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Bindhy Wasini Pandey
Subhash Anand *Editors*

Water Science and Sustainability

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ISSN 2523-3084 ISSN 2523-3092 (electronic)
Sustainable Development Goals Series
ISBN 978-3-030-57487-1 ISBN 978-3-030-57488-8 (eBook)
https://doi.org/10.1007/978-3-030-57488-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

In the Honour of Prof. R. B. Singh
Secretary General IGU, Member ICSU

About This Book

Water is the most vital resource for the existence of life on earth. It is a prime natural measure, a basic human need and a precious national asset. Water is indispensable for the existence of natural habitat, biosphere and forms an essential element in the socio-economic development of the ecosphere. Water forms the living mass, together with the soil and air, represents the living environment. Water is an important constituent of the geosystem. It is the most abundant substance on the earth which links the three components of the geosystem by means of an endless circulatory movement called the hydrological cycle. Water is a key factor in the air—conditioning the earth for human existence and delineating the geomorpho1ogy. Water is not only vital for the sustenance of life, but also essential for socio-economic development. The ecological balance maintained by the quality of water available to a large extent determines the way of life of the people.

The book *Sustainable Development Goal Series: Water Science and Sustainability* describes the importance of water resources for socio-economic and ecological development including geomorphic and ecological environments. Hence, conservation, management and development of water resources have become very necessary for the development of man and the environment.

This book is an outcome of the valuable contributions made by eminent scientists and research scholars who have been trying to develop alternative strategies, solutions and models for sustainable water resources development through research, monitoring and experiments varying from regional to global scale. This edition would be of immense use to the policymakers, environmentalists, ecologists, academicians, research scholars and people in general concerned with water resources management.

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Editors and Contributors

About the Editors

Bindhy Wasini Pandey is currently an Associate Professor of Geography at the Department of Geography, Delhi School of Economics, University of Delhi. He has to his credit 24 Years of Teaching and Research experience, 08 books and 70 research papers published in books and journals. He has supervised 0 Ph.D. and 05 M.Phil. Theses. He has received Young Geographers Awards of National Association of Geographers India (NAGI) and Shastri Indo-Canadian Institute (SICI) and Canadian International Development Agency (CIDA) Fellowship for the project on Hazard Zone Mapping in Himachal Himalaya and British Columbia, Canada in 1995. He has widely travelled and attended International Conferences and delivered lectures in about 35 countries. Dr. Pandey is specialized in Marginality Analysis and Vulnerability Assessment in High Altitudes. He is the Deputy Executive of International Geoscience Education Organization (IGEO), and Sectional Recorder, Earth System Sciences of Indian Science Congress (ISCA). He is also Secretary of IGU Commission on Biogeography and Biodiversity.

Subhash Anand is currently an Associate Professor of Geography at the Department of Geography, Delhi School of Economics, University of Delhi. He has to his credit 23 Years of Teaching and Research experience, 06 books and 40 research papers published in books and journals. Dr. Anand is a specialist in Urban Solid Waste Management and Planning, Sustainability, and Geoparks. He has widely travelled and attended International Conferences and delivered lectures in about 30 countries. He is the recipient of Dr. Rajendra Prasad Award by International Eminent Educationist Forum of India. He has supervised 06 Ph.D. and 06 M.Phil. Theses. He has done successful training UGEC & SARCS Advanced Training Workshop on Urban Spatial Planning in response to Climate Change in Asia, Taipei, Taiwan, and Commonwealth Geographical Bureau's Workshop on Human Consequences of Climate Change, University of Colombo, Sri Lanka. He is Vice - Chair, Commisssion on Geoheritage, International Geographical Union (IGU).

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1 Professor R. B. Singh

Shouraseni Sen Roy

Abstract

Professor Singh is the first Indian Geographer to have the dual distinction of holding the position of the IGU Secretary General and ICSU Scientific Committee Member. He was the first Indian and second Asian Secretary General and Treasurer of the IGU. He has been elected as the Vice President of IGU for two terms since 2012. Professor R. B. Singh is a Distinguished Geographer in Environmental Geography and GIS applications, who has made distinct academic contributions over the last five decades. His reputation spreads beyond academic and national boundaries. He is an excellent mentor, guide, and life-long advisor to his students. His success as a mentor to his students is evident from the fact that he has supervised 40 Ph.D., 82 M. Phil, Research Scholars and countless MA students. He was Chair, UGC National Committee-Learning Outcome Based Curriculum Framework since July 2018. Expert in the prestigious Committees of the Government of India-Ministry of Environment and Forests, Department of Science and Technology, National Disaster Management Authority (NDMA). Taught courses to M.A., M.Phil., and Ph.D. programs at University of Delhi. Undertaken Major International Collaborative Research Projects, he has written and edited more than 50 books and more than 230 Research Papers.

Keywords

Professor R. B. singh · IGU · ICSU · Secretary general · Vice president

Professor R. B. Singh is a distinguished Geographer in Environmental Geography and GIS applications, who has made distinct academic contributions over the last five decades. His reputation spreads beyond academic and national boundaries. All of his achievements are through sheer dedication and hard work in the field of Geography. Therefore, it comes as no surprise to anyone that Prof. Singh currently is the most well-known Indian Geographer and expert of environmental issues both inside and outside India. Throughout his career, he has achieved many "Firsts" as an Indian Geographer, thus making him a role model for the entire Geography community. Given his long list of achievements over almost five decades, it is not easy to describe his achievements in a few pages. In the sections below, I have summarized some of his major contributions throughout his long career.

Professor Singh has a great contribution in research particularly outside India, he is

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_1

considered to be an excellent research collaborator, who makes the impossible possible. Throughout my interactions with Prof. Singh, I have always been amazed at the variety of research collaborators that are in his office all the time. His research collaborations span across all six continents. He has written 14 books, 35 edited research volumes, and more than 200 research papers published in national and international journals. He was recently invited by the UN to moderate a Working Group on Exposure and Vulnerability at UNISDR Science and Technology Conference on Sendai Framework of Disaster Risk Reduction, 2015–2030, Geneva. He also served as a panelist on *Science Advise in Times of Disaster Emergencies* in South Africa. Thus he has been very generous with his time and sharing his knowledge with the wider academic and policymakers' communities. He has published in well-known high impact international peer-reviewed journals, including published in Journals-Climate Dynamics, Current Science, Singapore Jl. Of Tropical Geography, Energies, Theoretical and Applied Climatology, Environmental Science and Policy, Physical Geography, Advances in Meteorology, Physics and Chemistry of the Earth, Agriculture, Ecosystem and Environment, Hydrological Processes, Mountain Research and Development, Journal of Mountain Science. He is Springer Series Editor—Advances in Geographical and Environmental Sciences; and Sustainable Development Goals (SDGs), IAP–Global Network of Science Academies representative on Disaster Risk Reduction.

Professor Singh as a Project Director/Principal Investigator has Undertaken Collaborative Major Research Projects on Livelihood Security in Changing Socio-Economic Environment in Himachal Pradesh, India (2012 onwards) collaborated with University of Turku, Finland, Shastri Applied Research Project (SHARP) on Role of Public, Private and Civil Sectors in Sustainable Environmental Management (2003–2005) collaborated with University Of Manitoba and the University of Winnipeg, Winnipeg, Canada, ICSSR—Indo-Dutch Programme on Alternative in Dev. (IDPAD) on Environmental Implications and its Socio-Economic Implications in Rural-Urban Fringe of Delhi—University of Delhi & University of Groningen, The Netherlands. (1997–2002), CIDA-SICI Partnership Project-II on Urban Development and Environmental Impacts in Mountain Context, University of Delhi & University of Manitoba, Canada. (1998–2002), DFID Res. Project on Enhancing Food Chain Integrity…Pollution Impact on Vegetable System (2000–2002) in Peri-Urban Areas, Collaboration with Imperial College, London, UK., CIDA-SICI Partnership Project-I on Sustainable Development of Mountain Environment in India and Canada, University of Delhi & University of Manitoba, Canada, (1994–1997), Ministry of Agriculture Project for Preparation of Perspective Plan for Land Resources in N. Zone, India (1994).

Professor Singh, is the first Indian Geographer to have the dual distinction of holding the position of the IGU Secretary General and ICSU Scientific Committee Member. He was the first Indian and second Asian Secretary General and Treasurer of the IGU. He has been elected as the Vice President of IGU for two terms since 2012. He was awarded the prestigious Japan Society for Promotion of Science (JSPS) Research Fellowship at Hiroshima in 2013, and many travel fellowships/support from UNEP, UNITAR, UNISDR, IAP, UNU, UNCRD, WCRP, IAHS, IGU, NASDA, INSA, UGC, SICI, MAIRS, and University of Delhi etc. for participating and presenting papers at different international conferences. He was also the Chair of the Department of Geography, University of Delhi during 2013–2016, when the department was ranked as one of the best Geography Departments in India. He was invited by UGC for Preparing National Level CBCS Syllabus for Undergraduate Geography in 2015. He is also Chair of the UGC prestigious committee for preparing Learning Outcome based Curriculum Framework since July 2018. He has served as an expert on different prestigious Committees of the Government of India - Ministry of Environment and Forests, Department of Science and Technology, National Disaster Management Authority (NDMA), ICSSR, CSIR, etc. He has presented his research and participated in numerous research projects across more than 40 countries including the like USA, Canada, Mexico, Japan, Australia, France, Finland, Denmark, Spain, UK, Netherlands, Norway, Germany, Switzerland, Russia, Georgia, Armenia, Poland, Czech Rep., Mongolia, Malaysia, Thailand, Egypt, China, Taiwan, Tunisia, Sweden, Israel, South Korea, Ireland, South Africa, Brazil, Singapore, Italy, Luxembourg, Sri Lanka, Indonesia, Nepal and Bhutan. Recently, he was unanimously elected president of the Earth System Science Section of the Indian Science Congress Association (ISCA). In 1988, the UNESCO/ISSC (Paris) awarded Research and Study Grants Award in Social and Human Sciences. He has to his credit of several Travel Fellowships/Support from UNEP, UNITAR, UNU, UNCRD, WCRP, IAHS, IGU, NASDA, INSA, UGC, SICI, MAIRS, and University of Delhi etc. for participating and presenting papers, Chairing session and discussing research projects in USA, Canada, Mexico, Japan, Australia, France, Finland, Denmark, Spain, UK, Netherlands, Norway, Germany, Switzerland, Russia, Georgia, Armenia, Poland, Czech Rep., Mongolia, Malaysia, Thailand, Egypt, China, Taiwan, Tunisia, Sweden, Israel, South Korea, Ireland, South Africa, Brazil, Singapore, Sri Lanka, Indonesia, Italy, Luxembourg, Kyrgyz Republic, Nepal, and Bhutan.

Professor Singh is an excellent mentor, guide, and life-long advisor to his students. His success as a mentor to his students is evident from the fact that he has supervised 33 Ph.D., 80 M.Phil., and countless M.A. students. He always encourages his students to explore new research areas, and present at various national and international conferences. He actively publishes with his students, and many of them have followed him in his footsteps for an academic career. His effectiveness as a mentor is evident from the fact that his former students have stayed in touch with him many years after graduation. They often come back to him for advice and guidance, for which he is always available. He is never hesitant to showcase his students by recommending them to various opportunities. He has taught a wide variety of courses in Environment and Ecology, Remote Sensing, Urbanization Impacts, Natural Resources, and Biogeography. This is indicative of his wide scope of specialization and expertise. As one of his students, I myself will always be grateful to him for getting me interested in higher education and research, and choosing academics as my career.

Thus, many who know Prof. Singh aptly refer to him simply as “Guruji”!

2 Sustainable Development Goal Series: Water Science and Sustainability: An Introduction

Bindhy Wasini Pandey and Subhash Anand

Abstract

Life sustains on the foundation of natural resources and water is one of them, which are essential commodity for the existence of human being and flora and fauna. Any evidence of life cannot be imagined without water. Potentiality of becoming water as critically scarce resource in the coming years is increasing continuously due to various factors. Looking the importance of water from local to global level, its integrated, appropriate and long-term strategies are much needed for sustainable water resource management. Book consists of total 19 chapters on different dimensions of water resources having case studies adopting very relevant and useful methodologies and providing sustainable solutions for the rational utilization and consumptions of natural resources in the various parts of the world. Out of the total case studies, book covered seven case studies from different parts of the world along with 10 chapters from various regions of India. The successful attempt has been made to address all these issues and to create a responsible academic contribution to the field of sustainable water resource management. Scientific study considered as need of the hour for establishing its economic feasibility and technical applicability with the consideration of the eco-hydrological, environmental and social aspects. An in-depth hydrological study is required in the contemporary scenario and strategies are required to be formulated and implemented for maintaining freshwater quality for sustainable future of earth.

Keywords

Water resource · Hydrological · Sustainable solutions · Long-term strategies · Scientific study

Geohistorical evidence says that among the naturally found chemical compounds on this planet, water is the most significant one and it makes this planet unique in the universe known to the human being. Water plays an essential role in the existence of society (Anand et al. 2013). It is the water; in which life originated, took shape and became intricate and diverse with the time. Water determines the formation of biotic communities. Water is the key to the long vividness and the adaptability to survive. Any evidence of life cannot be imagined without water; its mere presence is indicative of life wherever it is found.

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_2

Significance of water has been immense for the development of civilizations (Singh and Pandey 1996b). Importance of water as a resource is indelible across the entire biotic community, including human beings (Igor 1993). Dating back to 5000 years during Indus Valley Civilization, Harappa produces the evidence that people of ancient civilization settled near the sources of water which were used for several (domestic, irrigation, public baths and rituals and other activity) purposes (Singh and Pandey 1993, 1996b). It is still used for almost all religious rituals and ceremonies as offerings to the Almighty God because it is considered as purifying source (Pandey 2004). Due to many reasons; today, the demand and need for water has exceeded the limit of its availability (Nair 2004). In the contemporary scenario, water resource is stressed with accentuating demands to fulfill the requirements and likely to arise in the near future (PAI 1997). It is getting strained due to consistent population pressure, increasing industrialization and rapid growth of urbanization (Gleick et al. 2002). Water degradation requires urgent attention as long with its quality, water quantity is also decreasing at a very rapid pace, hence, suitable inexpensive water treatment and recycling methods are needed for the development in present century together with reuse or conservation methods (Anand 2013). Thus, it should be the prime question to the world's intellectual dais because this is the core element of the factor to survive. The comprehensive, adequate, appropriate and long-term strategies are needed for sustainable water resource management (Agarwal et al. 2000). Its management is required not only for the economic prosperity but also to enhance the quality of life of human beings as well (FAO 2002). Moreover, these management practices should be based on managing the freshwater demand and supply under the stressed water availability conditions and increasing water supply (Cosgrove and Rijsberman 2000; Nolde 2005).

Today, water resource storage, retrieval and dissemination constitute significant monitoring system for sustainable development (Amarasinghe et al. 2007). Water resource availability is adequately enough for its present requirements, whereas geographically its allocation and quality are incredibly varied in quantities (Lal 2001). Precipitation is the main factor of the water cycle for considering the vital element for biome because it can alter and modify the allocation of water resources and also shaped it; while the average annual precipitation of India is estimated about 4000 BCM (Billion Cubic Meter) out of which some part is lost as evapotranspiration, some water gets percolated in the ground as groundwater recharge and the remaining appears as surface water (MoWRRDGR 2019). The water resource potential of India gets flowed as natural runoff in the rivers, and groundwater recharge is estimated at about 1869 BCM (Planning Commission of India 2013). It constitutes a little over 4% of the total river flows of the world (Pandey et al. 2004). However, topographical and climatic constraints allowed only about 1121000 Million Cusec Meters (MCM) freshwater to beneficial use annually worldwide (Suhag 2016). It can be achieved through 690 BCM of utilizable surface water and 431 BCM through groundwater (MoWRRDGR, GoI 2019). A large number of projects, including ongoing projects such as dams, barrages, hydropower structures, canal networks have come all over the country in successive Five-Year Plans (NCIWRD 1999). A milestone in water resources management is the creation of a huge capacity for storage (Rao 1973; Simonovic 2000). Now it has become possible to provide assured irrigation in the command areas and scarce regions of India (Gandhi and Namboodiri 2002).

Nowadays, several hydro and thermal power plants are actively seen in providing services to meet requirements for various uses in the country. Flood moderation and water storage techniques for fulfilling the essential requirements of people and have also been effectively regulated in many flood-prone areas (Seth 2000). Besides this, with the positive and productive approaches to the schemes of the government for drinking water supply in remote and harsh areas has also become possible due to various technological advancements (Allan 1998; Hassing et al. 2009).

This edited book is a compilation of the valuable contributions made by eminent scientists and research scholars, who are trying to develop alternative strategies, solutions and models for sustainable water resources development through various research, monitoring and experiments ranging from regional to global scale. This edition would be of immense use to the policymakers, environmentalists, ecologists, academician and research scholars for water resources management. Chapter 1 of the book is devoted to our Guru (Mentor) Prof. R. B. Singh by Prof. Shouraseni Sen Roy while Chap. 2 discusses the introduction of the book by Bindhy Wasini Pandey and Subhash Anand.

The next chapter (Chap. 3) by Volchak and Parfomuk discusses the runoff of the Neman River Basin in Belarus and Lithuania focusing on climatic factors as well as anthropogenic factor to be responsible for the change in the runoff. Changes in river water runoff for the Neman river basin using two scenarios of economic development and climate change (A1B and B1) were forecasted. The data sources are based on the materials taken from 24 hydrological stations from 1961 till 2009 and 23 meteorological stations from 1961 up to 2010 at the Neman River. They have used Mezentsev's method for the hydrological climatic calculations. They described that the A1B scenario indicates the increase of runoff from 7.4% to 33.9%. Scenario B1 has shown the change in runoff from 1.9% to 21.6%.

Integrated Water Resources Management (IWRM) has increasingly become an essential rallying theme for addressing the governance and management of water resources. They have also discussed how IWRM is perceived in southern Africa and the challenges for applying this concept in water resources governance and management within the region. Using the case study of Zimbabwe; they also have discussed the ongoing debate about the extent to which the implementation of IWRM has succeeded in the country. However, at the grassroots community level, the implementation of IWRM is constrained due to limited choices that these communities have. Due to poverty and impoverishment, these communities depend directly on land-based resources for their livelihood. Many of which lead to environmental degradation, which in turn undermines the availability of water in the environment (Chap. 4, Mukwada et al.).

Salahuddin in her chapter (Chap. 5) on 'urban heat island growth and health hazard in the megacity of Hyderabad' concluded that a linear relationship between the city size and the heat island growth. As Hyderabad has the largest urban sprawl among the Peninsular Indian cities, it has also recorded a considerable daytime and even higher nocturnal transition in the heat island intensity. Nocturnal urban heat island intensity has been recorded higher than the daytime effect. Urban Heat Island prevents the nocturnal radioactive cooling, which renders it more uncomfortable. Chapter 6 by Jana and Mondal on 'Physical environmental impact assessment of flood: A case study of lower Darakeswar-Mundeswari interfluve in West Bengal', discussed flood which is most natural disasters in the humid tropics, especially, in India. It has been estimated that 42.43% of the total area of the state is flood-prone. They have focused on the assessment of the physical environmental impacts of flood in Darakeswar-Mundeswari interfluve in Hugli District of West Bengal. The possible relevant measures toward reducing the magnitude of flood impact have also been suggested. It has been found that the anthropogenic activities such as building activity and eventual urbanization, channel manipulation through the diversion of the course of the river, construction of bridges, barrages and reservoirs, agricultural practices, deforestation, land use changes, etc. are major factors responsible behind the occurrence of flood in the study area.

Chapter 7 by Kirsta and Puzanov analyzed water quality management runoff, which involves mathematical models to assess quantitatively the hydrological and hydrochemical processes in river basins. They have emphasized on the models, which can take into account both temporal and spatial effects of natural and anthropogenic (if any) factors on hydrological and hydrochemical regimes of rivers. They have also discussed about the calculation of the seasonal runoff where four hydrological periods/seasons were specified: winter low water, spring-summer flood, summer low water and autumn low water. A total of 13 typological geosystem groups (landscapes) were selected to account for a landscape structure of river basins.

The combined models for normalization and spatial generalization of monthly precipitation, temperature and hydro-chemical runoff of river basin of the Altai-Sayan mountain country have been estimated and analyzed in Chap. 8. Aladyshkina (et al.) tried to understand the integrated water resource management, which is a process that promotes the comprehensive development and management of water, land and other resources. This promoted to enhance socioeconomic well-being inclusively without compromising the sustainability of the vital ecosystem. The sharing of water in different regions creates the social conflicts which later concluded with basin agreements. It is concluded only for interregional water objects, i.e., catchment area which is located within several subjects of the Russian Federation. It does not take into account the cross-border nature of water objects located in the territory of one subject of the Russian Federation but covers the boundaries of several administrative areas.

Chapter 9 on 'Water resources of Madhya Pradesh: Contemporary issues and challenges', by Sharma analyzes the regional variation in potential as well as utilization of water resources within the state following variations in hydrogeological aquifers, precipitation pattern, land use and cropping structure. Various issues such as inter-state river water disputes, rapid silting of reservoirs, water pollution; waterlogging and salinization have been addressed. Sergey V. Kholodkevich et al. in Chap. 10 have discussed the quality of the natural water incoming on water intakes of water supply in certain European countries. The uses of high level of chemical in drinking water are danger and economic losses in such cases depend on speed of acceptance of the management decisions directed to their prevention and elimination. They have analyzed that the BioArgus-W is a science-based, multi-parameter, multi-level biomonitoring system comprising several building blocks. Even a failure in one of them can reduce partly or entirely a whole system efficiency. The main distinctive features of the BioArgus-W system are test organisms (crayfish and fish) used as the sensors.

Chapter 11 by Ravi S Singh and Sarah Ahmad elaborated that water is regarded as the ultimate source of life in all the world religions including Hinduism, Christianity, Islam, Judaism and Zoroastrianism and provides a run-through of water symbolism of world religions followed by focusing on the various facets of water in Islam. Water is an essential element for the survival of living creatures on the globe. Our dependency on the water can be seen from the daily chores to economic activities such as agriculture, industries, or public health, safety and recreation. This chapter aims to outline different roles of water in the Islamic teachings and its applicability in today's world for instance, in water conservation.

Chapter 12 by Singh et al. analyzed 'Water resource management through ecological restoration in Garhwal Himalaya, Uttarakhand'. The study focuses on ecological restoration for the water resource management, integration of extreme events, climatic vulnerability, land use land cover (LULC) changes and natural resource for sustainable development planning. It has also been discussed that climate change and anthropogenic activities are continuously disturbing the natural system of the Garhwal Himalaya. Its impact on sustainable development and water potential is clearly visible according to the authors assessment output.

Jana et al. in their Chap. 13 on 'Changing rainfall patterns and their linkage to floods in Bhagirathi-Hooghly Basin, India: Implications for water resource management', have discussed the synoptic view of recent changes in the patterns of rainfall and their linkages to extreme floods in Bhagirathi-Hooghly Basin (BHB). This study provides a better understanding of long-term and short-term trends and variations in rainfall and ascertains whether the extreme floods. The analysis reveals a long-term insignificant declining trend of annual as well as pre-monsoon rainfall, on the other hand, the increasing trend in monsoon and post-monsoon season over BHB. Rainfall during winter seasons showed a decreasing trend and the changing rainfall trends during monsoon months is a significant concern for rainfed agriculture.

In Chap. 14, Selvakumar and Chandrashekar have focused on the coastal aquifer and impact of mining in southern Tamil Nadu, India. The inland Sand dunes area is the area with no active mining but receiving the impact of mining activity. Hydrological, geochemical and groundwater table characteristics of the shallow coastal aquifer systems, in the mining and non-mining areas, have been investigated to identify the salinization process. The NaCl ratio, correlation matrix and ionic relationship between major ions show a marked increase in salinization in the active mining area. Chapter 15 on 'Flood simulation modeling and disaster risk reduction of West Tripura district, Tripura, North-East India' has been authored by Bhowmick and Das. Both the authors have focused on the impact of the flood, which covers about 40% area and 41% population of the district, including Agartala (the capital of Tripura). They have analyzed flood risk and its reduction modeling done by using flood simulation model for 50 and 100 years return period with 46 years' water level of the HaoraRiver. It is indicating 11 meters above the mean sea level as the highest water level and 8–11 meters above mean sea level for the LoharNala.

Chapter 16 of the book deals with Remote Sensing and GIS Based Morphometric Analysis of Spiti River Basin by Arif Husain and Pankaj Kumar. Three different basins have been delineated by using hydrological tool given in the ArcGIS 10.1. They are named as Spiti, Tsarap Chu and Parechu basins with an area 5419 km^2, 781 km^2 and 651 km^2, respectively. The morphometric parameters of all the three sub-basins have been calculated. ArcGIS 10.1 software was used for delineation and computation of drainage parameters and also for generating map layout. Morphometric analysis of the study area of all three sub-basins represents sub-dendritic to dendritic drainage pattern with moderate to very fine drainage texture. The bifurcation ratio of all three basins indicates normal basin category and the presence of low drainage density suggesting that region has highly permeable sub-soil.

