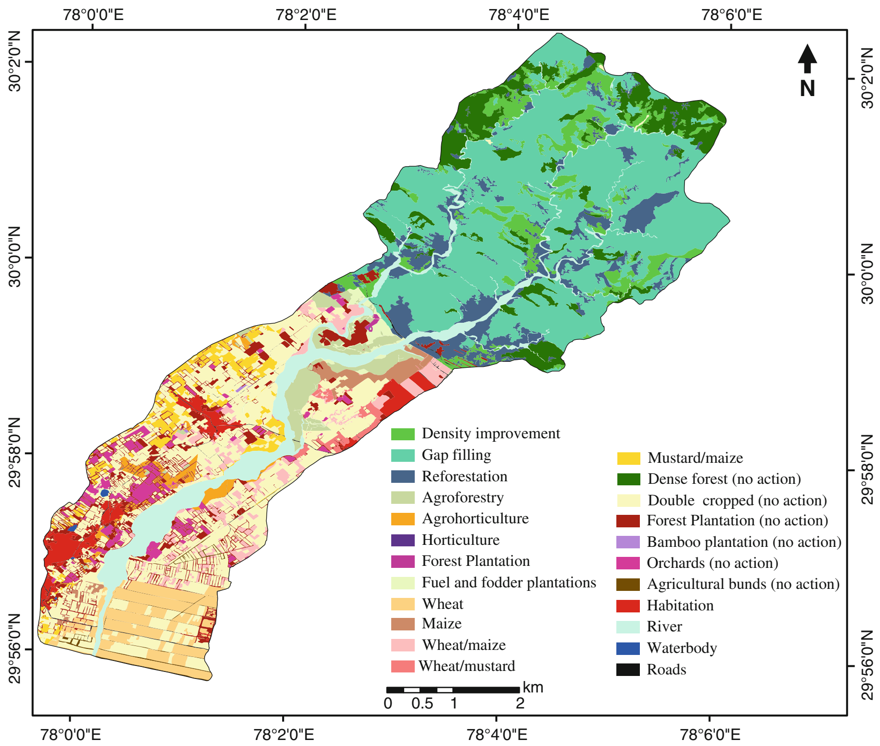


Fig. 5 Sustainable land use plan

The salient features of the recommendations were the suggestion for appropriate crops in areas that are suitable for agriculture but were not put under proper crop. Wastelands with scrub were recommended for fuel and fodder plantations to meet the increasing fodder requirements of the villagers. The forests with less than 70 % density were recommended for gap filling and density improvement. Agroforestry and agro-horticulture were found useful as alternate land use practices. Sugarcane is one of the major crops grown in the agricultural area but given the poor ground water situation and the scarcity of surface water in the area, it is not recommended for the area. Alternate crops such as wheat, maize and mustard, therefore, are suggested for the agricultural fields, where sugarcane is currently grown. Figure 5 depicts shows the recommended land use plan.

In rain-fed areas, rain water harvesting could provide water during lean season for crop production. The rainwater has to be conserved and stored in different storage structures for this purpose. The latter will recharge the groundwater for its use during non-rainy months. The water resources development action plan is aimed at mitigating the problem of water scarcity and riverbank erosion. Suitable sites for percolation tanks, check dams and gabion structures were identified for this purpose. Sites for waterholes, as sources of drinking water for wild animals in forest area, were also identified. Deepening and desilting of existing ponds and tanks was recommended for storage of rainwater during rainy season. There is also need for better road connectivity within the watershed since the existing roads get inundated during heavy rains. There is heavy demand for milk in Haridwar and Dehradun districts and, hence, dairy development could be a sustainable as well as a profitable occupation.

Coupled atmosphere–ocean general circulation models indicate general warming and higher rainfall over India in a greenhouse gas increase scenario, the changes becoming particularly conspicuous after 2040s (Rupa Kumar et al. 2006). The study area in Uttarakhand is also likely to be warmer and wetter together with the increased climate variability. Although a warmer and wetter climate may, in general, enhance production in tropical crops, it may decrease the productivity of crops such as wheat, mustard and potato requiring cool winter months. The enhanced summer rainfall will render the Pathri rao sub-watershed into a substantial risk area in terms of increased soil erosion and the loss of fertile agricultural land. Since Pathri rao is more or less a torrent rather than a perennial river, the study area might as well suffer from other high rainfall-related phenomena such as floods, loss of lives and the property, etc. Efforts, therefore, should be made to put in place a long-term land and water conservation and management policy and strategy by the local government.

5 Conclusions

Sustainable development occurs only when management goals and actions are ecologically viable, economically feasible and socially desirable. The underlying concept of sustainability is that of productivity and quality of the environment and the natural resources. This can be achieved through a set of actions that would help maintain the balance between the exploitation and regeneration/replenishment of the resources within the carrying capacity of the ecosystem. As demonstrated in this study, the geospatial techniques help in generation of a reliable spatial and non-spatial information database. Such a database helps immensely in the efficient and scientific decision making. The present approach of the sustainable land use planning, through use of high resolution data, is expected to provide a model methodology for similar watershed development programmes elsewhere. Since the study area is expected to be warmer and wetter by the end of the 21st century, efforts must be made to put in place a long-term policy and the strategy for land and water conservation and management by the local government.

References

Beinat E, Nijkamp P (1998) Multicriteria analysis for land use management. Kluwer Academic Publishers, Dordrecht

FAO (1989) The state of food and agriculture. Food and Agriculture Organization, Rome

Gugan DJ (1993) Integration of remote sensing and GIS. In: Proceedings of the International Symposium on the Operationalization of Remote Sensing. Enschede: ITC 77–85

Hellden U, Olsson L, Stern M (1982) Approaches to desertification monitoring in Sudan. In: Longman P, Lery G (eds) Satellite remote sensing in developing countries, European Space Agency, Paris, pp 131–144

Kushwaha SPS (1993) Applications of remote sensing in shifting cultivation areas. Technical Report. Abteilung Luftbildmessung und Fernerkundung, Albert-Ludwigs Unisersitaet, Freiburg, pp 23–28

Kushwaha SPS, Subramanian SK, Chennaiah GCh, Ramana Murthy J, Rao SVC, Perumal A, Behera G (1996) Interfacing remote sensing and GIS methods for sustainable rural development. Int J Remote Sens 17(15):3055–3069

Kushwaha SPS, Mukhopadhyay S, Hariprasad V, Kumar S (2010) Sustainable development planning in Pathri rao sub-watershed using geospatial techniques. Curr Sci 98(11):1479–1486

Marble DF, Peuquet DJ, Boyle AR, Bryant N, Calkin HW, Johnson T (1983) Geographic information system and remote sensing. In: Colwell RN (ed) Manual of remote Sensing. American Society of Photogrammetry Falls Church, Virginia

MEA (2005) Ecosystems and human well-being: synthesis. Island Press, Washington DC

Nellis MD, Lulla K, Jensen J (1990) Interfacing geographic information system and remote sensing for rural land use analysis. Photogram Eng Remote Sens 56:329–331

Rao DP, Behera G, Perumal A, Chennaiah GC, Subramanian SK, Kushwaha PS, Murthy YVS, Ramana Murthy G, Rao SVC (1991) Integrated sustainable development planning. Technical Guidelines. National Remote Sensing Agency, Hyderabad

Rupa Kumar K, Sahai AK, Krishna Kumar K, Patwardhan SK, Mishra PK, Revadekar JV, Kamala K, Pant GB (2006) High-resolution climate change scenarios for India for the 21st century. Curr Sci 90:334–345

Tejwani KG (1987) Watershed management in the Indian Himalaya. In: Khoshoo TN (ed) Perspectives in environmental management. Oxford & IBH Publishing Co., New Delhi, pp 203–227

Tideman EM (2000) Watershed management: guidelines for indian conditions. Omega Scientific Publishers, New Delhi

UNCED (1992) United Nations Conference on Environment and Development, 3–14 June, Rio de Janeiro

WCED (1987a) General assembly resolution 42/187, 11 Dec 1987a. Retrieved: 02 08 2011

WCED(1987b) Our common future. Oxford University Press, New York

WSSD (2002) World Summit on Sustainable Development, Johannesburg

Exergy: A Useful Concept for Ecology and Sustainability

Göran Wall and Dilip G. Banhatti

1 Thermodynamics: A Brief History

In early 19th century, the design and construction of steam engines was an important step in the industrial revolution. Efforts to understand working of steam engine quantitatively laid the foundations of the science of thermodynamics. Thermodynamics defines, prescribes how to measure, and relates to each other heat Q, temperature T, internal energy U, pressure p, volume V, density ρ, work W, entropy S and so on, especially as applied to the working substance of a heat engine like steam engine. Of these thermodynamic quantities, Q, U, V and S are called extensive properties since they are proportional to the amount of substance, while T, p and ρ are intensive, as they depend only on the state of the substance, independent of the amount. Work W is a measure of directed motion—of the steam engine piston, for example. By the mid-19th century, widespread application and theoretical analysis led to absolute scale of temperature T, and the absolute zero ($T = 0$ K) on this scale, the coldest possible. By considering changes in the state of a system, and applying the already well developed classical mechanics, first law of thermodynamics extended conservation of mechanical energy to include as a form of energy the heat dQ transferred to the working substance of a heat engine at temperature T.

Thus, for a heat engine, which is defined as a flow process designed to convert heat to work,

$$\mathrm{d}Q = \mathrm{d}U + \mathrm{d}W = \mathrm{d}U + p\mathrm{d}V.$$

Heat dQ transferred to the substance increases its internal energy by dU and moves the piston through volume dV at pressure p, thus, doing mechanical work

G. Wall
Öxbo gård, SE-443 92 Lerum, Sweden

D. G. Banhatti (✉)
School of Physics, Madurai Kamaraj University, Madurai 625021, India
e-mail: dilip.g.banhatti@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_28,

$dW = pdV$. This balance of dQ with $dU + dW$ is a statement of conservation of energy, also called first law of thermodynamics. Work dW must maximize for the greatest motive power, and the maximum possible work is obtained by minimum generation of entropy $dS = dQ/T$. Thus,

$$dQ = TdS = dU + dW.$$

In addition, the entropy of the ambient medium at temperature T_0 surrounding the heat engine also changes, both together increasing in the real irreversible process that takes place. The minimal increase of entropy of system + surroundings leads to maximum work and hence maximum efficiency η of energy conversion from heat to work. This is given by:

$$\eta = 1 - T_0/T,$$

also called Carnot efficiency, independent of working substance. Existence of this limiting efficiency is a statement of second law of thermodynamics, which can also be expressed as

$$dS(\text{system} + \text{surroundings}) > 0.$$

Towards end of the 19th century, empirical thermochemistry was theoretically systematized and incorporated into thermodynamics, thus, including chemical energy in addition to mechanical. This needed the concept of chemical potential μ, an intensive property, in combination with number of moles M of the chemical substance being considered. M is an extensive property. Energy conservation had already been extended from classical mechanics to other areas of physics like electromagnetism. Thermodynamics naturally used electric and magnetic potentials and energies when applied to such systems. Efforts to derive the macroscopic principles of thermodynamics from atomic structure of matter gave rise to statistical physics. As physics developed further into relativistic and quantum realms, these methods and results broadened the scope of thermodynamics further. For a more detailed history relevant for exergy, see articles listed at http://exergy.se, available as pdf files.

2 Exergy

Exergy is formed from Greek ex + ergon, meaning ‘external work’. Some synonyms (from Wikipedia) are: availability, available energy, energy, essergy, utilizable energy, available useful work, maximum (or minimum) work or work content, reversible work, and ideal work. ***Exergy is that part of energy which is convertible into all other forms of energy.*** It represents the potential of a system to deliver work in a given environment. The exergy E of a system of volume V having internal energy U and entropy S, and composed of many substances

i ($i = 1, 2, \ldots$), each amounting to M_i moles (and having chemical potential μ_{0i} in the surroundings), is defined as

$$E = U + p_0 V - T_0 S - \Sigma_i \mu_{0i} M_i = H - T_0 S - \Sigma_i \mu_{0i} M_i$$

relative to surroundings with pressure p_0 and temperature T_0. H is a derived thermodynamic property called enthalpy. For flow in an open steady state system, it includes, in addition, the kinetic energy (per unit mass) $(1/2)\rho v^2$ of the flow of fluid of density ρ and speed v. For the system, the internal energy U is given by

$$U = TS - pV + \Sigma_i \mu_i M_i,$$

where T, p and μ_i refer to properties of the system. Using this expression for U, exergy E can also be written as

$$E = S(T - T_0) - V(p - p_0) + \Sigma_i (\mu_i - \mu_{0i}) M_i.$$

This clearly shows that exergy is measured relative to a reference environment. For more details and relation of exergy to other thermodynamic quantities like Gibbs free energy, Helmholtz free energy, reference may be made to Wall (1977) Exergy—a useful concept within resource accounting, available as a pdf file from http://exergy.se. The same paper applies exergy to evaluate quality of substances like ores and others relative to Earth's average environment. This application of exergy has been developed further over the decades. There is as yet no consensus on its unambiguous use for this purpose—see references (Dalgado 2008; Gaudreau et al. 2009; Wall 1986) at the end for a discussion of this aspect.

3 Human Processes

The concept of exergy has been successfully used in engineering for assessing and improving various types of plants and processes—see references (Seager and Theis 2004; Toledo et al. 2011; Balomenos et al. 2011; Satyanarayana et al. 2010; Dewulf et al. 2001; Itard 2005; Cornelissen 1997; Davidsson 2011; Dubey and Tiwari 2010; Vispute et al. 2010; Reddy et al. 2010; Tyagi et al. 2011; Li et al. 2011). These include energy generation, manufacture of consumer goods, acclimatization units for housing, equipment utilized for agriculture, metallurgical processes to extract metals from ores, and so on. As an example, a thermal power plant is displayed and discussed briefly in Fig. 1.

This figure schematically shows a generic thermal power plant and compares and contrasts the energy and exergy flows through it. The widths of the thick arrows are proportional to the amounts of flow. The energy and exergy losses are clearly seen and can be compared for the same input and output. Arrows which turn downward indicate disposal to the environment. There is no narrowing of arrows in energy flow, while exergy arrow becomes narrow due to exergy loss to

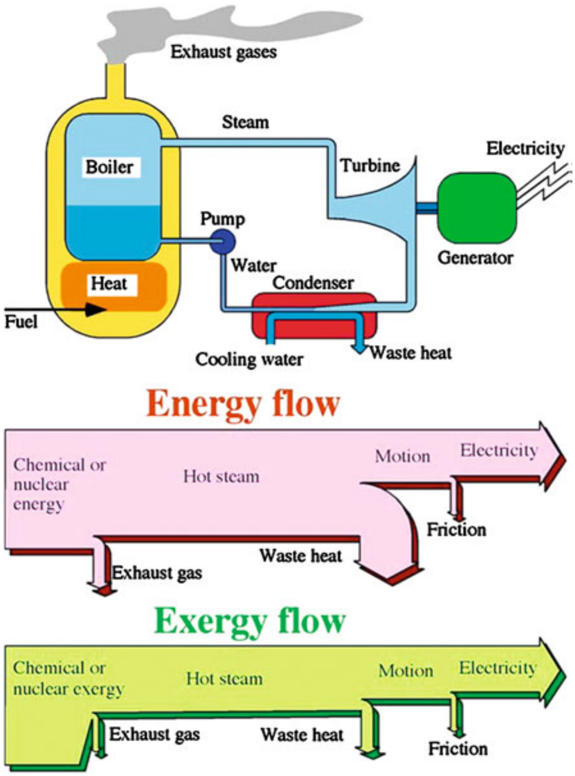


Fig. 1 Energy and exergy flows through a condensing thermal power plant (from G Wall and M Gong 2001 Exergy Int. J. 1(3) 128–45 on exergy and sustainable development—part 1—conditions and concepts—p. 137—cf [http://exergy.se])

irreversibility. Thus, boiler has largest irreversibility. So, improving it will enhance efficiency most.

4 Natural Processes

The grandest natural process consists of (our current understanding of) birth and evolution of universe in big bang theory on the timescale of 14 Gyr. Formation of Earth as a planet of our solar system occurred about 5 Gyr ago. Geological orogenic (i.e., mountain building) cycles occur every 300–500 Myr in Earth's evolution since its consolidation. There are also natural processes of a few Kyr to decades (e.g., nitrogen cycle and other climatic and ecological cycles), down to 1 yr (hydrologic cycle). In the biosphere, there are processes over millennia, centuries, decades, years, months, weeks, days and shorter, down to milliseconds, and perhaps even shorter cellular (sub)-processes in biological cells.

Exergy to drive all natural processes on Earth has its origin in sunlight. This is illustrated in a series of schematic diagrams and figures, each with brief comments (Fig. 2).

Fig. 2 The Sun–Earth–Space system (from Göran Wall preprint 2011 Exergy and sustainable development p. 7—cf [http://exergy.se])

Solar energy flows to Earth and out again without loss, while exergy is partially lost and partially stored via mainly the process of photosynthesis, while matter undergoes upheaval on many space and time scales from geologic to much smaller. Many bio- and geo-processes are involved (Fig. 3).

Although all energy incident on Earth from the Sun is radiated away, quality of incoming energy, measured by its exergy, is much higher than what is radiated away. Thus, incident energy equals radiated energy, but exergy content of incident energy is larger than the exergy content of radiated energy. Many symbiotic interconnected systems and processes are involved in the details. Over the last few decades, these have been described in detail in an overarching concept named Gaia after ancient Greek goddess of Earth. For details, the reader is referred to James Lovelock's book (1988, 1995 Norton) *The Ages of Gaia*: *a biography of our living Earth*. The relevance of such whole Earth studies for mitigating rapidly accelerating climate change cannot be overemphasized. We also refer readers to presentations at another Humboldt Kolleg held in Salem (Tamil Nadu, India) in September 2011 on a related theme abbreviated *Earth Future*.

Figure 4 shows spectrum of sunlight, i.e., intensity as a function of wavelength. The dotted line shows ideal sunlight, the curve closest to it shows sunlight incident

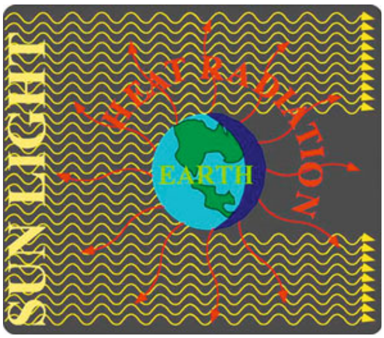


Fig. 3 Short-wave sunlight inwards and long-wave heat radiation outwards (from Göran Wall preprint 2011 Exergy and sustainable development p. 8—cf [http://exergy.se])

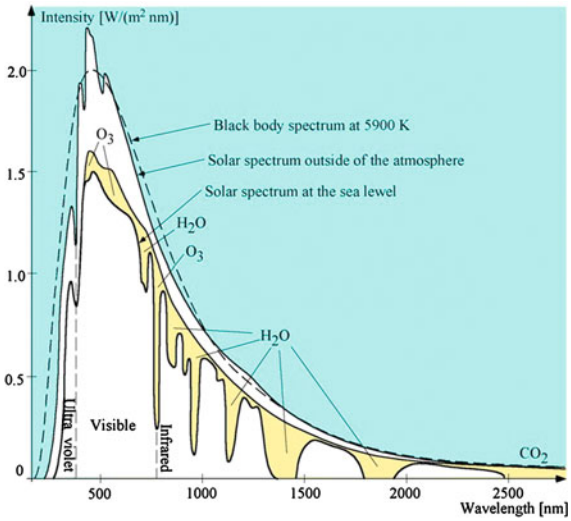


Fig. 4 The intensity of sunlight at the surface of the Earth with respect to wavelength (from Göran Wall preprint 2011 Exergy and sustainable development p. 8—cf [http://exergy.se])

on top of Earth's atmosphere, while other curves show absorption bands due to various constituents of Earth's atmosphere, as labelled.

Figure 5 presents a representation of energy audit of sunlight incident on Earth and partially used and stored, before some part is radiated away. This has remained more or less steady over aeons of time since Earth acquired an oxygen dominated atmosphere some 3 Gyr ago. Evidence for this near constancy comes from paleogeochronological indicators of various kinds as gauged by radioactive dating methods.

A representation of exergy audit of Earth is shown in Fig. 6.

There is no unanimity if materials can be assigned exergy, nor agreement on what should be taken as the reference state for exergy calculations. Even then, such evaluations can be helpful in thinking globally about Earth matters. At the

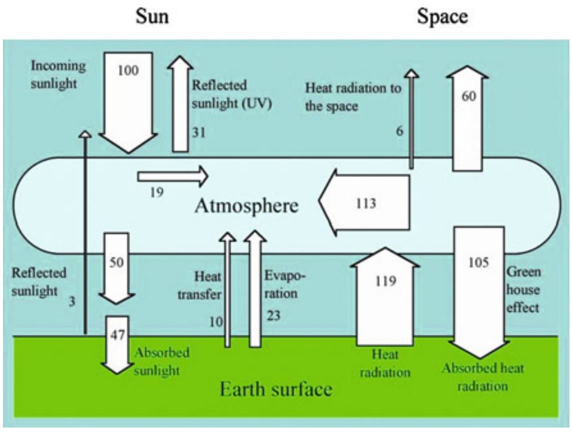


Fig. 5 The energy flows between the Sun, the atmosphere, the surface of the Earth and space. Numbers are in percent of incoming sunlight (from Göran Wall preprint 2011 Exergy and sustainable development p. 9—cf [http://exergy])

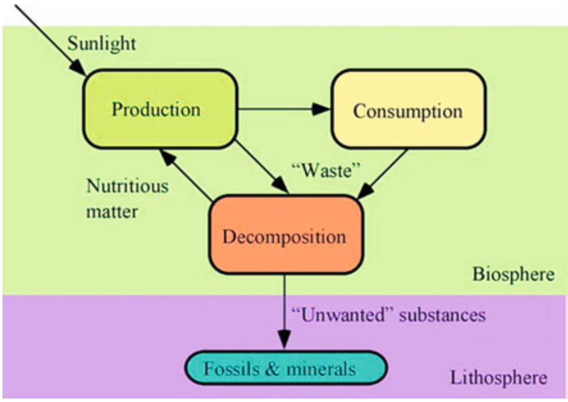


Fig. 6 The global exergy flows on the Earth, where 1x is equal to 1.2 × 10^{13} W (from Göran Wall preprint 2011 Exergy and sustainable development p. 10—cf [http://exergy.se])

present juncture in human history, such thinking and proactive measures are very essential for mitigating accelerated climate change.

Figure 7 is a schematic diagram for movement of matter on Earth. Bio- and geo-processes on many different time and space or size scales are involved in the details behind this sketch.

The next few sketches or diagrams indicate, by classifying resources of Earth, how human use of these has been unsustainable after industrial revolution ushered in by steam engine, and accelerated very rapidly of late (Figs. 8, 9 and 10).

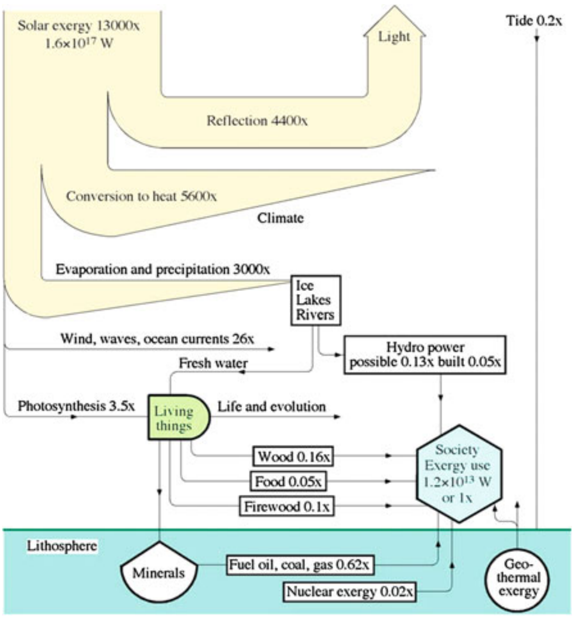


Fig. 7 The circulation of matter in nature is powered by sunlight (from Göran Wall preprint 2011 Exergy and sustainable development p. 11—cf [http://exergy.se])

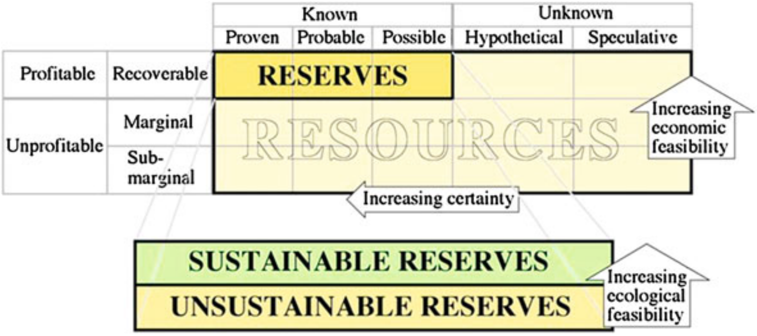


Fig. 8 Definition of resources and reserves (from Göran Wall preprint 2011 Exergy and sustainable development p. 18—cf [http://exergy.se])

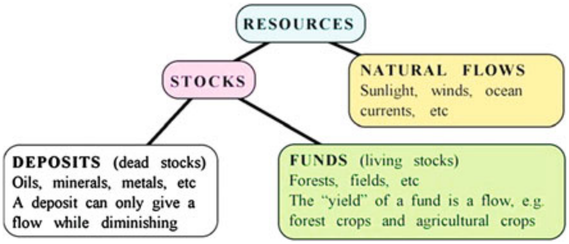


Fig. 9 Classification of resources (from Göran Wall preprint 2011 Exergy and sustainable development p. 18—cf [http://exergy.se])

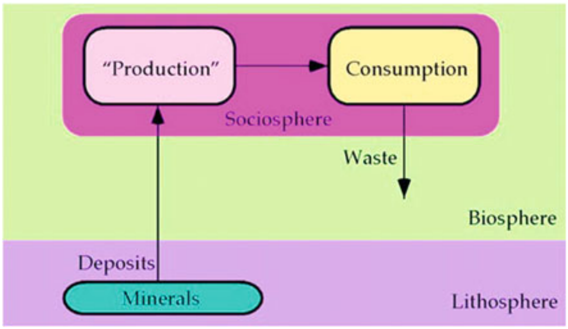


Fig. 10 Society takes deposits from nature and returns wastes (from Göran Wall preprint 2011 Exergy and sustainable development p. 19—cf [http://exergy.se])

Current unsustainable pattern of human societal use of vast but limited natural resources (Figs. 9, 10 and 15). The deposits take aeons to build up, but are used up within centuries at most, at current rate of use.

Figure 11 may be taken to be a brief description of James Lovelock's Gaia concept extended to our times. The sociosphere affects human decisions on use of Earth's resources which may alter irretrievably by the other spheres. Geologists have proposed that this effect is now large enough to be formalized in naming the present geologic epoch Anthropocene. Whether the biosphere of the far distant future will have place for humanity is a moot question. The same concept is illustrated below somewhat differently (Fig. 12).

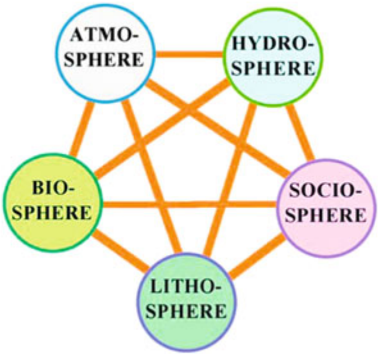


Fig. 11 The Earth as five spheres in mutual interaction [http://exergy.se]

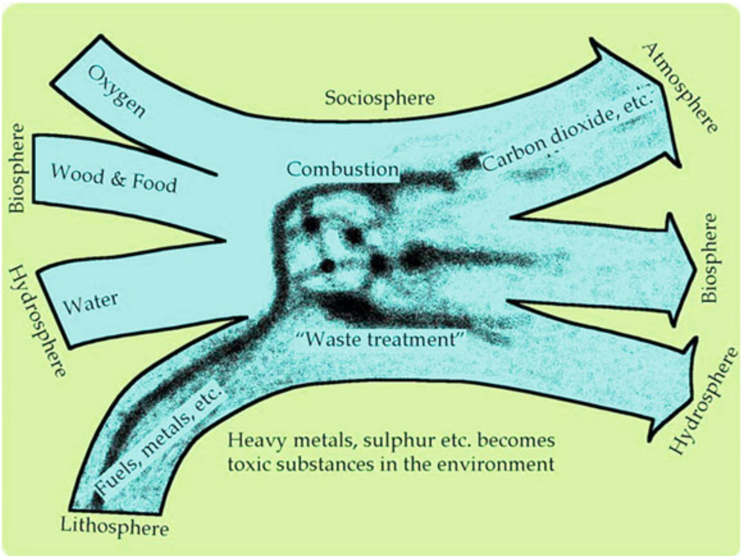


Fig. 12 Resource depletion and environmental destruction are two sides of the same problem (from Göran Wall preprint 2011 Exergy and sustainable development p. 20—cf [http://exergy.se]). Two diagrams below illustrate that traditional farming was sustainable, while modern industrial farming has irretrievably upset Earth's nitrogen cycle balance

Very clear dead zones exist near many coasts on Earth, especially as visible from satellites. Here, the only biotas are algae feeding on nitrogenous effluents coming into sea from land via surface rivers as well as underground streams. This toxicity has been a result of decades of using nitrogenous fertilizers for short-term gains in produce (Fig. 14). Before this, agriculture was sustained by age-old experience of organic farming, and nitrogen cycle was in balance (Fig. 13).

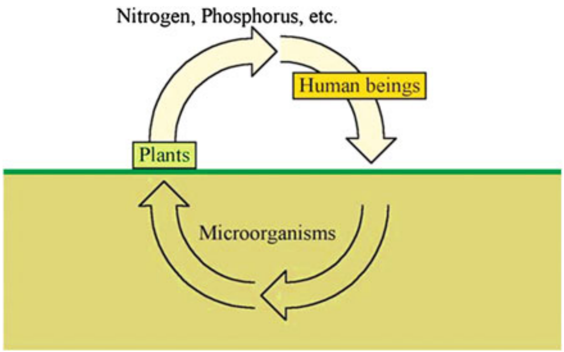


Fig. 13 Traditional farming with recycling of matter in order to be sustainable (from Göran Wall preprint 2011 exergy and sustainable development p. 30—cf [http://exergy.se])

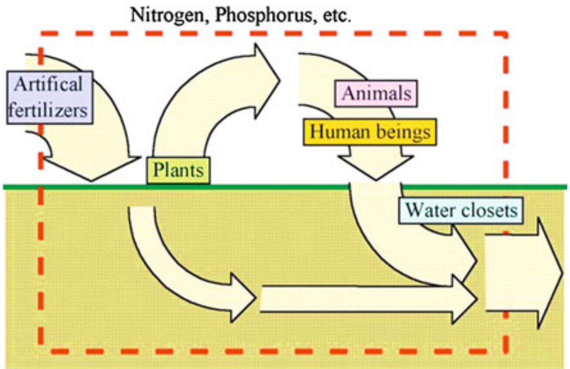


Fig. 14 Modern industrial farming with artificial fertilizers and water closets (from Göran Wall preprint 2011 exergy and sustainable development p. 31—cf [http://exergy.se])

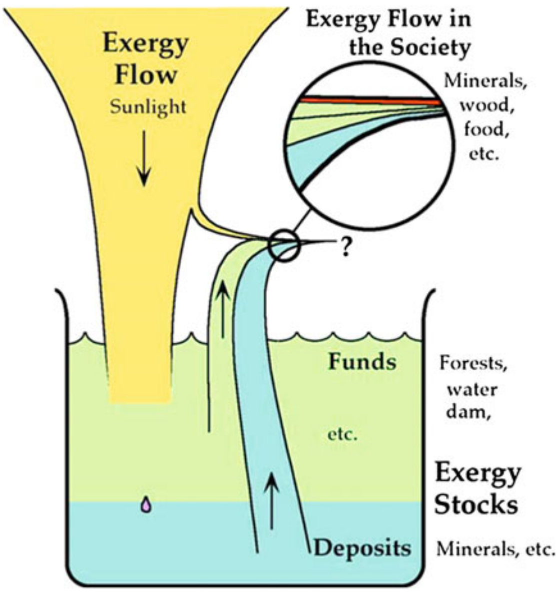


Fig. 15 The exergy flow from the Sun, and the exergy stocks on Earth create the resource base for human societies on Earth (from Göran Wall preprint 2011 exergy and sustainable development p. 21—cf [http://exergy.se])

5 Applicability of Exergy to Ecology and Sustainability

The application of exergy analysis for ecological questions and sustainability matters has just begun. Figure 15 depicts a combined unified gross picture of exergy flow from Sun to Earth and its use in various natural and human processes. Please see references (Ukidwe 2005; Ukidwe and Bakshi 2007, 2005; Zhang et al. 2010; Mayer 2008; Gutowski et al. 2009; Hepbasli 2008; Casillas and Kammen 2010; Coatanéa et al. 2006; Dewulf et al. 2008; Hau and Bakshi 2004; Rosen and Dincer 2001; Jørgensen 2006) for specific examples. One important point made in Ref. (Hau and Bakshi 2004) is that instead of categorizing resources as renewable or non-renewable, it is more practical to consider renewability over daily, short-cycle (say, year), long-cycle (a decade) or even larger geological timescales (the largest possible on Earth).

6 Conclusion

In this article, after giving a brief history of thermodynamics and presenting its essential concepts, exergy is introduced, defined and elaborated a little. An example of its use in a thermal power plant is then displayed. Further, as a pictorial survey of the exergy concept applied to natural processes on Earth, many figures and diagrams from [http://exergy.se] are presented, along with a commentary on each.

Acknowledgments We are grateful to organizers of Bengaluru Humboldt Kolleg for allowing the second author (DGB) to present this paper. Finally, DGB recalls fondly Prof B B Parulekar of IIT Bombay Mechanical Engineering Department for teaching Refrigeration and Air Conditioning very fruitfully using the exergy concept. In fact, it was this strong memory which reminded him of exergy as very appropriate for today's world, and he was pleasantly surprised to find that we are among many friends with this same consideration!

References

Balomenos E, Panias D, Paspaliaris I (2011) Exergy analysis of extractive vacuum metallurgy—sustainability prospects. Preprint

Casillas E, Kammen DM (2010) The energy-poverty climate nexus. Science 330:1181–1182

Coatanéa E, Kuuva M, Makkonnen PE, Saarelainen T, Castillón-Solano MO (2006) Analysis of the concept of sustainability: definition of conditions using exergy as a uniform environmental metric

Cornelissen RL (1997) Thermodynamics and sustainable development: the use of exergy analysis and the reduction of irreversibility, PhD thesis. University of Twente, Enschede

Dalgado V (2008) Exergy evolution of the mineral capital on Earth. PhD thesis, University of Zaragoza, Spain

Davidsson S (2011) Life cycle exergy analysis of wind energy systems, thesis. Uppsala University, Uppsala

Dewulf J, van Langenhove H, Dirckx J (2001) Exergy analysis in the assessment of the sustainability of waste gas treatment. Sci Total Environ 273:41–52

Dewulf J, van Langenhove H, Dirckx J (2008) Exergy: its potential and limitations in environmental science and engineering. Environ Sci Tech 42(7):2221

Dubey S, Tiwari GN (2010) Energy and exergy analysis of hybrid photovoltaic/thermal solar water heater. J Renew Sustain Energy 2(043):106

Gaudreau K, Fraser RA, Murphy S (2009) The tenuous use of exergy as a measure of resource value or waste impact. Sustainability 1:1444–1463

Gutowski TG, Sekulic DP, Bakshi BR (2009) Preliminary thoughts on application of thermodynamics to development of sustainability criteria. IEEE

Hau JL, Bakshi BR (2004) Expanding exergy analysis to account for ecosystem products and services. Environ Sci Tech 38:3768–3777

Hepbasli A (2008) A keyreview on exergetic analysis and assessment of renewable energy resources for sustainable future. Renew Sustain Energy Rev 12:593–661

Itard L (2005) Analysis of exergy consumption of 4 types of buildings. Undated preprint

Jørgensen SE (2006) Eco-exergy as sustainability. WIT, Southampton, NY, p 220

Li X, Zanwar A, Jayswal A, Lou HH, Huang Y (2011) Incorporating exergy analysis & inherent safety analysis for sustainability assessment of biofuels. Ind Eng Chem Res 50:2981–2993

Mayer L (2008) Ecologically based approaches to evaluate the sustainability of industrial systems. Int J Sustain Soc 1(2):117–133

Reddy VS, Kaushik SC, Tyagi SK, Panwar NL (2010) An approach to analyse energy and exergy of thermal power plants: a review. Smart Grid Renew Energy 1:143–152

Rosen MA, Dincer I (2001) Exergy as the confluence of energy, environment and sustainable development. Exergy Int J 1(1):3–13

Satyanarayana I, Gupta SKS, Govinda Rajulu K (2010) Second law analysis of supercritical Rankine cycle. Int J Energy 4(1):66–78

Seager TP, Theis TL (2004) A taxonomy of metrics for testing the industrial ecology hypothesis and application to design of freezer insulation. J Cleaner Prod 12(8):865–875

Toledo CEE, Mejia LA, Rayle BMR (2011) On exergy and sustainable development: some methods to evaluate energy and non-renewable resources waste using some plastics. Preprint

Tyagi VV, Pandey AK, Giridhar G, Bandyopadhyay B, Park SR, Tyagi SK (2011) Comparative study based on exergy analysis of solar air heater collector using thermal energy storage. Int J Energy Res 36(6):724–736

Ukidwe NU(2005) Thermodynamic input output analysis of economic and ecological systems for sustainable engineering, PhD thesis. Ohio State University, Ohio

Ukidwe NU, Bakshi BR (2003) Accounting for ecosystem contribution to economic sectors by thermodynamic input output analysis—part 1. Approach. Undated preprint

Ukidwe NU, Bakshi BR (2007) Industrial and ecological cumulative exergy consumption of the United States. Energy 32:1560–1592

Vispute TP, Zhang H, Sanna A, Xiao R, Huber GW (2010) Renewable chemical commodity feedstocks from integrated catalytic processing of pyrolysis oils. Science 330:1222–1228

G. Wall (1977) Exergy a Useful Concept within Resource Accounting, Report No. 77-42, 58 p., TF http://www.exergy.se/ftp/ex77c/pdf (updated with some color figures).

Wall G (1986) Exergy: a useful concept. PhD thesis, University of Göteborg, Gothenburg

Zhang Y, Baral AA, Bakshi BR (2010) Accounting for ecosystem services in life cycle assessments. Environ Sci Technol 44:2624–2631

A Model Based Method to Assess Climate Change Impacts on Rain-Fed Farming Systems: How to Analyze Crop-Yield Variability?

Benjamin Stuch, Rüdiger Schaldach and Jan Schüngel

1 Introduction

Since the introduction of the Millennium Development Goals (MDG) during the United Nations Millennium Summit in 2000, large efforts have been made to eradicate extreme poverty and half the number of starving people within the time span from 1990 to 2015 (to no more than 420 million). Nonetheless, statistics outline an increase in the number of food in-secured people with an estimated historical high of 1.02 billion through the economic crises in 2009 (FAO 2009). This development raises the alarm that the food security goal might not be accomplished. Climate change is expected to have spatially diverse impacts on future farming systems and can further challenge food security worldwide. In many parts of the world climate change already has been observed with notable changes in the crop production since 1980 (Lobell et al. 2011).

Several studies have been conducted to simulate climate change impacts on agricultural systems (e.g., Parry et al. 2005; Tubiello and Fischer 2007). Most of these studies emphasized food production without considering other aspects of food security (Schmidhuber and Tubiello 2007; Wood et al. 2010) such as food stability. At the same time, previous studies regularly analyzed climate change patterns at slow rates of change (mean values), but vulnerabilities to annual climate fluctuations have rarely been considered (for example Alcamo et al. 2008). Agricultural yields are highly vulnerable to climate fluctuations (Lobell et al. 2011; Schlenker and Roberts 2009; Tubiello et al. 2007). Increase in climate variability under climate change bears a high potential risk for temporal food production shortfalls and strongly affects food security and in particular food stability.

B. Stuch (✉) · R. Schaldach · J. Schüngel
Center for Environmental Systems Research—CESR, Kassel University,
34109 Kassel, Germany
e-mail: stuch@usf.uni-kassel.de

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_29,

The hypothesis is that climate change impacts are underestimated when relying only upon analysis of mean values. Research activities, policy making and project planning shall, therefore, put greater emphasis on food stability and the impacts of year-to-year crop yield variability in order to better guide agricultural development and climate change adaptations.

The focus of this study lays on a methodological development to better assess impacts of climate variability on agricultural systems. The method is designed to spatio-temporally analyze annual fluctuations in food production that could promote food-insecurity due to year-to-year variability in crop yields. Hence, this approach could complement existing, as well as future agricultural risk assessments, in order to better analyze climate change impacts on food stability. Thereby, the method can contribute to the food system concept (Ericksen 2008; Ericksen et al. 2009) due to the more comprehensive approach in assessing risks to food production systems.

In order to drive a dynamic impact model for assessing potential crop yield responses to climate change, we use the IPCC SRES A2 emission scenario (Nakicenovic and Swart 2000) to drive the IPSL-CM4 (Le Clainche et al. 2001) global circulation model. From the computation, we generate indicators that identify those agricultural regions threatened mostly by negative climate impacts as well as regions that can benefit from climate change. Finally, we analyze how potential developments in crop yield deviations correspond with potential developments in crop yield means. We test if climate change assessments could misinterpret impacts on agricultural systems, when only focussing on mean value analysis and additionally highlight the applicability of this new methodology in assessing changes in the year-to-year variability of food production.

2 Method

The aim of the method is to obtain a climate sensitive indicator that is suitable for scenario computations and spatio-temporal comparisons of potential climate change impacts. Instead of analyzing the climate parameters directly, the parameters are used as input variables for a dynamic crop model. Thereby, the monthly climate variables (temperature, precipitation, solar radiation) are bundled and aggregated to one crop specific annual yield variable (in t/ha). The indicator only encompasses those climate developments that are significant to plant physiological processes. It also takes into account potential buffer effects such as soil moisture as well as seasonal aspects in regard to plant maturity cycles. Therefore, the indicator considers agricultural droughts rather than climatic or hydrological droughts and directly assesses potential risks to rain-fed farming systems.

2.1 Study Scope

We apply and test the indicator based on maize yield patterns for continental Africa, although the methodology can be applied worldwide and for all crop types. Africa is, by far the continent with the highest rate of poverty and malnutrition in the world relatively to its total population (FAO 2011a). The farming system is predominantly characterized as low input, rain-fed system. In Sub-Sahara Africa only half of the potential maize yields are achieved (World Bank 2007) and coping capacities to climate change are low. Studies on yield fluctuations can, therefore, help to identify regions sensitive to changing climate dynamics. Since Africa's agriculture is underpinned by smallholders (Liverman and Kapadia 2010), studies on yield variability not only encompass food production, but also food access and food stability. Research on changing crop yield variability is, therefore, relevant to help achieve food security. Maize is a highly relevant crop for promoting food security. For example, it was the dominant crop type in Africa and globally among the top three crop types in terms of cultivated areas in 2009 (FAO 2011b).

For the purpose of this study, Maize, as a C4 crop, is also preferred due to its lower atmospheric CO_2 sensitivity compared to C3 crops such as wheat or rice (see Fig. 1). Several studies have stressed the CO_2 fertilization effect as well as associated uncertainties (e.g., Leakey 2009; Lobell and Field, 2008). Others highlighted the negative effect of increasing surface O_3 concentrations on crop yields due to climate change (Feng and Kobayashi 2009; Van Dingenen et al. 2009). The positive effect of CO_2 might be neutralized by the negative effect of O_3. By analyzing maize yields, this study reduces systematic uncertainties caused by the limited understanding of future CO_2 emissions and, additionally, reduces model uncertainties due to crop model structure and parameterization (regarding CO_2 effects). Nonetheless, crop responses to CO_2 concentrations entail significant uncertainties in global change research and need to be further clarified.

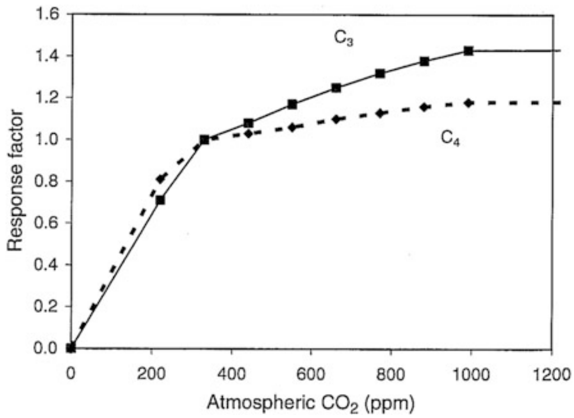


Fig. 1 Responses to atmospheric CO_2 assumed in the CSM-CERES models for radiation use efficiency of C3 and C4 crops (White and Hoogenboom 2010)

2.2 Climate Data and Time Frame

This study is based on two time intervals, a baseline period from 1971–2000 and a scenario period from 2041–2070 (the 2050s). Baseline computation depends on the climate input from the Climate Research Unit (CRU TS2.1—Mitchell and Jones 2005). These climate parameters are based on gathering station data that is interpolated to a global 0.5° grid. Climate input for the scenario period is taken from the IPSL-CM4 (Le Clainche et al. 2001) Global Circulation Model (GCM). The climate simulation is conducted with the IPCC SRES A2 emission scenario (Nakicenovic and Swart 2000).

Climate change impact assessments are constrained by the climate scenario input. They lack accuracies due to high uncertainties (Stainforth et al. 2005). Particularly, the variability in precipitation is difficult to project. Therefore, GCM raw data requires corrections before they can be applied in advanced impact models (Hansen et al. 2006; Piani et al. 2010). Two correction methods have been available. The so called bias-correction method as well as the delta change approach.

The bias-correction method corrects climate model output to produce internally consistent fields that share the same statistical intensity distribution as observations (Piani et al. 2008). The advantage of this correction method is that the year-to-year variability in the scenarios is delinked from the variability of the reference period. Bias-corrected scenario data are rarely accessible on the global scale (e.g., from the WATer and Global CHange project WATCH, Piani et al. 2008) due to the time intensive analysis. Therefore, global agricultural impact studies based on bias-corrected climate data are hardly ever available.

In contrast, the delta change approach is regularly applied in global change assessments. It adjusts the simulated climate parameters to historical measured climate dynamics. For temperature, only the delta of mean changes (between the 2050s and the baseline) are added to the baseline parameter course. Consequently, the mean values change, but the future month-to-month variability remains the same. The delta of the precipitation parameter is multiplied to the baseline value. Thus, for precipitation, the variability course remains the same, but the amplitudes changes proportional to the delta (see Eqs. 1 and 2). An exception to the multiplication of the baseline value to the delta occurs when present day precipitation is close to zero (<1 mm). In this case, the respective precipitation delta is added as described for temperature.

In our study, we correct the climate scenario data with the delta change methodology. The disadvantage is that the temperature course in the 2050s shares the same standard deviation as for the baseline. The temperature variability is, therefore, not assumed to change in terms of absolute deviation but in deviation relatively to the mean. However, the case for precipitation is different. Due to the delta multiplication, the two periods share the same standard deviation relatively to their means but not in terms of absolute deviations. Solar radiation is set constant to historic observations. Reference data for applying the delta change approach is obtained from CRU TS2.1. The functions of the applied delta change approach for temperature and precipitation are as follows:

$$Tcor(y, m) = Tpast + (Tscen - Tbase) \quad (1)$$

$$Pcor(y, m) = Ppast \times \frac{Pscen}{Pbase} \quad (2)$$

where:

T	Climate variable (temperature)
P	Climate variable (precipitation)
Cor	with delta change corrected scenario data
Past	baseline, based on climate observations (statistics)
Scen	modelled scenario for a future period (GCM raw data)
base	modelled baseline

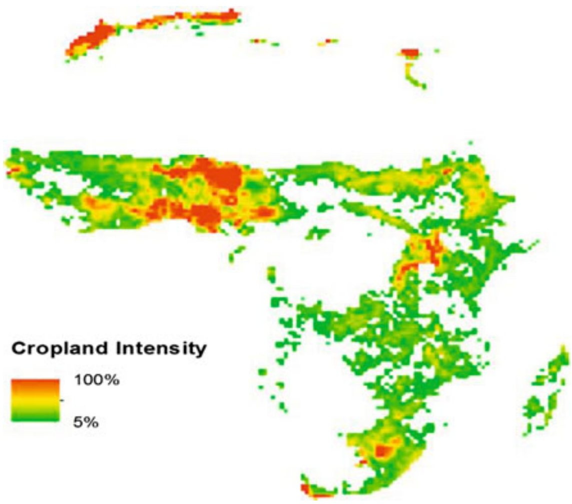
Over all cells of our study scope in Africa, the corrected climate data show an average increase in temperature of 2.6 °C and an average increase in precipitation of 36 mm between the baseline period and the 2050s.

2.3 Crop Yield Computation

We use the dynamic vegetation model Lund Potsdam Jena managed Land (LPJmL) (Bondeau et al. 2007) to compute potential yield developments on a global grid. The simulation is conducted for all cells that have been suggested by Ramankutty and Foley (1999) to have more than 5 % cropland intensity (see Fig. 2 for the intensity map of the year 2000). We utilize this crop intensity data set as it provides reconstructed information about historic cropland intensities in annual time steps. We calculated potential yields for all cells independently from the actual maize growing regions for each year of the baseline period. This annual information is required for the baseline computation of our validation in Sect. 2.5.

GCMs regularly constrain advanced crop modelling exercises by spatial and temporal scales as well as the dynamic, non-linear relationship between meteorological variables and crop responses (Hansen et al.2006). This is, in particular, for detailed crop models that are developed for farm scale applications. In contrast, the LPJmL model is a biogeochemical consistent, dynamic and flexible, parameter-scarce representation of global agriculture, that uses the crop functional type concept for global and century scale application (Bondeau et al. 2007). The model operates on a spatial resolution of 0.5° and utilises monthly climate input. It spatio-temporally corresponds well with the available GCM model outputs. Key climate variables are temperature, precipitation and solar radiation. We generate indicators from the LPJmL crop yield computation and validate their applicability for embracing year-to-year dynamics in Sect. 3.1. The daily weather generator (which

Fig. 2 Crop land intensity (Ramankutty and Foley 1999)



basically is a function to randomly distribute monthly precipitation) is not applied to enable reproduction of the model results. Detailed model validation, e.g., comparisons of mean yields with FAO statistics or single crop functional processes with field observations, can be reviewed in (Bondeau et al. 2007).

2.4 Indicators to Measure Year-to-Year Yield Fluctuations

The standard deviation (STD) and the coefficient of variation (CV) are suitable statistical parameters for the analysis of average year-to-year variability over a period of time. We test both parameters for their suitability to encompass changes in the year-to-year variability of maize yields. The assessment is carried out on the grid cell level.

$$STD = \sqrt{VAR(X)} \tag{3}$$

$$CV = \frac{STD}{mean} \tag{4}$$

The indicators are simple statistical parameters that are generalized and, therefore, appropriate for global scale application. While the STD describes the mean variability in absolute values, the CV analyzes these deviations relatively to its mean.

In our study, the average variability (STD and CV) is analyzed for time slices of 30 years, rather than between two specific years. The developments of maize yields are assessed relatively to the baseline. Both reduce sensitivities to potential errors such as systematic uncertainties, model uncertainties or the influence of single weather events. Thereby, we obtain average long-term climate signals that also increase the indicators robustness for scenario analysis.

The disadvantage of the CV is that it lacks accuracies for allowing comparisons between two time periods. This is caused by the delta change application for correcting the climate scenarios. For temperature, the mean values change from the baseline to the 2050s, but the standard deviation remains the same. An increased mean value causes a decrease in the CV after dividing the STD by its mean. The CV tends to have a negative correlation to the mean value developments. This methodological disturbance makes it difficult to properly interpret the obtained indicator signals. We, therefore, do not apply the CV for spatial analysis between two periods of time when the underpinning climate input is corrected by the delta change approach. However, analyses within one time slice are not negatively influenced. In this respect, we use the CV for validating the model computations with FAO statistics (see Sects. 2.5 and 3.1). For comparisons between two periods of time, we alternatively suggest using the STD. The advantage of the STD compared to the CV is that it is neutral regarding the above described negative correlation since the STD is not disturbed by changing mean values. We analyze the STD of the scenario period relatively to the baseline to obtain reliable proxies for potential changes in the year-to-year yield variability. Thereby, it provides useful signals for assessing climate change impacts on potential future crop yield fluctuations. The disadvantage of the STD is that it does not allow relative comparisons between regions at one period of time. For example, one grid cell has a slightly higher STD than the neighbouring cell, but their mean values may be double of that of the neighbouring cell. Comparing absolute deviations independently from mean values can mislead the impact analysis.

Since we use the LPJmL output, three climate parameters are influencing the plant growth in the model equation. The plant growth limiting parameter restricts the plant growth dynamics. When the delta of one climate parameter overshoots a model threshold (e.g., in regard to plant maturity performance), the crop yield indicators do not further correspond with that climate input beyond the threshold. Furthermore, if the model structure describes plant development with logistic functions (what the LPJmL model does), rather than applying linear functions, the crop growth and the indicator signals do not linearly correspond with the climate input dynamics. Changes between the set of climate input variables positively promote changes in the crop yield deviations.

2.5 Indicator Validation and Model Plausibility Test

We test the indicator's correspondence with independent data sources for the baseline period in two ways. At first, we analyse the general agreement between modelled CV and statistical CV. Secondly, we confirm the sensitivity of the model to the precipitation climate input. Without data constraints, we would select time series of annual yield observations on a cell level and compare them with the according modelled grid cell values. Since such data is not available to the authors, we utilize FAO country statistics. The FAO statistics have the advantage of being available for time series analysis for almost all countries in the world. Therefore, this quick validation assessment can also be transferred to the global context.

To enable comparison of the modelled CV (cell level) and the FAO CV (national level) we aggregate the annual model results to national average yields (see Eq. 5). In this regard, the potential crop yield from the LPJmL computation is multiplied with the according cropland intensity data from Ramankutty and Foley (1999) for each year of the baseline period. The obtained production data is then aggregated to the national scale by summing up all cells of a country. At the same time, we aggregate the cropland area of all cells per country and year. These calculations are done for all years within the baseline period. To finally obtain weighted national mean yields per year, we divide the country's production by the country's cropland area. In this regard, cells with higher cropland intensity are higher weighted in the national mean calculation than cells with lower cropland intensities (see equation below). On the basis of this weighted national mean yield series, we calculate the long term mean, the STD and the CV.

$$Y = \frac{\sum_{k=1}^{n} crop\text{int}_k * area_k * pot\text{yield}_\text{k}}{\sum_{k=1}^{n} crop\text{int}_k * area_k} \tag{5}$$

where:

Y	weighted mean yield per country and year [t/ha],
n	number of cells per country,
$crop\text{int}_k$	percent cropland per cell [%],
$area_k$	total cell area [ha],
$pot\text{yield}_\text{k}$	potential crop yield per cell [t/ha].

In our validation, we focus on the indicator's and model's ability to encompass average year-to-year deviations relatively to the according mean values, rather than on absolute deviations. For that purpose, we apply the CV indicator (and not the STD), as the CV is not influenced by potential mismatches between the absolute annual yield values of LPJmL and FAO. This validation procedure is particularly important, since the LPJmL model tends to overestimate maize yields in the tropics (Bondeau et al. 2007). In the later scenario analysis, we calculate the changes of the STD relatively to the baseline value. Thereby, also the scenario analysis emphasizes relative changes and not absolute changes in the deviation. Under this precondition, the introduced CV indicator validation is also valid for the later STD indicator application.

Additionally, we implement a plausibility test to prove the models sensitivity to the precipitation data input. In Sect. 3.1, we plot the precipitation series along with the maize yield series to visualize correlations as well as potential errors such as buffer effects. Both data are nominalized with their means equal to one. The precipitation data ($preci_k$) is weighted accordingly to the mean yields weighting (see Eq. 6).

$$X = \frac{\sum_{k=1}^{n} crop\mathrm{int}_k * area_k * preci_k}{\sum_{k=1}^{n} crop\mathrm{int}_k * area_k} \quad (6)$$

where:

X weighted mean precipitation per country and year

$preci_k$ precipitation value [mm]

2.6 Simulation Experiment

In this Section, we describe how the simulation experiment is designed in order to address three questions. At first, is the method applicable to assess changing year-to-year maize yield deviations? Secondly, do the trends in mean maize yield correspond with the trends in maize yield deviation? Thirdly, how do changes in the mean yields and changes in the yield deviations potentially affect food production stability?

We calculate for all cells, the mean and the standard deviation under baseline (1971–2000) and scenario (2041–2070) conditions. For both indicators, we calculate changes by subtracting the baseline values from the scenario values. The changes are finally analyzed relatively to the baseline values (see Figs. 8 and 9 in Sect. 3.2). In our entire analysis, we consider a parameter constant, if the changes lie between ±5 %. In this case, the parameter does not show significant responses. Changes beyond these thresholds are assumed to provide reliable proxies that indicate trends in respect to changing climate patterns.

To assess if climate change impacts are systematically underestimated when relying on mean analysis alone, we plot trends of mean yield changes along with trends in the STD changes. In Sect. 3.2 (Fig. 10 and Table 1), we group cells into three classes, positive correlation, negative correlation and no correlation to separate between parameter trends. A positive correlation exists when the changes of both parameters point in the same direction. In disparity, a negative correlation exists, when both parameters trends tend to opposite directions. No correlation exist when one indicator increases or decreases and the other indicator remains constant. Climate impact studies based on mean analysis alone would also account for trends in deviation when a positive correlation exists (in green). However, the conclusion would be misleading when the two parameters are either uncorrelated (in yellow) or negative correlated (in red).

Furthermore, when the STD increases relatively to the mean, climate impact assessments are at risk to underestimate impacts on rain-fed farming systems when

Table 1 Cell statistics for the analysis of trend correlations in Fig. 10, future trends of mean and STD parameters from the baseline to the 2050s: 0 no changes, + increase, − decrease

	Mean	STD	Cells	Cells (%)	Cells in the MGR	Cells in the MGR (%)
	0	0	126	3.8%	16	3.8%
	+	+	1005	30.2%	94	22.6%
	-	-	257	7.7%	26	6.3%
			∑ 1388	**∑ 41.7%**	**∑ 136**	**∑ 32.7%**
	+	-	728	21.9%	99	23.8%
	-	+	121	3.6%	25	6.0%
			∑ 849	**∑ 25.5%**	**∑ 124**	**∑ 29.8%**
	0	-	622	18.7%	84	20.2%
	+	0	235	7.1%	31	7.5%
	0	+	191	5.7%	27	6.5%
	-	0	46	1.4%	14	3.4%
			∑ 1094	**∑ 32.8%**	**∑ 156**	**∑ 37.5%**

only relying on mean analysis. The higher the change in the STD compared to the change in the mean, the higher the potential vulnerability to inter-annual crop yield variability (compared to the baseline). Then, again, when the STD decreases compared to the mean yield changes, simple mean analysis would overestimate climate impacts. In this respect, the rain-fed food production system becomes less vulnerable to inter-annual crop yield variability. In Sect. 3.2, we classify trends in the STD and the mean values in respect to their impact on food production stability (Fig. 11 and Table 2). The analysis provides an example for a qualitative impact analysis. We differentiate five classes: more stable, more stable tendency, uncertain, less stable tendency and less stable. Cells are classified as more stable when the yield deviation decreases and the mean yield increases (in dark green). The class more stable tendency (in light green) embraces all cells that either show an increase in the mean yield and no change in the yield deviation, or a decrease in the yield deviation and no change in the mean yield. Cells are classified to evolve towards a less stable tendency (in orange) when the mean yield decreases and the yield deviation remains constant or when the mean yield remains constant and the yield deviation increases. When the mean decreases and the deviation increases, cells are classified less stable in respect to potential future rain-fed systems (in red).

3 Results

3.1 Indicator Validation and Model Plausibility Test

We have tested the indicator for some African countries (Fig. 3). Although, there is a range of uncertainties (see Sect. 4.2), we found correlations between the indicators obtained from FAO statistics and those from the model computations. Some countries show high agreements (e.g., 99.9 % for Congo DR and 91.7 % for Tanzania) and other show rather low agreements (e.g., 50.7 % for Madagascar and 54.7 % for Guinea). Over all countries, the Correlation Coefficient of the CV indicators is $R = 0.76$ and the Coefficient of Determination is $R^2 = 0.57$. It illustrates the indicator‘s suitability to capture average deviations over time. In addition, the validation also provides hints that the modelled CVs tend to lower deviations than the CVs from FAO statistics.

In Figs. 4, 5, 6 and 7 we plot the year-to-year variability of maize yields against the annual precipitation data that drives the model computation. The scale is normalized with the mean equal to one. This simple plausibility test shows a general sensitivity of the LPJmL model to the precipitation input.

Table 2 Cell statistics of Fig. 11—Classification in respect to food production stability development trends from the baseline to the 2050s: 0 no changes, + increase, − decrease

	Mean	STD	Cells	Cells (%)	Cells in the MGR	Cells in the MGR (%)
	+	-	728	21.9%	99	23.8%
			∑ 728	**∑ 21.9%**	**∑ 99**	**∑ 23.8%**
	+	0	235	7.1%	31	7.5%
	0	-	622	18.7%	84	20.2%
			∑ 857	**∑ 25.7%**	**∑ 115**	**∑ 27.6%**
	-	-	257	7.7%	26	6.3%
	0	0	126	3.8%	16	3.8%
	+	+	1005	30.2%	94	22.6%
			∑ 1388	**∑ 41.7%**	**∑ 136**	**∑ 32.7%**
	0	+	191	5.7%	27	6.5%
	-	0	46	1.4%	14	3.4%
			∑ 237	**∑ 7.1%**	**∑ 41**	**∑ 9.9%**
	-	+	121	3.6%	25	6.0%
			∑ 121	**∑ 3.6%**	**∑ 25**	**∑ 6.0%**

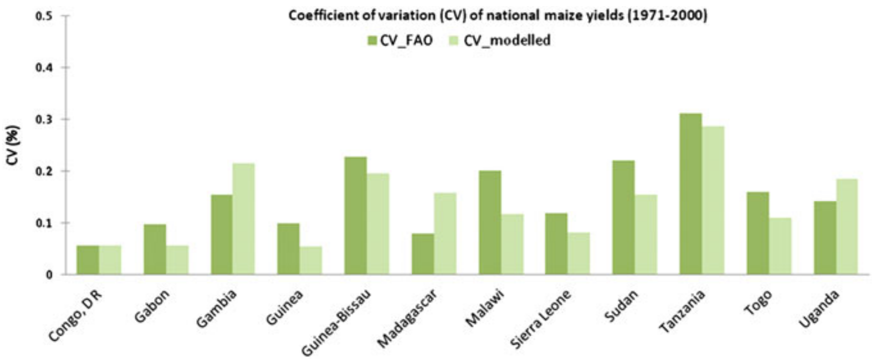


Fig. 3 Validation of the modelled CV with the CV from FAO statistics (FAO 2011b)

Fig. 4 Gambia, plausibility test

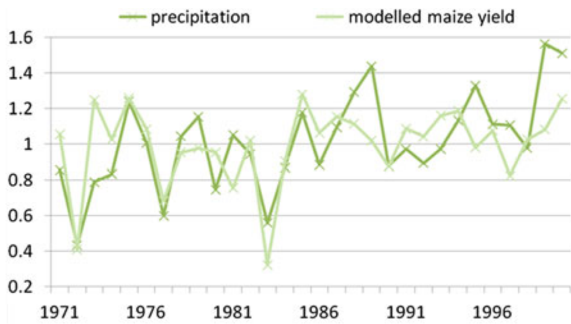
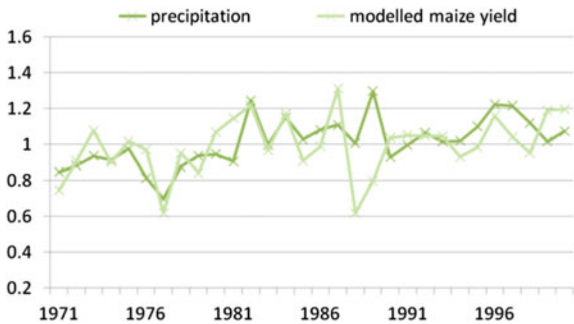


Fig. 5 Madagascar, plausibility test



3.2 Simulation Experiment

The simulation experiment is structured in three sections. We first test the indicator's applicability and compare changes in the mean crop yields with changes in the crop yield deviations (Figs. 8 and 9). We then analyze correlation classes between the two parameter trends (Fig. 10 and Table 1). Thereby, we assess if climate change impact assessments based on mean analysis would also be

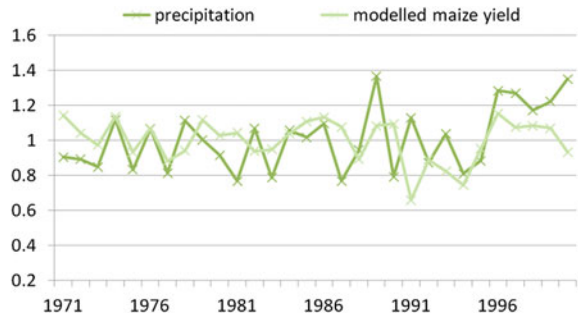


Fig. 6 Malawi, plausibility test

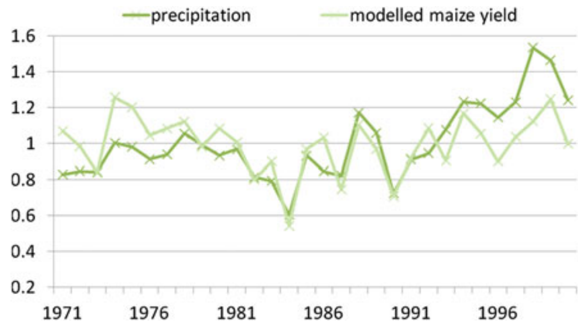


Fig. 7 Sudan, plausibility test

appropriate to encompass right trends in changing year-to-year crop yield dynamics. Finally, we qualitative evaluate how changing means and deviations could potentially promote food insecurity due to changing patterns of food production stability (Fig. 11 and Table 2).

In the figures, we provide polygons as references for the dominant maize growing regions (MGR) in Africa. The MGR, are identified based on the SPAM 2000 database (You et al. Spatial Production Allocation Model 2000 Version 3 Release 2). In this regard, we calculate the dominant crop-type in terms of physical area distribution on the SPAM's 5 arc minute grid before analysing the dominant crop-types of our 0.5° study grid. The polygons surrounding the MGR provide spatial references also in later figures.

Relative changes in the STD of maize yields are illustrated in Fig. 8 and relative changes in the mean maize yields are illustrated in Fig. 9. Red colours illustrate a decrease of agricultural suitability (e.g., due to an increase in the year-to-year crop yield deviations or a decrease in the mean crop yield) and green colours show an increase of agricultural suitability (e.g., due to a decrease in the year-to-year crop yield deviation or an increase in the mean crop yield). Cells that do not perform reliable trends are drawn in yellow.

While the development in deviation shows a heterogeneous highly scattered picture, the trends in mean yield changes are more regionalized and uniformly distributed. Western African mean yields remain rather constant, Eastern African yields are expected to get significant gains. Southern South Africa tends to a mean

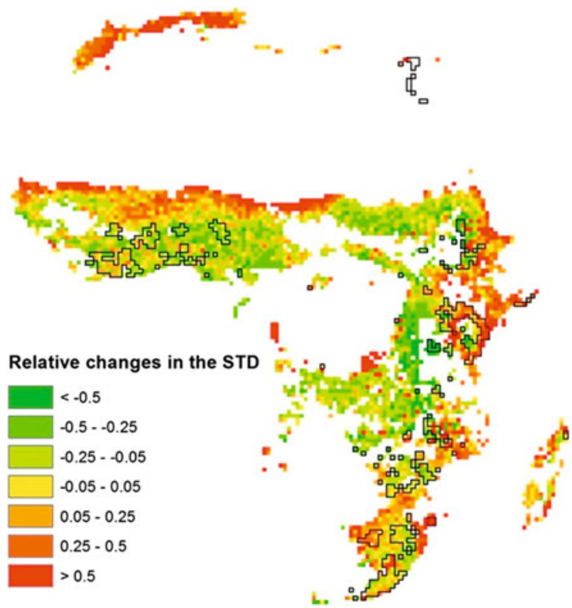


Fig. 8 Changes in the modelled STD maize yield values between the baseline and the 2050s

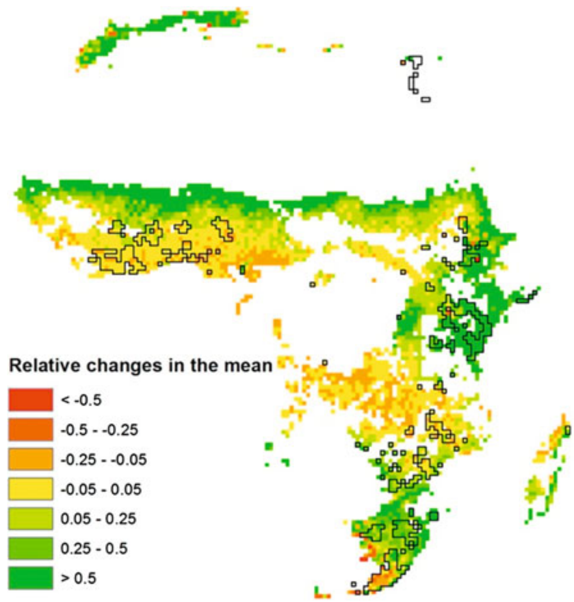


Fig. 9 Changes in the modelled mean maize yield values between the baseline and the 2050s

yield reduction and northern South Africa shows an increase. In Central Africa (not yet a MGR) mean yields are expected to decrease or remain stable.