Chapter 17 of the book is contributed by Sahila Salahuddin on 'Demarcation of hyper arid land in the Indian Desert: An Environmental Analysis' concluded that most parts of the Indian Desert are admittedly mild but there are small remote patches, which qualify themselves to be extreme desert. Central Arid Zone Research Institute delineated the semi-arid and arid lands in the Indian Desert. Semi-arid lands depicted a greater half of the desert and arid lands comprised lesser half of the Indian Desert. However, a micro-level analysis of the western frontier of the Indian Desert has revealed a narrow strip of hyper arid conditions in the Indian Desert adjacent to Cholistan Desert in Pakistan. The enquiry reveals meteorological, hydrographic and botanic evidences to this effect. The hyper arid conditions would become even more intense and further challenging in the wake of global and regional climate change.

(Chapter 18) Volchak et al. have described the prediction of the flood evolution is a complicated task, which makes it necessary to take into account a lot of factors. Particularly, long spring flood is typical for water regime of some rivers, having nourishment of a mixed type with prevailing snow one. Snow storage at the beginning of the active melting period is the main source of the maximal discharges causing material and social damage. Besides the amount of snow, weather also makes substantial influence on the spring flood formation. In the last, Chap. 19 presents the concluding remarks of the book by Bindhy Wasini Pandey and Subhash Anand.

The aforesaid chapters of the present book will look into the various issues related to environment in detail. The papers also suggest solutions for the rational utilization of natural resources in different parts of the world. Life sustains on the foundation of natural resources and water is one of the essential natural resources. Potentiality of becoming water as critically scarce resource in the coming years is increasing continuously due to various factors as discussed above. Fickle climatic characteristics both in time and space are responsible for unequal distribution of precipitation across India. Scientific and technically strengthened structural and non-structural measures are required for mitigating the droughts and floods. Mathematical models and techniques with an enhanced meteorological algorithm are needed for forecasting the monsoon rainfall accurately, which must be utilized by the farmers and decision-makers for adopting appropriate strategies for management of droughts and floods.

Further, there is a need for increasing the availability of water and reducing its demand equipped with better management. Encouragement for better management of existing system and creation of additional storages by constructing large, medium and small-sized dams in consideration with the environmental, economic and social aspects is need of the hour. Rejuvenation of dying lakes, ponds, rivulets and tanks by induced-artificial recharge of groundwater may further enhance the potentiality and availability of water resources. In addition to these measures, inter-basin transfer of water provides one of the best options for mitigating the problems of the surplus and deficit basins. A scientific study needs to be carried out for establishing its economic feasibility and technical applicability with the consideration of the eco-hydrological, environmental and social aspects. Integrated and coordinated development of surface water and groundwater resources and their conjunctive use should work under the bottom-up approach from the project pre-planning stage and should form an integral part of the project implementation. There is a need for proper groundwater resources management, which requires adequate inputs including financial, human resources, technologies etc. Improving public water supply, awareness, use of energy pricing and supply to manage agricultural groundwater reduce the dependency on agriculture and formalizing the water sector are some of the measures for sustainable development of groundwater resource (Rosegrant and Ringler 1999).

Considering anthropogenic changes, an accurate assessment of available surface and the groundwater resources is needed for planning, design and operation for watershed management. Based on logical and scientific techniques, there should be a periodic reassessment of the potential of ground and surface water. Consideration of the cost-benefit approach or quality of water available and the economic viability of its extraction needs to be taken care of. An in-depth hydrological study is required in the contemporary scenario for assessment of water resources under changing climatic scenario. Strategies are required to be formulated and implemented for maintaining freshwater quality.

Adhering toward environmental flow rate, a minimum flow must be maintained in the ecosystem of the river. The eco-hydrological approach based on the green and blue waters concept should be involved as an essential part of the water resources management practices by balancing water between natural availability and human needs. The concept of virtual water transfer in water resource management can be an essential step. Therefore, it needs to be presented on the table of policymakers and academicians. The capacity building and awareness campaign must be prepared for making the masses aware. Serious participation of people in water management practices has to be included. Developing resource morality for making efficient use of water resources has to be instilled in people across all strata. Building capacity for water resources is also needed for managers as well as users and developers for updating and implementing the knowledge and latest technology in the sector of water resources management. The book is an attempt to address all these issues and to create a responsible academic contribution to the field of sustainable water resource management.

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3 Forecast Changes in Runoff for the Neman River Basin

A. A. Volchak and S. Parfomuk

Abstract

Changes in river runoff for the Neman River basin using two scenarios of economic development and climate change (A1B and B1) were forecasted. The data sources are based on the materials for the 24 hydrological stations since 1961 till 2009 and 23 meteorological stations since 1961 till 2010 at the Neman River in Belarus and Lithuania. During the research, we devised a multi-factor model based on joint solution of the equations for water and thermal balances. Modeling the water balance was realized in a computer program. The results for the A1B scenario indicate the increasing of runoff from 7.4% to 33.9%. Scenario B1 has shown change in runoff from 1.9% to 21.6%.

Keywords

Runoff · Water · Balance · Model · Forecast · Change · Neman river

3.1 Introduction

The main hydrological parameters of the river runoff are not stable. These parameters change constantly under the influence of the complex variety of factors. The combination of these factors can be divided into climatic and anthropogenic those differ by the nature and consequences of impact on water resources (Water Resources 2012).

Natural causes determine spatial-temporal variations of water resources under the influence of the annual and secular climatic conditions. Intra-annual fluctuations occur constantly and consistently. Secular variations occur slowly and cover quite extensive areas. These variations are typically quasi-periodic and tend to some constant value. Studies show that in historical time, these deviations were not progressive. Periods of cooling and warming, dry and wet alternating in time and the general condition of water resources and their quality do not change significantly. The main feature of the natural reasons is that the changes have not unilateral tendencies (The Blue Book 1994).

Anthropogenic causes are the result of various human activities. They affect water resources and water quality relatively quickly and unilaterally, and this is their main difference from natural causes. The economic activities causing changes in quantitative and qualitative parameters of water resources are diverse and depend on the

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_3

physiographic conditions of the territory, the characteristics of its water regime and the nature of the use (Water Resources 2012).

The climate change and the increasing of anthropogenous effect on the river runoff during the last 20–30 years are observed. Hydrological regime for the Neman River basin is determined by the natural fluctuations of meteorological elements and anthropogenic factors. In this case, the role of the anthropogenic factors increases every year despite the economic downturn, and inadequate attention to these factors may lead to significant errors in the determination of estimated parameters (Ikonnikov et al. 2003; Volchak and Kirvel 2013).

The aim of our research is the forecasting changes in river runoff for the Neman River basin using two scenarios of economic development and climate change (A1B and B1).

Research performed under the UNDP project 00079039 "Management of the Neman River basin with account of adaptation to climate change".

3.2 Data Sources

The Neman River basin is shown in Fig. 3.1 (Korneev et al. 2014).

The data sources are based on the materials for the 24 hydrological stations at the Neman River in Belarus and Lithuania since 1961 till 2009 (Table 3.1).

The climatic information consisted of the air temperature, precipitation and deficits of air humidity since 1961 till 2010 for 23 meteorological stations were used (Table 3.2).

3.3 Research Methods

For the research purposes, Mezentsev's method of the hydrological-climatic calculations was adapted. The method is based on joint solution of the equations for water and thermal balances (Mezentsev 1995). During the research, we devised a multi-factor model that includes the standard equation of water balance. The developed model is used to assess the possible changes in runoff according to the various hypotheses of climate fluctuations and anthropogenic impacts on water resources.

The equation of water balance is following:

$$H(I) = E(I) + Y_K(I) \pm \Delta W(I), \qquad (1)$$

where $H(I)$—total humidity, mm; E(I)—total evaporation, mm; $Y_K(I)$—total calculated runoff, mm; $\Delta W(I)$—changes of humidity reserves of the active soil layer, mm; I—interval of averaging.

The total evaporation is given by:

$$E(I) = E_m(I)\left[1 + \left(\frac{\frac{E_m(I)}{W_{HB}} + V(I)^{1-r(I)}}{\frac{KX(I)+g(I)}{W_{HB}} + V(I)}\right)^{n(I)}\right]^{-\frac{1}{n(I)}}, \qquad (2)$$

where $E_m(I)$—maximum total evaporation, mm; W_{HB}—minimum humidity ratio of the soil, mm; $V(I) = W(I)/W_{HB}$—relative index of the humidity of soils at the beginning of calculating; $KX(I)$—sum of precipitation, mm; $g(I)$—soil–water balance component, mm; $r(I)$—parameter depending on water physical properties and mechanical composition of soils; $n(I)$—parameter depending on physical–geographical conditions of runoff.

Relative index of the soil humidity at the end of calculation period is determined from the following relations

$$V(I+1) = V(I)\cdot\left(\frac{V_{av}(I)}{V(I)}\right)^{r(I)}; \qquad (3)$$

$$V_{av}(I) = \left(\frac{\frac{KX(I)+g(I)}{W_{HB}} + V(I)}{\frac{E_m(I)}{W_{HB}} + V(I)^{1-r(I)}}\right)^{\frac{1}{r(I)}}. \qquad (4)$$

The values $V_{av}(I)$ are compared with the relative index of the total humidity V_{TH}. If $V_{av}(I)$ V_{TH} then must be taken the calculated value of the relative average humidity, otherwise, when $V_{av}(I) \geq V_{TH}$ then taken $V_{av}(I) = V_{TH}$ and the value $(V_{av}(I)\text{-}V_{TH})\cdot W_{HB}$ refers to surface runoff.

The maximum total evaporation is according to the method described in Volchak (1986).

Fig. 3.1 The Neman River basin

The thermal resources of the evaporation process for any calculation period are defined as:

$$LE_{mi} = R_i^+ + P_i^+ \pm \Delta B_i - \Delta E_{0i}, \qquad (5)$$

where E_{mi}—the equivalent of the thermal resources by the maximum possible evaporation, m; L—the latent warmth of evaporation, j/m^3; R_i^+—the positive component of the radiation balance, j/m^2; P_i^+—the positive component of turbulent warmth transfer, j/m^2; ΔB_i—changes of the warmth stocks of the active layer of soil, j/m^2; ΔE_{0i}—warmth consumption for melting of snow, ice, the warming of the soil, j/m^2.

Due to the limitations of the initial data for the radiation regime and turbulent warmth transfer, it is difficult to use the Eq. (5) in practical calculations. Studies have shown that the optimal distance between actinometric stations should be no more than 100 km. In the existing network of actinometric stations, this condition is not satisfied. Therefore, one needs to find the connection elements of the radiation balance with the climatic parameters.

Currently, there are a lot of dependencies to determine the annual standards of E_0 in the case of Belarus by the sum of temperatures above 10 °C. We have found the approximate solution of

Table 3.1 Hydrological stations

River	Station	Coordinates		Basin area, km^2
		Longitude	Latitude	
Neman	Stolbtsy	26° 42′ 56″ E	53° 28′ 43″ N	3070
Neman	Mosty	24° 32′ 10″ E	53° 24′ 11″ N	25600
Neman	Grodno	23° 48′ 23″ E	53° 40′ 43″ N	33600
Isloch	Borovikovshina	26° 44′ 16″ E	53° 57′ 26″ N	624
Gavya	Lubiniata	25° 38′ 40″ E	53° 59′ 26″ N	920
Schara	Slonim	25° 19′ 37″ E	53° 04′ 56″ N	4860
Svisloch	Sukhaya Dolina	24° 01′ 33″ E	53° 28′ 04″ N	1720
Vilija	Steshytsy	27° 23′ 39″ E	54° 33′ 50″ N	1200
Vilija	Mikhalishki	26° 09′ 59″ E	54° 48′ 50″ N	10300
Naroch	Naroch	26° 43′ 33″ E	54° 33′ 24″ N	1480
Oshmyanka	Bolshiye Yatsiny	26° 12′ 57″ E	54° 44′ 27″ N	1480
Dubysa	Lyduvenai	23° 5′ 14.1″ E	55° 30′ 23.1″ N	1134
Jūra	Taurage	22° 16′ 45.0″ E	55° 15′ 4.0″ N	1664
Merkys	Puvociai	24° 18′ 12.0″ E	54° 7′ 4.3″ N	4300
Šešupė	K. Naujamestis	22° 51′ 49.2″ E	54° 46′ 37.5″ N	3179
Minija	Kartena	21° 28′ 48.2″ E	55° 54′ 59.2″ N	1230
Šventoji	Anykščiai	25° 5′ 52.7″ E	55° 31′ 29.9″ N	3600
Šventoji	Ukmerge	24° 46′ 8.0″ E	55° 14′ 48.0″ N	5440
Žeimena	Pabrade	25° 46′ 21.0″ E	54° 59′ 1.7″ N	2580
Nemunas	Druskininkai	23° 58′ 48.7″ E	54° 1′ 9.4″ N	37100
Nemunas	Nemajūnai	24° 4′ 26.3″ E	54° 33′ 14.8″ N	42800
Nemunas	Smalininkai	22° 35′ 15.6″ E	55° 4′ 22.3″ N	81200
Neris	Vilnius	25° 16′ 36.5″ E	54° 41′ 31.1″ N	15200
Neris	Jonava	24° 16′ 54.9″ E	55°4′ 10.2″ N	24600

Eq. (5) for the monthly time intervals (Volchak1986). Based on the modal analysis of the available initial data from the actinometrical stations, the quantitative relation of the monthly values of the positive component of the radiation balance with the air humidity deficit was calculated. It is noteworthy that for all geographical areas, the type of relation is constant in general. The reasons for nonlinearity and hysteresis in this context are that the positive component of the radiation balance is one of the components of Eq. (5), which has warmth expenditure on evaporation, turbulent warmth exchange with the atmosphere and change the warmth content of the soil. The deficit of air humidity only characterizes the intensity of turbulent exchange with the atmosphere. In accordance with the sign of warmth transfer in soils and the intensity of warmth spent for evaporation changes of air humidity deficit in the first half of the year occurs on the convex curve and in the second—on the line. The effect of hysteresis increases with the continentality increasing, i.e. for the Neman River basin it means moving from North to South and from West to East.

The dependencies are corrected according to the available initial data for the conditions of the Neman River basin. An analytical approximation of the ascending and descending branches of the hysteresis was found.

Table 3.2 Meteorological stations

Station	Coordinates		
	Latitude	Longitude	Altitude, m
Baranovichi	53° 07′ 54″	25° 58′ 16″	193
Grodno	53° 36′ 13″	24° 02′ 39″	148
Volkovyssk	53° 08′ 05″	24° 27′ 34″	193
Lida	53° 54′ 25″	25° 19′ 24″	157
Novogrudok	53° 35′ 48″	25° 51′ 04″	280
Vileika	54° 30′ 25″	26° 59′ 23″	165
Volozhin	54° 05′ 42″	26° 30′ 56″	228
Naroch	54° 53′ 52″	26° 40′ 56″	171
Kaunas	54° 53′	23° 50′	76
Kybartai	54° 38′	22° 47′	58
Laukuva	55° 37′	22° 14′	165
Lazdijai	54° 14′	23° 31′	133
Panevėžys	55° 45′	24° 23′	57
Raseiniai	55° 23′	23° 07′	111
Šilutė	55° 21′	21° 28′	4
Ukmergė	55° 15′	24° 46′	72
Utena	55° 32′	25° 36′	105
Varėna	54° 15′	24° 33′	109
Vilnius	54° 38′	25° 06′	162
Biržai	56° 12′	24° 46′	60
Klaipėda	55° 44′	21° 04′	6
Šiauliai	55° 56′	23° 19′	106
Telšiai	55° 58′	22° 15′	153

The ascending branch for the period of growth of the air humidity deficits is as following

$$R^{+}_{Mi} = 2.26 + 6.77 \cdot \lg d_{Mi} \quad if \;\; d_{Mi} \leq d_{Mi+1}. \quad (6)$$

The descending branch for period of decreasing of the air humidity deficits is as following

$$R^{+}_{Mi} = 1.06 d_{Mi} \quad if \;\; d_{Mi} > d_{Mi+1}, \quad (7)$$

where d_{Mi}—the mean monthly values of the air humidity deficits, millibar.

Equations (6) and (7) are characterized by the correlation coefficients, respectively $r = 0.965 \pm 0.006$; $r = 0.945 \pm 0.010$ and values of the Fisher test, respectively $F = 14.31$; $F = 9.45$, which are much more acceptable at the 1% level of significance $F^{T}_{(107,\,106,\,1\,\%)} = 1.643$. Therefore, the obtained equations are statistically significant.

Without taking into account the phenomenon of hysteresis, the averaged equation is:

$$R^{+}_{Mi} = 1.79 + 6.59 \cdot \lg d_{Mi}, \quad (8)$$

$r = 0.937 \pm 0.007$; $F = 8.29 > F^{T}_{(215,\,214,\,1\,\%)} = 1.533$

The annual value of advective warmth is determined by the ratio (Mezentsev and Karnatsevich 1969):

$$P^{+}_{\Gamma} = 6.8 - 0.082 \cdot R_{\Gamma}, \quad (9)$$

where R_{Γ}—concentrated radiation balance, kcal/cm^2.

The positive radiation balance R^+ for the territory of Eastern Europe can be fairly accurately calculated using the dependence:

$$R_\Gamma^+ = 1.17 \cdot R_\Gamma + 2.10, (r = 0.995 \pm 0.002) \quad (10)$$

For the months, a similar dependence is offered:

$$R_{Mi}^+ = 1.0 \cdot R_M + 0.77, \quad (11)$$

($r = 0.985 \pm 0.002$; $F = 45.67 > F^T_{(215, 214, 1\,\%)} = 1.533$).

Taking into account formula (10), the Eq. (9) takes the form:

$$P_\Gamma^+ = 6.65 - 0.07 \cdot R_\Gamma^+ \quad (12)$$

The annual distribution of the positive component of turbulent warmth transfer (P) is as following (Belonenko and Valuev 1974):

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
12	12	9	7	6.5	5.5	6.5	6.5	6.5	7.5	10	11	100%

The changes in the warmth stocks of the active layer of soil ΔB are significantly less than the values of radiation balance. For this calculation, there are not always available data, so the calculation is made approximately using the data tables of the annual warmth exchange in the soil depending on annual amplitudes of air temperature and warmth transfer in the soil (Budyko 1971).

The winter climate in Belarus has a substantial impact of the Atlantic Ocean, causing frequent and prolonged thaws throughout the winter. In this regard, the correction to the melting of snow and frozen ground was distributed for the colder months and is equally determined by following equation (Marchuk 1982):

$$\Delta E_m = \frac{L_1}{L} \cdot (1.4 \cdot W_{CH} + W_{\Gamma P}), \quad (13)$$

where W_{CH}, $W_{\Gamma P}$—the water reserves in snow and frozen soil layer; L—latent warmth of melting water.

The parameter n was determined using the value of the maximum total evaporation under optimal moistening of the active layer of soil. Expressing the conditions of runoff formation using the average slope of the basin area and the coefficient of roughness, which in turn depends on the hydraulic radius or average depth of runoff, one can determine the parameter n (Mezentsev 1982).

The parameter n adopted differentiated both within the territory and years and varied in the range of 2.5–3.4. Analysis of data on runoff, precipitation and maximum total evaporation for the Neman River basin have shown the correctness of chosen parameter n.

The total humidity is defined as follows:

$$H(I) = KX(I) + W_{HB}(V(I) - V(I+1)). \quad (14)$$

The solution of the equations system (1)–(4) is carried out iteratively. During calculating the initial value of the humidity is taken equal to the value of the minimum humidity ratio of the soil, i.e. $W(1) = W_{HB}$, where $V(1) = 1$. The convergence of the solution method is achieved for the fourth step of the calculation.

Adjustment of the calculated runoff is carried out using coefficients that take into account the influence of various factors on the formation of the measured runoff, i.e.

$$Y_P(I) = k(I) \cdot Y_K(I), \quad (15)$$

where $Y_P(I)$—total measured runoff, mm; $k(I)$—coefficient taking into account the hydrographic parameters of the basin.

Modeling the water balance of the river is realized in a computer program and is performed in two stages. The first step is to configure the model for known components of water and thermal balances of the studied river. The first stage ends with plotting the calculated and measured runoff figures and outputting the modeling error. The example of modeling average annual runoff and its intra-annual distribution is shown in Fig. 3.2.

The measured and calculated runoffs are very close; therefore the model is correct. The obtained model parameters were used for the numerical experiment.

The second stage is a direct modeling the water balance of the river using the parameters

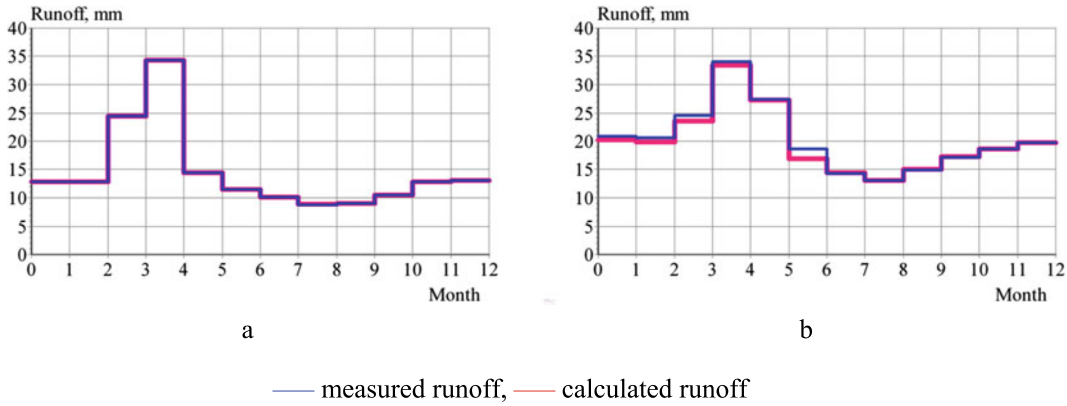

Fig. 3.2 Measured and calculated runoff (**a**—for the Neman River at the Stolbtsy station; **b**—for the Žeimena River at the Pabrade Station)

obtained during model calibration. The calculation of the water balance is tailored to the specific characteristics of the studied river. The simulation results indicate high accuracy of the calculation of the water balance for both practical applications and theoretical studies that tested for a lot of rivers in Belarus with basin area of about 1000 km^2 (Volchak and Parfamuk 2007).

Thus, the developed computer program with available data on precipitation, air temperature, air humidity deficits and modern values of the water runoff, as well as hydrographic parameters of the basin provide forecast values of the water balance of rivers.

The technique of simulation has been tested on almost all climatic parameters that gave the opportunity to attract additional large amount of hydrometeorological information that are included in the balance equations.

When setting up models by the proposed method have problems with the definition of parameters for the winter months. The fact that the model did not accurately include the thaw for the recent years. Therefore, we conducted an adjustment model taking into account the thaw. The obtained difference between measured and calculated runoff treated runoff formed during thaws, which were recorded in the settings of the model. When forecasting runoff, this component was added directly to the runoff and its value was subtracted from precipitation. The values of runoff during thaws were adjusted for the predicted temperature of the corresponding month. In the first approximation, the value of runoff can be taken from the ratio of monthly air temperatures and runoff during the period of thaw.

Forecasting changes of river runoff for the Neman River basin were carried out by the following scheme. The model was adjusted for average long-term data on river runoff, atmosphere precipitation, air temperature and deficits of air humidity, obtained parameters remained in computer. Then entered forecast value for those weather stations that were used in the setting model. The last stage was reading the settings of the model and carrying out the runoff forecast.

3.4 Discussion of the Results

Runoff forecasts for 24 rivers in the Neman River basin for two scenarios of A1B and B1 climate change were done in two options. The first option is forecasting without considering the thaw and the second option with regard to thaw. The results consist of the model configuration as well as modern and forecast calculated values of the river runoff. Based on the analysis of the obtained forecasts, the changes in river runoff for the Neman River basin preference should be given to the second option.

Tables 3.3 and 3.4 show the forecasted values of runoff changes for the two scenarios of climate change in percent to the modern level.