We qualitatively group cells into classes regarding their trends in mean and deviation (Fig. 10 and Table 1). Cells that show a correlation between both

Fig. 10 Correlation trends between mean and STD developments

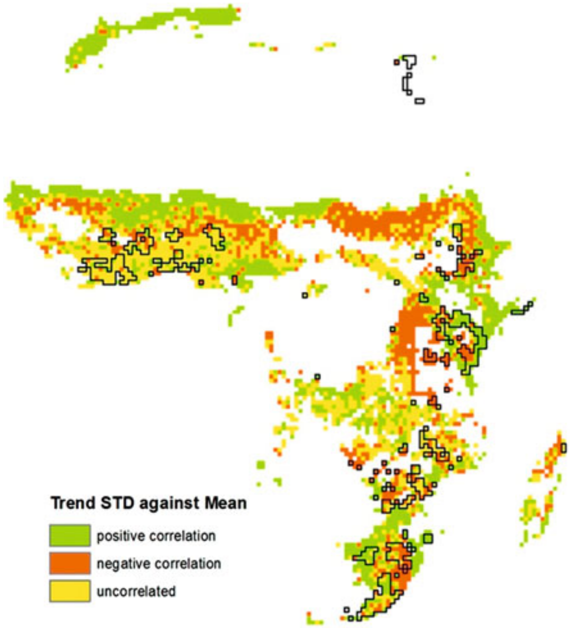
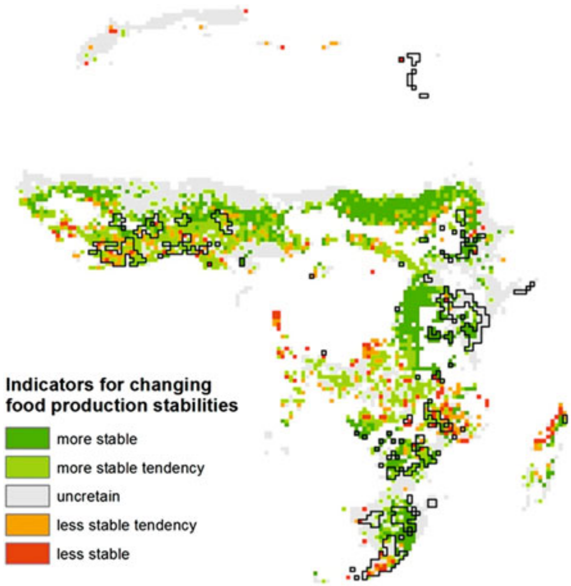


Fig. 11 Qualitatively trend analysis to indicate changes in respect to food production stability



parameters are grouped into the same class (positive correlation). Thereby, we can spatially address where conclusions from impact studies based on mean crop yield analysis alone would also count for trends in the year-to-year crop yield variability (in green). In addition, we plot cells in yellow (uncorrelated) and red (negative correlated) to highlight regions where such conclusions would mislead accuracies in terms of impacts from changing climate dynamics. While the West African MGR, basically show uncorrelated classes, the East African MGR are either positively or negatively correlated. No clear classification can be made for the South African MGR. Their classification is heterogeneous and highly scattered. Table 1 shows the constellations of parameter trends per correlation class (column 1 and 2) as well as according cell statistics. We provide absolute as well as relative numbers over all cells and, additionally, over the cells of the MGR. When focusing on the MGR, a positive correlation is drawn for 32.7 %, a negative correlation is drawn for 29.8 % and no correlations is drawn for 37.5 % of the cells.

In Fig. 11 and Table 2 we build classes that indicate how regions evolve towards the 2050s relatively to the baseline. The classification shows trends in respect to their potential impact on food production stability. It provides a proxy on whether the agricultural productivity becomes relatively more stable or instable. A trend is assumed more stable when the mean value increases and the deviation decreases (in dark green). In contrast, a trend is considered less stable when the mean decreases and the deviation increase (in red). Table 2 shows the constellations of parameter trends per indicator class for food production stabilities (column 1 and 2) as well as according cell statistics.

The qualitative classification indicates sophisticated changes in the West African MGR. While some cells tend to develop to relatively more stable maize yield patterns, others tend to higher year-to-year maize yield variability. The East African MGR drift towards more stable production systems, although the proportion of uncertain cells (in grey) is rather high. While southern South Africa shows a tendency to less stable maize production systems, northern South Africa tends to more stable production patterns. Over all MGR, an increase in maize yield stability is expected for 51 % of the cells in the 2050s relatively to the baseline period. In contrast, around 16 % of the cells show a relative decrease in maize yield stability. No clear signal can be drawn for around 33 % of the cells (class uncertain). Those cells have a positive trend correlation and cannot be assessed with this qualitative approach.

4 Discussion

4.1 Climate Data

For our study, we used the delta change approach as it has been widely applied for many impact analyses. Thereby, we considered the lack of accuracies in GCM outputs (as described by Hansen et al. 2006). However, due to the methodological disadvantages (see Sect. 2.2), the analysis of year-to-year yield variability might still underestimate the potential climate change impacts. Although we already obtain strong signals, we expect them to be clearer when applying bias-corrected climate scenarios. Due to the disadvantage of the delta change approach for the analysis of variability, it is recommendable to utilize impact models that operate with non-liner functions and several climate variables. Thereby, changes of the year-to-year variability can still be assessed even when some model input variables do not show changes in the deviation (e.g., temperature). However, the effect of the climate correction method (delta change approach versus bias-correction methodology) on agricultural impact studies is not yet properly assessed. It adds an additional uncertainty that requires further attention.

4.2 Indicator Validation and Model Plausibility Test

The model utilizes ensembles of climate input parameters (not only precipitation) to generate yield data. Therefore, yield developments must not correspond directly to a single climate parameter. For example, buffering effects, such as soil moisture and surface precipitation run off, may delink yield developments from the precipitation input. Additionally, plant water requirements may change in seasons and in respect to plant maturity cycles. Constraining effects can influence the degree of correlation (e.g., if water is not the limiting crop growth factor, the crop yield will not increase in respect to increasing precipitation rates). These can lead to time delays and/or oppose trends. Therefore, precipitation and yield developments are only loosely linked. Validation constraints do not only affect the linkage to climate variables, but also to FAO statistics. While FAO yield data is influenced by several factors apart from climate (e.g., management, plant pests, institutional problems, civil conflicts, etc.), we considered climate parameters as the only variable in our computations. Additionally, reporting errors for maintaining the FAO crop statistic may occur. Therefore, model uncertainties, wrong study assumptions and the uncertainties from other data sources, such as land-cover maps, cannot properly be separated and quantified. It makes the application of statistical validation methods such as the Coefficient of Determination (R^2) difficult in respect to time serial analysis. Instead, we apply the Correlation Coefficient and the Coefficient of Determination over the national CV indicators for all countries. Thereby, we validate the indicators usability for capturing long-term average trends in deviation. The results show that there is agreement between the modelled indicators and the indicators from FAO statistic ($R = 0.76$). It provides confidence that the indicator can provide useful proxies for scenario analyses.

4.3 Simulation Experiment

The experiment has shown remarkable potentials of the introduced method to help improving advanced impact assessments. Changes in the year-to-year yield fluctuations can be assessed in respect to changing climate patterns. The simulation experiment strongly supports the argument that climate impact analysis can lead to misinterpretations when only relying on mean values. As shown in Fig. 10 and Table 1, changing trends in mean values only correspond to around 42 % with changing trends in deviations. When considering the dominant African maize growing regions (MGR) the parameter correspondence declines to 33 %. Furthermore, around 30 % of the cells in the MGR show opposing trends. In other words, agricultural risk assessments based on mean maize yield analysis alone, would miss encompassing right trends in deviations for around 67 % of all cells in the MGR. Climate change impacts on agricultural systems can, therefore, not sufficiently be evaluated from mean analysis alone.

Figure 11 highlights regions where negative climate change impacts (in red) and positive impacts (in green) would have been underestimated in respect to food production stability. A positive development in respect to food production stability is here defined as a situation where the qualitative trends between STD and mean lead to a decline in the year-to-year variability relatively to the baseline and the mean yield developments. The analysis shows that 51 % of the cells of the MGR are expected to develop towards more stable production systems. In contrast, only 16 % of the cells drift towards more fragile production systems. In our analysis, we cannot assess developments in respect to food production stability for positive correlated cells. Their ratio may change due to different amplitudes of change between the parameters. Therefore, no trends for changing crop yield variations can be drawn for 33 % of the cells in the MGR.

Studies that only analyze mean values cannot identify these relationships between food production and food stability; hence, they bear higher uncertainties in respect to climate change impacts than studies that additionally consider changes in deviation.

Quantitative assessments are required to better differentiate between cells and areas. Then, also, positively correlated cells can be analyzed in respect to food production stability. Such an analysis is limited here by the methodological constraint posed by incorporating the delta change approach (see Sect. 2.4). Changing risks to food stability and the potential degree of misinterpretation by mean analysis alone can be better quantified when applying bias corrected climate data. For that case, we suggest dividing relative changes in the STD values by the relative changes in the mean values for the baseline as well as for the 2050s.

The aim of this study, to develop a methodology that better assesses climate change impacts on agricultural systems, has been achieved successfully. However, the study is based on a single GCM simulation run and has not assessed the large disparities among different GCMs. In addition, uncertainties from different socio–economic emission scenarios are not subject of this analysis. Comprehensive assessments with different GCM data qualities (referring to the correction method) and quantities (referring to multi model ensembles under different scenario assumptions) need to analyze uncertainties from the climate data input. In such a study scope, the introduced methodology can contribute with robust climate impact indicators that can promote agricultural adaptations to climate change.

5 Conclusion

In our study, we could show that the introduced method can contribute to better assess climate change impacts on agricultural systems. Due to the inclusion of year-to-year crop yield variability, we can analyze agricultural risks more comprehensively. It promotes addressing research questions that could not be assessed from mean crop yield analysis alone. We assessed limitations and misinterpretations that could potentially occur from mean analysis.

The methodology was tested for applicability in a small case study for continental Africa. In general, it provides evidence that climate change not only increases agricultural risks, but also promotes agriculture production in respect to mean crop yield changes and changes in the year-to-year crop yield variability. In our simulation experiment, we compared the changes in maize yield means with the changes in maize yield deviations from the baseline period 1971–2000 to the scenario period 2041–2070. For the dominant African maize growing regions (MGR), changing trends in mean values only correspond to around 33 % with changing trends in deviation. Agricultural risks assessments would, therefore, miss to encompass right trends in deviation for around 67 % of the cells, when only analyzing mean yield values. This disagreement between mean crop yield developments and the developments of crop yield deviations gives strong support to the hypothesis that climate change impacts can lead to misinterpretations when simply focussing on changes in mean values.

In a qualitative assessment, we further analyzed how the future ratio between the STD and the mean indicator is expected to change. The analysis provides a biophysical proxy whether rain-fed maize production systems are prone to higher yield fluctuations in the 2050s relatively to the baseline. The simulation experiment outlines that 51 % of the cells evolve towards a more stable maize production system. Only 16 % of the cells show an increase in maize production instability. Overall, this indicates that the rain-fed maize production system becomes relatively more stable in the future. However, the estimates rely on qualitative developments and the number of cells with uncertain trends is rather high (33 %). Quantitative estimates need to incorporate these assessments for more accurate differentiations.

Due to study constraints, the authors would like to point out that the results from the simulation experiment cannot be seen as a real impacts analysis in respect to content, but in terms of methodology. The approach needs application in the scope of different climate scenarios to better analyze uncertainties from global circulation models and emission scenarios.

We have shown that the introduced methodology can contribute to more robust climate change impact assessments. It complements mean value analysis and put the assessment into a wider context. As rural income in tropical and sub-tropical regions strongly depends on agricultural production, studies on yield fluctuations affect food availability, food access and food stability. In this respect, the methodology provides a useful tool for enhancing food security strategies and climate change adaptations.

As a next step, we plan a comprehensive impact analysis that utilizes the multi model approach to analyze uncertainties from different climate inputs in order to draw regions at highest risk for negative climate change impacts. In addition, we aim to implement the indicator in a dynamically, spatially explicit land use and land-cover change model in the near future. Thereby, we link the socio-economic system with the natural system and assess the potential for enhancing agricultural coping capacities against climate change.

References

Alcamo J, Acosta-Michlik L, Carius A, Eierdanz F, Klein R, Krömker D, Tänzler D (2008) A new approach to quantifying and comparing vulnerability to drought. Reg Environ Change 8:137–149

Bondeau A, Smith P, Zaehle S, Schaphoff S, Lucht W, Cramer W, Gerten D, Lotze-Campen H, Müller C, Reichstein M, Smith B (2007) Modelling the role of agriculture for the 20th century global terrestrial carbon balance. Glob Change Biol 13:1–28

Ericksen P (2008) What is the vulnerability of a food system to global environmental change? Ecol Soc 13:2

Ericksen P, Ingram JSI, Liverman DM (2009) Food security and global environmental change—Emerging Challenges. Environ Sci Policy 12:373–377

FAO (2009) The state of food insecurity in the world, economic crises—impacts and lessons learned. Food Agric Organ, Rome

FAO (2011a) The state of food insecurity in the world, how does international price volatility affect domestic economies and food security?. Food Agric Organ, Rome

FAO (2011b) Food and Agricultural Organisation of the United Nation, statistic division, 2011. Available at http://faostat.fao.org/site/567/default.aspx#ancor. Accessed 1August 2011

Feng Z, Kobayash K (2009) Assessing the impacts of current and future concentrations of surface ozone on crop yield with meta-analysis. Atmos Environ 43:1510–1519

Hansen JW, Challinor A, Ines A, Wheeler T, Moron V (2006) Translating forecasts into agricultural terms: advances and challenges. Clim Res 33:27–41

Le Clainche Y, Braconnot P, Marti O, Joussaume S, Dufresne J-L, and Filiberti M-A (2001) The role of sea ice thermodynamics in the Northern Hemisphere climate as simulated by a global coupled ocean-atmosphere model. Notes du Pôle de Modélisation 21, Institut Pierre Simon Laplace, Paris: 26

Leakey ADB (2009) Rising atmospheric carbon dioxide concentration and the future of C4 crops for food and fuels. Proceedings of the Royal Society, B 2009, 276: 2333–2343

Liverman D, Kapadia K (2010) Food systems and the global environment: an overview. In: Ingram J, Ericksen P, Liverman D (eds) Food Security and Global Environmental Change. Earthscan, Washington DC, pp 3–24

Lobell DB, Field CB (2008) Estimation of the carbon dioxide (CO2) fertilization effect using growth rate anomalies of CO2 and crop yields since 1961. Global Change Biol 14:39–45

Lobell DB, Schlenker W, Costa-Roberts J (2011) Climate trends and global crop production since 1980. Science 333:616–620

Mitchell TD, Jones PD (2005) An improved method of constructing a database of monthly climate observations and associated high-resolution grids. Int J Climatol 25:693–712

Nakicenovic N,Swart R (2000) IPCC Special Report on Emissions Scenarios. International Panel on Climate Change

Parry M, Rosenzweig C, Livermore M (2005) Climate change, global food supply and risk of hunger. Phil Trans R Soc B 360:2125–2138

Piani C, Haerter J O, Hagemann S, Allen M, Rosier S (2008) Practical methodologies to correct biases in climate model output, and to quantify and handle resulting uncertainties in estimates of future components of the global water cycle. WATCH Technical Report No 6 Sixed Framework Programme by the European Commission (036946)

Piani C, Haerter JO, Coppola E (2010) Statistical bias correction for daily precipitation in regional climate models over Europe. Theor Appl Climatol 99:187–192

Ramankutty N, Foley JA (1999) Estimating historical changes in global land cover: croplands from 1700 to 1992. Global Biogeochemical Cycles 1999;13–4(we used an update version: Global cropland and pasture data from 1700-2007. Available at http://www.geog.mcgill.ca/landuse/pub/Data/Histlanduse/). Accessed on 17.03.2011

Schlenker W, Roberts MJ (2009) Nonlinear temperature effects indicate severe damages to U.S. crop yield under climate change. PNAS 15:15594–15598

Schmidhuber J, Tubiello FN (2007) Global food security under climate change. PNAS 104:19703–19708

Stainforth DA, Aina T, Christensen C, Collins M, Faull N, Frame DJ, Kettleborough JA, Knight S, Martin A, Murphy JM, Piani C, Sexton D, Smith LA, Spicer RA, Thorpe AJ, Allen MR (2005) Uncertainty in predictions of climate response to rising levels or greenhouse gases. Nature 433:403–406

Tubiello FN, Fischer G (2007) Reducing climate change impacts on agriculture: global and regional effects of mitigation, 2000–2080. Technol Forecast Soc Change 74:1030–1056

Tubiello FN, Soussana J-F, Howden SM (2007) Crop and pasture response to climate change. PNAS 104:19686–19690

Van Dingenen R, Dentener FJ, Raes F, Krol MC, Emberson L, Cofala J (2009) The global impact of ozone on agricultural crop yields under current and future air quality legislation. Atmos Environ 43:604–618

White JW, Hoogenboom G (2010) Crop response to climate: ecophysiological models. In: Lobell D, Burke M (eds) Climate change and food security. Springer, Dordrecht, pp 59–83

Wood S, Ericksen P, Stewart B, Thornton P, Anderson M (2010) Lessons learnt from international assessments. In: Ingram J, Ericksen P, Liverman D (eds) Food Security and Global Environmental Change. Earthscan, Washington DC, pp 46–62

World Bank (2007) World development report (2007): Development and the next generation. World Bank, Washington DC

Mitigating the Water, Energy and Food Crisis: A Humane Solution

S. Subramanian and G. Bhalachandran

1 Introduction

Agricultural sector's contribution to *inclusive growth* of Indian economy is unique and encompassing. It is the largest unregulated private sector of India, employing around 58 % Ministry of Agriculture, Annual Report 2010–2011, GOI of the workforce and registered its share of about 14.5 %, according to the Economic Survey (2011–2012), of the national Gross Domestic Product (GDP) at constant 2004/2005 prices. It is the primary source of livelihood in rural areas, which account for 72 % of India's population (Bhatia 2007). India's share in the world's total land is just 2.3 %; but, its population share is about 17.5 % in the world population. This poses a major challenge for Indian Agriculture on food security. Though, the food-grains' production in India over the years has increased from 50.83 million tons (Mt) in 1950/1951 to 250.42 Mt in 2011–2012 (Economic Survey 2011–2012), it is estimated that, in order to sustain and support the projected population of 1.363 billion by 2025, agricultural production in India has to increase by 85 % and its productivity by 100 % from the present levels through the process of intensification in agricultural practices (TEDDY 2010). But, this has planted the seeds of anxiety in the minds of the people due to reduced public sector investments (Nelson et al. 2010).

S. Subramanian (✉)
Institute for Social and Economic Change, Dr. V. K. R. V. Rao Road, Nagarabhavi, Bangalore 560072, India
e-mail: prashantsubbu@gmail.com

G. Bhalachandran
Sri Sathya Sai Institute of Higher Learning, Prasanthinilayam, Anantapur, Andhra Pradesh 515134, India

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_30,

2 Agriculture and Water

Agricultural inputs play a significant role in determining the yield levels as well as the level of production in the long run. *Irrigation* is one of the most important inputs for enhancing the productivity and it is required at different critical stages of plant growth of various crops. Today, irrigation in India consumes almost more than 80–85 % of the fresh water resource in the country (Bhatia 2007; Mukheerji 2008). This fact is quite evident with the increasing requirement of water for irrigation for the current and future levels (Table 1).

India's irrigated area has expanded at a steady rate during the last few decades. The total irrigation potential in the country has increased from 81.1 million ha in 1991–1992 to 108.2 million hectares in March 2010 (Economic Survey 2011). The main sources of irrigation for the thirsty Indian agriculture are rainfall, canal or tank irrigation, and the well or underground water resources. *Rainfall* influences crop production and productivity in a big way in India, with agriculture still being largely *rain-fed* which is highly unpredictable (Briscoe and Malik 2007). The *rain-fed* agro-ecologies cover about 60 % of the net sown area of 140.3 million hectare and are widely distributed in the country (MoA 2011). The *canal-irrigated* area is exclusively dominated by government canals; whereas, the share of private canals in *canal-irrigated* area has continuously declined from 13.3 % in 1950/1951 to a mere 1.5 % in 2006/2007 (TEDDY 2010).

Ground water in India has taken the front seat pushing all the other players behind. The yields in area irrigated by ground water are often substantially higher than yields in areas irrigated from surface water sources, mainly due to its ease of control, reliability, flexibility and its support to act as a buffer against drought (Bhatia 2007; Iyer 2009). At present, approximately 231 BMC of groundwater is extracted annually in India (GOI 2009–2010), which is said to be the highest volume of annual ground water extraction in absolute terms in the world (Scott and Shah 2004; Shah 2005). The intensive installation of tube wells since 1970s has resulted in wells emerging as the dominating source of irrigation in Indian agriculture (Economic Survey 2011). During 2006/2007, canals (25 %), wells (59 %), tanks (3 %), and others (12 %) accounted for the total net irrigated. At a growth rate of 5.5 % a year, it is estimated that roughly 36 % of the blocks in the country

Table 1 Annual current and expected requirement of water in India (in BCM: Billion Cubic Meters)

Different uses of water	1990	2000	2010	2025	2050
Domestic	32	42	56	73	102
Irrigation	437	541	688	910	1072
Industry	–	8	12	23	63
Energy	–	2	5	12	130
Others	33	41	52	72	80
Total	502	634	813	1093	1447

Source TEDDY (2005) and (2010)

would be either *dark* or *critical* in terms of groundwater overuse by 2017–2018 (Moench 2002; Dubash 2007). Although ground water development has brought considerable economic growth and diversification in rural areas, but the consequences of negative groundwater draft have mostly been viewed as an *ecological disaster*.

3 Water–Energy Nexus

Water sustains human life and *energy* develops it (Gupta 2002) and these two can no longer be viewed as mutually exclusive and their inter-linkages and dynamics have to be carefully observed. Since they are complementary by nature, scarcity of either of the two can be met with by the surplus of the other (Gupta 2002). The increasing dependence of Indian agriculture on commercial energy is evident from the fact that the total energy use in the production of principal crops in India has increased 4.5 times between 1970 and 2005 to support the increase in productivity from 837 to 1583 kg/ha (NAAS 2008). However, the real complexity in the water–electricity link rests not in the proportion of electricity that is used by agriculture, but in the way in which the use of electricity by farmers has evolved overtime (Dubash 2007). Electricity provision for agriculture has its roots in the *Green Revolution* strategy of agricultural intensification. Perhaps, this strategy was successful, since the *Green Revolution* had lots of technological enhancements with better access to water and electricity. Of course, the country in the recent times has not witnessed any big technological breakthrough in agriculture since then (Economic Survey 2011).

Water-energy interactions in India have significant implications for growth, poverty reduction and environment. The agriculture sector is heavily dependent on fossil fuels; therefore, it is to be anticipated to have a direct and strong impact on energy prices on agricultural production cost and food prices. Though energy availability is an important factor for agricultural growth, more importantly, the efficient and reliable energy supply is critical. The average farm power availability in India has increased from 0.25 kilowatts (kW)/ha in 1951 to 1.502 kW/ha in 2005/2006 (MoA 2011). Irrigation water pumping is the second most important direct commercial energy end-use in Indian agriculture after land preparation (TEDDY 2002; cited in Batra and Mahajan 2009). There were, reportedly, more than 15 million electric and 6 million diesel irrigation pump sets in operation in the sector in 2003 (Batra and Mahajan 2009). Currently, the *irrigation efficiency* is only 20–50 % (Mukherjee 2008). In this process, not only the quality of water resources is degraded but, also, valuable habitats are destroyed. Iyer (2009) opines that the short term gains here can dramatic; but, the long term gains seem bleak, where not much water will be available to meet the projected growth.

According to (Shah 2009), the rise and fall of local groundwater economies follow a *four-stage* progression (Fig. 1). It underpins the typical progression of a socio–ecology from a stage where unutilized groundwater resource potential

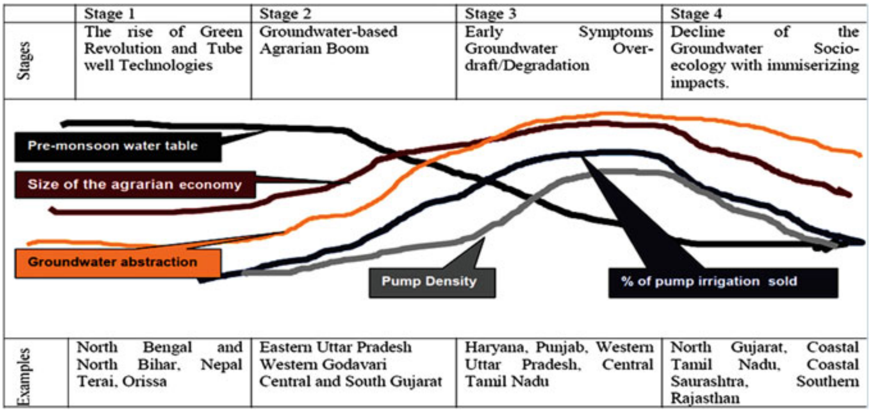


Fig. 1 Rise and fall of groundwater socio–ecologies *Source* Shah (2009)

becomes the instrument of unleashing an agrarian boom to a position in which exploiting of groundwater becomes a threat. The effect of the *Green Revolution* and mechanized tube well technology has nudged many regions of India from stage 2–4. In the absence of significant public investment in surface water-based irrigation infrastructure during the last 30–40 years, the need for reliable water supplies has translated into extensive and essentially unregulated groundwater pumping by individuals across the country (Narula and Lall 2010). Another reason cited in literature is that the rural electrification and power subsidies in the farm sector have accelerated groundwater utilization exponentially (Moench 1995; Shah 1993; Palmer Jones 1995) and heavy loss to the SEBs (Moench 1994). Figure 2 presents the continuous deteriorating status of the availability of water per capita in India with a projection up until 2041.

4 Vicious Circle in Indian Agriculture

Most of the inefficiencies, misuse and environmental damage relating to water and irrigation in India have their roots in the *mispricing* of water and electricity (Padmanaban and Totino 2001; Vaidyanathan 2003; Morris 2007). The pricing strategies adopted in the Indian system of *electricity pricing for irrigation* can be classified under *three* heads viz., (1) *Free electricity* to farmers (Punjab, Andhra Pradesh, and Tamil Nadu); (2) *Flat rates* (a flat rate regardless of actual power use) and (3) *Metered tariff* (levied on per unit cost of power consumed). By the mid-1970s and 1980s, many state governments' and State Electricity Boards (SEBs) had shifted away from *metering* of electricity sales to agricultural consumers and introduced giving power at *flats rates* in the beginning and eventually ended with *free power*, primarily to seize a powerful *vote-bank* (Shah 1993; Dubash Navroz and Rajan 2000), sprouting a notional rift between end-users and the precious

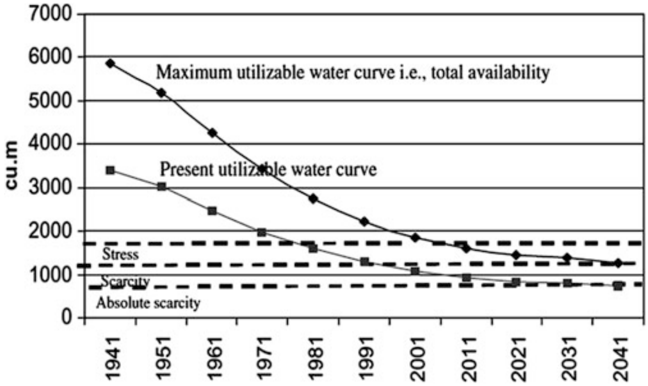


Fig. 2 Declining availability of water per capital (*Source* Narula and Lall 2010)

resource. Other reason behind this ploy was to avoid the high transaction cost and logistical difficulty in metering and collecting electricity charges (Shah 1993; Bhatia 2007; Mukherjee 2008). Moreover, in the *flat rate* system, the marginal cost of pumping water is zero and masks the true cost of power to the farmer and provides incentive to pump more for his own use or for the sale to other farmers (Padmanaban and Totino 2001; Bhatia 2007) and, thus, creating avenues for *Water Markets*. With long usage of low-priced or zero-priced free electricity, farmers get used to thinking of water as a *free public good* eventually and even the administrators and regulators have recorded the idea of *subsidy* in irrigation water-charges a must (Morris 2002).

Cropping patterns and farming practices also do not necessarily encourage the judicious use of water. Conservative estimates indicate that the same irrigation water used today can irrigate double the current area with optimized irrigation and farming practices (Varughese 2007). Despite the fact that this 'era of the individual coping strategies' has been remarkably successful, the decline in the quality of public irrigation and water supply services has produced social unrest and political pressure.

Indian electricity distribution system is characterized by poor design and installation with long lengths and undersized lines, resulting in high *transmission and distribution* (T&D) losses and large voltage drops. The effect of this is realized in the uncertain and unreliable supply of electricity to the farmers. Frequent motor burnouts and power cuts leave the farmer in flux. Farmers bear the brunt of additional costs of reinstallation and invariably switch over to inefficient, thicker armature-coil-windings to withstand burnouts and voltage drops (Padmanaban and Totino 2001). Unbranded and locally manufactured pump-sets with improper maintenance increase the energy inefficiency and further deteriorate the electricity quality (Tongia 2007). Thus, the frequent power cuts have led to an additional investment on the standby generators leading to the duplication of investments. The *power sequencing policy* of the State Electricity Boards (SEBs), regulating supply of power on a rotational basis in various blocks (supply restricted to 4–8 h per day), though is a commendable solution, has compounded the problem eventually and led to *system-failure*. To be precise, the *sequence- system* has nudged the farmers to keep the motors turned on always so that water is pumped out whenever the roster-schedule comes in effect. This has resulted in a large number of pumps being active at the same time, causing transformer burnout. Poor quality of power and the resultant impact on the performance and efficiency of pumps result in low crop yields, thus, affecting the farmers' incomes.

Under these conditions, farmers have neglected and are opposed to the payment of electricity bills, causing low cost-recovery. Low cost-recovery, in turn, is linked to the underfunding of operations and poor maintenance of the power delivery systems. Although, the agricultural electricity supply is compensated by the state, the distribution companies, on their part, have steadily reduced their investments, maintenance and staff budgets for rural distribution. This has resulted in reduced monitoring capacities and grid maintenance, high voltage fluctuations and increased transformer burnout rates. In short, this has resulted in a chain reaction and *vicious cycle* of events (Fig. 3) that have ended in illegal connections and thefts. Moreover, this has led to a steady deterioration of electricity infrastructure provision. The implicit philosophy is *build-neglect-rebuild* (Mohanty 2007), which is one of the culprits for mounting debts in farming communities and farmer suicides.

Whom should we blame? A section of official agencies blame farmers as the main offender for the uncontrolled exploitation of groundwater. In contrast to this argument, another section blames the government policies and institutional framework. The entire problem that agriculture faces today can be traced back to the *water laws* that are in force at present and the public good nature of water.

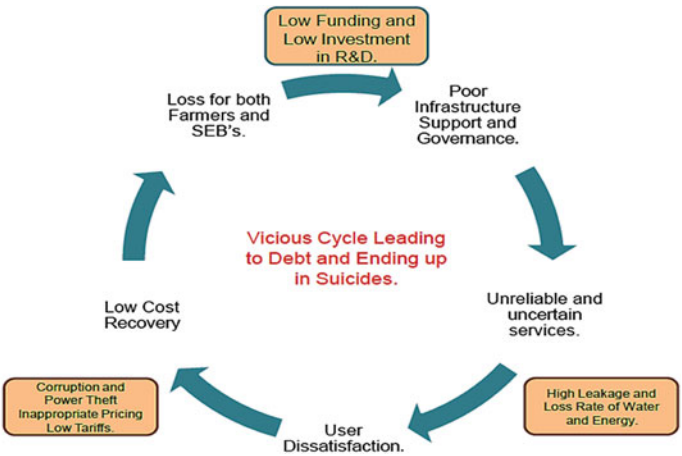


Fig. 3 The vicious circle (Authors)

5 Water Laws in India

Water is the *life-blood* of human development and there is a prevailing misconception that it is the fundamental *right* of everyone to have a dependable source of water since it is presumed to be freely and abundantly available for human use. Hence, a question arises as to how water is to be considered either as a common property or as a *res commune*, i.e., a thing owned by no one and subject to use by all, but usable within rational limits (Bhat 2007). Landowners generally regard wells as their own and view others, including the government, as having no power to restrict or otherwise control their rights to extract groundwater (Sinha and Sharma 1987). All laws relating to water and other natural resources have become very necessary because of unsustained progressive demand for resources, creating scarcity and problems of *free-riders*. India has followed the *common law approach* of land ownership doctrine (Bhat 2007) in the sphere of groundwater rights. Perhaps, this resembles a private ownership regime based on the basic principles of *Roman law* (Aithal 2007) added in jurisdiction by the British in 1882, which today appears to be archaic. Illustration (g) to Sect. 7 of the Indian Easement Act of 1882 states, *A land owner has the right to appropriate water which is below his or her land and no action will be taken against him even if it intercepts, abstracts or diverts water which remains under the land of another*. The next legislative effort was the *Forest Act of 1894,* which gave the state the right to acquire land, and along with its water resources. These two legislations shifted the rights of the communities to access water into the hands of the state and the individual (Somayajulu 2007).

Sensing the insufficiency in regulating the ground water, Ministry of Water Resources had drafted the 'Model Bill to Regulate and Control the Development of Groundwater' and circulated it to states in 1970. It was re-circulated in 1992, 1996 and 2005 to the States and Union Territories to enable them to enact suitable legislation on the lines of Model Bill (Ministry of Water Resources (MoWR) 1996; Hindu 2010; Ministry of Water Resources (MoWR) 2010). The bill proposes setting up of a *Groundwater Authority* in every State and Union Territory. The Authority will have powers to enter any government or private property, and survey wells and groundwater resources. People using groundwater, including wells, will have to seek its permission so that water resources are not wasted or overexploited.

As on 2010, only 11 States/UTs have enacted and implemented the legislation in this regard and 18 other States/UTs are in the process of enactment of legislation (MoWR 2010). However, implementation of various clauses of ground water legislation could not be effectively achieved on a large scale in India (Planning Commission 2007). National and international experiences indicate that enforcement of legislative measures for ground water regulation and management would be meaningful only when stakeholders are motivated through local self governing bodies and directly involved in the decision-making and enforcement process (Jha and Sinha 2007).

6 Mitigating the Crises

After having acquainted with the problems related to the two important inputs used in agriculture, it is pertinent to cull out solutions from various sources in which the principles of Economics have been applied.

(A) Traditional Methods

Irrigation in India has been practiced from pre-historic times and appears to have important lessons for the contemporary agriculture (Briscoe and Malik 2006). The uneven temporal distribution of rainfall and the nature of Indian ecology have perhaps been the driving force for water development (Mohile 2006) over the years. Evidence of this tradition can be found in ancient texts, inscriptions, local traditions and archaeological remains (Pande 1997). It is demonstrated that the ancient methods of groundwater management could provide a good example of human ingenuity to cope up with water scarcity in a sustainable manner. Ancients in India had applied the knowledge of hydrology in water resource engineering (Shenoy 2009). Numerous references are found in the *Ancient Sanskrit* treatises such as the *Vedas*, the *Bhagavad Gita* (Chapter 9, verse 19), Valmiki's the *Ramayana* (Kiskindha Kanda 28:3), the *Buddhist* and *Jain texts* and other ancient Indian literatures containing several references to wells, tanks, canals and dams and their importance to society (Agarwal and Narain 1997). Kautilya's the *Arthasastra*, speaks at length about the need to construct irrigation systems and reservoirs and sets out rules for collecting revenues and fines and establishes a the good management of the water systems (Agarwal 2007).

As the years rolled by, many kingdoms established its supremacy in this land of *Bharat*[1] and followed transparent and coherent policies, where the role of the state was limited. The rulers rarely built tanks. If they did, it was largely to meet their own water needs and thus, they avoided water bureaucracy. The rulers would encourage their subjects to build water harvesting structures by providing them with fiscal incentives (Agarwal 2007). This led to the development of many innovative, simple and eco-friendly techniques of water conservation. These techniques were in tune with the culture and traditions of the land at large. Table 2 gives a brief summary of various techniques practiced in the length and breadth of Indian sub-continent.

These traditional methods were very effective in flood control, prevention of soil erosion, reducing wastage of run-off and recharging groundwater (Agarwal and Narain 1999), and kept the local and global ecosystems intact. In short, the village folks practiced a decentralized system of water management, where in a *committee* was formed for protection, supervision and administration of the system.

The British westernized the whole water distribution system and took over the role of *main* provider of water and replaced the sustainable, traditional

[1] India is also termed as *Bharat* and it is believed that the term *Bharat* traces its origin from scripture attributed to a king who ruled this country.

Table 2 Traditional water harvesting system

Name	Date	Place	Description
Indus valley civilization	3000 B.C.	Dholavira, Great Rann of Kutch, one of the five largest Harappan cities	An intricate network of rainwater drains, connected to main ducts, and stored rainwater in the reservoirs would suffice for the whole year
Ahar-Pyne system	The *Arthashastra* (300 B.C.) *Aharyodaka setu*, Chandragupta Maurya (340–293 B.C.)	Bihar	*Ahar* means 'tank' that receives water from rivers through diversion channel called *Pyne*
Phad	Farukki kings (1370–1600)	Maharashtra	Stream or river fed storage structures, sometimes built in a series, with overflow from one becoming runoff for the subsequent one
Tanks, Anicuts and Barkuru	Chola king Karikalan (1st century A.D.), Vijaynagar kings (1336–1564 A.D.)	Andhra Pradesh, Tamil Nadu, Karnataka	Water-diversion or water-regulator structures for irrigation via canals. The concept of reservoir was first conceived and introduced by King Karikala
Zings of Ladakh		Jammu and Kashmir	The network of guiding channels that brings water from the glacier to the tank
Apatani		Arunachal Pradesh	The striking features are partially flooded rice fields and the intricate design of the *contour dams* dividing the plots with a gentle gradient and the terraced holdings

Source Information collected and collated from different sources by the authors decentralized system with centralized ones. The ownership of the natural resources was passed from the hands of the community into those of the state, while the management was ‘safely’ placed in the hands of engineers and bureaucrats. The Western engineering approach ushered in the era of large dams and resulted in the decline of traditional forms of small scale, local, community managed systems of water harvesting and management (Bhat 2007). Over the past 150 years, India has made huge investments in large-scale water infrastructure. But this has resulted in a dramatic economic shift, with once arid areas becoming the centres of economic growth, while the historically well-watered areas have seen much slower progress (Briscoe and Malik 2007). Perhaps, the key to the well-being of our country’s water resources lies in the indigenous water conservation systems which are being forgotten by today’s society (Center for Development Learning 2007).

(B) Integrated Policy

Management of ground water resources in the Indian context is an extremely complex proposition as it deals with the nexus between the human societies’ livelihood and the physical environment. Today’s competing demands on water and energy, urge for a *rational* management of groundwater and energy in an *integrated* and *holistic* fashion, with its link to environment for shaping a long-term program for optimal groundwater use and protection through conservation. But, due to its uneven distribution and utilization, no single management strategy can be adopted for the country as a whole (Jha and Sinha 2007). To tackle this issue, India needs to shift its focus from *water resources development* to *water resources management* by restructuring and strengthening its existing institutions for better service delivery and resource sustainability.

The current institutional arrangements in India do not provide incentives for the best possible use of water and energy resources in the country. The major huddle could be the partial and parochial view of water and energy resources by authorities controlling at the crest (Vyas 2007). This institutional confusion has been further compounded by the prevailing rules and norms that mainly focus on planning, rather than on actual implementations (Jagannathan and Vijay 2009). An inter and intra-reforms in the power sector have to be extended to include the water sector so that the synergy benefits in the use of these interdependent resources are maximized and negative externalities can be avoided (Roy et al. 2009). This, of course, needs a broad overarching *integrated* framework for guiding the policies; but, with a well defined institutional arrangement must be in place for governing the production and use (Bhalachandran et al. 2009; Bhatia 2007; Vyas 2007).

For such a synchronization, a lot of data are be collected and collated at the apex level along with the feedback and analysis at the base, which are essential for an *integrated* framework. A *multi-disciplinary* approach, encompassing the human, financial, natural and technological aspects is the need of the hour. But, the principled pragmatism in water and energy management requires every stake holder to understand each one’s role and commitment, while noting the impending problems and the possible solutions that can be arrived at (Jagannathan and Vijay 2009).

Now, the issue is how can synergies be produced between local policies and institutions with central government initiatives? The *classic* approach to planning is *top-down* and all programmes were directed from the centre, driven by narrow experience in isolation from local needs. The notion of good governance is related to effective public government institutions, wherein a *bottom-up* approach is also encouraged. *Bottom-up* tends to draw in wide experience based on local knowledge and perspectives and achieves a genuinely citizen centric solution. Empowering local citizens and community organizations in decision-making processes not only increases efficiency, but also provides a real possibility to individuals or groups to transform their choices into desired actions and outcomes (FAO UN 2011). According to the report of the *expert group* on ground water management and ownership, the *bottom up* approach in India may be traced back in 1960s and a constitutional mandate (73rd and 74th Constitutional Amendment Act 1992 and Article 243G) has laid the foundation of stake holders' participation and rural planning in great way on 'economic development and social justice'.

Further, an appropriate mix of *top-down* and *bottom-up* with the notion of 'subsidiarity' principle can bring about greater responsibility, awareness and solidarity in local governance (Carozza 2003). 'Subsidiarity' principle was first introduced in the European Union's 1991 *Maastritch Treaty*, ascertaining 'decision-making to be performed at the lowest possible effective administrative level' in the European multi-governance system (FAO UN 2011). Specifically, it is the principle, whereby, the union does not take action; unless, it is more effective than action taken at national or regional level.

(C) Demand-side Management (DSM)

For completeness in the *integrated policy*, it is very essential to have right *measures* to support the *approaches*. Thus, effective management of ground water resources and energy requires a combination of both *supply side* and *demand side* measures (Jha and Sinha 2007; Brown and Elliott 2005). 'Supply side' measures aim at increasing extraction of ground water depending on its availability and efficient transmission and distribution of energy as much demanded; whereas, 'Demand side' measures aim at controlling, protecting and conserving available resources for future use. A proper combination of *supply side* and *demand side* measures can reduce the widening gap of supply–demand.

Supply side measures, based on physical approaches towards supply augmentation and system-improvement cannot be the exclusive basis for water-sector strategies (Saleth and Amarasinghe 2009) as this is a time consuming process and it will not give a helping hand to mitigate the problem in the short-period. Moreover, the supply augmented measures are condemned because of the double whammy effects coming from the binding limits for adding new supplies and increasing inter-sectoral competition (Saleth and Amarasinghe 2009). The prominent instance is the availability of water through irrigation, wherein farmers start adopting a water intensive cropping pattern and move on to various cash crops, where more water is needed and extra desire to expand agriculture, which creates demand for more water. Thus, Supply management in a long run turns to be unsustainable in the resources use.

A sensible move with a resilient answer rooted in *demand management* is the need of the hour, which is a *short-term* remedy, simple to administer and effective in response. It is inevitable to harness demand strategy options by which it enables the supply system to meet the demand at all times in the most economical manner. *Conservation* and *demand management* can go hand in hand to make the best use of the existing electricity and water resources, and it would certainly contain the pressure on demand. It is important to understand that *Demand management* can only be a complement, but not a substitute to the various emerging supply management policies by the government, as it only avoids wastages and helps to eliminate or the need for an additional investment in augmenting new capacity.

Demand management is defined as the development and implementation of strategies aimed at influencing demand, so as to achieve efficient and sustainable use of a scarce resource to promote equity and environmental integrity (Savenije and van der Zaag 2002). It deploys various techniques for conservation and improves the efficiency in the use of resources by end-users. Thus, today, India certainly has a lot of potential for water and energy savings. The Planning commission notes that Indian agriculture has about 36 % of energy saving potential. Mere replacement of inefficient pumps can save an estimated 35–40 billion units annually and improve crop yields by three to four times (Sekhar 2007).

These potentials can be realized by implementing *demand side measures* involving judicious application of *two* kinds of strategies: first, *structural* measures (such as efficient motors, sprinkle and drip irrigation, control systems in distribution networks, etc.) and, second, *non-structural* measures i.e., economic and legal *incentives* (quota,[2] water market and license,[3] water rights,[4] water and energy pricing,[5] energy regulation) to change the behaviour of water users (Savenije and van der Zaag 2002). The purpose of DSM is not only the reallocation of water and energy from irrigation, but, also set a long term objective to gain efficiency and productivity in Indian agriculture (Saleth and Amarasinghe 2009).

Some of the options on DSM strategies, discussed in the Table 3 are *context specific*, whereas, others are applicable in a more broad sense. Knowledge of all these factors is very important as they will determine the relative scale of application and the overall impact of the demand management options (Saleth and Amarasinghe 2009).

(D) Water and Energy Pricing

Achieving an *efficient* relationship of the energy and water requires *consistency* in the policies that governs each segment of the energy and water sector, supported by a *productive pricing system* (Bhalachandran et al. 2009). Pricing of goods and services is central to Economics Gauri 1988) and it is very crucial in regulating an economic system. Today, agriculture requires a competent *demand management strategy* to evade the wrath of scarcity in future, coupled with a suitable pricing

[2] Setting an upper limit to the amount of water that may be used for a certain purpose.

[3] Issuing licenses for withdrawals or discharges, subject to control.

[4] Where stakeholders can buy and sell water rights within a well defined legal framework.

[5] Pricing of water services.

Table 3 Various strategies in demand side management

Sl. No.	Method	Description	Expected Efficiency	Authors
1	Delayed crop transplantation	Shifting in the plantation to make effective utilization of the rainfall	Reduction in the water table and dependences on ground water	Hira (2009)
2	Sprinkler method of irrigation	Water is sprayed into the air and allowed to fall on the ground surface somewhat resembling rainfall	Around 70 per cent efficiency	Narayanamoorthy (2008, 2009), Narayanamoorthy and Deshpande (1998)
3	Drip irrigation	This method allows water to drip slowly to the roots of plants, either on to the soil surface or directly on to the root zone	Around 90 % efficiency can be achieved if properly designed	Narayanamoorthy (2008, 2009)
4	Efficiency in motor pump sets	Procuring motors suitable to the needs with less energy intensity	to 30 % efficiency can be achieved	Batra and Mahajan (2009)
5	Crop diversification or choice of right crop	Some areas under farmers' idle time after the main harvest could be used for the sowing of other crops	Increase in farmer's income, higher willingness to pay, proper usage of resources	Hira (2009)
6	Conjunctive development and use of surface and ground water	Simultaneous use of surface water and groundwater to meet crop demand	From a pilot study by IWMI, 26 % rise in income; 75.6 mkwh energy saving; pump cost of 180 m saved; decrease in average depth of GW	Blomquist et al. (2001), IWMI (2002), Rao et al. (2004)

Source Information collected and collated from different sources the authors strategy for proper allocation and utilization. Thus, the agricultural sector necessitates that both the pricing of energy and water has to be done simultaneously.

Theoretically, demand for any normal good is inversely related with its *price*. Though price is an important demand management variable, the criticality of water for irrigation makes it *inelastic* to price (Ratna 2009a, b) and people need water, whatever the price is. Without adequate pricing mechanism, consumers have no incentive to use water more efficiently as they receive no signal, indicating its relative value as a resource they utilize (Asad et al. 1999; Mukherjee 2007). If water is made available *free of cost*, then the utility does not recover costs for its services, which, subsequently, affect the quality of its services and, finally, the burden will be on the poor farmers. This sort of phenomenon is widely observed in almost all the Indian states. The way out of this impasse could be compulsory installation of meters at the user's end. Quite a few authors insist on water metering and metered tariff as a basic demand management measure, which can provide the right economic signal (by charging a variable price with the level of water usage) and enable the farmers to restrain the usage of the resource as much it is essential (Mukherjee 2007). Scott and Shah (2004) and Godbole (2002) opine that the introduction of metering may not be a practical solution in the Indian context, unless innovative institutional arrangements are used to oversee them.

Savenije and van der Zaag (2002) asserts that if only water pricing is considered the main instrument of demand management and economic planning for agriculture, then it will be a major pitfall. Electricity costs form a significant part of irrigation costs of pumping ground water. The dynamics of optimal groundwater extraction depends on the price of energy and water jointly (Saleth 1996; Zilberman and Lipper 1999). Some of the changes in the water sector can be strict enforcement of spacing and depth regulations as well as a whole host of institutional and technical aspects related to establishment of legally sanctioned, but, locally enforced and managed volumetric water rights (Malik 2007). When these conditions are created, energy regulations can be a powerful tool within an overall strategy of irrigation demand management.

In order to improve the irrigation services and overall system efficiency, the cost recovery is equally important with pricing, so that the amount could be reinvested for improving the irrigation services to the users. But, currently, the pricing system followed in India promotes neither efficiency nor cost recovery, hence reflecting poor performance. The efficiency of any water management technology is dependent on the reliability of the water and energy supply rather than free and erratic power. (Mukherjee 2008). Often pricing policies are thwarted with the excuse that farmers are unwilling to pay for irrigation water (Reddy 2009a, b); contrarily, farmers in India are willing to pay for the water and electricity, provided the supply is reliable. Therefore, *willingness to pay* is not a bottleneck for charging higher prices but, it is the *willingness to charge*, which is the main obstacle (Reddy 2009a, b).

Direct supply regulations, involving rationed and fixed hours of supply, will be more effective and this would improve the situation of the notional scarcity and stop illegal practices to a large extent. It is critical to consider the scope for

Table 4 Impact assessment of *Jyoti gram* in Gujrat: A study by CII and IRMA (2005)

Economic impact on households	Impact on education	Impact on rural women	Impact on rural industries
Increase in employment and reduction in migration by 33 %	Drop out reduced by 80 per cent and average duration gone up by 81 to 92 %	Rise in-education 90 %, entertainment 88 %, income generation activities 18 %, reduction in household chores 26 %	Families in rural areas to work in night times 53 %

monitoring and enforcement of power with local involvement. The best example to cite here is of Gujarat government's initiative of *Jyotigram Yojana*. Gujarat has cut down its power supply from 3,000 to 1,200 hours. It is, thus, suggested that the rational tariff with intelligent power supply rationing to the farm sector holds out the promise of minimizing the wasteful use of both resources (water and power) and of encouraging a technical change towards water and power saving (Shah et al. 2003; Devika Devaiah 2010). The *Jyotigram Yojana* has restructured the power sector of Gujarat, and has gone far beyond the proposal made and unleashed a new wave of rural development (Shah et al. 2009; Shah and Verma 2008). It has boosted the power supply to the farm sector and introduced better energy accounting (Shah et al. 2009). Thus, the rural economy started witnessing 24 h of reliable power supply for domestic purpose and 8 h for farms on a *pre-announced* schedule, with a 3 phase power supply to 18,065 villages and also to the 9,680 suburbs attached to these villages.[6] According to the government's reports, the farm power use on tube wells has fallen from 15.7 billion units/year in 2001–9.9 billion units in 2006, i.e., nearly 37 % decline and cutting subsidies on farm power by half, i.e., from US $788 million in 2001–2002 to US $388 million in 2006–2007, resulting in a considerable decline in the aggregate ground water usage (Shah et al. 2009). This single initiative has brought a revolutionary change in the life-pattern and economic activities of rural Gujarat as presented in the Table 4. With this scheme, the Gujarat Electricity Board witnessed operating profits by the losses falling from Rs. 2200 Cr. in 1999–2000 to Rs. 475 Cr. in 2002–2003 and today Gujarat has a surplus of 600 MW of power and it is being sold directly or through the Power Trading Corporation to Tamil Nadu and Karnataka (TOI 2010).

(E) Subsidies versus MSP

While it is vital to establish the mechanism to enable cost recovery, the needs of the poor will have to be protected (Abu-Zeid 2001). It is a known reality that grain and energy prices have an effect on agricultural activity. When grain prices are low, activity drops and when energy prices are low, activity will increase (Rhonda et al. 1998). So, there is a sound inter-linkage between the prices that the farmers gain on the goods and pricing on energy and water. A right price for the produce would certainly induce the farmers to pay for the inputs used and an incentive to

[6] http://www.narendramodi.in/pages/power-uninterrupted-jyoti-gram

conserve water and energy. Therefore, it is up to the governments, in co-operation with major stakeholders, to choose the proper mechanisms to provide the necessary funds for sustaining the system and meeting the needs of the poor (Abu-Zeid 2001). This could be achieved in *two* ways: one, by well targeted *subsidy* and, two, through proper minimum support price (MSP).

Agricultural Price Policy has assumed a greater significance in the current phase of liberalization (Deshpande and Naika 2002). A well thought out price policy for agricultural commodities ensures remunerative prices to growers for their produce, with a view to encouraging higher investment and production, and safeguarding the interest of consumers by making sure that adequate supplies are available (Economic Survey 2010–2011). This will direct to have a fresh look at the major instruments of Price Policy, viz., MSP, Procurement and Public Distribution System. Moreover, these instruments have played an important role in achieving the objectives of food security and accelerated growth of the economy at large (The Hindu 2006). In fact, the prices play a much wider and more crucial role than the adoption of technology (Deshpande and Naika 2002).

Hira (2009) focuses on the benefits accrued by the farmers by raising the minimum prices and facilities by cutting the subsidies. This suggests that the economic incentive for efficient irrigation water use can be given by the government providing *incentives* on marketable agricultural produce. Moreover, it cites the examples of the Punjab state, where the government, in 2007, announced an increase in the procurement price for wheat from Rs. 7,500–10,000 per ton for the wheat crop harvested in 2008. This resulted in a net increase in the earnings of Punjab farmers of Rs. 25 billion during 2008. It points out that instead of the Punjab Government (PSEB) giving free electric power annually worth Rs. 24 billion, the government could have thought in terms of *bonus* worth Rs. 12 billion on wheat and rice sold in the market. This would have enabled farmers to adopt efficient irrigation technologies. Keeping this in mind, the Government announces MSP for major agricultural commodities in each season and organizes purchase operations.

Another important price instrument of the government is *subsidy*, which is a tailspin for the policy makers, regulators and even the end users. The World Bank estimated that the subsidies to the farmers accounted to approximately 25 % of India's fiscal deficit (Iyer 2009). Most of the subsidies are used either in energizing the pump sets to draw water or other inputs. The provision of agricultural subsidies has burdened the exchequer heavily. Generally, these input-subsidies are provided either to raise production and productivity levels, or to encourage small and marginal producers for adopting modern inputs (Jain 2006). But a question arises, whether the deserving groups receive the subsidies and enjoy the benefit of full entitlement allotted. To be precise, there is a need to direct the subsidies without any intermediaries. The only option possible today is to institute *direct subsidization*, i.e., the subsidy is handed over to the farmers in the form of electricity *stamps* or *coupons* through a well-crafted system (Morris 2007). This system would facilitate in reducing the losses incurred by the exchequer.

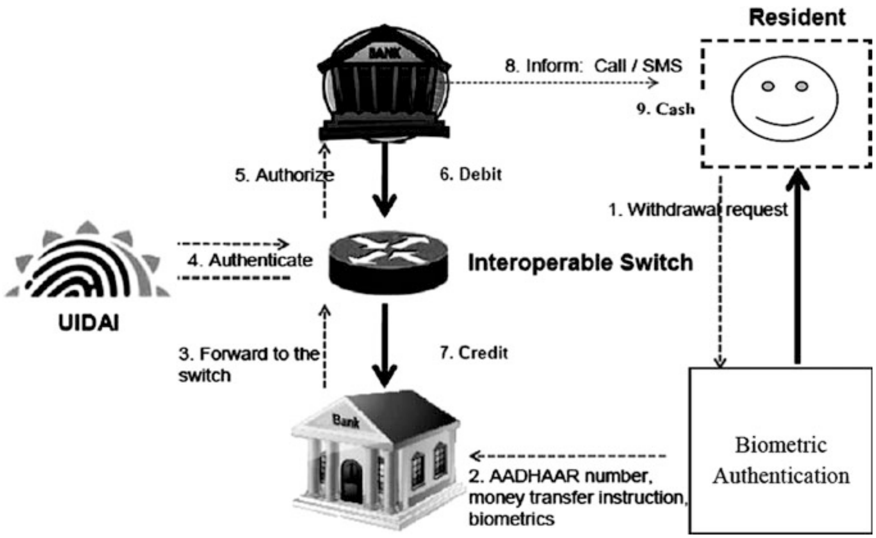


Fig. 4 Movement of money in UIDAI's scheme of Aadhaar (*Source* Discussion Paper on Aadhaar based Financial Inclusion, Planning Commission, 2011)

To streamline this process, Government of India (GoI) has embarked upon an ambitious initiative to provide a *Unique Identification* to every resident of India under the aegis of Unique Identification Authority of India (UIDAI). This initiative aims at an increased focus on financial inclusion through massive investments in various social sector programs in public services delivery through *e-Governance* programs. Under this arrangement, a citizen can access any bank/service-centre anytime from anywhere. This initiative will ensure that government payments/subsidies reach the targeted audience in time and cannot be misused by other people. The *schematic diagram* in the Fig. 4 gives an idea of the steps involved and the movement of money to the recipients directly.

(F) Decentralized Solutions

In managing the country's vast surface water resources, the bureaucracy has acquired a commanding position (Sanoff 2000) resulting in the development of a *dependency syndrome* (Vyas 2007) among the water users, where the logic of the so-called economies of scale and the self-perpetuating momentum of the engineering sector has fundamentally changed the way of considering the water resources (Varughese 2007). It is often argued that reasons for the poor condition of the irrigation management are the isolation of farmers from the process of planning and distribution of water resources (Vyas 2007). This is in sharp contrast to India's history, when the community recognized the value of collective monitoring of water resources (Vaidyanathan 2003). Participation by the local communities will lead to an improvement in water use efficiency which is a well recognized outcome from the experience of countries like Philippines, Japan, etc., (Vyas 2007). Cooperative management of water resource is necessary for the

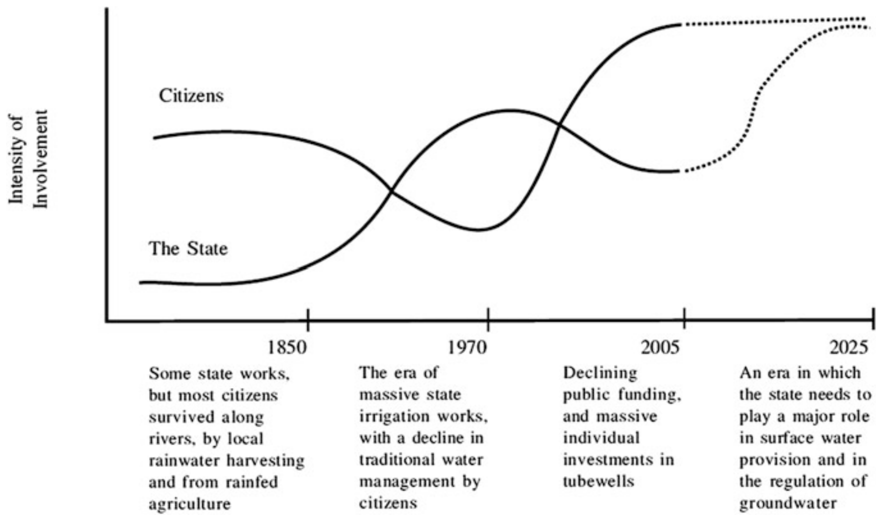


Fig. 5 The evolving role of the citizens and the state in water management. *Source* Briscoe and Malik (2006)

individuals to optimally utilize it (GoI 2007). Moreover, any scheme introduced in consultation with the end users can be easily pushed through by the local government, while ensuring *equity* in principle and practice. Figure 5 foresees a schematic sense of the needed next *stage* in the evolution of water management in India.

The idea of *community participation* can be traced back to 1950s and 1960s, when many programmes initiated took the poor and oppressed to be part of the planned development (Roy et al. 2009). The 73rd and 74th Amendments to the Constitution empowered panchayats and urban-local governments to manage their water resources with a view to creating a sense of ownership among local communities. Robust local institutions are an essential pre-requisite for decentralized management of water resources and they must also have access to higher level information and institutional support to manage these resources in an integrated manner (Varughese 2007). This information is useful for a *top-down* and *bottom-up* planning of agriculture and its inputs, which enables the governments to formulate policies, govern and regulate. To enhance the working efficiency, there is a need to develop institutional space and mechanism for both the governments and local communities to interact effectively. The aim of a decentralized solution is to ensure a sustainable use of resources in the long-run, keeping the objectives of poverty alleviation and equity in short-run. This is well represented in the Fig. 6.

In recent years, various promising micro-institutional efforts have been attempted that play some role in addressing the electricity groundwater conundrum (Dubash 2007). *Pani Panchayat and Akshay Prakash Yojana* in Maharashtra and

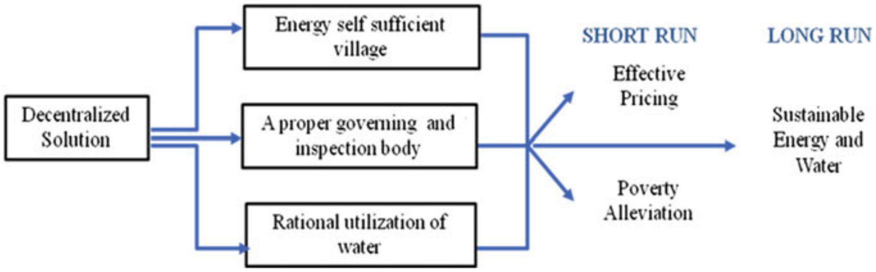


Fig. 6 Schematic representation of decentralized solution (Authors)

Community Irrigation Bore Wells in Karnataka are some of the models formulated and implemented to make the community irrigation projects to work viably. Here, a formal agreement is initiated to share the costs incurred on the operation and maintenance of the pump, the output of groundwater pumped, sharing of the energy used, etc., proportionately. This, in turn, internally limits the use of water and energy (Ishwarabhat 2007). The success of these community endeavours depends upon the perception of benefits to every member of the group, gained in a group, than by performing the activity on his/her own (Bhat 2007). One of the success stories, which is widely quoted, is that of *Ralegan Siddi,* under the able leadership of Anna Hazare. *Ralegan Siddi*, in the last 25 years, has proved to the world by demonstrating that it is possible to rebuild natural capital in partnership with the local economy and today it stands as a *model* for the rest of the country and the world. The World Bank has exalted the transformation of the village of *Ralegan Siddi*, from a highly degraded village ecosystem in a semi-arid region of extreme poverty, to one of the richest in the country. From the examples that have been discussed, it can be inferred that for proper functioning of any system, an *inspired leadership* is of prime importance that would combine the required workforce with proper technology and inputs.

New types of multi-stakeholder institutional bodies are required and innovative partnerships have to be developed to manage the ever growing complexities and challenges of water resource development and management (Varughese 2007). One such measure could be in promoting a novel concept of *Public–Private–Panchayat–People–Partnership* (5Ps). This 5*Ps model* is a blend of financial, managerial and innovative characteristics of various players. It is expected to add texture to the water resources development and management activities. Moreover, it has certain specific features, which happen to be

- A sense of ownership
- Freedom to innovate
- Corrective mechanism and
- Optimal use of resources.

7 The Need of the Hour: Humane Solutions

The management of water is not just building a physical edifice, but it is about building the relationship of society with its resource in nature. Each one must understand that from each raindrop, the best has to be produced (Center for Development Learning 2007). In the same way, one cannot think that either energy or food has to be produced and provided as and when required. As Gandhiji puts it, God has provided for everyone's basic *need* and not for his/her *greed*. One can understand that the present impending crisis is *man-made* and born out of his/her greed (Bhagawan Sri Sathya Sai Baba 1993). The ancients in India had used the guiding principle of *Dharma* for a sustainable living. The 21st century is governed by the *Homo Economicus Model* of economic development, guided by the principles of *self interest*, *rationality* and *perfect information* which has made the modern society utterly selfish and has made the life on planet Earth miserable. The triangular issue of economic imbalance—unlimited wants, limited means and maximizing the satisfaction—can be solved only if a *ceiling on desires* is adhered to. But, the ancients in India, under the banner of the *Philosophy of Love and Universal Welfare* (Bhalachandran 2011), had blended human values with economic, social, political and cultural activities. From this point of view, if one looks for the solution to the present day's crisis, the attitude of each stakeholder has to be changed. Each one has to literally enter into the shoes of the other and look for a *universal approach* in arriving at a solution that will not harm any one of the stakeholders.

Gandhiji's principle of *Trusteeship* works here as a handy tool. To be precise, one has to look beyond the materialistic gains in solving problems of this kind. What is required, at present, is to promote/develop the analytical tools that reflect human values rather than decisions taken on the basis of cold, calculative logic. Such an exercise must go with a feeling that humans are part of the creation and at no time any human behaviour must exhibit the supremacy of the human race over the other species in terms of arrogance, over exploitation of natural resources and spoiling the environment. In other words, each human being is expected to behave in a responsible manner, with a self commitment to be a *trustee* of other fellow beings, and within the natural resources bestowed with. This approach will certainly put an end to the present day crisis of water, energy and food production and lead the people and economy to *sustainable development*.