Table 3.3 Forecast changes in runoff for the A1B scenario in 2035, % to 2009

River	Station	January	February	March	April	May	June	July	August	September	October	November	December	Year
Neman	Stolbtsy	117.1	119.2	111.8	112.5	130.6	197.4	61.4	67.6	130.0	89.4	102.3	114.5	114.3
Neman	Mosty	118.8	124.8	126.2	111.8	153.6	178.3	98.2	99.1	102.5	66.2	110.9	116.5	119.0
Neman	Grodno	123.3	124.6	102.9	129.0	173.0	134.4	95.3	100.6	105.9	84.6	109.3	123.6	120.3
Isloch	Borovikovshina	123.5	123.1	113.5	114.5	145.1	207.6	82.0	90.6	102.3	90.8	103.9	118.9	118.1
Gavya	Lubiniata	123.5	120.5	101.1	121.1	186.9	173.3	96.3	81.1	102.4	83.8	118.4	123.9	119.8
Schara	Slonim	115.9	116.5	115.1	115.9	160.0	178.3	85.8	77.2	143.7	93.9	106.7	114.8	120.8
Svisloch	Sukhaya Dolina	118.8	127.1	94.3	121.6	177.3	115.7	79.4	97.0	104.3	81.9	108.5	121.9	113.0
Vilija	Steshytsy	119.9	116.9	116.5	109.2	137.5	143.2	82.0	72.3	71.7	94.2	98.7	114.7	108.6
Vilija	Mikhalishki	119.1	111.9	99.0	112.9	176.0	109.8	109.2	67.0	69.8	100.0	105.0	114.9	110.3
Naroch	Naroch	118.5	113.0	107.8	108.4	140.4	146.2	151.7	95.2	72.8	95.7	98.8	114.6	113.8
Oshmyanka	Bolshiye Yatsiny	121.3	119.5	116.4	118.6	133.9	228.3	78.8	88.1	102.2	91.0	103.4	117.7	118.9
Dubysa	Lyduvenai	128.6	125.3	109.2	130.9	48.6	93.3	150.9	66.8	128.1	116.2	116.9	124.9	115.7
Jūra	Taurage	134.0	126.7	143.5	107.7	276.2	159.2	168.3	133.8	128.6	118.7	114.8	130.1	133.9
Merkys	Puvociai	131.0	127.6	107.3	127.7	152.3	74.5	100.0	94.6	104.5	93.0	113.7	128.5	112.8
Šešupė	K. Naujamestis	129.9	134.6	116.0	129.0	201.7	106.5	108.8	228.0	147.0	104.4	111.3	125.0	132.3
Minija	Kartena	152.6	132.9	98.9	129.8	81.8	74.8	140.7	144.1	142.3	133.4	119.0	151.2	126.4
Šventoji	Anykščiai	129.9	123.7	106.8	114.0	198.0	119.1	170.1	119.0	131.5	114.8	112.3	126.2	127.8
Šventoji	Ukmerge	144.3	132.2	103.3	122.7	53.9	61.5	79.9	132.1	112.6	128.2	118.2	127.9	107.4
Žeimena	Pabrade	133.2	124.6	95.9	134.3	188.9	147.3	138.9	44.4	106.0	86.6	114.4	127.3	124.8
Nemunas	Druskininkai	118.9	123.9	112.2	114.0	135.2	99.2	70.1	106.9	107.9	82.9	109.6	118.9	111.1
Nemunas	Nemajūnai	117.4	118.1	144.6	115.4	142.4	160.0	113.0	126.2	117.5	86.0	110.3	119.2	123.8
Nemunas	Smalininkai	128.8	131.4	105.5	130.7	164.2	132.5	106.3	119.2	112.4	82.6	111.2	125.7	122.6
Neris	Vilnius	136.6	132.2	107.7	138.6	138.5	60.9	102.4	104.9	101.5	91.1	114.0	129.3	114.4
Neris	Jonava	128.7	126.8	155.1	117.9	154.4	161.9	135.0	142.2	122.9	92.0	111.0	123.6	131.4

Table 3.4 Forecast changes in runoff for the B1 scenario in 2035, % to 2009

River	Station	January	February	March	April	May	June	July	August	September	October	November	December	Year
Neman	Stolbtsy	106.2	111.5	112.2	90.7	110.4	187.8	25.5	64.5	133.3	109.5	110.2	114.5	105.7
Neman	Mosty	105.3	113.1	112.1	100.0	142.9	172.9	65.9	82.5	144.7	94.0	105.8	116.5	112.8
Neman	Grodno	102.3	114.9	101.9	111.4	138.0	134.4	77.5	78.2	157.8	104.4	103.1	121.1	112.8
Isloch	Borovikovshina	113.6	116.3	116.7	90.8	126.8	195.9	106.0	92.9	120.0	103.5	108.4	125.2	115.3
Gavya	Lubiniata	100.0	110.0	111.7	91.4	151.9	153.3	128.1	38.7	136.0	109.4	115.7	122.8	113.8
Schara	Slonim	101.8	107.8	108.6	97.1	134.4	172.6	61.2	76.3	153.3	113.5	115.0	113.0	112.3
Svisloch	Sukhaya Dolina	93.2	113.9	100.0	102.2	142.2	114.7	58.8	84.6	161.1	105.4	102.3	118.2	107.4
Vilija	Steshytsy	102.0	105.4	111.2	87.5	107.6	147.7	110.1	107.3	104.0	110.8	98.7	118.6	107.1
Vilija	Mikhalishki	98.5	100.0	102.9	90.6	137.7	128.8	139.5	90.4	106.1	118.1	104.3	117.9	109.2
Naroch	Naroch	101.3	103.9	119.8	84.4	107.9	151.7	85.1	84.2	100.9	111.6	98.8	119.5	105.2
Oshmyanka	Bolshiye Yatsiny	114.0	112.8	107.1	92.9	124.7	208.3	110.9	103.0	122.6	102.6	108.0	124.6	117.0
Dubysa	Lyduvenai	116.1	113.4	106.7	110.5	58.8	111.3	79.6	68.9	169.4	143.1	114.6	128.4	111.6
Jūra	Taurage	112.1	112.4	118.6	98.9	181.1	197.1	114.6	89.2	144.4	132.8	110.7	129.7	120.7
Merkys	Puvociai	103.8	117.8	109.7	109.1	128.6	56.4	77.8	98.6	144.2	111.0	108.2	125.8	106.6
Šešupė	K. Naujamestis	111.5	117.6	107.3	113.4	181.5	153.5	80.4	144.9	127.8	114.5	94.8	125.7	119.9
Minija	Kartena	105.0	113.9	103.5	100.5	67.3	77.9	84.7	107.9	134.5	169.2	116.2	142.0	114.5
Šventoji	Anykščiai	113.7	110.0	113.6	100.2	146.5	128.2	110.0	102.8	134.3	133.8	106.4	126.2	116.6
Šventoji	Ukmerge	119.8	118.8	104.7	108.1	66.4	78.8	61.3	101.3	74.0	156.5	122.0	129.1	101.9
Žeimena	Pabrade	102.4	114.3	99.6	108.7	169.3	149.5	133.3	61.8	120.0	120.3	108.6	124.2	119.4
Nemunas	Druskininkai	100.0	112.3	114.6	95.0	110.9	92.7	52.5	95.2	139.7	105.5	110.4	118.0	102.3
Nemunas	Nemajūnai	100.7	110.4	115.5	102.0	119.2	157.7	140.0	140.8	166.0	107.4	108.1	118.5	119.9
Nemunas	Smalininkai	103.9	117.0	103.0	112.9	140.3	158.7	79.5	81.5	141.9	105.8	100.0	125.0	114.2
Neris	Vilnius	108.5	119.1	114.0	111.6	110.9	47.6	83.5	99.2	122.1	119.2	107.0	127.3	105.0
Neris	Jonava	111.4	116.5	127.5	106.3	135.8	173.1	116.2	99.1	124.6	115.2	111.0	126.1	121.6

3.5 Conclusion

As a result of research, we developed a mathematical model to forecast runoff for the Neman River basin. Modeling of runoff changes for the two scenarios of climate change A1B and B1 taking into account the thaw was carried out. The results for the A1B scenario indicate the increasing of runoff from 7.4% for the Šventoji River to 33.9% for the Jūra River. Scenario B1 has shown a minor change in runoff from 1.9% for the Šventoji River up to 21.6% for the Neris River.

Development of compensation measures to reduce impacts from increased runoff of the Neman River is the subject of further research.

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4 Integrated Water Resources Management in Southern Africa Two Decades After the Dublin Conference: The Zimbabwean Experience

Geoffrey Mukwada, Desmond Manatsa, and Enock Makwara

Abstract

Integrated Water Resources Management (IWRM) has increasingly become an important rallying theme for addressing the governance and management of water resources. The objective of this chapter is to examine how IWRM is perceived in southern Africa and the challenges of applying this concept in water resources governance and management within the region, using the case study of Zimbabwe. Due to mixed views among researchers, there is an ongoing debate about the extent to which the implementation of IWRM has succeeded in the country. However, at grassroots community level, the implementation of IWRM is constrained due to the limited choices that these communities have. Due to poverty, these communities depend directly on land-based resources for livelihood, many of which lead to environmental degradation, which in turn undermine the availability of water in the environment. Despite all these limitations, community-based institutions are better placed to pursue IWRM than state-sponsored institutions.

Keywords

IWRM · Resource · Governance · Management · Southern Africa · Zimbabwean

4.1 Introduction

In 2014, more than two decades after the Dublin principles were proclaimed, the World Economic Forum (WEF) ranked water crises as one of the highest risks of concern (WEF 2014). While the famous 1992 International Conference on Water and the Environment, dubbed the Dublin Conference, had come and gone water problems remained critical across the globe, and to this day many human communities still do not have access to clean water despite the noble promises that were made at the conference. Since then Integrated Water Resources Management (IWRM) has increasingly become an important rallying theme for addressing the governance and management of water resources. The IWRM has become the most preferred framework for attaining water resources management (Manyanhaire and Nyaruwata 2014). IWRM is a

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_4

holistic approach to water resources management in which water-related ecological/environmental, social, and economic needs within an area (which could be a water basin, hydrological zone or an entire country) are met simultaneously (GWP 2000a). The scale at which this management takes place has to be appropriate (OECD Principles on Water Governance 2015). Gallego-Ayala and Juízo (2011) define IWRM as an approach to water development management that seeks a balance between the three dimensions of sustainable development, namely economic efficiency, social equity and environmental sustainability. Therefore, in its comprehensive form, IWRM is a complex multiple dimensional process in which multiple stakeholders, who are usually drawn from different sectors, are involved in the governance of water resources to ensure the sustainability of these resources. In southern Africa, IWRM has been touted as the solution to the numerous water problems bedeviling the region. It could even be used as way of averting transboundary water-related conflicts facing this region. Petersen-Perlman (2016), for instance, noted that hyropolitical conflicts are looming among states that share the Zambezi River Basin.

The call for IWRM is implied in Paragraph 1 of Chap. 18 of Agenda 21, which calls for the increasing need to manage freshwater resources as an integral and indispensable component of the global hydrosphere, biosphere and terrestrial ecosystems (United Nations 1992). Since its establishment in 1996, the Global Water Partnership (GWP) has been at the center stage of IWRM. For IWRM to succeed, GPW (2000a) recommends the development of an enabling environment through appropriate policies, legal instruments and financial support, as well as development of strong institutional structures and capacity building. However, in many developing countries, these requirements are non-existent due to a wide range of factors, some of which are linked to poverty.

While the ideals enshrined in the principles noted above are noble, it is also apparent that water managers, policymakers or water ministries and departments cannot resolve water problems individually, rendering collective efforts necessary. The realization that water-related problems are increasing in complexity due to the rapid changes brought about by demographic shifts, land use and land cover changes, as well as climate change and variability, requires a multi-dimensional approach to resolving water issues. Unlike in the past, demographic changes related to population growth and urbanization are exerting enormous pressure on water resources, adding to already escalating demands for water from industry, agriculture and leisure. Yet, the availability and quality of water resources are already strained by threats from climate change and variability, making it extremely difficult for society to balance water needs and what the environment can actually provide.

The objective of this chapter is to examine how IWRM is perceived in southern Africa and the challenges of applying this concept in water resources governance and management within the region, using the case study of Zimbabwe. Due to mixed views among researchers, there is an ongoing debate about the extent to which the implementation of IWRM has succeeded in the country (Dube and Swatuk 2002; Van der Zaag 2005; Saravanan et al. 2009; Butterworth et al. 2010). In our contribution to this debate, we use the case study of Zimbabwe's IWRM programme to illustrate how global developments in the water sector have influenced water resource management strategies in southern Africa and in the process shaping national water policies and management practices at the grassroots community level.

IWRM sought to accelerate the devolution of responsibilities to water users and build transparent and accountable mechanisms for resource allocations (GWP 2000). For instance, based on the principle of subsidiarity, Zimbabwe's Zimbabwe National Water Act (ZINWA) Act of 1998 handed the mandate of water resources management to the 'lowest appropriate authority', with the view to enhance efficiency, accountability and stakeholder participation in the management of water resources at the 'lowest appropriate level', that is grassroots community level.

The chapter is organized as follows. First, we relate to the historical background surrounding the adoption of the IWRM concept, then use content analysis of the national policy and empirical evidence from the Turwi River Basin to identify some of the conditions that favor the adoption of IWRM as well as the challenges that make it difficult to implement IWRM in the basin. While we discuss the importance of national policy in water resource management, we use empirical evidence from the Tuwri Basin to highlight the constraints militating against IWRM at grassroots community level, where it should matter the most. We explore how local communities are involved in IWRM by examining the sources of water resources at grassroots community level, how they interact with those resources and manage them alongside other stakeholders, including state institutions, and finally discuss the challenges of implementing IWRM at that level.

There are two central questions guiding the analysis of the role of grassroots communities in IWRM. The first is about whether grassroots communities are the appropriate level for the implementation of IWRM, while the second question is about whether these communities have the capacity to implement IWRM. These questions can help us to distinguish what grassroots communities can do and what they cannot do, as well as the conditions that apply to both. Accordingly, we draw from empirical evidence derived from focus group discussions (FDGs) and interviews to determine if the principles and objectives of reforming the water sector can be met at the local level in line with the 'principle of subsidiarity'. Our principal aim is to test if the objectives of IWRM that are prescribed in the Water Act of 1998, in line with the Dublin Principles, are achievable at that level. Is it possible to apply the polluter pays principle at the grassroots community level? Do local communities recognize the environment as a legitimate user of water that should be provided with its own share of the resource? Are the Catchment and Sub-Catchment Councils that were set up effective and appropriate state institutions for the successful implementation of IWRM? Which other institutions have the legitimacy to facilitate IWRM? How effective is the coordination of the parastatals involved in the development, management, utilization and conservation of water resources at the local level. Do local communities have the resources required for them to implement IWRM? It is these questions that we address in the remaining part of this chapter.

4.2 Historical Background of IWRM in Southern Africa

In southern Africa, there is a growing understanding of the need to implement IWRM. However, while governments are aware of the possible role that IWRM could play in promoting economic growth and social development there are many unknowns and factors that hinder its full adoption and hence implementation. In this section, we first highlight the Dublin Principles and the proceed to address factors that influence access to water, its management and governance, including its scarcity due to climate change.

The adoption of Agenda 21 provided the world with the opportunity to adopt programs, projects and strategies for implementing the four Dublin Principles. The first of these principles observes that freshwater is a finite and vulnerable resource, essential for sustaining life, development and the environment. Since water resources sustain both livelihoods and ecological systems, its effective management demands a holistic approach, which provides a mechanism for, linking social and economic development with the protection of natural ecosystems. The second principle proclaims that water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels. This principle suggests that every water user from grassroots level right up to the elites should be involved in water resources management. According to this principle, everybody has a stake in water resources and should thus be involved in its management. The third principle pronounces the importance of allowing women to be involved in issues to do with water. This principle is based on the reality that in most parts of the world women play a crucial role in providing and managing water in the communities in which they live. Globally, women are also the ones who are mostly involved in agriculture and therefore the role that they play in managing the water resources required in the agriculture sector is important for enhancing food security and poverty reduction. The fourth principle presents water as both an economic and social good, the pricing of which must mirror its true worth. In southern Africa, these principles have resonated with recent government policies and programs, most of which have set the foundation for IWRM as a working strategy.

It is therefore not surprising that in southern Africa, a number of regional water resource development and management initiatives have been associated with IWRM, including those resulting from inter-state cooperation and civic partnerships. One example of inter-state initiative was the formation of the Southern Africa Development Committee (SADC) Water Sector Coordination Unit in 1997, which eventually led to the signing of the SADC Protocol on Shared Watercourses among member states. In this initiative, SADC member states agreed to collaborate and create a platform for negotiating how the region's limited water resources can be utilized (Gallego-Ayala and Juízo 2011). Van der Zaag (2005) notes that this development took place at the same time that the United Nations General Assembly adopted the Convention on the Law of the Non-Navigational Uses of International Watercourses in New York in 1997. Shortly afterwards, in 1998 international cooperation between SADC and European Union states led to a planning workshop held by water ministers from the two regions and subsequently the founding of the Water Research Fund for Southern Africa (WARFSA) and WaterNet in 1999 and 2000, respectively (Van der Zaag 2005). WARFSA has been instrumental in promoting advanced training and research in IWRM in the region.

These inter-regional efforts complemented global developments that were sponsored by the United Nations, through its official organ, UN-Water. UN-Water was mandated to make a follow-up on water decisions that had been adopted at the 2002 World Summit on Sustainable Development and the subsequent Millennium Development Goals (MDGs) (Saravanan et al. 2009), one of which sought to provide safe drinking water and sanitation to the majority of the global citizenry by 2015. IWRM was seen as a critical aspect of solving global water problems. Consequently, the United Nations Development Programme placed emphasis on IWRM through effective water resource governance (Saravanan et al. 2009).

A parallel initiative has been driven by the Southern African Chapter of the GPW. Regional networks such as the GWP Regional Technical Advisory Committee and bilateral donors were active in the uptake and dissemination of ideas about water governance within the context of IWRM. Some donors have been instrumental in promoting IWRM within the region. For example, the German Technical Cooperation (GTZ) established an international IWRM Network that acted as an 'incentive for government and institutions to optimize water resources management'. Piloting began in southern Africa because of a perceived 'broad acceptance' of the IWRM approach by regional actors. At that time a key aspect of IWRM which was highlighted in the Framework for Action (FFA) by the GWP (2000a) is the devolution of water resource management to water users and user groups. The FFA advocated the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP 2000a). This approach sought to accelerate the devolution of responsibilities to water users and build transparent and accountable mechanisms for resource allocations (GWP 2000b). Many southern African countries, including South Africa, Mozambique and Zimbabwe have bought into this approach and adopted new policy structures and national plans in their water sectors in line with the approach. The Water Resources Management Strategy (WRMS) for Zimbabwe, for instance, was entitled 'Towards Integrated Water Resources Management', in conformity with the spirit of IWRM.

Other important regional initiatives on collaborative water resources management include the Regional Strategic Action Plan on IWRM Development and Planning, Regional Water Policy and Regional Water Strategy, which sought the adoption of a common approach to the management of the region's water resources. Consequently, over the past two decades, SADC countries have been working on a unified regional policy and an institutional water management framework, whose purpose is to encourage member states to synchronize their country policies and strategies for the development and management of the region's shared water resources. The current regional framework for water resources development and management advocates the adoption of IWRM principles and tools by all member states to create a common platform for regional integration and create equal opportunities for member states. Thus, most SADC countries are at various stages of implementing the IWRM framework.

However, in southern Africa, water resources management has been complicated by climatic variability (Gallego-Ayala and Juízo 2011). The 2007 Intergovernmental Panel on Climate Change report notes that southern Africa is one of the regions that are most vulnerable to climate change in Africa. Climate change has the potential to exacerbate water supply and demand pressures in southern Africa (Kusangaya et al. 2014). In recent years, the frequency and intensity of the occurrence of both droughts and floods have been increasing. In 2016, Zimbabwe and Malawi declared a state of disaster and emergency, respectively, due to drought. Climate change calls for southern African countries to develop new water resources development and management frameworks as well as competency in governance, accountability and the upholding of the rule of law (World Bank 2010, 2015), with the overall goal of promoting social and economic development. While water-related challenges can be location specific, there is an element of homogeneity regarding the way the role water plays in the development needs and aspirations of communities across the region. SADC countries also experienced common problems regarding to water governance and management. For example, in South Africa and Zimbabwe, there were serious distortions and inequities regarding access to water by the general populace. In these countries, Whites had better access to water compared with Blacks and other ethnic groups. However, even after the reforms, legal pluralism has remained intact, signifying a situation whereby custom practices co-exist with statutory law (Chikozho and Latham 2005).

In southern Africa, IWRM is viewed as central to the survival of rural communities, whose livelihoods still largely depend on rainfed agriculture. For instance, in Malawi, Botswana, Kenya, and Zimbabwe about 90%, 76%, 85%, and 70–80%, of the rural populations, respectively make their living from rainfed agriculture (Rockstrom 2000). Agriculture is generally considered as a key aspect of development and a means of improving livelihoods. Figure 4.1 shows the location of some southern African countries. In this region, there is a vast potential for using the available water resources to broaden the economic base of these countries, first by improving access to water, and second by managing the available resources in a sustainable manner.

4.3 IWRM in Zimbabwe

Zimbabwe committed itself to meeting one of the United Nations MDGs, in which it sought to provide safe drinking water and sanitation to at least two-thirds of its population by 2015 in line with government's recognition of the right to water as a fundamental human right in terms of the 1996 International Covenant on Economic, Social and Cultural Rights, to which the country is a signatory (Mutopo and Chiweshe 2014). Accordingly, the country adopted IWRM with much enthusiasm. For instance, institutional structures were established at watershed level across the whole country within 6 months,

Fig. 4.1 Location of Zimbabwe and some southern African countries. *Source* FAO 2012, http://www.eoearth.org/view/article/157012), Broken line indicates the main watershed while the area shaded in gray is the Turwi Basin

though its adoption and implementation was donor dependent (Saravanan et al. 2009). Water reforms were initiated by the state with assistance from donor states, particularly the Netherlands, UK, Sweden Norway and Germany and therefore it was a top-down process (Dube and Swatuk 2002). These reforms took place at a time when a wave of the New Public Management (NPM) approaches were being introduced to Africa and it is therefore not surprising that in Zimbabwe the initial step involved the setting up of the Water Resources Management Secretariat (WRMS), which was tasked with the responsibility of ensuring that water resources in the country are managed in an accountable, transparent, democratic and participatory way. At the same time, good governance was viewed as an important prerequisite for successful water governance and management. The WRMS spelt out the intentions of government as ensuring equal access to water by all Zimbabweans, improvement of management of water resources, increasing the protection of the environment and the administration of the Water Act.

In this chapter, we first analyze how IWRM has been conceptualized and how attempts to implement it are thwarted by a plethora of environmental, social and political conditions. We use the case study of Zimbabwe (Fig. 4.1) to illustrate how these conditions undermine water resources management in the region.

4.4 Challenges of Implementing IWRM in Zimbabwe

The challenges that undermine IWRM in Zimbabwe vary from the generic factors that affect Zimbabwe as a whole and those that affect local actors, including local communities. Among the former are conditions such as relief and drainage, prevailing climatic conditions, population growth, while the latter relate to conditions that are inherent in local communities, as noted below.

4.4.1 Relief and Drainage

Zimbabwe's major rivers radiate from a central watershed, with some rivers flowing mainly to the northwards into the Zambezi Basin and the rest southeastwards into the Save-Limpopo Basin. As shown in Fig. 4.1, Zimbabwe is characterized by a central northeast-southwest watershed from which four major rivers flow northwards into the Zambezi Valley, while another three flow southeastwards into the Save-Limpopo Basin.

There is a mismatch between population distribution and the distribution of surface water resources. Attempts to recover the huge water losses tumbling into the lower basin areas of the country have been fraught with failure due to the huge uphill pumping costs involved. For instance, the Zambezi-Water Project (ZWP), which was planned three decades ago still has not been implemented. The ZWP was designed to pump water from the Zambezi River to the drier western parts of the country, including Bulawayo (Fig. 4.1).

4.4.2 Climatic Conditions

As shown in Figs. 4.2 and 4.3, most of the areas that receive low rainfall are the once where average monthly temperatures are highest. Moreover with global warming, it means that the available water will be reduced by increased evapotranspiration.

Such a situation generally leads to scarcity of water due to the high rates of evaporation that prevail in these areas. Variations in rainfall are largely influenced by the north-south movement of the Inter-Tropical Convergence Zone (ITCZ). The ITCZ migrates southwards during the summer season, during which time much of the rainfall is received. The opposite is true for the winter season. Though the prevailing climate is savannah, with two distinct seasons, a hot wet summer and a cool dry winter (Fig. 4.4), the country is prone to drought, a phenomenon that has become more frequent in recent years. This situation renders water resources management, and let alone IWRM, problematic. Under such circumstances where water is scarce due to low and erratic rainfall, the state of the environment and subsequently water resources are compromised. Due to critical water shortages, the environment's entitlement to water is rarely observed. Thus, whereas the new water policy is based on an anthropocentric view which regards the environment as a one of the water users, in essence it is the state of the environment that actually determines how much water is available for all aspects of life that depend on it, including the state of the economy, livelihoods and biophysical conditions. The environment has been recognized as a legitimate user of water and provided an allocation is prioritized for environmental purposes in order to assist in its protection.