References

Abu-Zeid M (2001) Water pricing in irrigated agriculture. Int J Water Resour Dev 17(4):527–538

Agarwal A (2007) India's traditional water harvesting systems. National Law School of India University, Bangalore

Agarwal A, Narain S (eds) (1997) Dying wisdom: rise, fall and potential of India's traditional water harvesting systems, state of India's environment: a citizens' report. Centre for Science and Environment. New Delhi

Agarwal A, Narain S (1999) Making water management everybody's business: water harvesting and rural development in India. Gatekeeper Series IIED, London
Aithal KR (2007) Legal Framework of Groundwater Management. National Law School of India University, Bangalore
Asad M, Azevedo LGT, Kemper KE, Simpson LD (1999) Management of water resources: bulk water pricing in Brazil. World Bank, Technical Paper No. 432, Washington DC
Batra R, Mahajan D (2009) India's energy security: new opportunity for a sustainable future. TERI, New Delhi
Bhagawan Sri Sathya Sai Baba (1993) Thought for the day. Sri Sathya Sai Book Trust, Prasanthinilayam, pp K.2.s
Bhalachandran G (2011) Kautilya's model of sustainable development. Humanomics 27(1): 41–52 (Emerald Group Publishing Limited, Bingley)
Bhalachndran G, Aneja Ram P, Subramanian S (2009) Policy framework for energy sector: the need for demand side management. India Econo Rev 6: 98–107
Bhat S (2007) Water resource management in India: few reflections. National Law School of India University, Bangalore
Bhatia R (2007) Water and economic growth. In: Briscoe J, Malik RPS (eds) India's water economy: bracing for a turbulent future. Oxford University Press, New Delhi, pp 99–136, 206–246
Blomquist W, Heikkila T, Schlager E (2001) Institutions and conjunctive water management among three western states. Nat Resour J 41(3):653–684
Briscoe J, Malik RPS (2006) India's water economy: bracing for a turbulent future. Oxford University Press, New Delhi
Briscoe J, Malik RPS. (2007) India's water economy: an overview. In: Briscoe J, Malik RPS (eds) India's water economy: bracing for a turbulent future. Oxford University Press. New Delhi, pp 1–9
Brown E, Elliott NR (2005) Potential energy efficiency saving in the agriculture sector. American Council for an Energy-Efficient Economy (ACEEE), Report No IE053
Carozza PG (2003) Subsidiarity as a structural principle of international human right law. Am J Int Law 97(38):39–79
Center for Development Learning (2007) Waternama. Center for Development Learning, Bangalore 2007
Deshpande RS, Naika TR (2002) Impact of minimum support prices on agricultural economy: a study in Karnataka. ADRT, ISEC, Bangalore
Devika Devaiah P (2010) Government of Gujarat: Jyotigram Yojana. Erehwon Innovation Consulting
NAAS (2008) Sustainable energy for rural India. Policy Paper 41
Dubash Navroz K (2007) The electricity-ground water conundrum: Case for a political solution to a political problem. Econ Polit Wkly 45–55
Dubash Navroz K, Rajan SC (2000) Power politics: process of India's power sector reforms. Econo Polit Wkly 36(35):3367–3390
FAO (2011) Top-down and bottom-up approaches. Natural Resources Management and Environment Department, UN Policy Brief 9
Gauri G (1988) Pricing for welfare: petroleum products in India. Oxford and IBH Publishing, New Delhi
Godbole M (2002) Electricity regulatory commission: the jury is still out. Econ Polit Wkly 37(23): 2195–2201
Government of India (2010) Ground water scenario of India 2009–2010. Central Ground Water Board, New Delhi
Gupta RK (2002) Water and energy linkages for groundwater exploitation: a case study of Gujarat state, India. Int J Water Resour Dev 18(1):25–45
Hira GS (2009) Water management in northern states and the food security of India. J Crop Improv 23(2):136–157

IRMA (2005) Impact assessment of jyotigram yojana in Gujarat. Report of a study for the Confederation of Indian Industry by Institute of Rural Management, Anand

Ishwarabhat P (2007) Legal management of groundwater to ensure rational use and development with justice. National Law School of India University, Bangalore

IWMI (International Water Management Institute) (2002) Innovations in groundwater recharge. IWMI-TATA, water policy briefing No. 1. Available at http://www.iwmi.cgiar.org/waterpolicybriefing/files/wpb01.pdf. Accessed 2 Oct 2011

Iyer RR (2009) Towards water wisdom: limits, justice, harmony. Sage Publications Ltd, New Delhi

Jagannathan NV, Vijay K (2009) Bridging the practice gap in water management. In Singh S, Reddy VR (eds) Changing contours of Asian agriculture: policies, performance and challenges. New Academic Foundation 321–338

Jain V (2006) Political economy of the electricity subsidy evidence from Punjab. Econ Polit Wkly 4072–4080

Jha BM, Sinha SK (2007) Towards better management of ground water resources in India. Central Ground Water Board, Government of India

Malik RPS (2002) Water-energy nexus in resource-poor economies: the Indian experience. Int J Water Resour Dev 18:47–58

Malik RPS (2007) World bank policies and lending assistance. In: Briscoe J, Malik RPS (eds) India's water economy: bracing for a turbulent future. Oxford University Press, New Delhi, pp 69–98

Malik RPS (2009) Energy regulations as a demand management option: potentials, problems and prospects. In: Saleth RM (ed) Strategic analysis of the national river linking project (NRLP) of India Series 3. International Water Management Institute 71–92

Ministry of Agriculture (MoA) (2011) Annual report 2010–2011. Government of India

Ministry of Finance (2011) Economic survey 2010–2011. Government of India

Ministry of Finance (2012) Economic survey 2011–2012. Government of India

Ministry of Water Resources (MoWR) (1996) Model bill to regulate and control the development of ground water. Government of India

Ministry of Water Resources (MoWR) (2010) Enactment and implementation of the model bill for ground water legislation dated 4 Feb 2010. Press Information Bureau, Government of India

Moench M (1994) Selling water: conceptual and policy debates over groundwater markets in India. VIKSAT, Pacific Institute, Gujarat

Moench M (1995) When good water becomes scarce: objectives and criteria for assessing over development in ground water resources. In: Moench M (ed) Ground water availability and pollution: the growing debate over resources condition in India. VIKSAT, Ahmedabad

Moench M (2002) India's ground water challenge. Available at http://www.india-seminar.com/2000/486/486percent20moench.htm. Accessed on 25 Sept 2011

Mohanty N (2007) Scaling up water infrastructure. In: Briscoe J, Malik RPS (eds) India's water economy: bracing for a turbulent future. Oxford University Press, New Delhi, pp 327–352

Mohile AD (2006) Government policies and programmes. In: Briscoe J, Malik RPS (eds) India's water economy: bracing for a turbulent future. Oxford University Press, New Delhi

Morris S (2002) Country paper: (INDIA): overcoming the policy failures and the mess in the power sector in India today. Paper presented at the Fifth Afro–Asian international conference on resource mobilization and corporatization of the power sector to achieve commercialization and efficient

Morris S (2007) Pricing, regulation, and financing strategies. In: Briscoe J, Malik RPS (eds) India's water economy: bracing for a turbulent future. Oxford University Press, New Delhi, pp 247–281

Mukherjee S (2007) Groundwater for agricultural use in India: an institutional perspective. ISEC, Working Paper 187

Mukherjee S (2008) Impact of power subsidy on groundwater extraction for agriculture: a study in Madhya Pradesh. ISEC

Narayanamoorthy A (2008) Drip and sprinkler irrigation in India: benefits, potential and future directions. In: Amarasinghe UA, Shah T, Malik RPS (eds) India's water future: scenarios and issues, International Water Management Institute, Colombo, pp 253–266

Narayanamoorthy A (2009) water saving technologies as a demand management option: potentials, problems and prospects. In: Saleth RM (ed) Strategic analysis of the national river linking project (NRLP) of India series 3; International Water Management Institute, pp 93–126

Narayanamoorthy A, Deshpande RS (1998) Micro-irrigation for sustainable agriculture. The Hindu, Madras, 8 Jan1998, p 28

Narula KK, Lall U (2010) Challenges in securing India's water future. J Crop Improv 24(1):85–91

Nelson GC, et al (ed) (2010) Food security, farming and climate change to 2050: scenarios, results, policy options. IFPRI

Padmanaban S, Totino J (2001) Energy efficiency in Indian agriculture. Energise + 1. issue 1

Palmer Jones R (1995) Ground water markets in South Asia: a discussion of theory and evidences. In: Moench M (ed) Electricity prices: a tool for ground water management in India. VIKSAT, Natural Heritage Institute, Ahemdabad

Pande BM (1997). A multi-millennial mission. In: Agrawal A, Narain S (eds) Dying wisdom, CSE, New Delhi, pp 11–23

Planning Commission (2007) Ground water management and ownership. Report of the Expert Group Government of India, New Delhi

Rao SVN, Bhallamudi SM, Thandaveswara BS (2004) Conjunctive use of surface and ground water for costal and deltaic systems. J Water Resour Plann Manage 266–287

Reddy VR (2009) Water pricing as a demand management option: potentials, problems and prospects. In: Saleth RM (ed) Strategic analysis of the national river linking project (NRLP) of India Series 3, International Water Management Institute, pp 25–46

Reddy VR (2009) Water pricing as a demand management option: potentials, problems and prospects. Centre for economic and social studies, Hyderabad. Available at http://www.iwmi.cgiar.org/Publications/Other/PDF/NRLP%20Proceeding-3%20Paper%20-%202.pdf. Accessed on 12 Sept 2011

Rhonda L, Weseen S, Kowalski J (1998) Energy efficiency trends in the agriculture sector. Available at http://www.docstoc.com/docs/32723458/ENERGY-EFFICIENCY-TRENDS-IN-THE-AGRICULTURAL-SECTOR. Accessed on 5th Sept 2011

Roy AR, Uttam K, Ganguly M (2009) Irrigation of top down and bottom up approach in urban and regional planning: West Bengal experience of draft development plans (DDP) and beyond. National Town and Country Planners Congress, Goa, pp 1–8

Saleth RM (1996) Water institutions in India: economics, law and policy. Commonwealth Publishers, New Delhi

Saleth RM, Amarasinghe UA (2009) Promoting irrigation demand management in India: policy options and institutional requirements. In: Saleth RM (ed) Strategic analysis of the national river linking project (NRLP) of India series 3. International Water Management Institute, Colombo, pp 1–24

Sanoff H (2000) Community participation methods in design and planning. Wiley, New York

Savenije HHG, van der Zaag P (2002) Water as an economic good and demand management paradigms with pitfalls. Water Int 27(1):98–104

Scott CA, Shah T (2004) Groundwater overdraft reduction through agricultural energy policy: insights from India and Mexico. Int J Water Resour Dev 20(2):149–164

Sekhar A (2007) Development and management policies: perspective of the planning commission. In Briscoe J, Malik RPS (eds) India's water economy: bracing for a turbulent future. Oxford University Press, New Delhi, pp 47–68

Shah T (1993) Ground water markets and irrigation development: political economy and practical policy. Oxford University Press, New Delhi

Shah T (2005) Community management of ground water resources: an appropriate response to ground water overdraft in India. IWMI-TATA water policy program: Comment 4

Shah T (2009) India's ground water irrigation economy: the challenge of balancing livelihood and environment. IWMI

Shah T, Verma S (2008) Co-management of electricity and ground water: An assessment of Gujarat's Jyotigram scheme. Econ Polit Wkly 59–66

Shah T, Scott C, Kishore A, Sharma A (2003) Energy-irrigation nexus in South Asia: improving ground water conservation and power sector viability. IWMI Research Report no 70, Colombo

Shah T, Gulati A, Hemant P, Shreedhar G, Jain RC (2009) Secret of Gujarat's agrarian miracle after 2000. Econ Polit Wkly XLIV 52: 45–55

Shenoy Narayana K (2009) Traditional water harvesting methods of India. Organizer, 16 Aug 2009. http://organiser.org/archives/historic/dynamic/modulese00e.html?name=Content&pa=showpage&pid=304&page=22. Accessed on 25 Sept 2011

Sinha BPC, Sharma SK (1987) Need for legal control of groundwater development: analysis of existing legal position. Bhu-Jal News: 10–13. In: Aithal KR (ed) Legal framework of groundwater management. National Law School of India University. Bangalore. 2007. Available at http://www.nlsenlaw.org/water/articles/legal-framework-of-groundwater-management/. Accessed on 2 Sept 2011

Somayajulu DSN (2007) Ground water management and law. National Law School of India University, Bangalore

TERI (2005) TEDDY. Teri Press, New Delhi

TERI (2010) TEDDY. Teri Press, New Delhi

The Hindu (2006) States told to ensure MSP to farmers. Available at: http://www.hindu.com/2006/09/27/stories/2006092724610300.htm. Accessed on 27 Sept 2011

The Hindu (2010) Six states reject model bill on groundwater. Available at Http://www.Thehindu.Com/News/National/Article103442.Ece. Accessed on 27 Sept 2011

Times of India (TOI) (2010) Bangalore edition, 13th Apr 2010

Tongia R (2007) The political economy of Indian power sector reforms. In: Victor DG, Heller TC (eds) The political economy of power sector reform: the experiences of five major developing countries. Cambridge University Press, New York

UIDAI (2011) Discussion Paper on Aadhaar based financial inclusion. Planning commission; Government of India

Vaidyanathan A (2003) India's economic reforms and development. Academic Foundation, New Delhi

Varughese GC (2007) Water and environmental sustainability. In Briscoe J, Malik RPS (eds) India's water economy: bracing for a turbulent future. Oxford University Press, New Delhi, pp 184–205

Vyas VS (2007) Economic reforms through principled pragmatism. In: Briscoe J, Malik RPS (eds) India's water economy: bracing for a turbulent future. Oxford University Press, New Delhi

http://europa.eu/scadplus/glossary/subsidiarity_en.htm

http://www.narendramodi.in/pages/power-uninterrupted-jyoti-gram

Zilberman D, Lipper L (1999) The economics of water use. In: Van den Bergh R, Jeroen CJM (eds) Handbook of environmental and resources economics. Edward Elgar Publishing Ltd, UK

Impact of Mahatma Gandhi National Rural Employment Guarantee Scheme on Livelihood Security and Eco-Restoration in Andhra Pradesh

P. Leelavathi

1 Introduction

The Mahatma Gandhi National Rural Employment Guarantee Act is in implementation from 2006 onward in 200 most backward districts and was extended to all rural districts of India in 2008 with renewed vigour and mandate to enhance the rural livelihood opportunities. In addition to 100 days guaranteed employment in a financial year to a household, MGNREGA, aims at regenerating the environment by developing productivity of land and forests by execution of works such as irrigation tanks, ponds, water harvesting trenches, and check-dams. These assets will persist for a longer time, if well managed by the locals, create sustainable livelihoods, and promote local and regional economic growth. In this context, MGNREGA should be seen more as livelihood-generating programme than a wage-earning scheme (CSE 2006).

During the last five years of MGNREGS implementation, various organisations and individual scholars have conducted many studies by focusing upon implementation issues, with specific reference to employment generation. However, none of these studies focused on the nature of assets created and their usage by the beneficiaries for productive purpose (AFPRO 2010).The availability of large amount of resources provides an opportunity for the creation of productive assets such as water conservation and harvesting structures. A shift from employment provision to creation of productive assets could possibly help in better

This paper is derived from the PhD thesis submitted to Acharya Nagarjuna University, Andhra Pradesh, India, in August 2011 and presented in the International Humboldt College, 'Regional and Expert International Conference On Adaptive Management of Ecosystems: The Knowledge systems of societies for ADAPTATION and MITIGATION of impacts of CLIMATE CHANGE' held during Oct 19–21, 2011, at ISEC, Bangalore.

P. Leelavathi (✉)
Centre for Wage Employment and Poverty Alleviation (CWEPA), National Institute of Rural Development (NIRD), Hyderabad 500030, India
e-mail: leela.petals@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_31,

implementation of the scheme in the states like Andhra Pradesh as the physical assets are more easily perceptible than wages paid to individuals. This may be one of the reasons why the schemes such as Pradhan Mantri Gram SadakYojna (PMGSY) and the Watershed Development Programmes perform well in some states (CSE 2008). So far, the relationship of MGNREGA to eco-restoration has not been studied, but it is clear that afforestation (which also serves as a carbon sink) and water conservation efforts of MGNREGA would have a significant effect on food, water and livelihood security (MoRD 2009).The MGNREGS works, apart from providing employment and income, provide multiple environmental services such as increased ground water recharge, water percolation, and water storage in tanks, increased soil fertility, reclamation of degraded lands and carbon sequestration (Ravindranath et al. 2009). By taking into account the location of the impact area, life of the assets, actual use of assets by the beneficiaries, environmental services like soil loss prevention etc. Kareemulla et al. (2010) concluded that the soil and water conservation works carried out under MGNREGS are yielding better returns in districts with lower cropping intensity. However, a few researchers argue that the partial withdrawal of labour from the farm sector has affected the agricultural operations and food prices (Harsha 2010).[1]

The relationship between the natural resources, agriculture and livelihoods is an interesting dimension and it reinforces that the degraded natural resources affect the agricultural productivity which in-turn reduce the rural livelihood opportunities. Any improvement of natural resource base leads to regenerate employment opportunities which can improve the livelihoods of the poor. This paper mainly focuses on the status of MGNREGS works, their usefulness, quality and durability, contribution to natural resources, agriculture and improvement of livelihoods of the sample households in the study Gram Panchayats (GPs).

2 Methodology

In order to study the plausible impact of MGNREGS on livelihoods and eco-restoration, a survey has been conducted in nine Gram Panchayats (GPs)[2] of three districts,[3] viz., Anantapur, Nizamabad and Vizianagaram of Andhra Pradesh (AP) and 315 households were selected following the multistage stratified random sampling method. Both primary and secondary (from www.nrega.ap.gov.in) data along with worksite visits are used to assess the status of MGNREGS assets. The primary data on assets was collected directly from the sample worker through survey schedule and Focused Group Discussions (FGDs) to assess their quality,

[1] A former Ambassador to UN Millennium Development Goals.

[2] Lowest level of unit of administration.

[3] The three sample districts are Phase-1 MGNREGS districts where it has been started during 2006–2007.

durability and usefulness. Further, from the list of completed works in the sample GPs, 55 works that are important from the point of the agro-climatic region were selected randomly and assessed directly through worksite visits. The impact of MGNREGS assets on agriculture and livelihoods was measured by analysing primary data on benefits gained by the sample households. The reference period for the study is 2006–2007 to 2010–2011 (until December).

3 Performance of MGNREGA

In India, of the 192.8 m ha gross cropped areas, only 79.44 m ha is under irrigation and 146.82 m ha is degraded. About 8 % of total geographical area is under fallow. The per capita availability of land declined from 0.89 ha in 1951 to 0.37 ha in mid-1990s and is estimated to reduce further to 0.19 ha by 2035 (GTZ 2002). The per capita availability of agriculture land is 0.14 ha in 2009 (MoEF 2009a). Further, the water security is emerging as an increasingly important and vital issue for India. The stage of Ground Water Development for the country as a whole is 58 %. Highly intensive development of ground water in certain areas in the country has resulted in over exploitation leading to decline in the levels of ground water and seawater intrusion in coastal areas. Out of 5,723 numbers of assessment administrative units, 839 units are 'overexploited', 226 units are 'critical', 550 units are 'semi-critical', 4,078 units are 'safe' and 30 units are 'saline' (MoWR 2008). The forest and tree cover of the country is 690,899 km^2 in 2007 (21.02 % of geographical area). However, the pressure on India's forests continues to be very high, with more than 200 million people being dependent on forests for livelihood. There is an everincreasing demand for diverting forestlands for construction activities like dams, roads, power stations, townships, etc. (MoEF 2009b).

In this situation, the MGNREGA acts as a growth engine for sustainable development of agriculture economy through rejuvenation of natural resource base, i.e., land, water, forests. The Ministry of Rural Development (MoRD 2008b) also claims that the MGNREGA works not only to provide local environmental services, they also have the potential to yield co-benefits of adaptation and mitigation in the context of global climate change as its assets rejuvenate the livelihood base and enhance carbon sequestration in agricultural soils, pasturelands, and woody perennials.

3.1 Status of Assets at National Level

The data relevant to the works created at the national level in all five years of MGNREGS were accessed from www.nrega.nic.in and analysed and presented in Figs. 1 and 2.

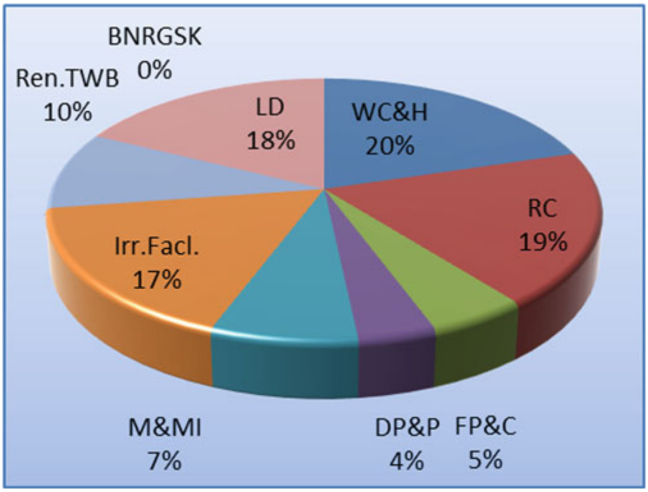


Fig. 1 Share of different categories of works (*Note LD* land development, *BNGRSK* bharat nirmanrajiv gandhi sevakendras, *WC&H* water conservation and harvesting, *RC* rural connectivity, *FP&C* flood protection and control, *DP&P* drought proofing and protection, *M&MI* micro and minor irrigation, *Irr. Facl.* irrigation facilities to land owned by SC, ST, BPL, Small and Marginal Farmers etc., *RenTWB* renovation of traditional water bodies)

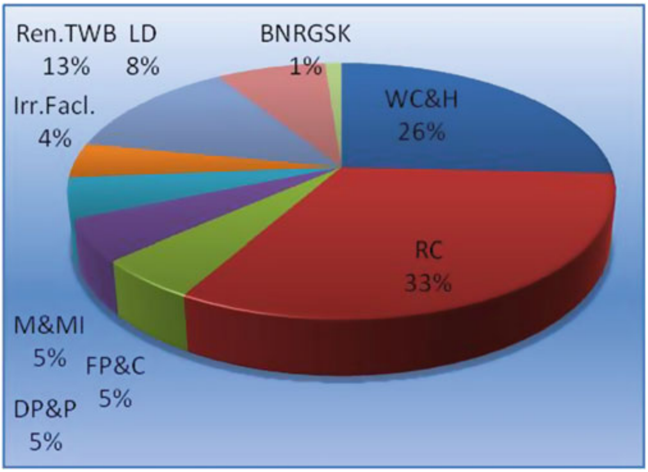


Fig. 2 Share of expenditure on various categories of works (*Note LD* land development, *BNGRSK* bharat nirmanrajiv gandhi sevakendras, *WC&H* water conservation and harvesting, *RC* rural connectivity, *FP&C* flood protection and control, *DP&P* drought proofing and protection, *M&MI* micro and minor irrigation, *Irr. Facl.* irrigation facilities to land owned by SC, ST, BPL, Small and Marginal Farmers etc., *RenTWB* renovation of traditional water bodies)

It is evident from Fig. 1 that high priority has been given to water conservation and harvesting works at the national level and about one-fifth of total works have been taken up for the purpose. Keeping in view, the need for infrastructure development in rural area, the next priority was accorded to rural connectivity. As the rural connectivity works (different types of roads) have higher material costs and may defeat the main objective of MGNREGA, i.e., provision of manual work, the MoRD has suggested the convergence approach between the MGNREGS and the PMGSY.[4] Even then, the expenditure on rural connectivity works was about one-third of the total expenditure incurred under MGNREGA during the last five years (Fig. 2). This indicates gradual shift of focus from NRM related activities to infrastructure development works under MGNREGS by the states.

As agriculture production and productivity was the main concern, the works related to land development, provision of irrigation facilities and horticulture plantation have also been given importance in a few states like Andhra Pradesh and Chhattisgarh. Further, the analysis of year wise data indicated that drought proofing and, micro and minor irrigation works were taken up on a large scale during 2010–2011 at national level.

3.2 Status of Assets in Andhra Pradesh State

The Andhra Pradesh state has spent about Rs. 1,600 bn. under MGNREGS until 2010–2011. A summary of works taken up under MGNREGS-AP during last five years is presented in Table 1.

In AP about 17.6 lakh works were taken up and of which about 15.04 lakh (85 %) of works were completed in the last five years (GoAP 2008). The state's contribution towards natural resource productivity through MGNREGS works is highly appreciable as its share of works at the national level in micro and minor irrigation canal repairs (45.42 %), water conservation (40.44 %), land development (30.68 %) and renovation of traditional water bodies (20.6 %) was high. At the state level, more than one-third and one-fourth of the total works accounted for water conservation and land development, respectively. These works are very important for agriculture productivity as the available land for agriculture reduced from 110.42 lakh ha in 1990s to 100.42 lakh ha during 2004–2005 in the state. Similarly, the irrigated area has come down from 54.2 lakh ha in 1990s to 47.7 lakh ha in 2004–2005 (GoAP).[5] Further, the report of the Commission on Farmer's Welfare (2006) clearly indicates that inadequate and declining water supply is one of the most significant problems and constant concern of the farmers in Andhra Pradesh. It has recommended a massive programme for restoration of tanks and

[4] PMGSY is a centrally sponsored rural road programme of India.

[5] GoAP (2008), "Human Development Report 2007: Andhra Pradesh", *Centre for Economic and Social Studies,Government of Andhra Pradesh,* Hyderabad, 2008.

Table 1 Year wise and category wise works completed in Andhra Pradesh

Category of works	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	Total completed works	Share in national level works (%)
Water conservation	47,032 (3.13)	30,075 (2.00)	38,533 (2.56)	161,391 (10.73)	258,310 (17.18)	535,341 (35.60)	40.44
Drought proofing and Plantation	10,171 (0.68)	5,083 (0.68)	7,051 (0.47)	19,625 (1.30)	14,900 (0.99)	56,830 (3.78)	21.98
Irrigation canals (micro and minor irrigation works)	4,110 (0.27)	4,771 (0.32)	16,044 (1.07)	64,737 (4.3)	131,164 (8.72)	220,826 (14.68)	45.42
Provision of irrigation facilities	207 (0.01)	3,566 (0.24)	12,795 (0.85)	34,000 (2.26)	78,275 (5.20)	128,843 (8.57)	11.70
Renovation of traditional water bodies	6,222 (0.41)	3,971 (0.26)	5,292 (0.35)	27,256 (1.81)	86,598 (5.76)	129,339 (8.6)	20.60
Land development	23,083 (1.53)	31,056 (2.07)	40,619 (2.70)	136,361 (9.07)	133,698 (8.89)	364,817 (24.26)	31.68
Flood control	0 (0.0)	586 (0.04)	1,123 (0.07)	4,241 (0.28)	4,228 (0.28)	10,178 (0.68)	3.11
Rural connectivity	209 (0.01)	203 (0.01)	1,118 (0.07)	12,154 (0.81)	44,018 (2.93)	57,702 (3.84)	4.67
Total number of works	91,034 (6.05)	79,311 (5.27)	122,575 (8.15)	459,765 (30.57)	751,191 (49.95)	1,503,876 (100.0)	21.85

Source www.nrega.ap.gov.in as on 20.2.2011
Figures in parentheses are percentages to total completed works

other minor water bodies on priority basis in the drought-affected regions (Ghosh 2006). The ground water table has depleted in the state due to increased number of bore-wells and dugout wells, which need to be recharged by putting more efforts on rainwater harvesting structures. Based on these recommendations, the Rural Development Department in collaboration with the Minor Irrigation Department has renovated about 19,000 Minor Irrigation (MI) tanks under MGNREGS until 2009–2010. In each village, in the name of 'Indiramma Cheruvu', one tank was renovated through the tasks like bush clearance, desilting, bund strengthening, repairs to sluices, breach closing, etc. Priority has also given to soil and water harvesting structures to recharge the ground water.

Next in the order of magnitude is creation of irrigation facility and horticulture plantation in the lands owned by SC/ST/Land Reform beneficiaries (9 %). This was done by digging of new channels or desilting of existing feeder and field channels and execution of farm ponds. The category of works under which very few works were taken up include drought proofing (3.8 %) and flood control and protection works (>1 %). However, their number has been increased in recent years. It is further evident from the above table that the high growth of works related to 'Rural Connectivity' in all the five years. From the discussions with the officials, it is understood that the state is allocating 25 % of MGNREGS funds towards rural connectivity works due to pressure from political elites. It is also one of the causes for increased material cost year by year.

The discussions with the state level functionaries revealed that in the first year of MGNREGS, it has encouraged Jatropha plantation under 'drought proofing' category but failed copiously as farmers were unable to provide water for the survival of plants during peak summer months. Hence, in 2009–2010, the forest department has taken the responsibility of afforestation works. As per the official data, about Rs. 5,963 lakh was spent and about 31.9 lakh person days of employment was generated by rising nurseries, social forestry works and boarder plantation in the fields of farmers till December 2010 by the forest department. As the forest department will not allow the outsiders to work in the forest areas, these works have enabled the forest dwellers to get employment under MGNREGS. Similarly, the horticulture department has played a major role in horticulture plantation. As per the official data, during 2010–2011, an estimated cost of Rs. 503.07 cr was shared among State Horticulture Mission (46.92 %), AP Micro Irrigation Project (0.002 %) and MGNREGS (53.3 %) to develop horticulture plantation in about 79,000 ha in three years. Until December 2010, about one-third and two-third of targeted plantation were completed in Anantapur, Nizamabad and Vizianagaram districts, respectively. A high percentage of works under drought proofing and horticulture plantation works are under progress, as the plantations works will be maintained for three years under MGNREGS. The details of completed works in the three sample districts are given in Table 2. Before examination of types of works, it is appropriate to brief the profile of the sample districts.

Table 2 Distribution of category wise completed works in the sample districts

Category of work	Anantapur	Nizamabad	Vizianagaram	Total
Water conservation	74,013(58.97) {20.08}	16,285 (34.16) {19.81}	11,866 (26.35) {7.62}	102,164 (46.82) {23.3}
Drought proofing and plantation	10,265 (8.18) {3.31}	2,354 (4.94) {0.86}	845 (1.88) {0.39}	13,464 (6.17) {1.0}
Micro and minor irrigation works	2,384 (1.9) {0.13}	6,259 (13.13) {1.4}	4,412 (9.8) {6.02}	13,055 (5.98) {1.83}
Provision of irrigation facilities	9,222 (7.35) {39.68}	3,224 (6.76) {9.48}	1,899 (4.2) {5.19}	14,345 (6.57) {21.19}
Renovation of traditional water bodies	2,084(1.66) {3.68}	7,252 (15.21) {45.26}	19,773 (43.91) {70.77}	29,109 (13.34) {26.18}
Land development	26,166 (20.85) {31.04}	9,875 (20.72) {20.85}	4,880 (10.84) {7.95}	40,921 (18.75) {23.30}
Flood control	54 (0.04) {0.09}	598 (1.25) {0.98}	16 (0.04) {0.02}	668 (0.31) {0.63}
Rural connectivity	1,315 (1.05) {2.0}	1,819 (3.82) {1.36}	1,344 (2.98) {2.04}	4,478 (2.05) {2.61}
Total works	125,503 (100.0)	47,666 (100.0)	45,035 (100.0)	218,204 (100.0)

Source www.nrega.ap.gov.in as on 02.2.2011
Figures in () are percentages of total completed works in the district
Figures in { } are percentages of employment contributed by the category of works

3.3 Status of Assets in the Three Sample Districts

The three sample districts are having three different agro-economic conditions. Anantapur is a desert prone and agriculturally backward district due to its geographical position and lack of irrigation sources and poor soils. The incidence of drought was more frequent in Anantapur (Athreya 2009) compared to the other two districts. On the other hand, Nizamabad is an agrarian district with more than 60 % net-cropped area under irrigation. In Vizianagaram 80 % of cultivation is purely under rain-fed conditions and the irrigation sources (tanks and ponds) are also mostly depending on the rainfall. All the three districts included a significant number of Scheduled Castes, Scheduled Tribes and Other Backward Classes. The human development indices of Vizianagaram and Anantapur districts are much lower than that of Nizamabad. The state has laid strong emphasis on rural development and poverty alleviation strategies. High female work participation rate was reported in the state but the wage rates for females are lower than that of males before the MGNREGS implementation (GoAP 2007).

It can be seen from the Table 2 that there is an association between the type of works executed in a sample district and its agro-climatic zone. For example, tanks are the main source of irrigation in Vizianagaram and, hence, a greater number of MI tank works have been completed. In the drought prone Anantapur, drought mitigation works followed by land development and provision of irrigation facilities has been preferred. In Nizamabad, the main source of irrigation are canals and tanks and, hence, more works related to renovation of traditional water bodies, micro and minor irrigation canal repairs, and water conservation works have been taken-up. The discussion with officials revealed that flood control works have been mostly executed to protect the low-lying residential areas in all three districts. The percentage of drought proofing works is moderately higher in all three study districts compared to the state level.

The number of rural connectivity works was higher in Nizamabad compared to the other two districts. From the discussions with the Mandal level functionaries, it was understood that the Mandal Parishads and Zilla Parishads[6] have executed the internal-habitation roads and link roads with MGNREGS funds. The analysis of data revealed that the share of wage employment was akin to the paid wage amount in all the districts and state. Such relationship was also found to be valid for all the categories of works. During 2010–2011, the GoAP has linked the Comprehensive Land Development Programme (CLDP)[7] with MGNREGS and integrated with Watershed Development Programme of MoRD to mitigate the environmental and climate risks. Such climate smart investment strategies need to be incorporated in MGNREGS guidelines.

3.4 Status of Assets in the Sample Gram Panchayats

The secondary data on completed works in the sample GPs was collected from the offices of Programme Officers' and presented in Table 3.

Table 3 District wise details of MGNREGS works in the sample GPs

Districts	Total works taken up	Completed works			Works in progress		
		Number	Amount spent (₹.)	Person-days of employment generated	Number	Amount spent (₹.)	Person-days of employment generated
Anantapur	570	340	(59.6)	405,58,947		3,85,237	230 (40.4)
3,47,69,251			2,30,810				
Nizamabad	322	235	(72.9)	651,85,448		5,56,129	87 (27.1)
149,69,517			1,19,149				
Vizianagaram	228	153	(67.2)	477,94,154		3,94,398	75 (32.8)
51,55,220		34,412					
Total	1120	728	(65.0)				
15,35,38,549			13,35,764	392 (35.0)		5,48,93,988	3,84,371

Source Data from the offices of Programme Officers concerned

[6] Local administrative units in a District.

[7] A State Government Programme supported by National Bank for Agriculture and Rural Development (NABARD).

Table 4 Category wise completed works and their existence

Category	Total works completed	No. of works non-existing
Water conservation	369 (50.69)	62 (16.80)
Drought proofing and plantation	24 (3.3)	18 (75.00)
Irrigation canals (micro and minor irrigation works)	14 (1.92)	1 (7.14)
Provision of irrigation facilities	31 (4.26)	4 (12.90)
Renovation of traditional water bodies	108 (14.84)	3 (2.78)
Land development	174 (23.9)	9 (5.17)
Flood control	3 (0.41)	0
Rural connectivity	5 (0.69)	0
Total works	728 (100.0)	97 (13.32)

Source Primary data collected through FGDs
Figures in parentheses are percentages to row total

Keeping in view of the importance of agriculture sector and food security, the state government has provided clear instructions to adopt Farmer Centric Planning in 2010–2011. Accordingly, the lands of all SCs and STs Farmers should be given priority to make them into productive resources. Hence, about 169 horticulture plantation works, 238-land development works, 13 works related to provision of irrigation facilities are under progress in the sample GPs. This clearly shows the contribution of MGNREGS to primary sector.

3.5 Results of FGDs on Quality, Durability and Usefulness of Assets in the Sample GPs

Of the total works taken up under MGNREGS, 65 % were technically completed in the study GPs. The highest percentage of works was completed in the sample GPs of Nizamabad, which have also spent the highest amount compared to the other sample GPs of Anantapur and Vizianagaram. More than the number, their existence, quality and usefulness are important. Hence, the status of completed works was discussed in the FGDs and the results are presented in Table 4.

- As per the community version, the impact of these works was very substantial as they had the potential to fill some critical gaps in the agriculture sector. For example, in Vizianagaram, most of the workers expressed their happiness with the restoration of MI tanks and small ponds as these works reduced the intensity of flood damage during 2010 and had saved thousands of acres of crop. Similarly, in Anantapur district, the community was mobilised in a large way to take up dry land horticulture. The district administration was able to complete the plantation in more than 1,000 acres in just 5 months, i.e., during 2009–2010 in the sample (Utakal) village. The FGDs with workers revealed that about 80–85 % survival of horticulture plantation was reported. The main fruit crops taken up so far for cultivation were Mango, Guava, Sapota, etc. The data also indicates that 49 and 29 % of beneficiaries of plantation are SCs and STs, respectively (more than their share in the state population), indicating the inclusive nature of the programme, which is highly appreciable. The workers also reported that horticulture would emerge as a lifeline for their families after 5–6 years. In Rampur GP of Nizamabad district, the community appreciated the development of 100 acres land and of which 80 acres were put under paddy cultivation. Most of the soils in this village are saline in nature and, hence, silt application has benefited agriculture.

- In Anantapur, about 17 types of works were executed under MGNREGS. The workers reported that the works like pebble bunding, clearance of Juliphera bushes, earthen bunding, MPTs, CCTs, dugout ponds, horticulture plantation and silt application are very useful and qualitative both for individual agriculture as well as for restoration of soil fertility. Similarly, assets like pebble bunds, RFDs, boulder removal, stone bunds, MPTs, bush clearance, land development were perceived as durable works by the respondents. However, the works related to irrigation channels, ponds and tanks were treated as less useful due to arid climatic conditions. Of all the works, roads were given the least priority by the community in terms of their usefulness in promoting livelihoods.
- In Nizamabad, out of 22 types of works, few works, viz., digging of wells, horticulture plantation, land levelling, earthen bunds, excavation of ponds, etc. were rated as useful works by the individual respondents as well as community. Few works like land development, diversion drains, bush clearance, feeder channels were treated as good quality works. As perceived by the workers, the most durable and long lasting works were check-dams, MPTs, excavation of ponds, earthen bunds, silt application, horticulture plantation etc.
- It is interesting to know that in Vizianagaram about 10 types of works were executed and most of them were water conservation and tank restoration works. About one-third of ponds were rated as very good in quality and almost all tanks works were ranked as durable and useful assets. However, few works like bush clearance and check-dams were perceived as not much useful to community in this district by the workers.

In all the sample villages, the community has ascertained that MGNREGS works greatly influenced the in situ water harvesting and conservation.

Of the total completed works, 86.7 % of the works are found to be existing while the rest (13.32 %) not existing as per the FGDs. The results show that the works falling mostly under drought proofing (75 %), water conservation and water harvesting (16.8 %), provision of irrigation facilities (12.9 %) did not exist due to their short life span and lack of annual maintenance. The incidence of non-existing works is slightly higher in Nizamabad (20.56 %) as compared to the other two districts.

Table 5 Details of works inspected and their physical status

Type of works	No. of works inspected	No. of existing works	No. of works maintained	Works useful to community/individual farmer
Soil and Water conservation works (bunds and ponds, CCTs, MPTs, loose boulders & check dam)	25 (45.5)	21 [84.00]	16 [64.0]	20 {80.0}
Drought proofing (forest nursery and bio-diesel plantation)	5 (9.1)	3 [60.0]	3 [60.0]	3 {60.0}
Micro and minor irrigation works (channels desilting and widening works, deepening of wells)	5 (9.1)	5 [100.0]	1 [20.0]	5{100.0}
Provision of irrigation facilities and horticulture plantation (mango plantation)	4 (7.3)	4 [100.0]	4 [100.0]	4 {100.0}
Restoration of MI tanks	4 (7.3)	4[100.0]	4 [100.0]	4 {100.0}
Land development (land development and silt application works)	7 (12.7)	7 [100.0]	5 [71.4]	7 {100.0}
Flood control works (diversion drains, filling up of water logged areas)	5 (9.1)	4 [80.0]	2 [40.0]	4 {80.0}
Total works	55 (100.)	48[87.27]	35[63.64]	47 {85.45}

Source Physical inspection of randomly selected works
Figures in () are share of total inspected works
Figures in [] are percentage of works existing/maintained in that category
Figures in { } are percentage of useful works to total existing works

3.6 Observations of Worksite Visits

Based on the list of completed works in the sample GPs, 55 works were selected randomly for verification based on the importance of work to that particular agro-climatic region. The selected schemes were physically inspected at the ground level for existence and usefulness. These works pertain to Farm Ponds (4), Pebble bunds (3), Stone bunds (3), Earthen bunds (6), Continuous Contour Trenches (CCTs) (2), Mango Plantation (3), Bio-diesel plantation (2), MI tank works (4), Desilting and widening of feeder channels (4), Cashew plantation (1), Forest Nursery (3), Dug out ponds (3), Mini Percolation Tank (MPT) (2), Agriculture fields with silt application (3), Restoration and deepening of well (1), Diversion drains (3), Land development (4), Loose Boulder Structures (3), Check Dam (1) and Filling up water logged areas (2). The physical status of these works is given in Table 5.

On field inspection of 55 works, existence of 87 % of works on the ground and usefulness of 85 % of works to the community was observed. However, lack of maintenance of these works by the concerned beneficiaries was noticed. The following are some of the critical observations made from the worksite inspections.

- Water availability has increased significantly due to MGNREGA in Vizianagaram and Nizamabad districts. In all, 72 and 68.4 % of the respondents agreed that NREGA had led to increased water availability in these two districts, respectively. This is mainly due to renovation of traditional bodies such as tanks, ponds and desilting of open wells. In Anantapur, even though the number of completed works mostly related to water harvesting there is hardly any impact to report due prevalence of drought situation during 2009–2010.
- As per the data, the highest percentage of non-existing works were under water conservation category, mainly the earthen bunds that were laid in small and marginal farmers' fields have been ploughed again during the rainy season to avoid loss of land for cultivation.
- Under drought proofing category of works, the survival rate of Jatropha plantation was negligible in Nizamabad district and 100 % mortality was observed in Anantapur.
- The official data indicated that about one-fourth of the completed works fall under 'land development' category. However, the impact of land development was not fully realised, as the comprehensive development of fallow lands had not taken place. Further, under land development, the government had taken up the land levelling work for weaker section families towards construction of basement of houses that were provided under 'Indiramma Housing' (a state government scheme). This work may not contribute to eco-restoration but improve the well-being of the beneficiary workers.
- Under Provision of irrigation facilities and land development category, broad beds and furrows[8] were executed during the last two years in the fields of farmers of Anantapur to harvest the rainwater but these works are mainly seasonal. Yet, the beneficiary farmers ascertained that these are useful practices for in situ water harvesting.
- The FGDs revealed that ponds are very appropriate water harvesting structures as they provide lifesaving irrigation to standing crops, simple to execute (technology) and can easily maintained by the local community. The construction of ponds/MPTs provides opportunity to generate unskilled employment, as these are labour intensive works. It was observed that these small ponds are providing drinking water to cattle in the month of February in arid Anantapur district.
- The desilted and widened feeder channels and field channels helped the tail end farmers in getting the irrigation water in lesser time than before, but maintenance of these field channels is a concern in Nizamabad and Vizianagaram.
- It also observed that some works like desilting of tanks, comprehensive restoration of MI Tanks were shown as different works on the same worksite. On enquiry, it was observed that for administrative convenience, one large work

[8] A method developed by ICRISAT.

was divided into a number of small works. Similarly, the horticulture plantation was under 2nd or 3rd year of maintenance and annual maintenance was shown as a separate work. However, these works are very useful to the community/ individual farmers.

- Out of the 55 sites visited, the works at five sites were technically incomplete. That means the construction was not carried out as per the planned dimensions. In all other sites, communities have been drawing benefits from the structures.
- The Field Assistants' salaries and worksite facilities were shown as water conservation works and these expenditures were booked as wages in the first two years.

4 Changing Livelihood Conditions of Sample Households

Many critics feel that MGNREGA may focus on employment and not on production; and the scheme merely redistributes the proceeds of a limited production. The scheme no doubt inflates workforce demand but, without a corresponding increase in production of useful asset, leads to inflation (Dey 2005).[9] However Shah (2009) in his article briefed that the investment on eco-friendly works ensures the employment growth by regenerating environment and by easing the agrarian limitations. Hence, effect of the MGNREGS assets and wage earnings on the livelihood status of the sample households is examined in this session.

4.1 Socio-Economic Status of Sample Households Before and After 5 years of MGNREGS

Of the 315 sample respondents, about 74 % of respondents were illiterate and most of them belonged to SCs and STs. It indicates the social backwardness of all the three regions. The average size of the household was four and economic dependency ratio is marginally reduced from 1.99 (2005–2006) to 1.86 (2010–2011) after five years of MGNREGS because of participation of women workers in the economic activity. For about 68 % of the sample households, 'agriculture labour' was the main livelihood source. For 6 % of households' agriculture was the main source of income before MGNREGS and this share has increased to about 10 % due to land development and other related activities of the Rural Development Department. The number of landholding families increased from 38.4 to 44.8 % in 5 years of MGNREGS due to identification and handing over the land that was assigned long back. Nearly one-fourth and half of the sample households' income had been less than Rs. 18,000 and Rs. 16,000, respectively, before MGNREGS

---

[9] Dey (2005). Interview with Dr Manmohan Singh, Prime Minister of India, 25 Aug 2007 http://www.deeshaa.org/2005/08/29/the-national-rural-employment-guarantee-scheme/

works were undertaken. These shares were reduced to 7.6 and 24.4 % after MGNREGS due to increased local wage rates and wage incomes of MGNREGS. The MGNREGS has become a lifeline to about 4 % of sample households and this clearly points out the contribution of MGNREGS to livelihoods through creation of assets useful to agriculture and by providing wage employment.

4.2 Benefits Gained by the Sample Households from MGNREGS

The primary data on number of days of employment and wages earned from MGNREGS and impact on agriculture was collected from the sample households and presented in Table 6.

The primary data analysis indicated that the mean acreage of land and total land under cultivation of the sample households marginally increased from 2.32 and 213.8 acres to 2.57 and 267.36 acres, respectively, at the aggregate level. Similarly, the number of cultivators increased from 92 to 104. That means 12 households have been brought back to their own agriculture that may raise demand for labour in their villages. The increase in cultivated land is visible in all three districts due to fallow land development followed by horticulture plantation. However, one cannot attribute it solely to MGNREGS. The contribution of other RD programmes like Comprehensive Land Development Programme (CLDP), Andhra Pradesh Micro Irrigation Programme (APMIP)[10] and additional investment by the beneficiary households must also be acknowledged here. Further, an enquiry has been made regarding creation of assets and additional benefits gained by individual farmers.

About 18 sample households have been provided with one or more assets for agriculture productivity enchantment and most of these households benefitted with the assets created in their fields. In all, 53 (16.8 %) farmers of the sample households got additional 40 days of employment in their own fields. The imputed value of which is about Rs. 1,238. It is a significant achievement of the programme. During field visits, it was observed that the number of paddy cultivating farmers has increased after MGNREGS in Nizamabad due to availability of irrigation water. Many poor farmers were benefitted from horticulture plantation. Similarly, in Kotarubilli GP of Vizianagaram, for the first time, many farmers, who earlier depended on rainwater, have gone for the second crop, as water is available due to increased storage capacity of MI tanks. The respondents also reported an increase in cultivated area after the work done under NREGA over the last 4 years. In 6 out of 9 villages, the FGDs revealed that there had been an increase of 50–80 acres area under crops. This land was previously left fallow.

[10] One of the state government projects supported by GoI.

Table 6 Benefits gained from MGNREGS since inception by the sample households

Asset creation and impact	Anantapur	Nizamabad	Vizianagaram	Total
Status of cultivated land during 2005–2006 among the sample HHs				
No. of HHs cultivating land	43	33	16	92
Extent of land under cultivation	140.85	50	23	213.85
Avg. size of cultivated land	3.28	1.52	1.44	2.32
Extent of land possessed	171.18	73.79	66	311.61
Assets created in number of individual farmer's fields	27 (25.7)	6 (5.7)	24 (22.9)	57 (18.09)
Positive impact of asset created	26 (24.8)	5 (4.8)	22 (2.1)	53 (16.8)
Average Additional employment days (in days) due to asset creation	48.6	57.8	26.09	39.96
Avg. additional income (in ₹.) got due to asset creation	1,486	1,280	947.73	1,238.46
Status of cultivated land during 2010–2011 among the sample HHs				
Number of HHs cultivating land	45	35	24	104
Extent of land under cultivation	171.18	64.3	26.4	267.36
Avg. size of cultivated land	3.80	1.84	1.10	2.57
Per cent of increase in land under cultivation in 2010–2011	21.53	28.60	14.78	25.02
Benefits gained from MGNREGS employment by the sample HHs				
Average number of days of employment provided to (Landholding)sample HH	53.8	87.47	77.29	73.96
Average wage earnings (₹.) of (landholding) sample HHs	4,988.03	8,223.08	7,382.23	6,926
Average number of days of employment provided to (landless)sample HHs	45.5	66.9	70.3	61.98
Average wage earnings (in ₹.) of(landless) sample HH	4,210.57	6,018.05	6,627.72	5,703.44
Average wage earning of participating household per year	6,530.17	8,146.322	9,138.278	7,994.454

Source Primary data
Note Figures in parentheses are percentage to total respondents

The data analysis relating to year wise wage earnings of the participating households clearly shows that the participating households of Vizianagaram, which is the most backward district among the sample districts, have gained more benefits in terms of wage earnings from MGNREGS. At the aggregate level, the average wage income of a participating household in a year was around Rs. 8,000. This was assured income to those households that have participated in MGNREGS work in a year. However, not all the sample households might have participated in all the five years in MGNREGS work. Further, it was interesting to note that the landholding households benefitted more than the landless, either in terms of days of employment or wage earnings. The landless households, on an average, were provided 61.98 days of employment against 73.96 days of employment to the landowning families. The situation is similar across the sample districts. The development of their own agriculture lands is another important incentive for the participation of the landholding households. The government should correct this situation and the landless should be given more opportunities under MGNREGS as the resource poor are more vulnerable to natural calamities.

Thus, MGNREGS is solving two critical problems in the state, namely poverty and eco-degradation. MGNREGS provides environmental services through increased soil fertility, restoration of water bodies and plantation which, in turn, provide livelihoods to the rural poor.

5 Conclusions and Recommendations

The aim of MGNREGS, apart from providing employment, is useful asset creation for drought proofing, natural resource management and amelioration of poverty. The study has estimated that at the state level, one-third and one-fourth of the total completed works fall under water conservation and land development categories, respectively. An association between the types of works and agro-climatic zones of sample districts was observed, and these assets have the potential to generate second-round employment by revitalising the agriculture sector. In the sample districts, 1,120 works were taken up for execution and about 65 % of them were completed and the remaining works are under execution. The FDGs in the sample villages revealed the existence of 86.7 % of executed works. The rest of the works were non-existing due to their short lifespan and poor maintenance. Works like land development, horticulture plantation, SMC works with rock or stone, dugout wells, MI tanks, farm ponds, CCTs, etc., were qualitatively good, useful and durable. However, under the current implementation regime, maintenance is not covered. While assets are created in large numbers, the Panchayats are being told to maintain them. The problem is that Panchayats don't have the money to undertake such large-scale maintenance works. This means that most of the assets are going to be put into disuse. Hence, the equity of beneficiary farmers also needs to be ensured for creating a sense of ownership and for maintenance of these assets.

Given the degraded condition of natural resources, the MGNREGS works have the capacity to enhance the productivity of degraded land. This was proved by 10.5 % of sample farmers who are able to get additional 40 days of employment. Thus, the MGNREGS has greatly influenced the agriculture sector through the labour market. This phenomenon needs to be studied in both irrigated and rain-fed areas to estimate the impact on cost of cultivation. Although scientific evidence in terms of impact of these assets is not available at this stage, yet it is learnt that MGNREGS works enhanced the livelihoods in all GPs. The successful cases are to be documented for replication elsewhere in the country. The study clearly indicated that there is no convergence between Department of Rural Development and Department of Agriculture which requires to be strengthened for adoption of technologies such as zero tillage, laser-levelling, broad-bed plantations, System of Rice Intensification (SRI) for productivity enhancement in arid and semi-arid regions of the state.

Keeping in view the gigantic nature of MGNREGS, the implementing departments and PRIs should work together on mutual trust and cooperation for the purpose of creation of durable and productive assets. Further, the government has not given importance to strengthen the participatory planning process by involving the local community. The state should develop perspective plans for GPs through community participation and MGNREGS needs to be implemented in the directions of the perspective plan so that the immense potential of MGNREGS for transforming rural livelihoods will be realised fully in the state. Additionally, to ensure effectiveness of the delivery system, monitoring and evaluation systems should be strengthened at all levels and the Community Based Organizations should be empowered to decode the assets details for the purpose of evaluation.

References

AFPRO (2010) Infrastructure development and beyond: exploring the scope for sustainable livelihood support under NREGA. A Study Commissioned by United Nations Development Programme, Action for Food Production, New Delhi

Ravindranath NH et al (2009) Environmental services, vulnerability reduction and natural resource conservation from NREGA activities. Indian Institute of Science, Bangalore

Athreya V (2009) Economic crisis and rural livelihoods. M.S Swaminathan Research Foundation, Chennai

CSE (2006) An ecological at: a backgrounder to the National Rural Employment Guarantee Act. Centre for Science and Environment, New Delhi

CSE (2008) An assessment of the performance of the NREGP in terms of its potential for creation of natural wealth in India's villages. Centre for Science and Environment, Report prepared for MoRD

Dey A (2005) Interview with Dr Manmohan Singh, Prime Minister of India. 25 Aug 2005. http://www.deeshaa.org/2005/08/29/the-national-rural-employment-guarantee-scheme/

Ghosh J (2006) Report of the commission on farmers' welfare. Government of Andhra Pradesh, Hyderabad

GoAP (2007) Human Development Report 2007: Andhra Pradesh. Prepared by Centre for Economic and Social Studies, Government of Andhra Pradesh, Hyderabad

GoI (2009) India: state of forest report. Forest Survey of India, Ministry of Environment and Forests, Government of India, Dehradun

GTZ (2002) Principles and practices of integrated watershed management in India, Indo-German bilateral project: watershed management. Gesellschaft fur Technische Zusammenarabeit (GTZ), New Delhi

Harsha A (2010) National Rural Employment Guarantee Act Review. Policy Proposals for India, 19 Feb 2010

Kareemulla K, Kumar S, Reddy KS, Rama Rao CA, Venkateswarlu B (2010) Impart of NREGS on rural livelihoods and agriculture capital formation. J Indian Agric Econ 65:524–539

MoEF (2009a) State of Environment Report, Ministry of Environment and Forest, Government of India, New Delhi

MoEF (2009b) India State of Forest Report, Forest Survey of India, Ministry of Environment and Forests, GoI, Dehradun

MoRD (2008a) Report of the Task Force on Convergence, Ministry of Rural Development, Government of India, September

MoRD (2008b) The national rural employment guarantee act 2005, Operational guidelines 2008. Ministry of Rural Development, Government of India, New Delhi

MoRD (2009) Presentation on diffusion of technology for sustainable development. Ministry of rural development, GoI, 23 Oct 2009

MoWR (2008) Annual report 2007–2008. Central Ground Water Board, Ministry of Water Resources, Government of India, New Delhi

Shah M (2009) Multiplier accelerator synergy in NREGA. The Hindu, Opinion Leader Page article, 30 April 2009

Promoting and Enhancing Sustainable Livelihood Options as an Adaptive Strategy to Reduce Vulnerability and Increase Resilience to Climate Change Impact in the Central Himalaya

R. K. Maikhuri, L. S. Rawat, Sunil Nautiyal, Vikram S. Negi, D. S. Pharswan and P. Phondani

1 Introduction

In the rural landscape of the central Himalaya, livelihoods of the people depend heavily on agriculture, animal husbandry and forestry sectors and they are inextricably connected with each other. The role of forest goods and services in sustaining the productivity of the agriculture and animal husbandry is immense. The central Himalayan region has a number of characteristics that increase the region's vulnerability to climate change impacts. Higher population and poverty, coupled with low resilience to climate risks, make the region highly vulnerable to climate change. Livelihoods of majority of the poor/marginal and traditional societies are heavily dependent on natural resources particularly in the hilly region. Changes in the availability of the resources, accentuated by climate risks, are expected to have far-reaching implications. These risks could undermine the gains made in poverty reduction and livelihoods and impede progress towards meeting the desired national development goals. International Panel on Climate Change (IPCC) has confirmed that we are now locked into inevitable changes in climate system. Changes on climate such as mean temperature, increased frequency and intensity of extreme weather events as well as changes in precipitation pattern, sea level rise and glaciers retreat have been projected. Although there is a lack of certainty in predicting and quantifying climate change impacts on socio-economic systems, it is well known that climate change impacts threaten a major dimension of human well being, namely food security. These climate change related risks threaten approximately 70 % of the rural people largely dependent on rain-fed agriculture

R. K. Maikhuri (✉) · L. S. Rawat · V. S. Negi · D. S. Pharswan · P. Phondani
G B Pant Institute of Himalayan Environment and Development, Garhwal Unit, Srinagar Garhwal, Uttarakhand, India
e-mail: rkmaikhuri@rediffmail.com

S. Nautiyal
Centre for Ecological Economics and Natural Resources (CEENR), Institute for Social and Economic Change (ISEC), V.K.R.V. Rao Road Nagarabhavi, Bangalore 560 072, India

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_32,

in the central Himalaya. For the rural poor, human security is synonymous with food security. Extreme droughts or untimely heavy rains have often led not only to loss of life, but also an exacerbation of poverty conditions through the degradation of the natural resource base, leading to increase in poverty particularly in low income groups. Hence, low income group or poor people are the most vulnerable to the impacts of climate change.

Thus, using sustainable livelihood approach for developing adaptation strategies and measures can assure people centered and bottom up approach to adaptation, which addresses future climate change by reducing existing vulnerabilities. This chapter examines how hard won lessons prioritized and provided a viable option for promoting livelihood, thereby reducing poverty based on harnessing the potential of natural resources in order to assure the design of locally relevant adaptation strategies that effectively lead to reducing adverse consequences of climate change. In addition, natural resources management based successful cases of the central Himalaya are used to illustrate how these activities may build the resilience of the rural poor.

2 Study Area

The central Himalaya fall in the state of Uttarakhand covering an area of 55,845 km^2 (of which 90 % is hilly and 10 % is plain area) constituting 1.63 % of the land area of the country (FSI 1999). Uttarakhand came into existence as the 27th state of Republic of India on 9th November 2000 and due to its geographic and strategic location, it has been given "Special Category Status by Union of India". It is rich in forest and has 35,392 km^2 of forest area which constitutes 64.8 % of its total geographical area. The total population of Uttarakhand as per the Census (2001) was estimated about 8.5 million with 963 female per 1,000 males. The state ranked 9th among the states of India in terms of literacy which accounts 72.28 % in 2001. The topography of the state is characterized by hilly terrain, rugged and rocky mountains and deep valleys with widely scattered habitation. Climate varies from sub-tropical in the valleys to temperate on the higher slopes with a summer monsoon. The high Himalayan ranges and glaciers form most of the northern parts of the state while the lower reaches are forested with habitat of wild animals. Two of India's mightiest rivers, the Ganga and the Yamuna take birth in the glaciers of Uttarakhand and are providing water for almost half of the country.

3 Key Vulnerabilities

The frequent and increasing occurrence of climate related disasters, particularly droughts and floods, underscores that the region's adaptive capacity is often overwhelmed under climate conditions. Livelihoods and economic activities are heavily dependent on natural resources and ecosystem services. In central Himalaya, livelihood of over 8.5 million people, almost 70 % of the regions' population, are centered on agriculture, livestock and bioresources collected from forest (Maikhuri et al. 2000a, b, 2001a, b). In this region, agriculture continues to be the main pillar of the economy in terms of livelihood. With limited access to irrigation, livelihood activities are highly vulnerable to variations in rainfall. The agriculture productivity in this region directly follows variation in annual rainfall (Maikhuri et al. 2009). For the large number of subsistence-based livelihoods, however, it is particularly the impact on non-monetary assets that reinforces conditions of food insecurity and poverty. Among other factors, climate related vulnerabilities are affected by land use change, environmental degradation and demographic trends. Agricultural growth in this region has been largely contributed and achieved through the Tarai plain areas (Maikhuri et al. 2009).

In the light of existing vulnerabilities, the impact of climate change on natural resources and ecosystem services and associated implications for food security and agricultural productivity represent key concerns. Climate change lends further urgency to the sustainable management of land and water resources and reduction of environmental degradation. Other key vulnerabilities that need to be considered include the effect of climate change on the disease burden in humans and livestock, given the prevalence of water and vector-borne diseases. Another grave concern is the loss of rural settlements/housing and infrastructure due to sinking of land/floods/landslide etc. in the geologically young and ecologically fragile mountains and other processes, which is well documented earlier (ICIMOD 2007) and recent natural disaster (landslides and floods) caused due to heavy rains in September 2010 is the eye witness. Mountain fragility which is geologically more sensitive also hampers efficient emergency relief and access to markets when it is most needed particularly during rainy season. Changes in extremes and run-off also will have future implications for hydropower energy infrastructure in the central Himalaya.

4 Adaptation to Climate Change and Climate Risk Management

4.1 Adaptation

Current changes in the climatic system tend to increase the vulnerability of livelihoods in two main ways. First, due to the fact that many of such livelihoods are exposed to more frequent and intense extreme events causing increasingly negative impacts. The second reason is related to the long term impacts of changes in temperature and rain patterns. Some potential impacts are conversion of irrigated and rainfed land into waste/barren land due to extended drought periods, irregular, less and no rainfall. Understanding the interrelationship between changes in the climatic system and development is therefore crucial for increasing adaptation capacity at the local level. This represent a challenge for scientists as for policy makers and those engaged in development and extension activities. As with many other natural phenomena, adaptation to changing climate has been reactive, in the sense that until now, adaptation measures are carried out only when the natural phenomenon triggering this behavior has already occurred. However, in order to plan and carry out more cost-effective adaptation measures, anticipatory measures and actions aimed at reducing vulnerability and increasing resilience are based on some assessment of conditions in the future. Therefore, there is need to explore appropriate alternatives and cost-effective adaptation measures. The Himalayan environment, economies and traditional communities are highly vulnerable to the impacts of climate change, while human and institutional capacities have limited responsive capacities. The most vulnerable are the marginal societies and rural poor, whose subsistence largely depends on the natural and forest resources. Under the pressure of climate change, the environment is responding in many different ways, some of which are difficult to foresee. Due to the changes in environmental patterns, existing problems are exacerbated and new ones can appear. As a consequence many vital factors for sustainable development such as water, food security, bioresources, health, infrastructure and natural ecosystems are seriously endangered.

4.2 Adaptation in Action

According to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2001), adaptation to climate change is defined as an adjustment in ecological, social or economic systems in response to observed or expected changes in climate change stimuli and their effects and impact in order to alleviate adverse impacts on change or take advantage of new opportunities. Adaptation can involve both building adaptive capacity thereby increasing the ability of individual, groups, or organizations to adapt to changes, and implementing adaptation decisions, i.e. transforming that capacity into action. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation. Both dimensions of adaptations can be implemented in preparation for or in response to impacts generated by a changing climate. Hence, adaptation is a continuous stream of activities, actions, decision and attitudes that informs decisions about all aspects of life, and that reflects existing social norms and processes (Adger et al. 2003).

Securing local livelihoods through environmental/natural resource management is not a new concept or goal. Decades of conservation/management and developmental activities have been designed and implemented to support traditional societies in strengthening their livelihoods without undermining the natural resources base upon which they depend. Whether these activities are labeled with the name i.e. conservation through people participation (CTPP), integrated natural resource management (INRM), participatory approaches for rehabilitation of degraded lands/forest land, they have produced a wide range of lessons on the challenges, complexities and enabling conditions that shape livelihood security in the face of different social and environmental risks (Maikhuri et al. 1997a, b; Rao et al. 1999; Maikhuri et al. 2000a, b). These hard-won lessons must not be overlooked but rather built in devising climate change adaptation strategies. One way of building upon these lessons is to examine the so-called successful cases whereby programme, projects and activities have successfully restored or enhanced ecosystem services, diversified local livelihoods, and therefore increased community resilience to changes and trends such as climate variability. Here we are highlighting successful case studies from different parts of the Garhwal region in the central Himalaya carried out by the Garhwal Unit of GBPIHED. In all these cases, the longer term implications of climate change were not taken into consideration during programme/project design and implementation. Yet their contribution towards reducing vulnerability to climate change impacts has translated into improving livelihood of local communities that are better prepared and more capable of dealing with the long term implications of climate change. In this sense, it can be said that adaptation is already happening—a message that resonates with communities and other stakeholders, who are all seeking a better understanding of the process, investment and activities associated with climate change adaptation.

5 Experience from Central Himalayan Mountain

5.1 Livelihood in the Context of Climate Change

The hill/mountain region of the central Himalaya represents the economic base for the majority of the rural population. With the bulk of traditional crops, cash crops i.e. potato, *Ramdana*, *Rajma* and various forest goods come from hilly region, their importance to local/regional livelihoods is clear. But the livelihoods of the traditional/marginal societies are becoming increasingly vulnerable due to severe soil and landscape degradation. Deforestation has led to an overall deterioration in mountain watersheds (Rao et al. 1999; Saxena et al. 2001; Maikhuri et al. 1997a, b), leading to a reduction in the absorbing capacity of exposed soils (Sen et al. 2002; Semwal et al. 2004), let-up in water infiltration rates, and reduced water resources (Negi and Joshi 2002). Water shortage during summer seasons and landslides/floods during heavy rainfall are becoming more frequent. Drought and floods have led to decreased agricultural productivity, yield losses, malnutrition and even poverty in the rural sector (Maikhuri et al. 2009).

Based on the experiences of past one decades, researchers predicting more frequent and prolonged droughts, more irregular rainfall patterns and more frequent and intense extreme rainfall events, will directly undermine the livelihoods of the hill/mountain communities (Kripalani et al. 1996). Heavy dependence on local production and a general lack of resources and infrastructural facilities for coping with climate impacts only reinforce the vulnerability of these livelihood options. Climate change adaptation strategies therefore, must understand and address these different aspects of vulnerability if livelihoods are to be secured.

6 GBPIHED (Garhwal Unit) Efforts Towards Participatory Action Research and its Relevance to Climate Change Adaptation

Since 1989, GBPIHED—Garhwal Unit has been helping local communities in harnessing the potential of natural resources for livelihood improvement in Garhwal Himalayan region. As regional network of more than 60 institutions including NGOs, village institutions, Govt. line agencies—GBPIHED-Garhwal Unit promotes waste/degraded land rehabilitation/eco-restoration through people's participation (Maikhuri et al. 1997a, b), organic cultivation and value addition of traditional agro-biodiversity in mountains (Maikhuri et al. 1996, 1997a, b, 1999, 2001a, b; Nautiyal et al. 2003), medicinal plant cultivation/conservation (Nautiyal et al. 2001; Maikhuri et al. 2005), bioprospecting of wild edibles and agro-products for livelihood improvement (Maikhuri et al. 1994, 2004; Rao et al. 2003; Maikhuri et al. 2007b), eco-and climate friendly appropriate technologies for livelihood enhancement (Rawat et al. 2010; Maikhuri et al. 2010) and biodiversity conservation in protected areas (biosphere reserves/national parks/sanctuaries) (Nautiyal 1998; Maikhuri et al. 2001a, b; Nautiyal et al. 2002, 2003; Maikhuri and Rao 2005) by offering skill development, technical and methodological support in natural/bioresources management practices. The programme/activities uses a participatory and demand-driven approaches to building capacities and promoting co-operation among number of organizations/village institutions to encourage the long term adoption of viable and potential option for sustainable livelihood and natural resource management (Nautiyal et al. 2005; Maikhuri et al. 2007a, 2010a; Rawat et al. 2010).

Although the impacts of climate change were not part of the original programme, design, GBPIHED, Garhwal Unit's activities have addressed problems associated with extreme climatic events which are expected to increase as global temperature rise. In fact, several project/programme activities and results have provided evidence that these programmes are helping to reduce the vulnerability of local communities to droughts and uncertainties of rainfall while improving their livelihood through harnessing the potential of natural resources. Organic cultivation and diversification of agriculture, improvement of soil fertility through bio and vermin-composting, application of simple and appropriate technologies for yield improvement of off-season vegetables, bioprospecting of wild edibles and carbon sequestration through rehabilitation of degraded land with suitable multipurpose trees. Some concrete indicators demonstrating the increased resilience of local livelihoods to climate hazards are mentioned as:

6.1 Carbon Sequestration Through Rehabilitation of Degraded Forest and Abandoned Lands

The participatory approaches for rehabilitation of degraded land have not only helped enhancing green cover but also identification of number of plant species of multiple values. The social programme successfully demonstrated the local/national/global environmental benefits (in terms of carbon sequestrated by planted species and rate of carbon build up in rehabilitated soils over a period of time) accruing through such land rehabilitation/restoration programme (Maikhuri et al. 1997a, b, 2000a, b; Saxena et al. 2001). The practice and framework developed (Maikhuri et al. 1997a, b; Rao et al. 1999) for degraded land rehabilitation is now widely accepted, particularly by the locals. It has also been accepted as a major source of inspiration for the Forest Department, policy makers, NGOs, environmentalists, village institutions and other government departments involved in development. Many village institutions/NGOs and individual farmers have adopted/replicated these models on their own land (Table 1). More research is required to develop and cultivate species that are ecologically and socio-economically appropriate to further improve the rehabilitation framework developed by Maikhuri et al. 1997a, b. Considering the diversity of ecosystems, indigenous knowledge, and socio-economic conditions in the mountains, a rehabilitation strategy has to be location-specific. There is a need for developing rehabilitation models suited to diverse sets of ecological and socio-economic conditions in the Himalaya Mountains (Maikhuri et al. 1997a, b; Rao et al. 1999).

6.2 Promotion of Traditional Crops Cultivation: An Option of Climate Proof Crops

In spite of the many virtues of traditional crops, precious genetic diversity, the rivet of ecosystem stability, is gradually being lost (Maikhuri et al. 2001a, b). Varied edaphic, topographic and climatic factors as well as different selection pressures over

Table 1 Carbon sequestration at abandoned agricultural land (AAL) and degraded forest land (DLF) sites in Garhwal Himalaya

Component	Mean Annual carbon sequestration (t ha-1 yr-1)	
	AAL After 5 years of plantation	DFL After 5 years of plantation
Total in plantation (for 10 species of MPTs) bole biomass component	0.915	0.326
Increase in soil carbon stock	2.210	1.462
Total carbon sequestration	3.125	1.780

centuries of cultivation resulted in immense variation (Arora 1987; Arora and Nayar 1991; Maikhuri et al. 1996, 1998a, b, 2001a, b). Indigenous varieties evolved over a span of centuries and are adapted to particular areas. The old varieties of traditional crops/millets/pseudomillets, pulses, wheat/rice etc. (usually called primitive cultivars or land races) withstood the rigors of time, escaped attacks from insects, pests, diseases and tolerated harsh climatic conditions (Table 2). Farmers always select and practice sowing of appropriate variety of rain fed landraces as per the land suitability, slope aspects and weather conditions (Table 3).They possess the desired agronomic and genetic traits from which high yield and resistant sources could be developed (Altieri and Merrick 1987; McNeely et al. 1990). They are defined as native domesticated or semi-domesticated plant species which are yet to receive the attention of scientists who will exploit their full potentials in the wake of climate change events such as drought etc. They are an integral part of the subsistence agricultural system, suitably adapted to the native farmer's small plots, poor soil, mixed farming, diet and way of life of the family, village and community. Those crops are known by different names, such as under-exploited crops, crops for marginal lands, poor person's crops and neglected mountain crops. More recently they have also been called life- support crops, the lost crops, organic crops etc. Unfortunately, these traditional crops only attain special status in times of natural calamity and famine. Yet these are staple crops that farmers are already very familiar with, offering several ideal qualities as crops for food security in the fragile Himalayan mountains. They have high tolerance to the poorer soils resulting from soil erosion on steep slopes, require less fallow periods and reduce population pressure on the land and in the case of millets and pseudo cereals, they have more tolerance of insects and pests encountered in the middle agro ecological zones of the Himalaya. Some harvests of certain traditional crops can, if necessary, be made during the growth cycle within 50 to 60 days, such as *Panicum miliaceum, Setaria italica, Fagopyrum* spp. although harvest should preferably not begin within a minimum period of 120 days.