4.4.3 Population

Previous research on the communal areas of Zimbabwe has made reference to the considerable pressure exerted on natural resources due to rapid population growth, leading to the worsening of

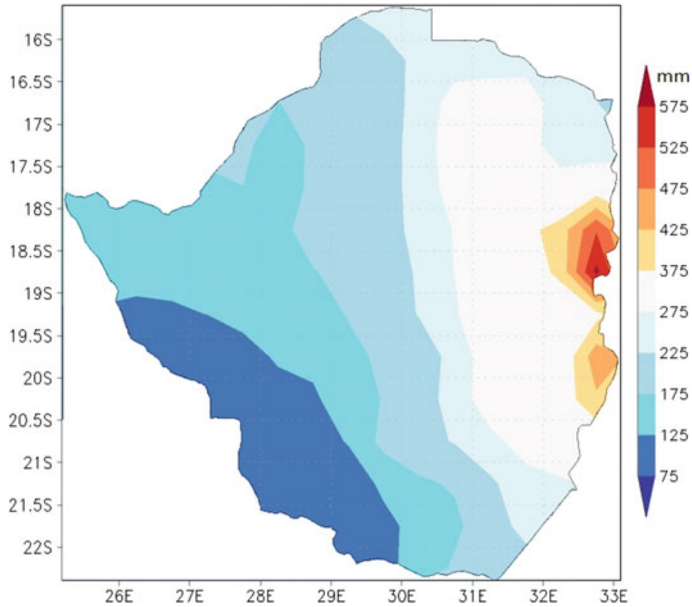

Fig. 4.2 Variability of average monthly rainfall recorded (in mm) between 1984 and 2014 (Data obtained from the CRU TS3.23 Dataset)

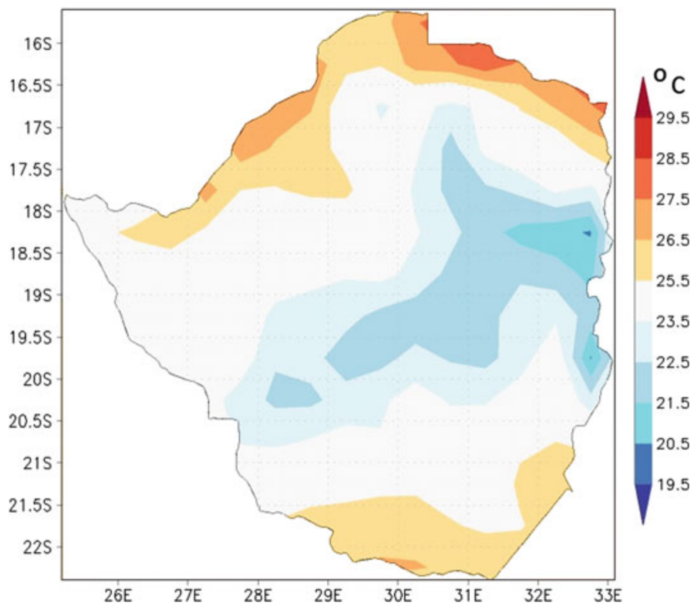

Fig. 4.3 Spatial variability of average monthly temperature (°C) across Zimbabwe (Data obtained from the CRU TS3.23 Dataset)

poverty. Population growth and accelerating economic development, together with climate change impose huge demands on water resources. In Zimbabwean rural areas, where the majority of the people depend on agriculture for livelihood, rapid population growth has been associated with land use and land cover changes. In some areas, especially in the communal areas, population growth has been accompanied by deforestation, siltation and water shortages. It is also mostly in the drier areas that the communal areas are located and rural population densities are highest, posing enormous pressure on both the environment and water resources.

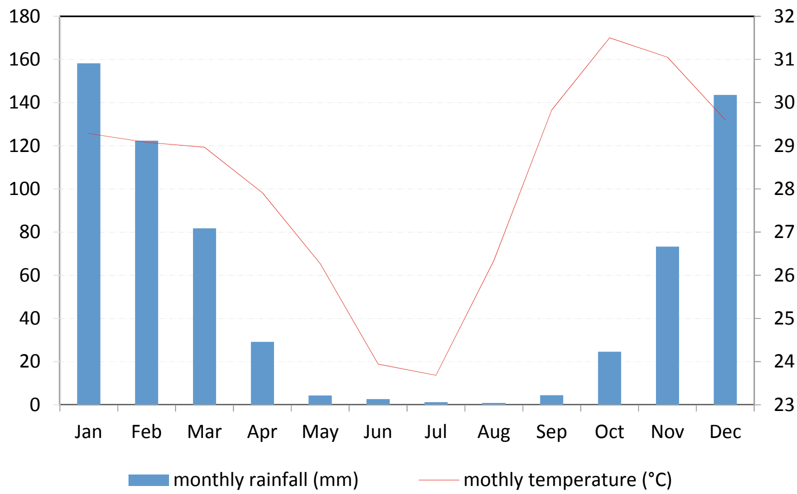

Fig. 4.4 Monthly variability of rainfall (blue line) alongside temperature (red line), for the period between 1984 and 2014 (Data obtained from the CRU TS3.23 Dataset)

In many rural areas of the developing world, rapidly increasing population pressure often leads to changes in land use in terms of deforestation, reclamation of wetlands, etc. with the aim of increasing agricultural production. In addition, land mismanagement has inadvertent negative effects on the hydrological regime, leading to the increasing occurrence of floods and decreasing dry season flows (Lørup et al. 1998). UN population projections indicate that Zimbabwe's population will reach 17.7 million by 2025 and 19.1 million by 2030 (ZimStat 2015). It is also assumed that the amount of water potentially available for internal development in Zimbabwe is approximately 8.5 billion km^3, which will only be sufficient to meet the country's water requirements up to 2025, after which the country has to find new sources of water.

4.4.4 Infrastructure

Over 90% to the country's water supply comes from surface water resources, with rivers supplying the highest proportion. However, annual and inter-annual variability of river regimes associated with the tropical and subtropical climate that prevails in Zimbabwe makes water supply unreliable. National statistics regarding water resource infrastructure are not up-to-date, though it can be established that the supply of surface water resources is supplemented by dam construction. According to Mtisi and Nicol (2003) in 1998 Zimbabwe had a total of 140 dams with a capacity of one million cubic meters, and 10,747 smaller ones providing more than five billion cubic meters of impounded water capacity. Patterns of water use vary spatially according to demands related to irrigation, commercial/industrial, domestic supply, power generation, and recreation.

4.4.5 Complex Institutional Arrangements

Zimbabwe's water sector is characterized by complex institutional arrangements. The huge number of stakeholders involved in these arrangements makes IWRM difficult to implement, due to the cumbersome nature of the coordination and the harmonization of the roles of these stakeholders. Table 4.1 shows some of the government institutions that play an important role in water resource management.

Other government institutions include the Ministry of Health and Child Welfare; Ministry of Environment and Tourism; Ministry of Finance; the National Economic Planning Commission and parastatal organizations. Some of the parastatals that were involved are the Regional Water Authority, the District Development Fund

Table 4.1 Institutions and stakeholders involved in IWRM

Ministry	Department involved
Ministry of rural resources and water development	Department of water development
Ministry of local government, public works and national housing	National action committee for the integrated rural water supply and sanitation programme
Ministry of agriculture, lands and resettlement	Department of Agricultural, Technical and Extension Services (AGRITEX)

and Agribank, Urban and Rural District Councils, as well as stakeholder institutions such as Catchment Councils and research organizations. The Institute of Water and Sanitation Development (IWSD) and universities were also incorporated as stakeholders. The efforts and roles of these stakeholders have to be harmonized and integrated. Other legitimate stakeholders include traditional leaders such as chiefs, village heads and local councils, as well as ordinary community members.

It was this realization that led government to set up an Inter-Ministerial Review Committee in 1993 to review the national water laws. The committee consisted representatives from the AGRITEX, Regional Water Authority, Department of Water Development, Ministry of Local Government, Rural and Urban Development, Zimbabwe Farmers Union, Commercial Farmers Union, an Administrative/Water Court Judge, and a retired judge of the Water Court. The Ministry of Lands, Agriculture and Water Development chaired the Inter-Ministerial Review Committee (Mtisi and Nicol 2003). The ensuing review gave rise to water reforms that introduced new water management institutions, including Catchment and Sub-Catchment Councils, which complicated the water sector even further. The Zimbabwe National Water Authority (ZINWA) was set up to improve the institutional coordination of the roles of these players, in terms of the ZINWA Act of 1998, as well as to collect revenue required for water management in the country.

4.5 Implementation of IWRM at Local Level: Experiences from the Turwi River Basin

In this section, we draw from the empirical data that were gathered through FDGs and interviews that were held with water management stakeholders in the Turwi River Basin (Fig. 4.1). The Turwi Basin is approximately 4 500 km^2 in extend. It is a sub-catchment of the Save River Basin (Fig. 4.1). The Save River Basin is one of Zimbabwe's seven major catchments. Rivers in this basin flow southeastwards into the Save-Limpopo River Basin. In order to tackle the questions that we raised in the introduction we first had to establish the availability of water resources in the Turwi Basin, the sources of water that the grassroots communities had access to, how they were using these resources and managing them, before examining the challenges experienced.

Empirical evidence from the Turwi River Basin shows that though grassroots communities are the appropriate level at which the IWRM can be implemented, there are a number of conditions that constrain it. Contrary to conventional wisdom, the conditions that underlie the potential of local communities to contribute positively towards IWRM include the legitimacy of informal institutional structures rather than government-driven institutions. These institutional structures are evident in the way water is managed in smallholder irrigation schemes, as well as the role that traditional institutions and cultural practices play in land conservation at household level. On the other hand, there are several conditions that militate against the role of local communities in IWRM. Among these conditions are water scarcity and poverty.

4.5.1 Institutional Arrangements in Smallholder Irrigation Schemes and IWRM

In the Turwi River Basin, a relationship exists between economic or productive uses of water and practices in water resources management. Cooperation among water users tends to be high in most smallholder irrigation schemes. This suggests that irrigation farmers recognize the economic value of water, and recognize it as a good whose management requires the cooperation of all irrigators. The responsibility to repair damaged infrastructure such as damaged canals or fences rests with the farmers. The Irrigation Management Committees (IMCs) ensure that contributions are made towards the payment of labor costs. Through such an initiative, a general ‘fund’ for repairing damaged infrastructure has been established in all schemes. On average each irrigation scheme member makes a monthly contribution of US$2.00 towards their respective funds. At the time when the survey was conducted, none of the irrigation farmers was in arrears. The economic uses of water increase household income, which in turn arguably motivates and increases the capacity and willingness of households to contribute towards the upkeep of the water infrastructure they rely on for livelihood. This indicates that local communities can fully participate in IWRM where incentives are available.

4.5.2 Role of Traditional Institutions and Cultural Practices in Water Resources Management in the Turwi River Basin

Traditional institutions play a significant role in water resources management in the Turwi River Basin. Communities participate in making decisions that are closely linked to their beliefs and culture. This applies to rainfall, surface and underground water. Rains are ‘requested’ from the Almighty God (*Mwari*) through the area’s ancestral spirits (*midzimu yedunhu*) by means of a ritual called *dundu* (rain-making ceremony). The ceremony is a collective responsibility of village community members, so every household within the area of jurisdiction of each of the chiefs in the basin contributes *rapoko* (*rukweza/zviyo*), also known as finger millet, for the ceremony. The ceremony though is organized and conducted at village level.

In some villages, there are certain water points and sources such as wells and fountains that are considered as sacred. Custom dictates that metal objects and sooty clay pots should not be used to fetch water from such pools, wells or fountains. Similarly, the use of detergents like soap around such water points, most of which are regarded as homes of mermaids (*Ninga/Njuzu*) and the area’s ancestral spirits, is strictly forbidden. In addition any misdemeanor, such as conducting sexual activity around such revered sites is strictly prohibited. Disobeying such convention is regarded as an invitation of misfortunes by the perpetrators and their communities. The misfortunes include the inexplicable illness, death or disappearance of the offender, the splashing of water onto the offender by invisible beings, the blowing of mysterious winds, the drying up of the sanctified water point or the occurrence of an extensive drought in the area. The remedy to such a situation is the performance of certain rituals by the chief, involving seeking forgiveness on behalf of the community. Such a ceremony requires the participation of the community through their elderly representatives.

The offender is usually sought and is seriously reprimanded, demonstrating the importance of cultural beliefs in traditional water resources management within the basin. Fears induced by these traditional beliefs indirectly contribute to environmental protection and water resource conservation.

Traditional leaders such as chiefs and village heads are both actively involved in the management of vegetation within the Turwi River Basin. Traditional leaders prohibit villagers from cutting down trees without prior permission from them. Equally, they forbid veld fires. Village 'policemen' are responsible for enforcing these rules. Anyone caught flouting these rules gets heavy sanctions which are determined by the village court (*dare*, in Shona, a local language). Deterrent penalties for contravening conservation rules include brewing traditional beer for the village community in addition to paying the village head a minimum fine of a goat or its cash equivalent. Sanctions get sterner when the matter is referred to higher level traditional courts. If one defies the village head, the matter is referred to the chief. Once the matter is reported at the chief's court, the offender is required to pay the whole chain of traditional leadership what they would demand from them. For the chief, at least two head of cattle are required–one for the chief and the other which will be slaughtered to feed those participating in the chief's court during the trial. Thus, through enforcing vegetation conservation, traditional leadership indirectly contributes towards soil and water resources management since all the three are connected through the hydrological cycle.

4.5.3 Household-Level Land Conservation Practices

An analysis of household data collected during interviews revealed practices that demonstrate a close relationship between field management practices, soil conservation and water management. This section highlights the major household practices that are undertaken by individual villagers, which have a bearing on IWRM. In the Turwi Basin, the lowest level at which water management is undertaken is the household level. Most households unknowingly promote water conservation through contour ridging. Contour ridges are a soil conservation technique that is universally encouraged by agricultural experts. They have a long history of use across the world but in Zimbabwe, the practice of using contour ridges to reduce soil erosion was introduced in the 1920s. Contour ridges regulate the flow of water (Plate 4.1). They increase infiltration, and thus reduce surface runoff and erosion. According to the Jerera-based district agriculture mechanization officer, their department provides communal farmers with free technical expertise required for pegging contour ridges. Farmers only need to request for the officer's services.

4.5.4 Adequacy and Access to Water Resources by Grassroots Communities Within the Turwi Basin

In the Turwi River Basin, water is used for domestic purposes, including washing, bathing, and brewing of traditional beer. Commercially it is used for livestock drinking water, irrigation and for moulding bricks for sale. Laundry and bathing are usually undertaken in rivers and dams, where the quality of the water is generally poor. However, water for drinking and cooking is fetched from boreholes and protected wells, though in cases of scarcity water from unprotected wells and springs (singular-*chitubu* and plural- *zvitubu* in the local Shona language) is also often used. Non-potable water sources, including river-bed wells and abstraction points (singular-*mufuku, plural- mifuku* in local Shona language), are used for multiple purposes. Since many of the sources that local communities depend on are neither safe nor protected, the conditions related to safety, health sanitation and hygiene are not addressed in a holistic manner, as required in IWRM.

There are a number of factors that characterize the way water resources are used and managed in the Turwi Basin. These include economic,

Plate 4.1 Typical contour ridge configuration, Njerere village

cultural and environmental factors, as noted below. Interactions between water users and water point committees (WPCs) are a function of the season. During the dry season, (late August-early November), temperatures soar especially in the drier southern parts of the basin.

Consequently, rivers, streams, shallow wells and even boreholes dry up. Due to scarcity of water, community members start to converge at the few available water points such as boreholes from as early as 4 O'clock in the morning. Because of the resulting high water demand at these points, petty conflicts and squabbles are inevitable, often arising where community members attempt to jump the queue. At some boreholes, especially in the drier parts of the catchment where water shortages are severe, timetables for water fetching have been set up. In order to ensure equitable access to water in such areas, communities have developed rules to limit the amount of water that a household is allowed to fetch at any one moment. The boreholes are locked at certain times of the day in order to conserve water, thus ensuring that every household has access to drinking water while at the same time preventing the misuse of the facility, especially by children.

At these times, queues will be relatively shorter and it will be cool enough for them to walk long distances (of up to 10 km in some cases) to fetch clean water in groups (Plate 4.2 and Box 1).[1]

[1]Basin community members in the dry resettlement areas like Angus, Humani and Matendere ranches expressed dissatisfaction with water availability. In these areas, protected water sources are scarce and hardly reachable for some households. This means that they spend a lot of time scavenging for safe clean water. Here women wake up at dawn (around four o'clock in the morning) or wait until dusk (after seven O'clock in the evening) to access water. The resettlement areas were set up during Zimbabwe's recent land reform programme, which led to the transfer of land from whites to landless black

Plate 4.2 Women foraging for water in Humani Ranch, a resettlement scheme that was established during the post-independence era

Those who visit the water points late have to endure long winding queues. In some resettlement areas, most families have bought ox-drawn carts which they use to ferry water from distantly located water points. Households who do not have their own carts often have to ask for assistance from neighbors, relatives and friends, especially when it comes to the collection of drinking water. Those who may be unlucky not to get such assistance either have to endure the nightmare of head loading water for long distances or they have to content with unsafe and unclean water from abstraction points which they share with livestock. Water from unprotected sources such as riverbed wells exposes households to diarrheal diseases, which mostly affect children. Unclean or unsafe water from these sources is known to be one of the main factors responsible for spreading waterborne diseases. Women in this part of the basin kept narrating the same ordeal which they endure on a daily basis in their attempts to access water for domestic use. Most women spend no less than five hours a day collecting water for their households (Plate 4.2).

When and where they queue for water, quarreling even over trivial issues is quite common. To avoid conflict, some women claimed to have resorted to collecting water at dawn or dusk when queues will be shorter.

Fetching water either very early in the morning or late in the evening in the ranches exposes women to all sorts of hazards including potential attacks by wild animals and snake bites. As a way of coping with the water shortage crises, some community members have resorted to bathing once every 3 days, a luxury in which household members now take turns. According to one elderly woman who was giving a vote of thanks at the 'commissioning' of a borehole in their area:

> We would walk for six hours to and from an abstraction point or the river to fetch water. We would carry buckets full of water on the return journey and we were not even aware that the water was dirty. We would suffer from diarrheal diseases especially children.

people, the majority of whomlived in the crowded communal areas, formerly known as African reserves. During resettlement, water infrastructure on the former white farms, including boreholes, pipes and tanks, was vandalized or collapsed due to poor maintenance, rendering water resources unavailable.

The water challenge also extends to livestock, which in the dry season have to skip a day or two without drinking, largely due to the distant nature of watering holes. Cases of livestock falling into abstraction wells or even death are particularly common in the driest and hottest parts of the basin.

4.5.5 Ineffectiveness of Government Institutions

Interviews held with the Zaka District Environmental Management Agency (EMA) officer and the Lower Save West Sub-Catchment Council (LSWSCC) outreach officer, revealed that their institutions are active in Turwi Basin.[2] The two officers reported that they hold regular meetings with local communities, educating them about the value of forests, land and water resources and how best to manage these resources. The EMA District Environmental Officer and LSWSCC's outreach officers maintained that they educate local communities about environmental protection, and catchment protection. The catchment protection activities that are carried out in the basin include reforestation, establishment of woodlots, development of community nutrition gardens and contour ridging, all which indirectly involve local communities in water resource protection within the basin.

In an endeavor to promote and improve environmental management, EMA officials have roped in traditional leaders to assist in organizing their communities in undertaking these activities, signifying the failure of government institutions to cope with the implementation of IWRM. While EMA imposes heavy financial penalties involving the issuing of tickets to those who flout environmental laws, this by itself has not created any meaningful opportunities for IWRM. There are many cases where EMA officials report grave environmental offences to the police yet the culprits have never been prosecuted, demonstrating that there is poor law enforcement too.

4.5.6 Poverty

To cushion themselves from poverty and food insecurity basin residents often set up nutrition gardens, a practice that has become widespread across the entire basin. Almost without exception, individual gardens are makeshift structures, which need to be repaired annually because they are branch fenced. This means that trees are cut down every year for fencing purposes. This accelerates deforestation and subsequently soil erosion and siltation in the Turwi Basin. Ultimately, these processes compromise water resources availability and consequently undermine prospects for IWRM. However, in most villages, community gardens have reduced the need for individual gardens. On average, each village has a garden of its own. The gardens are run on a cooperative basis. Indirectly, communal gardens help to curb deforestation, soil erosion and siltation, and promoting environmental rehabilitation. This is because communal gardens are constructed with more durable fencing materials, most of which are donated by community-based organizations.

However, individual household gardens are still prevalent within the basin. Unfortunately, some gardens are located in steeply inclined areas, as well as along stream banks or other environmentally sensitive areas such as wetlands. Due to poverty, many villagers are unable to maintain the fertility of the land they till. Once the soils in their gardens or fields are exhausted the villagers open new ones in new locations because they cannot afford inputs like fertilizers to maintain land fertility. With increasing basin population pressure, environmental degradation is expected to worsen as a result of this practice.

[2]The LSWSCC is an example of a sub-catchment committee, the lowest level institution recognized by law within the Turwi River Basin. Though this level would be regarded as the "lowest appropriate authority" in legal terms, the actual level at which water resources are being effectively managed are traditional structures such as chiefs and villages heads, which are at a much lower level than what the law prescribes. In practice government officials involved in water management, including EMA, LSWSCC and AGRITEX officials, deal with these traditional authorities in order for their operations to be effective.

Plate 4.3 A newly created field on steep slopes

Plate 4.4 A field in a wetland

Consequently, massive deforestation, soil erosion, and river and dam siltation prevail, as illustrated in Plates 4.3 and 4.4, and Plates 4.5 and 4.6, respectively.

Elderly people and traditional leaders recollected the past with nostalgia. In their oral accounts, they talked of a past when only a few people lived in dispersed settlements away from rivers, forests and mountains. They recounted a past that was characterized by plentiful clean river, spring and well water, abundant fertile land, pastures and thick forests, which no longer exist. People are encroaching environmentally sensitive and prohibited areas such as wetlands, river banks, hills and mountains, signifying heavy pressure on local woodlands, farmland and water resources as evidenced by overstocking, overgrazing, deforestation and cultivation of unsuitable land. These activities lead to the degradation of water resources. Indeed there is evidence of serious deforestation, soil erosion and siltation of rivers and reservoirs, all of which have serious implications on IWRM. Due to poverty, communities in the Turwi Basin have little options for survival besides tilling the land. In due course, the forms of environmental degradation noted above are therefore expected to worsen.

4.5.7 Community Wrangles and Conflicts

Due to high population densities, conflicts and disputes often loom between village heads and between village heads and their subjects. Such conflicts and disputes result from access to pastureland, competition for scarce water resources, encroachment on grazing land or allocation of fields in areas that have been designated for grazing. Most conflicts and disputes are resolved through the village courts, if they are minor, while more serious once are dealt with by the chief's court. Rivalries over chieftaincies are also common. However, conflicts undermine social cohesion and the cooperation that communities require for IWRM to succeed.

4.6 Discussion

It has been demonstrated in the foregoing discussion that IWRM is a multidimensional and multi-sectoral process in which different levels of stakeholders must participate, from national departments that deal with water management and governance to grassroots communities. In


Plates 4.5 and 4.6 The heavily silted Turwi River downstream and upstream of Turwi river bridge

Zimbabwe, like in other countries in southern Africa, IWRM has been state driven and donor funded. Water management experiences drawn from the Turwi Basin allowed the exploration of the implementation and performance of IWRM in the basin so far. This way, insights into the underlying practical and conjectural challenges to the execution of IWRM emerged. The analysis of the empirical data that were collected in the Turwi Basin revealed that people cannot be separated from their physical resource base (environment), especially its integral components such as water and land. As demonstrated above the Turwi basin the socio-economic processes that define livelihoods are interconnected with environmental resources, including water. Therefore, the argument that IWRM can only be achieved through coordinated development and management of water, land and related resources, in a manner that promotes economic efficiency and social equity without compromising the sustainability of vital ecosystems is valid (GWP 2000). At drainage basin level, there are factors that promote as well as hinder the implementation of IWRM. In the case of the Turwi River Basin, poverty and landlessness pose the greatest threats to prospects for IWRM.