In situ conservation of traditional crops and cultivars could succeed only when these crops are strongly linked with the economic development of hill farmers. Therefore, pragmatic multidisciplinary research efforts are needed to evolve farming systems with appropriate selection of crops in view of future climate change which can provide enough quality food and economic security for the people of the region together with conservation of the traditional crop wealth, sustainability of the production systems and environmental conservation.

Table 2 Drought resistance rainfed paddy landraces by farmers perception

Rainfed agriculture		
Severe drought (non-rainfall)	Moderate droughts (less rainfall)	Normal weather
Bagseri Dhan	Jauli	Khimu
Bakul	Jhokia	Lal Dhan
Bauran Dud	Jhusyav	Lal Jhiruli
Dangoli Dhan	Kauthuni	Uprau Gajai
Dud		

Table 3 Climate proof crop varieties for central Himalayan region for rainfed agriculture (farmer's perception)

Botanical name	Crop name	Local name
Millets		
Pannicum milliaceum	Hog-millet (rainfed)	Cheena
Echinochloa frumentacea	Barnyard millet	Jhangora
Eluecine coracana	Finger millet	Koda
Setaria italica	Foxtail millet	Kauni
Sorghum vulgare	Pearl millet	Junyali
Oil seeds		
Sesamum indicum	Sesame	Till
Pulses		
Glycine spp	Soyabean	Kala bhatt
Macrotyloma uniflorum	Horsegram	Gahat
Pisum spp.	Kong	Bheda
Vigna angularis	Adkuki bean	Rains
Cajanus cajan	Pigeon pea	Tor

6.3 *Capacity Building and Skill Development in the Field of Eco and Climate-Friendly Appropriate Technologies*

Technological change is an important instrument in the continuous process of socio-economic development but due to poor access to suitable technologies is one of the main cause of poverty, drudgery and natural resource degradation in the Himalaya. The appropriate technologies suitable for high altitude region include protected cultivation, organic compost and bio-fertilizers, off-farm technologies and other supporting technologies (Maikhuri et al. 2007a).

The Garhwal unit of G.B Pant Institute of Himalayan Environment and Development (GBPIHED) is one among very few organizations in the Indian Himalayan region involved in testing, developing, upgrading, validating, demonstrating and disseminating appropriate technologies through action and participatory research (Maikhuri et al. 2010a, b in press). The technological interventions aimed to improve agricultural productivity through protected cultivation, improved composting and soil/water management practices, value addition to forest/farm products and improved product storage devices (Rawat et al. 2010). A total of 35 training programmes (each of 2–3 days) on rural technologies were organized during 2000–2008 reaching out to 1086 farmers, 280 extension workers, 67 government officials and 1436 students (Table 4). As a result of these efforts, a number of farmers and other stakeholders including some NGOs and some educational institutions have adopted some of the potential rural technologies at various levels (Table 5). The technologies preferred and adopted by the farmers include protected cultivation, water harvesting tank technology, zero energy cool chamber, bio and vermi-composting, bioprospecting of wild resources, biobrequetting, mushroom cultivation and sloping watershed environmental engineering technology (SWEET) (Maikhuri et al. 2007a, b).

Table 4 Capacity building/skill development and on site training and exposure visit of different stakeholders (user groups) in the field of eco-friendly, hill specific rural technologies at three rural technology demonstration sites

Capacity building/skill development

Category of Participants	Tehri district (Maletha)	Rudraprayag district (Triyuginarayan)	Chamoli district (Tapovan)	Total
Farmers	885 (398)	79 (102)	122 (89)	1086 (589)
NGOs	166 (87)	35 (36)	12 (23)	213 (146)
Students (from secondary to Ph.d)	689 (564)	23 (25)	11 (19)	723 (608)
Students (junior level)	456 (486)	201 (156)	56 (149)	713 (791)
Ex- Army personnel	47 (89)	7 (15)	9 (16)	63 (120)
Official of Govt. line depts	49 (75)	11 (16)	7 (11)	67 (102)
Academicians/policy planners/and officials from financial institutions	37 (49)	9 (19)	5 (7)	51 (75)
Total	2,329 (1,748)	365 (369)	222 (314)	2,916 (2,431)

Values in parenthesis for exposure visit

6.4 Bioprospecting, Conservation and Management of Wild Edibles and NTFPs

Interest in wild bioresources has grown significantly with the increasing awareness in linking forest conservation with rural development and poverty alleviation. Thus the ability of a given wild bioresources to continue meeting both subsistence and market needs however, largely depends upon sustainable harvesting and appropriate management practices. It is realized that in order to influence policy planners and forest management practices one must understand the broader context such as sustainability, extraction rates, growth, yield, and biological possibilities for increasing production and the local variations in the value of wild edible species (Maikhuri et al. 1994, 2004; Rao et al. 2003; Maikhuri et al. 2007b). More than 25 (Table 6) wild edible plant species screened for making a variety of edible value added products (i.e. jam, jelly, sauce, squash, juice, pickles) as a source of income. Besides, sustainable harvesting of some more potential species has been worked out. The capacity of 405 local people/youths has been improved in this field.

6.5 Cultivation, Conservation and Value Addition of Medicinal and Aromatic Plants

Domestication and cultivation of MAPs is one of the viable options to meet the growing demands from the industries and to reduce the extraction pressures in the

Table 5 Rural technologies adopted by farming communities and other stakeholders and economic impact assessment

Name of different categories of technologies	Size of land treated/ covered and plant species used	Adoption (no. of villages)	Adoption (no. of families)	Average income/ family/year (Rs ± SE)
Protected cultivation				
1. Polyhouse (low-cost)	10 × 5 × 2.5 m	8	41	4,256(±185)
2. Nethouse(low-cost)	10 × 5 × 2.5 m	3	16	3,958(±135)
Organic composting and biofertilizer				
1. Biocomposting	5 × 2 × 1 m	13	64	1,260(±98)
2. Vermicomposting	5 × 2 × 1 m	16	84	3,645(±148)
3. Azolla culture	10 × 2 × 1 m	9	37	842(±82)
Off-farm technologies				
Mushroom cultivation	120 kg base material	15	78	3,856(±172)
Honeybee rearing	Single improved wooden box	7	24	1,578(±123)
Bioprospecting of wild/ semi-domesticated fruit species	Five potential plant species used	15	75	4,826(±265)
Other supporting technologies				
Biobrequetting	1 × 1 × 1 m	11	39	6,845(±212)
Sweet technology	1 ha	5	7	2,630(±132)
Water harvesting tank	6 × 3 × 1.5 m	8	19	1,443(±120)
Zero energy cool chamber	3 × 1.5 × 1 m	5	6	1,130(±90)

Table 6 List of selected wild edible plant species for value addition locally

Botanical name	Local name	Botanical name	Local name
Bauhinia purpurea	Guiral	*Pyrus pashia*	Melu
Rhododendron arboreum	Burans	*Rhus parviflora*	Tungla
Emblica officinalis	Aonla	*Rubus ellipticus*	Hinsal
Ficus auriculata	Timla	*Rubus niveas*	Black Hinsal
Ficus cunea	Khaina	*Viburnum mullaha*	Bhatmolya
Berberis aristata	Kingore	*Prunus armeniaca*	Khubani
Pyracantha cranulata	Ghingaru	*Ficus palmate*	Bedu
Cornus capitata	Bhamora	*Myrica esculentum*	Kaphal
Allium strechyei	Faran	*Angelica glauca*	Choru
Allium humile	Lado faran	*Pleurospermum angelicoides*	Chhipi
Allium rubellium	Bhotiya faran	*Principia utilis*	Bhenkal

natural habitats of MAPs. Farmers-to-farmers training programme (FFTP) is a tool to build and strengthen capabilities of farmers, extension workers associated with NGOs and government department in selecting potential species and enhancing the area under medicinal and aromatic plant (MAP) cultivation in the Himalaya. The programme has helped participants change their attitudes considerably towards the role and values of medicinal plant in current changing scenario at the local, regional, national and global level (Maikhuri et al. 1998a, b, Maikhuri et al. 2000a, b, 2005). These programmes are conducted in the farmer's field itself, and this enables the participants to have a better understanding of the problems faced by the farmers and how they overcome them. A total of 536 participants were trained in the area of medicinal plant cultivation, conservation and value addition between 1997 and 2005(Table 7). During these programmes, a holistic understanding of domestication (nursery raising) and cultivation and conservation of medicinal plants and exchange of indigenous knowledge are facilitated among participants. Participatory approaches and training programmes facilitated the farmers' demand for knowledge and provided them with an opportunity to choose, test and start cultivating MAPs according to their land capability and climate (Maikhuri et al. 2005). Scientific assessment and impact analyses carried out by researchers identified the need for further research and sustained government programme interventions to strengthen the infrastructure and extension inputs. Furthermore, the programme has shown that there is a need to adopt appropriate policy, which must integrate the cultivation of MAPs with local people's socio-economic development and also develop location specific technologies so as to maximize the use of local resources and reduce the use of external inputs. A large numbers of wild herbal spices of Uttarakhand Himalaya are valued not only that they enhance taste and aroma of the traditional cuisine but also for their medicinal properties and source of nutrition. The term value added products indicates that for the same volume of primary products, a high price is realized by means of processing, packaging, quality up-gradation. Processed spice prepared from the medicinal plant species such as *Allium strechyei, Allium humile, Allium rubellium, Angelica glauca, Carum carvi, Cinnamomum tamala* and *Pleurospermum angelicoides* will carry novelty value as they are natural, non-narcotic, having no side effect, cost efficient, curative and moreover being rich in nutrients regular use can help contribute towards the goal of "Health for all". A variety of wild and domesticated

Table 7 Capacity building for medicinal plant cultivation/conservation through farmer-to-farmer training programme (FFTP) and participatory action research

District	No. of FFTP organised	Farmers/local people trained	NGO staff trained	GO staff trained	Total
Almora	1	40	5	2	47
Bageshwar	2	36	4	–	40
Pithoragarh	4	45	3	–	48
Chamoli	4	180	20	12	212
Rudraprayag	1	68	2	4	74
Pauri	1	75	5	8	88
Uttarkashi	1	25	–	2	27
Total					536

spices already contributing as an important source of income to Bhotiya tribe of Garhwal region of Uttrakhand Himalaya since long time. These farmers have established market for their produce in the lower valleys within the region where they sell the above described spices and often exchange these with food grains in return with local people using the barter system. The value-added products of these spices are now in great demand in the rural as well as urban areas of Uttarakhand.

6.6 Promoting Organic Cultivation and Value Addition of Traditional Crops

The agriculture practiced in the hills/mountains is also known as low external input agriculture. As the steep slopes lead to high percolation losses of water, farmers have traditionally overcome this by adding large quantities of farmyard manure (FYM) to the fields, more for its contribution to enhance soil fertility. The application of chemical fertilizers, pesticides, insecticides, herbicides/weedicides etc. are lowest in the mountains. Since the agriculture practiced in the hills is organic, therefore, there is a need to look at sustainability for both agricultural production as well as food security. To give further impetus to organic agriculture as well as to locally based food security, government needs to widen the food basket to include locally grown traditionally and nutritionally rich organic food crops. Ecological and organic farming mitigate climate change by reducing greenhouse gas emissions and increasing carbon sequestration in plants and soil (Maikhuri et al. 2001a, b).

6.7 Enhancing Adoptive Capacity in Traditional Agroforestry Through Tree Management

A successful and well managed integration of multipurpose trees in agricultural land inevitably results in diversified and sustainable crop production, in addition to providing a wide range of environmental benefits. Scattered agroforestry trees are distinguishing features of settled upland farming. Lopping is a tool to regulate tree-crop competition for optimizing multiple benefits from the system. Farmers usually lop all branches during winter season when access to as well as availability of fodder/fuelwood from forests are constrained by harsh climate. Semwal et al. (2002) have shown that retention of 25 % of branches together with increase in tree density in private farmland will improve tree vigour and ecological functions without any decline in crop yields. Research is needed to identify interventions that lead to agricultural sustainability such that pressure on forests is reduced. As adaptation is yet developing as science, the role of agroforestry in reducing the vulnerability of agricultural systems and the rural communities that depend on them for their livelihood to climate change or climate variability should be more strongly emphasized.

6.7.1 Management of Water Resources Through Water Harvesting Tank and Spring Sanctuary Development

Global warming will aggravate water stress, a factor often limiting crop yields and life quality. The traditional systems centered on minimum inputs for water purification, storage and canalization, minimal interference with natural hydrological processes and minimal risks of damages likely from high rainfall events were by and large abandoned when water supply was treated as a government service to the people. With experiences of the large scale failure of the new system over the last few decades (Maikhuri et al. 1997a, b; Rao et al. 1999), innovations in water technology and management sectors that can be sustained in the likely global warming scenarios are needed. Technology of harvesting the excess s runoff from catchment along with seepage from perennial flows seems to be beneficial in a broader perspective of the existing situation. In this regard GBPIHED, made a critical evaluation of the people's perception and responses to the technologies demonstrated so far to mitigate the current crisis. The spring sanctuary development aims at field experience improving agricultural production/agricultural redevelopment and agro-forestry development was considered most viable option for improving economic returns and was attempted here. Enhancing the infiltration and retention of rain water in the spring recharge zone through engineering and vegetative measures is essential so as to increase discharge in the spring down slope. Presence of vegetative cover and organic matter in the soil acts as a sponge and absorbs rainwater, which is released slowly in the following season. The prime focus of this technology is to increase water retention time and improvement in the water holding capacity of soil for greater water infiltration in the catchment zone of springs for ground water recharge. It require multi-dimensional approach and action in which people's participation is to be given due consideration.

6.7.2 Improvement in Traditional Soil Fertility Management

As agriculture is dependent on forests for manure and fodder, reduction in intensity of biomass removal from forests without any threat to agro-ecosystem functions is crucial for forest conservation. Application of oak residue based manure enables crop yields 15 % higher compared to pine residue based manure because of higher rates of nitrogen mineralization coupled with better synchronization of nutrient release and crop uptake in the former (Rao et al. 2003).

7 Institutional Cooperation, Coordination, Collaboration and Capacity Building to Address Climate Change in Various Sectors

In central Himalayan region particularly Uttarakhand state has many Research and Development institutions with significant infrastructure and scientific/technical capacity. However, so far these institutions have not much focused on climate change research, which includes modeling, field ecological and biodiversity related studies etc. There is inadequate capacity in several research and developmental institutions working on environmental and conservation issues in relation to climate change. There is an utmost need to create awareness and enhance capacities at individual and institutional level and also include other stakeholders i.e. NGOs etc. Local communities depending on natural resources for their livelihood have poor financial, technical and institutional capacity to adapt to adverse impacts of climate change. Therefore, it is important to enhance capacities of local people's (whose survival entirely depends on their surrounding forest vegetation) who are likely to be vulnerable to projected climate impacts.

8 Conclusions

Although adaptation is not a new concept, unprecedented changes in climate system call for more rapid and effective adaptation measures for those most vulnerable to climate related impacts. Traditional and marginal mountain communities have learned to thrive in a variety of adverse conditions despite having inadequate resources, and their living strategies aim at livelihoods that have high resilience and low sensitivity to shocks, stresses and adverse trends. However, climate change impacts threaten the mountain rural poor adaptive capacity and ability to recover from shocks. Given the reliance of many of the traditional mountain poor communities on environmental services for their livelihoods, they are the most severely affected by deteriorating environmental conditions and factors limiting resource access. While absorbing sudden and extreme external shocks, mountain rural poor may deplete their natural, physical, financial and human capitals. Designing climate change adaptation strategies thus become urgent for securing their livelihoods. As poverty reduction is at the centre of climate change adaptation, poverty assessment can shed light on the design of locally relevant adaptation measures. Designing climate change adaptation requires a reliable comprehension of the vulnerability context, and rural poor local realities. The ability of vulnerable marginal mountain communities to cope with climate variability is largely determined by the way in which they conduct and secure their livelihood.

The term 'livelihood' comprises the capabilities, assets (material and social resources), and activities required for ensuring a means of living (Carney 1998).

Sustainable livelihood includes the idea of coping with and recovering from stresses and shocks, and maintaining or enhancing existing capabilities and assets. Climate change has made the future of mountain indigenous people and their livelihoods more vulnerable and uncertain. The available scientific evidence suggests that climate change will place significant stress on the rural livelihoods of the people living in mountains. Efforts to reduce vulnerability and enhance the adaptive capacity of vulnerable groups need to take a proactive approach that addresses the social processes leading to vulnerability and the structural inequalities that are often at the root of social-environmental vulnerabilities. Adaptation to climate change is both related to vulnerability, which can be defined as the "degree to which individuals and systems are susceptible to or unable to cope with the adverse effects of climate change" (Smit and Pilifosova 2001), and to future potential impacts, either avoidable or unavoidable. Effective adaptation includes both the establishment of adaptive capacity (awareness, governance, and knowledge) and the adaptation itself (change of behaviour, practices, and livelihoods according to new conditions) (Mirza 2007). Adaptation consists of a multitude of options depending on the scale, context, and approach. The scale of adaption may be local, national, or regional; the context of the adaptation will determine the type of adaptation (e.g. new farming practices in a rural context or water demand management in an urban context); and the approach to adaptation may focus on general poverty alleviation, enhanced transparency in decision making, or the empowerment of women, among other things. Structural inequalities that make adaptation by poor people more difficult need to be levelled. It is important to note that poor and marginalised people already face all of the difficulties that we usually associate with climate change. This is nothing new to them. They are already facing poor health, susceptibility to floods and landslides, and lack of adequate shelter, food, and water. While they do need climate change adaptation, they need poverty alleviation even more. Examples of enhancing adaptive capacity at different levels may include introducing and/or enhancing governance to climate focusing on development, mainstreaming climate change into development planning; and institutional and policy reforms (Mirza 2007), general political reforms and associated openness (ibid), health education programmes (WHO 2005), and the development of early warning systems for floods, flash floods, and droughts.Mountain people are increasingly exposed to growing physical, social, and economic risks and vulnerabilities. The three main interrelated drivers of change are: (a) environmental change induced by climate change that leads to extreme and unpredictable conditions affecting the crucial natural resources and ecosystem services; (b) economic and social globalisation with its increased societal and cultural interdependencies that impact on livelihood options (e.g. food security) of mountain people; and (c) population dynamics with lower population growth rates in the mountains and strong rural–urban migration. The goal to conserve and maintain Livelihoods and Ecosystem Services in the Himalayas should be to: Enhancing Adaptation Capacity and Resilience of the Poor to Climate and Socioeconomic Changes is to reduce rural poverty and increase the resilience of the rural poor to the changing environmental and socioeconomic situations in the mountain areas.

Adaptation and poverty reduction should not be treated separately; they need to be brought together under their common goal to secure livelihoods. Natural resource management may be a central strategy for rural poor adaptation as those resources are particularly important for the poorest livelihoods. Successful case studies of natural resource management originally intended to contribute to reducing poverty illustrate how to build resilience in rural poor settlements (Rawat et al. 2010; Maikhuri et al. 2010). This article has thus indicated that restoring or enhancing ecosystem services as well as diversifying local livelihoods achieve community resilience to shocks and trends such as climate variability. In such successful cases, adaptation is already taking place by securing livelihoods through environmental/natural resource management, maintaining poor people's local safety nets as well as expanding their range of options for withstanding and recovering from disruptive shocks and trends (Maikhuri et al. 2009). These lessons can be built into the elaboration of climate change adaptation strategies.

9 Lessons Learnt

The examples of community level adaptation programme/projects generate knowledge that is beneficial for the development of longer term adaptation strategies to meet the challenges of climate change impact in Himalayan Mountains. These lessons demonstrate that awareness of certain factors is crucial, including:

- Local livelihoods and vulnerabilities:

Knowing the capacities that comprise people's livelihoods and the factors (including climate related risks), that shape vulnerability to ensure the design of appropriate framework and locally available resources to meet the needs of the people on short and long term basis.

- Information and knowledge network to deal present and future climate risks in the region:

Information on current climate hazards is increasingly reaching the communities most affected but there is a gap in understanding and awareness on the projected climate change impacts. This calls for more research, awareness raising and better access to necessary information and data base.

- Community participation and community organization

Community driven implementation strategies emphasize the active participation of local people in the initiation, design, implementation and monitoring of the livelihood related project activities to secure community support and promote a strong sense of ownership. Therefore, there is a need to establish or build upon social institutions/community self-help groups and women's groups to carry out activities in a structured, participatory and efficient manner.

- Women participation and empowerment:

Recognizing their role as household and community resource managers, promoting their active involvement in programme activities to ensure the success and sustainability of achievements.

- Training, capacity building and skill development at various level:

Enhancing the local human resource base and the effectiveness of the programme activities by developing skills and imparting knowledge to the people in a range of technical, financial and managerial aspects and subjects.

- Blending of traditional and modern scientific approaches:

Using local traditional ecological knowledge supplemented/complemented through science and technological interventions is urgently required to develop appropriate framework to solve the problems/issues properly.

- Reconciling short-term needs with long-term goals:

Investing in the long-term success of the programme/projects activities that meet the immediate development needs of the community and build local capacity to conserve and manage natural resources in a way that meet the present and future needs on sustained basis.

- Supportive policy environment and governance:

Policies that help reduce pressures on forests that emanates from other sectors such as agriculture, livestock and energy would help forest regeneration and maintaining healthy carbon sink. It may also be ensured that the areas suffering climate change stresses are well served by social livelihood earning schemes like Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) in ties to come.

Acknowledgements The authors are thankful to Director, G.B. Pant Institute of Himalayan Environment and Development, Kosi-Katarmal, Almora for providing facilities and to the TSBF/GEF/UNEP for financial support.

References

Adger WN, Khan SR, Brooks N (2003). Measuring and enhancing adaptive capacity, UNDP Adaptation policy framework technical paper 7, New York

Altieri MA, Merrick LC (1987) In situ conservation of crop genetic resources through maintenance of traditional farming systems. Econ Bot 41:96

Arora RK (1987) Ethnobotany and its role in domestication and conservation of native. In: Jain SK (ed) Manual of Ethnobotany. plant resources, pp 94–102, Scientific Publications, Jodhpur

Arora RK, Nayar ER (1991) Wild relatives of crop plants in India. NBPGR Science Monograph, p 7

Carney D (1998) Sustainable rural livelihoods: what contribution can we make?. Department for International Development, London, DFID, London

FSI (1999) State of forest report. Forest Survey of India, Ministry of Environment & Forests, Dehradun, India

ICIMOD (2007) Inventory of glaciers, glacial lakes and identification of potential glacial lake outburst flood (GLOFs) affected by global warming in the mountains of Himalayan region (DVD ROM). ICIMOD, Kathmandu

Kripalani RH, Inamdar SR, Sontakke NA (1996) Rainfall variability over Bangladesh and Nepal: comparison and connection with features over India. Int J Climatol 16:689–703

Maikhuri RK, Rao KS (2005) Promoting eco-tourism in Nanda Devi biosphere reserve. G.B. Pant Institute of Himalayan Environment and Development, p 16

Maikhuri RK, Semwal RL, Singh A, Nautiyal MC (1994) Wild fruits as a contribution to sustainable rural development: a case study from the Garhwal Himalaya. Int J Sustain Dev World Ecol 1:56–68

Maikhuri RK, Rao KS, Saxena KG (1996) Traditional crop diversity for sustainable development of Central Himalayan agroecosystems. Int J Sustain Dev World Ecol 3:8–31

Maikhuri RK, Semwal RL, Rao KG, Saxena KG (1997a) Rehabilitation of degraded community lands for sustainable development in Himalaya: a case study in Garhwal Himalaya. Int J Sustain Dev World Ecol 4:192–203

Maikhuri RK, Semwal RL, Rao KS, Nautiyal S, Saxena KG (1997b) Eroding traditional crop diversity imperils the sustainability of agricultural systems in Central Himalaya. Curr Sci 73(9):777–782

Maikhuri RK, Nautiyal S, Rao KS, Saxena KG (1998a) Medicinal plants cultivation and biosphere reserve management: a case study from Nanda Devi Biosphere Reserve. Curr Sci 74(2):157–163

Maikhuri RK, Nautiyal S, Rao KS, Saxena KG (1998b) Role of medicinal plants in the traditional health care system: a case study from Nanda Devi Biosphere Reserve. Curr Sci 75(2):152–157

Maikhuri RK, Rao KS, Saxena KG, Semwal RL (1999) Traditional crops in the Central Himalaya. Plant Genet Resour Newsletter (IBPGR) 120:1–7

Maikhuri RK, Semwal RL, Rao KS, Singh K, Saxena KG (2000a) Growth and ecological impacts of traditional agroforestry tree species in Central Himalaya, India. Agrofor Syst 48:257–272

Maikhuri RK, Nautiyal S, Rao KS, Saxena KG (2000b) Indigenous knowledge of medicinal plants and wild edibles among three tribal sub-communities of Central Himalaya, India. IKDM 8:7–13

Maikhuri RK, Rao KS, Semwal RL (2001a) Changing scenario of Himalayan agroecosystems: loss of agrobiodiversity, an indicator of environ-mental change in Central Himalaya, India. Environmentalist 20:23–39

Maikhuri RK, Semwal RL, Rao KS, Saxena KG, Das AK (2001b) Indigenous knowledge for agriculture soil fertility maintenance in the Central Himalaya. Ecol, Environ Conserv 7:15–20

Maikhuri RK, Rao KS, Saxena KG (2004) Bioprospecting of wild edible for rural development in Central Himalayan mountains of India. Mountain Research and Development, 24(2): 110–113

Maikhuri RK, Rao KS, Kandari LS, Joshi R, Dhyani D (2005) Does the outreach programme make an impact? A case study of medicinal and aromatic plant cultivation in Uttaranchal. Curr Sci 88(9):1480–1486

Maikhuri RK, Rawat LS, Negi V, Purohit VK (2007a) Eco-friendly appropriate technologies for sustainable development of rural ecosystems in Central Himalaya. G.B. Pant Institute of Himalayan Environment and Development. Dolphin Printo Graphics, New Delhi, p 45

Maikhuri RK, Negi V, Rawat LS, Purohit VK (2007b) Promoting value addition in potential wild edibles of central Himalaya for sustainable livelihood and small scale enterprise development. G.B. Pant Institute of Himalayan Environment and Development. Dolphin Printo Graphics, New Delhi, p 38

Maikhuri RK, Rawat LS, Phondani P, Bahuguna A, Chamoli KP, Farooquee N (2009) Impact of climate change and coping strategies in Nanda Devi biosphere reserve (NDBR), Central

Himalayas, India. In: Proceeding of global mountain biodiversity and climate change, ICIMOD, Kathmandu, pp 138–148

Maikhuri RK, Rawat LS, Negi VS, Bahuguna A, Agarwal SK, Farooquee NA, Phondani PC, Negi CS (2010a) Demonstration and dissemination of simple eco-friendly technologies for natural resource management in central Himalaya. Indian J Sci Technol 7:822–830

Maikhuri RK, Rawat LS, Negi VS, Agarwal SK, Rao KS, Saxena KG (2010b) Managing natural resources through simple and appropriate technological intervention for mountain development, *Current Science* (In press)

McNeely JA, Miller KR, Reid WV, Mittermeier RA, Werner TB (1990) Conserving the world's biological diversity. IUCN, WRI, CI, WWF and World Bank, Gland, Switzerland, p 193

Mirza M (2007) Climate change, adaptation and adaptative governance in water sector in South Asia. Scarborough (Canada): Adaptation and Impacts Research Division (AIRD), Department of Physical and Environmental Sciences, University of Toronto

Nautiyal S (1998). Ecosystem Function of Buffer Zone Villages of Nanda Devi Biosphere Reserve. Ph.D. Dissertation, Department of Botany, H.N.B. Garhwal University of Srinagar, Garhwal

Nautiyal S, Maikhuri RK, Rao KS, Saxena KG (2001) Medicinal plant resources in Nanda Devi Biosphere Reserve in the Central Himalaya. J Herbs, Spices Med Plants 8:47–64

Nautiyal S, Rao KS, Maikhuri RK, Negi KS, Kala CP (2002) Status of medicinal and aromatic plants on way to Vashuki Tal in Mandakini Valley Garhwal Himalaya, Uttaranchal. J Non-Timber Forest Prod 9:124–131

Nautiyal S, Maikhuri RK, Rao KS, Semwal RL, Saxena KG (2003) Agroecosystem function around a Himalayan Biosphere Reserve. J Environ Syst 29:71–100

Nautiyal S, Rajan KS, Shibasaki R (2005) Interaction of biodiversity and economic welfare-a case study from Himalayas of India. J Environ Inform 6(2):111–119

Negi GCS, Joshi Varun (2002) Drinking water issues and development of spring sanctuaries in a mountain watershed in the Indian Himalaya. Mt Res Dev 22(1):29–31

Rao KS, Maikhuri RK, Saxena KG (1999) Participatory approach to rehabilitation of degraded forest lands for sustainable development: a case study in a high altitude village of Indian Himalaya. Int Tree Crop J 10:1–17

Rao KS, Semwal RL, Maikhuri RK, Nautiyal S, Sen KK, Singh K, Chandrasekhar K, Saxena KG (2003) Indigenous ecological knowledge, biodiversity and sustainable development in the Central Himalayas. Trop Ecol 44(1):93–111

Rawat LS, Maikhuri RK, Negi VS, Bahuguna A, Rao KS, Agarwal SK, Saxena KG (2010) Managing natural resources with eco-friendly technologies for sustainable rural development: a case of Garhwal Himalaya. Int J Sustain Dev World Ecol 17(5):423–430

Saxena KG, Rao KS, Sen KK, Maikhuri RK, Semwal RL (2001) Integrated natural resource management: Approaches and lessons from the Himalaya. Conserv Ecol (Electron J) 15(2):1–14

Semwal RL, Maikhuri RK, Rao KS, Singh K, Saxena KG (2002) Crop productivity under differently lopped canopies of multipurpose trees in Central Himalaya, India. Agrofor Syst 56:57–63

Semwal RL, Nautiyal S, Sen KK, Rana U, Maikhuri RK, Rao KS, Saxena KG (2004) Patterns and ecological implications of agricultural land-use changes: a case study from Central Himalaya, India. Agric Ecosyst Environ 102:81–92

Sen KK, Semwal RL, Rana U, Nautiyal S, Maikhuri RK, Rao KS, Saxena KG (2002) Patterns and implications of land use/cover change: a case study in Pranmati watershed (Garhwal Himalaya, India). Mt Res Dev 22(1):56–62

Smit B, Pilifosova O (2001) "Adaptation to climate change in the context of sustainable development and equity", in climate change 2001: impacts, adaptation and vulnerability, Chapter 18. Cambridge University Press, Cambridge

WHO (2005) Human health impacts from climate variability and climate change in the Hindu Kush- Himalaya region. Report from an Inter-Regional Workshop, Mukteshwar, India, October

Emerging Technological Intervention Models with Scalable Solutions for Adaptation to Climate Change and Livelihood Gains in Indian Himalayan Region: Case Studies on Action Research at the Grassroots Level

Sunil K. Agarwal

1 Introduction

Climate change is a global issue which demands immediate action in order to avert its impacts at local, regional and global levels. There are immediate and responsible calls from every nook and corner of the world particularly from Inter-governmental panel on climate change (IPCC) to take effective measures for maintaining the natural balance in the climate system due to anthropogenic release of green house gases (GHGs). Increase in emission of green house gases, particularly carbon dioxide, has been a major cause of global warming. Due to global warming various activities like habitat loss, deforestation and over exploitations will increase the impact of climate change on biodiversity and local livelihoods. Therefore, the major focus is on reducing the emission of carbon dioxide, by curbing consumption on fossil fuel. This will have to be done through introduction of energy efficiency and clean technologies. Although global warming is a phenomenon being experienced all over the world, the problems are more serious in India as this will pose a serious threat to our resource production systems, food security and rural livelihoods. Global warming will also accelerate melting and receding of Himalayan glaciers, which in turn will reduce flow of water in the rivers emerging from the Himalayas. It has been reported that warming in the Himalayas has been much greater than the global average of 0.74 °C over the last 100 years (IPCC 2007) thus inducing stresses on resources and livelihoods of mountain people and downstream populations. Indeed, the strategy for India should be to promote such eco-friendly activities which will help in mitigating climate change while supporting sustainable livelihoods for the resource

S. K. Agarwal (✉)
Science for Equity, Empowerment and Development Division, Department of Science and Technology, GOI, New Mehrauli Road, New Delhi 110016, India
e-mail: skagr99@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_33,

dependent people residing in remote rural areas particularly in Indian Himalayan Region (IHR). Thus, it is being realized that an effective means of ensuring that climate adaptations are undertaken is to mainstream them in practical way into existing or planned development programmes to enhance people's livelihoods with access to appropriate technologies which will bring both immediate societal benefits and capacity to deal with vulnerability (Huq et al. 2003; Smit and Wandel 2006; Pouliotte et al. 2009). In this direction, present paper aims to discuss such practical strategies though working model(s) as pilot showing potential for low carbon emission; and to improve end user productivity and profitability with enabling environment as a good adaptation and mitigation practices in remote mountain areas where communities are vulnerable to changing conditions.

2 Climate Change, Sustainability of the Himalayan Ecosystems and Livelihoods

Sustainability of the Himalayan ecosystems is crucial for the livelihood of about 1.3 billion people in Asia. The impact of climate change are also considered in Indian Himalayan states which are a home to many endemic, endangered and threatened species and local people are dependent on its biological resources. For instance, with over 15 important rivers and over a dozen of major glaciers, Uttarakhand is a valuable freshwater reserve (UCOST 2012). Hydro power continues to be a prime resource bases for the state's economy with more than 200 large and medium sized hydro-projects. A large portion of the state is under forests with several forest based industries. Thus, the livelihoods in Himalayan states are almost totally based on natural resources—water, forest, agriculture, etc. Yet, Himalayan region with a rich natural resource heritage is vulnerable to the impacts of climate change affecting local livelihoods (ICIMOD 2007; Eriksson et al. 2009; Varma 2010; Negi et al. 2012). On the basis of observed patterns, the Indian Network for Climate Change Assessment (INCAA) has identified that among all the major regions of the country, the Himalayan region is most vulnerable to climate change which have a direct bearing on natural ecosystems and rural livelihoods. The emerging need is for change in development planning procedures to cope with and recover from such vulnerability by maintaining or enhancing capabilities and assets with good practices, and activities required for a means of living as sustainable livelihood. (Carney 1998; UNDP-GEF 2007; G-SHE 2009).

Thus, critical issues of concern are how changes to ecosystems including climate change, will impact the livelihoods of the mountain community who depend on ecosystems, and how ecosystems can be better managed to continue to support such resource dependent people and reducing carbon foot print to move towards green path of development. Need is being felt for improving climate change response planning and governance systems that facilitate sustainable use of natural resources across different ecosystem types for balancing low-carbon growth and synthesizing knowledge to scale up potential solutions (Schild 2008).

3 Mitigation and Adaptation Measures: Technological Solutions and Innovation

Given the above facts, there is a need to develop suitable strategies that mitigate climate change and also promote sustainable use and equitable development of natural resources. Both mitigation and adaptation are necessary on a local as well as at a global scale. Adaptation research is needed to develop strategies to cope with the impact of climate change and ecosystems, particularly biodiversity loss, and impacts on food security and agriculture; and to adapt to worsening droughts, water shortages and rising sea levels etc. The focus of mitigation efforts in India essentially revolves around energy choices as low carbon development strategy to reduce GHG emissions. Harnessing renewable energy is now being considered centre to any long term mitigation strategy. Research into how low carbon technology can contribute not only to climate change mitigation but also to support societal and economic development and environmental sustainability, has been felt as immediate need for sustainable development (Parikh and Parikh 2002; Parry 2009). Examples could include innovative approaches with good practices towards soil and water conservation; improve and stabilize crop yields under variable conditions; improved irrigation technologies; rainwater harvesting and groundwater management and clean energy access through solar and hydro power; and biomass based gasifier systems and so on.

Similarly, need is being felt to facilitate and accelerate proactively action research in tackling climate change and its impact, and evolving practical strategies for contributing to a low-carbon global economy and addressing associated social dimensions of climate change including its connections with growth and sustainability. Besides, need is to support adaptation to climate change by rural and urban people, particularly the most vulnerable, through action research supported with good quality science based knowledge including the institutional arrangements for managing the same locally (Huq et al. 2003; Klein et al. 2007; APHDR 2012). This requires both systems approach and effective governance of innovation systems and technology delivery through localized strategies to ensure that efforts made in evolving required technological solutions meet the needs of the vulnerable population living in complex, diverse and difficult settings such as Himalayan mountain eco-systems (Agarwal and Joshi 2006).

To address above, the available human capital in mountains must be enabled to tap technology to increase the output of traditional production, provide specialized services and even affordable scientific services into natural resources, clean energy, transport and information technology. In such an endeavor, field based technological interventions made in some of these sectors have led to develop strong livelihood options in mountain areas showing potential not only to integrate conservation and livelihood in IHR, but also to contribute significantly towards sustainable development while mitigating climate change. Strategy has been to ensure that such interventions are need based and beneficial to the participating mountain community to earn their livelihood while conserving eco-system, biodiversity and environment. Accordingly, present paper discuss and highlight some field level interventions as case studies of emerging models of different scales showing application potential for visible change to strengthen local livelihoods needs in IHR. These case studies though not exclusively directed at future climate change, but, attempt to understand the role of different stakeholders in designing, development and effective delivery of need based technology driven interventions and identify important factors responsible for better adoption by the mountain community to promote livelihoods and their linkages with conservation and climate change issues.

4 Technology Intervention and Adaptation to Climate Change: Case Studies of Emerging Models for Livelihoods Gain

4.1 Water Resource Management

Hundreds of small rivulets and thousands of streams make the Himalayas popularly known as “Water bank of Asia”. Out of total 18 major rivers of the country, 12 are part of the Himalayan Mountain Ecosystems. Despite of these large resources, mountainous regions are currently facing acute water shortage. The traditional water sources like Dhara, Nala, Chaal, Khaal and Taal have depleted in recent past due to poor water management (Rautela 1998). The opportunities that exist in the mountains include the huge potential of hydropower and irrigation system with revival of springs taking into account indigenous technical knowledge systems for diversification of local economies. According to an estimate IHR has 79 % of total hydro power potential of the country and only 21 % has been harnessed. But, in view of sensitivity to climate change and natural fragility, strong need is emerging to promote community owned decentralized hydro-power generation through small hydro-power units in IHR.

Considering above, micro level field study with impact analysis and measurable indicators for techno-economic and socio-ecological benefits was carried out to understand the potential and limitations of technological interventions related to improved watermill and spring recharging in remote mountain areas of Garhwal Himalayas, Uttarakhand.

Case Study 1: Improved Water Mill and Multiple Use of Water

Traditional watermills have been in use in the Indian mountain region since time immemorial. This eco-friendly device that harnesses waterpower for clean energy production at a small scale is a symbol of local technical excellence and the traditional wisdom of the people inhabiting the mountain region. The system worked harmoniously with nature for over 2,700 years and is abundantly scattered across the Himalayas. The widespread use of watermills and their popularity owed much to their simple and cost-effective mechanism.

According to Saxena (1998), there are nearly 2 lakh watermills in the Himalayas from Uttarakhand, Himachal Pradesh, Jammu and Kashmir to the North-Eastern States of the country. In Uttarakhand alone there are about 15,448 watermills. However, with the passage of time, it was realized that due to centuries old design, their low output does not provide enough profit to the owners. In recent years, several watermills have thus become non-functional. This is probably due to the fact that they were serving only the remote rural communities of the IHR and their potential in the overall energy framework remained hidden or was neglected. In the absence of appropriate technology, watermills were not used for any purpose other than grain grinding. The importance of watermills was further overshadowed by the introduction of diesel and electricity powered mills, motivating the people towards high-speed grinding machines. Moreover, owners of traditional watermills were often forced to move to the plains to seek better employment, therefore, were unable to do anything to save their watermills.

To address these issues, sporadic efforts have been made by Government and Non—Government developmental agencies to develop and demonstrate upgraded design of watermills at select locations. But, performance evaluation and impact analysis for such technological interventions under field conditions is lacking (Rijal 2000), which is very essential to revive traditional watermills (functional as well as non functional) existing in IHR for macro level application to strengthen livelihood support to watermill owners as well as local community residing in non grid remote and inaccessible mountain areas.

Considering the above facts and need, the research approach was conceived to evaluate technological interventions made at field level in Garhwal Himalaya, which has shown potential for improving the efficiency of traditional watermills, not only for grain grinding, but also to produce electricity to meet local energy requirements and promote multi-purpose use for agro-processing like paddy de-husking and spice grinding to enhance local income. A detailed impact analysis of upgraded water mill with relevant data was done for 3 years at study village Dokhwala, Dist Dehradun to evaluate the performance and viability of existing three improved watermills (3 kW capacity) in the area in terms of cost-benefit and technology adoption by the community as compared to traditional watermill. It was found that watermills which were traditionally functioning in a single mode i.e. only for grinding purpose were upgraded with innovative elements (like replacement of wooden turbine with steel fabricated one and introduction of ball-bearings etc. to harness maximum energy with better efficiency) for multiple uses.

To harvest the optimum use of available water and available land in the proximity of watermills, feasibility of new components like fish culture, nursery raising of vegetables and ornamental plants and bee-keeping showing potential to supplement the income of mill owners and village community were studied from techno-economic sustainability point of view. Detailed case analysis revealed following specific process characteristics that enabled this rural innovation evolving as community based green enterprise model for macro level application to strengthen small scale livelihoods in remote mountain regions:

1. **Inducing Economic Potential and Scaling Up**

Improved watermill has won community approval and is widely accepted, as shown in Table 1. Techno-economic impact analysis of improved watermills shows that technological innovations in terms of effective water use and management (upgraded watermills, agro-processing and electrification, nursery management, beekeeping, etc.) is standardized for hilly conditions to manage and use natural resources sustainably. Study also shows that such changes have inspired improvements in some watermills of different capacity across the Uttarakhand and also in remote forest areas of Himachal Pradesh. Increased net income and utilization of watermill of bigger capacity may further add to process of scaling up to significant benefit to the community at large. Impact assessment and cost-benefit results of all improved systems in the study area also show significant increase in net income value along with subsidiary activities, from 2nd year after recovering the initial capital investment in 1st year itself which get established in 3rd year.

2. **Integrated Technology Components for Multi-Purpose Use**

Given the abundant availability of wasteland and water in the vicinity of improved watermills, water-millers were encouraged to initiate nursery raising and floriculture related activities linked to beekeeping for income generation. Since water is an essential component for mills as well as for fisheries, a composite fish culture was made part of this integration at one location to get the maximum advantage from available water. In addition, integration of vegetable and ornamental plants in areas measuring 1500–1800 square feet, with assured irrigation from the water channel of a watermill, provides further returns to water-millers and the local community. These activities are seasonal and can be integrated and managed locally.

It was found that technological up gradation with small and affordable changes have improved the functional efficiency of the watermill in a user-friendly way to generate power. Besides, providing shaft power, watermills can be converted into electrical generating systems that can be used by villagers for lighting at night and operating small-scale enterprise in the daytime. The different options of integrated use of water in present study show how a water stream can be useful to the local community through various applications (Fig. 1). Specifications for an improved watermill with multiple uses of water as complete package including adoption factors, technology flow, and development indicators, are given in Table 1 justifying its immense potential as replicable model.

3. **Community Empowerment: Adopting Technology to Improve Livelihoods**

Considering the economic incentives for households and communities as a whole, the adoption of improved watermill as integrated and multipurpose model had an important impact on socio-economic conditions. It was found enterprising

Table 1 Improved watermill model (3 kW) for decentralized power generation and multiple use: technology inputs, adoption and impact factors for replicable green technology package

Upgraded technology	Multipurpose use (activities)	People's contribution	Adoption rate	Technology package flow	Development indicators/ response variables
Water Mill • Cemented Channel • Flume covering with aluminum sheet/GI sheet • Change in runner/turbine • Alternator • Use of single ball bearing • Stone dressing	• Grain grinding • Village electrification • Additional provision for: Paddy De-husking Spices grinding Cotton Combing or Oil expelling	• Land • Labor • 25 % input cost with repayment of bank loan in three years.	High (Increased output performance > 6–8 times)	• Extension to local artisans and unemployed youth. • Village to village in other Himalayan regions for revival of traditional watermills • Creation of multi-purpose common facility centre • Model accepted by State Govt. UREDA, Uttarakhand and HIMURJA, HP • Now in other Himalayan states including HP (Mangrah Panchayat), Kullu –Bhuthi Forest Range (3–5 kW); North Eastern Region including border areas of J and K region, especially in non-grid remote areas.	• **Human resource development** - Local skill developments - (Masons, blacksmiths) - Local employment and prosperity • **Natural resource management** - Clean Eco-friendly energy - Value addition by agro-processing - Additional income generation • **Facilities** - Electricity - Communication facility - Irrigation facilities • **Socio-cultural Values** - Check on migration - Conservation of traditional wisdom - Local empowerment and self-dependency
Other components/additional components (seasonal)					
Fishery	Major carps	• Land • Labor • Seed	Medium		
Nursery raising	Ornamental plants and vegetables	• Land • Labor • Seed	High		
Bee-keeping : **Bee-boxes with frames**	• Alternative use of *Lantana,* an invasive weed to make bee-boxes • Quality honey production	• Land • Labor	High		

Impact Benefits: Economic, Ecological and Social

Economic: Livelihood diversification with technology inputs, improved income and household level food security

Ecological: 1. Average Annual Carbon Abatement Potential of Improved Watermill: Very High

2. Proper utilization of uncultivated (waste) land, improved plant bio-diversity, less run-off, environment friendly

Social: Lightening facility for recreation and education to children, reduced drudgery of women and check on migration

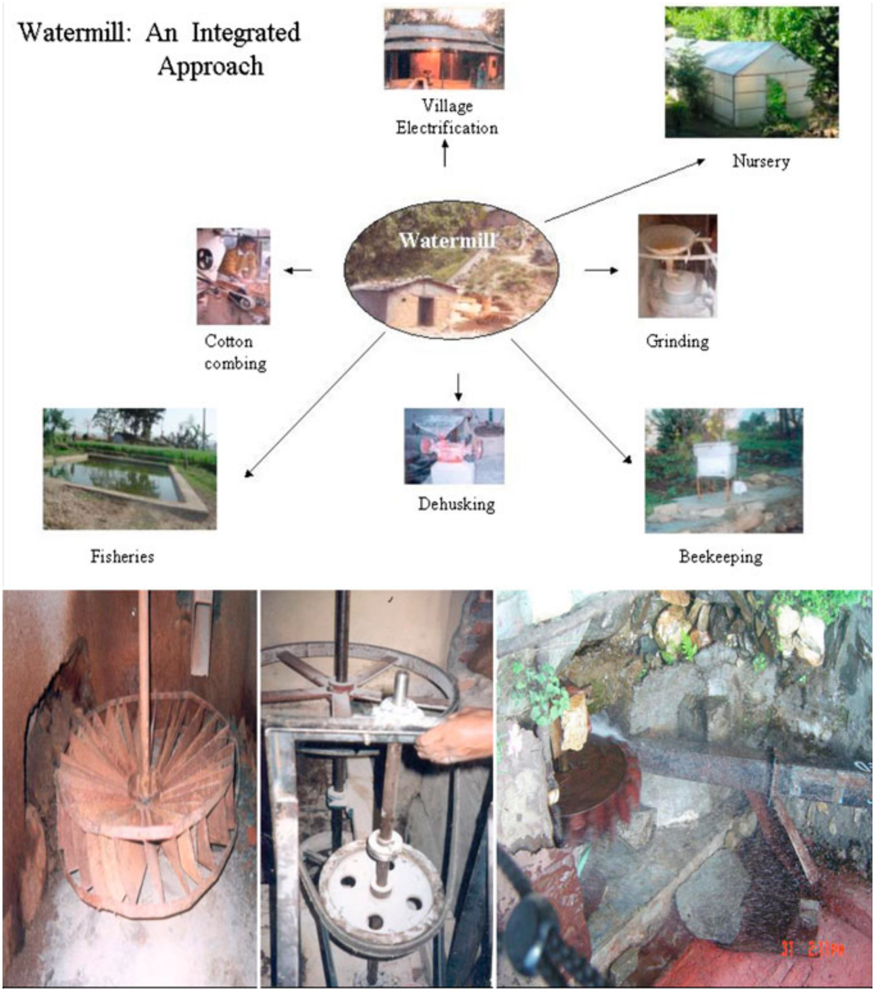


Fig. 1 Outcome model of technology development and transfer: multipurpose use of improved water mill in non-grid mountain areas

millers who had set up diesel and electric mills are now switching over to the improved watermill model because of cost-effectiveness, multipurpose benefits, and the environment friendly way this system functions. Survey and discussion with field level developmental agencies at the later part of the study shows that technology flows from village to village and within IHR have been very effective and efficient, but it was also noted that this requires initial stimulus and continuous support from local voluntary organizations and developmental agencies to empower communities with a complete technology package in partnership mode, ensuring forward and backward linkages. Community based model for improved watermill with three optional modes for multiple use of water was found to be of immense utility to provide cost-effective energy services for agro-processing, micro-enterprises like cotton combing and rice de-husking; and village electrification—though of small scale but contributing effectively to the livelihoods of people in non grid mountain areas. This technology model is now being replicated in other Himalayan states including Himachal Pradesh to upgrade old watermills by Forest Department and State Energy Development Agency like HIMURJA as well as Indian Army in remote North and North–Eastern region.

4. **People's Participation Index and Stake holder's Perceptions**

Considering the potential of the technology it was felt that participatory assessments of representative samples for technological intervention model will be particularly useful for policy making because they will provide valuable insights into how community or users groups assess their situation with such technology based interventions from the point of view of appropriate ness and overall feasibility (Singh and Gill 1993; Singh and Padaria 2005). It will also help to know how technology based developmental programmes have helped/empowered them in terms of skill, capacity building and economic returns etc. or failed if properly not disseminated. Therefore, the study tried to analyze people participation index (PPI) during planning, implementation and post intervention period of this livelihood related technology intervention model evolved. A stakeholders' analysis for people's perceptions with respect to 15 indicators of appropriateness which influence feasibility and effective delivery was also done to understand the appropriateness of the improved watermill model and its impact and utility from users' perspective. Overall people's participation index (PPI) was found 72–72.44 % for improved watermill clearly indicates highest adoption and sustainability of this technological solution customized to location specific livelihood needs and available natural resource base. It is interesting to note that users' perceptions was also high for all fifteen indicators (perceived mean score 4.90 and above on the scale of 5 with representative sample of N = 30) particularly in terms of simplicity, feasibility, adoptability, profitability, natural resource compatibility, livelihood security, technology flow and technological empowerment.

Thus, above trend analysis for overall PPI ranking as high shows establishment of participation process with technological empowerment and hand-holding of local community in entire process of participatory action research for design, testing and diffusion of improved watermill as complete technology model/package which is in consistent with Lilja and Ashby (2001). Further, users' perception and socio-economic factors for technology appropriateness in entire innovation process of delivery and adoption clearly justify and suggest potential of such model for macro level application in Himalayan mountain ecosystems. These findings are in confirmation with Ghosh et al. (2005) about the importance of people's participation, their perceptions and socio-economic factors that contribute immensely in the process of technology appropriation and adoption.

5. **Technology Success Factors**

One-time low investment to improve the capacity and efficiency of traditional watermills, and added value combined with high income and employment opportunities with multiple usage of water are important factors in adoption and technology flow, as indicated in Table 1. The watermills in study area have been in operation almost 5 years now, and have had some minor breakdowns, but people are able to repair and manage upgraded mills and other activities locally.

The study also shows that a community responds quickly to new income generating opportunities and readily adopts new activities for economic benefits. Power generation through three watermills in the Dokhwala village has also provided minimum electrification needs to all households to address minimum energy needs. Water millers and other families in the village, are now making use of surplus water for multipurpose activities such as nursery cultivation, fisheries, and bee-keeping near watermills. This integration of technology components has empowered local community to manage and make sustainable use of local resources, thus reducing the risk of migration to seek income-generating opportunities. Impact assessment demonstrates that simple up-gradation of watermills has impacts for both the water-miller, who can sustain and improve a declining business, and the end user, who saves time and money. This is particularly true for women, who previously had to wait for long periods to grind grains. It was found that reliable functioning of all three improved water mills with other multiple utility has not only reduced the drudgery of women but also changed the division of labour of gender. Moreover, improved systems do not have many of the disadvantages, such as costly transmission and environmental risk problems, dependence on fossil fuels and need for highly skilled manpower associated with large hydro plants.

6. **Institutional Success Factors: The Process Approach and Innovative Elements**

The role of Science and Technology—based voluntary organization i.e. Himalayan Environmental Studies and Conservation Organization (HESCO), located in Dehradun was found crucial in improvement of design for multipurpose use of watermill and effective use of available water for other income generating activities to provide livelihoods opportunities for local artisans and unemployed youths. As local institutional support ensuring forward and backward linkages with inbuilt component for social engineering and capacity building led to effective community's participation and empowerment in technology design, testing and diffusion with high adoption rate as discussed above. Thus, **demand-driven approach** by providing the initial technical and financial support for technology transfer with partnership amongst the community, VOs and government has ensured the institutionalization and subsequent sustainability of this innovative initiative by the community on their own. Moreover, harnessing of hydro-power with such system's approach led to decentralized use and local management, thereby contributing towards mountain development possible through self reliance and use of local natural resources judiciously.

7. **Green Technology Model: Potential of Carbon Abatement, Scaling Up and Employment Opportunities**

Observations form above field based study suggest that traditional watermills could be directly used for improved grinding of the grains through technological interventions which will also help in power generation and development of other farm and non farm artisanal activities across the Himalayas. Surplus power generated could be transmitted to far-flung and remote mountain areas through small hydropower grids. Indeed, upgrading of existing watermills in the IHR for effective water usage would provide alternative livelihood opportunities to make value added products by managing local natural resources. It is estimated that 2 million people or nearly 5 lakh families with 4 members each could directly benefit from technological upgrading of watermills and related activities. Moreover, in terms of intangible benefits, it has been estimated that running of single improved watermill (3 kW capacity) with an average operating time of 6 h/day for 300 days/year. will help in carbon abatement of about 5.67 tons of CO_2 annually replacing power generation from coal, while, it will be 4.3 tons of CO_2 by displacing small diesel genset. Thus, it also justifies the immense potential of improved watermill as environment friendly clean technology system in remote non grid mountain areas to address the small energy needs for lightening and running micro-enterprise for income generation thereby increasing the productivity and economic efficiency of the local resource use of mountain areas.

Overall, above findings also validate the premise that mini hydro based renewable power systems are reliable and feasible alternatives for supporting small loads operating units independently to isolated communities. If this is applied appropriately especially in remote non—grid mountain areas where high transportation cost of fossil fuel and maintenance costs of diesel stations are major constraints which can be rightly overcome through this field tested system on economically viable costs. Thus, considering mountain specificities such as inaccessibility, fragility and marginality, improvement of existing traditional watermills and knowledge system for small hydro power use as well as end use diversification as discussed above by appropriately integrating local management skills can contribute to create jobs in a small and medium sized community enterprises. This will bring socio-economic cohesion within the community with a positive implication for security of energy supply and protection of environment in IHR states.

Case Study 2: Technology Intervention for Spring Recharging

In the mountainous areas water for domestic use (drinking, washing, cooking, etc.) is largely derived from shallow wells and springs. An increasing problem nowadays is the deterioration in discharge from springs, which sometimes even causes the springs to dry up entirely. It is reported that currently 30 % of the springs have almost dried up, and an additional 45 % of the springs are on the verge of drying up, affecting approximately 60 % of the population in mountainous villages. Factors contributing to this deterioration include poor rainfall and earthquakes as a consequence of climate change. To address such burgeoning problems affecting livelihood base of mountain community linked with depletion of natural resources, innovative initiative has been made by HESCO to work towards appropriate technological solutions through institutional arrangement and linkages as discussed in Box. 1 involving community as major stakeholder. Under this initiative, emphasis has been given to increase the discharge of mountain springs that are suffering, and to manage the storage and distribution of the water. In collaboration with Bhabha Atomic Research Centre, Mumbai (BARC), HESCO is working using isotope hydrology technique to identify recharge areas of springs for rainwater harvesting in the mountainous region of Gaucher area, Chamoli District, Uttarakhand. Data analysis for 2005–2011 after identification of recharge areas and subsequently implementing vegetative and engineering measures for controlling the subsurface flow, rain water harvesting and ground water augmentation—have shown substantial increase of discharge rates of the existing springs, and also reappearance of old springs, below subsurface dykes that were constructed. This case study of decentralized model for water resource management has shown potential of technology flow and its adoption for macro level application for spring recharging in other Himalayan states thus contributing to adapt and mitigate problems associated with deforestation and climate change.

Box 1. Technology intervention for Spring Recharging in Mountain Areas

Problem Identification: In Uttarakhand alone 10,000 out of 16,000 villages are troubled with water scarcity and only about 15 % can use water for irrigation. As a result of this scarcity, lots of drudgery is being faced to collect water from distant sources and even there have been reports of conflicts over the distribution of the water. Springs are fed by aquifers. The aquifers are fed by water from recharge areas, often originating from precipitation. Due to deforestation of recharge areas water cannot percolate to the natural aquifer but instead runs off the mountain, resulting in deterioration of discharge in springs later on.

Technology Solution and Institutional Arrangements: To address above problems being faced by the mountain community, HESCO, a science based organization has taken an imitative to increase the discharge of drying mountain springs and to manage the storage and distribution of the water. With the support of Bhabha Atomic Research Centre, Mumbai (BARC), HESCO has carried out pilot scale experiments using Isotope techniques to identify recharge areas of springs for rainwater harvesting in the mountainous region of Gaucher area, Chamoli District, Uttarakhand. Rainfall samples are taken at locations of the approximate altitude for establishment of the recharge areas, by comparison of isotope compositions. This characterization works because water in a certain environment develops a certain "fingerprint"—especially with regard to altitude, which is conserved once the water percolates to the aquifer. After the successful identification of recharge areas, implementation of social, engineering (digging of trenches along the contours to prevent water runoff, construction of check bunds for water retention and water harvesting ponds) and vegetative measures (replanting and afforesting recharge area with protection measure from grazing and cutting of plants or trees*)* were taken in consultation with local community especially with regard to protection of the recharge areas.

Recharge area with sub-surface dykes

Revival of old spring below constructed subsurface dykes

Outcome and Way Foreword: So far 16 springs have already been recharged, through the use of artificial recharge structures, used for groundwater augmentation but also for water harvesting benefiting local people. The success of this unique intervention is also reflected in the agricultural sector, where yield of wheat, paddy and vegetables increased significantly with 2 fold increase. The fisheries and animal husbandry have also been initiated at commercial level by the villagers. Seeing the success impact of spring recharging interventions which revives ecological niches and retains tradition by providing a decentralized model for water resource management, an additional 10 sites across three Himalayan states (Uttarakhand, Himachal Pradesh, Jammu and Kashmir) have been identified for spring recharging involving community and local S & T institutions to ensure effective technology flow with foreword and backward linkages.

4.2 *Mountain Communities and Forest Dependence: Reducing Fire wood Consumption and Mitigation of Carbon Emission*

According to current estimate (IEA 2010), almost 800 million in Asia–Pacific region have no access to electricity, with more than 1.9 billion depending on traditional use of biomass (firewood, animal dung and agricultural residues) for cooking and heating particularly in rural areas, where almost 70 % of Indian population lives. While, most of the total energy consumed by the rural population in the Indian Himalayan Region (IHR) consists of non-commercial fuels, mainly fire wood collected from forests and agriculture fields. The practice of burning fire wood in the traditional open type cook stove serves three objectives i.e. cooking, water heating and space heating which LPG and Kerosene fail to achieve even on cost. This heavy dependence on biomass fuels has serious consequences for people's health, with women and children being most vulnerable. On account of limited resources the rural areas are facing grave energy crisis and high dependence on fire wood poses a potential threat to the ecology, health of household inmates and also involve women's drudgery in fire wood collection traveling long distances. In this context, following two case studies from field highlights efforts being made at the grassroots level to provide affordable, efficient and eco-friendly renewable energy technological solutions to meet day to day energy requirements in remote mountain areas and for addressing local livelihoods needs in a decentralized way.

Case Study 3: Solar Passive Retrofitting and Cluster Solar Water Heater

Though technology based on solar energy provides solutions to solve rural energy problems but cost and post installation maintenance are the major constraint in rural scenario. Therefore, Himalayan Research Group (HRG), another science based voluntary organization working in middle Himalaya took an initiative to develop solar passive retrofitting for space heating and solar water heater for household clusters in villages of Mashobra Block of District Shimla to understand the effectiveness of solar devices in mountain rural households to reduce their dependence on fire wood. Taping of solar energy with these simple local installations for domestic use in existing houses was aimed to reduce dependence on fire wood and household carbon emission. Solar passive retrofitting was designed locally through skill training of carpenters and fabricators using wood, glass and steel sheets blended with insulation material to tap maximum solar energy for inner warmth of the houses backed with scientific principles. In this process, extensive work was done by HRG on designing, short listing of material for fabrication and capacity building of the rural artisan in installing them in individual houses to meet with space heating requirement during the day time in winter months. Three solar water heater of 200 l capacity were also installed for the cluster of households in three villages to cater the requirement of households in the villages to meet requirements for hot water. Thermal efficiency and comfort evaluation of solar passive retrofitting during winter season indicated thermal comfort during day time and to save fire wood and prevent compulsive sitting in kitchen.

Impact analysis of above intervention covering 82 households from three villages, has indicated that installation of solar retrofitting for space heating and solar water heater will reduce consumption of fire wood to 40 % and on an average there will be a reduction of 4.14 tonne carbon/household in temperate rural household during 6 winter months (from October to March). Besides, use of such eco-friendly solar aided devices in space and water heating provide respite to women from indoor pollution and drudgery involved in collection of fire wood. Thus reduced time invested in collection of fire wood has facilitated time investment in other livelihood activities in addition to forest conservation and mitigation of household level carbon emission.

The projection related to reduction in carbon emissions and saving of carbon/household is reported very encouraging in the above case study. Therefore, the concept of such technological intervention to overcome energy vulnerability having essential component of capacity building with local institutional arrangement needs to be disseminated with policy level decision for customization and use of solar aided devices as per local needs at the household level in the IHR. This will ultimately contribute to the recent initiatives of carbon neutrality and in conservation of natural resources with reduced extraction of fire wood from forests and natural habitats which is a priority at the local as well as at the national level.

Case Study 4: Scalable Solutions for Energy Efficient Devices

Technology Informatics Design Endeavour (TIDE), a science based field group in Bangaloru has recently won International Ashden Award for excellence in the field of sustainable energy recognizing their work for disseminating energy efficient woodstoves and kilns which save at least 30 % of fuel and are tailor-made for specific micro, small and artisanal industries. This becomes pertinent as people in rural India as well as in other South Asian Countries relies on biomass for most of their domestic and industrial energy use, using traditional low-efficiency wood burning technologies which have resulted in social, economic and environmental impact such as loss of forest resources and hazardous exposure to smoke and fuel (Sarvekshana 1955; Smith 2002). In this direction, TIDE has worked to improve the efficiency and environmental impact of biomass use in informal industries in India by promoting the use of energy-efficient biomass stoves, dryers and kilns (Table 2) which also have immense utility to meet safe and clean energy requirements for the benefit of community residing in remote mountain areas of IHR.

Such scalable interventions are highly fuel-efficient, improve working conditions and bring environmental benefits. Indirect assessment of impact by collecting field data has indicated that TIDE has disseminated so far about 11,840 energy efficient industrial stoves, dryers and kilns and 7,000 domestic stoves during 1998–2009 (UNDP 2012). It is estimated that these energy efficient devices installed in the field are saving about 50,000 tons of fire wood every year with an annual saving of more than 75,000 tons of CO_2. In terms of economic benefits, an estimated 1.50 lakh people have directly or indirectly benefited from such innovative work of TIDE including entrepreneurs, end users and device operators, fabricators, contractors, masons and plumbers with two fold increases in income as compared to conventional practices. TIDE initiatives have helped about 75 self help groups (SHGs)/technology user groups/community based organizations (CBOs) with technology linked livelihood options in Tamilnadu, Karnataka and Kerala state. Such linkages were essentially to involve them not only as beneficiaries but also as active partner in whole process chain innovation and technology delivery encompassing baseline survey, data collections, awareness creations and training programmes, testing of products in the field and also market linkages in the local area. Recent study indicates that 46 women trained by TIDE to create viable livelihood options to run energy efficient enterprise are self reliant, contribute in their children education, role models and are good communicators.

Analysis of field work indicates that TIDE's technology initiatives linked with livelihood enhancement is largely through biomass based energy efficiency technology with a strategy to:

- Create sustainable livelihoods by efficient use of biomass energy, wherever possible, with an attempt to fuel shift to agricultural residues to further save firewood.
- Constantly innovate products in accordance with market research and user feedback—aligned with its ethos of environmental sustainability.

Table 2 TIDE's energy-efficient devices and their application: demand driven entrepreneurship model for technology dissemination

Device	Application
Stoves	Water heating and community cooking, commercial cooking, arecanut boiling and drying, jaggery and khova production, rubber-band vulcanizing, ayurvedic medicine production, silk reeling, textile bleaching and drying, cashew processing.
Dryers	Areaca, cardamom and coconut drying.
Kilns	Brick making, lime burning, tile and pottery making.

- To create different types of enabling mechanisms for access to the entire range of energy efficient biomass combustion technologies developed or adapted.
- To secure livelihoods in small businesses, enhance their competitiveness by reducing the consumption and hence cost of thermal energy.
- Improve the working environment and thereby contribute to better respiratory health of the workers.
- Conserve biomass and reduce GHG emission reduction with considerable reduction in fuel cost every month to arrest deforestation.
- Involve the local community in the creation of delivery systems for the technology application; and strengthening the supply chain. This requires developing social learning institutions to achieve results on ground as part of the conservation planning for local decision making and assessing communities need.
- Identifying rural youth with marketing skills and building their capacity as entrepreneurs to fabricate, install and service the energy-efficient devices.

From operational point of view to make visible impact, it was found that TIDE innovates for better interface of science and society and it carries out activities that enable the creation of social, economic and environmental impact in rural and semi rural areas. In this process, institutional partnership with Centre for Sustainable technologies (IISc) was found critical to ensure delivery of quality products. Overall, strategically TIDE intervenes in three different ways:

- Through sister concern i.e. Sustaintech India Pvt. Ltd. to develop business models in fuel-efficient stoves dissemination. This business model has secured investments and has been identified as one of the top 3 business models in the Asia Pacific region.
- Through grass root entrepreneurs for dissemination of onsite constructed stoves for artisanal industries (areca boiling, silk reeling, textile dyeing and bleaching, jaggery making, herbal medicine preparation, rubber band vulcanizing, drying of horticultural produce etc.).
- Through women enterprises for household stove fabrication and drying based enterprises.

Similarly, TIDE has also helped WWF-India in its conservative initiative in Southern Western Ghats (SWG) which are known for ecological goods and services they provide as fire wood, fodder, food and shelter to local communities and indigenous communities living in and around them. It was found that extraction of firewood for lemon grass distillation was one of the major dependence of the tribal communities living within SWG as assured source of income. But, the technology of the conventional distillation units used by the tribal was crude and the volume of firewood consumption was also reported high in the distillation process. Therefore, from conservation point of view strong need emerged for process innovation to develop fuel efficient distillation technologies. Accordingly, TIDE developed an alternative process and improved design of lemon grass oil extraction unit to ensure that it meets the livelihood needs of the tribal while reducing firewood consumption due to better heat utilization efficiency with introduction of chimney and redesigning of combustion chamber with proper insulation to prevent heat loss (Uppal et al. 2011). Such an intervention has drawn great interest among the communities as they have realized the less consumption of wood and to get higher income generation from better quality of oil produced through a fuel efficient intervention strategy adopted through a collective consultative process of WWF-India, TIDE and community itself to build local capacity with appropriate technological intervention for sustainable livelihoods and conservation.

5 Conclusions: Technology Led Scalable Solutions, Ecosystems Services and Responsible Factors for Adaptations

Mountains are nationally and internationally important assets, for their natural beauty, flora, fauna and cultural heritage and for leisure and eco-services. In changed scenario of climate change in the mountains, strong need is emerging towards rural resource management i.e. carbon, soil and water management to attain self-sufficiency in food and energy sector. As discussed above, this can be achieved through appropriate technology applications and investments planning in participatory mode. But, changing climate affecting the mountain habitat and people can not be fixed with technology alone, but, it requires certain tools and methodology to mitigate this to some extent with enabling management/services and change in perception and behaviors of dependent population. Science based scalable technological solutions for sustainable livelihood for people in mountain areas as evident from above field based case studies for macro level application can certainly address the key issue of conservation and community demands on natural resources in sectors of water, energy, health, and employment leading to conservation of mountain biodiversity. Such technology benefits will open new alternative livelihoods opportunities to local community with reduced dependency on forest resources through good management practices. Studies also revealed and support that local communities of Himalayan states should be provided incentives in terms of technology benefits(for saving firewood, reduce carbon losses) relating to livelihoods improvements for their ecosystem services flowing from Himalayan states to the rest of the country and world (APHDR 2012; Singh 2012). These measures would speed up restoration of degraded forests and enhance their capacity to sequester carbon and enable them to contribute to the conservation of ecosystems.

Though there are many entities interested in doing related action research work to the development and dissemination of technologies for rural development in mountain areas, the spread of rural technology has been diffuse, uneven, and slow and its full potential for generating a rapid multiplier effect in mountain economy has remained unrealized. The main constraint preventing advances in technologies for rural application from reaching most villages in mountain areas seems to be the lack of local technology action groups who can assist in the assessment of the technology needs and the current technology status/gaps of different rural occupation groups, i.e. farmers, rural artisans and the landless, to enable them to add value to their products and services with upgraded technology of appropriate scale. Further, mountain people who get their land based livelihood support and energy needs directly from ecosystems are often hit hardest due to visible adverse impact of changing climate on agriculture, water and forest resources. Thus, adequate measures and strategic support are needed to adapt to such climate change impacts for positive impact on natural resources and ensuring better income and livelihoods opportunities.

Comprehensive analysis of above discussed four case studies clearly show the ways that attention is required to embedding the results of such field level action research in policy; using research intermediaries with system approach and communication channels to ensure the results of research and knowledge generated reach large section of affected communities in mountain areas. In such efforts both environmental and societal adaptations to climate change are programmatically to be embedded. Studies also point out that capacity building to adapt towards likely climate change really requires local institutional arrangements on facilitating to identify suitable technological options and scale up existing knowledge tools and approaches with appropriate one for adaptation (mitigating the effect of climate change) to tackle emerging issues primarily related to energy and water resources as part of the development plan. These studies also illustrates ways in which communities in climate-sensitive areas are vulnerable to changing conditions, and how climate change adaptation initiatives by enhancing livelihoods provide a practical means of improving people's immediate requirements, and provide them with increased capacities in terms of clean and affordable technological solutions to deal with changes in climate.

Thus, for traditional activities in the mountains, there is a need to strengthen the knowledge, skills, and infrastructure already available and scale them up in a business model, in order to bring significant impacts in terms of better output and efficiency. A range of skilled and unskilled employment opportunities for pre- and post-installation services related to electricity supply and mechanical and civil work can be generated as evidently found in the case of improved watermill and energy efficient devices. If properly pursued, such emerging models for efficient water usage and energy efficient systems as described above through case studies would provide immense employment opportunities to local young people in Himalayan regions, who are currently migrating to bigger cities or industrial areas in search of jobs. Large scale replication and application of such emerging model(s) at the grassroots level can play a lead role to diversify mountain economies, to improve the productivity of mountain areas and to reduce the existing environmental damages of the eco-systems.

Further, technological intervention in each case has also indicated its contribution towards **attainment of Millennium Development Goals (MDGs)** particularly for improved income and livelihoods; gender equality and women's empowerment, environmental sustainability, and developing partnership and linkages. Analysis of all cases explore adaptations approach at the two levels i.e. establishment of adaptive capacity for awareness, governance and knowledge; and the adaptation itself for change of behavior, practice and livelihoods as per local needs (Mirza 2007). Technological intervention in these case studies also suggest that adaptation strategies should be designed with priority to most vulnerable groups as water millers in case 1 for improved watermill, whole community in case 2 for spring recharging, women groups in case 3 for solar aided devices and artisans in case 4 for small energy efficient devices. These studies derived from field observations and tested by local communities also identify that focus only on technological solution is not enough; approach should also include enhanced capacity to adopt new adaptation strategies in holistic way with more livelihoods options. Critical analysis on successful technology delivery and adoption aspects justifies the role of civil society organizations with S & T capacitates on 'problem based intervention' for pro-poor innovation rather than 'solution based thinking' with systems approach covering managerial and social engineering aspects as well. Most remarkable feature of almost all these technology models evolved is that they have been designed and can be scaled further in the form of standardized mode for replication as per location specific needs through intensive collaboration process amongst technology generator, providers and users. In view of climate change adaptation, it was found that if community based adaptation initiatives are in tune with development activities, then this bring both immediate livelihoods benefits as well as strengthen people's ability to deal with climate change (Huq and Reid 2007). It also recognizes and identify the practices of civil society organizations as important actors of change in innovation system (to enable technological as well as non-technological or process innovations together) and in delivery process chain i.e. through technology user's groups or women's Self-help Group working within the settlement who understand the system and accept the responsibility as catalysts of innovation. This process mechanism is absolutely essential to bring better local participation and diverse actors together who have capacities for innovation and to perform various roles/support knowledge inputs in sustaining developmental programmes (Padaki and Vaz 2003; Kochendorfer-Lucius and van de Sand 2000).

In all the case studies discussed, it may be concluded that for effective adaptation and mitigation to climate change and to ensure livelihoods' security in Himalayan region, following factors/approaches with **local institutional arrangements** are crucial for mountain development and to ensure ecological sustainability:

- **Decentralized way of Functioning** to transform institutional tools and enable people to be participants and beneficiaries of development governance. Institutionalization of development governance at the local level could increase participation of the people in the mobilization and sustainable management and utilization of resources for development in their respective areas.

- Gender integrative participatory technology development/appropriation to support S & T based developmental efforts in mountain production system.
- **Systems Approach: Grass roots' Innovation, Linkages and Institutional Management**: Eco-restoration and employment generation through judicious use and transfer of appropriate technology package appropriated with involvement of people at all levels from planning to implementation stage ensuring post intervention sustainability. Need is to adopt **systems management approach** for technology absorption with social and managerial inputs. Institutional management and innovations (locally generated or the result of research interventions), people's participation, NGO-institution partnership and gender issues are important aspects for participatory research at the grass roots level particularly in the context of technology percolation *vis-à-vis* natural resources management and utilization. During impact study, special emphasis was laid on to isolate and identify the role of local institutions-community organizations to directly articulate people's needs and priorities, people's participation, technological innovations, social engineering and linkages amongst stakeholders. This was necessary to understand their contribution in the success of demand driven interventions and post intervention sustainability of technology developmental and adoption initiatives that allow local networking, scaling up participatory research and technology development and evolution of change, rather than blueprint models. It was found during study of above discussed technological interventions that for effective rural technology base and rural transformation in mountain areas, there is a need for development and introduction of such appropriate technologies coupled with sound delivery system having 'systems approach' for need identification, technology choice and appropriate scaling, technology modulation/innovation, economic and ecological sustainability and optimum use of local resources and material with emphasis on technology capacity building amongst local people. Such systems approach requires designing of intervention programme to infuse technical skills in local people and enhance capabilities of artisans/small and marginal farmers/landless labourers through application of S & T inputs for creation of sustainable livelihoods. This bottom-up approach suggests development of a complete process of identifying needs, appropriate technology design and development, systems engineering resulting in creation of systems based on sustainable technology packages and maintenance of assets created (Raghunandan 1988).
- **Appropriate Technology:** In the context of climate change adaptation in mountain areas, it is necessary to develop and introduce appropriate technologies coupled with sound delivery system, which ensures economic and ecological sustainability and optimum use of local resources *(with positive impact on forest resources and community health due to substantial reduction in usage of firewood with improved burning of biomass leading to reduced indoor air pollution and CHG emissions in subsequent years due to cumulative effect)* emphasizing on technology capacity building amongst rural people. The

technologies should be such as would upgrade traditional skills and capabilities; be innovative and capable of easy assimilation; generate significant and assured added value to existing methods of operation; generate employment and use local resources; be capable of replication and adoption and should blend harmoniously with existing eco-systems leading to tangible improvements in the living conditions and self sustained development of the people with conservation of resources. Therefore, technology and its scale must be carefully chosen to enable mountain people to acquire and imbibe knowledge of technologies appropriate to their needs, priorities and environment (Agarwal 2005; Agarwal and Joshi 2006)

- To make any intervention successful, other areas of interest and **support activities to provide basic facilities** like drinking water, health and sanitation, and social security etc. should be taken care for overall sustainable community development and to have a catalytic effect for planned adaptation in climate sensitive mountain areas.
- **Importance of S & T base (science based VOs) in the actual area for effective technological intervention/to develop location specific technology package** taking into account the perceptions of people. Focus must be towards **community—led adaptation** to improve their access to affordable, environmentally sound technologies and generate meaningful employment in local economic structure leading towards poverty reduction. This can also help in bridging the Rural Urban divide by retaining human capital in rural areas with potential to arrest urban migration.
- **Involvement of local motivator as active change agent or natural carrier of technology** through dove tailed approach of motivation through talks and audio-visuals, awareness build up through demonstration, and hands on the job training in relevant field. Emphasis on capacity building at local level is observed as the centerstone in ensuring sustainability of technology with perfect exit plan for the programme implemented.
- Access to financial services and to subsidize energy efficient systems for better outreach.
- **Strong institutional linkages between S & T based field groups/VOs, R & D institutions with an extension machinery to disseminate the proven technological package at grassroots** which empowers and enable community to seek local solutions and have face-to-face interaction between them and scientists for proper scientific know-how. Programme sustainability is the critical issue which should be ensured though such linkages and local institutional arrangements to organize different functions for forward and backward integration and **community mobilization** through suitable planning and capacity building to develop sense of ownership and responsibility as a driving force to sustain the programme. In this approach, local communities should be at the centre of the economic and ecological arrangement. Their role in mitigation and adaptation measures to climate change becomes crucial as they are ideally placed to innovate, design and disseminate field-tested proven technologies with appropriate modulations which address location-specific problems and concerns

on the prevailing natural and socio-economic conditions, needs and priorities. They can facilitate the articulation of felt needs on one hand, and also match those needs with potential source of technology. It is being felt that such science based field groups can play a crucial and catalytic role in developing field tested and viable models of green technologies for socio-economic up-liftment through skill up-gradation, income generation, drudgery removal, sustainable use of resources, etc. by adopting localized technological strategies for technology absorption with social and managerial inputs. Such interventions will bring in visible changes in the lifestyles in rural areas and having multiplier effects in different parts of the IHR.

6 Way Foreword: Challenges and Policy Suggestions

Since it is being realized that climate change is gradually changing the ecological and socio-economic landscape in the Himalayan region, it is imperative to revisit and design developmental programmes/policies, conservation practices to create better livelihoods opportunities using appropriate technologies as adaptation measure to cope with possible climate changes in IHR states. Though climate change is not new to mountain people, but flexibility in livelihood strategies and institutional arrangements is required to build the capacity at the local level to adapt and strengthen the socio-ecological systems which is extremely important in achieving sustainable livelihoods. Thus, effective means of ensuring climate adaptations is to mainstream them in the sense that they contribute into development initiatives such as livelihood enhancement, environmental management and sustainable development. In such an endeavor, the success of technology development and application oriented programmes of societal nature clearly indicates that more than technology development it is the total system which is important for acceptance by the people leading to creation of sustainable livelihoods. Such interventions in 'process approach' with local institutional support for technology up scaling and delivery couples with financial services will brought in visible changes in the lifestyles in mountain areas with multiplier effects for livelihood gain through effective management of natural resources as also advocated by Gladwin et al. (2002), Pound et al. (2003) and Panda (2011).

Given the current scenario of resource utilization and the inherent institutional weakness, one of the major conditions for climate change adaptation and mitigation policies will be to understand how policy implementation for technology component can be integrated with local development efforts and partnerships. Besides, climate change adaptation and mitigation in Himalayan ecosystems requires a no. of methodological tools/dimensions to deal with managements investments, technological changes, equity and other human well being issues. Inefficiencies or constraints in any of these areas will enhance to vulnerability to climate change impacts. Experiences from case studies demonstrate that need is for stronger institutional and programmes synergies on planning, designing and expanding specific action research programmes linking economic and social well-being based on conservation and sustainable use by all relevant stakeholder groups, including private sector with bottom up approach.

The outcome emanating from the present case models also suggest to bring in required changes in the policies and procedures related to local human resource development through participatory technological empowerment of remote mountain community for ecosystem-based solutions to adaptation and more for diversified rural livelihoods. Therefore, natural resource management (NRM) and S & T policy of Himalayan states should encourage adoption and development of such replicable models of different scale for efficient use and conservation of available natural resources based on technologies and practices that are environment friendly focusing on decentralized planning, employment generation to address the problem of rural poverty and economic growth (Agarwal and Joshi 2006; Ramakrishna 2007).

Acknowledgments Author wish to expresses special gratitude to Dr K.S. Kapoor, HFRI, Shimla, and Dr. Santosh Satya, IIT, Delhi, for providing the necessary guidance to carry out the research study related to improved water mills. Special thanks are also due to development agencies i.e. HESCO, Dehradun; TIDE, Bangaloru; and HRG, Shimla whose expertise and work contributed to the critical analysis of above case studies. The case studies also benefited from the fruitful interaction with community and users who generously provided information and shared knowledge and data.

Notes

1. The views expressed in this chapter are those of the author alone, and do not reflect the views of the organization to which he belongs.
2. Avoided annual carbon emissions were calculated by using a conversion factor for diesel as 0.8 kg CO_2 per kWh; and for coal as 1.05 kg CO_2 per kWh. While, it was calculated using a conversion factor of 1.46 kg CO_2 abated per kg of firewood conserved.

References

Agarwal SK (2005) Technological empowerment for sustainable livelihood in mountains: some initiatives and experiences in participatory technology development and transfer. In: Dewan ML, Bahadur J (eds) Uttaranchal; Vision and Action Programme. Concept Publishing House, New Delhi, pp 336–352

Agarwal SK, Joshi AP (2006) Technology on the move in the Himalayan region: from empowerment to sustainable livelihoods In: Joshi AP, Agarwal SK Rakesh Kumar (eds)

Mountain technology agenda: status, gaps and possibilities, Bishen Singh Mahendra Pal Singh, Dehradun, pp 140–160
Asia Pacific Human Development Report (2012) One planet to share: sustaining human progress in a changing climate. UNDP Publication, pp 242
Carney D (ed) (1998) Sustainable rural livelihoods. DFID, London
Ghosh S, Chandra D, James BK (2005) Appropriateness of recommended agricultural water management technologies: an assessment from the perspective of stakeholders 191–200. In: Singh B, Padaria RN, Singh PL (eds) Impact assessment studies: agricultural extension and rural development programmes. IARI, New Delhi
Gladwin C, Peterson J, Mwale A (2002) The quality of science in participatory research: a case study from Eastern Zambia. World Dev 30(4):523–543
G-SHE (2009) Governance for sustaining himalayan ecosystem: guidelines and best practices. Ministry of Environment & Forests (GOI) & GBPIHED, Almora
Huq S, Rahman A, Konate M, Sokona Y, Reid H (2003) Mainstreaming adaptation to climate change in least developed countries. International Institute for Environment and Development Climate Change Programme, London
Huq S, Reid H (2007) Community based adaptation; a vital approach to the threat climate change poses to the poor. International Institute for Environment and Development, London
ICIMOD (2007) The melting Himalayas. Regional challenges and local impacts of climate change on mountain ecosystems and livelihoods. Technical Paper. Kathmandu: ICIMOD
INCAA-Indian Network for Climate Change Assessment (2010) Climate change and India: A 4 × 4 Assessment: a sectoral and regional analysis for 2030. Ministry of Environment and Forests, Government of India
International Energy Agency (2010) World Energy Outlook 2010. OECD & IEA, Paris
IPCC (2007) Climate change 2007: the physical science basis. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Contribution of working group to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge
Kochendorfer-Lucius G, van de Sand K (2000) New ways towards poverty alleviation: institutional development to supersede conventional project approach. J Dev Cooperation 200:21–24
Klein RJT, Eriksen SEH, Naes LO, Hammill A, Tanner TM, Robledo C, O'Brien KL (2007) Portfolio screening to support the mainstreaming of adaptation to climate change into development assistance. Clim Change 84:23–44
Lilja N, Ashby JA (2001) overview: assessing the impact of using participatory research and gender/stakeholder analysis. In: Lilja N, Ashby J, Sperling L (eds) Assessing the impact of participatory research and gender analysis, CGIAR system wide program on participatory research and gender analysis. CIAT-PRGA publication, Cali
Eriksson M, Jianchu X, Shrestha AB, Vaidya RA, Nepal S, Sandström K (2009) The changing Himalaya: impact of climate change on water resources and livelihoods in greater Himalaya. ICIMOD Publication, Nepal
Mirza M (2007) Climate change, adaptation and adaptative governance in the water sector in South Asia. Scarborough (Canada): Adaptation and Impacts Research Division (AIRD), Department of Physical and Environmental Sciences, University of Toronto
Negi GCS, Samal PK, Kuniyal JC, Kothyari BP, Sharma RK, Dhyani PP (2012) Impact of climate change on the western Himalayan mountain ecosystems: an overview. Trop Ecol 53(3):345–356
Padaki V, Vaz M (2003) Institutional development in social interventions. SAGE Publications, New Delhi
Panda GR (2011) Budgeting for adaptation to climate change. The India Economy Review 8:46–54
Parikh JK, Parikh K (2002) Climate change: India's perceptions, positions, policies and possibilities. OECD paper: climate change and development, pp 30

Parry M (2009) Climate change is a development issue, and only sustainable development can confront the challenge. Clim Dev 1:5–9

Pound B, Snapp S, Mc Dougall C, Braun A (2003) Managing natural resources for sustainable livelihoods: uniting science and participation. IDRC, Earth Scan Publication Ltd., London, pp xix–252

Pouliotte J, Smit B, Westerhoff, L (2009) Adaptation and development : livelihoods and climate change in Subarnabad, Bangladesh. J Clim Dev 1: 31–46

Raghunandan D (1988) Rural development through science and technology application. Kurukshetra 37(1):77–81

Ramakrishnan PS (2007) Sustainable mountain development: The Himalayan tragedy. Curr Sci 92(3):308–316

Rautela P (1998) Water resources in the Himalayas: harvesting, tradition and change. Concept Publishing Company, New Delhi, p 123

Rijal K (2000) Mini and micro hydro power development: status, issues and strategies for the Hindu Kush Himalayan Region. J Eng, NESS, Inst Eng 9. Nepal

Sarvekshana (1955) Survey of unorganized manufacturing sector. NSS 45th round. Department of statistics, GOI, New Delhi 19(1)

Saxena NC (1998) National convention of the water millers of Himalayas. In: Proceedings of national convention of the water millers of Himalayas. CAPART & HESCO Publication, Delhi, pp 21–30

Schild A (2008) The case of Hindu Kush-Himalayas: ICIMOD's position on climate change and mountain systems. Mt Res Dev 28(3/4):328–331

Singh A, Gill SS (1993) Review of adoption research studies from 1980–87. Indian J Extension Educ 29(1&2)

Singh SP (2012) Valuing ecosystem services flowing from the Himalayan states for incorporating into national accounting. UCOST Publication, Dehradun

Singh B, Padaria RN (2005) Methodological paradigms in participatory impact assessment. In: Singh B, Padaria RN, Singh PL (eds) Impact assessment studies: agricultural extension and rural development programmes. IARI, New Delhi, pp 32–43

Smit B, Pilifosova O (2001) Adaptation to climate change in the context of sustainable development and equity. Climate Change 2001: impacts, adaptation and vulnerability. Cambridge: Cambridge University Press, Cambridge, MA

Smit B, Wandel J (2006) Vulnerability, adaptation and adaptive capacity. Glob Environ Change 16(3):282–292

Smith KR (2002) Indoor air pollution in developing countries: recommendations for research. Indoor Air 12(3):198–207

UNDP-GEF (2007) Climate change impacts, vulnerability and adaptation in Asia and the Pacific. A background note for the Training Workshop on Environmental Finance and GEF Portfolio Management, 22–25 May 2007, Bangkok, Thailand

UNDP (2012) Entrepreneurship at grassroots: Diffusion of biomass devices in informal industries in India. Case study 15, pp 15

Uppal V, Mullai P, Nandikesh S (2011) Reducing fuel wood consumption in lemon grass distillation, Chinnar Sanctuary, Kerala. WWF-India Publication, New Delhi, p 21

UCOST (2012) Uttarakhand S & T Vision, UCOST Publication, Dehradun. pp 59

Varma PD (2010) Reflection of climate change leaders from the Himalayas –Case studies detailed –Livelihoods and People's Perceptions. Lead India Publication, New Delhi, p 183

Environmental and Socio-Economic Impacts of Climate Change in the Sundarban Delta and the Need for Green Management

Udayan De

1 Introduction

The Sundarbans (often also called Sunderban) of the Indian sub-continent is a complex ecosystem (Figs. 1, 2, 3, 4), consisting of forest-land, mud-flats and rivers (including hundreds of creeks) in the estuary of the two mighty rivers—the Ganges or Ganga (flowing into Bangladesh as Padma) and the Bhagirathi. *Ban* means forest. The forests (mainly mangrove forests), originally covered a much wider area northwards, including what is Kolkata today, as seen in old British paintings of tiger hunting in forests near their Kolkata (Calcutta) settlement. The present Forest of Sundarbans covers some 10,000 km^2 of forest land and water-covered area, of which some 40 % is in India and the rest in Bangladesh. The Indian Sundarbans include another 5,400 km^2 of somewhat inhabited fringe areas of the forest. Hence, the total area of the Sundarban region in India is $\sim$9,600 km^2 which constitutes the Sundarban Biosphere Reserve.

Sundarban is a part of the world's largest delta (80,000 km^2), formed from sediments, deposited mainly by three great rivers (Fig. 4), the Ganges, Brahmaputra and Meghna. Sundarbans National Park (21°31′–21°53′N, 88°37′–89°09′E) is a World Heritage Site, southeast of Calcutta, and in West Bengal. It is bound by the Bay of Bengal in the south, and Matla/Bidya and Haribhanga/Raimangal rivers to the east and west, respectively. The northern boundary is buffered by Netidhopani and Chandkhali forest blocks. River Matla divides the Sundarbans Reserved Forest into the Sundarbans Tiger Reserve (on the east) and Reserved Forest of South 24 Parganas Forest Division. There are also bird, crocodile and other sanctuaries in the Indian part.

Sundarbans West Wildlife Sanctuary is a UNESCO World Heritage Site and animal sanctuary in Bangladesh. Actually, this is one of the three wildlife

U. De (✉)
Kendriya Vihar, C-4/60, VIP Road, Kolkata 700052, India
e-mail: ude2006@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_34,

Fig. 1 A map of 323 BC Asia shows the kingdom of Ganga-Ridi (Ganga-Ridai) in what is Bengal today

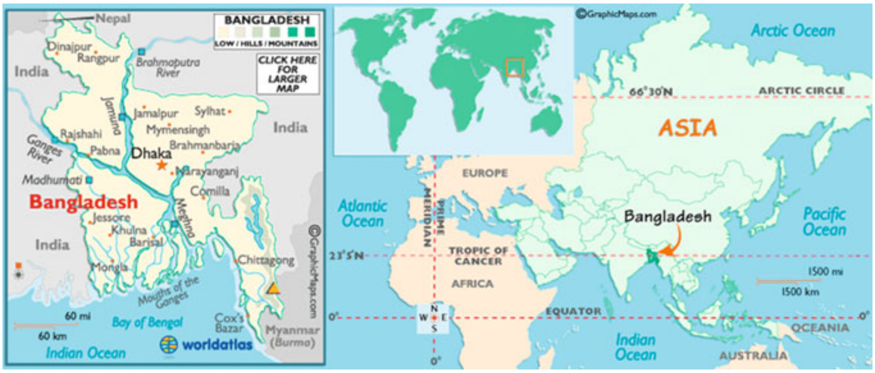


Fig. 2 Bangladesh part of the Gangetic Delta plus, world map. From http://www.worldatlas.com/webimage/countrys/asia/bd.htm

sanctuaries within the Bangladeshi area of Sundarbans—Sundarbans East, Sundarbans South, and above-mentioned Sundarbans West.

UNESCO included the Sundarbans Biosphere Reserve in the World Heritage List in 1987. Moreover, it is recognized as one of 21 most pollution free zones, a status that must not be upset. Sundarbans is also the world's single largest mangrove forest. Its complex geomorphologic and hydrological characters are now affected by climatic hazards linked to global warming (Ali 1996). Two global warming effects, the rising sea level and fall in flow of fresh river water in particular, are becoming death blows to the Sundarbans.

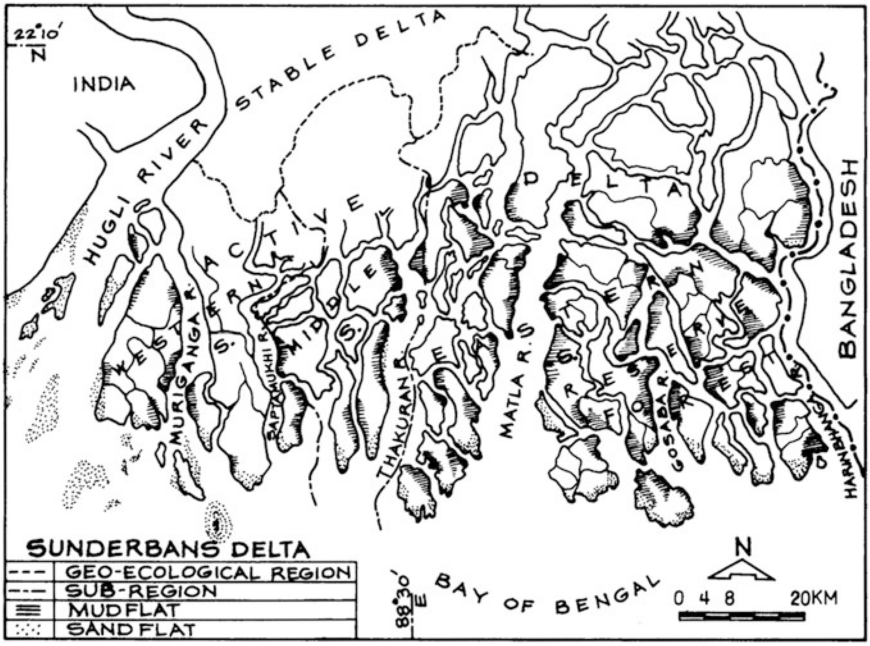


Fig. 3 Indian part of the Sundarban area of the Gangetic Delta showing some rivers and a few geographical details. Taken from Shivashish Bose, 'Mangrove forests in Sunderbans active delta—ecological disaster and remedies'

Fig. 4 This is a map of the Ganges (*orange*), Brahmaputra (*violet*), and Meghna (*green*) drainage basins with full view of Indian and Bangladeshi parts. From: http://en.wikipedia.org/wiki/File:Ganges–Brahmaputra-Meghna_basins.jpg

The ecosystem of the Sundarban is not only complex, but unique in the world. It is a delicate balance of several interdependent sub-systems.

1. The dense forest of Sundarbans acts as the lungs of the thickly populated cities and towns (like Kolkata), and attract rain over a large area of the southern part of Bengal. So, the Sundarbans also play a protective role beyond its boundary.
2. The vast forest hosts a variety of flora (Appendix I) and diverse fauna (Appendix II), and it is the only mangrove tiger land on the globe, home to the famous but endangered Royal Bengal Tiger.
3. Sundarban creeks and rivers have an interestingly rich aquatic collection (Appendix II) including dolphins, crocodiles, and Olive Ridley and other turtles. It forms the largest nursery for fishes and shell fishes. The Sundarbans is responsible for the coastal fishery of whole of eastern India (DISHA 2006).
4. It is also a reality that the people of Sundarbans form an important sub-system of the complex ecosystem of the Sundarbans. Yet, they are very often forgotten or ignored in plans like 'Project Tiger', meant to improve the Sundarbans. This article will focus on the people, showing their age-old bond with the Sundarbans. Our emphasis will be on the socio-economic impacts of climate changes and of some man-made 'improvement' plans on the Sundarbans inhabitants.

So, we will observe in the Results section how the natural environment, coastal ecosystem and human life of this Biosphere Reserve are under threat of physical disasters and wrong planning (like plans for luxury hotels and speedboats to promote tourism). For this, our review of other researchers' observations will be supplemented by our primary observations at a few sites in the Sundarbans. Before that we will develop in the Discussions section, optimum and green steps of necessary conservation and environmental management for the above-mentioned problems in the Sundarbans.

Climate changes in the last hundred years, and noticed more in recent decades, are mainly from what is called global warming (Solomon 2007). Let us outline it. Green house gases (GHGs) are infrared (IR) absorbing carbon-containing-gases like CO_2 and CH_4, and these originate from burning of carbon-based fuels, mostly in industry and the transport sectors. Green house gases get distributed globally through air and wind, irrespective of the location of their production. Solar radiation, ranging from low energy infrared waves to high energy near-UV waves, reach the earth (with some loss of its IR part, a negligible part of total intensity) and warm the earth's surface. The warmed surface radiates out a significant part of the heat (Figs. 5, 6), but only as infrared waves (heat waves) as the surface temperature is not so high as to radiate higher energy (shorter wavelength) waves. Increased amount of GH gases in the atmosphere in the post-industrialization period is absorbing increased amount of heat radiated out from earth's surface, re-radiating the absorbed heat and, finally, sending most of the heat back to earth. This is causing excess warming of the globe since industrialization. It is called global warming. Such blanketing of solar heat by natural green house gases has been occurring since the creation of earth and its atmosphere to keep the earth warmer than many other planets. That much of warming is essential to sustain life

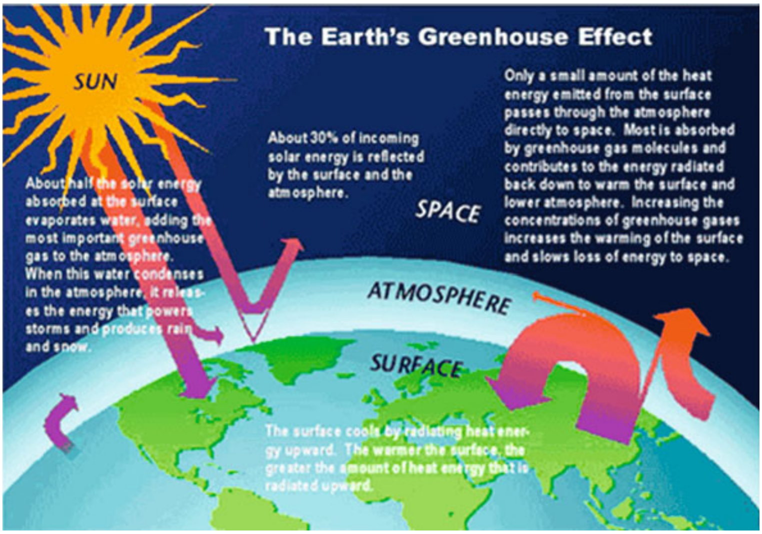


Fig. 5 This illustration (De 2008) shows that green-house gas (*GHG*) molecules absorb most of the re-emitted solar energy, since the re-emission from the earth is mostly as IR. This absorption finally causes further and significant warming of the earth so that it neither becomes a cold planet nor heats up so much as to affect life forms. Excess and continuous warming, since industrialization and due to industry-generated GHG, is called global warming. IPCC estimates that the rise was as high as (0.74 ± 0.18) °C during the 100 years that ended in 2005

on this very special planet called earth (De 2008). Knowingly or unknowingly, few groups often confuse this life-sustaining warming (that maintained a fairly stable average temperature up to ~1,850 or even beyond) with the present problem of steep and continuous increase of the average temperature (referred to as global warming).

Down to Earth, November 30, 2011, confirms: 'As the world continues to pump greenhouse gases into the atmosphere, the global temperatures could rise by 3 °C by mid-century, says a soon-to-be-released report of the Intergovernmental Panel on Climate Change. Extreme weather events will become even more intense. Erratic monsoons and severe cyclones have already battered large parts of India this century.'

Global warming harms warm regions like the Sundarban region from the beginning. This warming brings some benefits to cool regions (Europe and parts of America, for example), but only in the initial decades. Factors like melting of Antarctic Ice and Greenland Ice due to global warming will raise the sea levels to submerge low-lands, including the Sundarbans. This is the major cause for sinking or disappearance of the Sundarbans Islands like Lohachar. Another effect of global warming is the shift of the snow-line to higher heights so that the glaciers retreat upwards. Such shortening of the Himalayan glaciers is already visible and this reduces the amount of water in rivers. It will be further discussed that the reduction

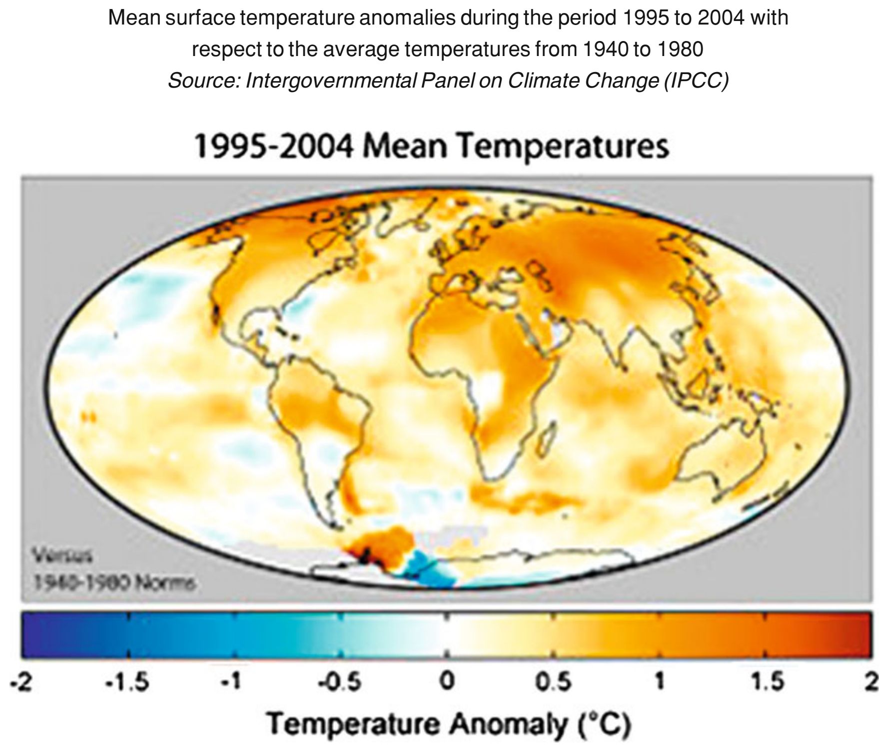


Fig. 6 Mean surface temperature for the period 1995–2004 with respect to the average temperature in 1940–1980 period, at different locations of the earth. *Source* intergovernmental panel on climate change (*IPCC*)

of river water due to global warming in delta-regions like the Sundarbans causes extra problems like advance of sea water into the rivers and the soil. Global warming and other man-made pollutions are causing climate changes, disrupting the rhythm that sustains agriculture and life. Since delicately balanced ecosystems, like that in Sundarbans, will be most readily affected by these factors, there is a need to review the Sundarbans problems in a logical manner and take preventive steps. Best possible green preventive steps and possibility of socio-economic progress with conservation, will be explored. For a river delta system like the Sundarbans, mitigation of climate change or its bad effects is more important and much more difficult.

We finally show that in each improvement or conservation plan, a green approach must replace the currently adopted approach that is city-centric and predominantly commercial—if we want to save the Sundarbans, the wider region that includes cities like Kolkata and, in a way, the globe.

2 Methodology

A Training Workshop on 'Fundamentals of Global Warming and Climate Change with special reference to Sundarbans Ecosystem' was organized in Kolkata by the Sundarbans Biosphere Reserve on 6th December 2010. In the last lecture of that workshop, Dr Anurag Danda, of WWF India's Sundarbans Programme like earlier speakers, emphasized on scientific researches to build a database that is lacking at present.

We also feel that compared to the huge number of publications on climate effects on the Sundarbans, the amount of available and useful data is much less. One reason is that some of the reports and papers published on environmental and socio-economic impacts of climate change in the Sundarbans aim more on advertising an organization, or a commercial effort or view-point, than on fact finding or real solutions to the problems. In fact, presenting a biased view of a problem for commercial advantage is globally well-known. Scaling up harmful industrializations and so-called eco-tourism in the Sundarbans to commercial levels in the name of economic development, for example, may actually disturb its ecosystem and affect the inhabitants, as will be discussed in a later section. So, one task in this work is to compile and present in our Results section, a balanced status report on the impacts of climate change and global warming on the environment, flora and fauna, and people of Sundarbans from a scanning and critical review the earlier workers' findings and newspaper reports. We had informal discussions with Sundarbans people and experts as well.

Another problem is that there has previously been a wrong mind-set that the local inhabitants are outside the ecosystem of the Sundarbans. In fact, the existing literature on socio-economic impacts of climate change on the Sundarban inhabitants, the main topic of the present work, is limited in number. The PhD. thesis by (Danda 2007) is an excellent document in this direction. Webpage of Sundarban Biosphere Reserve, operating from Bikash Bhawan, Salt lake City, is also a good source of information. Both sources have been utilized in drafting this review. But many of the published reports are incomplete, with some carrying the remark 'project unsuccessful'. For example, the Completion Report of Asian Development Bank Project Number: 30032 (Loan Number: 1643), May 2008: Bangladesh: Sundarbans Biodiversity Conservation Project writes under Point 54—'Further Action or Follow Up: Termination of the Project left many initiatives incomplete. The Forest Department could continue several activities to a logical conclusion, thereby ensuring that the investments under the Project yield some positive returns.'

As a more direct and confirmatory source of information, we have banked also on field trips for the last five years to several sites inside the Sundarbans, and conversations with the affected people. We observed the nature and their life there as far as possible. However, the impacts of climate change and global warming on the environment, flora and fauna, and the people is discussed mainly for the whole of Sundarbans. In our trips, small animals, crocodiles, deer and pug-marks of tigers have been seen (Appendix II), and a symphony of birds heard before sun-rise.

One site for field trips was to the well populated (5,000 in 2001) island of Ghoramara. It even has a school. Ghoramara can be reached only by boats and steamers so that there are no petrol or diesel vehicles plying in the island. The island, due north of Sagar Island, is quickly disappearing due to erosion and sea level rise—an issue that should have been highlighted internationally.

The field trip to the twin towns of Bakkhali and Fraserganj, both on the Bay of Bengal, was made more fruitful by adding a visit by powered boat through the Bay of Bengal to the isle of Jambudwip, $\sim$8 km South-West of Fraserganj. It is completely uninhabited except in the fishing season when the fisher folk come for work. The conflict between the socio-economic need to recognize this fishing activity as a right of the poor fishermen and concept of biosphere protection led us to plan this trip.

Another field trip, using waterways for the deeper part, was to Netidhopani and Satjelia, both located within the Sundarbans Mangrove Forest, with a seminar 'Global Warming and Sundarbans' held at a newly built resort at Satjelia. Netidhopani has a tiger observation facility where human visitors go through a cage into the jungle. According to Bengali legends, Neti Dhopani was the washer-lady for the haven.

Geographically, the Haldia and Sundarbans area are practically on the opposite banks of the river Bhagirathi. We organized a conference on Green Approach to Energy and Environment in Haldia and made a steamer trip to Nayachar. It is the new (Naya) sandbar (char) cum island that came up near Haldia in the last 60 years or so. This island, inhabited by a few families, has shot into the larger public view and controversy as the proposed site of either a chemical hub or a petro-chemical hub with gas from Myanmar through an undersea pipeline. We wanted to feel the socio-economic condition of the inhabitants, in addition to seeing the geographical condition of the young island with respect to setting up of heavy industries here.

In another trip, we went by road from Kolkata via Mathurapur, first to Nimpith Ramkrishna Ashram and then to Kaikhali, a small island adjoining the confluence of the mighty river Matla and a smaller river called Nimaniya, both flowing into the Bay of Bengal. With a 2-night halt, we took a long motor boat cruise along Matla River towards the sea. A variety of trees such as Garan, Golappata, Hogla and Sundri line the muddy banks of the river, in addition to mangroves. But the forest is not thick at all locations. This allowed occasional view of herds of deer to be clearer. The motor-boat was actually a mobile dispensary belonging to the Ramkrishna Ashram of Nimpith that controlled the guest-house in Kaikhali. The Ashram runs a school in Kaikhali and a college and schools in Nimpith. In the remote areas of Sundarbans, these NGOs are as important as the Government departments for education and medical welfare of the people.

3 Results: Observed Problems of Sundarban Arising from Climate Change and Global Warming

3.1 Dying Rivers, Salinity and Erosion

The three rivers (Figs. 2, 4)—Ganga (called Ganges by the British), Brahmaputra (called Jamuna in Bangladesh) and Meghna—are fed by many other rivers, as they flow into the Bay of Bengal, so as to carry huge amounts of fresh water and soil towards the Bay of Bengal. These rivers are fairly active, they often change their course or branch or form new sandbars (chars) or wash away old sandbars.

Ghoramara Island is presently reduced to $\sim$5 km^2, about half of its size in 1969, while the Lohachar island, previously existing (with a sizable population) due north of Ghoramara, went under water about a decade back. Erosion in Ghoramara was clearly visible from its broken shoreline with chunks of land falling into the sea. Lack of mangrove growth was also noticed. We talked to many inhabitants including a teacher. The inhabitants have not been promised any help yet by national or international bodies. Nothing has been done for such environmental refugees of earlier lost islands like Lohachar. Prof Sugata Hazra, an oceanographer at Jadavpur University, points out that four islands have already gone under water and ten more are under attack. In last 30 years, $\sim$80 km^2 of the Sundarbans have thus disappeared, displacing more than 600 families.

Global warming and the consequent melting of Himalayan glaciers is reducing the glacier length and, hence, the flow rate of water in the Himalayan Rivers making them dying rivers. It is illustrated well by reduction of water in rivers like Ganga and Teesta, originating from Gangotri Glacier (Fig. 7) and Dzongu Glacier (Fig. 8). This reduction of total water in these rivers, flowing from India to Bangladesh, is affecting agriculture and other activities in the Bengal Basin (that includes the Sundarbans). It is also affecting the sharing of river water between the two countries.

Bhagirathi, now a branch of Ganga from the Farakka area, flows into the Bay of Bengal independently, flowing past the city of Kolkata and lapping Sagar Deep (Sagar Island) just before falling into the sea (called Sagar in Bengali). Bhagirathi was presumably the main channel in ancient times as suggested by the mythology of Prince Bhagirathi bringing Ganga to Sagar Island. The lower part of the Bhagirathi River was called Hoogly River by the British. The outflow of Ganga has shifted from the Hoogly-Bhagirathi channels progressively eastwards (i.e., to Bangladesh) since the seventeenth century. This is due to subsidence of the Bengal Basin and a gradual eastward tilting of the overlying crust (UNEP-WCMC 2008). So, West Bengal and the Indian Sundarbans receive almost no fresh water from the Ganga, unless the Farakka barrage on Ganga delivers the same (in limited amount only). Smaller rivers of West Bengal flowing into Bhagirathi bring some fresh water. So, only the western portion of Indian Sundarbans receives some freshwater through the Bhagirathi-Hoogly river system. But the portion designated as the tiger reserve is in the east. It is essentially landlocked, its rivers having become almost

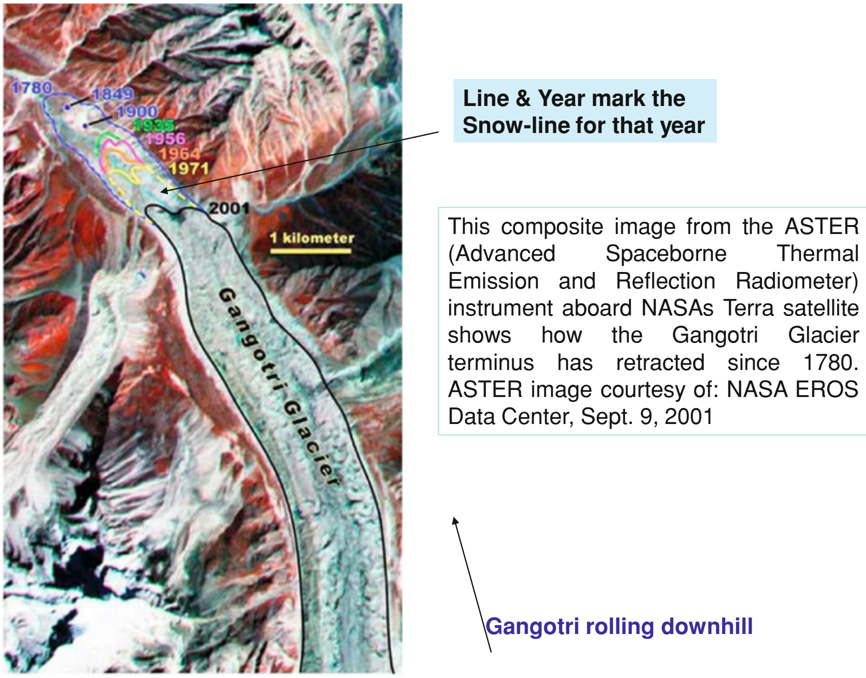


Fig. 7 Receding, over the years, of the mouth of Gangotri Glacier (De 2008) in Uttrakhand in India

completely cut off from the main freshwater sources over the last 600 years. Thus, waterways in the tiger reserve are maintained largely by the diurnal tidal flow. Sea water proportion in Bhagirathi has now increased so much that even in Kolkata and its northern areas, those saline water mangroves have been noticed in recent years.

So, there is a drinking water problem for tigers and other animals, and also for human beings in the Sundarbans. The average tidal rise and fall are about 2.15 m on the coast. Saline water of the sea is now pushing inland the hazy but life-defining underground confluence of sweet water (from the rivers and rain) and sea water, with alarmingly negative result on the people and the rich flora and fauna. In fact, Sundarbans feature two eco-regions: Sundarbans freshwater swamp forest away from the sea and Sundarbans mangroves next to the sea.

3.2 Sundarbans People Through Ages: Changing Sociology

A recent internet map (Fig. 1) of 323 BC Asia shows the large kingdom of Ganga-Ridi (Ganga-Ridai) in eastern India, formed from at least the 7th century BCE and described by the Greek traveller Megasthenis. The Greek and Latin historians

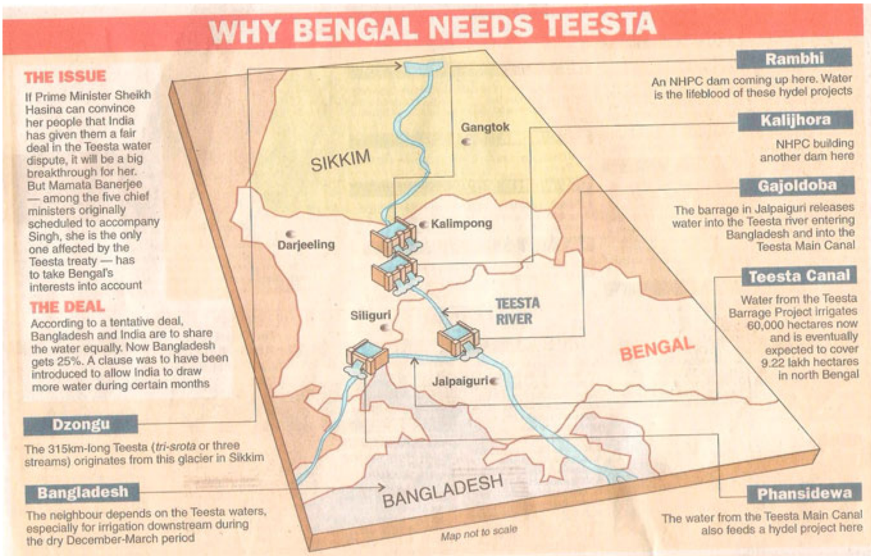


Fig. 8 Origin of Teesta River from a Himalayan Glacier in Sikkim, India, and its flow over West Bengal into Bangladesh based on internet data

suggested that Alexander the Great withdrew from India anticipating a valiant counter attack jointly by the mighty Gangaridai and Prasii Empires. Ganga-Ridi was a highly developed civilization with towns in and around Sundarbans as evidenced by archaeological findings of household and other objects. In fact, Ptolemy (c. 90–168), wrote that the Gangaridai occupied the entire region at the 'five mouths of the Ganges' and that the royal residence was in the city of 'Ganges'. Its capital, the city of Gange, could not be located exactly. Recent excavations (Fig. 9) of Chandraketugarh (Haque 2001; De and De 2004), Deganga and Wari-Bateshwar ruins prove that these cities are strong contenders to be the city of Gange. A large number of ship seals have been found during excavation of Chandraketugarh. Ruin of a city built by Chand Sadagar (~ 200–300 AD), has been found in the Baghmara Forest Block (UNEP-WCMC 2008). These and other ruins at Netidhopani and elsewhere prove that there were many ancient cities and villages in and around. The Sundarbans in Bengal was probably the wealthiest part of the subcontinent until the 16th century, and the towns and ports played their role.

The above details on human settlements have been included here to establish the strange fact that towns or villages and deep forests co-existed in the Sundarbans region for 2500 years or more. This is unique in world history. This human factor must be considered in understanding the environmental and socio-economic impacts of climate change in the Sundarbans Delta and in formulating green solutions.

Finally, the Sundarbans were a gift in the year 1757 to the East India Company from Mir Jaffar, the traitor Nawab (King) of Bengal. Subsequently, it practically

Fig. 9 21st century BCE Terra-cotta piece excavated from Chandraketugarh, South Bengal, and preserved in Paris, www.guimet.com/. It depicts a mother with child in fine detail

became the private property of Lord Clive. Large scale migrations from neighbouring regions and reclamation were organized by the British rulers, for agriculture, human settlement and Government's profit. The present situation is as follows. There is no resident human population within the tiger reserve. In 1981, the population in the fringe area was 2.5 million, but by 1991 it had increased to 3 million. Some 35,330 people work in the forest, annually, of which ~4,580 collect timber and firewood, ~24,900 are fisherman, ~1,350 collect honey (Chakrabarti 1987) and ~4,500 are involved in other activities. On the average, some 4,000 fishermen are active each day, and the mean annual catch is 2,500 tonnes.

Sundarbans has till recently been a fairly peaceful confluence of wild nature and man. It implied a co-existence of wild animals plus pristine nature (mostly in deeper forest) with local people (mostly in adjoining habitats), and the two parties could maintain a respectable distance with only occasional encounters. That delicate balance is now terribly disturbed with tiger attacks killing 100 and 250 people per year. UNEP-WCMC (2008) comments: The tiger, *Panthera tigris* (E) population, estimated at 251 in 1993, is the largest in India. High population density, relative to the availability of prey, and the relatively high frequency of encounters with local people (within the tiger reserve) is probably largely responsible for the notorious man-eating habits of the Sundarbans tiger. We have shown that although these human encounters existed earlier, they were much less frequent. Local people even worship tigers under the name ‘Dakshin Ray’. Worship of ‘Ban Bibi’, the goddess of the forest, is also popular.

Spread of hunting as a hobby came to India with the European invaders-cum-rulers. Mass scale killing of kangaroos in Australia, and of different wild and other animals by Europeans in Europe, Americas, Africa and Asia had not been in search of food alone. Hunting in ancient India by poor people had been for food, and that as a hobby has really been limited to few princes. Hunting as a hobby was never respected in ancient India. It is important to note that no attempt was ever made by the residents of the Sundarbans, in about 2,500 years of recorded history, to kill tigers for fun or to wipe out the tiger population completely. Wildlife Conservation Plans would therefore be more effective and more welcome if they include human welfare for the people who truly belong to the Sundarbans.

After the super-cyclone Aila of 2009 and till recently, there have been no agriculture and related jobs possible in Sundarbans. So, about 70 % of the men were forced to go to places like Bangalore, Chennai and Andamans, creating an imbalance and social problems in the Sundarban. One earns $\sim$Rs. 180 per day in these cities instead of $\sim$Rs. 120 a day often possible in Kolkata. But with this low earning of Rs. 120–180, own expenses in a new city and often falling prey to city recreations, these men can send back hardly any money to the families left behind in the Sundarbans. About 30 % of men left in the Sundarbans are mostly old people and children so that the ladies left behind in Sundarbans have a harder life. Moreover, children and girls are frequently stolen out of the Sundarbans for unlawful purposes. While these socio-economic problems had been there for decades as occasional mishaps, increasing poverty and Aila have enhanced them greatly.

3.3 Sundarbans Waterways

Boats and steamers form the backbone of transport within both parts of the Sundarbans. This should continue. Steamers are widely used for tourism, and transport of goods and passengers for short and long distances. But we found, particularly during our field trips, that most of the boat and steamer engines were very noisy and highly polluting. We often saw congestion of tourist launches at sites chosen for crocodile and tiger views.

The Sundarbans waterways provided eco-friendly water communication for various goods between Kolkata region and the Brahmaputra Valley or North-East regions till the deadly division of Bengal and of India as a by-product of freedom from the British occupation. A recent ADB Report *Viability of Inland Water Transport in India* by Narayan Rangaraj, IIT (Bombay), and G. Raghuram, IIM (Ahmedabad), confirmed that domestic movement from/to the Assam region to/from Haldia/Kolkata areas through Bangladesh is still possible. Modern India had to ignore such river transport due to political constraints and use the costly options of either air-flights or detours by land for linking the North-East.

The Jamuna is a very important waterway in Bangladesh. It is navigable at all seasons of the year by large cargo and passenger steamers. Before the partition of Bengal, passenger and goods steamers used to ply up to Dibrugarh in the State of Assam. River transport from North-Eastern India and North Bengal to Kolkata via South Bengal (Sundarban river network) was in vogue (Roy 2011) as traditional river-ways were used to carry goods and passengers as discussed already. At present, limited steamer ferry services interlink the district of Pabna with the districts of Mymensingh, Tangail and Dhaka. However, the waterfront of Dhaka is now highly polluted from steamers and other vessels.

The saga of the Vidyadhari River, which flows through the Deganga area in northern fringe of the greater Sundarbans, has been part of local folklore since time immemorial. The river had formed a major navigation route for earlier civilizations. In the 3rd century BC, the nearby river port of Chandraketugarh was on the banks of this river. There are tell-tale signs of that from the bygone era, and efforts are on to find more evidence of a lost civilization. The source of the river is located near Haringhata in Nadia. Later it winds down through the area before meeting at Roymangal at the confluence of Sundarbans. The upper part of this river is almost a dead river now.

3.4 Life in New Islands

We saw that the fishing operations, fish landing and drying in Jambudwip, is absolutely seasonal and transient between the months of October and February. The forest department of the Government of West Bengal has been issuing seasonal permits against prescribed fees to these fishermen and they also got forest passes to collect dry branches as fuel. This implies the forest department's recognition of the customary rights of these fish-workers for several decades, and well before the enactment of Conservation of Forest Act and the Wildlife Protection Act (trying to stop fishing activities in Jambudwip). Accordingly, the Hon'ble Supreme Court of India passed the landmark judgment of 11.12.1996 (WP {Civil} No. 561/1994) to clearly say that 'the right of the fishermen and farmers living in the coastal areas to have their living by way of fishing and farming cannot be denied to them.' More details can be seen in an internet report *Legal Status on Jambudwip Fishing Community* prepared by Sunita Dubey. Influence of this judgment is being felt nationally well beyond Jambudwip.

Quite surprisingly, people get non-saline water by digging wells in Nayachar. The soil of the island appeared to be relatively loose and unstable. Detailed soil tests and geological survey are essential before setting up heavy industry or buildings in Nayachar. Our conversation with the present residents of this new island of Nayachar revealed that they are mostly climate refugees coming from other sunken areas of the Sundarbans. A few families, who we talked to, were displaced people from Sagar Island shore areas.

A grand proposal of India-Myanmar gas pipeline and West Bengal SEZ (Special Economy Zone) at the Nayachar-Ghoramara Island was discussed in April 2007 by Reggie Sinha in South Asia Analysis Group webpage, claiming that it is not a pipedream. It proposes (a) dredging a deep navigation channel between Kolkata and the sea (or Haldia port area), (b) creation, using approximately 300–350 million cubic meters of dredged material, of a large (100 km^2, $\sim$3 times the size of Jurong Island, Singapore) offshore-island by joining Nayachar and Ghoramara island and extending it southwards, (c) bringing natural gas from Myanmar through $\sim$1,000 km under-water pipeline, (d) setting up of SEZ petro-chemical industries, airport, sea-port, power-plant, etc., (e) building a bridge to the mainland (Haldia) for rail-road link, (f) tourism and education. It appears that the scaled down version of this plan involving chemical industries, etc., in Nayachar only and without Bengal-Myanmar gas pipeline is being pursued.

3.5 Climate Hazards and Water Pollution

Sundarbans along with the adjoining areas in Bangladesh and West Bengal is, in fact, recognized as one of the regions most vulnerable to climate change. Natural hazards that come from increased or irregular rainfall, rising sea levels, and tropical cyclones are expected to increase as climate changes. Each factor will seriously affect agriculture, water and food security, human health and shelter. It is believed that in the coming decades, the rising sea level alone will create more than 20 million climate refugees in Bangladesh.

Moreover, water in many places in West Bengal and Bangladesh is now contaminated with toxic arsenic. Up to 77 million people are exposed to toxic arsenic from drinking water in Bangladesh alone.

So, Sundarbans is now really the confluence of a host of co-related eco-problems like global warming, climate change, sea level rise, land erosion in some places, silting in some other sites, tsunami and frequent cyclones, in addition to the problems outlined above. A review of the problems will be made and their mitigation in optimum ways explored. Green solutions (De 2011) to supply power and water (agricultural and drinking) will be proposed, as simple deep tube-well solution is sure to backfire. In fact, toxic arsenic has surfaced through tube-wells. Scientific community should make plans against arsenic. There should, also, be plans for prevention of submergence (by sea-level rise, erosion, high tides and tsunami) in Sundarbans islands and coastal areas. We also feel that a plan, like wildlife conservation plan or eco-tourism plan, has to adapt itself to the ground realities of the locality instead of being a copy of a plan successful elsewhere in some other situation.

A report of the World Health Organization (WHO) states: 'In Bangladesh, West Bengal (India), and some other areas most drinking-water used to be collected from open dug wells and ponds with little or no arsenic, but with contaminated water transmitting diseases such as diarrhoea, dysentery, typhoid, cholera, and hepatitis. Programmes to provide 'safe' drinking-water over the past 30 years have helped to control these diseases, but in some areas they have had the unexpected side-effect of exposing the population to another health problem—arsenic.' The acceptable level as defined by WHO for maximum concentrations of arsenic in safe drinking water is 0.01 mg/L. The Bangladesh government's standard is slightly relaxed, 0.05 mg/L being considered safe. WHO has defined the areas under threat: 7 of the 19 districts of West Bengal have been reported to have ground water arsenic concentrations above 0.05 mg/L. The total population in these seven districts is over 34 million while the number using arsenic-rich water is more than 1 million (above 0.05 mg/L). That number increases to 1.3 million when the concentration is above 0.01 mg/L. According to a British Geological Survey study in 1998 on shallow tube-wells in 61 of the 64 districts in Bangladesh, 46 % of the samples were above 0.01 mg/L and 27 % were above 0.050 mg/L. When combined with the estimated 1999 population, it was estimated that the number of people exposed to arsenic concentrations above 0.05 mg/L is 28–35 million and the number of those exposed to more than 0.01 mg/L is 46–57 million. In Bangladesh, as tube wells get tested for concentrations of arsenic, ones which are found to have arsenic concentrations above the safe level are painted red to warn residents that the water is not safe to drink.

The arsenic contamination of drinking water in Bangladesh and parts of India is a tragic one, in which many people have died. It is another example of man's tampering of nature without understanding her completely.

UNICEF and the World Bank Programmes directed use of deep tube-wells to tap 'safe' groundwater for a quick and inexpensive prevention of water transmitted diseases like diarrhoea, ignoring the tradition of using groundwater. Millions of deep tube-wells were constructed as a result. Because of this action, diarrheal illness and resulting infant mortality were reduced by 50 %. However, approximately one in five of these deep wells (over 8 million constructed in last two decades) have been found contaminated with arsenic above the government's drinking water standard. Prof. Dipankar Chakraborti, Jadavpur University, West Bengal, investigated it in West Bengal from 1988, publishing the result first in 2000. His study in Bangladesh involved the analysis of thousands of water samples as well as hair, nail, and urine samples. At that time, they found 900 villages with arsenic above the government limit. He brought the crisis to international attention in 1995. Chakraborti has criticized aid agencies, saying that they denied the problem during the 1990s while millions of tube wells were sunk. Arsenic Treatment Plants, recommended by their foreign experts were not appropriate to the conditions here, breaking down regularly, and were not removing the arsenic properly.

In the Gangetic Delta, the affected wells are typically more than 20 m and less than 100 m deep. Groundwater closer to the surface typically has spent a shorter time in the ground, absorbing a lower concentration of arsenic. Water deeper than 100 m is exposed to much older sediments which have already been depleted of arsenic.

3.6 Harmony of the Sundarbans Development Projects and Environmental Protection

3.6.1 General

A project can be advocated to be a Development Project for Sundarban for securing environment protection. If examination shows that the project or a part of it is not in harmony with the environmental protection or rather environmental improvement in the long run, it is no longer a green project. It has to be modified or scrapped. Often a project designed to prevent or compensate climate change damages has unknowingly or knowingly included harmful effects on the environment and, hence, net damage to nature and people. One example is: Introduction of deep tube-wells to prevent water transmitted diseases like diarrhoea and deep tube-well water actually causing arsenic poisoning as already outlined. The situation is more or less the same on two sides of the international border.

3.6.2 Controversial Projects in Bangladesh Sundarban

The Sundarbans Bio-diversity Conservation Project (SBCP), estimated to cost $81 million, was initiated and funded by several international organizations, the ADB, the Global Environment Facility (GEF), and the Governments of the Netherlands and of Bangladesh. This major project of Bangladesh operated from Jan. 1999 to Dec. 2006. The August 2003 Bulletin No 73 of WRM (World Rainforest Movement) exposes damaging aspects of the SBCP. The SBCP Watch Group, an initiative of the people and peoples' organizations inhabiting the Impact Zone of the Sundarbans, asked for an effective re-design of SBCP in line with local peoples' concerns. They find the Project to be more a profit-led business—since unlimited shrimp farming industry (WRM Bulletin 51), as well as careless exploration activities of oil and gas companies (WRM Bulletins 15 and 72) can harm the environment badly. Stress on silvicultural trials is suspicious. WRM correctly writes: 'The main solution promoted by the SBCP for poverty mitigation is eco-tourism, and the great emphasis put in it does not give due consideration to the possible destructive effects of eco-tourism on such a highly sensitive ecosystem as the Sundarbans.'

3.6.3 Controversial Projects in the West Bengal Sundarbans

Kulpi, situated north of Sagar Island, is just outside the official boundary of Sundarbans blocks. But being adjacent and immediately upstream, any severe environmental problem at Kulpi will have a direct impact on the ecology and livelihood of Sundarbans. Ship-breaking has been one of the most polluting industries ever known. The world is yet to experience an environment friendly ship-breaking yard. Kulpi Port Complex with the Kulpi Industrial Park (including a ship breaking unit, and all together claiming 8,000 acres of prime land) and Sahara mega tourism including luxury hotels (Sect. 5.2) have been proposed (DISHA 2006), perhaps because of commercial gains, although each of the two involve intense pollution and influx of more people into the Sundarbans area. In the background of an undeclared apathy of the authority to the real population of the Sundarbans and their projection as a stumbling block towards forest conservation, this injection of fresh population and pollution into the Sundarbans is open to criticism. Mainly skilled or semi-skilled workers will be recruited by these facilities. Since there is no advance plan to train some of the Sundarbans youths for such jobs, we can safely conclude that these are not meant to benefit them. The impacts of the Kulpi shipping and ship breaking complex will:

- cause Severe Air, Water and Soil Pollution,
- Significantly affect the delicate ecology of Sundarban, as Kulpi is immediately upstream,
- Directly hit the most vulnerable with occupational hazards,
- affect fishing.

The Government of India has already invited expression of interest from global consultants for a modern deep-sea port, off the Sundarbans' coast near Sandhead. On the one hand, it will serve regional and national interest for importing coal and other import/export for the whole of east and N-E India, and provide many jobs. On the other hand, building the mega-port in the fragile mangrove and estuarine ecosystem invites problems:

- it threatens fishermen's access to prime fishing area,
- port pollution can destroy the fishery,
- massive construction efforts may wreck havoc to existing mangrove & estuarine ecology,
- It affects ~30,000 fisher-people and another 50,000 fish-workers down the stream in the most important fishery in the Bay of Bengal region.

The mass catch of tiger prawn seedlings, mainly by women and children, has been a direct result of the demand of corporate induced prawn farming. It destroys the Sundarbans' ecosystem in two ways:

- The massive by-catch (up to 1000 + other juveniles are destroyed to catch a single seedling of tiger shrimp *Penaeus monodon*)
- Encroachment and continuous disturbance of riverbanks by fixed and drifting bagnets hinder mangrove regeneration.

This man-made catastrophe is destroying major parts of a fish community (species). It will have importance relative to the fact that a large part of the human population of an area has had its protein source eliminated or reduced. In the mean time, sale price of tiger prawn seedling has fallen. It fetched up to Rs. 2,000+ per 1,000 in the past. Now it has crashed even to Rs. 20–30 per 1,000. This is due to the closure of Bangladesh market, and the current preference for hatchery seedlings.

The late 1980s and 1990s witnessed a spurt of big and intensive prawn farms by corporates in the Sundarbans. The 1988 collapse of shrimp farms across Taiwan provided evidence of the environmental unsustainability of modem shrimp aquaculture—the intensive farming that produced mainly for export market. The price of the produce has been beyond the capacity of local residents. In December 1996, the Supreme Court of India ordered closure of all semi intensive and intensive shrimp farms within 500 m of the high tide line, banned shrimp farms from all public lands, and required farms that closed down to compensate their workers with 6 years of wages in a move to protect the environment and prevent the dislocation of local people. Prawn farms have encroached upon agricultural lands, silted river banks, wetlands and mangroves. Use of pre-existing ponds was also reported.

We know that earlier Government of West Bengal had signed a MOU and backed Sahara Group plan to build a 5-star Hotel chain in Sundarbans (750 acres of land on the islands), before it was rightly stopped by public protest to protect the environment, animals and above all the original people around the five sites of the proposed hotel chain. However, it has been reported in 2012 that a new proposal by Gulshan Group to set up a 4-star hotel Mark Sundarban in Gosaba in Sundarbans (5 acres) has been approved by the present Government. It talks of getting environmental permission for expansion. It is shocking that aggressively commercial eco-tourism is coming back to the Sundarbans.

Some details of one of the eco-tourism projects are presented now to explain its harm to socio-economic and environmental aspects of the Sundarbans, while ensuring high profit to a few high income groups and the government. The West Bengal Government signed a MoU with SAHARA industries in 2002 for Rs. 700 cr investment to develop the 5 Star Sahara Mega Tourism in the Sundarbans (DISHA 2006). Although Sahara publicly declared its commitment to preserve the ecology of Sundarbans, its own website, in 2002–2004, declared that the project would involve: (1) converting five virgin islands in the 36,000 km^2 of water area in the Sundarbans Delta to tourist destinations of global standing; (2) 750 acres of land at Sagar Island (spot I), Fraserganj (spot II), L- Plot (spot III), Kaikhali (spot IV), Jharkhali (spot V) and other islands; (3) Extensive encroachments on water space—declaredly 75 % of the accommodation would be floating Boat Houses and 25 % on-shore cottages, stylish huts and fabulous tents; (4) The complex would also have a 30-seater, multi-utility high-speed power craft for a floating clinic, fire fighting and ultra modern security system, and small and big ships; (5) Helipad, Mini-Golf Courses and Water Sports; and (6) High Speed Boats to explore the creeks of the deltaic estuary. Recreation centres cum hotels at the above mentioned Spots (I–V) would provide a Kolkata-based luxury round trip through waterways and land routes.

The State Government was to make available the above mentioned 750 acres of land on the islands for a paltry sum of only Rs. 20 cr. The responsibility of developing and *running the initiative* would be that of Sahara India Pariwar's sub-agency—the Sahara India Tourism Development Corporation Ltd. That will make these areas out of bound to the locals. It appears that many beaches and waterways were also to be cleared of locals to provide privacy to the tourists. Sahara Mega Tourism in the Sundarbans would:

- obstruct Fisher peoples' Access to Sea,
- shrink On-Shore Working Area,
- displace Habitats—Evicting Local Residents,
- destroy Community Livelihood Economy,
- degrade Environment—with Pollution and Biodiversity Destruction,
- trigger Cultural Shock and Dislocation.

Let us elaborate a few of the problems. The floating hotel and its satellite structures will disgorge a large quantity of sewage and waste into the surrounding waters. This refuse will include grease, oil and detergents. The increased level of pollution is certain to have a negative impact on the crabs, fishes and other aquatic living beings. A sharp increase in pollution could have a potentially devastating effect on the food supply of the entire region. Second type of pollution will be from lights and noises of the hotels. The hotel's lights would disorient certain species like Olive Ridley turtles that may not be able to find their way back to their nesting places. The Sahara Project would deploy a large number of speedboats and other high-powered watercraft, possibly even jet skis. Fast moving craft such as these pose a great danger to marine mammals, particularly to such endangered species as the Irrawaddy Dolphin (*Orcaella brevirostris*). The high-pitched noise of speedboats is known to disrupt their echo-location systems, often resulting in casualties.