This chapter reflects on the extent to which local actors are conscious of the steps that are necessary for sustainable use of the environment. This is a critical component in the use, management and conservation of water resources. Sustainable water resource management is interpreted as dealing with the relationship between people and the environment. Hence, there is need to examine how the basin community uses the environment and the impact of their use of the environment on water resources. There is need to check if land use practices in the basin are compatible with conserving the environment (forest, land and water). Thus, there is need to reflect on land use practices in the basin, i.e. stream bank, slope and wetland cultivation and deforestation. These activities are central in water resources management in Turwi Basin.

4.7 Conclusion

While governments are quick to adopt IWRM because of its perceived value as a tool for guiding water resource governance, implementing this process is not easy. In the case of Zimbabwe, lack of resources has been the critical limiting factor. The process was hinged on donor funding. State contribution to IWRM diminished with economic decline that started around 2000. However, at grassroots community level, the implementation of IWRM is constrained due to the limited choices that these communities have. Due to poverty, these communities depend directly on land-based resources for livelihood, many of which lead to environmental degradation, which in turn undermine the availability of water in the environment. The polluter pays principle is not compatible with the aspirations of grassroots communities, which lack basic sanitation, or which rely on wood fuel and thus require trees to be cut. Nevertheless, we conclude that despite all these limitations community-based institutions are better placed to pursue IWRM than state-sponsored institutions. Accordingly, we also conclude that both the water laws and water policies must reviewed to ensure that grassroots community structures, including village heads are noted as the 'lowest appropriate authority' in IWRM. However, without the involvement of all key stakeholders, IWRM will remain a toll order which might never be realized in practice. Due to their link to local culture, traditional institutions can be used as a coercive tool for rallying local communities in water resources management. Unfortunately, this violates the principle of voluntary and democratic participation envisaged in IWRM. However, the willingness of communities to participate in supporting common goals in smallholder irrigation schemes gives hope that where incentives exist local communities can voluntarily promote IWRM. Therefore, not all is lost after all.

Acknowledgements We would like to acknowledge the organizers of the CRU TS3.23 Dataset, which was freely available on internet and accessible from Climate Explorer. The data they provided were useful in the analysis of climate conditions in southern Africa.

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5

Urban Heat Island Growth and Health Hazard in the Megacity of Hyderabad

Ghazal Salahuddin

Abstract

Urban heat island refers to considerably higher temperatures in the large and contiguous high density built-up surface of a city as compared with its surrounding open countryside. Hence, urban heat island is a phenomenon of excessive heat dome in the C.B.D. of large cities. Urban heat island is one of the major environmental issues of microclimate. At the same time, heat islands are the nuclei of global warming and climate change. The paper hypothesizes that the intensity of urban heat island grows in proportion to the city size and function. It also hypothesizes that the nocturnal heat island of megacities heavily erodes the comfort level of the hard-working city dwellers and tends to undermine their health. Although the problem of heat islands has already attained a critical level in the megacities, even then megacities are more rapidly growing in the developing countries, particularly India than in the developed countries. It is because the concentration of factors of production and migrant sustainability is highest in the megacities of disequilibrated centralized economies as compared with the equilibrated economies of the developed countries. This is evident from the fact that India with just over 30% urban population has more number of megacities than the USA with 75% urban population. The paper examines the urban heat island growth of Hyderabad in relation to its area and population growth during 1961–2011. The megacity of Hyderabad has an areal extent of over 851 sq.km. with a corresponding population exceeding 7.74 million persons. The city has witnessed an areal growth of 673 sq.km. and a population growth of 6.62 million persons since 1961. Urban heat island growth has been calculated through linear regression analysis of the mean monthly daytime and mean monthly nocturnal temperature data for a period of 50 years. It has been found that the higher nocturnal heat island growth is more hazardous to health than the relatively lesser daytime heat island growth.

Keywords

Hyderabad · Megacity · Urban climate · Urban heat island · Health hazard

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_5

5.1 Conceptual Frame

The term 'heat island' refers to urban air and surface temperatures that are higher than the nearby rural areas. Meteorological data measure the long-term air temperature. Air temperature is a measure of sensible heat along with other meteorological variables of humidity, wind velocity and calm conditions. This study is an attempt to enquire the growing Urban Heat Island Intensity in the megacity of Hyderabad. It is a study on the climatic transition in a major city of peninsular India. Thermal imageries have been utilized by some scholars for the study of Urban Heat Island (UHI), which do not draw a cumulative temporal perspective. Several studies on urban heat island have taken up the problem largely relegated to temperature changes. Urban heat island is not a cognizable problem of towns and small cities. It is a matter of great concern for the million and megacities. The problem of urban heat island is already critical in the megacities. Still, however, the megacities are more rapidly growing in area and population. This is because the factors of production and relative sustainability are higher only in the large Indian cities. The study of urban heat island helps to understand the air quality, energy use, water use efficiency and the level of human comfort. As compared with rural areas, the urban districts have high heat absorption, low evaporative heat loss and slow transmission of heat. Heat emitted in urban districts is much higher than that in rural areas. The tall buildings within the megacities provide multiple-tier surfaces for the absorption of sunlight, increasing the propensity with which urban areas are heated. Urban micro climates are complex because of a number of diverse meteorological factors in varying interaction. Solar radiation and temperature can vary significantly according to topography and local surroundings.

The annual mean air temperature of a city with one million or more people can be 1–3 °C warmer than its surroundings (Oke 1997). Smithson et al. (2008) find out that the warmth of concrete and brick on a summer's evening is due to the high heat capacity of the built-up surfaces. Goudie (2006) compared the rural and urban areas and distinguished that the city surfaces absorb significantly more solar radiation, because concrete city surfaces have both great thermal capacity and conductivity, so that heat is stored during the day and released by night. Oke (1978) noted a relationship between heat island intensity and city size. Nabeshima et al. (2008) brought out a relationship between rural-urban temperatures. Stone (2006) studied the temperature data from urban and proximate rural stations for 50 large U.S. metropolitan areas and analyzed the mean decadal rate of change in urban temperatures and heat island intensity.

5.2 Hyderabad: City Size and Morphology

Hyderabad is the primate city of the new Telangana State. Hyderabad is also capital city of the land-locked Telangana state. The city is located on the visibly feeble Musi River, which is the tributary of Krishna—the second largest river basin of Peninsular India. Hyderabad is situated at an altitude of 542 metres or 1778 feet above mean sea level. Figure 5.1 illustrates the physiographic outlay of Hyderabad along with the prominent water bodies. This sixteenth century city was founded by Muhammad Quli Qutb Shah in 1591. The city's Golconda Fort was developed to the north of Musi River on the hillock as has often been the strategic preference for most of the forts in the world. There are a number of large water bodies like Hussain Sagar, Osman Sagar and Himayat Sagar, which have been built to sustain the city water supply.

5.3 Geographical Personality and Meteorological Profile

Geographically, Hyderabad is a distinctly sprawling megacity. The undulating topography and the resultant water bodies have played a crucial role in its scattered growth. The megacity of Hyderabad is thoroughly tropical in its

Fig. 5.1 Hyderabad: City outlay and the surroundings (*Source* Adapted from Google Earth, Image Landsat, 2013)

meteorological parameters. This is because Hyderabad is located well within the tropics at 17° north latitude as well as in the middle of the tapering Indian peninsula. Hyderabad experiences longer and more pronounced summer. The decadal growth in the geographical dimension of the megacity of Hyderabad for the period 1961–2011 has been analyzed. Table 5.1 reveals the changing demographic profile related to population, density and growth for the corresponding period. In 1961, Hyderabad had a geographical area of 178.3 sq.km. Its total population was 1.12 million persons. The average population density was a moderate 6,282 persons per sq.km. Throughout the city growth, there has been considerable intra-city variation in the population density. In 1981, Hyderabad had recorded an increase in its geographical area to 371.5 sq.km. The total population of Hyderabad was 2.54 million persons in 1981. The 1971–1981 aggregate decadal growth was 7,50,000 persons. The average population density remained a moderate 6,852 persons per sq.km. In 1991, Hyderabad had registered a massive increase in its geographical area to 726.6 sq.km. The total population of Hyderabad was 4.34 million persons in

Table 5.1 Hyderabad: Area, Population, density and growth, 1961–2011

City	Hyderabad urban agglomeration				
Year	Area Sq.km.	Area growth Sq.km.	Population (Millions)	Density persons/km^2	% Pop. growth
1961	178.3	–	1.12	6,282	–
1971	298.5	120.2	1.79	6,017	59,82
1981	371.5	73.0	2.54	6,852	41.90
1991	726.6	355.1	4.34	5,978	70.86
2001	778.1	51.5	5.75	7,391	32.48
2011	851.0	72.9	7.74	9,106	34.60

Source Computed by the Researcher from Census of India and Municipal Data

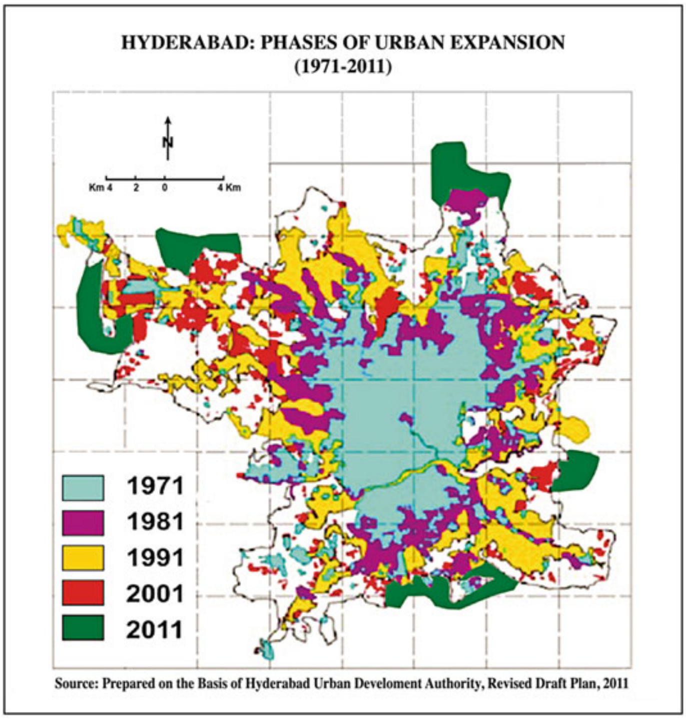

Fig. 5.2 Hyderabad: Phases of urban expansion, 1961–2011 (*Source* Prepared by the Researcher on the basis of Hyderabad Urban Development Authority, Revised Draft Plan, 2011)

1991. The average population density was moderately low with 5,978 persons per sq.km. In 2001, Hyderabad recorded a geographical extent of 778.1 sq.km. The total population of Hyderabad was 5.75 million persons. The average population density was a moderate 7,391 persons per sq.km.

In 2011, Hyderabad registered a geographical area of 851 sq.km. The total population of Hyderabad also increased to 7.74 million persons. The average population density grew to 9,106 persons per sq.km. The persistently moderate population density depicts a sprawling urban expansion of Hyderabad. This may have a distinct effect on the urban heat island growth. The built-up density is very high in the inner nuclei of the city. The built-up density tends to decrease towards the city periphery. There is a visible core-periphery differential in the built-up density of the city.

Figure 5.2 depicts a decadal urban expansion of Hyderabad from 1971 to 2011. In 1971, Hyderabad had a moderate core area extent of 298 sq.km. In 1981, Hyderabad experienced an expansion to 372 sq.km. In 1991, the city recorded a geographical expansion to 727 sq.km. In 2001, the geographical area of Hyderabad expanded to 778 sq.km. By 2011, the geographical area of Hyderabad expanded to 851 sq.km.

5.4 Hyderabad: Urban Heat Island Growth Characteristics

The study reveals urban heat island growth of Hyderabad for the mean monthly daytime, mean monthly nocturnal and average monthly temperatures. The city experiences a unique heat island character. The urban heat island intensity is over and above the tropical heat of the peninsula with prolonged summer conditions. Infact, the urban heat island is more a cause of concern during the longer tropical summers in comparison to the winter season.

5.4.1 Mean Monthly Maximum Temperature Transition: Hyderabad

The mean monthly maximum temperature transition has been analyzed in Fig. 5.3. It depicts the mean monthly maximum temperature changes or the daytime urban heat island growth in Hyderabad. The urban heat island temporal changes in Hyderabad have been shown for a period of 50 years from 1961 to 2010 through linear regression analysis of the mean monthly maximum temperature data. It also reveals the mean maximum annual changes. The figure illustrates that Hyderabad has experienced an annual daytime temperature rise in the urban heat island intensity by a measure of 1.127 °C over the last 50 years.

The figure reveals a considerable seasonal and monthly variation in the daytime urban heat island intensity. The intra-seasonal winter variation in the daytime urban heat island growth at Hyderabad ranges from 1.47 °C in December to 1.813 °C in February. The average winter heat island growth from December to March has been noted 1.519 °C. As against it, the early summer season daytime urban heat island intensity has nominally grown from 0.539 °C in April to 0.686 °C in the month of May. The daytime average urban heat island intensity for the early summer months of April to May has grown by 0.612 °C over the last 50 years. Hyderabad depicts a different seasonal pattern in the daytime urban heat island growth. Here, the average winter season daytime urban heat island growth has been 2.48 times higher than the corresponding heat dome growth in the early summer season.

The higher winter heat island growth in comparison to early summer heat island growth is all the more alarming because from this trend one can visualize that in future the winters would be warmer than the present mild winters. The mild winters would turn into warm winters in the next 50 years. As a result of it, the future summers would become still longer and unbearable. The extended monsoon season daytime urban heat island intensity has grown by 1.091 °C from June to October in the last 50 years. Its intra-seasonal temperature growth has witnessed a variation ranging from 0.49 °C in August to

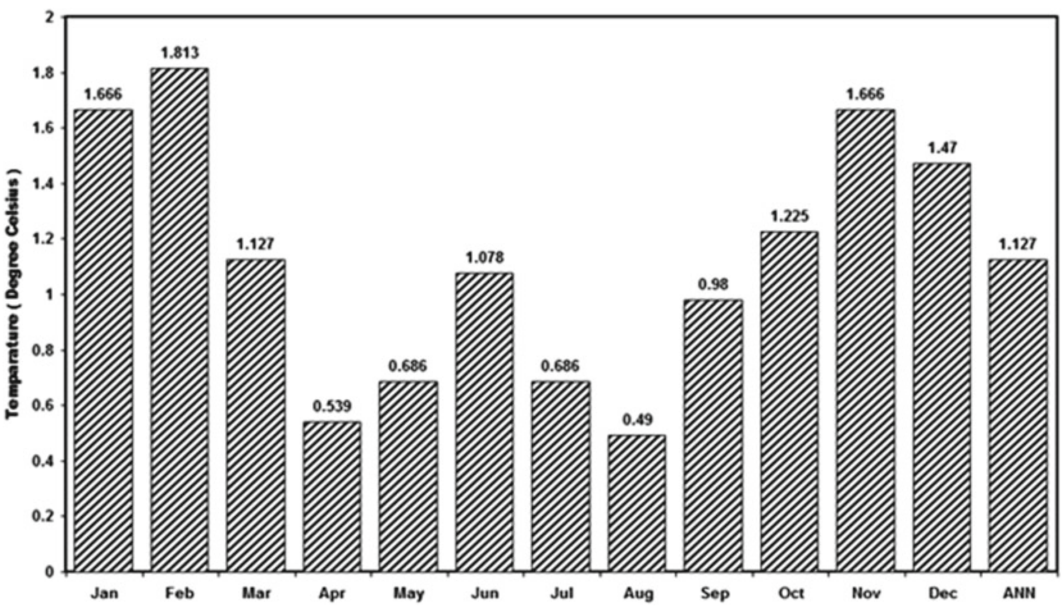

Fig. 5.3 Hyderabad City: Transition in Mean Monthly and Annual Maximum Temperature, 1961–2010 (*Source* Computed and Cartographed by the Researcher from IMD Data, Pune)

1.225 °C in October. The daytime urban heat island growth in the transitional season of November is 1.666 °C. The monthly daytime heat island growth was the highest 1.813 °C in February while the lowest daytime monthly heat island growth was 0.49 °C in August. The monthly daytime heat island growth has a warming amplitude of 3.7 times between the minimum and the maximum heat intensity. However, a significant daytime heat island finding is that all the months have recorded a consistent rise in the urban heat dome.

5.4.2 Mean Monthly Minimum Temperature Transition: Hyderabad

Figure 5.4 analyzes the mean monthly minimum temperature transition. The figure illustrates nocturnal temporal changes in the urban heat island intensity in the megacity of Hyderabad. These temporal changes have been revealed for the period 1961–2010 through linear regression analysis of mean monthly minimum temperature data. Along with this, it also highlights the mean minimum annual changes. The figure illustrates that Hyderabad has recorded an annual nocturnal temperature rise in the urban heat island intensity to a measure of 1.372 °C in the past 50 years. As against this nocturnal heat island growth, the daytime annual temperature rise was 1.127 °C. It reveals that the nocturnal annual heat island growth is 1.217 times higher than the annual daytime heat island growth.

The seasonal and monthly variation in the nocturnal urban heat island intensity is quite pronounced. The intra-seasonal variation in the nocturnal urban heat island growth during the winter season in Hyderabad ranged from a maximum of 2.303 °C in December to a minimum of 1.029 °C in March. This variation is 2.238 times within the season. The average winter heat island growth during December to March has been 1.506 °C. As against this, the early summer nocturnal variation in the urban heat island growth ranged from a minimum of 0.784 °C in April to 1.274 °C in May. During the extended monsoon season, nocturnal urban heat island intensity has grown by an average

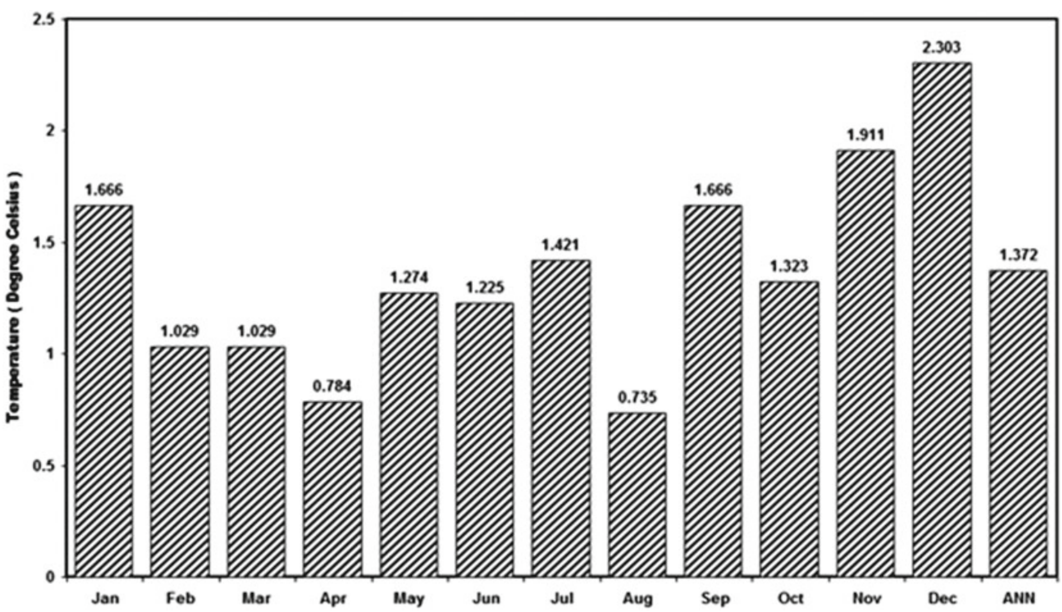

Fig. 5.4 Hyderabad City: Transition in mean monthly and annual minimum temperature, 1961–2010 (*Source* Computed and Cartographed by the Researcher from IMD Data, Pune)

1.274 °C from June to October in the last 50 years. Its intra-seasonal temperature growth has witnessed a variation ranging from 0.735 °C in August to 1.666 °C in September. The monsoon season nocturnal temperature growth has exceeded the corresponding daytime temperature growth by 1.17 times in Hyderabad. The winter season nocturnal urban heat dome growth has been 1.46 times higher than the early summer season nocturnal heat dome of April to May.

During the transitional month of November, the nocturnal heat dome in the tropical city of Hyderabad shows a still higher heat growth by an additional 1.911 °C. This transitional month recorded a much higher heat growth in comparison to the overall summer season heat growth. In case of Hyderabad, the winter season warming is more pronounced both during the daytime as well as the nights. A pronounced winter warming indicates a rapidly warming winter in Hyderabad both during the day as well as night. It appears a very dangerous sign of urban heat island with a diluting winter effect.

5.4.3 Mean Monthly Average Temperature Transition: Hyderabad

The mean monthly average temperature transition is indicative of the average values of mean monthly maximum and mean monthly minimum temperature changes. In diagram 5.5, the mean monthly average temperature transition has been analyzed. The average monthly heat island growth represents the moderated figures of the nocturnal and daytime rise of the heat dome. Figure 5.5 demonstrates that the thermal transition trends for the mean monthly average temperatures considerably endorsed the trends of mean monthly maximum and mean monthly minimum temperatures. The average annual urban heat island growth has been noted as 1.249 °C.

There appears a considerable seasonal and monthly variation in the average urban heat island growth in Hyderabad. The intra-seasonal variation in the average urban heat island growth during the winter season in Hyderabad ranged

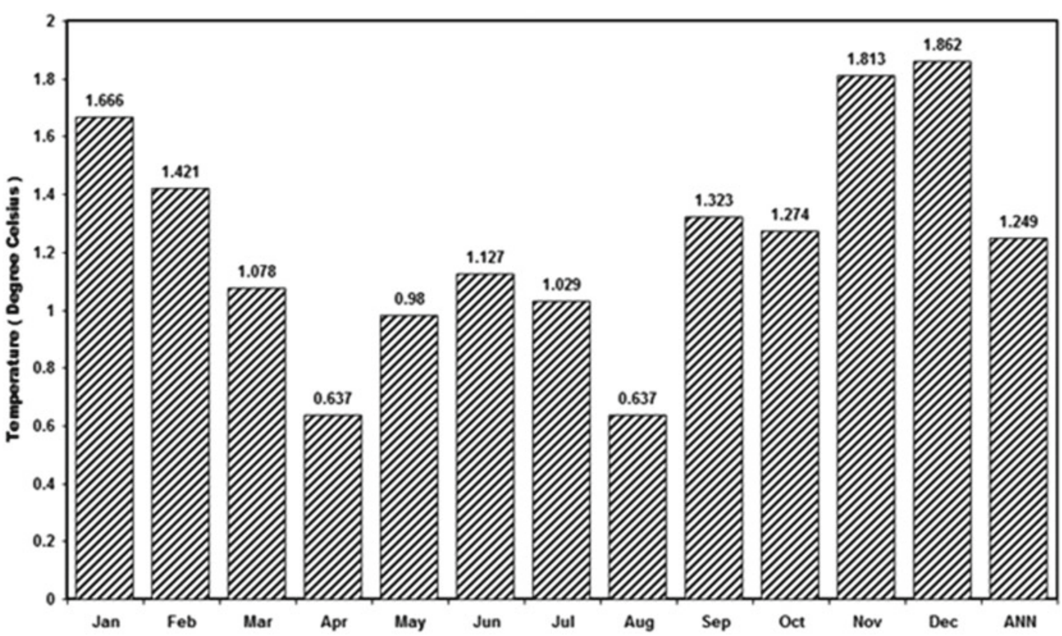

Fig. 5.5 Hyderabad City: Transition in mean monthly and annual average temperature, 1961–2010 (*Source* Computed and Cartographed by the Researcher from IMD Data, Pune)

from a maximum of 1.862 °C in December to a minimum of 1.078 °C in March. This heat island growth in winters is no less alarming. The average winter season heat island growth during the 4 months from December to March has been 1.506 °C. On the other hand, the average intra-summer season variation including monsoon showed an urban heat island growth ranging from a minimum of 0.637 °C in April to a maximum of 1.323 °C in September. The average urban heat island growth in the characteristically hot months of June and July is also considerably high at 1.127 °C and 1.029 °C, respectively. This will have long-term adverse effects on the urban living and the rising energy demand for a cooling effect. The increased cooling energy consumption would have a compound effect on the heat island seasonal expansion and the heat dome height. Of all the months, the highest monthly average heat island growth has been recorded 1.862 °C in the winter month of December. This nearly 2 °C heat rise is indicative of the rapidly warming winter season. The seasonal average heat dome rise for the summers was 1.001 °C during April to October. The average winter season urban heat dome rise was 1.5 times higher than the average summer season heat dome rise. The extended monsoon season daily average heat island intensity has grown by 1.078 °C from June to October. Its intra-seasonal temperature growth has witnessed a variation ranging from 0.637 °C in August to 1.323 °C in September. The average monthly heat dome rise in the transitional month of November was 1.813 °C.