Locals in Sundarban and NGOs like DISHA, i.e., Society for 'Direct Initiative for Social & Health Action' (2006) realized the dangers and protested. There is violation (of environment norms and rules) on every single front, as was found (The Hindu 2004) by a team of independent observers who investigated the project area in March 2004. This included, among others, representatives of People United for Better Living in Calcutta (PUBLIC), Kolkata, Bombay Environment Action Group (BEAG), Mumbai, and the Bangalore-based EQUATIONS that works on issues related to tourism. It is fortunate that the Sahara project has been stopped at present. But caution is needed against its possible revival for Sahara or any other bidder.

4 Discussion: Green Solutions for Sundarbans

4.1 General

Focus of international attention to Sundarbans is on wildlife conservation, i.e., conservation of tigers, birds and crocodiles. This is in progress through efforts of the Government of India, Government of West Bengal and the Government of Bangladesh, initially with some financial and other support from abroad. Some specific steps have already been taken for wildlife conservation by starting new laws and by creating different sanctuaries for birds, tigers, crocodiles and other animals in India and Bangladesh. So, this issue will not be elaborately discussed in the present work.

On basis of various reports and our own survey in a few of the Sundarbans spots, wildlife conservation here seems to be fairly on the right track, except the following points: (a) Indian and Bangladeshi efforts need to be co-ordinated, as far as possible, with joint surveys and joint planning on flora and fauna of Sundarbans (like tiger count), its aquatic life and human welfare, (b) emphasis on wildlife conservation must not stop human welfare to which the people of Sundarbans are eligible as Indian or Bangladeshi citizens, (c) new projects, apparently aimed at economic development or conservation, but actually harming, in the long run, the delicate environmental balance and life in Sundarbans must be identified and either corrected or discarded, and (d) If freeing some pieces of land in existing villages is essential for forest development, as appeared to be the case in Ranathambar Tiger Reserve (India), sustainable rehabilitation of the villagers is necessary.

Since the residents of the Sundarbans have shown respect for wildlife for centuries at the cost of their lives, they have a right to live in Sundarbans with honour. National and international law makers and investors are, in a way, outsiders as compared to these residents so far as knowledge of Sundarbans is concerned. So, local knowledge must be found out and given due consideration in planning projects.

4.2 International Mitigation of Global Warming and Climate Change

All local solutions of Sundarbans problems, caused by climate change and global warming, are partial and temporary. Global warming and climate change, the root causes of Sundarban problems (like water shortage in rivers and sea level rise), need to be mitigated on a global scale to bring back the nature-created water cycle. That alone can, for example, can stop and perhaps reverse the retreat of glaciers and re-fill rivers towards their pristine levels. It may also slowly replace saline ground water with non-saline river water in some of the Sundarbans locations.

Protection of families residing in the Sundarbans against ill effects of climate change and global warming in normal times, as well as their rehabilitation in case of tsunami and on-going submergence of low lands should be national cum international responsibility, since the problems are mostly due to international crimes like emission of more greenhouse gases than a population-based quota permits. We have already mentioned that in the coming decades, the rising sea level may create more than 20 million climate refugees in Bangladesh alone, with additional climate refugees in the Indian part. Where will they go in this overpopulated and financially poor sub-continent? Is it not a global responsibility, particularly for the countries like USA, who preach globalization for areas of their interest?

The above demands are based on bare facts. For example, Bangladesh contributes only 0.1 % of the world's emissions, although it has 2.4 % of the world's population. In contrast, the USA has ~5 % of the world's population, and produces as much as 25 % of the pollution that causes global warming; 5 % of population should be limited to a maximum of 5 % pollution. So, this 25 % pollution by USA highly exceeds their logical quota of 5 %. These polluting countries should fund worldwide mitigation cost in proportion to the excess pollution they cause.

The highly industrialized or advanced countries like the USA, Australia, Japan, New Zealand, Canada, EU nations, etc., produce an overwhelming bulk of green house gases and associated effect of global warming for the benefit of a small fraction of the world population. Now that the facts are known, it should be their moral and legal responsibility to drastically reduce (Narain 2011) their contribution to greenhouse gas generation to a percentage determined by their low percentage of world population.

The Kyoto Protocol demands that industrialized countries cut emissions marginally, roughly 6 % below the 1990 levels by 2008–2012. The agreement in this Protocol is that rich countries, major historical and current emitters, go first, creating ecological and economic space for the developing world to grow. In time, the rest would follow. To facilitate actions in the developing and emerging world, technology and funds would be committed. All this done well would lead to a real deal. But it was not to be. It is sad that the stage is getting set (http://www.cseindia.org/node/2936) by the most polluting nations to sound the death knell for the Kyoto Protocol during the 17th Conference of Parties (CoP) in Durban. The Durban deal (like its predecessors Copenhagen and Cancun) will be bad for all, if it is not based on accepting the hard truths of climate change.

4.3 *Re-forestation and Conservation of Yet Overlooked Species in the Sundarbans*

4.3.1 Re-forestation of Mangrove and Sundari

It is known that the mangrove provides shelter for a large number of euryhaline/brackish water algae, shell-fish and fin-fish species, prawns, crustaceans, estuarine crabs, ghost shrimps, molluscs, nematodes, annelids, animals like various types of jungle cat, the deer, rhesus monkey, wild pig, otter, water monitor, various snakes including python, estuarine crocodiles, sharks, dolphins, marine turtles, large variety of local birds and migratory pelican, migratory rock bees from the Himalaya and the world famous 'Royal Bengal Tiger' (Ghosh and Mandal 1989; Banerjee 1998).

But, in last two centuries, more than 5,000 km^2 of the mangrove forests in the Indian part of the Sundarbans were reclaimed (Banerjee 1998; Ghosh 2001) There has been further loss of mangrove forest, a natural protection against wind, sea erosion and pollution (including absorption of CO_2 gas). Sundari, the Sundarbans tree that may have given the forest its name, is now endangered. Re-forestation of both has been recommended in many Government and non-Government reports like *Mangrove forests in Sundarban active delta—ecological disaster and remedies* by Shivashish Bose.

The Government of West Bengal started a 10 hectares mangrove eco-park in Jharkhali Island in 1999 with the additional objective of rehabilitating Sundari (*Heritiera fomes*) trees. Protection of mangroves has been one of the basic targets of establishing the Biosphere Reserve, various Sanctuaries (at Sajnekhali, Lothian and Halliday Islands), Tiger Reserve and Crocodile Park. Mudflats close to the periphery of the reserve are being artificially regenerated with mangrove plants to meet local demand of small wood and fuel wood and reduce the pressure on the buffer.

4.3.2 Vanishing Fishes: Food and Commerce

Hilsa fish comes from the sea to the Sundarban Rivers, mainly Padma and Bhagirathi (Ganga), to breed in a sweet water environment. Traditional knowledge, preserved as a local Hindu tradition, forbids eating Hilsha, a mouth-watering favourite for Bengalees, between Durga Puja end (September/October) and Saraswati Puja (January/February). This is the time for their breeding and growing of the new-born fishes into larger size. So, this religious tradition, which turns out to be scientific too, offered fair protection to hilsa till the so-called secularism led Bengalees to almost forget the tradition. It happened in the last few decades. This and reduction of river water have reduced significantly the hilsa population in the Bhagirathi. However, the recent 11-day ban in Bangladesh on catching Hilsa fish in Padma, is in line with their Sep. 27 government order, and meant to boost Hilsa fish production. The ban continued until Oct. 16, 2011, a period marked as the main breeding season by their fisheries ministry.

Koi fish, previously found in paddy fields of many Sundarbans villages, has now almost vanished. Too much of insecticides and fertilizers pollute the standing water in paddy fields. That harms the life of Koi fish. Sweet water fishes like Magur, Shol, Layta and Mourala are no longer found in Sundarbans Rivers that are turning saline. Boosting the population of hilsa and other fishes is desirable from nature conservation as well as food production aspects. This should be included in the Sundarbans development programme. Dolphin is becoming rarer with no significant effort for dolphin conservation. Such issues need attention.

The above conservation efforts need to be added to the nature conservation programmes already in progress in the two parts of the Sundarbans.

4.4 Polluting Industries in the Sundarbans?

1. There should be no permission for highly polluting industries like ship breaking in Kulpi or elsewhere in Sundarbans that has a very fragile environment. Moreover, in the Sundarbans, the poor and simple people may not be able to understand the health hazards of ship breaking, resulting in mass scale health problems in society. Ship breaking in Gujarat (India) is known to be harming the workers and the environment. Petro-industries generally involve oil spill into water and toxic pollution of the air. That can irreversibly damage the rich but delicate ecology of Sundarbans, killing much of the aquatic life and the fishing business. Chemical industries pose similar problem, unless expensive anti-pollution devices are installed.
2. Environmental and socio-economical damage of building and operating a deep sea port in Sagar Island or elsewhere in Sundarbans can include damage to mangrove, estuarine ecology and fishery, affecting $\sim$30,000 fisher-people and another 50,000 fish workers down-stream. This can be avoided, if one can find an alternative site where these damages will be minimal. Otherwise, the Experts Committee has to judge whether the advantages of the port outweigh the potential damages and has to chalk out steps to reduce the environmental damage to a minimum.
3. Small scale agro-industries after reviving vegetable and fruit cultivation in the Sundarbans buffer zones will be green paths for additional income of the poor residents. Honey bottling and even refrigerated fish packaging should be tried in Sundarbans' villages. Now, a part of the catch is unwillingly wasted due to poor storage and transport systems. Traditional 'Shutki' system or sun-drying of cleaned and spiced fishes, however, prevents a part of the waste.

4.5 Eco-tourism or Assault on Ecosystem of Sundarbans?

The Sundarbans will survive better if there is no mass scale or aggressive tourism. Core areas must not be opened to any outsider. Tribes in far away Andaman and Nicobar islands suffered heavily by forced interaction with the British occupiers. Diseases unknown in these islands killed more people than in unequal wars. Some tribes are almost extinct at present. Damage to a similar degree in the Sundarbans need not be invited through unchecked tourism that aims more at recreation than at nature study. Regulated nature study trips with limited activity in Sundarbans may be allowed for real researchers and a limited number of tourists. The maximum number of persons that will be allowed per day through entry points should be decided by experts taking the capacity of the fragile ecosystem into account. Their exit at the declared dates needs to be checked and rule-breakers to be heavily fined. Even at present, there is often traffic jam of tourist launches in the Sundarbans creeks. Mushrooming of resorts and hotels in the Sundarbans area must also be prevented.

4.6 Follow-up of Natural Recovery from Aila 2009

Aila devastated the Sundarbans on 25 May 2009. It poisoned the agricultural land and ponds with salt water. Due to bad management of Government compensation, damage due to the super-cyclone Aila in Sundarbans villages like Harekrishnapur, in Basanti block, remain mostly unhealed even in 2011 (Bhattacharyya 2011b). However, the last three monsoons have washed away much of the salt water from the fields, and paddy has been cultivated in 2011 in many areas with success, as reported by Bhattacharyya (2011a) from a survey of Mathurakhand, an island about one and half hour's motorboat ride from Gosaba, Harekrishnapur and Ramapur near Dhamakhali.

It is significant that in the fight against remaining salinity in paddy fields, the local long-grained Dudher Sar variety has performed better than the high-yielding hybrid ones. Here one has a choice: the traditional cum local varieties of paddy are more resistant to local problems like saline water and insects, while the new hybrid varieties (like Mini Kit) have higher yield and require more insecticides and fertilizers.

Now that the nature has somewhat restored paddy cultivation in Sundarbans, it is high time that the Government and NGOs help revive cultivation of optimum varieties of paddy, dal (pulses), vegetables and fruits, for which Sundarbans was once famous.

Mangrove re-forestation initiatives by the Government and some NGOs are very much welcome, as costal mangrove protects the banks from erosion by the sea and hosts some fishes. Mangrove re-plantation has already been discussed. There has to be parallel initiative, with necessary R&D, for post-Aila re-plantation of such fruit trees, vegetable and dal plants as had been known to grow in the inner areas. The Sundarbans was famous for fruits like watermelon, banana, mango, blackberry, bel (wood apple) and guava—that no longer tend to grow. Huge quantities of chillies and pulses were cultivated in the olden days after harvesting paddy. Jhall (meaning hot) was a popular Sundarbans chilly. Ladies' finger, barboti, pumpkin, jhinga and cucumber in the rainy season and spinach and mulo (radish) in winter used to come from Sundarbans fields to Calcutta and other markets. Such cultivation on basis of new R&D and traditional knowledge of the people of Sundarbans will be more eco-friendly than ship breaking, tourism and hotel industries. It is a national duty and also a definite gain, in terms of more food, for the nation. Income from these cultivations should bring back the men who left in disgust, but had to settle for low grade jobs in distant places.

4.7 Enforcement of Embankments

Real rise of the Sundarbans from sorrows of Aila 2009 has to involve prevention of its gradual loss of land into the sea or to the sea-like rivers. Sea level rise (45 cm by the end of the 21st century being feared by IPCC) due to global warming, and subsidence, lead to loss of land and challenge the people, the animals and plants of the Sundarbans. In fact, a few populated islands like Lohachar are already gone under water in the last decades, with no compensation, national or international, to the affected poor. We visited the half submerged Ghoramara Island in 2009, and feel that one can perhaps start with this half lost island, a robust protection project. We should initiate a Project for better embankments, as in Holland, to be built in at least one of the islands. Here, the influx of river water into the islands often brings fertile silt into land. Allowing fertile silt and preventing flooding will be welcome. This should also take care of cyclones (super-cyclone like Aila) and tsunami that destroy existing mud embankments with sea-water rushing into agricultural lands. Steps need to be based on hydrodynamic investigation and prediction. It has to be an international project to save all the Sundarbans islands as a model for the world.

4.8 Life Saving Water for All

4.8.1 Avoiding Toxic Arsenic in Potable Water

In general, the best solution of arsenic problem in water, according to Prof. Dipankar Chakraborti, is '…using surface water and instituting effective withdrawal regulation. West Bengal and Bangladesh are flooded with surface water. We should first regulate proper watershed management. Treat and use available surface water, rain-water, and others. The way we are doing [it] at present is not advisable.'

A review by Chakraborti shows that arsenic removal plants (ARPs), installed in Bangladesh by UNDP and WHO, were a colossal waste of funds due to breakdowns, inconvenient placements and lack of quality control. However, there is a simpler and less expensive form of arsenic removal, known as the Sono arsenic filter. It consists of three pitchers containing cast iron turnings and sand in the first pitcher and wood activated carbon and sand in the second, the third collecting purified water. Plastic buckets can also be used as filter containers. Thousands of these systems are in use and can last for years.

In subterranean arsenic removal (SAR), aerated groundwater is recharged back into the aquifer to create an oxidation zone. This traps iron and arsenic on the soil particles through adsorption process. The oxidation zone created by aerated water boosts the activity of the arsenic-oxidizing microorganisms which will oxidize arsenic from +3 to +5 state. No chemicals are used and almost no sludge is produced during operational stage since iron and arsenic compounds are rendered inactive in the aquifer itself. Thus, toxic waste disposal and the risk of its future mobilization is prevented. Also, it has a very long operational life, similar to the long lasting tube wells drawing water from the shallow aquifers.

Ramakrishna Vivekananda Mission, Barrackpore, India, and Queen's University Belfast, UK, constructed 6 such SAR plants in West Bengal, with funds from the World Bank. Each plant has been delivering more than 3,000 L of arsenic- and iron-free water daily to the rural community. The first of these community water treatment plants based on SAR technology was set up at Kashimpore near Kolkata in 2004 by a team of European and Indian engineers led by Dr. Bhaskar Sen Gupta of Queen's University Belfast for TiPOT. The SAR Project was selected by the Blacksmith Institute—New York and Green Cross—Switzerland as one of the '12 Cases of Cleanup & Success' in the World's Worst Polluted Places, Report 2009 (Reference: www.worstpolluted.org). Currently, large scale SAR plants are being installed in USA, Malaysia, Cambodia and Vietnam. For most of the other processes, arsenic removed from water forms sludge, and the safe disposal of the sludge has to be a part of the arsenic removal process.

4.8.2 Water for Man and Animals in the Sundarbans

Even the arsenic free surface water can be contaminated, in many parts of Sundarbans, by salinity. Seepage of saline sea water into the costal underground water reserve in some Sundarbans areas is making the earlier sweet water ponds saline and, hence, unfit as drinking water source for animals and the people. Agriculture depending on these ponds cannot be continued with saline water.

Getting agricultural and drinking water by deep tube wells invites arsenic contamination in most cases. So, tube wells do not offer a green, long-term and real solution. It is also not OK for animals in deep forest areas. Rainwater harvesting has to compete with the counter flow of saline water. So, it will not provide a quick solution. Whether rainwater harvesting can finally recharge groundwater with non-saline water is a matter of research and worth doing.

The present work proposes large-scale collection and preservation of rain-water for use throughout the year in villages and deep forests for human and animal consumption. This is an attractive and green idea in view of the high rainfall in this area. However, the challenge lies in designing and building an economically viable facility. A preliminary test project is being planned.

We also propose that desalination plants in the Sundarbans area for drinking, agricultural and other water requirements using solar, wind and tidal power can be viable for the Sundarbans area and be discussed.

4.9 Energy for Progress and Preservation

We do recommend, for pollution prevention, scientific restriction on high power consuming machines in large numbers and display of light (as is likely in the recently proposed 5 star or similar hotels) in the Sundarbans villages and forests. But even after preserving the pristine nature in Sundarbans, there is need for electricity and other energy—for telecommunication, basic civic facilities including modest lighting and fans in villages, battery—based green transport and for winning fresh water from sea-water. Electricity from mainland now feeds only

3 out of 10 villages in Sundarbans according to West Bengal Government website on Sundarbans Development.

To us, Sundarbans appears to be suitable for producing electricity from solar, wind and tide energy, and we plan further work with the Government and NGOs, Indian and foreign. Solar photovoltaic units can be developed for isolated islands and distant places in the Sundarbans.

A recent review on Solar Fuels and Materials (Steinfeld and Meier 2004) lists three basic pathways for making solar fuels (viz., hydrogen) from solar energy:

- Solar electrochemical path: solar-made electricity from photovoltaic or solar thermal systems followed by an electrolytic process,
- Solar photochemical path: direct use of the photon energy to get the fuel (hydrogen) from water,
- Solar thermochemical path: solar-made heat followed by a thermochemical process.

These approaches need to be tested for ecologically balanced exploitation in the Sundarbans for meeting its own demand and possibly selling solar fuels and materials to other regions.

In fact, by using only 0.1 % of the earth's land space with solar collectors that operate with a collection efficiency of 20 %, one could gather enough energy to cover the current yearly energy needs of all inhabitants of the planet. However, solar radiation is dilute (only B1 kW/m^2), intermittent, and unequally distributed (mostly by the equator). These drawbacks can, however, be overcome by converting solar energy into chemical energy carriers—solar fuels—that can be stored long term and transported over long distances, from the sunny and less populated regions to the industrialized and more populated regions, where much of the energy is needed. Solar fuels can be burned to generate heat, further processed into electrical or mechanical work, or used directly to generate electricity in fuel cells and batteries. Solar process heat can also assist in the processing and recycling of energy intensive materials and, thus, avoid emission greenhouse gases and other pollutants associated with the combustion of fossil fuels.

4.10 Transport in and Through the Sundarbans

People in the Sundarbans, particularly many fisher women, walk hours first to reach the waterfront in the morning (often from 04-00) to catch fish or crab, to the bazaar to sell, back home to cook and feed the family, then to the field for cultivation and back home in the evening. Bicycle and modest village roads can save two-third of the walking time and increase happiness and productivity. Bicycles will come handy for children attending schools and for all in emergencies and other jobs. Community motorboats for islands and for longer distance travels can be considered. We propose (1) Government subsidy in the Sundarbans area for purchase of individual bicycle and van rickshaw, and special motorboats for community ownership, say for medical transport or children attending nearest school at 10–20 km distance, and (2) To stop free movement of diesel/petrol buses and cars deep into the Sundarbans by introducing special electric vehicles as seen in hospitals and the Taj Mahal. There should be solar/electric charging stations under local co-operative control—if one is keen on motorized land transport in the inner areas.

River transport should preferably be by special speedboats or crafts having a combination of wind and diesel power. Government and international incentives can be given to develop and use boats with such dual power—wind power and diesel or petrol power, in addition to rowing arrangement for smaller boats. Old waterways like Vidyadhari River can be revived by de-silting and other necessary steps to connect northern fringes of the greater Sundarbans to the Sundarbans and river transport be re-introduced as a greener alternative to road transport, which is getting congested day by day.

Following is the minimum requirement with respect to presently available water-transport in Sundarbans region. Remedial steps are immediately needed in terms of engine condition, oil and smoke emission, and the maximum number of tourist launches or steamers to be allowed each day. Too many tourists put a strain on the environment. Eco-tourism appears to be mostly an illusion in eco-tours of the Himalayas and Indian forests.

Even for longer distance river transport ($\sim$100 km to few hundred km) for goods, not needing urgent transport, use of wind-power as and when available, in a dual-powered craft is recommended as it is a green solution. Economical transportation through rivers is an example of the knowledge of the local society that has been ignored in India. Dual power—wind power and diesel or petrol power—will minimize expenditure, exhaust gases and noise in the Sundarbans, an eco-sensitive area. There should also be strict check against oil-leak and other pollution for all transport plying in the Sundarbans area on land or water. The proposal for setting up National waterway through the Sundarbans has to take care of possible oil-leak into the waterways.

India has to use either air-flights or a costly detour by land for linking the North-East. These means of transport are more expensive and less eco-friendly than river transport that uses well-maintained diesel ships or above-mentioned dual-powered ships. River transport with such ships between Kolkata region and N-E India through the Sundarbans waterways and Bangladesh rivers, as it existed in un-divided India, needs to be explored.

5 Conclusion

The present work is, at best, a peep into the complex eco-system of the Sundarbans forest that includes two World Heritage Sites, its problems arising out of global warming and climate change, and the possible green solutions. We stress that present efforts need to be improved, the socio-economic problems of the Sundarbans inhabitants be taken into account, Indian and Bangladeshi efforts be further integrated, and only green options be allowed, to safeguard this delicate ecosystem.

The majestic Royal Bengal Tiger is the best known logo of Sundarbans. Near overlap of animal kingdom and human settlement areas, due to growth of tiger population and human population, needs to be avoided. The maximum number of tigers that the present tiger reserves in the Sundarbans can reasonably accommodate must be scientifically estimated, and steps taken accordingly.

On the one hand, Sundarbans is the home for a wide variety of flora and fauna spreading over its land, air and water. On the other hand, Sundarbans is equally the home to a unique group of people who worship the forest and the man-eater tiger, in spite of the fact that they have to fight the tiger on land and the crocodile in water for mere survival. However, these people have never tried to wipe out wild animals, as has been done elsewhere in the world. Welfare of these inhabitants of Sundarbans and their protection in case the sea drowns their homes and farmlands should be a national cum international responsibility, due to the global nature of global warming, the root cause of most of the problems. But climate refugees coming from sunken areas of Sundarbans to new found lands like Nayachar and making the new lands habitable are officially illegal immigrants to this Government land. So, they can, in principle, be evicted by the Government without any compensation. Compensations to these and future climate refugees appear to be deliberately overlooked.

Worldwide reduction of global warming, particularly in most polluting countries like USA, is the long term but real solution. That has to be the main target.

Other solutions, cited here, include green methods of supplying (1) non-saline and arsenic-free water to animals and human beings, (2) protection from ravages by the sea, (3) power, (4) proper livelihood, (5) better food, and (6) safer and eco-friendly transport. Ecological problems in Sundarban and their solutions have complicated social, economical and commercial aspects. Super-cyclone Aila of 2009 and other cyclones break mud embankments and flood agricultural lands with saline water. This results in agriculture being discontinued in Sundarban. Safer embankments or, better, dykes (as in Holland to protect land and even win land from the sea) should be constructed first in one island like the half-submerged Ghoramara Island as an R&D project. It should then be extended to the whole of Sundarban. Over and above civil construction of embankments and storm shelters, it is essential to restore the mangrove cover of the Sundarbans banks as planned by the Governments. Revival of traditional cultivation of food grains, fruits and chilly in the Sundarbans is suggested. It will be a green livelihood for men who left the Sundarbans after 2009 Aila. We discourage luxury hotel, ship breaking industries and large scale shrimp farming, all suggested from basically commercial considerations, as these are damaging to the fragile environment of the Sundarbans.

Wildlife and forest conservations with the help of the inhabitants, providing the rightful welfare to the inhabitants and green development of Sundarbans, based on traditional knowledge and modern science and technology, will ensure a better

Sundarban in coming years. In 2011, the monsoon flushed away the saline water from many farmlands in Sundarban. Paddy cultivation followed. Golden harvest greeted visitors in many farmlands of Sundarban.

Appendix I: Sundarban Flora

The Sundarbans forests fall under the sub-group 4B tidal swamp forest, according to Champion and Seth classification. It can be further sub-divided into: Mangrove type 4B/TS1, 4B/TS2, Salt water type mixed forests 4B/TS3, Brackish type 4B/TS4 and Palm type 4B/E1.

The northern boundary and new depositions are generally characterized by Baen (*Avicennia marina*, *A. alba*, *A. officinalis*) flanked by foreshore grassland of *Oryza coarctata* (Dhani grass). Baen is gradually replaced by Genwa (*Excoecaria agallocha*) and then Goran (*Ceriops spp.*). The southern and eastern associates include Garjan (*Rhizophora spp.*), Kankra (*Bruguiera spp.*), and few patches of Sundari (*Heritiera fomes*). Hental (*Phoenix spp.*) forest exists in relatively high land and compact soil. Dhundul (*Xylocarpus granatum*), Passur (*Xylocarpus mekongensis*) and *Nipa fruticans* (Golpata) palm swamps are extremely limited. There are 26 true Mangrove species, and a comparable number of Mangrove-like plants.

Details of some of the main plants:

Gewa (*Excoecaria agallocha*): Mangrove species—primary use is for newsprint pulp by some Mills, preferred species for matchmaking, also used as low-value firewood and for other general purposes.
Golpatta (*Nypa fruticans*): Stemless palm, the fronds of which are used for roof thatching.
Goran (*Ceriops decandra*): Mangrove species which grows as a small tree or shrub—highly valued for firewood.
Hantal (*Phoenix paludosa*): A slender, straight, small palm used for rafters, fences, and house posts.
Shingra (*Cynometra ramiflora*): Used as firewood.
Sundri (*Heriteria fomes*): Mangrove species, the most valuable timber resource—large stems used as electricity power poles; sawn timber used for structural purposes; poles used for housing, bridges, jetties, and brushwood sold to Hardboard Mills and used as firewood.

Appendix II: Faunal Diversity of Sundarban

Hunter's Statistical Account of Sundarban (1878) recorded: Tigers, Leopards, Rhinoceros, Wild Buffaloes, Wild Hogs, Wild Cats, Barasinga, Spotted Deer, Hog Deer, Barking Deer, and Monkeys are the principal varieties of wild animals found in Sundarbans. Some of these animals, like Javan Rhino, Wild buffalo, Swamp deer and Barking deer, became extinct in Sundarban in the last two centuries. But even now, Sundarban mangrove forest is the single largest home of the Royal Bengal Tiger (*Panthera tigris*). As per 2004 census, the tiger population in Indian Sundarban is around 274, out of which $\sim$249 tigers live in Sundarban Tiger Reserve and $\sim$25 in South 24-Parganas Forest Division. There are 58 species of mammals, 55 species of reptiles and around 248 bird species in Sundarban. Other mammals comprise of Wild boars, spotted deer, Porcupines and Rhesus macaque. Among the reptiles, the King cobra, the common cobra, Banded krait, Russells Viper comprise the community of venomous reptiles, while the Python, Chequered Kil-Back, Dhaman, Green Whip Snake and several other species constitute the non-venomous snakes.

Sundarbans also has a good number of rare and globally threatened animals including Estuarine Crocodile (*Crocodilus porosus*), Fishing Cat (*Felis viverrina*), Common otter (*Lutra lutra*), Water Monitor lizard (*Varanus salvator*), Gangetic Dolphin (*Platinista gangetica*), Snubfin dolphin (*Orcella brevirostris*), River Terrapin (*Batagur baska*), marine turtles like Olive Ridley (*Lepidochelys olivacea*), Green Sea Turtle (*Chelonia mydas*), Hawksbill Turtle (*Eritmochelys imbricata*). Six species of Shark and Ray, which are found here, are included in Schedule I of Wildlife (Protection) Act. These indicate that Sundarban Reserved Forest is a natural biodiversity hot spot.

Cetaceans like Snubfin (Irrawady) and Gangetic Dolphin are frequently found in the estuarine rivers, the former being more abundant. The Black Finless Porpoise (*Necmeris porosus*) is also found in the rivers near the estuary. The marshes and river offer asylum to the Estuarine Crocodile, one of the most endangered and the largest of crocodiles. A wide variety and assortments of fish, molluscs, crabs and prawns inhabit the estuaries. The amphibious mud-skipper fish such as *Periopthalmus sp.* and *Boleopthalmus sp.* arouse considerable interest. Also found are Whale Shark, Tiger Shark, Hammer Headed Shark, Saw fish, Guitar fish and some common edible fish, e.g., Hilsa ilisha, *Setipinna breviceps*, *Setipinna taty*, *Gudusia chapra*, etc. Among the crustaceans, commonly found are the One Armed Fiddler Crab (*Uca spp.*) and the two species of trilobite (*Tachypleus gigus and Carcinoscorpius rotundicauda*). The latter is also known as the Horse Shoe Crab, which is known as a living fossil and needs serious protection owing to its medicinal value and uncontrolled collection by quack doctors for commercial purpose.

Sundarbans is rich in avifauna as well. There are 248 species of birds including a large number of migrants from the higher latitudes that visit the area in winter. It consists of Herons, Egrets, Cormorants, Storks, Green Pigeons, Sand Pipers, Large and Small Spoonbills, Darters, Seagulls, Teal, Partridges, great variety of Wild Geese and Ducks.

Among the insects found in the Sundarbans forests, honey bee (*Apis dorsata*) is a source of considerable income for the poor people living in fringe areas.

References

Ali A (1996) Vulnerability of Bangladesh to climate change and sea level rise through tropical cyclones and storm surges. Water Air Soil Pollut 92:171–179. doi:10.1007/BF00175563

Banerjee A (1998) Environment, population and human settlements of Sunderban Delta, 1st edn. Concept Publishing Company, Kolkata

Bhattacharyya CS (2011a) Bring the spice back. Metro on the Sunday Telegraph, 20 Nov 2011. Kolkata: 24

Bhattacharyya S (2011b) Aila 2011 (in Bengali). Rabibasariya Anandabazar Patrika, 13 Nov 2011: 9

Chakrabarti K (1987) Sundarbans honey and the mangrove swamp. J Bombay Nat Hist Soc 84:133–137

Danda AA (2007) Surviving in the Sundarbans: threats and responses. PhD. Dissertation, University of Twente

De G, De S (2004) Chandraketugarh: a lost civilization. Sagnik Books, Kolkata

De U (2008) Harmony of development, global warming and economic aspects—some burning issues. In: Ghosh S (ed) Proceedings of the Humboldt foundation Kellog on 'Global Warming in context to the Indian Subcontinent', Puri, Orissa (India), December 2008, Humboldt Club Kolkata, 2009

De U (2011) Convener. Seminar on "Green approach to energy and environment", Haldia, West Bengal (India), 14–16th Jan 2011. Kolkata: Humboldt Club Calcutta, Max Muller Bhawan Goethe-Institut; Kolkata; 2011

DISHA (2006) A study on—Corporate Abuse in Sundarban. Society for Direct Initiative for Social & Health Action, Kolkata

Ghosh S (2001) Environmental parameters in agri-aqua culture development in tidal swamps and estuaries—case study: Sunderbans deltaic region, India. In: EMECS Conference. Kobe, Japan

Ghosh RK, Mandal AK (1989) Sunderban—a socio bio-ecological study, 1st edn. Bookland Pvt. Ltd, Calcutta

Haque Enamul (2001) Chandraketugarh: a treasure house of Bengal Terracottas. The International Centre for Study of Bengal Art, Dhaka: 416

Solomon S et al (eds) (2007) Climate change (2007): The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change (IPCC). Cambridge University Press, Cambridge

Narain Sunita (2011) EDITORIAL: how to rewrite the Durban script. CSE's Fortnightly News Bulletin, New Delhi, November 2, 2011

Miller Frederic P et al (2011) Gangaridai. Alphascript Publishing. Available at http://pothi.com/pothi/book/frederic-p-miller-gangaridai-9786132906564

Roy AK (2011) Personal email communication from AK Roy, UGC Professor, Centre for Advanced Research in Sciences, Dhaka University, Dhaka

Steinfeld A, Meier A (2004) Solar fuels and materials. In: Encyclopedia of Energy, Elsevier Inc, vol 5

The Hindu (2004) ECO-WATCH/Biosphere in peril. The Hindu Magazine Sunday. 13 June 2004

UNEP World Conservation Monitoring Centre (2008) Sundarbans National Park. India: Encyclopedia of Earth 2008. Available at http://www.eoearth.org/article/Sundarbans_National_Park,_India

EMPRI's Approach Towards Development of State Action Plan on Climate Change, Karnataka

Papiya Roy and Felix Nitz

1 Background and Rationale

United Nations Framework Convention on Climate Change (UNFCCC) at the Earth Summit in Rio, in 1992, noted that climate change is a global phenomenon that requires mitigation measures at all levels. Soon after, an intense and growing international debate over the future response to climate change has emerged. Countries like India and China have particularly high stakes because of the region's high population, burgeoning economies and vulnerabilities to the impact of climate change. After Kyoto, there is a general consciousness about the climate change reality perceived (Reid and Huq 2007). Under the UNFCCC, every country is required to develop a climate response programme that integrates climate change activities into all relevant sectors, including energy, transport, industry, agriculture, forestry and waste management. UK has been at the forefront of climate security policy and international efforts to embark on greater responsibility to the climate challenge through multilateral organization.

India is considered to be a highly vulnerable country, as vital livelihoods in the country depend on agriculture, forestry and coastal activities. The magnitude of the possible consequences of climate change is yet to be fully understood. But certain impacts on agriculture, coastal areas, as well as increased frequency of extreme weather events would have considerable long-term effects in India. The overriding apprehension for India is sustainable development giving primacy to economic growth with unique resource endowment. So the immediate issue is to derive a better strategy which will give us flexibility of choice of energy and its usage. To answer these points, India has developed her National Action Plan on

P. Roy (✉) · F. Nitz
Department of Forest, Ecology & Environment, Government of Karnataka, Environmental Management and Policy Research Institute, Bangalore 560078, India
e-mail: royguddi@gmail.com

F. Nitz
e-mail: EMPRI.BLR@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_35,

Climate Change (NAPCC) in 2008 to adapt a climate friendly approach of sustainable development. Government of India pooled in number of economic institutions across the country in preparing a viable action plan of NAPCC for a climate resilient development. This approach also sought for better integration of the economic dimension into the policy and regulatory structure, along with the specific vulnerabilities of climate changes (Parikh and Parikh 2002)[1].

India's climate change action plan does not sacrifice its developmental goals while considering the farsighted burgeoning economic prospects. Instead, it accentuates on long-term mitigation strategies inclusive of development and growth with climate 'co-benefits'. Intending deeper intervention of the issues, NAPCC proposed eight national missions to elucidate a roadmap of the NAPCC objectives. NAPCC has also laid out a strategy which consists of a policy framework linked to specific actions that a state would use to address climate change and vulnerabilities. It is apparent from the framework that implementation activity of specific action is deeply region specific. Thus, preparing a state level action plan is required to translate NAPCC objectives into the local context. This will further help to decode national policies into action at the local level. In view of the above, MoEF has prepared a common framework to harmonize national and state level actions. The core features of the Karnataka State Action Plan on Climate Change (SAPCC) will comprise the identification of risks and opportunities related to climate change, regional climate profile, specific mitigation and adaptation strategies, and definition of priority options with integration of development planning. In response to Government of Karnataka's (GoK) request, EMPRI has initiated the preparation of a state level conceptual climate change action plan. The initiation stressed upon in the involvement of GoK as a most prominent stakeholder and eventual implementer. This action plan will be formulated giving due importance to the seven national missions (as 'Mission for Himalayan Ecosystem' is not applicable to the state) of NAPCC. It also put efforts on identifying the challenges and the responses at the state level to address the issues. The 'Mission on Strategic Knowledge' emerges as an anchor point for many components of the project because it responds directly to the threat of climate change, in contrast to the more development oriented other missions of the national plan.

2 Process

GoK is considered to be the most important stakeholder of the action plan prepared in the SAPCC. The development process was initiated with an inhouse brainstorming session in December 2011. Institutions like Ashoka Trust for Research in Ecology and the Environment (ATREE), the British Deputy High Commission (Chennai), Dakshin Foundation, Indian Institute of Sciences (IISc), Institute for Social and Economic Change (ISEC), Karnataka Forest Department (KFD),

[1] Climate Change: India's Perceptions, Positions, Policies and Possibilities, 2002

Karnataka State Natural Disaster Monitoring Cell (KSNDMC) and World Institute of Sustainable Energy (WISE), Pune, whose corpus of work related to climate change participated in the session. Existing informations from academic institutions and NGO's were collected to prepare a baseline scenario. 24 major departments of GoK were also requested to provide information on developmental activities with climate co-benefits so far achieved by them. Despite a fairly good cooperation from the departments, the target level remained unachievable. Policy, intervention plan, time frames and future plans for sustainable development of the state remained to be conceptually developed. The understanding of institutional preparedness was deepened in an individual consultation process with 24 GoK departments in March 2011. Senior representatives of the departments ensured adequate knowledge of actions and the relevant works initiated by the departments. Individual interactive session also seeks a painstaking discussion on the possible alignment of these actions in line with climate change actions.

The magnitude of the work suggested pooling in of additional expertise to compliment sector expertise of EMPRI. This will also expedite the process of the documentation within a relatively short timeframe. An institutional collaboration was established with The Energy & Resources Institute (TERI), Bangalore, to support the preparation of the sectoral analysis.

The process adopted a review of existing state of knowledge. This includes information from departments, academic institutions, observed trends and likely impacts accordant with climate change. More than 80 documents were identified as substantial input for the work and, subsequently, the document repository was established. Of them, the Bangalore Climate Change Initiative—Karnataka (BCCIK)[2], State of Environment report Karnataka[3], and Economic Survey of Karnataka[4], played a significant role. Its concise corroboration of relevant data paired with first projections for the state aided the preparation process[5].

3 Developing Karnataka's State Action Plan

Nine months after the release of the NAPCC action plan, the Government of Karnataka had constituted a Coordination Committee under the chair of Additional Chief Secretary to the Government and the Development Commissioner to oversee and coordinate the state's response to climate change. Environmental Management & Policy Research Institute was mandated to prepare the State Action Plan on Climate Change (SAPCC).

[2] Karnataka Climate Change Action Plan—An Interim Report. Bangalore Climate Change Initiative—Karnataka (BCCI-K), Prof B K Chandrashekar et al. 2011

[3] State of Environment Report Karnataka 2010 pre-submission draft—EMPRI, 2011

[4] Economic Survey of Karnataka 2010–2011

[5] Karnataka Action Plan on Climate Change "Rapid Assessment of Sectoral Actions Initiated", EMPRI, 2011

An initial rapid assessment was prepared and presented to the committee on February 2011. Developmental priorities are foreseen in all the actions perceived in response to climate change.

Unsurprisingly, most of the actions are restrained to mitigation options. A majority of the initiatives taken by the departments offer climate change co-benefits as envisaged by the NAPCC, even in the absence of a coordinated inter-departmental response to climate change. It was noted, with concern, that most of the actions and strategies proposed by the departments are uncertain about the timeframe and budget. It is apprehended that despite noble intentions, the major achievements of these strategies may not be realized, if not planned. Existing sectoral plans and programmes are favourable for the state's action plan on climate change but these do not substitute the requirement of a coordinated climate specific action plan.

Thus, SAPCC is built up considering national priorities as a frontage. Based on the climatic trend and projected vulnerabilities, a set of specific priorities at the policy level is proposed in the document. It also includes sectoral assessment of Karnataka, where immediate attention is given in setting of state priorities for policy and action with respect to adaptation and mitigation.

4 Key Findings

The Indian Meteorological Department observed a significant increasing trend for both seasonal (southwest monsoon) and annual rainfall for North Interior Karnataka which is one of the three meteorological subdivisions of Karnataka state[6]. But, so far, there is no evidence of large scale abnormalities across Karnataka. But it is anticipated that any kind of future extreme event due to the climate change is likely to be impact the agriculture and food sector of the state. Since Karnataka has already experience some extreme events, it is anticipated that rainfed agriculture may experience challenges to a large extent.

It also emerges that till date some modelling studies have been conducted for the region by BCCIK. It is too early to pursue any strong corroboration of climate change and its likely impact zone. But at the same time, mitigation options are definitely beneficial with 'climate co-benefits'. Uncertainties evolved in changes scenario also remain unaddressed in the corresponding study. All in all, timeframe and nature of extremities of climatic variability are yet unknown and it is difficult to respond to unknown threats in terms of adaptation while mitigation should definitely follow.

[6] Letter communicated to EMPRI by Indian Meteorological Department on Impacts of Global Warming and Climate Change in Karnataka, March 2011

5 Conclusion

Climate change is the issue that needs to be discussed from various aspects. The SAPCC, in line with NAPCC, also proposed sustainable growth in respect of natural resources of the state with co-benefit for addressing climate change issues. Keeping in view that Karnataka's climate may already have experienced changes going by the increased occurrence of floods and droughts, it is apparent that steps towards mitigation and adaptation to a gradually changing climate and its consequences will make a Karnataka climate resilient state. So the orientation of action plan is mainly mitigation.

One of the issues 'strategic knowledge support' for proper planning, implementation and execution still remains a challenge. At this juncture, it has been anticipated that more research on the subject is needed to fill the gaps. Subsequent integration of incremental findings will further sharpen the focus on revision of Karnataka SAPCC. Conclusions emerged from the more developmental oriented research activities will also consequently resolve the policy level intervention of the work. Revisiting and updating of the SAPCC process will also help to identify budgetary requirements in major intervened areas of the action plan.

Reference

Reid H, Huq S (2007) How we are set to cope with the impacts. IIED Briefing, International Institute of Environment and Development, London

Challenges Faced by South Africa When Adapting to Climate Change

Ernst Uken

1 Introduction

The intention of this presentation is to indicate what barriers many developing countries may be experiencing in attempting to align themselves with global programmes trying to alleviate *global warming*. In the southern hemisphere, including South Africa, *climate change* is a more acceptable concept, since this is what is being experienced in the south. The reason for this is that the Antarctic region displays different climatic conditions to that occurring at the Arctic circle. A German helicopter pilot, who has continuously been ferrying scientific staff and equipment to the South African base camp in the Antarctic for the past 13 years has witnessed a progressive increase in ice and snow over the past 6 years (E. Erik, 2011, Personal Communications). The icing up is so severe that the ships can no longer get as close to their destination as they used to 7 years ago. The only noticeable exception is a volcano on the west bank, which at most affects about 4 % of the surface area of the Antarctic. This view has been confirmed by numerous TV shows, showing a very different state of affairs than what is commonly experienced by visitors to the arctic region.

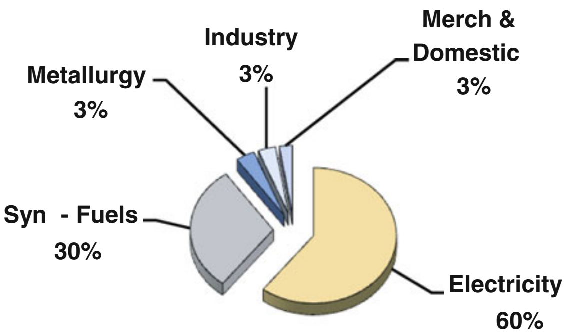
1.1 Background

Countries like South Africa, with an abundant supply of coal, find it economically difficult to switch from their coal-based economy. Unlike the dwindling global coal reserves, the South African reserves have been estimated to be 55,333 Mt. At a production rate of 224.3 Mt per annum this yields coal ore reserve of 237 years

E. Uken (✉)
Head: Energy Institute, Cape Peninsula University of Technology,
Cape Town 8000, South Africa
e-mail: Ukene@cput.ac.za

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_36,

Fig. 1 Domestic use of coal in South Africa



at present production rates (South African Yearbook 2001, pp. 114–115). Apart from exporting 30 % of the coal volume mined, the so-called 'black gold' is being used internally in the proportions shown in Fig. 1.

According to Fig. 1, almost two-thirds of the coal is being used to generate electricity, followed by almost one-third for Sasol synthetic fuel, being processed by a modified Fischer-Tröpsch process. In the interest of the environment, a concerted global effort needs to be made to clean up, particularly the coal-based power generation plants. They are the country's worst polluters, placing South Africa among the 10 worst polluters in the world. For socio-economic reasons the Government has openly declared that environmental issues, although important, will have to play second fiddle to costly, more urgent social developmental issues until 2025. Due to rapid urbanization, these popular policies include proper housing and sanitation for all; improving public health services and education; offering clean running water and electricity; alleviating poverty; fighting crime; creating 5 million new jobs by 2020, etc. During the last decade, over 3 million homes have been connected to the electricity grid, without any major new power stations being commissioned. This has had the effect of gobbling up the electricity spinning reserves. Two open-cycle gas turbines of 700 MW capacity each, were commissioned as standby for when the nuclear power station at Koeberg has to be serviced. The pump storage plant at Palmiet, also in the Western Cape, is an excellent resource to help balance the 42,000 MW national grid (Eskom 2010). Currently the national demand for electricity is greater than the supply. In order to retain and promote economic growth, new power stations have to be built urgently. Wind and solar power generators can technically be built within months, but take a few years in practice to be allowed to be connected to the grid. In countries with little potential for hydro-power stations, the other alternatives would be to build more coal-powered or nuclear power stations. Both take at least a decade until they can be commissioned, largely because of environmental impact studies and other socio-political issues, which have to be overcome and addressed.

Various sources claim that renewable energy programmes promote job creation. This sounds very logical, but recently a closer look was taken at these so-called 'new jobs'. It was reported by the Spanish Wind Association and the United States (Alvarez 2010) that 'Each "green" megawatt installed destroys 5.28 jobs on an average elsewhere in the economy: 8.99 by photovoltaics, 4.27 by wind energy, 5.05 by mini-hydro.' It would be most useful if developing countries could be guided in this regard by other nations, who have already gone this route. At this stage, importing developing nations are at the mercy of foreign investing companies, who individually push their own technologies and products.

1.2 Climate Change in the South

Nothing in nature is constant, so it is only a normal, natural phenomenon to have the climate changing over hundreds and thousands of years. The recorded changes have been found to be of a cyclic nature and they were already following certain patterns, long before man's industrial revolution started playing its alleged part. By definition, 'Climate Change' implies that the extremes will become more severe. In other words, when it gets hot, it will be hotter and when it becomes cold, it will be colder. In fact, other events like volcanic eruptions and tsunamis will also become more frequent and more severe. This is what is truly being noticed globally. Greenhouse gas concentrations are rising and it is getting warmer at times in some parts of the world. Other parts of the world have experienced exceptional heavy downpours. In Africa, water is generally getting scarcer, due to a lower rainfall, and yet other parts in the East have had major floods. Some summer rainfall regions have had unusual heavy rains in winter (Uken 2009).

According to (UNWTO 2010) the rainfall in southern and eastern Africa is expected to drop between 66 and 90 %. This confusing weather pattern, which is being recorded across the globe, was originally explained by the IPCC as possibly being due to mankind's activities. The confusing term, 'global warming' unfortunately was later coined, placing all the blame fairly and squarely on human beings across the globe. According to the (IEA 2009), the energy demand and carbon dioxide levels will rise by 50 % by the year 2030. It has been estimated that interventions could reduce this level down to 38 %. This is good news and should be supported, especially by those culprits pumping mega tons of CO_2 into the atmosphere. This was the fundamental approach of the Kyoto Protocol, which is still lacking commitment by the first world countries (Zuma 2012).

1.3 Possible Global Warming in the North

At the Arctic, ice caps are melting and glaciers are shrinking. Sea levels allegedly rose by 1.8 mm from 1963 to 2003 due to higher ocean surface temperatures (Uken 2009). The IPCC claims that, globally, the surface temperature could rise by 2–4 % by the end of the 21st Century. It is also claimed that the destruction of the ecosystem could lead to more and longer droughts. The icy cold weather, during the Copenhagen World Summit, did not help to align the delegates and convince them that Global Warming was really occurring. Climate change, yes, since extremes were being felt by all.

1.4 Shaky Global Warming in the South

The skeptics (Uken 2009), however, noted that the Arctic ice cover was 21 % in 2007, dropped to a mere 9 % in 2008; and rose to 32 % in 2009 (NSIDC 2010). The Antarctic, on the other hand, now has the lowest ice melt measured value in the past 30 years (JCEST 2010). Over 130 years, the southern hemisphere is hardly getting any warmer, at a mere +0.4 °C. The engineering models used by the IPCC to predict the climatic conditions and climate change, apparently ignore the presence and influence of water vapour. Climatologists, on the other hand, know that the secret of weather forecasts rests in the clouds. The carbon concentrations grow at 0.3 % per annum and not at 1.0 % per annum as per model. The models used also do not match the satellite data collected over the past 30 years. Claims that global sea-surface are hottest since 1880 appear to be incorrect, due to the poor siting of 90 % of climate stations and the exclusion of satellite data (AMS 2010).

Another shocker (Uken 2009) is that in 1908 the meteorite Tunguska shaved off the Earth's ozone layer completely. It recovered within 5 years. Some sceptics even go as far as saying that warmer climates have tourism benefits. It should also be remembered that about 1,000 times more people die from cold than from excessive heat. In just over a month, COP-17 is about to be launched in Durban, South Africa's warmest holiday resort. Many observers expect business as usual, since nothing has changed. If one searches for Global warming then the ambient temperature in Durban should at least be warmer than in Copenhagen.

2 Addressing Climate Change in the South

Reducing energy consumption by improving energy efficiency and demand side management have been found to be the most cost effective approach, being cheaper than installing new solar or wind power stations. The EEDSM Programme has therefore been launched in South Africa together with the promotion of renewable energy sources in the long term. These are discussed in more detail in the following sections.

Table 1 Permissible levels of grid-connected renewable energy in South Africa (Creamer 2011)

Source type	Size (MW)
Onshore wind	1,850.0
Solar photovoltaic (PV)	1,450.0
Concentrated solar thermal	200.0
Biomass and biogas	12.5
Landfill gas capacity	25.0
Small hydro	75.0
Small-scale IPP of <5 MW	100.0
Unspecified	12.5
Total	**3,725 MW**

2.1 Renewable Energy Programme

Details were finally released by the South African Department of Energy on 3 August 2011, inviting bids from potential independent power producers (IPPs) to produce South Africa's first 3,725 MW of grid-connected renewable energy by 2014. The breakdown of permissible renewable energy to be fed into the extensive national electricity grid is shown in Table 1:

This is a welcome move away from the previously proposed 'renewable-energy feed-in tariffs' (Refit), which would have been non-compliant with government procurement regulations and which have been found to be unsustainable in other countries. The new approach (Creamer 2011) allows for decisions to be made according to price and other criteria as well. Conditions which have to be met include:

- Commercial operation by June 2014
- Approval of land security and environmental requirements
- Availability of primary energy. For example, for wind power, 12 month wind data for that specific site must be supplied, etc.
- National grid connectivity
- Technical feasibility
- Generation forecasts
- Legal requirements, including Black economic empowerment
- Economic development and regulatory thresholds.

In addition to meeting the above technical, financial and legal criteria, South Africa, as a developing nation, has embedded a number of political targets, which the IPPs also have to observe, like job creation; local content and local manufacturing; rural development and community involvement; education and development of skills, enterprises, etc.

2.2 EEDSM Programme

In order to speed up the process of balancing the supply with the ever-increasing demand, the more affordable energy efficiency (EE) and demand side management (DSM) programmes were launched. Improving the efficiency of lighting is a typical low-hanging fruit, yielding immediate benefits at a relative low cost. To date, the national utility company, Eskom, has replaced over 45 million incandescent light bulbs with energy-efficient, compact fluorescent lamps (CFLs). Typically 100 and 60 W lamps were replaced with 14 W CFLs in the residential sector. In the commercial and industrial sectors, luminaires with magnetic ballasts were replaced with modern, shorter and thinner fluorescent tubes with electronic ballasts. A start has been made with fitting some buildings with LEDs and motion sensors.

Bredenkamp (2011) senses the need for a 20 year lighting strategy to be developed to scientifically meet the changing needs towards sustainable development. The approach so far has been driven commercially rather than on sound research, which would be of great help for forward planning and policy formulation.

In warm countries, where little space heating is required, other priorities emerge. Although the residential sector is responsible for approximately 20 % of the total electricity demand, its peak demand dominates the maximum load demand, thus, dictating when more power stations have to be built. An analysis of this sector (Uken 2010) revealed that water heating (at 47 %) was the most important; followed by cooking (21 %); and refrigeration (16 %). Hence, the following programmes were launched to reduce the energy consumption by residential hot-water cylinders.

2.2.1 Geyser Blankets

Research was conducted at the CPUT Energy Institute to measure the potential energy savings achievable with additional insulation of hot-water cylinders (geysers) and adjoining piping, in an effort to reduce the standing losses. The results obtained under optimum, laboratory conditions were reported (Harris et al. 2007) as shown in Table 2.

According to Table 2, standing losses may be reduced by up to 27 % by properly wrapping both the hot-water cylinder plus 2 m of outlet piping plus 1 m

Table 2 Standing losses of hot-water systems

	No lagging	Pipes lagged	Cylinder covered	Cylinder + Pipes covered
Standing losses kWh/day	2.3	2.0	1.8	1.68
Energy savings (%)	–	13.4	21.7	27.0

of inlet piping. In practice this was not achieved in approximately 300,000 installations, since the geyser blankets could not and were not secured properly; the metal fittings into the cylinder could not and were not covered adequately; the piping was not always accessible and was often bricked in; the geyser set-point settings were too high and with age the element became even hotter than shown by the setting. This programme can therefore only be recommended with caution.

2.2.2 Solar Water Heaters (SWH)

In warm climates, one can recommend the use of either stand-alone solar water heaters (low pressure geysers), or in more affluent homes, solar water heaters with an electric back-up (high pressure geysers). The latter type will ensure a hot-water supply throughout the day. In both cases, Eskom offers a rebate of approximately 30 % of the supply and installation costs, provided strict criteria are observed by the supplier/installer. The product must be approved by the SA Bureau of Standards and the installer must be accredited. On this basis, Government aims at having 1 million solar water heaters installed within 5 years. After the first 18 months, over 103,250 low pressure and over 40,460 high-pressure geysers were installed, giving a total just short of the monthly target (Eskom 2010). Installations are being audited by independent measurement and verification teams, revealing that correct timer settings are important, if the targeted energy savings are to be achieved. Early indications are that the target savings will not be achieved, because of a skewed rebate system, favouring low-pressure geysers, which save half as much energy (Uken 2012).

2.3 Instant Water Heaters and Aerated Shower Roses

These have also been tested by the Energy Institute. Instant Showers gave appreciable savings, but in South Africa the municipal water pressures are above the recommended 2 kP, causing the fittings to burst, creating a safety risk. The reason for this is that the fire brigades (requiring high water pressures) share the normal water reticulation system.

With aerated shower roses it is most important that pressure reducing valves be fitted to achieve maximum savings.

2.4 Other Initiatives

Energy conservation aimed at addressing shortages and environmental issues is also being addressed on a broader front, including the following:

- Creating an awareness at home and in schools that energy is a valuable, scarce commodity that needs to be preserved.
- Mass media (TV, radio, the press and posters) are being used in support of the above campaigns.
- Messages are flashed on the TV screen whenever the electricity demand is dangerously high, advising householders to switch off electric appliances that need not be switched on at that particular time.
- Commerce and industry are being encouraged to avoid wastage with set conservation targets that need to be aimed at, before penalties will come into effect soon.
- Industry is being advised to replace inefficient motors, etc.

Public participation, although not quantified as yet, is most important, since the positive results observed are often in access of the technical aids, which are being rolled out.

3 Discussion of Results

This presentation is aimed at taking South Africa as an example and quoting the problems it faces in trying to align itself with first-world environmental programmes, aimed at halting global warming. The object is not to get involved in a debate on global warming, but an invitation is extended to qualified experts in the field to produce scientific evidence to show whether global warming also occurs in countries similar to South Africa. An important point is that developing nations may have other, more pressing national priorities. If poverty, unemployment, hunger, crime and corruption dominate the scene, then the South African government should be forgiven in saying that the environmental issues will only be addressed more seriously after 2025, once the more pressing socio-economic issues have been addressed.

In the meantime, energy efficiency and demand side management strategies are in place to reduce the growth for coal-based electricity—the worst polluter in South Africa. Both strategies were combined as EEDSM, a most affordable programme. In countries where governments do not subsidise renewable energy, it appears to be cheaper to use less energy than to erect renewable energy plants. Sceptics are advised to conduct their own surveys, since capital costs vary from country to country. In South Africa, real low-hanging fruit benefits were achieved at minimum cost, by rolling out more efficient light bulbs, as has been done in many other countries. Next in line was residential water heating by solar thermal means, followed by the options given in Sects. 2.2, 2.3 and 2.4.

4 Conclusions and Recommendations

An attempt has been made to illustrate the challenges faced by a developing nation, like South Africa, when asked to align itself with climate change, or even global warming protocols. The economy of poorer states appears to be one of the most important reasons why so little real progress has been made during the past 20 years, since the Kyoto Protocol was formulated.

Although climate change is affecting us all, the major driver for change in poorer countries is probably the desperate and more urgent need for more energy. Electricity is a very convenient source of energy, which has become essential in modern, civilized society. In many countries in Africa, less than 30 % of the population has access to electricity. It is hoped that these nations will leap frog their choice for energy sources and go directly for renewable energy. Unfortunately unsubsidised solar energy is still very expensive, which should hopefully come down in price through mass production of panels and also as concentrated solar technology advances. Wind power is a most affordable choice, especially in dry regions without hydro-power. The ultimate prize will, no doubt, be fuel cells or hydrogen technology, since nuclear has recently, after Fukushima, fallen in disfavour in many countries.

References

Alvarez GC (2010) Study of the effects on employment of public aid to renewable energy sources, vol 7(1). Procesos de Mercado

Bredenkamp B (2011) National lighting strategy. South African national energy efficiency agency, Johannesburg (Unpublished, personal correspondence, 2011)

Creamer T (2011) Renewables project developers pore over tender documents. Available at newsdesk@engineeringnews.co.za. Accessed on 4 Aug 2011

Eskom (2010). Available at www.Eskom.co.za. Accessed Aug 2011

Harris A, Kilfoil M, Uken E-A (2007) Domestic energy savings with geyser blankets. In: Proceedings of the international conference on the domestic use of energy, Cape Town, pp 10–13

Minerals and Energy, South African Yearbook (2001) Government communication and information system, 7th edn. Pretoria, pp 114–115

Uken E-A (2009) Environmental challenges in South Africa. First Humboldt Kolleg in Daka, Bangladesh, pp 19–21

Uken E (2010) Domestic water usage in South Africa. In: Proceedings of 10th Rehva world congress, Antalya, Turkey, Clima, 9–12 May 2010, pp 438–439

Uken E (2012) Policy pitfalls with solar water heating. In: Proceedings of the 1st international conference on solar heating and cooling for buildings and industry, San Francisco, USA, 9–11 July 2012

Zuma J (2012) President of South Africa at G20 meeting. Rio de Janeiro

Tourism, Environment and Economic Growth in Himalayan Kingdom of Bhutan

Komol Singha

1 Introduction

At present, tourism has become one of the fastest growing industries in the world (Singha and Elangbam 2009; Rinzin et al. 2007), and probably there is no other economic activity which transects so many industries, levels and sectors as tourism does (Cater 1995). It contributes approximately 11 % of the global Gross Domestic Product (GDP), making it the world's biggest industry, accounts for 12.2 % of world exports and 8.1 % of global employment (WTO 2010; Vu and Turner 2008; Roe and Khanya Penny 2001; Brunet et al. 2001). With the growth of divergent market economy, tourism has become an environment-dependent industry, in which tourists are the consumers of environment (Goodall 1995). Hence, there is a positive correlation between the environment and tourist flow in a region (Cater 1995). It means, as environmental quality increases, number of tourist inflow also increases, but not vice versa. However, in the long run, if it is not managed properly, rapid expansion of tourism and tourist visits have some detrimental effects on the *environment*, including congestion and pollution (Taylor et al. 2005; Brunet et al. 2001). Having seen some considerable impacts on tourist destinations in the world, the industry has become highly-climate sensitive, especially after the Copenhagen Conference in 2009 (WTO 2010).

Tourism industry in Bhutan is grounded on the principle of sustainability, meaning that tourism must be environmentally and ecologically friendly, socially and culturally acceptable (TCB 2010; Rinzin et al. 2007; DoT 2005), but not forgetting the primary objective of revenue generation, especially foreign exchange earnings (Tobgay 1997). Perhaps, Bhutan is the best example in the world where controlled tourism has been effective in ensuring the sustainability of the industry (Dorji 2001). The credit behind this sustainability is that the country has adopted a policy called 'High Value Low Volume'. Recently, the policy has

K. Singha (✉)
Institute for Social and Economic Change, Bangalore 560072, India
e-mail: komol@isec.ac.in

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_37,

been slightly modified as 'High Value-Low Impact (negative)' (HVLV hereafter), but the essential principle remains the same (TCB 2010). In other parts of the world, a similar policy is also found in Botswana[1] and Canada (Draper 2000).

The present paper tries to evaluate the impact of tourism on the country's economic development and at the same time preserving the pristine environment. Still, the specific objectives of this study are of two folds. One, it is to evaluate whether the foreign tourist (excluding tourist from SAARC) inflow in Bhutan enhances the country's revenue or not, considering the primary objective of the tourism industry is to generate income. Two, how does the tourism policy of the country HVLV balance the country's economy without sacrificing the pristine environment? What will be the limit of the growth of number of tourist vis-à-vis the available tourism infrastructures, environment stock of the country?

To achieve the two objectives mentioned above, two sets of time series secondary data (1985–2010) have been collected from different sources, like World Development Indicator, Royal Monetary Authority of Bhutan and Asian Development Bank, etc. The first set of data consists of two variables—number of foreign tourist visited Bhutan during the reference period and its contribution to country's GDP. With the help of simple regression analysis, tourism revenue elasticity was estimated, aims at achieving first objective of economic impact with the growth of tourist in the country. The second set of data consists of three variables related to the indicators of environment—CO_2 emission (in '000 kg), Particulate Matter Concentration (PM10 in μ/m^3), Natural Resource Rent (NRR in %)—Details of these variables are given in the text below. With the help of semi-log model, growth rate or relative change of the variables ($\log Y_t$) with respect to a given absolute change in time (t) was measured (Gujarati and Sangeetha 2007). As there is no perfect parameter to measure the impact of tourist flow on environmental quality, a rough estimation/approximation was made. Therefore, the second set of data aims at achieving the second objective that the relative growth rate of tourism and environmental variables. What is the threshold level of tourist inflow in the country as compared to the stock of environment, can be assessed. Further to substantiate secondary data in understanding the status of environment of the country, a primary field survey was made and collected some relevant information from 61 foreign tourists during the period from October to December 2010. Opinions of the tourists regarding the status of environment of the country were also assessed. It was followed by personal interview of the many stakeholders of tourism industry and officials of government departments.

2 Bhutan and its Tourism Policy

Bhutan, the last Buddhist Kingdom on the earth, also known as *Druk Yul* or the *Land of Thunder Dragon* is sandwiched between China and India (refer to Fig. 1),

---

[1] For Botswana, refer to http://ec.europa.eu/development/body/publications/courier/courier198/en/en_062.pdf.

Fig. 1 Bhutan and its neighbouring nations

comprising a land area of 38,394 km^2 with a total population of 671,083 in 2008 (NSB 2009). It is one of the most thinly populated countries in the world with 18.19 people per km^2 in 2010 (WDI 2012) and most rugged mountain terrains with elevations ranging from 160 m along its southern border to its highest peak of Kulha Gangri at 7,554 m above sea level (asl) along its northern border with Tibet (Chinese region) (Singha 2010).

Till 1961, Bhutan lived in a self-imposed isolated manner without any metalled road, motor vehicles, electricity, telephones or postal services and certainly no tourists, and lived in a small world centred upon community kinship, family relationships and living in harmony with the natural environment (NHDR 2000). Since that time, Bhutan has undergone a major transformation, and became one of the fastest developing nations. The population is primarily rural and relies on subsistence agriculture for their livelihood. Bhutan has a very rich biodiversity with a diverse ecosystem including many endemic and rare species, and is recognized as one of the ten global biodiversity hotspots (ADB 2004). This is one of the most important factors for tourist attraction. Hydro-power and tourism industry are the two main industries to support the country's economy.

As of tourism industry, the number of tourists visiting the country continues to increase each year as Bhutan becomes better known globally. However, Bhutanese are very cautious about their environment and pay highest respect to forest and natural *environment* as it is an intrinsic part of their way of life (Singha 2010). In view of protecting the environment and culture, tourist arrivals are controlled by a pricing policy of the country—*High Value Low Volume* (*HVLV*). It means the tourists must come to Bhutan on a package tour, organized by one of the Bhutanese tour operators (foreign travel agents are not allowed to operate in Bhutan) and the tour operators are supervised by the government (Tobgay 1997). With the objective to limit the tourist to high-end (to get more revenue with least exploitation of environment and culture), the tourism tariff rate was fixed in 1974 at USD 130 per tourist per night halt when the industry was first opened to the world.

Thereafter, tariff had risen to USD 200 in 1989 (DoT 2005), and for the second time, the tariff had been revised to USD 250 per tourist per night halt, which will be effective from January 2012 (Bhutan Travel 2011). Theoretically, a high-end tourist will spend more (high tariff, luxury hotel, vehicle, etc.), stay for shorter period and reduce relative resource use, and have an expenditure pattern that directs receipts to the local host economy (Vu and Turner 2008).

With the emergence of modernization and globalization, the tourism industry in Bhutan was privatized by the Royal Government of Bhutan (RGoB) in 1991. Today, it has become a vibrant business with nearly 200 private tour operators (who strictly follow government policy) at the helm of affairs. The RGoB adheres strongly to a policy of *High Value Low Impact/volume* tourism. It is based on the principle of sustainability, meaning that tourism must be environmentally and ecologically friendly, socially and culturally acceptable, and economically viable. In order to minimize the problems, the number of tourists has been maintained at a manageable level and this control on number is exercised through a policy of government regulated tourist tariff (TCB 2010). To encourage the industry and for the growth of the country's economy, income tax holiday of 10 years has been announced to newly-established high-end tourist hotels and hospitality units. Various levels of sales tax and customs duty exemptions are also being given to tourism related activities (RMA 2011).

3 Impact of Tourism on Economy

As discussed above, there can be no denying the fact that tourism is one of the largest economic forces. International tourism has grown substantially in recent years, with technological improvements, rising living standards and broader processes of globalization. As a result of this, the World Tourism GDP is expected to increase, in real terms, by 3.0 % per annum in this decade (Milne and Ateljevic 2001). For Bhutan too, at present, tourism has become one of the largest foreign exchange earning industries. Tourism continues to remain the kingdom's largest source for convertible currency earnings. Tourism revenue to the government consists of royalties and taxes collected from tour operators.

The growth of tourist inflow in Bhutan can be seen from Annexure I that the number of tourist visiting Bhutan has increased manifolds from 1,896 in 1985 to 28,463 in 2010. It is also expected to increase in the coming years as the government is giving more priority in this sector. Though, tourist inflow in the country was somewhat stagnant till 2003, thereafter, the industry became the fastest growing industry in the country. However, tourism performance in the fiscal year 2009/2010 suffered from the impact of the global financial crisis and the AH1N1 pandemic in 2009. In terms of source markets (not given in the Tables), tourists from the United States continues to dominate the market, both in terms of numbers (20.4 % of total arrivals in 2009) and bed nights (22.3 % of total bed nights in 2009). While Japan and the United Kingdom were the second and third largest sources of international tourists in terms of absolute figures in 2009 (RMA 2011).

To find out the revenue (income) elasticity with the growth of foreign tourist inflow over the period of 26 years from 1985 to 2010, a simple log linear regression model was applied and estimated elasticity from the data given in Annexure I.

$$\text{LogTREV}_{\text{t}} = \alpha + \beta \log TRST_t + \upsilon_t \tag{1}$$

Where, TREV = Revenue from Foreign Tourist; TRST = Foreign tourist inflow

$$\overline{LogTREV} = -7.586 + 1.103 \text{ logTRST}$$

$$(-34.253)\ (43.216)^{*} \qquad [^{*} \text{ refersto significant } 1\% \text{ level}]$$

$$R^2 = 0.987;\ \text{Adj.}R^2 = 0.987;\ F_{1,24} = 1867.63;\ \text{D-Watson} = 1.711$$

The model shows that one per cent increase in tourist flow in the country leads to 1.103 % increase in the country's revenue. The elasticity of tourism revenue with respect to tourist flow is greater than one. Overall fitness of the model is verified by R^2 value of 0.987, the 't' statistic is significant at 1 per cent level, and D-Watson value is equal to 1.711. This shows that the impact of tourism on country's revenue is very significant. It is also clear that the growth of tourism tariff in Bhutan from \$130 to \$200 per night does not make any negative impact on the tourist flow and GDP growth in the country. In other words, the tariff hike has a positive impact on the economy.