Figure 5.6 gives a synoptic view of the average annual and average diurnal heat dome rise in the megacity of Hyderabad. The average annual daytime heat dome rise has been up to 1.127 °C during 1961–2010. It is alarming to note that the average annual nocturnal heat dome rise has been still higher to 1.372 °C for the corresponding period. Hence, it is evident that the night-time urban heat has increased more than the average daytime temperature rise. The average annual urban heat dome rise was 1.249 °C in Hyderabad. There appears a considerable relationship between the above urban heat island intensity and the urban population growth, urban area growth as well as the urban infrastructural growth in the form of decadal growth in the number of automobiles. For instance, the megacity of Hyderabad has experienced 591% population growth from 1.12 million people in 1961 to 7.74 million people in 2011. This is followed by 377% area growth from 178.3 sq.

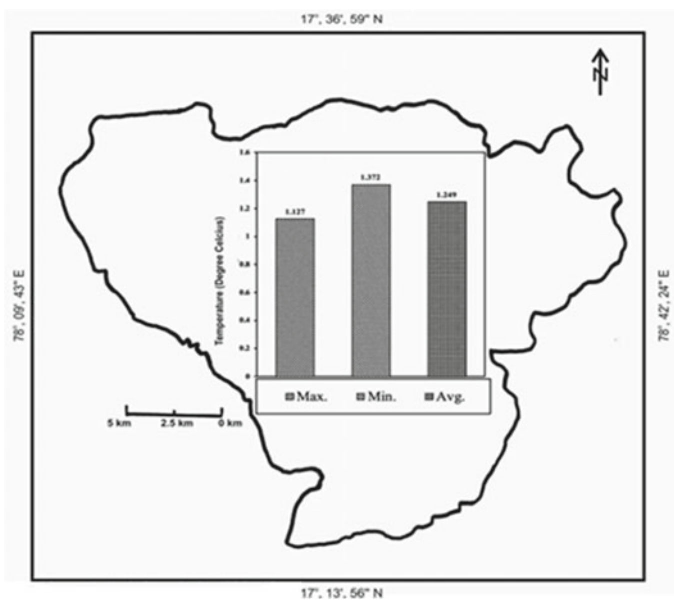

Fig. 5.6 Hyderabad: Average annual and Diurnal heat island growth, 1961–2010 (*Source* Computed and Cartographed by the Researcher from IMD Data, Pune)

km. in 1961 to 851 sq.km. in 2011. The number of vehicles recorded a 113% growth from 1,091,734 road vehicles in 2001 to 2,326,028 vehicles in 2011.

In the megacity of Hyderabad, urban heat island growth has been estimated in view of the corresponding urban expansion and population growth during 1961–2011. The city of Hyderabad had a sporadic growth in isolated nuclei. It has not been a contiguous and compact city. This may be due to the rocky and hilly topographic constraints. The corresponding population growth recorded a total growth of 6.62 million people. In 1961, the population density of Hyderabad was 6,270 persons per sq.km. By the year 2011, the average population density of Hyderabad grew to 9,106 persons per sq.km. This could perhaps be attributed to the absence of any labour intensive industry worth the name in Hyderabad. The vast and spacious growth of modern Hyderabad could be seen in relation to the burgeoning service sector and the software industries with lots of infrastructural growth and large commercial area extent.

5.5 Conclusion

The problem of urban heat island is more critical in the already hot and longer summer tropics. Urban heat island is not a problem of temperature alone. It is a 'Compound Effect' of heat, humidity and calm conditions. It is a matter of great concern to the urban planners, environmentalists, administrators and the citizens of large million and megacities. The paper finds out a linear relationship between the city size and the heat island growth. As Hyderabad has the largest urban sprawl among the Peninsular Indian cities, it has also recorded a considerable daytime and even higher nocturnal transition in the heat island intensity. Nocturnal urban heat island intensity has been recorded higher than the daytime effect. Urban Heat Island prevents the nocturnal radiative cooling which renders it more uncomfortable. The urbanites are unable to get a relaxing respite during the nights of longer summers. This condition would adversely affect the health, working efficiency and per capita productivity of the middle class inhabitants and industrial–commercial labour, which comprises the majority of population in the megacities.

Acknowledgements The author acknowledges the DST-INSPIRE for the research fellowship.

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6 Physical Environmental Impact Assessment of Flood: A Case of Lower Darakeswar–Mundeswari Interfluve in West Bengal

N. C. Jana and Soumen Mandal

Abstract

Flood is one of the most dreadful natural disasters in the humid tropics especially in India. It appears from the research studies and government reports that the Mundeswari (the main distributary of River Damodar) and Lower Darakeswar are the endemic flood-prone tropical rivers. Both natural and anthropogenic causes are responsible for flood of the rivers. The causes of floods of the rivers become highly complex and their relative importance varies from place to place. Anthropogenic activities such as building activity and eventual urbanization, channel manipulation through diversion of river's course, construction of bridges, barrages and reservoirs, agricultural practices, deforestation, land-use changes etc. induce floods in the study area. The main objectives of the paper are: (i) to assess the physical environmental impacts of flood in Darakeswar–Mundeswari Interfluve in Hugli District of West Bengal and (ii) to suggest possible relevant measures towards reducing the magnitude of flood impacts in the study area.

Keywords

Flood · Environment · Impact · Model · Assessment · Interfluve

6.1 Introduction

Flood is undoubtedly the most dreadful natural calamity that West Bengal has experienced over the years. It has been estimated that 42.43% of the total area of the state is flood prone. The Darakeswar–Mundeswari Interfluve of Hugli District is no exception in this regard. This interfluve has been suffering from flood since time immemorial. The objective of the present paper is to assess the impact of floods on physical environment and to suggest appropriate measures towards controlling and management of flood.

The Lower Darakeswar–Mundeswari Interfluve in Hugli District of West Bengal is situated in the south-western part of the district. The study area (73 N/13 & 73 N/14 in SOI Topographical Map) lies between 22°36′15″N and 22°57′35″N and 87°45′E and 88°58′10″E. In the north, it is bounded by Burdwan District, in the south by West Midnapur and Howrah Districts,

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_6

in the West by Goghat-I (Hugli District)) and West Midnapur and in the East it is bounded by Tarakeswar, Dhaniakhali, and Jangipara Blocks (Hugli District) and also by Howrah District (Figs. 6.1 and 6.2). The study area falls under Arambagh sub-division of Hughli District in West Bengal. Arambagh has six Blocks, which includes Khanakul-I, Khanakul-II, Arambagh, Goghat-I, Goghat-II, and Pursurah. The study in the present context covers only four blocks viz. (i) Arambagh, (ii) Pursurah, (iii) Khanakul-I, and (iv) Khanakul-II.

6.2 Causes of Flood in Lower Darakeswar–Mundeswari Interfluve

Both natural and anthropogenic factors are responsible for flood of the rivers. The causes of floods become highly complex and their relative importance varies from place to place. Anthropogenic activities such as building activity and eventual urbanization, channel manipulation through diversion of rivers' courses, construction of bridges, barrages and reservoirs, agricultural

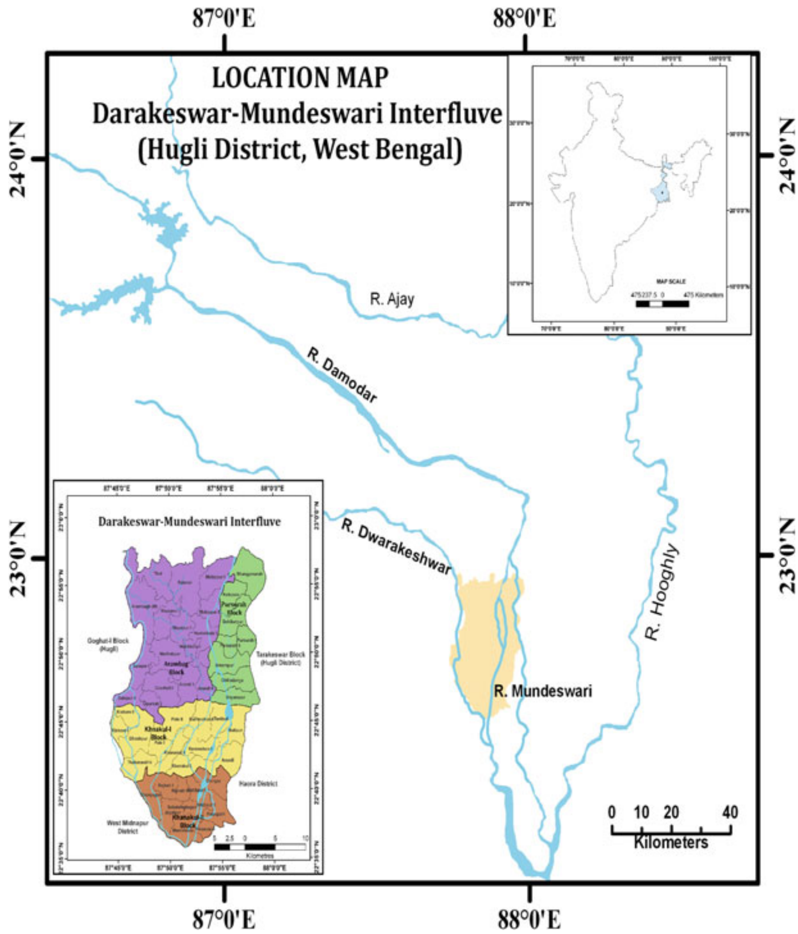

Fig. 6.1 Location map Darakeswar–Mundeswari interfluve (Hugli District, West Bengal)

LOWER REACH
Darakeswar-Mundeswari Interfluve

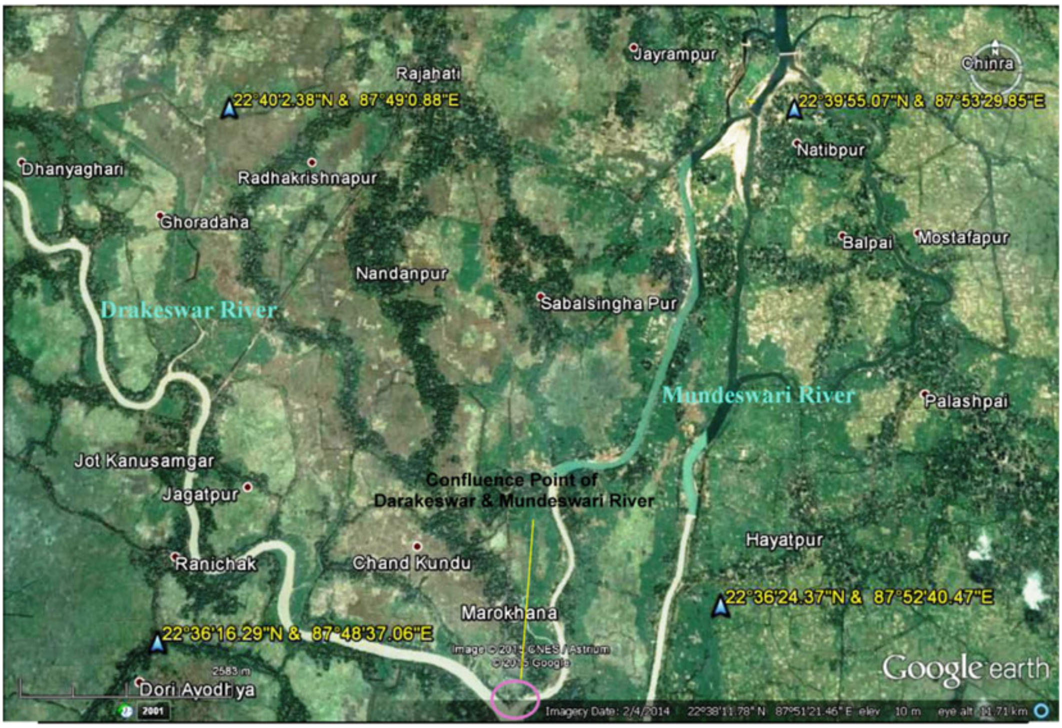

Fig. 6.2 Lower reach of Dwarakeswar–Mundeswari interfluve

practices, deforestation, land-use changes, etc. by man induced flood. The main causes of flood in this study are as follows:

(i) High discharge of water from DVC is one of the most important factors of flood in this area (Table 6.1 and Fig. 6.3).
(ii) Heavy rainfall at the Darakeswar–Mundeswari basin area (Table 6.2 and Fig. 6.4).
(iii) Overflow of water from the Rivers Mundeswari, Darakeswar, Kana-Darakeswar, Rupnarayan is one of the major causes of flood in this area.
(iv) River is severely affected due to sedimentation on river bed. As a result, the carrying capacity of the rivers decreases (Plates 6.1, 6.2 and 6.6).
(v) Deforestation in the upper catchment.
(vi) Construction of road, rice mill, brick industry and embankment on the floodplain across the natural drainage line (Plates 6.3 and 6.5).
(vii) Very gentle slope of the River Darakeswar and Mundeswari. The average slope of the River Darakeswar is approximately 0.369 meters/km.
(viii) Unwise construction of flood embankment on spill zone of rivers resulting in deposition of solids in the river bed itself (heavy siltation).
(ix) Due to inadequate waterways in the road bridges, accumulation of water on the upstream.
(x) The administration is not at all alert about the situation.
(xi) Narrowing of channel width due to agricultural encroachment in some parts of the lower basin (Plate 6.4).

Table 6.1 Year-wise discharge from DVC at Durgapur and Horinkhola station

Years	Discharge in cumec		Remark
	Durgapur	Horinkhola	
1978	10732.3	6208.7	Food
1979	1025.8	855.4	
1980	4598.6	2899.7	Flood
1981	1471.0	1247.4	
1982	621.6	384.9	
1983	2181.7	1963.9	
1984	5174.0	3044.1	Flood
1985	3458.1	2878.5	Flood
1986	3560.4	2950.2	Flood
1987	5349.9	3327.3	Flood
1988	1402.4	1075.6	
1989	2187.0	1794.7	
1990	3323.8	2774.1	Flood
1991	2450.9	2031.9	
1992	1035.0	415.1	
1993	3862.5	2702.3	Flood
1994	3326.1	2473.1	
1995	8631.1	4599.1	Flood
1996	3505.6	3013.7	Flood
1997	2329.1	1455.9	
1998	4104.5	3029.6	Flood
1999	6122.2	3465.4	Flood
2000	6323.0	3848.1	Flood
2001	1732.6	1357.0	
2002	1617.6	942.9	
2003	1590.3	1273.7	
2004	1638.3	1440.0	
2005	819.8	520.1	
2006	7699.5	4464.1	Flood
2007	8380.4	3499.8	Flood
2008	2666.9	1577.7	
2009	8823.7	5104.5	Flood
2010	243.7	120.2	
2011	4077.1	2175.3	Flood

Source Irrigation and Waterways Directorate, Harinkhola, 2012

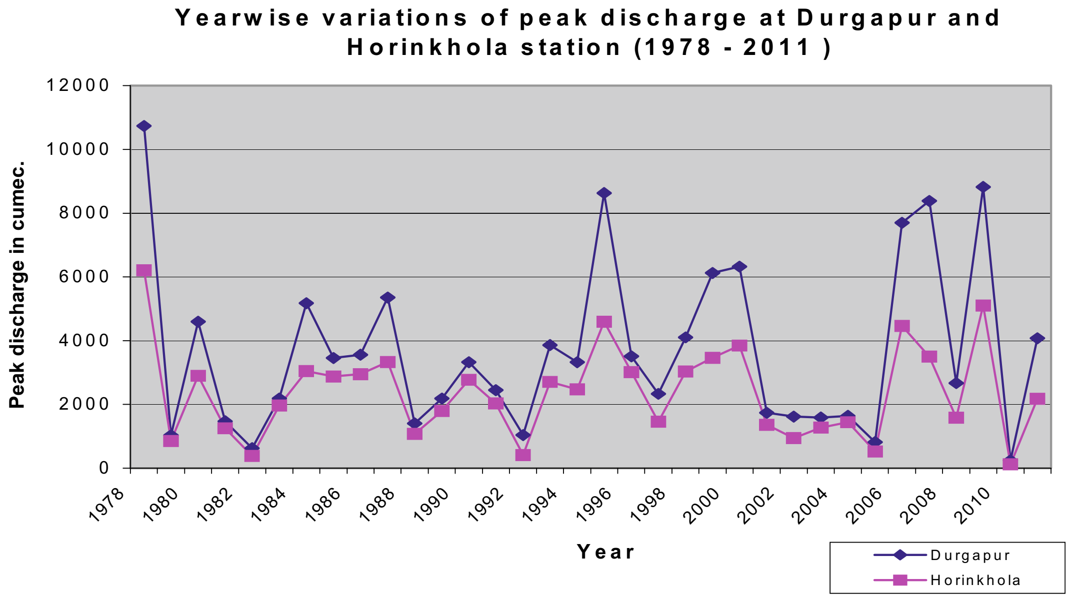

Fig. 6.3 Yearwise variations of peak discharge at Durgapur and Horinkhola Station (1978–2011)

Table 6.2 Yearwise rainfall data at Arambagh and–Champadanga stations

Year	Rainfall in mm	
	Arambagh	Champadanga
1980	1759.29	1237.0
1984	2315.0	1385.5
1985	2114.0	1105.1
1986	2757.0	1476.75
1987	1849.5	1325.5
1990	1332.6	1391.5
1993	1583.5	1425.0
1994	1472.0	1195.0
1995	1380.0	1462.62
1996	1610.5	1444.65
1999	1384.5	1605.25
2000	1335.0	1658.75
2006	1413.5	1461.0
2007	1665.0	1338.0
2009	1190.5	1140.0
2011	1325.5	1610.0

Source Irrigation and Waterways Directorate, Arambagh, Hugli, 2012

Fig. 6.4 Yearwise variation of rainfall at Arambagh and Chanpadanga

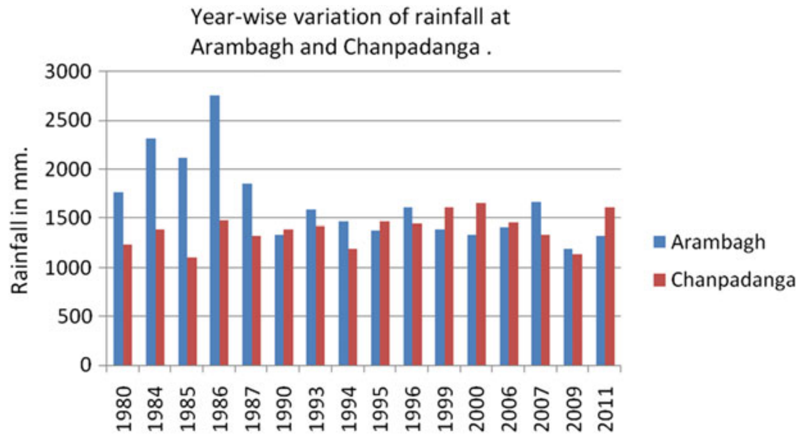

Plate 6.1 Sedimentation on channel bed in Mundeswari River, which reduces the carrying capacity thereby induces flood during rainy season

(xii) The Government is not in a position to allocate fund for repairing the Dams during that period.

(xiii) Worst condition of embankment and natural leeves in both side of the Rivers Mundeswari, Darakeswar, Kana-Darakeswar and associated channels (Hurhurh Khal, Arora Khal, Karakdha-Panjhula Khal, Kata Khal, Deb Khal etc.) (Table 6.3).

(xiv) Beside this, back pressure of river water of Rupnarayan River and connected Canals which run over the Mundeswari–Darakeswar basin are responsible for flood (Plate 6.7).

Plate 6.2 Dry channel bed with heavy sedimentation in Darakeswar River aggravates flood problems in rainy months increases the probability of floods

Plate 6.3 Establishment of brick industry in the channel bed of Darakeswar River near Arambagh, a clear evidence of encroachment, which obstructs the natural flow and increases the chances of flood during the period of heavy rainfall

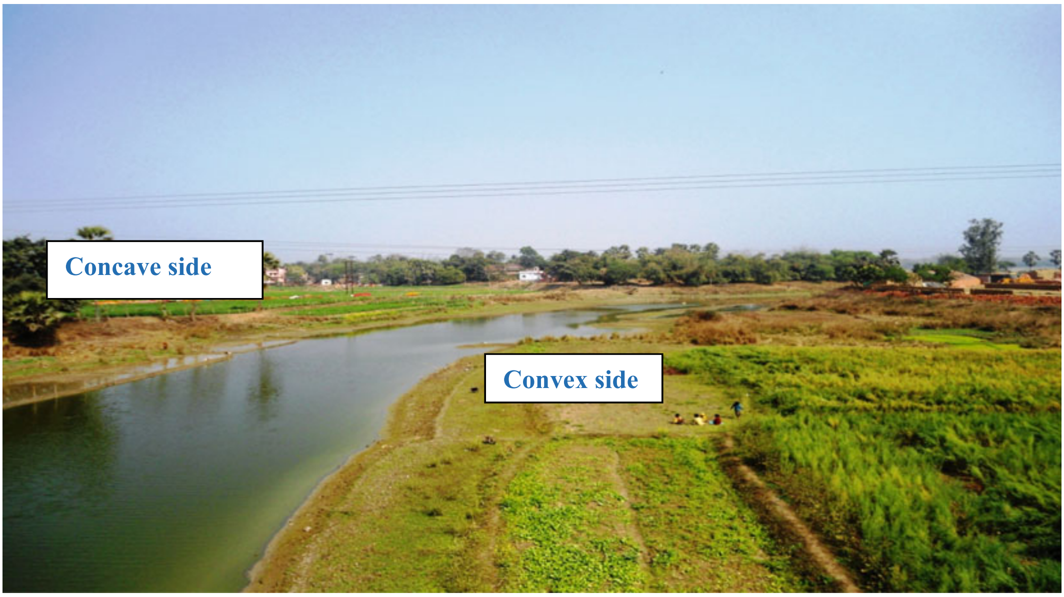

Plate 6.4 Convex depositional tract in the left bank of Kana-Darakeswar has been encroached for agricultural practices

Plate 6.5 Encroachment of riverbed by the construction of commercial building at the confluence point of Darakeswar–Mundeswari in Marokhana, Hooghly

Plate 6.6 Kana-Mundeswari (palaeo-channel of Mundeswari River) plays a vital role in the diversion of water during monsoon season. Sometimes it becomes terrible and causes flood and inundation in the adjoining region as this palaeo-channel does not have the carrying capacity to store excess water during the time of heavy precipitation due to increasing siltation

Table 6.3 Embankment condition of important rivers in the study area

River	Affected parts of Embankment
Darakeswar	(a) Right embankment from Mohisgot to Bandipur—6 km (b) Right embankment from Bandipur to Paschim Thakuranichak (via Kulat, Benejda, Paschim Ghoshpur)—10 km (c) Left embankment from Ghasua to Raghunathpur—3 km (d) Left embankment from Raghunathpur to Purbathakuranchak (via Mayal, Ghoshpur, Narendra Chak, Malaucha)—13 km
Kana-Darakeswar	(a) From Tilakchak to Srirampur—5 km (b) Rest part of Kana-Darakeswar: both side river embankment from Srirampur to Udaypur
HorinaKhala	(a) Left embankment of River Horinkhali from Balipur to Jagikundu—10 km (b) Right embankment from Kanakpur to Purba-Radhanagar (via Chhatrasal, Arunda and Sudamchak)—10 km (c) Circuit embankment of Harinkhali at Arunda (Island)—10 km
Mundeswari	(a) Right embankment at Baligori under Natibpur-I G.P. (b) Left embankment at Hait Hana under Natibpur-II G.P. (c) Left embankment at Sosapota near the House of Sagar Rong under Marokhana G.P. (d) Right embankment at Pansuli Bazar point under Marokhana G.P. (e) Right embankment from Maira Hana to Bankanogori under Natibpur-I G.P.

Source Sub-divisional Disaster Management Department, Arambagh, 2010

Plate 6.7 Confluence point of Darakeswar, Mundeswari and Rupnarayan Rivers. It is also a tri-junction of Hooghly, Howrah and West Medinipur Districts. River Mundeswari frequently used to spill over for the back-pressure of water of Rupnarayan River due to tidal waves and high-velocity flow of Darakeswar

6.3 Physical Environmental Impact Assessment

6.3.1 Sand Splay Problem

The most prominent effect of the breaching of embankment and the occurrences of flood is the sand splay as post flood hazard (Mukhopadhyay 2010). Sand splay affects land both in short term and long-term basis. Due to breaching of embankments, thick deposition of sand takes place on the river astride areas. So, the fertile alluvial land is converted into sterile sandy land.