Indian tourists are concerned; unlike foreign tourists as mentioned in the HVLI policy, they do not require to travel by luxury vehicle, not require to stay in standard star hotels set by Bhutan government, need not to pay tariff and make advance payments like international tourists. In the recent years, the number of Indian tourist visiting Bhutan has increased significantly, outnumbering the foreign tourist in 2010. In October 2010, considered as a peak month because of the festivals in India, and officials of immigrant office said issuance of permits (tourist permit issued on arrival, for Indians) went as high as 600 per day. On an average, 200 permits were issued daily over the year (Immigration Department, Phuentsholing). Though, the Immigration Department in Thimphu refused to share statistics, media report shows an average of 40,000 Indian tourists (including business activities) visit the country every year.[2] For instance, the growth trend of Indian tourist was 20 % in three years from 2008 to 2010 (e.g., 25,000 Indian tourists [only tourist purpose] in 2008; it went up to 27,000 in 2009 and above 30,000 in 2010). Though, no accurate estimation was made for the Indian tourist, the growth of Indian tourists in Bhutan is many fold, outnumbering foreign tourists as the country improves its environment (Brunet et al. 2001).

---

[2] Refer to http://www.bhutantour.bt/bhutan-news/bhutan-travel-saw-increase-in-the-number-of-indian-tourists.html.

4 Tourism, Environment and Environment Policy

On the environmental aspect, the nexus between environment and human profit making activities was explored in the 1960s. Hardin (1968) opined, though the impact on environment due to the growth of population and human activities was inevitable, it could be maintained with the help of cooperation, extension and morality of the people in the society. Similarly, tourism has become an economic activity and it has at least some impact on the pristine environment. Improvement in environmental quality attracts tourist inflow and tourism became an environment-dependent industry (Goodall 1995), but it requires proper management and control over the tourism activities, otherwise, may lead to negative impact on environment (Taylor et al. 2005).

Bhutan maintains a conservation-based policy in regard to its natural assets. Fortunately, the country is endowed with a relatively pristine environment, boasting a high percentage of forest cover and very high levels of biological diversity at the ecosystem, species and genetic levels. With almost 72 % of the country's total area under forest cover against the minimum of 60 % requirement of the legislation (GNH Commission 2009; NEPA 2007). With the recent addition of the Centennial Wangchuck Park in December 2008, the ratio of protected to total territorial area has increased from 26.3 % in 1993 to 51.4 % in 2008. There is an extremely strong national policy framework for promoting environmental sustainability. The Constitution enshrines the protection of the environment as an important aspect of state policy under Article 5, which emphasizes the responsibility of every Bhutanese to preserve environment to ensure long term sustainable use of natural resources and stipulates a minimum forest cover of legislation (60 %), to be maintained for posterity (GNH 2011). Therefore, the economic activities that do not impede environment are encouraged in the country. As a result of which, Bhutan has become the largest forest coverage in proportion to its land mass in Asia, and the environmental degradation in Bhutan is minimal or negligible compared to the neighbouring nations like, Nepal, India and other parts of the Himalayas (GNH Commission 2009; Choden 2007; Karan 1987).

The status of environment in the country can be measured by some of the identified computable parameters and their growth/degradation trend over the years is included for rough estimation of the variables. In this section, three standard parameters of environment, namely, Carbon Emission (CO_2), Particulate Matter Concentrations (PM10), and Natural Resources Rents (NRR), have been used (refer to Annexure II). The carbon dioxide (CO_2) emission is given in thousand kilograms: lesser this value of CO_2 better the quality of environment. The second variable, PM10 is expressed in terms of micrograms per cubic meter (μ/m^3). It is caused by outdoor particulate matter and causes significant health damages when it penetrates inside the respiratory tracts. The state of country's technology and pollution control is an important determinant of PM10. It has positive correlation with health hazards. The third variable, NRR is the difference between the value of natural resources production at world prices and their total costs of production. It is given in percentage term: a greater value of it indicates a better environment.

To have a quick glance of correlations between the dependent and independent variables, simple correlation analysis is shown in Table 1. The correlation coefficients of the variables are significant at 1 % level. From the Table, one can find that two variables—PM10 and NRR have negative correlation with number of tourist. However, CO_2 has positive correlation with tourist inflow. Detailed explanation can be found from the growth trend equations given below.

As both the variables—dependent variables (environmental parameters) and independent variable (number of tourist inflow), are not co-integrated (but correlated), further econometric analysis could not be done. To achieve our objectives in the present study, the variables have been computed as a simple growth trend over time. The growth rate of three variables with respect to time (1985–2010) can be estimated through semi-log growth model (estimated from the data of Annexure II) given below.

$$\mathrm{LogY_t} = \mathrm{a} + \mathrm{bt} \tag{2}$$

where, $\mathrm{LogY_t}$ is the environmental variable in log form, ‘a’ is the constant, ‘b’ is the growth rate, and ‘t’ represents trend.

$$\begin{aligned} \overline{LnCO_2} &= 11.213 + 0.096\ \mathrm{t} \\ &\quad (107.02)\ (14.18)^* \qquad R^2 = 0.983 \end{aligned} \tag{2a}$$

$$\begin{aligned} \overline{LnPM10} &= 4.157 - 0.043\ \mathrm{t} \\ &\quad (199.83)\ (-32.40)^* \qquad R^2 = 0.977 \end{aligned} \tag{2b}$$

$$\begin{aligned} \overline{LnNRR} &= 3.378 - 0.016\ \mathrm{t} \\ &\quad (47.07)(-8.33)^* \qquad R^2 = 0.743 \end{aligned} \tag{2c}$$

where, * indicates significant at 1 %

From the above Eqs. (2a–2c), one can find that the last two variables—PM10 and NRR grow negatively at the pace of 0.043 and 0.016 %, respectively, over the

Table 1 Correlation coefficients

Variables	Correlation (N = 26)	Tourist	CO_2	PM10	NRR
Tourist	Pearson correlation	1	0.844[a]	−0.841[a]	−0.665[a]
	Sig. (2-tailed)		0.000	0.000	0.000
CO_2	Pearson correlation		1	−0.988[a]	−0.864[a]
	Sig. (2-tailed)			0.000	0.000
PM10	Pearson correlation			1	0.887[a]
	Sig. (2-tailed)				0.000
NRR	Pearson correlation				1
	Sig. (2-tailed)				

[a] Correlation is significant at the 0.01 level (2-tailed)

26 years in Bhutan. It implies that with the development of technology and the country's stringent law, the pollution level measured by PM10 has been declining (−0.043 rate). It is the indicator of good environment provided by the nature in the country. However, NRR and CO_2 are depleting at the pace of 0.016 and 0.096 %, respectively. These indicate that the degradation of environment over the years.

For understanding comparative analysis of tourism on one hand and environment on the other hand, a relative growth trend of tourist inflow during the same period is also estimated using the same time series data of 26 years from Annexure I.

$$\overline{LnTourist} = 7.115 + 0.112\ \text{t} \quad (62.65)(15.30)^{*} \tag{3}$$

where, * indicates significant at 1 %.

The difference between the values of 'b' given in the Eqs. (2) and (3) reveal relative growth pace of environmental parameters and tourist flow respectively over the period of 26 years (1985–2010). Growth trend of tourist during the period was estimated at 0.112 %, given in Eq. (3). This growth rate is relatively larger than the growth trend of environmental parameters (degradation) represented by CO_2 and NRR with the coefficients of 0.096 and 0.016, respectively, given in Eqs. (2a) and (2c) (0.112 > 0.096 and 0.016). Nevertheless, the trend of environment indicated by PM10 shows an improvement at the pace of 0.043 %, given in Eq. (2b). It is the contribution of country's state of technology and stringent law in preserving the pristine environment. It means environment has not been affected much by the growth of tourism and any other economic activities in Bhutan. Even if we have not verified by sophisticated econometric models, one can easily infer that the intervention of tourism policy (HVLV) makes the tiny Kingdom beneficial in developing tourism industry. In a nutshell, growth trend of economic development or revenue contributed by tourism is greater than the degradation rate of environment in the country.

To substantiate the argument made through the secondary data, the stock and status of environment of Bhutan, perceived by tourists (primary survey), was also incorporated in this paper. Out of 61 tourists randomly interviewed, 18 of them were found to have visited the country more than once. For the analysis of the paper, tourists were categorized into two age groups: 40 years and above, and below 40 years; two educational levels: -degree and above, and below degree. An opinion was also asked from the 61 tourists that the tourist inflow in Bhutan in the next 5 years will degrade environment or not. The detail summary of the primary survey report is summarised in Table 2.

The Table 2 shows that the quality of environment of Bhutan, when compared to other countries as perceived by 88.9 % of revisiting respondents (tourists visited Bhutan more than once) in the country. Altogether 59.0 % of tourist responded that the tourism will not degrade the country's environment in 5 years and 62.3 % of the tourists have exclusively visited Bhutan for its environment, culture and

Table 2 Environmental status perceived by tourists in Bhutan

(N = 61) age of tourist	Education level of tourist		Purpose of visit by tourist to Bhutan		Environment of Bhutan is still pristine in 2nd visit (N = 18)[a]		Tourism will degrade environment in Bhutan in 5 years	
	Degree and above	Below degree	Environment, culture and religion	Others	Yes	No	Yes	No
Age >40	38	4	26	16	14	1	18	24
Age <40	11	8	12	7	2	1	7	12
%	*80.3*	*19.7*	*62.3*	*37.7*	*88.9*	*11.1*	*41.0*	*59.0*

Source survey
Note [a] out of the 61 tourist, 18 have visited more than once

tradition. This supports secondary data that the country has still not disturbed the environment much, especially by the tourism industry.

5 Stock of Environment and Depleting Factors

According to land cover assessment study based on the satellite images, forest cover has increased from 64.36 % in 2006 to 70.46 % in 2010. The shrub cover has also increased from 8.13 to 10.43 % during the same period. The overall forest cover (forest plus shrub) has, therefore, increased from 72.5 % in 1995 to 81.27 % in 2010. Thus, it is well above the constitutional requirement of 60 % forest area in the country. This makes Bhutan the 17th most forested country in the world, much ahead of the other SAARC countries which have alarmingly low forest cover, Sri Lanka, India and Nepal at less than 30 %; Bangladesh at less than 11 % while Afghanistan, Pakistan and Maldives are at less than 4 %.[3]

Bhutan's ecological footprint[4] was rated at 1.0 as compared to 1.6 for Asia and 2.7 for the world according to the *WWF Living Planet Index* 2008. In terms of the ecological reserve or deficit, the rating for Bhutan was 0.8 as compared to −0.8 in the Asia/Pacific region and was rated the best in South Asia. Bhutan's bio-capacity rating was also assessed at 1.8 as compared to 0.8 for the Asia Pacific region (GNH Commission 2011). The air and water quality in Bhutan are still relatively good compared to the neighbouring nations. The *Respirable Particulate Matter* (PM10) was found to be a concentration of 20 $\mu g/m^3$ (measured at Thimphu, capital city of the Kingdom) in 2009, which are significantly lower (lower the value of PM10, better the environment) than the United States and European Union stipulated standards of 50 and 40 $\mu g/m^3$, respectively. This implies that the other parts of

[3] This portion is retrieved from RGoB (2011).

[4] Lesser the ecological footprint value, better the environment.

the country will be much lower than the capital city, Thimphu, as it is the most congested and populous city in the country. In terms of Ozone Depleting Substances (ODS), as the *Vienna Convention* and the *Montreal Protocol* in 2004 was bound to decrease its annual import of ODS by half. It has exceeded its target to reduce ODS import by 72 % in a year, from 170 to 63 kg in the country, which was achieved after a complete ban was imposed from January 2005 on ODS-based equipment and the promulgation of ODS licensing system in 2005. The nationwide survey conducted by the Ozone unit of the National Environment Commission (NEC) found that ODS in use in Bhutan was about 2,500 kg, and of which about 450 kg were used by nine major industries (manufacturing). In the world, Bhutan is in the low volume consumption category, meaning it consumes less than 30 tonnes of ODS a year.[5]

With the emergence of globalization and growth of the country's infrastructural development activities, some detrimental effect on environment is being perceived by the country (Singha 2010). Some of the factors responsible are soil erosion, vehicle emission, urbanization and industrialization, and water pollution, etc. (Dorji 2001; Karan 1987). The soil erosion occurs because 50 % of the land in Bhutan is situated on mountainous slopes which are subject to landslides during the monsoon season (Karan 1987). Other contributing factors affecting environment in the country are over-cutting of timber, road construction, and the building of irrigation channels (Singha 2010). However, the impact of tourism on environment is still not rated very high.

Though the tourism industry was not rated as a pollutant, the recent growth of tourist flow in the country has made some complaints that the modest number of trekkers are damaging Bhutan's environment, leaving behind litter and eroding the habitat. As experienced by Rai and Sundriyal (1997), in Sikkim (India) and Nepal, on an average, 1 kg of non-biodegradable garbage is generated by a tourist during their trekking, and little more than 1 kg of non-burnable per day. In reality, though some minimum amount of degradation of environment is inevitable by trekkers (Rinzin et al. 2007), the share of trekker to the overall tourist population is very negligible and declining in Bhutan. For instance, the share of trekkers in 2006 was 13.3 %; 12.2 % in 2007, and slightly increased to 15.1 % in 2008 and again fell down to 10.2 % in 2009 (RMA 2011). In totality, the impact of trekkers on the country's environment is not an issue till today.

6 Findings, Argument and Drawbacks

Though Bhutan being one of the costliest destinations for international tourists (refer to Annexure III), the country is identified one of the world's most preferred destinations (Brunet et al. 2001). It is basically due to its pristine environment,

---

[5] This portion is retrieved on 8th Oct. 2011 (http://www.un.org/wcm/webdav/site/ldc/shared/Bhutan.pdf).

culture and internal security on the one hand, and recent terrorist activities and different forms of agitations and violence erupted in different parts of the world, on the other. Taking this advantage, the country has increased tourism tariff ($130 in 1974–$200 in 1989 and still rose to $250 from 2012) with the aim to balance environment, culture and economy under the principle of HVLV. Nevertheless, the number of tourist visiting Bhutan has been increasing substantially in the recent years. For instance, Taylor et al. (2005) found that in Hvar Island, the demand for tourism (tourist flow) will not be greatly impacted by tourist eco-taxes, which makes up a relatively small part of the total cost of a trip, if the destination is worth visiting. Therefore, pricing policy of tourism in Bhutan is a right choice in balancing economy and environment. Moreover, the country has advantages of being small and less populated, especially for making the nation's law effective and in controlling over the natural resources. Given the example of Kenya's natural resources, Cater (1995) revealed that, the *third world* economies can benefit more than the rich nations from tourism. Therefore, preservation of environment would be an investment for sustainable development of tourism in the country. Otherwise, tourism is in danger of being a self-destructive process, destroying the very resources upon which it is based. In a similar manner, citing the example of Thailand, Dearden (1991) opined that tourism in a small nation, if managed properly, could facilitate both in increasing domestic income and minimize environmental degradation. If it is left uncontrolled, Routledge (2000) echoed that tourism often not only degrades environment of the host country but also brings increased levels of crime, prostitution and drug use into local communities and effects the manipulation of their cultural traditions, which Bhutan has been cautious of very much for long.

Fortunately, with the help of HVLV tourism policy, coupled with stringent laws of the Kingdom, the country could preserve its environment and culture when the ratio between number of tourist and country's citizen reached 1:3 (in the year 2009, the total tourists visited was 23,480 and country's population was 69,735). However, in Hvar Island in 2005, the ratio was 3:1; still the environment was not affected much in the Island (Taylor et al. 2005). In the opinion of (Rinzin et al. 2007), with the growth of tourist inflow some form of environmental degradation (negligible) is visible in Bhutan and it is inevitable as the intensity of trekking increases. However, they concluded, in the long run, this activity (tourism) does not create high negative impact on overall environmental conditions of the country due to three factors. First, the trekking and tourism rules and regulations are stringent in Bhutan. Second, most visitors are educated, well-to-do communities and mostly older than 40 years (can be verified from Table 2). Third, their main objective for visiting Bhutan is to witness the pristine natural environment and the beauty of the landscape (as Table 2 reveals). Besides, the tour operators are being trained on a regular interval in the country (RMA 2011).

In nutshell, the growth of tourism revenue is statistically more elastic ($1.103 > 1$) than the number of foreign tourist inflow in the country. With the available stock of country's environment and infrastructures, the number of tourist coming in the country is still not a big issue as the environmental degradation rate is much lower than the tourist inflow rate or tourism revenue growth rate. In reality, tourism industry is still below the *Tourism Carrying Capacity* (TCC).[6] Since the numbers of tourists are quite low compared to other countries, it is not seen any major environmental degradation attributable to tourists. To support this argument, Mr. Thuji Dorji Nadik (Tourism Council of Bhutan) commented that the *Limits to Acceptable Change*[7] of tourism industry is still positive in Bhutan (email interviewed by author). Country's tourism policy of HVLV succeeds in balancing the two divergent behaviours—economic growth contributed by tourism on one hand and preserving pristine environment on the other, in the country.

On the grim sides of the industry, Brunet et al. (2001) cautioned that India's rapidly expanding economy on the one hand and Bhutan's highly attractive tourism assets, its low population density, and proximity to India on the other, will make it difficult for Bhutan to sustain benefits of HVLV in future, if not regulated and controlled before it is too late. Indian tourists have outnumbered foreign tourists, and they do not need to pay tariff, visa, less spenders in terms of hotel, transportation and other consumptions, etc. (compared to foreign tourist). The reason for increasing number of Indian tourists visiting Bhutan has three factors: (1) the unrest situations in many parts of the country's tourist destinations—Agra, Kashmir, Mumbai, and other hill stations like, Darjeeling, Sikkim and the North Eastern Region states which are very close to Bhutan, (2) Bhutanese currency is pegged with Indian rupee, does not have exchange rate difference, and (3) no visa or restriction for Indians to visit Bhutan.

Secondly, Thinley W. Dorji of *Bhutan Tourism Corporation Limited* (interviewed by the survey team) exposed that finding accommodation for the tourists was the biggest glitch, especially during the festival season (e.g., Paro Tshechu, Coronation of King). At present, altogether 35–40 standard hotels, approved by the government are available in Bhutan. These hotels are small in size with the capacity of maximum 52 rooms (ranges from 15 to 52 rooms), e.g., standard hotels, like *Hotel Druk* in Thimphu has only 52 rooms.[8] Though the quality of service and facilities may differ but usually tourists are kept in all the hotels, resorts, guest houses and lodges approved by government. This may create some shortage of accommodation when Indian tourists are added during the peak season because of infrastructure and accommodation constraints in the country.

---

[6] TCC is defined by the World Tourism Organisation as 'The maximum number of people that may visit a tourist destination at the same time, without causing destruction of the physical, economic, socio-cultural environment and an unacceptable decrease in the quality of visitors' satisfaction.'

[7] The LAC was based on the recognition that (1) specific objectives were needed to identify what it was that management was to protect, (2) change is always present in nature-dominated systems, (3) any recreational use leads to some change, (4) management is therefore confronted with the question of how much change is acceptable, and (5) monitoring of the outcomes of management is needed to determine if actions were effective.

[8] Refer to 'Bhutan Tourism, 24 March, 2007', accessed on 6th October 2011: http://www.jachungtravel.com/bhutantourism.html.

7 Conclusion and Suggestions

To conclude, only a few thousand foreign tourists (e.g., 28,463 tourists in 2010) visiting Bhutan is not an issue compared to the stock of country's environment, culture and tradition (Brunet et al. 2001). With the available stock of environment, Bhutan still can increase number of tourist inflow till it reaches an equilibrium level, where the growth rate of tourists and the degradation rate of environmental parameters become equal. Unlike the people of other economic activities, literally, tourists are educated, financially sound and civilized people. Besides, they are fully guided by the trained tourist operators, and not left free to themselves during their stay in the country (TCB 2010). There is no need to be panic much for degradation of the country's environment by foreign tourists. Some negligible damage to natural resources, i.e., vegetation, made by the tourists (especially the trekkers) can be easily rejuvenated during the off season (as tourists do not go for trekking during the rainy season). Pace of growth of forest vegetation in Bhutan is faster than the rate of destruction made by the few thousand foreign tourists. Therefore, the tourism policy of HVLV of Bhutan can be considered as an effective means in balancing economy and environment. However, the major issue of tourism in Bhutan remains with Indian tourists, if not exposed. Though the number (Indian tourists) is not estimated accurately it outnumbers foreign tourist and it may have some negative impact on country's environment in the near future.

For the development of tourism industry and at the same time preservation of environment and culture of Bhutan, some of the possible suggestions are given below.

1. As the growth of Indian tourists in the recent years has reached an alarming rate, some basic necessary regulations are to be made. For instances, nominal environmental tax requires to be imposed on each and every Indian tourist and the amount is to be utilized exclusively for preservation of environment in the country. Indian tourists should also be guided by trained tour operators for the safeguarding nature and culture of the country.
2. As finding of accommodation, especially during the festival season in the country, some of the world class hotels and guest houses are to be built, and other basic infrastructures facilities should be created.
3. The visit of the tourists should be arranged spatially across the seasons, not rushing only in the festival seasons and few months in a year. Tourist visit should also be arranged rotationally across the length and breadth of the tourist spots of the country with mutual communication of the tour operators to reduce congestion in the tourist spots.

Acknowledgments I to thank ***Mr. Ugyen Thinley***, Royal Institute of Management (PGDFM Trainee), Thimphu, for conducting personal interview with Government officials and other stakeholders for the purpose of this paper. Secondly, I also thank ***Mr. Thuji Dorji Nadik***, Tourism Council of Bhutan, for his support and cooperation extended to my email interview. My heartfelt thank also goes to ***Mr. Istvan Harnadi***, Sr. Lecturer (Gedu College of Business Studies, Royal University of Bhutan) for his support in completing this paper.

Annexure I: Tourist Flow and Revenue in Bhutan (1985–2010)

Years	No. of foreign tourist	Tourism revenue in US $million[a]	% of tourism revenue to GDP[a]	GDP growth rate (year to year)
1985	1,896	1.67	1.0	4.4
1986	2,405	2.16	1.1	8.0
1987	2,524	3.40	1.5	20.2
1988	2,129	2.00	0.8	15.1
1989	1,480	1.95	0.7	6.2
1990	1,528	1.91	0.7	9.1
1991	2,106	2.30	0.9	4.9
1992	2,763	2.99	1.3	2.1
1993	2,984	3.30	1.5	3.2
1994	3,971	3.97	1.6	3.5
1995	4,769	6.00	2.1	6.0
1996	5,138	6.51	2.2	6.2
1997	5,363	6.50	1.9	5.4
1998	6,204	7.98	2.2	5.6
1999	7,051	8.70	2.2	6.9
2000	7,559	9.90	2.3	7.5
2001	6,393	9.20	2.0	7.0
2002	5,599	7.98	1.6	8.9
2003	6,261	8.32	1.4	8.6
2004	9,249	12.50	1.8	8.0
2005	13,626	18.50	2.3	8.8
2006	17,342	23.90	2.7	6.9
2007	21,094	29.90	2.5	17.9
2008	27,636	38.80	3.1	4.7
2009	23,480	31.90	2.5	6.7
2010	28,463	39.50	2.6	7.4

Source RMA (2011; 2001), WDI (2011), Tashel (2009), ADB (2006), Tobgay (1997)

[a] Only revenue from royalties of Foreign Tourist, excluding the tourist from SAARC nations including India

Annexure II: Status of Environment in Bhutan (1985–2010)

Years	Natural resources rents (%)	CO_2 (in '000 kg)	PM10 (μ/m^3)
1985	25.51	62,290	56.5
1986	26.09	54,960	55.0
1987	26.00	102,590	53.4
1988	21.62	109,920	51.9
1989	20.27	62,290	50.4
1990	21.00	128,240	47.5
1991	24.74	186,860	47.1

(continued)

(continued)

Years	Natural resources rents (%)	CO_2 (in '000 kg)	PM10 (μ/m^3)
1992	26.44	216,180	46.1
1993	27.01	186,860	45.9
1994	24.88	212,510	43.0
1995	23.34	249,150	41.9
1996	21.24	304,110	39.3
1997	17.93	395,710	37.8
1998	17.06	384,720	36.1
1999	16.77	384,720	35.7
2000	15.45	399,380	33.7
2001	14.21	414,030	31.9
2002	13.42	512,960	29.8
2003	11.38	465,330	28.4
2004	10.59	468,990	26.5
2005	9.49	564,260	25.2
2006	9.29	545,940	24.3
2007	14.02	578,910	23.1
2008	11.46	583,199	22.4
2009	14.40	663,431	19.7
2010	13.59	678,963	18.2

Source WDI (2012)

Annexure III: Travel Budget in the Different Countries (As of October 2009)

Region/country	Average cost/day	Budget in US $
Bhutan[a]	US $250	US $250 (from 2012)
Western Europe	€ 60–70	US $80–90
Eastern Europe	€ 35	US $47
Australia	AU $60	US $58
New Zealand	NZ $85	US $65
East Asia	US $70	US $70
USA	US $50–60	US $50–60
Central America	US $25	US $25
South Asia	US $20	US $20
India	US $20	US $20
China	US $20	US $20
South America	US $20	US $20

Source Travel Budgets (accessed on 21st June 2010 http://www.how-to-travel-the-world.com/trip-planning/travel-budget/)

[a] As provided by TCB (2010), and till today (2011), it is only $200 per night in twin sharing basis

References

ADB (2004) Bhutan-Country environmental analysis (Draft). Prepared by: Maunsell Limited, New Zealand. Available at: http://www.adb.org/Documents/CEAs/BHU/BHU-CEA-Nov2004.pdf. Accessed 6th Oct 2011

Bhutan Travel (2011) Bhutan travel newsletter, 1 (MBT/08/11): 1–4. http://www.medievalbhutan.com/newslettervol1.pdf. Accessed 6th Oct 2011

Brunet S et al (2001) Tourism development in Bhutan: tensions between tradition and modernity. J Sustain Tourism 9(3):243–263

Cater E (1995) Environmental contradictions in sustainable tourism. Geogr J 161(1):21–28

Choden T (2007) Bhutan—balancing growth and environment conservation through hydro power. Asian Development Bank Publication, Manila. Available at http://www.adb.org/annualmeeting/2007/essay-competition/winning-entries/thinley-choden.pdf. Accessed on 10th Mar 2010

Dearden P (1991) Tourism and sustainable development in Northern Thailand. Geogr Rev 81(4):400–413

Dorji T (2001) Sustainability of tourism in Bhutan. J Bhutan Stud 3(1):84–104

DoT (2005) Sustainable tourism development strategy, department of tourism. Royal Government of Bhutan, Thimphu

Draper D (2000) Towards sustainable mountain communities: balancing tourism development and environment protection in Banff and Banff National Park, Canada. Ambio 29(7):408–415

GNH Commission (2009) Tenth five year plan 2008–2013, vol 2. Royal Government of Bhutan, Thimphu. Available at: http://planipolis.iiep.unesco.org/upload/Bhutan/Bhutan_TenthPlan_Vol2_Web.pdf. Accessed 6th Oct 2011

GNH (2011) Keeping promises: a report on the status of implementation of the brussels programme of action in Bhutan for the decade 2001–2010. Royal Government of Bhutan, Thimphu. Available at: http://www.un.org/wcm/webdav/site/ldc/shared/Bhutan.pdf. Accessed 6th Oct 2011

Goodall B (1995) Environmental auditing: a tool for assessing the environmental performance of tourism firms. Geogr J 161(1):29–37

Gujarati DN, Sangeetha (2007) Basic econometrics. Tata McGraw-Hill Education Private Limited, New Delhi

Hardin G (1968) The tragedy of the commons. Sci, New Ser 162(3859):1234–1248

Karan PP (1987) Environment and development in Bhutan. Hum Geogr 69(1):15–26

Milne S, Ateljevic I (2001) Tourism, economic development and the global–local nexus: theory embracing complexity. Tourism Geogr 3(4):369–393

National Environment Protection Act (2007) National environment protection act of Bhutan. Royal Government of Bhutan, Thimphu. Available at http://www.oag.gov.bt/images/acts/National%20Environment%20Protection%20Act%20of%20Bhutan%202007(English%20version).pdf. Accessed 20 Mar 2010

National Statistics Bureau (2009) Statistical handbook of Bhutan 2009. Royal Government of Bhutan, Thimphu

NHDR (2000) Bhutan National Human Development Report. Royal Government of Bhutan, Thimphu

Rai Suresh C, Sundriyal R (1997) Tourism and biodiversity conservation: the Sikkim Himalaya. Ambio 26(4):235–242

RGoB (2011) 3rd Annual report of Lyonchhen JY Thiley to the 7th session of the first parliament on the state of the nation on 1st July 2011. Available at: http://rtm.gnhc.gov.bt/RTMdoc/state_of_nation_2011.pdf. Accessed on 6 Oct 2011

Rinzin C, Vermeulen WJV, Glasbergen P (2007) Ecotourism as a mechanism for sustainable development: the case of Bhutan. Environ Sci 4(2):109–125

RMA (2011) Annual Report 2009/10. Royal monetary authority of Bhutan. Royal Government of Bhutan, Thimphu

Roe D, Khanya Penny U (2001) Pro-poor tourism: harnessing the world's largest industry for the world's poor. International Institute for Environment and Development, London

Routledge P (2000) Consuming Goa tourist site as dispensable space. Econ Polit Wkly 35(30):2647–2656

Singha K (2010) Environment and development in Bhutan. S Asian J 28:51–67

Singha K, Elangbam HS (2009) Sustainable tourism for sustainable development: an observation. J Commer VI 1:139–152

Taylor T et al (2005) Sustainable tourism and economic instruments: international experience and the case of Hvar, Croatia. In: Markandya A, Lanza A, Pigliaru F (eds) The economics of tourism and sustainable development. Edward Elgar, Cheltenham

Tashel (2009). Bhutanese tourism in 2008. [Accessed september 14, 2011: tashel.com/bhutanese-tourism-in-2008/]

TCB (2010) About tourism council of Bhutan. Available at http://www.tourism.gov.bt/about-tcb. Retrieved on 20 June 2010

Tobgay Sonam (1997) Overview of tourism in Bhutan and how it fits into the general development plans of Bhutan. Presented at international seminar on ecotourism for forest conservation and community development on 28–31 Jan, Chiang Mai, Thailand. Available at: http://www.recoftc.org/site/fileadmin/docs/publications/Seminar_Proceeding/Bhutan.rtf. Accessed on 28 Feb 2010

Vu J, Turner L (2008) Economic significance of high-value tourists. Int Rev Bus Res Pap 4(1):189–206

WDI (2011). World Development Indicator. Public Data, World Bank, Washington DC

WDI (2012) World development indicator. Public Data, World Bank

WTO (2010) Tourism outlook 2010, world tourism organisation. Available at http://www.onecaribbean.org/content/files/UNWTOTOURISMOUTLOOK2010.pdf. Accessed on 28 Sep 2011

Green Buildings; Benefits to Our Environment

Tejaswini B. Yakkundimath

1 Introduction

Today over 50 % of world's population live in urban areas and it is projected that this would rise to 70 % by 2050. With this current demographic trend we foresee that it would be difficult to provide adequate infrastructure, institutional support and proper public service. In many urban areas the lakes and earths arable lands are being encroached for constructing the buildings. Many informal human settlements are also mushrooming in cities. Hence, scientific urban planning is the need of today. In Second United Nations Conference on Human settlement habitat II (1996), it is stated that 'Cities and towns have been engines of growth and incubators of civilisation and have facilitated the evolution of knowledge, culture and tradition as well as industry and commerce. Urban settlements, properly planned and managed, hold the promise for human development and the protection of the world's natural resources through their ability to support large number of people while limiting their impact on the natural environment.'

The anthropogenic theory predicts that global warming will continue apace with greenhouse gas (GHG) emissions. The International Panel on Climate Change (IPCC) indicates that 'most of the observed increase in global average temperature since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations (IPCC 2007). Thus, climate change is a subject of major concern. The Kyoto Protocol was signed to control and combat it.

This is an agreement encouraging the reduction of polluting emissions, mainly CO_2. But, unfortunately, CO_2 emissions have risen by 35 % since 2000, when the Kyoto agreement was signed. One of the most important comprehensive solutions in the fight to reduce the effects of climate change, in the medium and long term, is the adoption of effective policies for decarburizing economies. As climate change

T. B. Yakkundimath (✉)
Government First Grade College, Dharwad, India
e-mail: tejaswini.umesh@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_38,

has quickly moved up the list of critical issues, to stabilize atmospheric carbon and maintain the climate, a number of strategies were adopted.

Among climate change mitigation strategies, turning to green building was one of the natural moves. In America, it has been estimated that buildings account for 39 % of energy use, 68 % of total electricity consumption, and 38 % of carbon dioxide annually. There might be little variations in the above mentioned statistics with respect to other countries, but definitely buildings have contributed to climate change.

Construction of homes generates a huge amount of waste material and a toxic environment for the people who live there. Most of the houses are being built with no regard for ecology and future generations. Building better for the future requires consciousness that goes beyond resale value and colour schemes. It involves considering the resources and materials it takes to make a healthy, pleasant living space that is in harmony with nature. It has been predicted that, if urban sprawl continues at the current rate over the next 25 years, there will be almost no green space left and, in the long-run, the result will be the destruction of thousands of species of flora and fauna.

With respect to environmental dimensions, the most recent Global Report on Human Settlements (U.S. Environmental Protection Agency 2005) offers certain goals for sustainable development. These include reduced greenhouse gas emission, conservation and sensible use of non-renewable energy and increased use of renewable energy. All these goals can be met by implementing the concept of green building.

The paper is organized as follows: I have discussed the concept of green building in Sect. 1.3. Steps to green building, benefits, green building cost and conclusion are given in Sects. 1.4 and 1.5, respectively.

The objective of the study is to understand the concept of green buildings, ways of the green building and, in turn, understand how it benefits the ecosystem. The study is entirely based on secondary data. The limitation of the study is that since no primary data is used in the study, no statistical tools are used.

1.1 Concept of Green Building

Green building is a broad concept that encompasses ways of designing, constructing, and maintaining buildings to decrease energy and water usage and costs, improve the efficiency and longevity of building systems, and decrease the burdens that buildings impose on the environment, economy and public health (Wolf 2006). Green buildings use key resources like energy, water, materials, and land more efficiently. They provide more natural light and better air quality to people who reside in them.

Green building does not mean that it is all about gadgets. Some assume that advanced appliances and materials are needed to make the building environment friendly. Leadership in Energy & Environmental Design (LEED), developed by

US Green Building Council (USGBC), is an internationally recognized green building certification system, providing third-party verification that a building or community was designed and built using strategies intended to improve performance in metrics such as energy saving, water efficiency, Carbon Dioxide emissions reduction, improved indoor environmental quality, and stewardship of resources and sensitivity to their impacts. It is intended to provide building owners and operators a concise framework for identifying and implementing practical and measurable green building design, construction, operations and maintenance solutions.

This provides a system to award points for achieving certain levels of sustainable performance in six categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation in design. They are discussed in detail in the next segment.

1.1.1 Sustainable Sites

It is insisted to avoid development of inappropriate sites and reduce the environmental impact from the location of a building on a site. It clearly specifies not to build roads, buildings or parking areas on the site that meet any of the following criteria.

- Prime farmland as defined Department of Agriculture.
- Land whose elevation is lower than 5 feet above the elevation of the 100 year flood.
- Land which is specifically identified as habitat for any species on Government threatened or endangered lists.
- Within 100 feet of any water including wetlands and isolated wetlands, or areas of special concern identified by a state or local rule, or greater than distances given in the state or local regulations, as defined by local or state rule or law, whichever is more stringent.
- Land which prior to acquisition for the project was public parkland, unless land of equal or greater value as parkland is accepted in trade by the public landowner (Park Authority projects are exempt).

1.1.2 Development Density

This clause channels development to urban areas with existing infrastructure, protect Greenfields and preserve habitat and natural resources. This emphasise on increased localized density to confirm to existing or desired density goals, by utilizing sites that are located within an existing minimum development density of 60,000 square feet per acre.

1.1.3 Brownfield Redevelopment

This clause has an intent to, rehabilitate damaged sites where development is complicated by real or perceived environmental contamination and, thereby, reducing pressure on undeveloped land.

1.1.4 Alternative Transportation

Public Transportation Access

This clause suggests considering the construction area near the public transport facilities such as commuter rail, subways, trams light rails and bus stations.

Bicycle Storage and Changing Rooms

For commercial or institutional buildings, provide secure bicycle storage with convenient changing/shower facilities (within 200 yards of the building) for 5 % or more of regular building occupants. For residential buildings, provide covered storage facilities for securing bicycles for 15 % or more of building occupants in lieu of changing/shower facilities.

Alternative Fuel Vehicles

Provide alternative fuel vehicles for 3 % of building occupants and provide preferred parking for these vehicles, or install alternative-fuel refuelling stations for 3 % of the total vehicle parking capacity of the site. Liquid or gaseous fuelling facilities must be separately ventilated or located outdoors.

1.1.5 Reduced Site Disturbance

This clause suggests conserving existing natural areas and restoring damaged areas to provide habitat and promote biodiversity.

1.1.6 Water Efficiency

To maintain water efficiency the following measures should be adopted.

- Limit or eliminate the use of potable water for landscape irrigation.
- Use high-efficiency irrigation technology.
- Use only captured rain or recycled site water for site irrigation.

- Reduce generation of wastewater and potable water demand.
- Increase the local aquifer recharge.
- Treat 100 % of wastewater on site to tertiary standards.

1.1.7 Energy and Atmosphere

The essential steps for the optimum utilization of energy and energy sources and, thereby, benefitting the atmosphere are given in this section.

- Establish the minimum level of energy efficiency for the base building and systems.
- Reduce ozone depletion.
- Zero use of CFC-based refrigerants in new base building.
- Encourage and recognize increasing levels of on-site renewable energy self supply in order to reduce environmental impacts associated with fossil fuel energy use.

1.1.8 Materials and Resources

- Facilitate the reduction of waste generated by building occupants that is hauled to and disposed of in landfills.
- Divert construction, demolition and land clearing debris from landfill disposal.
- Use of building materials that are extracted and manufactured in the region, thereby supporting the regional economy and reducing environmental impacts resulting from transportation.

1.1.9 Indoor Environmental Quality

- Meet the minimum requirements of voluntary consensus standard.
- Prevent exposure of building occupants and systems to Environmental Tobacco Smoke (ETS).
- Install a permanent carbon dioxide (CO_2) monitoring system.
- Design ventilation systems that result in an air change effectiveness greater than or equal to 0.9.
- Reduce the quantity of indoor air contaminants that are odorous, potentially irritating and/or harmful to the comfort and well-being of installers and occupants.

1.2 Steps to Green Building

It has been the need of the day to build buildings those meet the deepest wants and needs without compromising the environment of future generations.

1.2.1 Assessing Needs and Priorities

What are our needs? What would be our lifestyle in the next 10 years? Will this building provide us access to basic services? These are some of the questions for which one should find an answer for constructing a building. If you were planning to build your dream house now, what would the top goals be? What purposes, needs, and desires do you want to satisfy in your life that the right home can contribute to? These could include low building and operating costs, minimal maintenance, short commuting times to work and school, and a desire for greater independence by producing solar electricity, or harvesting rainwater. Answering these questions helps in making a good decision.

1.2.2 Forming a Team

To build a dream house, one needs to take help from many people; designer, architect, contractor, electrician, workers, plumbers, appraisers and many more. Having a good team, with each member having proper communication, results in a quality building at a lesser price.

1.2.3 Designing

Any project without a proper design is always bound to fail. There are various aspects and conditions that need to be taken care for a good design. Understanding the region of construction includes understanding the temperature in that region. What would be the temperature in the winter and summer? What is the average temperature variation? What will be the ground temperature? One needs to consider the arc of sunlight in various seasons, average annual rainfall, relative humidity in the region, wind patterns and special conditions like earthquakes, hurricanes, soil stability, nearby water bodies. Finding answers to these questions helps in deciding the windows size and position, building materials, choice of landscaping, construction methods, roof shaping and foundation.

1.2.4 Choosing Green Materials

Following criteria need to be considered while choosing the construction material.

- Is the material effective in your conditions?
- Materials need to be healthy and safe for the workers who extract, harvest, manufacture and install them, and for the inhabitants who are exposed to their fumes and particles in tight modern buildings.
- Construction material should be safe for disposal so that it does not add to the pollution, global warming loss of habitat and depletion of irreplaceable recourse.

- Material should be long lasting.
- The material for construction should be selected in such a way that it should be manufactured in the same region to reduce the pollution resulting from transportation.
- Material should be used in its natural state or with very little processing.
- Material should be cost effective.

1.2.5 Right Energy Systems

In the present day lifestyle, heating, cooling, ventilation and appliances play a major role in providing comfort, convenience and good health. It is very much essential to have a few basic appliances to obtain a cost effective yet safe house. A cost-effective way to feel comfortable in a building is to control your environmental conditions by passive means. But many a times it is not possible to attain the goal. We need to depend on energy systems.

- Choose a system with higher efficiency.
- Equipment size should meet the needs.
- Select the best possible location for the equipment.
- Equipment should be installed properly.
- Install vent fans in high humid regions.
- Use of the system should not affect the air quality in the building.
- Design of windows to enable the deep penetration of sunlight.
- Based on the needs of light choose the electric fixtures.

1.2.6 Outdoor Benefit from Your Site

It is widely accepted to consider the house and site as a single unit and understand how they interact in the planning stage itself.

- Choose appropriate landscaping.
- Select the best suited vegetation in the region for landscaping.
- Maintain sufficient green space around the house.
- More leaving space that includes a play area for children, sport courts and patios.
- Rain water harvesting facility.
- Design a better storm water and erosion control.

1.3 Benefits of Green Buildings

The role of green buildings in combating climate change is discussed in this segment. Examining the projected benefits of some of the cities where green building program is adopted, we can get some insight into the actual value of this program in the effort to address climate change. Here, we have taken the examples of two American cities Los Angeles and San Diego. The program, approved unanimously by the City Council and signed into law by Mayor Villaraigosa on Earth Day 2008, requires all building projects of 50,000 square feet or 50 residential units or greater to meet the intent of the US Green Building Council's LEED rating system at the Certified level. As a part of assistance to the city in establishing the program, Global Green analyzed the energy, water, and construction waste savings and prepared an estimate of the avoidable carbon emissions that would result from the approximately 150 projects estimated to be subject to the program annually. The results show that the Los Angeles Program would yield approximately 5,500 tonnes of avoided emissions each year (Global Green 2008). The Los Angeles Department of Water and Power's most recent submittal to the California Climate Registry provides a useful reference point. As the city's electricity and water provider, DWP reported 4,129,368 total tonnes of carbon dioxide emissions represent a large portion of the overall carbon footprint for Los Angeles (California Climate Action Registry 2008). In year one, the green building program would result in just a 0.13 % reduction in overall emissions. Given the time and effort that went into creating the program this seems under whelming.

But the picture changes dramatically as more buildings come on line. By year fifteen, the annual emissions reductions increase to 14 % (California Environmental Associates 2007). This is because buildings that come on line in year one, continue to generate energy and water savings in future years. As time goes by, the benefits of the green building program increases exponentially. Translated into quantities that are perhaps easier to grasp than 'tonnes of avoided emissions', by the end of its 15th year the benefits of the Los Angeles program are equivalent to planting 14 million trees or removing 100,000 cars off the roads, permanently.

The city of San Diego's new green municipal building, which is a green building, used 65 % less energy than a conventional building yielding a savings of $70,000 in utility costs (Turcotte et al. 2006).

From Table 1, it is clear that green buildings help in sustainable urban development. Green building provide economic benefits to both developers and homeowners. It helps in generating employment in the green material manufacturing sector. Green building promise a safe, healthy quality lifestyle. In summary we can say green buildings help to minimize that impact of urban development on the environment and the ecosystem.

The built-up environment has a vast impact on the natural environment, human health, and the economy. By adopting green building strategies, we can maximize both economic and environmental performance. Potential benefits of green building are listed below:

1.3.1 Environmental Benefits

- Reduction in water consumption, decreases maintenance and life cycle cost of the building. This in turn helps in maintaining the water table.
- Reduced pollutants from use of fossil fuel helps in reducing global warming.

Table 1 Benefits of green building

Economic	Social	Environmental
Create, expand, and shape markets for green products and services	Enhance occupant comfort and health	Enhance and protect biodiversity and ecosystems
Improve occupant productivity	Heighten aesthetic qualities	Reduce waste streams
Optimize life-cycle economic performance	Improve overall quality of life	Conserve and restore natural resources

- Using building materials with fewer chemicals and toxins leads to better air and water quality.
- Enhance and protect biodiversity and ecosystems.
- Conserve and restore natural resources.

1.3.2 Economic Benefits

- Resource efficient strategies and integrated design provides a no more cost or even a less cost than the conventional buildings.
- Green buildings attract higher resale value in the market.
- Productivity of employees working in green building increaseDs. An increase of one per cent in productivity (measured by production rate, production quality, or absenteeism) can provide savings to a facility that exceeds its entire energy bill (Snowmass 1994).

Green buildings use less energy than non-green buildings. ENERGY STAR qualified homes use substantially less energy for heating, cooling, and water heating, delivering $200 to $400 in annual savings (Energy Star 2011). There are currently over 1 million ENERGY STAR qualified homes in the United States and, in 2010 families living in these homes, saved more than $270 million on their utility bills (McGraw hill Construction 2007,2008).

- Energy efficiency and renewable energy sources can lessen this dependence and help improve national security.
- They reduce operating costs. According to the Construction Marketplace Smart Market Report, commercial green buildings have demonstrated an 8–9 % decrease in operating cost, a 7.5 % increase in building value and a 6.6 % return on investment improvement (ibid).
- Create, expand, and shape markets for green products and services.
- Optimize life-cycle economic performance.
- According to the Greening of Corporate America Smart Market Report, commercial green buildings experience a 3.5 % occupancy ratio increase and a 3 % rent ratio increase. In a comparison of ENERGY STAR buildings and market comparables, in the first quarter of 2008, ENERGY STAR buildings achieved 3.6 % higher occupancy rates (Miller et al. 2011).

1.3.3 Social Benefits

Green buildings, avoid many health problems with good ventilation systems, indoor air quality and use of non-toxic building materials. Enhanced Occupant health and well-being, Genzyme's, Cambridge, MA, has reported that sick time of employees has decreased 5 %compared to other facilities (Palmeri 2006).

- Heighten aesthetic qualities.
- Minimize strain on local infrastructure.
- Improve overall quality of life.

1.4 Green Building Costs

It was observed that often when a LEED rating is pursued, the cost of initial design and construction rises. One reason for the higher cost is that sustainable construction principles may not be well understood by the design professionals undertaking the project. This could require time to be spent on research. Some of the finer points of LEED (especially those that demand a higher-than-industry-standard level of service from the construction team) could possibly lead to misunderstandings between the design team, construction team, and client, which could result in delays. Also, there may be a lack of abundant availability of manufactured building components that meet LEED specifications. Pursuing LEED certification for a project is an added cost in itself as well. This added cost comes in the form of USGBC correspondence, LEED design-aide consultants, and the hiring of the required Commissioning Authority—all of which would not necessarily be included in an environmentally responsible project, unless it also sought a LEED rating.

It is not wrong if said that buildings consume a large portion of water, wood, energy, and other resources used in the economy. If green building saves costs, a broad shift to green construction would be a promising way to face many challenges that present day development is facing.

A statement from 2003 New York Times 'Not Building Green Is Called a Matter of Economics' makes us to think how much more it would cost to build green. Many firms and groups took initiative to investigate the cost criteria for going green. United states Green Building Council (LEED) capital E analysis surveyed 33 buildings all across United States. The report summary is given in table below.

From Table 2, we come to know that the average cost of green building would increase by 2 % or \$3–\$5/Sq Feet. Majority of the cost incurred is because of

Table 2 Cost of going green

Certified	Silver	Gold	Platinum
0.66 %	2.11 %	1.82 %	6.50 %

Source USGBC, Capital E

Table 3 Financial benefits of green building

Category	20 year net present value
Energy savings	$5.80
Emissions savings	$1.20
Water savings	$0.05
Operations and maintenance savings	$8.50
Productivity and health value	$36.90–$55.30
Subtotal	$52.90–$71.30

Source USGBC, Capital E

initial increase in Architectural Design and Engineering. With more builders moving to green building this cost is declining. A study conducted in Portland, three LEED silver buildings constructed in 1995, 1997 and 2000 had incurred a higher cost of 2, 1 and 0 %, respectively. With this secondary data we can conclude that the additional cost of green building is no more than conventional building.

However, these higher initial costs can be effectively mitigated by the savings incurred over time due to the lower-than-industry-standard operational costs typical of a LEED certified building. This Life Cycle Costing is a method for assessing the total cost of ownership, taking into account all costs of acquiring, owning and operating, and the eventual disposal of a building. Additional economic payback may come in the form of employee productivity gains incurred as a result of working in a healthier environment. Studies have suggested that an initial up-front investment of 2 % extra will yield over ten times the initial investment over the life cycle of the building.

Green buildings on an average consume 30 % less energy than the conventional buildings. From Table 3 it is clear that nearly 25–30 % is saved on energy. For instance, as mentioned above the city of San Diego's new green municipal building used 65 % less energy than a conventional building. The overall savings of the green building is 70 %. Building green reduces the cost incurred on hospital bills and helps in increase productivity value. The cost saved by building green is over 5–10 times the cost incurred on building green.

1.5 Conclusion

Though the need for green buildings is growing rapidly throughout the world, still all countries have a long way to go. It has been estimated that green buildings comprise only 5 % or less of the market. There is scarcity of educated builders to provide a green building choice to people. So engineers and architects must be well trained about these green buildings during their courses.

In addition to this, people who want to buy a home also lack education about green buildings. It has been accepted by everyone in any country that a house is the single largest expenditure in a lifetime of any person and, unfortunately, they get no training at any stage during their education about what a reasonable home is and what a quality residence is. So, the information about green building should be incorporated in the school and college curriculum. Along with this, print and electronic media should also be intensively involved in the process of awareness generation among public.

In India, the Energy and Resource Institute plays a very important role in developing green building capacities in India. TERI came up with a rating system called GRIHA which was adopted by the Government of India as the National Green Building Rating System for the country. GRIHA aims at ensuring that all kinds of buildings become green buildings. In India, the CESE building in IIT Kanpur became the first GRIHA rated building in the country and it scored 5 stars, highest in GRIHA under the system. Measures are being taken to spread awareness about the GRIHA-National Green Building Rating System of India.

To overcome the problems of urban sprawl and traffic congestion, city centres should be well planned, where homes are within walking or cycling distance of businesses, entertainment, services, shopping and schools. Waste created in home building must be reduced and, if possible, it should be recycled.

In USA, recent federal tax incentives have been enacted to encourage the design and construction of energy-efficient green buildings, both residential and commercial. Many state and local governments have also passed tax provisions to encourage energy-efficient buildings. This kind of tax incentives should be announced in every country.

Home buyers are sold homes based on price per square feet instead of value. But this should be changed and home buyers have to look into the real value of the buildings.

It is doubtful that the building industry will change much towards green buildings in the near future and efforts are on by the government and also by people who are worried about climate change and have concern about ecology. Building for a better future requires vision and the desire to have places and materials for our future generation to build houses.

Economic activity around the globe, measured by Gross World productivity, is growing at 4 % a year. The current rate of resource harvesting and waste generation deplete the nature faster than it can regenerate (WWI 1994). The accelerating resource consumption has degraded the forest, soil, water, air and biological diversity of the planet. Hence, construction of more number of green buildings is one of the best solutions for mitigating climate change and environmental conservation.

References

California Environmental Associates (2007) Design to win: philanthropists role in the fight against global warming. Available at http://www.ceaconsulting.com/CaseStudyFiles/DesignToWin_FinalReport.pdf

Energy Star (2011) Available at http://www.energystar.gov/index.cfm?c=new_homes.hm_index. Accessed 5 June 2011

Global Green USA analysis (2008). Available at http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/ns/nbm_presentation_51908.pdf. Sept 2008

IPCC: climate change (2007) Synthesis report. Contribution of working groups I, II and III to the IPCC's fourth assessment report on climate change. IPCC, Geneva, Switzerland, p 16

McGraw-Hill Construction (2007) Greening of corporate America smart market report

McGraw-Hill Construction (2008) Key trends in the European and U.S. construction market place smart market report

Miller N, Jay S, Andy F (2008) Does green pay off? http://www.costar.com/uploaded Files/JOSRE/pdfs/CoStar-JOSRE-Green-Study.pdf. Accessed 10 June 2011

Palmeri Christopher (2006) Green stamp of approval. Business week, 11 Sept 2006. Available at: www.businessweek.com/magazine/content/06_37/b4000083.htm

Romm JJ, Browning WD (1994) Greening the building and the bottom line: Increasing productivity through energy efficient design. Rocky Mountain Institute, Snowmass, CO. http://www.greenbiz.com/files/document/O16F8527.pdf.

Second United Nations Conference on Human Settlements (Habitat II) (1996) Paragraph 5 of the Habitat Agenda, June 1996

Turcotte D, Villareal J, Bermingham C (2006) The benefits of building green: recommendations for green programs and incentives for the city of Lowell. Available at:http://www.uml.edu/centers/CFWC

U.S. Environmental Protection Agency (2005) Green buildings: why build green?

Wells Walker (2008) California climate action registry. Los Angeles department of water and power annual emission report for 2005. Available at http://globalgreen.org/docs/publication-157-1.pdf

Wolf V (2006) Houston as a model city: facing the challenges of an environmental crisis building better for the future put our very survival at risk

World watch Institute (1994) W. W. Norton, New York

Impact of Education, Age and Land Holding on Understanding the Aspects in Climate Change: A Case Study

M. B. Rajegowda, H. S. Padmashri, N. A. Janardhana Gowda, C. N. Shilpa, B. V. Pavithra and D. V. Soumya

1 Introduction

Agriculture in India is a gamble with the monsoon. Whatever the resource based research, new varieties found or technology be developed, the production is ultimately decided by climate. Farmers are unaware of the future behaviour of monsoon for making decisions in their day to day agricultural operations. The farming community needs to be advised in time by producing custom-tailored weather forecasts to initiate suitable measures to increase the production and to minimize the impact of unfavourable weather on agriculture. Any such advisories yield results only when they realize its importance. Universities or any organizations that deliver these advisories need to know the existing perception of farmers on climate change without which attaining fruitful results stays as a dream. Thus, we decided our hypothesis as: age, education and their land holding, play a key role in understanding the aspects of climate studies. Brody et al. (2008) also opine that so far, the evidence available to test this hypothesis is limited and in part, contradictory. In general, basic tools like correlation, regression or just percentages are used in representing the perception of the farmers. The present study uses a multivariate tool known as Correspondence Analysis in testing the hypothesis. It is an appropriate method for the analysis of categorical data. This technique addresses the problem with two basic objectives. They are: association among row or column categories and association between row and column categories. It produces a visual representation of the relationships between the row categories and the column categories in the same space. A correspondence map displays two of the dimensions which emerge from the analysis.

M.B. Rajegowda (✉) · H. S. Padmashri · N. A. Janardhana Gowda · C. N. Shilpa · B. V. Pavithra · D. V. Soumya
Department of Agrometeorology (AICRP), University of Agricultural Sciences, G. K. V. K, Bangalore 560065, India
e-mail: mbraj2001@yahoo.combng.aicrpam@gmail.com

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_39, © Springer-Verlag Berlin Heidelberg 2013

2 Methodology

2.1 Data Base

A field survey was conducted in the eastern dry zone of Karnataka, which comes under Chintamani taluk of Chikkaballapur district. A simple random sample of 60 farmers was selected for our study. Primarily, the survey was conducted with motto of creating awareness among the farmers about the impact of climate change on agriculture. In the process, a questionnaire was distributed to the farmers. Responses from these farmers are being decoded into master sheet. Further, decoded data is used for the analysis. Here, Age is coded as: young (<35), middle (35–50) and old (>50). Education is coded as: Illiterate, Primary (<7th), High School (8–10th), PUC and Degree. Land holding is coded as: Marginal (<2.5 acres), small (2.5–5 acres) and large (>5 acres). This study has made an attempt to brief out the association between these three variables and their perception on trends (increasing, decreasing or no change) in some climatic variables like annual rainfall, heavy rainfall, cyclone, summer and winter temperatures, south west monsoon and mist. Technique used in tracing out the association is Correspondence Analysis. Initially, all 60 farmers were considered as a whole sample and Model-I was developed. Model-I depicts the associations among climatic variables. Model-II was established by considering age, education and land holding as row attributes and climatic variables as column attributes.

2.2 Correspondence Analysis

Analysis starts with obtaining the eigen values and vectors. There is one eigen value for each dimension. Each eigen value is the amount of inertia (variance) a given factor explains in the correspondence table. Eigen values reflect the relative importance of the dimensions. The first dimension always explains the most inertia (variance) and has the largest eigen value, the next the second-most and so on. The sum of eigen values is total inertia. Total inertia is the sum of Eigen values and reflects the spread of points around the centroid. Total inertia may be interpreted as the percent of inertia (variance) in the original correspondence table explained by all the computed dimensions in the correspondence analysis. However, usually only the first two dimensions are used in the correspondence map, so the effective model will explain a percent of inertia in the original table equal to the sum of eigen values for the first two dimensions only.

Discrimination measure explains the contributions. The contribution of dimensions to points is the percent of variance in a point explained by a given dimension. One would like the points on which one's analysis focuses to have a high contribution of dimensions to points value. Less analytic focus must be placed on points which are not well described by the model. The contribution of

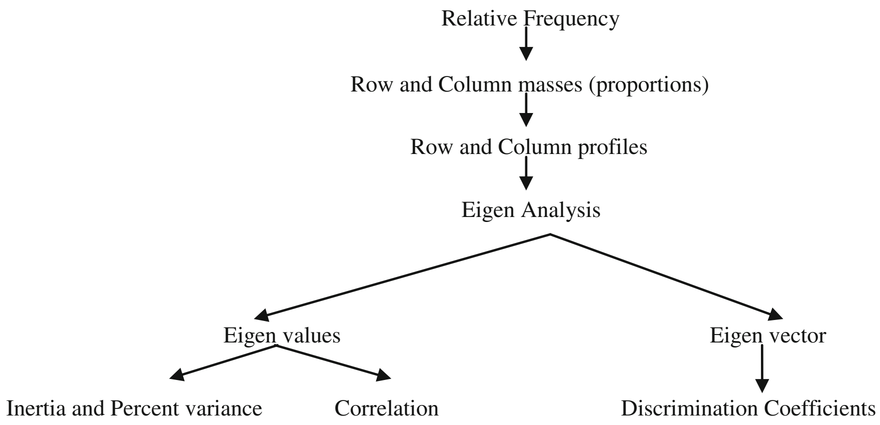


Fig. 1 Procedure followed in correspondence analysis

points to dimensions, show the percent of inertia (variance) of a particular dimension which is explained by a point. By looking at the more heavily loaded points, one may induce the meaning of a dimension Note that high contribution of points to dimensions implies a high squared correlation, but the reverse is not true. That is, if a point explains a lot of the variance in a dimension, usually that dimension will also describe the point very well (high squared correlation). However, just because a dimension describes a point well does not mean the point will necessarily be important in explaining the dimension.

Procedure of analyzing the data (Hair et al. 2010) is presented as a flow chart (Fig. 1). To assess the overall fit, the researcher must identify the appropriate number of dimensions and their importance. The maximum number of dimensions that can be estimated is one less than the smaller number of rows and columns. For example, with seven rows and eight columns, the maximum number of dimension would be six, which is seven (the number of rows) minus one. Eigen values (singular values) are derived from each dimension and indicate the relative contribution of each dimension in explaining the variance in the categories. The researcher selects the number dimension based on overall level of explained variance desired and the incremental explanation gained by adding another dimension. A rule of thumb is that dimensions with inertia (eigen value) greater than 0.2 should be included in the analysis. With regard to perceptual mapping, using a two-dimensional or lower representation facilitates interpretation.

3 Results and Discussions

In this case, Inertia or percent variance explains the variability in the perception about the trends of changing climate that could be modelled. Dimensions mean their views. Both situations we could only get two dominant views regarding the order, trend and association. Contribution of points explains the order of preference of each factor to the total variability of each dimension. Order under both situations is being presented below. Correlation of transformed attributes means association among the attributes only with respect to that view.

3.1 Model: I

Though eigen values of first six dimensions are above 0.2 (Table 3), first two dimensions together explains 63.2 % (Table 1) of the variability in their perception. Any other combination would end up with lesser extent so discrimination measures (Table 2) and the Correspondence plot (Fig. 2) are calculated and presented only for first two dimensions.

Dominant way of (Dimension-1 of Table 2) their thinking says that order (max to min) of attributes that exhibit change over time is: mist, heavy rainfall, winter temperature, cyclone, south west monsoon, summer temperature and annual rainfall. Next dominant view (Dimension-2 of Table 2) says that the order of change from (high to low) is mist, heavy rainfall, cyclone, summer temperature, annual rainfall, winter temperature and south west monsoon.

Table 1 Model-I summary

Dimension	Variance accounted for		
	Total (eigen value)	Inertia	Percentage of variance (%)
1	2.902	0.415	41.452
2	1.514	0.216	21.628
Total	4.416	0.632	63.2
Mean	2.208	0.315	31.55

Table 2 Discrimination measures of model-I

Attributes	Dimension		Mean
	1	2	
Summer temperature (St)	0.043	0.189	0.116
Annual rainfall (Ann)	0.019	0.152	0.086
Winter temperature (Wt)	0.677	0.086	0.381
South west monsoon (Sm)	0.170	0.073	0.121
Heavy rainfall (Hea)	0.688	0.324	0.506
Cyclone (Cyc)	0.597	0.286	0.441
Mist	0.708	0.404	0.556
Active total	2.902	1.514	2.208
Percentage of Variance	41.452	21.628	31.55

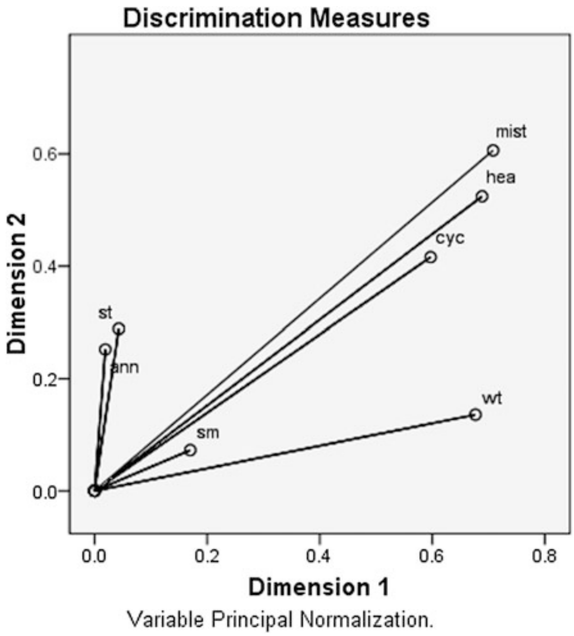


Fig. 2 Discrimination measures of model: I

Table 3 Correlations of transformed attributes—as per dimension 1 of model-I

Attributes	St	Ann	Wt	Sm	Hea	Cyc	Mist
Summer temperature (St)	1.000	−0.213	0.145	0.000	0.099	0.239	0.046
Annual rainfall (Ann)	−0.213	1.000	−0.201	0.369	0.112	0.259	0.034
Winter temperature (Wt)	0.145	−0.201	1.000	0.130	0.520	0.414	0.898
South west monsoon (Sm)	0.000	0.369	0.130	1.000	0.294	0.289	0.190
Heavy rainfall (Hea)	0.099	0.112	0.520	0.294	1.000	0.695	0.541
Cyclone (Cyc)	0.239	0.259	0.414	0.289	0.695	1.000	0.413
Mist	0.046	0.034	0.898	0.190	0.541	0.413	1.000
Dimension	1	2	3	4	5	6	7
Eigen value	2.902	1.514	1.040	0.693	0.529	0.257	0.065

As per farmers most explained view (Dimension-1) mist and winter temperature, heavy rainfall and cyclone, heavy rainfall and mist and heavy rainfall and winter temperature are the pairs of climatic attributes that exhibit higher extent of association (Table 3) with respect to change over time.

3.2 Model: II

Though Eigen values of first eight dimensions are above 0.2 (Table 6), first two dimensions together explains 57.6 % (Table 4) of the variability in their perception. Any other combination would end up with lesser extent so discrimination measures (Table 5) and the Correspondence plot (Fig. 3) are calculated and presented only for the first two dimensions.

Dominant way (Dimension-1 of Table 5) of their thinking says that order (max to min) of attributes that exhibit change over time is: mist, heavy rainfall, cyclone, winter temperature, south west monsoon, annual rainfall and summer temperature. Next dominant view (Dimension-2 of Table 5) says that the order of change from (high to low) is heavy rainfall, mist, summer temperature, cyclone, winter temperature, annual rainfall and south west monsoon. In both views education is the most influencing factor that alters their perceptions, followed by their land holding and then their age.

As per farmers most explained view (Dimension-1) mist and winter temperature, heavy rainfall and cyclone and heavy rainfall and mist are the pairs of climatic attributes that exhibit higher extent of association (Table 6) with respect to change over time.

Table 4 Model-II summary

Dimension	Variance accounted for		
	Total (Eigen value)	Inertia	Percentage of variance (%)
1	3.243	0.324	32.426
2	2.518	0.252	25.179
Total	5.760	0.576	57.6
Mean	2.880	0.288	28.802

Table 5 Discrimination Measures of Model - II

Attributes	Dimension		Mean
	1	2	
Land holding (Irrign)	0.202	0.133	0.167
Mist	0.666	0.490	0.578
Heavy rainfall (Hea)	0.618	0.514	0.566
Cyclone (Cyc)	0.565	0.368	0.466
Winter temperature (Wt)	0.522	0.228	0.375
Summer temperature (St)	0.000	0.419	0.209
South west monsoon (Sm)	0.211	0.008	0.109
Annual rainfall (Ann)	0.081	0.159	0.120
Age	0.066	0.002	0.034
Education (Edu)	0.312	0.198	0.255
Active Total	3.243	2.518	2.880
Percentage of variance	32.426	25.179	28.802

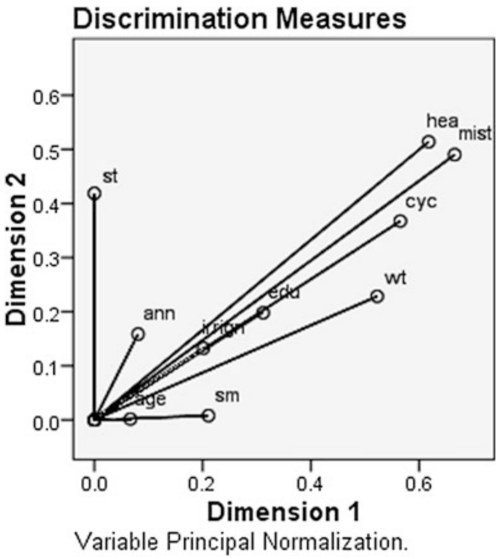


Fig. 3 Discrimination measures of model: II

3.3 Comparison of Model: I and Model: II

Even after having considered their age, education and land holding, the variability in extent of their knowledge on trends in annual rainfall, heavy rainfall, cyclone, summer and winter temperature, south west monsoon and mist could be reduced by only 2.75 % (Mean of Tables 1 and 4: 31.55–28.802). Weber (2010) obtained similar results saying that indeed, public perceptions typically reflect a much lower concern about climate change, potentially owing, in part, to the public's lack of personal experience with climate impacts.

Farmers opine that change that they could note over time in the order (Mean of Table 2) from high to low is mist, heavy rainfall, cyclone, winter temperature, south west monsoon, summer temperature and annual rainfall. Except for mist, cyclone and heavy rainfall, orders of other parameters have no much change. Thus, we can say that age, education and land holding had least impact on their perception in the higher order and slight change in the lower order (Mean of Table 5 of summer temperature, annual rainfall and south west monsoon).

There exists no difference (Tables 3 and 6) in the associations of changing climatic attributes. Similar results were exhibited even after grouping their perceptions with respect to their age, education and land holding. Zahran et al. (2006) obtained similar result saying that there is little and mixed evidence on whether living in a place physically vulnerable to climate change impacts, or with experiences that could be attributable to climate change, leads to changes in perceptions of climate change and in support for related policies on mitigation or adaptation.