Along the both sides of Mundeswari and Darakeswar Rivers, sand splay problems are found particularly downstream of Chanpadanga and Arambagh respectively. Sand depositions have been taken place in isolated pockets as a result of breaching of embankment. Approximately 150 acres of agricultural land were converted into barren land by sand splay at Balidayanganj in 1978. The sand splay was also deposited at Balidanga (1983), Jagatpur (1987), Srimantapur (1993) and Balarampur (2007) in Khanakul-I Block and Ranjitbati (2000), Baligori (2009), Doulotchak (2009), Narendrapur and Harischak (2009) in Khanakul-II Block. The areas converted into sand splay were 20–30 acres in Srimantapur and 40 acres in Balarampur.

The maximum thickness of Sand splays has been found up to 6 ft. On the basis of field survey conducted at Baligori Mouza, a cross-section has been drawn (Fig. 6.6). It shows that the depth of sand deposition is inversely proportional to distance from riverbank. It has been observed that at the breaching place of embankment, the thickness of sand deposition is not considerably higher, but immediately after the breaching place at about 50–75 meters distance towards countryside, the thickness of sand deposition is maximum and the thickness gradually decreases with distance from the embankment. From the laboratory analysis of sample collected from the field, it has been found

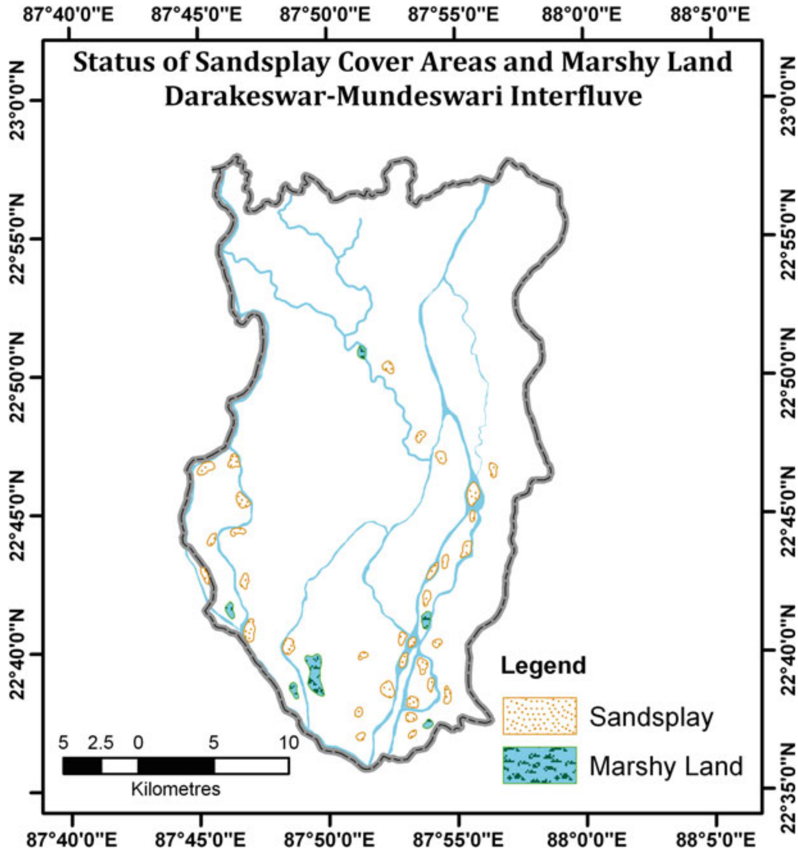

Fig. 6.5 Status of sandsplay cover areas and marshy land in Darakeswar-Mundeswari Interfluve

that about 90% of the Sand varies in grain size from 0.1 mm to 1 m. The grain size of Sand became coarser near breaching place of embankment and became finer towards countryside (Figs. 6.5 and 6.6, Plate 6.8).

6.3.2 Origin of Marshyland and Its Problem

Marshyland is a transitional zone between terrestrial and aquatic ecosystem, hence it is an ecotone. Wetlands play a dominant role in the environment, principally water purification and flood control.

The marshylands of the study area are seasonal and formed mainly by trapping of floodwater. It is found mainly at the lower reach of the study area. The remarkable marshylands observed at Telua-Velua and Bolundi in Arambagh Block, Kabilpur in Khanakul-I block, Nandanpur mud, Mainan, Dhanyagori Dakshinpara, Daulatchak in Khanakul-II Blocks (Plate 6.9).

6.3.3 River Channel Widening

River channel widening is a perpetual process in the study area. It is mainly due to lateral erosion. It is noted that the graves of the floodplains in the study area which were once developed on the river banks are now located within the channel beds (sometimes 25 m to 50 m from bank). The process of River channel widening repeats in the lower reaches (Khanakul-I and Khanakul-II Block) of study area and is responsible for more destruction in the existing floodplains (Plate 6.10).

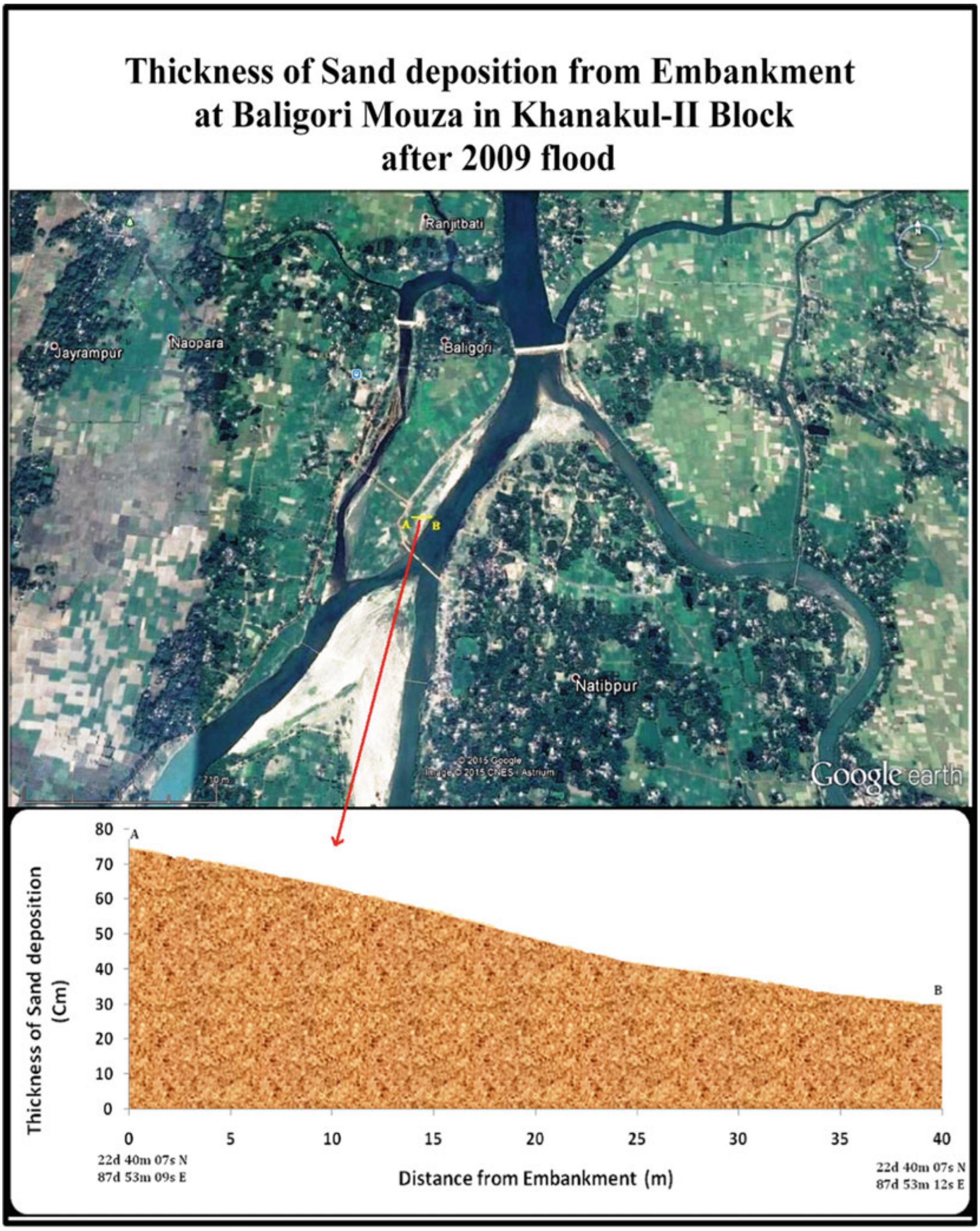

Fig. 6.6 Source Result of Field Survey conducted by author Date- 20 and 21 November, 2010

6.3.4 Shifting of River Course

The early maps of Jao De Barros, 1550; Bleva, 1645; Vanden Broucke, 1660; Rennel, 1779–81 and other maps and charts of the unknown Cartographers provided cognizable evidence of changing courses of lower Damodar or Mundeswari. According to De Barros (1550), the main flow of the Damodar in the sixteenth century was restricted to the present channel of Kana

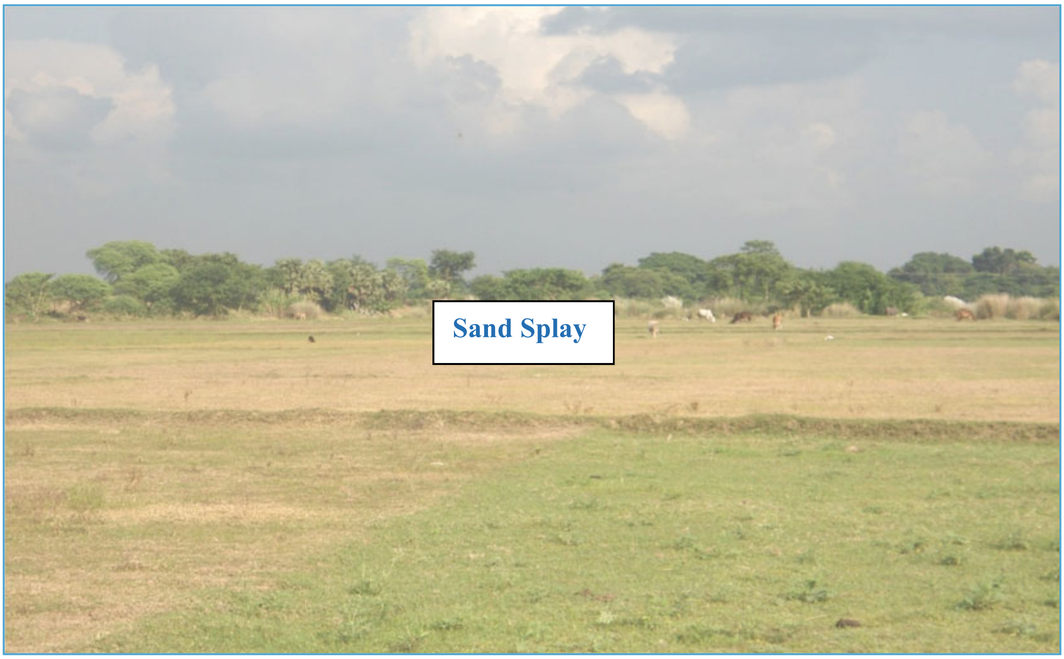

Plate 6.8 Sand Splay at Doulatchak in Khanakul-II Block, which has converted the agricultural plot into barren land

Plate 6.9 Marshy land at Narendrapur Village (adjacent to Mundeswari River) in Khanakul-II Block. This land once used for the storage of excess floodwater, now has become shallow marshy land due to siltation and is of no use

Plate 6.10 Channel widening in Mundeswari River at Natibpur in Khanakul-II

Damodar taking off below Selimabad and meeting the River Hugli at Uluberia (Bhattacharyya 1998). At present the River Mundeswari migrated easterly and south-easterly in Khanakul-II Block due to back pressure of tidal flood. It also shifted westerly in Khanakul-I Block. Darakeswar River has changed its course towards east in Khanakul-I and Khanakul-II.

The migrating river course, mainly occurred during flood, can change the block or district's administrative boundary and making a big barrage useless because of its destructive nature. Such shifting nature is found in almost all the rivers of the study area but among them Mundeswari River is dominating.

6.4 Impact of Flood on Embankment Breaching

Embankment is built with earth or rock to contain floodwater or to construct a road, railway, canal, etc. It is an important structural measure of flood control. The performance of embankment varies from case to case. It is quite effective for short-term flood elevation, but it puts a question regarding the long-term viability of embankment and become harmful to the adjacent floodplain. It creates drainage congestion in the protected areas. In the post- construction period, the floodplains get deprived of silt deposition and thereby, choking the natural process of floodplain development. Due to confinement of river flow within embankments, rapid siltation takes place on the river bed. It reduces the depth of the river flow within embankment (Molla 2010).

Mundeswari and Darakeswar are two important rivers in west Bengal. Embankment constructed along Mundeswari and Darakeswar is subject to frequent breach. Breaching of embankment causes devastating flood and results in huge sand deposition on the floodplain. The length of Embankment varies from year to year and block to block (Table 6.4 and Fig. 6.7).

6.5 Structural Measures

Actually, flood cannot be stopped or controlled as it is a natural phenomenon but it can be mitigated as much as possible. Over centuries, a variety of structures have been evolved to

Table 6.4 Damage of embankment in three major floods

Year	Khanakul-I (km)	Khanakul-II (km)	Arambagh (km)	Pursurah (km)	Total (km)
2006	27	18	20	12	77
2007	23	13	16	8	60
2009	35	29	58	19	141

Source Disaster Management Department, Arambagh, Hugli, 2010

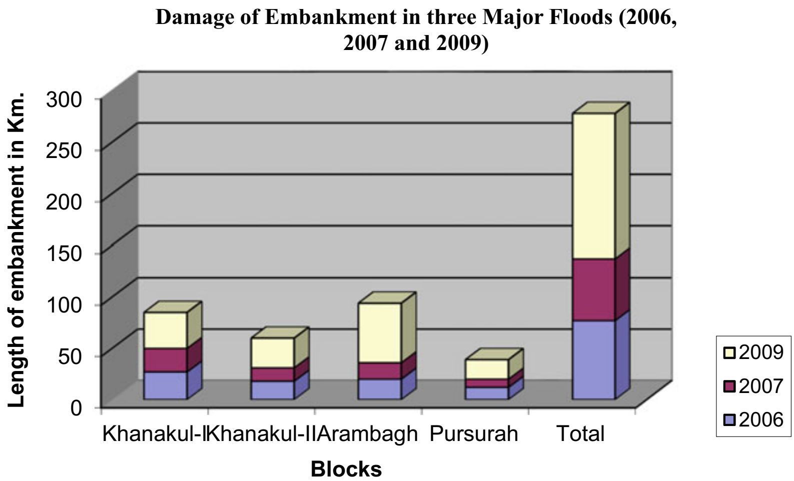

Fig. 6.7 Damage of embankment in three major floods (2006, 2007 & 2009)

mitigate flood hazards. Their aim was to achieve at least one of the following objectives:

- A reduction in the area flooded
- A reduction in the depth of floodwater
- A reduction in flood discharge

Flood in Darakeswar–Mundeswari Interfluve is a recurrent problem. So, it cannot be avoided, but the magnitude of its impact on life and property can definitely be mitigated through proper management measures. The suggested structural measures are as follows.

1. **River Channel Improvement**

The primary consideration of the planner of the Damodar Valley Scheme (DVS) was to provide adequate protection to the left embankment along the Damodar River which protects the arterial railway line, Grand Trunk Road (present name Shersha Suri Road), industrial establishment etc. by restricting the flows at Durgapur Barrage to 250,000 cusec (7079 cumec), which was considered to be the safe maximum carrying capacity of lower Damodar channel. The carrying capacity of lower reaches of the river below Damodar barrage, later, diminished due to heavy siltation. In some places, it has reduced to even about 50,000 cusec. The lockage of tidal channels at outfalls, further adds to the flood problem of the area.

The State Government has now commenced implementation of a scheme: 'Improvement of drainage of lower Damodar to increase the capacity of the channel'. The left bank embankment has also been strengthened to withstand a controlled flow up to 450,000 cusec (12,743 cumec). The moderate flow from the dams was planned also to prevent excessive flooding in the fertile agricultural land on the right bank of Damodar in this region. However, in the absence of frequent floods of higher intensities and due to low releases of less than 100,000 cusec (2,832 cumec) from the dams during the monsoon period, the lower valley has gained undue value and importance due to false sense of security and there has been extensive encroachment into the floodplains. The Government of West Bengal realized the importance of the productive value of the floodplains of Damodar–Mundeswari, given the density of population and high level of investment on floodplains and that such protection can only be imparted at great cost and at the cost of denying the reductive use of flood-prone land. While there are losses in the high flood-years, the floodplains are utilized gainfully by the people living in the area during the low flood-years. The approach, therefore, has been to 'bear the losses' at the time of flood disaster while enjoying the benefits of the land during the rest of the periods/years (Chandra 2003).

This was a natural approach adopted by the State Governments of India from the very beginning itself, i.e. after India became independent in 1947. The policy emerged out of the necessity to safeguard the interest of already densely populated floodplains and the difficulty envisaged in the uprooting and resettlement of the floodplain occupants who were living off the floodplains and also that it was considered more beneficial to accept occasional flood losses against large benefits accruing out of the use of floodplains. But taking this problem into account it is necessary to replan so that the interest of the common people (densely populated) can be protected.

After the construction of Damodar Valley Corporation (DVC), the river bank erosion at upstream (before Durgapur) of Damodar is increased due to high velocity and discharge of water, which provides siltation problem at the lower reach of Damodar and Mundeswari (the main distributary of Damodar) because of very gentle gradient. This silt can be reduced by destroying sand bars or dredging the riverbed.

6.6 Proper and Scientific Reservoir Control

6.6.1 Controlling Measures of DVC Project

Earlier it was proposed that eight dams would be constructed over the River Damodar by DVC. But unfortunately, only four dams have been constructed viz. Tilaiya (1953), Konar (1955), Maithon (1957) and Panchet (1959). A pick up structure Durgapur Barrage was constructed downstream of the four dams in 1955 with head regulators for canals on either side for feeding an extensive system of canals and distributaries. One more reservoir Tenughat (1978) came up on Damodar River constructed by the Govt. of Bihar (now Jharkhand).

Up to 1970s the function of the dams was satisfactory but the problem restarted after that period owing to heavy siltation on all the dams. As a result, the carrying capacity of all the dams decreased which increased the probability of flood. On that circumstances the following measures should be taken-

- Reduction of siltation from the dams on an immediate effect by afforesting the upper catchment area.
- With the help of early flood prediction water may be released systematically with increasing intensity of rainfall.
- Increase the carrying capacity of Tilaiya, Konar, Maithon, Panchet and Tenughat dams by dredging the reservoirs bed.
- For the reduction of pressure on the dams controlled by DVC rest of the four dams should be constructed.
- The General Secretary of the Officers Forum of DVC Mr. S.K. Singh suggested that one barrage at Belpahari should be constructed, approximate cost of which would be Rs. 8000 crore and also suggested at least 25 small regional dams in Purulia which may cost 3 lakhs each. The Government of India granted an insufficient amount to DVC in last 20 years where an amount of Rs. 3000 crore is required only for dredging (Anandabazar Patrika, Oct 22, 2013).
- The officials and common people (Krishak Sabha) of Khanakul-II Block are raising the most important point that the carrying capacity of River Rupnarayan must be increased by drazing regularly from Panshiuli (junction point of Howrah, Hugli and West Midnapur) to Geonkhali.

- The encroachment of the lower reach of Mundeswari by agriculture and brick industry should be prevented by the joint endeavor of State Govt., DVC as well as local administration and politicians by providing proper rehabilitation.

6.6.2 Controlling Measures of Mukutmonipur Barrage

- Reduction of siltation from the Mukutmonipur Dam.
- Reduction of water through the cyclonic period with above danger level to reduce pressure from the dam.
- Increase the carrying capacity of Mukutmonipur Barrage to store excess water.
- Several small dams may be constructed in the upstream of Mukutmonipur dam to reduce pressure from the main dam.
- The uncontrolled discharge of River Darakeswar should be regulated in a scientific way and appropriate plan should be taken up in this regard.

6.7 Reducing Flood-Peaks by Volume Reduction

The Damodar Valley Reservoirs play an important role for the reduction of flood peaks by discharge reduction. Examination of actual inflow and outflow data for the two terminal dams at Maithan and Panchet shows that tangible flood moderation has been achieved during the past years. Table 6.5 shows the performance of these reservoirs in terms of major flood inflows into these reservoirs and the moderation achieved. All flow figures are in cubic meters per second.

It is evident from the above table that flood moderation to the extent of 53% to 80%had been achieved in the high flood-years. Detailed examination of flow data as available at Rhondia revealed that maximum flow of 650,000 cusec

Table 6.5 Year-wise flood moderation achieved (%)

Year	Date	Maximum inflow (cumec) into Maithon and Panchet	Maximum outflow (cumec) into Maithon and Panchet	Flood moderation achieved (%)
1958	16–27 Sep	15.7	5.0	68
1959	1–2 Oct	17.6	8.2	53
1960	27–29 Sep	10.0	2.6	74
1961	2–3 Oct	14.6	4.6	68
1963	2–3 Oct	12.8	3.4	73
1963	24–25 Oct	13.2	2.6	80
1971	16–18 July	12.0	5.1	58
1973	12–13 Oct	16.7	5.0	70
1975	25–27 Sep	9.7	3.1	68
1978	26–27 Sep	21.9	4.6	79
1984	25 June	10.6	4.8	55
1993	14–17 Sep	7.0	2.8	60
1995	27–28 Sep	17.5	7.1	59
2000	19–21 Sep	9.2	2.8	70

Source Damodar Valley Corporation (1995)

(18,406 cumec) had occurred twice in August 1913 and August 1935 before the implementation of Damodar Valley Scheme. Examination of actual inflow for the two terminal reservoirs at Maithon and Panchet shows that major floods nearing or exceeding this maximum observed flow of 18,406 cumec occurred only in 1959, 1978 and 1995.

During 1959, the peak inflow into the reservoir was 17,641 cumec which was moderate to 8,155 cumec. However, the outflow from Durgapur Barrage was 9,911 cumec due to the contribution from intermediate catchments. It has been estimated by DVC that had there been no dams, a flood of 22,937 cumec would have been experienced below Durgapur which was much higher than the highest record i.e. 18,406 cumec till that date.

The 1978 was an all-time high with a combined inflow peak of 21,900 cumec. If this peak was allowed to pass without any flood moderation, it would have generated a probable peak of 33,414 cumec (1.18 million cusec) at Durgapur Barrage, thus surpassing the design flood (1 million cusec) of the structure as is shown in Table 6.6.

It is useful to recall that it was the havoc caused by the 1943 flood which led to the establishment of DVC and the water resources development structures. With the significant industrial development that has taken place below Durgapur, the potential of damage due to floods of the magnitude of 1959 or 1978 or 1995 in the event of a breach in left embankment assumes frightening proportions. In the year 1978, but for the DVC dams the whole of the industrial belt of Asansol, Durgapur, Burdwan, Bankura, Hugli, Howrah, the Grand Trunk Road and the Eastern Railway line would have been devastated (Chandra 2003).

6.8 Maintenance of Embankment

After Independence of India, the scenario of flood control has been changed. *Directorate of Irrigation and Waterways Department*, Government of West Bengal, has made extensive attempts to control flood of Lower Damodar—Mundeswari and Darakeswar Basin. Thereafter, the ex-Zamindary embankments have been remodeled, realigned and maintained by the concerned authority. As already mentioned, construction of embankments is the only structural measure available with the Irrigation Department to give relief to the people from the menace of flood. This Department has made some remarkable advancement through renovation of embankments in flood control sector by taking up remodeling and strengthening of its existing embankments ravaged by 1999 and 2000 floods with the assistance of *National Bank for Agricultural and Rural Development* (NABARD).

The vulnerable spots, which are sensitive Zone during high flood period, Directorate of Irrigation and Waterways Department is always alert for any palliative measure at these spots (Table 6.7).

A list of embankment and natural levees which are in a bad condition have been identified at both sides of the River Mundeswari, Darakeswar, Kana-Darakeswar and associated channels (Hurhurh Khal, Arora Khal, Karakdha-Panjhula Khal, Kata Khal, Deb Khal etc.) are also necessary to improve (Table 6.8).