Table 6 Correlations of transformed attributes—as per dimension 1 of model-II

Attributes	Land	Mist	Hea	Cyc	Wt	St	Sm	Ann	Age	Edu
Land holding (Irrign)	1.000	0.206	0.185	0.269	0.177	0.037	0.034	0.144	0.477	0.331
Mist	0.206	1.000	0.553	0.457	0.830	−0.021	0.209	0.119	0.114	0.359
Heavy rainfall (Hea)	0.185	0.553	1.000	0.693	0.495	0.029	0.314	0.113	0.037	0.294
Cyclone (Cyc)	0.269	0.457	0.693	1.000	0.405	−0.182	0.274	0.254	0.050	0.259
Winter temperature (Wt)	0.177	0.830	0.495	0.405	1.000	−0.143	0.130	−0.199	0.101	0.255
Summer temperature (St)	0.037	−0.021	0.029	−0.182	−0.143	1.000	0.000	0.213	−0.035	0.299
South west monsoon (Sm)	0.034	0.209	0.314	0.274	0.130	0.000	1.000	0.369	0.138	0.281
Annual rainfall (Ann)	0.144	0.119	0.113	0.254	−0.199	0.213	0.369	1.000	0.176	0.224
Age	0.477	0.114	0.037	0.050	0.101	−0.035	0.138	0.176	1.000	0.030
Education (Edu)	0.331	0.359	0.294	0.259	0.255	0.299	0.281	0.224	0.030	1.000
Dimension	1	2	3	4	5	6	7	8	9	10
Eigen value	3.243	2.518	1.506	0.913	0.576	0.454	0.363	0.240	0.128	0.065

4 Conclusions

Interestingly, results of correspondence analysis showed that knowledge level and perceptions with respect to climate change is not much influenced by age, education and land holding of the farmer. Neither its impact is seen in associations and order of climatic attributes nor do they reduce variability in larger extent. Thus, training programmes and mass awareness creations, etc.… are to be conducted irrespective of their socio economic status. In future, as per their demands and our observation information regarding rainfall (in particular) and other climatic attributes, viz., actual and forecasts has to be disseminated through any means may it be agro met advisory or any media.

5 Notes

Correspondence analysis is now supported by several programs, some of which are:

1. SPAD, a French program
2. SPSS (CORRESPONDENCE in the CATEGORIES module; when installed, look under Analysis, Data Reduction, Correspondence in the menus)
3. SAS (PROC CORRESP)
4. BMDP
5. SIMSTAT
6. EDA (Exploratory Data Analysis), whose ANACOR module supports correspondence analysis
7. ViSta from Visual Stats,

   R (in package “MASS”, as corresp)

References

Brody SD, Zahran S, Vedlitz A, Grover H (2008) Examining the relationship between physical vulnerability and public perceptions of global climate change in the United States. Environ Behav 41:72–95

Hair JF, Anderson RE, Tatham RL, Black WC (2010) Multivariate data analysis, 5th Edn. 2005, pp 548–571

Weber E (2010) What shapes perceptions of climate change? Wiley Interdiscip Rev Clim Change 1:332–342

Zahran S, Brody SD, Grover H, Vedlitz A (2006) Climate change vulnerability and policy support. Soc Nat Res 19:771–789

Rural India as Key Factor to Cope with Climate Change

H. Kaechele, T. Kutter, K. Specht, S. Nautiyal, T. S. Amjath-Babu, K. Müller and K. V. Raju

1 Introduction

The global climate pattern has been changing fast and observational evidence indicates that high carbon emissions and climate changes in the 20th century have already affected a diverse set of physical and biological systems (IPCC 2001; IPCC 2007a, b). Scientific debates concerning the drivers of these changes to human activities have, over more than two decades of intensified research and discussion, reached the conclusion that there is no other plausible explanation for the observed warming (of 0.1 °C per decade) for the last 50 years (IPCC 2007b). Without changes in the current policy framework, the world appears set on a path of rising global temperatures of up to 6 °C, with catastrophic consequences on the environment (OECD-IEA 2009). Even with temperature increases far below 6 °C, there is a broad consensus on the environmental challenges with far reaching implications for food production, natural ecosystems, freshwater supply, and healthcare (IPCC 2007a). Climate change could soon become a major security risk (WBGU 2008) in terms of large scale migration and conflicts over existing resources (Reuveny 2007). Guiding the world through the climate change effect and associated environmental uncertainties, and maintaining its existing biodiversity may turn to be one of the major political challenges of the 21st century. Our collective responsibility to effectively mitigate the toughest climate change uncertainties requires global cooperation on an unprecedented scale (Stern 2009). The timeframe for avoiding potentially dangerous consequences is drawing to a close.

H. Kaechele (✉) · T. Kutter · K. Specht · T. S. Amjath-Babu · K. Müller
Institute of Socioeconomics, Leibniz-Centre for Agricultural Landscape Research (ZALF), Eberswalder Str. 84 15374 Müncheberg, Germany
e-mail: hkaechele@zalf.de

S. Nautiyal · K. V. Raju
Centre for Ecological Economics and Natural Resources, Institute for Social and Economic Change, Nagarabhavi, Bangalore 560072, India

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_40,

Climate change mitigation within the United Nations Framework Convention on Climate Change (UNFCCC), from Rio to Copenhagen, has led to a set of policy responses. The most important ones concern the voluntary reduction commitments made by the industrialized countries under the Kyoto protocol and the related Kyoto carbon trading scheme. Annex B of the Kyoto protocol contains reduction commitments agreed upon by the industrialized countries, i.e., an overall reduction of 5.2 % of green house gas (GHG) emissions by 2012, relative to the base year 1990. However, reduction commitments differ widely across countries. For instance, Germany intends to reduce CO_2 emissions by 21 %, Great Britain by 12.5 %, while the United States, in spite of its earlier commitment, does not intend to reduce green house gas emissions at all. The same is the case with a group of eastern European countries in transition, like Russia and Ukraine, which have agreed only to stabilize their emissions to the levels of 1990. The fact is that the developed nations, representing 20 % of the world population, are held responsible for 76 % of total carbon emission, on the one hand (IPCC 2007a, b), and, on the other hand, the developing nations have not adopted emission reduction target so far. Thus, the future consequences on the biological and physical system of planet earth will be more catastrophic. However, the present policy framework is dependent on reduction commitments/targets that the governments have agreed to, keeping in view the opportunities for economic and social development. In the meantime, setting reduction target of different countries is driven by development considerations, i.e., it is for the governments to decide on the desirable reduction levels without compromising too much on economic development.

Considering the fact that the developing countries are responsible for a relatively small amount of historic GHG emissions as compared to some of the highly developed countries, and many of them are still reluctant to commit themselves to legally binding CO_2 cuts because of lack of transparency in the international climate policy, they have not adopted emission reduction targets so far. While some of the industrialized economies have already started reducing emissions through a series of measures, therefore, at joint endeavours, the expectation for subsequent emissions cuts from developing economies is increasing for protecting the environment.

To help meet these reduction targets and also to make reductions more efficient, the Kyoto protocol allows for some flexible mechanisms with a strong emphasis on international collaboration. The European Union (EU) has decided to follow a Burden Sharing strategy that includes all members of the Union. EU has developed an overall reduction scheme that equals to 8 % and allows some countries that feel unable to reduce greenhouse gas emissions, like France, to benefit from Germanys reduction target of 21 %. In addition, the EU has introduced the European Union Emission Trading System (EU-ETS) that limits the collective greenhouse gas emissions to within the EU and allocates tradable green house gas certificates to enterprises. ETS creates incentives for innovations for save certificates that can be sold within the European Union. Other mechanisms for increasing the efficiency of climate change mitigation measures include the so called Clean Development Mechanism (CDM) and Joint Implementation (JI). CDM allows industrialized countries to invest in green house gas reduction measures in the developing countries that transfer credits against reduction targets to the industrialized nations. Joint Implementation is similar to CDM, though a recipient country must be registered for reduction commitments as recorded in Annex B as well.

The present policy does not address a measurable environmental goal such as predefined atmospheric carbon content at a certain time which, with a certain probability, can lead to certain climatic conditions. There is also lack of an enforcement element in the climate policy. As for Kyoto, the voluntarily agreed emission reductions are not carried out by force, nor are their failings subject to sanctions. Emission reductions within the UNFCCC and the Kyoto protocol, in their current state, are clearly inadequate to address the problem (Sathaye et al. 2006). Leading climate scientists today are convinced that our present political environment with regard to mitigating climate change is driving us into an unsafe future.

To improve this situation, the German Advisory Board of Global Change (WBGU) has come out with a framework for redesigning the international climate policy (Schellnhuber et al. 2009). This policy framework is based on the Kyoto protocol, but with a different conceptual backdrop, and it is referred to as the budget approach. The framework was put forth as a policy recommendation at the United Nations Climate Change Conference (UNCCC), held in Copenhagen in December 2009, with a view to influencing the conference outcome. Following the global aim to keep temperature increase to below 2 °C, as has already been endorsed by the European Commission (01/2007), the major G8 economies (07/2009), the UK Low-carbon transition plan (07/2009), and recently at the Copenhagen Conference (12/2009) (See UNFCCC, 2009), WBGU suggests adopting a defined atmospheric carbon content into legally binding agreements. WBGU's framework is based on the assumption that certain atmospheric carbon contents would lead to a certain climatic responses with a certain probability. The difference between the actual and the potential carbon content that allows for meeting the 2 °C guard rail is regarded as the global carbon budget. A global carbon budget of 750 Gt CO_2 of future emissions till 2050, followed by worldwide per capita emissions below 1 t after 2050, providing a 67 % guard rail probability, is considered as the final viable policy option. This concept implies almost complete decarbonization of the industrialized world within the next 40 years and low carbon development growth of the developing countries. As high emission prone countries are not able to follow these reduction requirements as per the schedule, trading of emission allowances, supervised by a world climate bank, is considered a central instrument for this framework together with a set of emission reduction measures. Based on the principle of future responsibility, the global carbon budget is divided into annual per capita emission budgets[1] for the world's population.

[1] The per capita allocation of emission allowances also ties in with the vision of climate justice involving in the long-term convergence of per capita emissions, jointly formulated by German Chancellor Angela Merkel and the Indian Prime Minister Manmohan Singh (Bundesregierung 2007).

National budgets are arrived at by multiplying the annual global average per capita emission allowance with a country's population.

India is considered a key player in future climate mitigation efforts and carbon trade, and a major beneficiary of the WBGU framework. Due to its low emission figures and a large share of the world population, WBGU considers India to be holding a vast trading power in emission allowances and the key to cope with the climate change threat worldwide. The WBGU framework holds a promising option for India to combine low carbon development with sustainability criteria in terms of obtaining attractive funding through carbon trade. This trading power depends on India's ability to provide for tradable carbon surplus through emission reductions and avoided carbonization. It is further likely that any action undertaken by the emerging economies, regarding climate change policy and emission reductions, would follow the Indian example (Kantikar et al. 2009).

In India, majority of the population lives in rural landscapes and is composed of rural farmers who emit almost a negligible amount of carbon but are the first victims of climate change effects (Nautiyal 2010). Thus, in the present paper, we seek to prove the hypothesis that rural India is a key factor in terms of coping with global climate change uncertainties in the WBGU framework. With a focus on emission trade and rural areas, we, therefore, apply the budget approach with respect to India with a view to discussing some options and difficulties that might occur in the event of emission trade on a per capita basis turning into a reality. Before this, we would like to explain the basic principles of the approach besides providing an overview of India's emission related behaviour.

2 WBGU's Budget Approach to Solving the Climate Dilemma

The WBGU assumes that from now on, global temperature increase above 2 °C must be avoided. According to Meinshausen et al. (2009), global CO_2 emissions not exceeding 1,160 Gt CO_2 from anthropogenic sources between 2000 and 2050 provide a 67 % probability to meet this aim. As approximately 350–380Gt CO_2 has already been emitted by anthropogenic sources between 2000 and 2009 and emissions of 60 Gt CO_2 are expected from land use changes between 2010 and 2050 with a result that a stock of about 750 Gt CO_2 remains. To meet the 2° guard rail, WBGU argues that the industrialized world would have to reduce emissions by 50–80 % below the 1990 level by 2050. Developing countries are expected to initiate the transition towards a low carbon society as soon as possible. Their efforts in that direction will be largely supported by transfer payments from industrialized countries. Post 2050, convergence of emission levels of around 1 ton of CO_2 per year should be achieved. The reversal of current global emission trends is expected to start as soon as possible. Any further delay might result in almost unachievable reduction targets. Both emission reductions and low carbon development are a prerequisite for achieving these aims.

Among other instruments suggested by WBGU, global emission trade is regarded as the single most powerful tool to finance these efforts. With a view to reflecting India's role within the WBGU framework and also to extend this framework in Sect. 4, we would like to briefly touch on the WBGU budget approach. For further reading, we may refer to the original document which is available online free of charge.

2.1 The Principles

For limiting global warming, the WBGU budget approach focuses on some simple principles:

1. **The 2 °C guard rail**: Global warming in excess of 2 °C above the pre-industrial level would lead to dangerous, irreversible and practically uncontrollable consequences for both nature and mankind. This must be avoided.
2. **Focus on CO_2**: Global warming is directly correlated to an increase in atmospheric CO_2. Human-induced climate change largely depends on the total amount of carbon dioxide emitted by anthropogenic sources. Considering its longevity and quantity present in the atmosphere, CO_2 is the most important greenhouse gas which should be the policy focus with regard to emission trading.
3. **Define a global carbon budget**: A certain amount of CO_2 emissions generates atmospheric CO_2 concentrations that, with a certain probability, lead to certain climate scenarios. These can get reflected in global warming together with other indicators. The amount of emissions left for meeting a certain climate target is called the global carbon budget. It is subject to political decisions in terms of choosing a certain probability and a related carbon budget. For example, a global carbon budget of 750 Gt CO_2 meets the 2 °C guard rail with 67 % probability while a budget of 600 Gt CO_2 holds a 75 % probability.
4. **Legal basis**: The 2 °C guard rail, a focus on CO_2 and the agreement on a global carbon budget, compatible with the 2 °C guard rail, must be turned into an international law.
5. **National emission allowances**: On the basis of the future responsibility of countries, their responsibility is expressed in terms of their share in a global carbon budget. This is calculated by multiplying the average annual emission allowances of the world population with the number of inhabitants. For the period 2010–2050, average annual emission allowances of 2.7 t per capita of the world population is envisaged and a pathway to zero emission is also pursued.
6. **Carbon trade**: For several reasons, a global trade system for emission allowances is suggested. Inter alia, trade of allowances would increase

efficiency of mitigation efforts and allow industrialized countries with per capita emissions much higher than 2.7 t CO_2 buffer for implementing reduction schemes and enabling low emission countries for funding financial resources.

7. **A world climate bank**: National emission budgets and decarbonization roadmaps are elaborated. A world climate bank supervises the elaboration of national emission budgets and decarbonization efforts besides organizing carbon trade schemes.
8. **Additional measures**: GHG emissions other than CO_2, should be treated under separate regulations. The Reduction of Emissions through Deforestation and Degradation (REDD) in the developing countries is enforced. Flexible tools such as joint implementation and the clean development mechanism are implemented. Climate partnerships between countries are envisaged. Additional reduction commitments for countries, presently with high per capita emissions, are agreed upon to avoid delay in decarbonization.

Although many elements of this framework need detailed arrangements, the concept is simple and transparent. Here, we would like to focus on the carbon trade system as recommended by WBGU.

2.2 *WBGU Within the Current Policy Framework*

Although the budget approach offers mechanisms similar to the Kyoto protocol and later arrangements such as the EU-ETS or the Chicago Climate Exchange (CCX), the carbon trading system is based on a different conceptual framework. Present arrangements offer voluntary emission reductions where compensation seeking clients pay for the storage of natural or artificial sinks of carbon containing materials on the principle, ‘How much can you afford to save?’ WBGU favours reduction commitments based on a physical benchmark that follows a clearly defined climate target for translating into ‘How much saving of emissions is needed?’ This approach offers carbon trading through avoided carbonization. This, in other words, amounts to turning non-consumption into an economic activity that allows for providing a tradable good, if some market principles are followed. The introduction of property rights on atmospheric pollution turns emission allowances into a resource. A legal framework allowing for an emission market converts this resource into a tradable good. Non-consumption of emission allowances and emission reductions are then considered as an economic activity. The idea of global emission trade, based on per capita emission, also differs from the north/south transfers within the framework of economic cooperation or development aid which follows a helping-hand approach or attitude. The budget approach pursues an economic concept of equal partners trading in a very valuable scarce resource and, thereby, setting a path towards new economic arrangements.

The budget approach is further arranged around ethical principles. The polluter pays principle (PPP) is applied as emitters are required to compensate for exceeding their personal carbon budgets. The principle of equality guarantees individual equal emission rights without distinction to everyone. As for the precautionary principle, timely actions to prevent dangerous climate change are pursued as the risks are already evident.

2.3 Global Emissions and Carbon Trade Within the WBGU Approach

The WBGU suggests calculating national emission budgets based on per capita emissions of a country's population. Looking at the present emission reduction pathways, three groups of countries (viz., Group 1, Group 2 and Group 3) are identified and guidelines provided, i.e., how these groups could meet their emission targets in line with the 2 degree guard rail, are precisely described in the following sections.

Group 1: Per capita CO_2 emissions **above 5.4 t**—*Comprehensive Decarbonization before 2050*: Group 1 countries are mainly industrialized economies (e.g., EU 8.1 t, USA 19 t, Japan 10.1 t), oil-exporting countries (e.g., United Arab Emirates 32.9 t, Kuwait 32.2 t) and a small number of newly-industrializing countries (e.g., South Africa 8.6 t, South Korea 9.9 t). They emit far more than the sustainability mark of 2.7 t CO_2 per capita and are expected to exceed their national emissions budget in less than 20 years with some of them, like the United States or oil-exporting countries, even much earlier than the assumed time period. They must engage in a rapid and comprehensive decarbonization process, as they are found unable to reduce their emissions to the extent expected of them. However, during the transition period, they can depend on carbon trade with other countries (not exceeding their budgets) which can provide them with emission allowances.

Group 2: Per capita CO_2 emissions **between 2.7 and 5.4 t**—*Stabilization of Emissions and Transition to Decarbonization:* Many newly-industrializing countries (e.g., China, Mexico, Thailand), whose per capita emissions range between 2.7 and 5.4 t, belong to this group. As dramatic emission reductions are generally not feasible, these countries would have to show a gradual declining rate of emissions growth to a peak in 2025 followed by decarbonization in 2050, i.e., around a decade later than the industrialized countries. Some of the Group 2 countries might even be able to sell a proportion of their emission allowances and, in the process, generating additional revenues to fund the transformation to a sustainable economy. However, it seems plausible that this group of countries, as a whole, will have to purchase emission allowances.

Group 3: Per capita CO_2 emissions **below 2.7 t**—*Trading power through avoided carbonization:* Group 3 comprises all the other developing countries (95 in total), which emit less than 2.7 t CO_2 per capita per year. The group consists of developing countries (e.g. Burkina Faso, Nicaragua, Vietnam), and some large newly industrializing countries (e.g., India and Brazil). These countries account only for about 12 % of current global CO_2 emissions; but by 2010 they will be home to more than 50 % of the world's population holding more than half the global emission budgets. While Group 3 countries are below their emission limits, Group 1 and 2 countries are dependent on the 'carbon buffer' provided by Group 3 countries. For the climate policy to succeed, it is essential that those Group 3 countries that are not fully exploiting their emission budgets, even while experiencing rapid economic growth, invest their revenue from the sale of allowances in low-emission technologies rather than remaining on conventional fossil trajectories. They should set national decarbonization milestones which could be partly financed from the revenues earned from inter-country emission trading.

WBGU provides an idea how emission trade could influence the per capita emission paths of all the groups of countries (Fig. 1). While it has been made clear that all countries have to follow their emission reduction goals for meeting the guard rail, emission trade is providing several opportunities in that it allows high emission prone counties to reduce their emissions at a relatively slower rate, providing, in the process, a strong motivation for substantial emission reductions in the future. Low emission based countries could sell emission allowances and a substantial proportion of this revenue might be invested on low-emission technologies, especially in the energy sector based on renewable sources.

Examples of per capita CO_2 emission trajectories from fossils based sources for all the three groups (Group 1, 2 and 3) under the WBGU budget approach are presented here. The broken curves show theoretical per capita CO_2 emissions trajectories without emission trading. These allow for compliance with the national budgets, but would be partly unrealistic in practice. The unbroken curves show

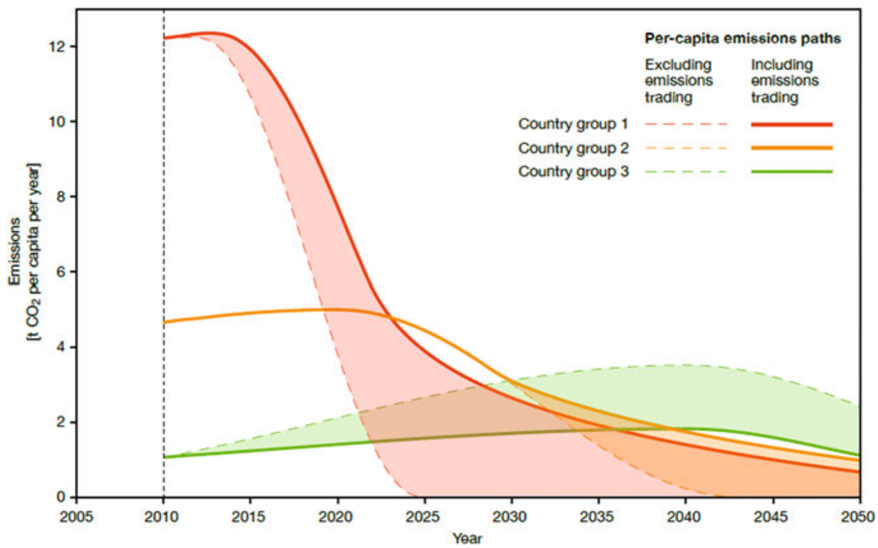


Fig. 1 Per-capita emission paths (*Source* WBGU)

emission trajectories that could result from emission trading. It is assumed that Group 1 countries would increase their budget by 75 % by purchasing emission allowances for 122 Gt CO_2. Group 2 countries are assumed to purchase emission allowances totalling 41 Gt CO_2. The suppliers of the sum total, i.e., 163 Gt CO_2, are the Group 3 countries effecting a decrease of around 43 % in their own emission budgets. Towards the end of the budget period, convergence of real CO_2 emissions occurs at around 1 t per capita per year (based on the population in 2010). The areas between the curves represent the traded quantities of emission allowances. As this is a per capita based presentation with the country groups having different populations, the sum of the areas between the curves for buying Groups 1 and 2, is not equal to the area between the curves of selling Group 3. Country groups are organized according to CO_2 emissions per capita per year from fossil sources, whereby, CO_2 emissions are estimates for 2008 and population figures are estimates for 2010. Red: country group 1 (>5.4 t CO_2 per capita per year), mainly industrialized countries (e.g., EU, USA, Japan), also oil-exporting countries (e.g., Saudi Arabia, Kuwait, Venezuela) and a small number of newly-industrializing countries (e.g., South Africa, Malaysia). Orange: country group 2 (2.7–5.4 t CO_2 per capita per year), which includes many newly-industrializing countries (e.g., China, Mexico, Thailand). Green: country group 3 (<2.7 t CO_2 per capita per year), all developing countries (e.g., Burkina Faso, Nicaragua, Vietnam), also some large newly industrializing countries (e.g., India, Brazil) (WBGU 2009).

2.3.1 Role of India in Carbon Trading

India belongs to the group 3 countries. Considering its low CO_2 emission figures (close to 1 t CO_2 per capita), a large share in the world population and a high rate of economic growth, WBGU considers India to holding a substantial potential trading power from carbon trade. The country is expected to be a major beneficiary of the proposed trade system. In 2008, India emitted roughly 1.5 Gt CO_2 amounting to 1.7 Gt CO_2 below its WGBU budget of 3.2 Gt CO_2. This calculation says that if India's future emissions stay at their 2008 levels, the country could annually sell 1.7 Gt CO_2 emission allowances as international carbon buffer and still meet its sustainability mark. This might allow India to undergo a somewhat slower transformation process towards a low-carbon economy than China. India, therefore, has more time than China to free its economy from fossil fuels and set the criteria towards a sustainable low carbon economy. The timing when India recognizes its potential as a supplier of emission allowances will have an impact on its ability to provide this resource.

Emission trade on per capita basis between counties also raises several questions. Differing emission patterns can also be found both within and across countries. We would like to highlight here which groups are responsible and to what extent in terms of emissions, and how the groups that contribute little to this bulk could benefit from emission trade, particularly in the Indian context.

3 India's Emission Profile

For applying the WBGU budget approach to India as a case study, it is of interest to know how the country is positioned in the international context. Starting with a policy background, we would like to show how the current emission status is attributed to the different economic sectors and societal groups, and what kind of emission scenarios are expected in the near future.

3.1 National Climate Policy

India has politically responded to the environmental and other pressures related to climate change. The country has signed the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol and is currently working on the Second National Communication (SNC or NATCOM II)[2] to UNFCCC. NATCOM II provides information on the emission of greenhouse gases of anthropogenic origin by sources and removals by sinks. India is engaged in a series of national climate relevant policies, i.e., aiming at reducing emissions and/or promoting renewable energy sources.[3,4] India's power sector is largely coal based, therefore, causing more than half of the country's CO_2 emissions. At the national level, the Indian Electricity Act (2003), the National Electricity Policy (2005) and the Tariff Policy (2006) of the Ministry of Power are the most important climate relevant policies. In 2006, the Indian Planning Commission (2006) released a report on Integrated Energy Policy that contained mandatory and voluntary measures for increasing efficiency in power generation and distribution. The report was a contribution to its 11th Five Year Plan (2007–2012) which is a central element in India's economic policy. A council on climate change was setup in 2007 and announced the Government National Action Plan on Climate Change (NAPCC) in 2008. But energy security is a major political goal. The Indian government has tentative plans to add more than 50 GW of new coal-based

[2] Ministry of Environment and Forests, United Nations Development Programme, Global Environmental Facility (2008) India's Second National Communication to the United Nations Framework Convention on Climate Change Work Programme. Available at http://www.natcomindia.org/brochure5.pdf. Accessed on 29.04.2010.

[3] The Government of India set up a Commission for Additional Sources of Energy in the Department of Science and Technology in 1981. Later on, this was followed by the setting up of a full fledged independent department, the Department of Non-conventional Energy Sources in 1982, converted into the Ministry of Non-conventional Energy Sources (MNES) in 1992 and renamed to the Ministry of New and Renewable Energy (MNRE) in 2006.

[4] A short overview on Policies to Promote Energy Efficiency and Renewable Energy is provided in Ministry of Environment & Forests, Ministry of Power, Bureau of Energy Efficiency, Government of India (2007) addressing Energy Security and Climate Change. Available at http://envfor.nic.in/divisions/ccd/Addressing_CC_09-10-07.pdf. Accessed on 29.04.2010.

generating capacity during the period covered by its 11th power plan. An increased use of nuclear power and renewable energy is envisaged and it is also estimated that these initiatives would reduce, by as much as one-third, the GHG intensity of the economy.

Post Kyoto, India has remained non committal either about reduction targets or the 2 °C guard rail. At the UNFCCC conference held in 2002, the former Indian Prime Minister, Atal Bihari Vajpayee, had reaffirmed India's commitment to reduce emissions through sustainable development.[5] He had further made clear that the '…ethical concept of democracy can't support any other norm other than the equal per capita rights to global environmental resources'. WBGU's proposal to arrange for carbon trade on future per capita emissions with equal emission rights for all has used a similar line of argument. India's position on per capita emission in climate negotiations has been reiterated by India's Prime Minister Dr Manmohan Singh on several occasions; it is also further enshrined in the National Action Plan on Climate Change (2008). The action plan states that the principle of equity underlying the global approach (…negotiable within UNFCCC) must allow each inhabitant of the earth an equal entitlement to the 'global common atmospheric resource'. The action plan also states that India's per capita emissions would never exceed those of industrialized countries if they fulfilled their UNFCCC commitments in terms of transferring additional financial resources and environmental friendly technologies to the country. Currently, there is discussion going on whether India could abandon its per capita stance as the government has called for tenders on economic studies for deriving a formula to ensure a fair burden sharing in the reduction of future greenhouse gas emissions.

While it is fairly true that the country is expected to be badly hit by the impacts of climate change (Cruz et al. 2007) and also that there is a need for reducing GHG emissions, in self defence some authors argue that India's climate policy today is not so much motivated by domestic demand as by external pressures (Somanathan and Somanathan 2009). It is often argued that maintaining a strong and steady economic growth rate, and providing of secure and reliable energy is opposite to increasing costs via potential carbon reduction strategies (Shackley and Verma 2008). Development, and not emission reduction per se, must be the political priority (Reddy and Assemza 2009). However, some authors claim that aligning development with climate actions is advisable and feasible (Shukla 2006). But the question as to how to finance emission reductions and low carbon development, and also how to obtain and distribute the required funding remains unsolved.

[5] Speech of Prime Minister Shri Atal Bihari Vajpayee at the High Level Segment of the Eighth Session of Conference of the Parties to the UN Framework Convention on Climate Change New Delhi, October 30, 2002, http://unfccc.int/cop8/latest/ind_pm3010.pdf; last access: 29/04/2010.

Table 1 India's contribution to GHG emissions by sector, 2000

Sector	Share in total GHG emissions	Share of total CO_2 emissions
Energy transformation and use	56	93
Electricity/heat	30	53
Manufacturing/construction	12	21
Transportation	5	9
Other fuel combustions	8	9
Industrial processes	3	4
Waste	5	–
Agriculture	34	–*

Source Baumert et al. (2005)
Note Several authors attribute CO_2 emissions to the agricultural sector. Indirect sources are fertilizer and pesticide and machinery production; direct emissions result from the use of fossil fuels for agricultural production, soils and burning of residues (Bellarby et al. 2008; Shukla 2006; Rastogi et al. 2002; Smith et al. 2007; Lal 2004)

3.2 Sectoral Emissions and Emission Reduction

There is debate, whether India should be treated more as a major GHG emitter or as a disadvantaged newcomer (Dubash 2009). In 2006, India's estimated total CO_2 emissions from fossils based sources were estimated to be around 1.331 Gt CO_2 as compared to 0.842 Gt CO_2 in Germany, and 5.770 Gt CO_2 in the US. India ranks as global number 9 in the world with regard to historic CO_2 emissions (excluding Land-Use Change and Forestry) going by the 1850–2006 time frame (World Resource Institute). Today, its economic sectors largely differ in their relative shares to total GHG and CO_2 emissions (Table 1).

Even though the country faces difficulties on the energy front, with about 380 million people living without access to electricity in rural India, in 2005 (IEA 2007), energy transformation and use are responsible for 93 % of India's total CO_2 emissions (Baumert et al. 2005). Industrial processes add another 4 %, while CO_2 emissions from agriculture and disposable waste are considerably negligible. Coal, the most carbon-intensive fossil fuel, plays a central role in the Indian energy-mix. Contrary to the limited gas and oil reserves, large amount coal is available within the country.[6] The Indian energy system has evolved around it and is projected to remain so in the future (Khadse et al. 2007; Shukla 2006). Further, coal is a major source of energy and heat for the industries (Shukla et al. 2008). In terms of electricity generation, India presently has roughly 161 GW of installed capacity connected to the grid. Roughly 103 GW are generated by thermal power plants of

[6] Coal India Limited (CIL) is a Schedule 'A' 'Navratna' Public Sector Undertaking under Ministry of Coal, Government of India, with Headquarters in Kolkata, West Bengal. CIL is the single largest coal producing company in the world and the largest corporate employer in the country, with manpower of 409,332. India disposes on proven coal reserves of 105.82 Billion Tonnes out of total reserves of 267 Billion Tonnes (as on 1 April 2009). Available at. http://www.coalindia.in/Company.aspx?tab=0; last access: 29/04/2010.

which 85 GW come from coal, 17 GW from gas and 1.1 GW from oil, respectively. Further, there are 37 GW which come from hydro and 16.4 GW from other renewables, mostly wind, and 4.6 GW come from the nuclear energy source.[7] One hundred largest single point sources of CO_2, consisting of 65 power plants, 7 steel plants, 6 refineries, 16 cement plants, 3 fertilizer plants, 1 aluminium plant and 2 petrochemical plants (a majority of these are coal based) have contributed to 58 % of India's CO_2 emissions (Garg and Shukla 2009). Agriculture is the dominating sector in terms of other GHG emissions because of the presence of methane and nitrous oxide in the various forms of inputs used in agriculture. Translated into CO_2 equivalents, agricultural emissions account for one-third of India's national equivalent carbon dioxide (CO_2e) stock (Ramakrishna et al. 2003).

To reduce emissions in the energy sector, improved energy efficiency and decentralized energy systems fed by renewables are suggested in literature (Urban et al. 2009). Although the required technologies are not yet ready for use, there is lively debate on reducing emissions through Carbon Sequestration and Storage (CCS) techniques in the coal and industry sector (Kapila and Stuart Haszeldine 2009; Shackley and Verma 2008; Hetland and Anantharaman 2009). Emission reductions from agriculture are usually suggested via adapted farming practices such as the use of less water intensive paddy varieties, improved cultivars, less use of inorganic fertilizers, etc.

3.3 Distribution of Per Capita Emissions

With per capita emissions of 1.2 t CO_2 per year in 2008 (WBGU 2009), as compared to the European average of 8.4 and 19.3 CO_2 of the US, India is considered one of the lowest per capita emitters in the world (World Resource Institute 2010). This can be explained in terms of the economic structure of the country being dominated by a sizable agricultural base and a growing service sector. Although India is considered as one of the most politically powerful nations in the world because of its economic potential, unfortunately poverty is still reflected in energy consumption patterns at the household level, i.e., low levels of energy use, lack of access to cleaner commercial fuels, efficient equipment and electricity, and a high dependence on traditional biomass based energy, most of which gets lost in the burning process because of inefficient and polluting stoves (IEA 2002). In rural India, villagers mostly rely on Kerosene for lighting purpose and biomass fuels such as wood, agricultural crop residues and animal dung for cooking, often with poor energy efficiency (Ramachandra 2008). Therefore, access to clean and reliable energy is commonly regarded as a major factor in poverty alleviation.

[7] Available at http://www.cea.nic.in/. Accessed on 16.06.2010.

Individual carbon emissions within India differ, though this fact is little reflected in literature and the climate policy discussion. Billett (2010) shows in a study that this fact is barely addressed in the public discussion, which mainly focuses on historical and international inequalities existing in GHG emissions, leaving national inequalities untouched. These inequalities can be measured at the household level with energy consumption as a key indicator (Murthy et al. 1997). If commercial and non-commercial energy as well as the embodied energy present in all goods and services purchased by households is considered, the Indian household sector as a whole represents 70 % of the total energy use of the economy (Pachauri and Spreng 2002).

Pachauri (2004) demonstrated that for India, energy requirements of different household groups in urban and rural areas differed, and that this difference was expressed in their lifestyle and consumption patterns measured by expenditure. Energy consumption patterns were calculated for the use of food beverages & tobacco, housing & household effects, education & recreation, other services, non-commercial energy, clothing & footwear, medical care & hygiene, transport & communication, and commercial energy. Due to higher incomes and, therefore, higher per capita expenditure levels on an average, urban energy requirements per capita were found 25 % higher than those of rural residents. While rural households were still found reliant on non-commercial energy sources for their direct energy needs, the share of commercial energy sources was much higher in urban areas. The rich urban consumers exhibited energy requirements of more than three times the bottom rural/urban household groups.

Ananthapadmanabhan et al. (2007) identified correlations between income and energy consumption in India, and calculated CO_2 emissions based on consumption and transport patterns for seven income classes. The findings reveal that a small group of people was emitting a large part of the country's CO_2 emissions, while few had reached western levels. Roughly 800 million Indians emit less than 1.55 t CO_2 per year, with about 430 million even below 1.1 tonnes.

Similar findings were presented by Parikh et al. (2009). By using a social accounting matrix, they established 10 income classes, 5 rural and 5 urban, to find out the extent of emissions generated, directly and indirectly by the consumption basket. The population distribution by various monthly expenditure classes was arranged in the ascending order of mean per capita expenditure (Table 2). Thus, one might view EC1 as abjectly poor, EC2 as poor (below poverty line), EC3 as average, EC4 as above average, and EC5 as relatively rich. Following this classification, varying emissions for different income classes were identified. The urban top 10 % of the population accounted for 4099 kg emissions per capita per year which was found one-fifth of the per capita emissions in the US. The rural bottom 10 % accounted for only 150 kg emission per capita per year, whereas, 28 % of Indians living in urban areas, accounted for 49 % of the emissions.

Following the literature, we may conclude that agriculture-based and low-consumption lifestyles of the majority of the Indian population have led to the present low per capita emissions on an average. More than 200 urban and almost 700 rural dwellers emit less than 1 tonne of CO_2 per year. Roughly 500 rural

Table 2 Population, Expenditure class and CO_2 emissions in India 2003–2004

Expenditure Class (2003–2004)	Population (millions)		CO_2 emissions (tonnes per capita per year)	
	Rural	Urban	Rural	Urban
EC1	77.2	30.0	0.15	0.272
EC2	154.4	60.0	0.215	0.432
EC3	308.7	120.1	0.336	0.802
EC4	154.4	60.0	0.677	1.567
EC5	77.2	30.0	1.365	4.099

Source Distribution of population and income class from SAM 2003–04, Saluja and Yadav (2006) in (Parikh et al. 2009); CO_2 emissions per income class from (Parikh et al. 2009)
Note EC1, EC2, EC3, EC4 and EC5 represent 10, 20, 40, 20 and 10 % of the rural/urban population arranged in ascending order of per capita monthly expenditure, respectively

dwellers stay even below 0.4 tonnes of CO_2. It is only some urban better off societal groups that are moving towards emission levels of the industrialized states. However, things are changing as the country is developing rapidly. As more than two-thirds of India's population is living in rural areas, its future emission behaviour is of key importance. From a climate change perspective, it is crucial to understand what kind of emission scenarios are likely to emerge in the Indian context and, also, how they can be influenced to move towards desirable levels.

3.4 Emission Scenarios

In 1994, India's initial communication to the UNFCCC[8] was that 1.229 Gt, equivalent carbon dioxide (CO_2e), of anthropogenic GHGs were emitted from India, while CO_2 emissions were the largest at 0.793 Gt, i.e., 65 % of the total national CO_2e emissions. CO_2 emissions of 1.5 Gt in 2008 were estimated by WBGU (2009). This could in fact be regarded as a dramatic increase. Roaming economic growth rates and rapid urbanization with emerging mega cities longing for more energy and infrastructure indicate this trend. The rural masses are waiting for electrification and mobility to boost India's energy demand. India is already following China as one of the largest emitters of GHG among the emerging economies. Both countries together could match the USA's GHG emissions (year 2000) within a few decades. In a high growth scenario, fast developing countries like India and China might represent 54 % of the global increase in the demand for primary energy by 2030 (IEA 2007). On the other hand, even if one were to consider only CO_2 emissions from fossil fuel consumption, developing countries,

[8] Ministry of Environment and Forests, Government of India, (2004) India's Initial National Communication to the United Nations Framework Convention on Climate Change. http://unfccc.int/resource/docs/natc/indnc1.pdf; last access: 22/06/2010.

as a group, might even overshoot industrialized countries in the near future (Sathaye et al. 2006).

A number of studies (Shukla 2006; Shackley and Verma 2008; IEA 2007) have elaborated emission scenarios for India that differ according to the accounting methodology, scenario definition and datasets used. The 2006 Integrated Energy Policy Report of the Indian Planning Commission (2006) assumes a massive increase in emissions by 2031/32. The potential for emissions saving has been mainly identified in the power and transport sectors in terms of efficiency increase in coal use, forced nuclear energy, an increase in renewables within the energy mix, and energy savings on the demand side.

An increase in agricultural energy requirements due to extensive mechanization is assumed by Baruah and Bora (2008); this might also lead to increased CO_2 emissions from this sector. Further, methane emissions are expected to stay rather stable, while N_2O emissions related to the use of chemical fertilizers are assumed to increase (Shukla 2006).

In 2009, the Indian Government released a combined report of five modelling studies estimating future emission scenarios.[9] Per capita GHG emissions by 2030–2031 have been postulated to vary from 2.77 to 5.00 tonnes of CO_2e, while in absolute terms, India's GHG emissions by 2031 might vary from 4.0 billion tonnes to 7.3 billion tonnes. Four of the five studies estimated that India's GHG emission per capita would stay under 4 tonnes per capita. As compared to the 2005 global average of 4.22 t CO_2e, even two decades from now, India's per capita GHG emissions would be well below the global average registered 5 years ago (Fig. 2).

India's future emission scenarios are largely dependent on national policies. This is due to the fact that major savings are expected from energy and transport sectors coming under the public sector undertakings. It is of interest to know if and how renewables are integrated with the energy mix, and how individual or public transport is supported. As mentioned before, India is a major victim of the projected climatic changes. But, in the meantime, it is very likely that emission reductions by force are not an attractive political option for the country. Strong incentives are needed for motivating authorities, companies and individuals to invest in emission saving through introducing energy efficient technologies and other low-carbon options. Following WBGU, these incentives could be partly obtained through emission trading on per capita basis.

[9] Climate Modelling Forum, India, supported by Ministry of Environment and Forests, Government of India (2009) India's GHG Emissions Profile: Results of Five Climate Modelling Studies. Available at http://moef.nic.in/downloads/home/GHG-report.pdf. Accessed on 29.04.2010.

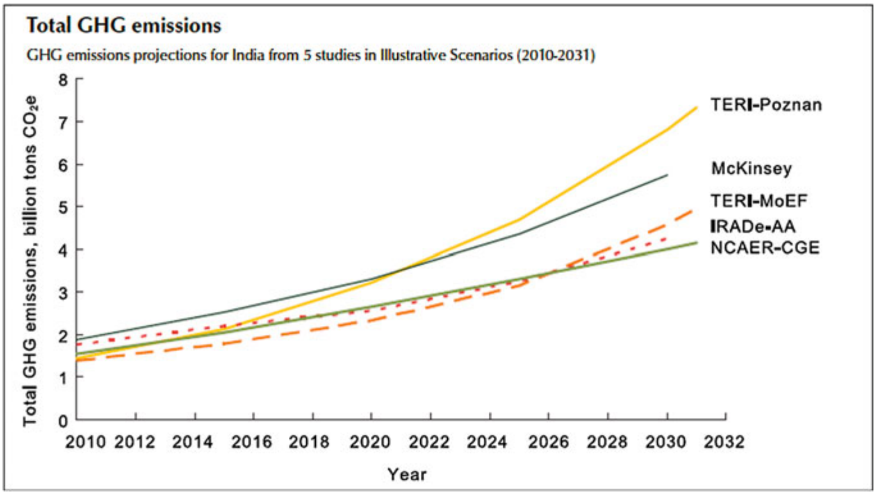


Fig. 2 GHG emissions from India (*Source* Climate Modelling Forum 2009)

4 Applying WBGU to India as a Case Study

What does the WBGU approach mean to India in the context of predicted GHG emissions?

4.1 There is Little Time Left for Providing CO_2 Buffer for International Exchange

As explained in Sect. 3, India's CO_2 emissions have increased rapidly during the last 20 years and are expected to do so at an even faster pace in the near future (Fig. 2). This increase in emissions is due to a fast-paced economic growth path pursued by the government and a heavy reliance on coal as a source of energy. Applying the WBGU budget approach, we may say, in other words, that India's tradable carbon buffer budget is declining. As stated in a previous section of this article, several studies indicate that Indian per capita emissions could exceed the 2.7 t CO_2 sustainability mark as projected by WBGU within a few decades from now. This assumption is based on the CO_2 contribution of India's CO_2e emissions of around 65 % as proposed in India's first reporting to the UNFCCC. However, if the current trend continues or, more likely, if patterns rapidly increase, India's time frame for trading CO_2 emission allowances is closing. There is still a lot of carbon space left for India and the sooner emission trading starts, the better it will be for the country, as the more India will sell.

4.2 Right for Emitting CO_2 as a New Limited Global Resource

After more than two decades of intense research and discussions, we are now beginning to accept that the deposition of GHGs in the atmosphere might not be unlimited or priceless. WBGU has taken the next step by defining the right to emit GHGs as a global limited resource. In addition to the existing Kyoto mechanisms, based on measures to reduce, store and capture CO_2, the new paradigm advanced by WBGU allows for trading in CO_2 without committing on reducing or storing activities. It would also allow for selling allowances from the non-utilization of CO_2-emission rights. The atmospheric carrying capacity, expressed in terms of absorbing and storing GHGs, is no longer unrestricted but a scarce, valuable and, therefore, a limited public good. Turning the atmosphere into a limited public good depends not only on the marker mechanism but also government policy interventions. As the sky is a global property, this intervention has to be undertaken by the international community. International resolutions could turn CO_2 space into a tradable resource through a set of government and market instruments. Even though within the present concept paper, we are not discussing these options, we would like to draw others attention to the paradigm change in the climate change policy as proposed by the WBGU approach.

4.3 Buffer Budget Stems from the Poor

One big question is whether Indian society will be able to provide a substantial tradable carbon buffer for national or international trading and, if so, how long would such a scenario last? Another question is how those Indians staying below the carbon footprint of 2.7 t CO_2 per capita per year (which may not allow them to expand their CO_2 budget) will be rewarded for doing so. More than 900 million Indians might come under this group while the country's economy continues to grow rapidly. We assume that at the individual level, the feasibility of providing a buffer budget is negatively correlated to the level of development or living conditions of various social groups. In other words, the poorer the people and the worse their access to infrastructure and power supply, the lower will be their carbon footprint and the higher their tradable buffer budget. We, therefore, suggest that considering the less developed parts of the Indian society, not only as being poor and underdeveloped, and in need of help, but also as a decisive factor in coping with climate change. These groups provide deferment for the high emission groups within the country and abroad. Their budget can be used as a window of opportunity for implementing emission reductions and decarbonisation.

4.4 Less Developed Agricultural Societies Produce a Good for International Markets

Another implication we can derive from the WBGU is that by not utilizing their individual CO_2 budgets, India's poor would become actual producers of a tradable good available on international markets. This is very remarkable as today the market integration of this group only refers to local goods. We may interpret that implementing carbon trade following WBGU could offer a promising opportunity for certain societal groups in India. The framework could be extended in a way that low consumption groups would bend on market relations for trading their no-consumed stock. This transfer would have a strong influence on the perceptions of India's rural society. These people would then provide a good that is pivotal for people living in developed countries for coping with climate change.

4.5 CO2 Buffer Budget as Option for Sourcing Regional Development in India

As mentioned in a previous section of this article, in 2008 India emitted roughly 1.5 Gt CO_2 which was 1.7 Gt CO_2 below its WGBU budget of 3.2 Gt CO_2. This calculation says that if future emissions stayed at their 2008 levels, India could annually sell 1.7 Gt CO_2 of CO_2 emission allowances as international carbon buffer and still maintain its sustainability mark. The annual mean of CO_2 certificates amounts to approximately 15 €/t (European Climate Exchange 2010). Given these values, about 25.5 billion Euros could have been obtained from carbon trade in 2010. If we consider that a WBGU like agreement would turn CO_2 into a scarce resource, the carbon pricing might explode. Depending on the policy regime implemented and the demand and supply, CO_2 prices may increase to many times more than their present value. At the same time, the availability of tradable carbon is declining as explained earlier. The question of how to organize the allocation of carbon trade funding is left to be solved by the policy makers. Following the paradigm of justice, we would argue that those people who do not consume their personal CO_2 budget should benefit from carbon trade agreements. This might be a strong argument for spending a good portion of India's carbon trade revenues on rural development.

4.6 Maintaining Feasibility for Providing Buffer Budgets in Future

For analysing the potential of trading CO_2 buffer budgets as a fundraising mechanism, its dynamic aspects must be considered. It is of critical importance to utilize these funds in a way that does not limit India's ability to continuously provide a tradable carbon buffer. Maintaining its buffer budget for trade purpose may be a strong policy instrument for directing funds from emission trade and other sources into low-carbon technologies such as renewable energy. The expected prices for emission allowance will be of much more importance in this respect. The higher the expected prices for buffer budgets, the stronger will be the incentives for investment in carbon saving technologies. This development must be supported by the Indian society and for this a high level of transparency is needed. We believe that the proposed trading scheme is beneficial for the whole society. Those who pay receive a clean sky and there is less risk to climate change, and those who limit their emissions get rewarded. To balance carbon pricing negotiations, allocation and administration of revenues and/or payments, the Indian government will need public support. Implementing a carbon trading scheme beneficial for all Indians, accompanied by research and pilot projects, may be helpful.

4.7 Tradable CO_2 Budgets Calls for More Resilient Means for Carbon Foot-Print

One of the most important conditions for trading in emission allowances is a reliable methodology to quantify carbon emissions. It should be physically explicit and allow for calculating carbon budgets. Most of the quantitative data on GHG emissions available at present focuses on the emissions from economic sectors. Following the WBGU, we suggest that focus should also be on personal carbon footprints, including the climate relevance of different life styles and consumption habits. While economic sector-wise considerations concentrate on the supply side, the consumer's perspective brings in the demand side. Little work has been done on personal carbon emissions in India. It is a big task for the scientific community to devise resilient means for providing a sound data-set that could serve as legal basis for compensation payments. The integration of the rapid changes taking place in lifestyles and consumption habits may turn to be a challenging task in this respect.

4.8 CO_2 Emission as the Sole Reference Point is Inadequate for Agri-Based Societies

Due to the anthropogenic contribution of CO_2 to climate change, the WBGU argues for concentrating on carbon trade, exclusively CO_2, and for handling other GHGs through separate regulations. As described in a previous section of this article, CO_2 plays a secondary role in the emission portfolio of agricultural societies; but agriculture, as a sector, accounts for 10–12 % of total global anthropogenic emissions of GHGs (Smith et al. 2007). Indian agriculture with mainly methane stemming from deepwater rice cultivation, livestock and manure management, and nitrous oxide (N_2O) emissions mainly from fertilizer use, at present, account for roughly one-third of India's national emission of CO_2 equivalents (Ramakrishna et al. 2003). We, therefore, conclude that narrowing the focus on CO_2, as suggested by WBGU, undermines the contribution of agricultural societies in India to climate change, while overestimating their potential for supplying a carbon buffer. Further, agricultural societies show heterogeneous GHG emissions. While paddy and livestock imply large scale methane emissions, agro-forestry and low input systems in terms of chemical fertilizers tend to be almost carbon neutral. Therefore, climate change awareness should be created for all parties concerned, and in particular for farmers. This could be a starting point for reducing GHG emissions from the agriculture sector and for adding additional value to certain less carbon intensive practices.

5 Conclusions

Mitigating potentially dangerous climate change effects should become the immediate policy focus the world over. The WBGU suggests the integration of the 2 °C guard rail and a compatible global carbon budget in the form of an international law. It further recommends emission allowances on a per capita basis and, also, setting up of a world climate bank for supervising national de-carbonization and emission trade roadmaps. We do perceive WBGU's approach as a paradigm shift in environmental roadmaps and climate policy. The danger of climate change is set in front of the political agenda and, given the power to reallocate large amounts of resources, to hopefully persuade societies become more climate friendly. The framework also foresees payments from the industrialized world to developing countries to compensate for their high emission rates. These could be a major incentive for developing countries to engage in emission reduction measures and low carbon development.

Reflecting on India's emissions, we have identified that the emission pattern varies across regions, economic sectors and income groups. In a business as usual scenario, India might consume its tradable carbon space within 30 years. Today, India's lower income groups, especially the rural poor, virtually provide the 'carbon buffer' to the upper income groups in India and beyond.

If a system of an international carbon trade based on per capita emission allowances and international cooperation similar to the WBGU framework is turned into a reality, it would have a huge impact on the country in that India would be a major beneficiary. To maintain tradable carbon stocks following the WBGU concept, India would have to enforce emission reduction of the high emitters as well as low-carbon development strategies for the rural dwellers. Carbon trade stimulating low-carbon development that allows for meeting certain sustainability criteria, might offer promising development pathways. The WBGU approach offers a promising way of handling CO_2 emissions (combining climate science with economics) and a sound basis for policy discussions.

References

Ananthapadmanabhan G, Srinivas K, Gopal V (2007) Hiding Behind the Poor. Available at http://www.greenpeace.org/india/press/reports/hiding-behind-the-poor. 1–16

Baruah DC, Bora GC (2008) Energy demand forecast for mechanized agriculture in rural India. Energy Policy 36:2628–2636

Baumert KA, Herzog T, Pershing J (2005). Navigating the Numbers-Greenhouse Gas Data and International Climate Policy. http://pdf.wri.org/navigating_numbers.pdf, 30-09-2010

Bellarby J, Foreid B, Hastings A, Smith P (2008) Cool Faming: climate impacts of agriculture and mitigation potential. Greenpeace International, Amsterdam

Billett S (2010) Dividing climate change: global warming in the Indian mass media. Climatic Change 99:1–16

Bundesregierung (2007) Gemeinsame Erklärung zur Weiterentwicklung der strategischen und globalen Partnerschaft zwischen Deutschland und Indien. In: Bundesregierung, Berlin. Available at http://www.auswaertiges-amt.de/diplo/de/Laenderinformationen/Indien/Links/071030-GemeinsameErklaerung.pdf. Accessed on 29.04.2010

Climate Modelling Forum (2009) India's GHG Emission Profile: results of Five Climate Modelling Studies. Ministry of Environment and Forests, Government of India, New Delhi

Cruz RV, Harasawa H, Lal M, Wu S, Anokhin Y, Punsalmaa B, Honda Y, Jafari M, Huu Ninh N (2007) In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Asia. Climate change 2007: impacts, adaptation and vulnerability contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 469–506

Dubash NK (2009) In: Michel D, Pandya A (eds) Climate politics in India: how can the industrialized world bridge the trust deficit?. The Henry L Stimson Center, Washington, pp 1–69

European Climate Exchange. Available at http://www.ecx.eu. Accessed on 29.04.2010

European Commission (2007). Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, 'Limiting Global Climate Change to 2 degrees Celsius - The way ahead for 2020 and beyond'. COM(207)2. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0002:FIN:EN:PDF. Accessed on 29.04.2010

G8 (2009). Declaration of the leaders of major economies forum on energy and climate. Available at http://www.g8italia2009.it/static/G8_Allegato/MEF_Declarationl.pdf. Accessed on 29.04.2010

Garg A, Shukla PR (2009) Coal and energy security for India: role of carbon dioxide (CO_2) capture and storage (CCS). Energy 34:1032–1041

Hetland J, Anantharaman R (2009) Carbon capture and storage (CCS) options for co-production of electricity and synthetic fuels from indigenous coal in an Indian context. Energy Sustain Dev 13:56–63

IEA (2002) World energy outlook. International Energy Agency, Paris

IEA (2007) World Energy Outlook 2007 China and India Insights. International Energy Agency. Available at http://www.iea.org/textbase/nppdf/free/2007/weo_2007.pdf. Accessed on 29.04.2010

IPCC (2001) Climate Change 2001: Impacts, adaptation, and vulnerability contribution of Working Group II to the third assessment report of the intergovernmental panel on climate change, 2001. Cambridge University Press, Cambridge

IPCC (2007a) IPCC, 2007: Climate change 2007: Impacts, adaptation and vulnerability contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change, 2007. Cambridge University Press, Cambridge

IPCC (2007b) IPCC, 2007: Climate change 2007: the physical science basis contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Kantikar T, Jayaraman T, D'Souza M, Purkayastha P, Raghunandan D, Talwar R (2009) How much 'Carbon Space' do we have? Physical constraints on India's climate policy and its implications. Economic & Political Weekly XLIV:35–46

Kapila RV, Stuart Haszeldine R (2009) Opportunities in India for carbon capture and storage as a form of climate change mitigation. Energy Procedia 1:4527–4534

Khadse A, Qayyumi M, Mahajani S, Aghalayam P (2007) Underground coal gasification: a new clean coal utilization technique for India. Energy 32:2061–2071

Lal R (2004) Carbon emission from farm operations. Environ Int 30:981–990

Meinshausen M, Meinshausen N, Hare W, Raper SCB, Frieler K, Knutti R, Frame DJ, Allen MR (2009) Greenhouse-gas emission targets for limiting global warming to 2 °C. Nature 458:1158–1162

Murthy NS, Panda M, Parikh J (1997) Economic development, poverty reduction and carbon emissions in India. Energy Econ 19:327–354

Nautiyal S (2010) Climate Change: copenhagen to Karnataka. State Macro Scan 2:5

OECD-IEA (2009) World energy outlook 2009. 1–696

Pachauri S (2004) An analysis of cross-sectional variations in total household energy requirements in India using micro survey data. Energy Policy 32:1723–1735

Pachauri S, Spreng D (2002) Direct and indirect energy requirements of households in India. Energy Policy 30:511–523

Parikh J, Panda M, Ganesh-Kumar A, Singh V (2009) CO_2 emissions structure of Indian economy. Energy 34:1024–1031

Planning Commission (GoI) (2006) Integrated energy policy, report of the expert committee. Government of India, New Delhi. Available at http://www.planningcommission.gov.in/reports/genrep/rep_intengy.pdf. Accessed on 29.04.2010

Ramachandra TV (2008) Geographical information system approach for regional biogas potential assessment. Res J Environ Sci 2(3):170–184

Ramakrishna KL, Jacobsen L, Thomas R, Oglom E, Zubkova G (2003) Case study India. In: Ramakrishna KL, Jacobsen L, Thomas R (eds) Action versus words: implementation of the UNFCCC by select developing countries, The woods hole research, Woods hole, Massachusets, pp 48–58

Rastogi M, Singh S, Pathak H (2002) Emission of carbon dioxide from soil. Curr Sci 82:510–517

Reddy BS, Assemza GB (2009) The Great climate debate: a developing country perspective. Curr Sci 97:50–62

Reuveny R (2007) Climate change-induced migration and violent conflict. Polit Geogr 26:656–673

Saluja MR, Yadav B (2006)Social Accounting Matrix for India - 2003–04, India Development Foundation, Haryana, India

Sathaye J, Shukla PR, Ravindranath NH (2006) Climate change, sustainable development and India: global and national concerns. Curr Sci 90:314–325

Schellnhuber H, Messner D, Leggewie C, Leinfelder R, Nakicenovic N, Rahmsdorf S, Schlacke S, Schmidt J, Schubert R (2009). Solving the climate dilemma—the budget approach. WBGU special report. WBGU, Berlin. Available at http://wbgu.de/wbgu_sn2009_en.pdf. Access on 29.04.2010

Shackley S, Verma P (2008) Tackling CO_2 reduction in India through use of CO_2 capture and storage (CCS): prospects and challenges. Energy Policy 36:3554–3561

Shukla PR (2006) India's GHG emission scenarios: aligning development and stabilization paths. Curr Sci 90:384–395

Shukla PR, Dhar S, Mahapatra DR, Upadhyay J (2008) Multi-gas emissions inventory of india with disaggregated region and sector trends. In: 13th AIM international workshop, Tsukuba, Japan

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O (2007) Agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds) Climate change 2007: mitigation contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 497–540

Somanathan E and Somanathan R (2009) Climate Change: challenges facing india's poor, economic and political weekly, 44:51–58

Stern N (2009) The global deal. Bodly Head, UK

UK(2009) Low-carbon transition plan. Available at http://www.decc.gov.uk/en/content/cms/publications/lc_trans_plan/lc_trans_plan.aspx. Accessed on 29.04.2010

UNFCCC (2009) Decision 2/CP.15 Copenhagen Accord. Available at http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf#page=4. Accessed on 29.04.2010

Urban F, Benders RMJ, Moll HC (2009) Energy for rural India. Appl Energy 86:S47–S57

WBGU (2008) World in transition—climate change as a security risk. Earthscan, London

WBGU (2009) Solving the climate dilemma: The budget approach. Scientific advisory council on global change. WBGU, Berlin

World Resource Institute, Climate Analysis Indicators Tools (CAIT). http://cait.wri.org. Accessed on 29.04.2010

Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change: Epilogue

Sunil Nautiyal, K. S. Rao, H. Kaechele, K. V. Raju and R. Schaldach

The highly successful Humboldt Kolleg on "Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change" convened by Sunil Nautiyal, CEENR, ISEC showed a high relevance of climate change research in more or less in all relevant scientific areas. Today, adaptation and mitigation research plays an important role in all scientific and social science disciplines. In addition interdisciplinary climate change research covers all scales, from macro to micro. The Humboldt Kolleg proved that there is a high degree of awareness in scientists both in India and Germany about the challenges related to climate change research and the need for improvement of our knowledge system concerning adaptation and mitigation strategies. Even though an impressive plenitude of research is going on, substantial research still has to be done and a lot of research questions need further investigations. The most important outcome of the Humboldt-Kolleg is that it provided a platform for all the stakeholders to share their research outcomes indicating their awareness of climate change related challenges.

Since its inception in 1988, the Intergovernmental Panel on Climate Change (IPCC) has worked with the growing recognition that uncertainty is pervasive in our understanding of the climate system: what drives climate change, what will determine its future course, and what influence it will have on important social and

S. Nautiyal (✉) · K. V. Raju
Centre for Ecological Economics and Natural Resources (CEENR), Institute for Social and Economic Change (ISEC), Dr. VKRV Rao Road, Bangalore 560072, India
e-mail: nautiyal_sunil@yahoo.com

K. S. Rao
Department of Botany, University of Delhi, Delhi 110007, India

H. Kaechele
Institute of Socio-Economics, Eberswalder Straße 84, Müncheberg D-15374, Germany

R. Schaldach
Centre for Environmental System Research, University of Kassel, Wilhelmshöher Allee 47 34119 Kassel, Germany

S. Nautiyal et al. (eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-36143-2_41,

ecological aspects of our world. IPCC has struggled, with varying degrees of success, in its efforts to describe these uncertainties and to judge the confidence with which it can offer its major conclusions (Yohe and Oppenheimer 2011). As IPCC and its supporting communities continue to devise and implement strategies to cope with the process, it is important to recognize the value of doing it right. In the discourse of climate research where coping with uncertainty is a common thing, communicating conclusions in a more easily comprehensible and implementable way is essential. As scientific knowledge evolves our conclusions may change. Sometimes the validated knowledge may strengthen the existing conclusions and at other times, this may prove that our accepted wisdom is not a solution for the future. When we work with uncertainty, errors will be made but, any set of policy guidelines in how we treat uncertainty should have active and engaged cooperation of the participating stakeholders. Such an effort will require that our community brings as much enthusiasm and originality to the task of increasing the transparency, comprehensibility, and utility of the assessments in climate change research (Saxena and Rao 2009; Rao et al. 2012).

While the communities at large recognize the need to adapt to changing climatic conditions, there is an emerging discourse in scientific literature on the limits to such adaptation. Limits are traditionally analysed as a set of immutable thresholds in biological, economic or technological parameters. Any limits to adaptation depend on the ultimate goals of adaptation underpinned by diverse values. While adaptation need not be limited by uncertainty around perceived future risks, social and individual factors limit adaptation actions. Systematic undervaluation of loss of places and culture disguises real, experienced but subjective limits to adaptation. The issues of values and ethics, risk, knowledge and culture construct societal limits to adaptation, but that these limits are mutable (Adger et al. 2009).

Within the climate change literature, adaptation is generally defined as 'adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities' (McCarthy et al. 2001). In essence, adaptation describes adjustments made to changed environmental circumstances that take place naturally within biological systems and with some deliberation or intent in social systems (Gallopin 2006; Nelson et al. 2007). The discourse around limits to adaptation is frequently constructed around ecological and physical limits, economic limits, and technological limits. These dimensions offer various analytical capabilities for investigating adaptation to climate change and allowing adaptation to be present in various forms of policy assessment. Attention to ecological or physical limits to adaptation offers the prospect of investigating such limits through mathematical modelling. Consideration of economic limits to adaptation lends itself to investigation through the use of cost-effectiveness analysis or cost-benefit analysis. Approaching limits to adaptation through an appreciation of technology suggests value in various types of technology mapping and innovation analysis. Such ways of conceiving limits to adaptation are attractive because they offer analytical functionality, a functionality which sits easily alongside other key dimensions of climate change analysis: modelling changes in the Earth system and energy economic modelling of mitigation policy. Energy economy models capture key elements of the energy system on the wider economy and explore least-cost pathways or options for development (Jebaraj and Iniyan 2006; Strachan and Warren 2011). Indeed, the framing of Article 2 of the UNFCCC points in this direction, suggesting that there are independent, objective measures and thresholds of danger (Dessai et al. 2004; Oppenheimer 2005). On the other hand, these conceptions of adaptation limits imply that such limits can be defined predominantly in either exogenous or analytical terms. The conceptions give great weight to limits imposed from 'outside society' or limits where the risk can be quantified.

A common theme that has emerged is that economic consideration based adaptation tends to lower the expected cost of climate change. To achieve these analyses of adaptation must reveal important opportunities in areas and contexts that related to technological changes in adaptation process. In implementing some strategies of adaptation we might prolong the lifetime of a system indefinitely. However, in other, more likely circumstances, adaptation might extend a system's productive lifetime so that substitute structures and/or systems can be envisioned and created. Our current research has not progressed sufficiently to support a comprehensive description of all the significant options for adaptation that might materialize across the globe. The scientific community has not progressed to the point where it can even offer an efficient prioritization of research initiatives designed to create such a description (Maikhuri et al. 2003; Nautiyal and Nayak 2009; Maikhuri et al. 2011).

Integrated assessments of climate change have concentrated on developing diverse scenarios of future greenhouse gas (GHG) emissions, and on analyzing the economic and environmental (e.g. the IMAGE model) consequences of emission mitigation policies. A pervasive limitation of existing integrated assessment models (IAMs) is their highly stylized and aggregated representation of climate impacts and the economic responses thereto, and the omission of specific investments related to climate change adaptation. This is due to our incomplete understanding of the channels through which anthropogenic emission of greenhouse gases forcing induces changes in meteorological variables and through these, various other biophysical impact endpoints at regional scales as well as what the concomitant damages to the various economic sectors within these regions might be. While we are progressing in our understanding of interrelationships, systemic challenges to modeling the adaptation continue to impede progress (Wing and Fisher-Vanden 2013).

The assumption that mitigation and adaptation to climate change impacts could be approached by the individual countries based on their resource status and existing policies is a major impediment in achieving a global strategy through which the existence of mankind on this Earth could be sustained longer than which it could be at the present pace of changes. The chapters that are part of this volume indicate that the present knowledge systems in countries such as India are diverse and the level of human capacity to tackle the issues is highly varied. Both the developing and developed countries could draw valuable lessons by documenting and scientifically validating the knowledge systems and use them for developing better adaptation strategies.

References

Adger WN, Dessai S, Goulden M, Hulme M, Lorenzoni I, Nelson DR, Naess LO, Wolf J, Wreford A (2009) Are there social limits to adaptation to climate change? Clim Change 93:335–354

Dessai S, Adger WN, Hulme M, Turnpenny J, Kohler J, Warren R (2004) Defining and experiencing the dangerous climate change. Clim Change 64:11–25

Gallopin GC (2006) Linkages between vulnerability, resilience, and adaptive capacity. Glob Environ Change 16:293–303

Jebaraj S, Iniyan S (2006) A review of energy models. Renew Sustain Energ Rev 10:281–311

Maikhuri RK, Rao KS, Patnaik S, Saxena KG, Ramakrishnan PS (2003) Assessment of vulnerability of forests, meadows and mountain ecosystems due to climate change. ENVIS Bull Himalayan Ecol 11(2):1–9

Maikhuri RK, Rawat LS, Negi VS, Farooquee NA, Rao KS, Purohit VK, Agarwal SK, Chamoli KP, Negi CS, Saxena KG (2011) Empowering rural women in agro-ecotechnologies for lifelihood improvement and natural resource management. Outlook Agric 40(3):229–236

McCarthy JJ, Canziani O, Leary NA, Dokken DJ, White KS (eds) (2001) Climate change 2001: impacts, adaptation and vulnerability (IPCC Working Group II). Cambridge University Press, Cambridge

Nautiyal S, Nayak BP (eds) (2009) Climate change: data requirement and availability. ISEC and MoSPI publication, p 188

Nelson DR, Adger WN, Brown K (2007) Adaptation environmental change: contribution of a resilience framework. Ann Rev Environ Resour 32:395–419

Oppenheimer M (2005) Defining dangerous anthropogenic interferences: the role of science, the limits of science. Risk Anal 25:1399–1407

Rao KS, Maikhuri RK, Semwal RL, Rawat LS, Saxena KG (2012) Climate change adaptation and mitigation: insights from Nanda Devi Biosphere Reserve in Indian Himalaya. In: Saxena KG, Liang L, Tanaka K, Takahashi S (eds) Land management in marginal mountain regions: adaptation and vulnerability to global change. Bishen Singh Mahendra Pal Singh, Dehradun, pp 305–324

Saxena KG, Rao KS (2009) Climate change, biodiversity and livelihoods in Indian Himalaya: the elements of uncertainty and diverse perceptions. In: Nautiyal S, Nayak BP (eds) Proceeding of national seminar on climate change: data requirements and availability, institute for social and economic change, Bangalore and ministry of statistics and programme implementation, Government of India publication, pp 78–88

Strachan N, Warren P (2011) Incorporating behavioural complexity in energy-economic models. www.ukerc.ac.uk/support/tiki-download_file.php?fileId=1965

Wing IS, Fisher-Vanden K (2013) Confronting the challenge of integrated assessment of climate adaptation: a conceptual framework. Clim Change. doi:10.1007/s10584-012-0651-x

Yohe G, Oppenheimer M (2011) Evaluation, characterization, and communication of uncertainty by the intergovernmental panel on climate change: an introductory essay. Clim Change 108:629–639