Table 6.6 Regulation of 1978 flood

Gauge station	With 4-DVC dams		Without dams	
	3-hourly peak Inflow (cumec)	3-hourly peak Outflow (cumec)	3-hourly peak Inflow (cumec)	3-hourly peak Outflow (cumec)
Maithan and Panchet	21,917	4,615	26,958	26,958
Durgapur	10,732	10732	33,414	33,414

Source Damodar Valley Corporation (1995)

Table 6.7 Location of vulnerable spots

Sensitive zones	River	Name of bank/Embankment	Name of spot	Name of block/P. S.
Mundeswari	Mundeswari	Right bank	Madanpur	Khanakul-I
Mundeswari	Mundeswari	Right bank	Durgapur	Khanakul-I
Mundeswari	Mundeswari	Right bank	Amarpur	Khanakul-I
Mundeswari	Mundeswari	Left bank	Balipur	Khanakul-I
Arambagh	Darakeswar	Left bank	Chandra	Arambagh
Arambagh	Darakeswar	Right bank	Kalipur and Haripur	Arambagh
Arambagh	Darakeswar	ATP embankment	Kalipur bridge to Sishuguchha school	Arambagh
Arambagh	Darakeswar	ATP embankment	Sweeper's colony to burning ghat at Arambagh	Arambagh
Arambagh	Darakeswar	Left bank	Salepur Paschimpara	Arambagh
Arambagh	Darakeswar	Sheikpur circuit embankment	Gugra to Bondipur	Khanakul-I
Arambagh	Darakeswar	Left bank	Manikpath to Pratiharpur including Doharkundu	Arambagh
Arambagh	Darakeswar	Left bank	Raghunathpur to bandipur (Moyal)	Khanakul-I
Arambagh	Darakeswar	Leftbank (Sheikpur circuit)	Basantabati and Harighat	Arambagh
Arambagh	Darakeswar	Sheikpur circuit	Mohisgota, Baraberia, Dongol	Arambagh and Khanakul-I

Source Directorate of Irrigation and Waterways Department, West Bengal, 2008

Table 6.8 List of embankments having bad conditions

River	Location of embankments
Darakeswar	(a) Right embankment from Mohisgot to Bandipur—6 km (b) Right embankment from Bandipur to Paschim Thakuranichak (via Kulat, Benejda, Paschim Ghoshpur)—10 km (c) Left embankment from Ghasua to Raghunath pur-3 km (d) Left embankment from Raghunathpur to Purbathakuranchak(viaMayal, Ghoshpur, Narendrachak, Malaucha)—13 k
Kana-Darakeswar	(a) From Tilakchak to Srirampur—5 km (b) Rest part of Kana-Darakeswar both side river embankment from Srirampur to Udaypur
HorinaKhala	(a) Left embankment of river Horinkhali from Balipur to Jagikundu—10 km (b) Right embankment from Kanakpur to Purba—Radhanagar (via Chhatrasal, Arunda and Sudamchak)—10 km (c) Circuit embankment of Harinkhali at Arunda (Island)—10 km
Mundeswari	(a) Right embankment at Baligori under Natibpur-I G.P. (b) Left embankment at Hait Hana under Natibpur-II G.P. (c) Left embankment at Sosapota near the House of Sagar Rong under Marokhana G.P. (d) Right embankment at Pansuli Bazar point under Marokhana G.P. (e) Right embankment from Maira Hana to Bankanogori under Natibpur-I G.P.

Source Disaster Management Department, Arambagh Subdivision, 2009

6.9 Sheet Erosion Control and Soil Conservation by River Bank Protection

6.9.1 Construction of Dyke

The construction of protective dykes limits the occurrence of flooding. Construction of dyke in the river bank can control its erosion due to more rigidity and diversion of river's turbulence from the sidewalls towards the middle. So, it reduces pressure from river bank and the chance of erosion becomes less. Due to highly rigid guard-wall by hard boulders water cannot erode it quickly and saves the nearer villages, towns or important places as it is done in River Manja in North Bengal (Jha and Bairagya 2011).

This is applicable for the non-perennial rivers of the study area like Darakeswar, Kana-Darakeswar and Mundeswari (the main distributary of Damodar River) because here erosion occurs only in rainy season and as a result proper construction can be done in the summer only.

6.9.2 Concretization of River Bank in Vulnerable Spots

It is very costly method but is very useful. Occasionally, this method is used to save the important town (Arambagh), Bigger villages (Rajhati, Bandar, Horinkhola, Chanpadanga, Marokhana etc.) or danger zones (Natibpur, Dhanyagori, Sabalsinghapur, Balipur, Mohisgota, Basantabati, Bondipur, Raghunathpur) of the study area.

6.10 Reducing Flood Levels

6.10.1 Stream Channelization

Channelization is a general term for various modifications to stream channel itself that are usually intended to increase the velocity of water flow, the volume of the channel or both. These modifications, in turn increase the discharge of the stream and the rate and hence surplus water is carried away. The channel can be widened or deepened, especially where soil erosion and subsequent sediment deposition in the stream have partially filled in the channel. Alternatively, a stream channel might be rerouted, for example, by deliberately cutting off meanders to provide a more direct path for the water flow.

6.10.2 Bypass and Channel Diversion

The construction of bypass and diversion channels is to be excavated to carry some of the excess floodwater away from the area, which needs to be protected. This method already adopted in the study area. A bypass has been constructed from Kulti to Gaighata. But the incomplete part which will meet with Rupnarayana at Baski in Howrah district has to be completed as soon as possible. The view of local people is that the intensity and magnitude of flood will probably be decreased after the completion of this Khal (bypass).

6.11 Non-Structural Measures

6.11.1 Flood Vulnerability Zoning

Floodplain zoning means restricting any human activity in the floodplains of a river. Generally, the term 'floodplain' includes water channel, flood channel and nearby low land areas susceptible to flooding by inundation. The zoning involves the division of floodplain into specific zones. Zoning is also used to restrict riverine area for particular uses, specify where the uses may be located and establish minimum elevation or flood-proofing requirements for the uses. The Government of India drafts a *Flood Plain Zoning Model Bill, 1975* and the same was forwarded to the various state Governments for necessary action.

Based on the areal extension of inundation and flood elevation, the Darakeswar–Mundeswari Interfluve has broadly been divided into three vulnerable zones (Table 6.9 and Fig. 6.8).

Flood Zone Mapping (FZP) and the associated zone-wise land-use regulations would be

Table 6.9 Flood vulnerability zones

High vulnerable zone	Moderate vulnerable zone	Low vulnerable zone
All mouzas of GPs like Marokhana, Dhanyagori, Chingra, Sabalsinghapur, Jagatpur, Rajhati-I, Natibpur-I and II and Palaspai-I and II fall under high vulnerable zone of Khanakul-II Block Most of the mouzas of the GPs like Tantisal, Balipur, Arunda, Rammohan-I and II, Pole-II and Thakuranichak falls under this zone of Khanakul-I Block A few mouzas of GPs like Horinkhola-I and II, Mayapur-I, Moloypur-I, Arandi-II and Batanal falls under this zone in Arambagh Block Some mouzas of the GPs like Chiladangi, Pursurah-I and II, also falls under this high vulnerable zone (Fig. 6.8) The average height of water level in this zone is 10–15 feets. The average time for the release of water from this zone is 15–20 days	A very few mouzas of GPs like Rajhati-II, Jagatpur, and Palaspai-I falls under the moderate vulnerable zone in Khanakul-II Block Most of the mouzas of GPs like Pole-I, Pole-II, Rammohon-II and some mouzas of Tantisal, Thakuranichak and Rammohan-II fall under this moderate vulnerable zone in Khanakul-I Most of the mouzas of GPs like Horinkhola-I and II, Mayapur-I, Moloypur-I, Arandi-II, Salepur-I and II and Batanal falls under this zone in Arambagh Block Most of the mouzas of the GPs like Chiladangi, Pursurah-I and II, Srirampur and Bhangamorah may also be considered as the moderate vulnerable zone in Pursurah Block (Fig. 6.8) The average height of water level in this flood zone was 5–10 ft. from the local base level. The average time for releasing floodwater from the mouzas is nearly 10–15 days	Most of the mouzas of GPs like Tirol, Batanal, Mayapur-I, Madhabpur, Gourhati-I, Moloypur-I, Arandi-I and Salepur-I falls under low vulnerable zone in Arambagh Block A few mouzas of the GPs like, Pole-I and II, Ghoshpur Arunda, Rammohan-II, Khanakul-II and Thakuranichak fall under this zone in Khanakul—I Block Some mouzas of the GPs like Kelepara, Dehibatpur, Srirampur also fall under this low vulnerable zone (Fig. 6.8) The average height of water level in this zone is less than 5 feets. The average time for release of water from this zone is 5–10 days

essential inputs for formulation of future developmental programs, land-use policy and introduction of flood Insurance in the area. All these data have been collected directly by the field investigation.

6.12 Flood Management

1. **Zone-wise Mitigation Measures**
   Keeping in view the magnitude of vulnerability of flood in the study area, zone-wise mitigation measures have been suggested for reducing the risks in future (Table 6.10).

2. **Zone-wise Land-Use Recommendations**
   Zone-wise land uses have been recommended as per the vulnerability of floods (Table 6.11).

6.13 Conclusion

Flood in Lower Darakeswar–Mundeswari Interfluve is a recurrent problem. It has already been mentioned that flood cannot be fully stopped. But the risks and vulnerability of flood can be reduced by adopting some structural and non-structural measures. From the whole study of Physical Environmental Impact Assessment of flood in Lower Darakeswar–Mundeswari Interfluve, it may be mentioned that both the rivers, which are curse during rainy months become blessings for the people of the study area in the post-monsoon season because of bumper crop production in their floodplains and adjoining region due to heavy siltation in the flood-affected areas.

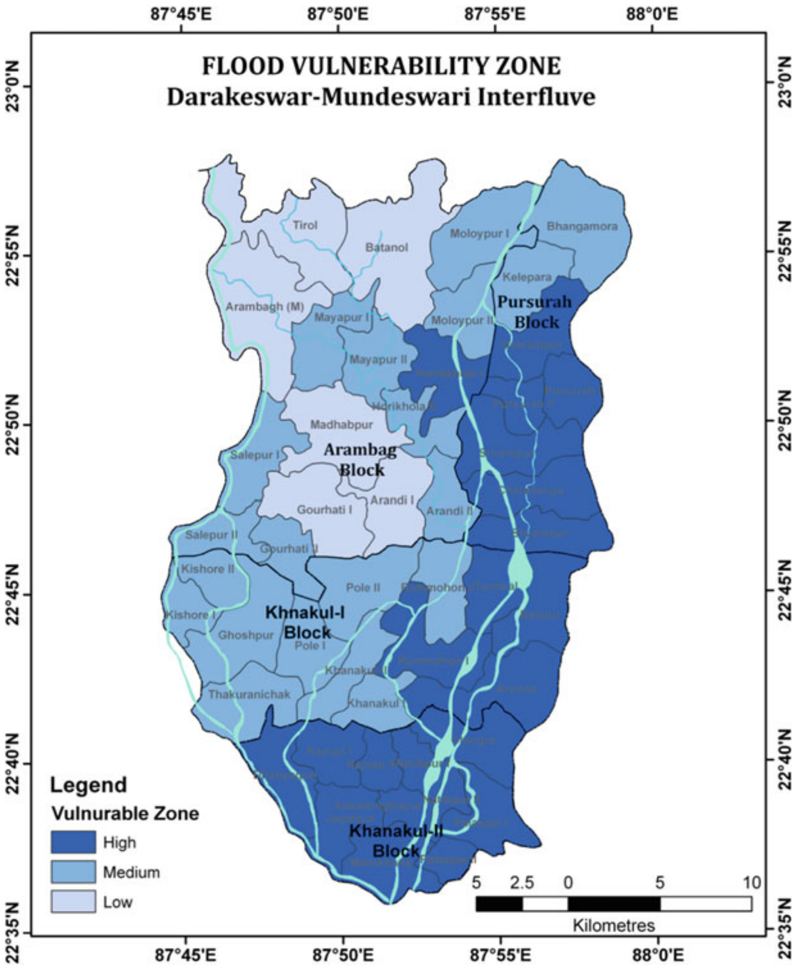

Fig. 6.8 Flood Vulnerability Zone in Darakeswar-Mundeswari Interfluve

Table 6.10 Zone-wise Mitigation Measures

High vulnerable zone	Moderate vulnerable zone	Low vulnerable zone
• Concretization or bouldering the embankments and increasing their heights in vulnerable spots (Plate 6.11) • Frequent monitoring of the embankments in pre-monsoon period and their regular repairing and maintenance • Prevention of encroachment of settlement • De-siltation of channel bed through dredging • Construction of permanent lock gate instead of temporary sand bar (borobandh) • Number of boats should be increased • Timely forecast and people's awareness • Help line services for rescue and rehabilitation • Search for alternative job opportunity	• Concretization or bouldering the embankments in vulnerable spots (Plate 6.11) • Monitoring of the embankments in pre-monsoon period and repairing and maintenance if required • Buildings should be constructed above 10–15 m from the ground surface (Plates 6.12 and 6.13) • Ensuring family coverage under flood insurance • Equipping the hospitals and activating the mobile medical vans • Emphasis on more vacation in rainy months to increase the number of working days • Distribution of adequate relief among flood-affected people • Providing adequate number of boats • Timely forecast and people's awareness • Help line service • Encouraging alternative agriculture	• Buildings should be constructed 5–10 m from the ground surface • Selective family coverage under flood insurance • Equipping the existing health centers • Relief is to be distributed among the actual affected people • Emphasis on multiple cropping practice

Table 6.11 Zone-wise Land-use Recommendations

High vulnerable zone	Moderate vulnerable zone	Low vulnerable zone
• Rural recreation • Open space environment • Social forestry along the embankment • Burial ground and crematorium • Play ground • Pasture land • Jute cultivation (Dry season)	• Rural recreation • Open space environment • Social forestry along embankment • Burial ground and crematorium • Play ground • Pasture land • Boro-paddy (post-monsoon) • Fishing ground * • Residential * • Commercial and Industrial* • Schools, clubs, public institutions, police station* • Permanent flood shelter* ***with special control**	• Rural recreation • Social forestry along embankment • Burial ground and crematorium • Play ground • Pasture land • Alternative agriculture like horticulture and boro-paddy, jut, nut, watermelon etc. (post-monsoon) • Fishing ground • Residential • Commercial and Industrial • Schools, clubs, public institutions, police station • Permanent flood shelter

Plate 6.11 Partly concretization of the vulnerable left bank of River Mundeswari at the tri-junction point near Marokhana in Khanakul-II Block for preventing bank erosion due to tidal back-pressure of Rupnarayan River and high-velocity flow of Darakeswar

Plate 6.12 Structural modification of a school building (construction above 12 feet) for protecting the same from the ravages of flood in Khanakul-II Block

Plate 6.13 Construction of residential building above 15 feet from the ground to reduce the magnitude of damage during the occurrence of flood in Khanakul-II Block

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7 System-Analytical Modeling of Water Quality for Mountain River Runoff

Yuri Kirsta and Alexander Puzanov

Abstract

The method of system-analytical modeling of complex natural systems is proposed to construct the simulation balance models for water and hydrochemical runoff of mountain rivers. An integral set of universal models for seasonal and long-term runoff dynamics was developed based on the example of 34 mid-size and small rivers of the Altai-Sayan mountain country as a regional case study. The set includes (a) regional climate model, (b) water runoff balance model, and (c) seven hydrochemical runoff balance models. The latter characterizes the hydrochemical composition of the river runoff: three nitrogen mineral forms (NO_2^-, NO_3^-, and NH_4^+), phosphates (PO_4^{3-}), ions, total dissolved iron, and suspended matter. To calculate the seasonal runoff, four hydrological periods/seasons were specified: winter low water, spring–summer flood, summer low water, and autumn low water. A total of 13 typological geosystem groups (landscapes) were selected to account for a landscape structure of river basins. In "b" and "c" models, the hydrological and hydrochemical regimes of river basins are divided into 13 standard types that correspond to selected hydrological seasons and landscapes. Each type depends on spatially generalized monthly dynamics of precipitation and air temperature. These meteorological characteristics are calculated in "a" model and expressed in percent of specified long-term mean values to be the same throughout the Altai-Sayan mountain country. GIS data on the relief and landscape structures of mountain river basins represent the input information for the "b" and "c" models. These data include the area and average altitude of the basins, the area and elevation of landscapes, the altitude of the outlet, the length of river channels (between the river head and the outlet), and the area of arable land. The spatially generalized for the Altai-Sayan mountain country normalized monthly precipitation and mean monthly air temperature as well as water runoff estimated for individual landscapes in river basins with "a" and "b" models serve as input factors for seven "c" models. The sensitivity of models to variations of input factors was evaluated. The sensitivity is expressed as a contribution of a particular factor to the variance of the observed values of the output variable (water or hydrochemical runoff). A quantitative assessment of the water and hydrochemical runoff sensitivity was

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_7

obtained for the following factors: landscape structure of river basins, basin lateral slope, precipitation, temperature, arable land area. Both RSR < 0.60 (RMSE-standard deviation ratio) and NSE > 0.65 (Nash–Sutcliffe model efficiency coefficient) estimated for each of the developed runoff models represent their good or very good performance. The most probable water and hydrochemical runoff can be forecasted for 3–4 months ahead with a twice reduced variance as compared with the similar forecast by the observed mean runoff. The elaborated balance models with anew selected landscapes and the updated values of parameters can be applied to any mountainous area and allow to estimate and manage the seasonal and long-term dynamics of water quality.

Keywords

Water quality · Hydrochemical runoff · Mountain rivers · System-analytical modeling · GIS · Altai-Sayan

7.1 Introduction

The problem of water resources management under the influence of climate change is constantly growing in importance (Deng et al. 2015). The present-day water management calls for the development of adequate mathematical models to assess quantitatively hydrological and hydrochemical processes in river basins. The models should take into account both temporal and spatial effects of natural and anthropogenic factors on these processes (Loucks and Beek 2005; Singh et al. 2014). The complicated orographic structure of mountain areas and space–time composition of climatic fields impede the task solution greatly (Sevast'yanov 1998).

Water runoff (**WR**) and hydrochemical runoff (**HCR**) are of prime interest for management. For their assessment, various methods (among them distributed hydrological modeling) making allowance for physiographic and hydrographic features of river catchments were developed (Jarrett 1990; Koren et al. 2004; Sene 2008). The application of GIS technologies makes it possible to automatize the calculations to a greater or a lesser degree. For instance, they are used to calculate spatial (areal) distribution of such climatic elements as precipitation, temperature, air humidity, etc., which are essential for WR estimation but monitored only in some sites of the territory under study. GIS technologies used for data interpolation often have errors close to that of traditional statistical analysis (Konovalova et al. 2006). The same holds true for the methods that estimate hydrological characteristics (Brus 1993). In the case of mountains, a computational error of areal meteorological characteristics is predominantly responsible for the inaccuracy of WR/HCR models.

At present, GIS tools are combined with complex physicomathematical models describing hydrological and hydrochemical processes. The GIS is applied here for processing the spatially distributed input data and visualization of the derived spatial distributions. In turn, the models consist of differential equations of hydrodynamics, hydrochemistry, and mathematical physics supplemented by experimentally found relationships between elements of the modeled system (Vinogradov and Vinogradova 2010; Rumynin 2013). The differential equations require detailed spatially distributed data on precipitation, air temperature, evaporation and plant transpiration, subsurface aquifers, basin morphometry, properties of water-saturated soils and rocks, flow resistance on slopes and in the river network, etc. For example, in different parts of the mountain river basin, the following processes can occur at the same time: rain, snow or absence of any precipitation, snow melting, and substantial change in evaporation with altitude. All this important information is practically absent for mountain countries, and complex physically grounded models become unavailing (Vinogradov and Vinogradova 2010). The simplest hydrological and hydrochemical models, which ignore this information, also become useless due to an unacceptable increase in calculation error. Instead of such models, it is reasonable to practice just the long-term mean value of observed river WR and HCR.

Let us consider the prospects of using the differential equations of liquid and gas motion in modeling the mountain river WR. Their construction is based on well-known physical laws, including the continuity of the simulated continuum, conservation of its mass and momentum, physical force influence; however, after the 50-year efforts, the mathematical models of 3D fluid flow (e.g. past 3D objects of relatively simple shape) have still many unresolved problems and require time-consuming experiments. The question is how many years it will take to develop adequate differential equations for mountain river WR. They should describe concurrently streamflow in channels of a very complex profile, flow around various bars (rapids, waterfalls, changing thickness of channel gravel), surface, subsurface and groundwater runoff, changing water phase states (solid, liquid, gaseous) under daily and seasonal temperature changes. Obviously, even after the creation of such a hypothetical system of hydrological/hydrodynamical equations, it would require a huge amount of experimental data to determine the parameters and specify initial and boundary conditions. The second question arises whether it is essential to describe the mountain river WR by using differential equations calling for a detailed specification of the processes.

All the previously mentioned is true for river HCR. A system approach with appropriate methods for modeling complex natural systems can be a feasible solution to the problem. One of such methods is the application of single-valued functions with multiple arguments analytically defined on specified time intervals. The system approach and the functions were used as a basis for proposed system-analytical modeling of WR/HCR.

We have chosen the whole Altai-Sayan mountain country (50–56° N and 83–100° E) for our investigation. Its territory is interesting for WR/HCR analysis since its climate undergoes some destabilization responsible for increasing the number of catastrophic hydrometeorological events. Such a destabilization was corroborated by spatial clustering of continental meteorological fields (Kirsta et al. 2014). The analysis of the interannual dynamics of surface air temperature and precipitation allowed us to define the areas with the largest deviations from the evolutionary developed statistical regularities of these factors. Two types of spatial clusters with a relatively stable and destabilized climate were detected in Eurasia (Figs. 7.1 and 7.2). The first one is formed at the stabilizing influence of natural vegetation, whereas the second—because of resonant human impact.

The territory of the Altai-Sayan mountain country represents a part of the world watershed between the humid zone of the Arctic Ocean and the arid drainless area of Central Asia (Altai-Sayan 1969). In the Altai, the mountain ridges reach 3500–4500 m above sea level, while in the Sayan—3000–3500 m. The climate is extremely continental with cold winters and cool summers (Sevast'yanov 1998). Atlantic cyclones freely penetrate the region. The distribution of precipitation in the Altai-Sayan mountains has not been adequately explored. According to observations of rare weather stations, its annual amount varies very widely. For instance, the northern slopes at altitudes over 3000 m get 1200–2500 mm of precipitation per year, the middle parts of the slopes—up to 600 mm, and the bottom ones—about 200 mm. In all rivers, the largest WR is observed during a warm season and accounts for up to 80–90% of the annual one. The flow regime depends mainly on snowmelt in springtime and the amount of precipitation during summer and autumn periods. The share of snow water in the annual flow is not less than 50%. Glacier melting in river basins also contributes to the river flow (Revyakin et al. 1979).

7.2 System-Analytical Modeling

The method of system-analytical modeling (**SAM**) (Kirsta 2006a; Kirsta and Kirsta 2014) allows to avoid the abovementioned problems and to create the simulation models having an adequate description of real physical, hydrological and chemical processes. Following Beven (2002), adequacy is conformity of the model to physical principles and laws completed by appropriate assumptions. Unlike Refsgaard

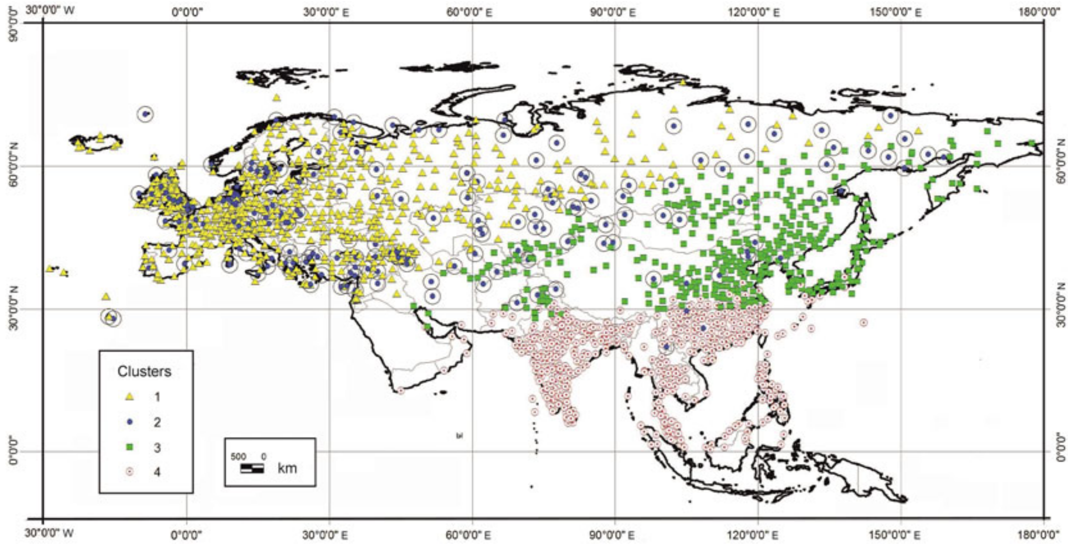

Fig. 7.1 Climate destabilization areas were established via spatial clustering of precipitation in Eurasia (see weather stations marked by a large circle) (Kirsta et al. 2014)

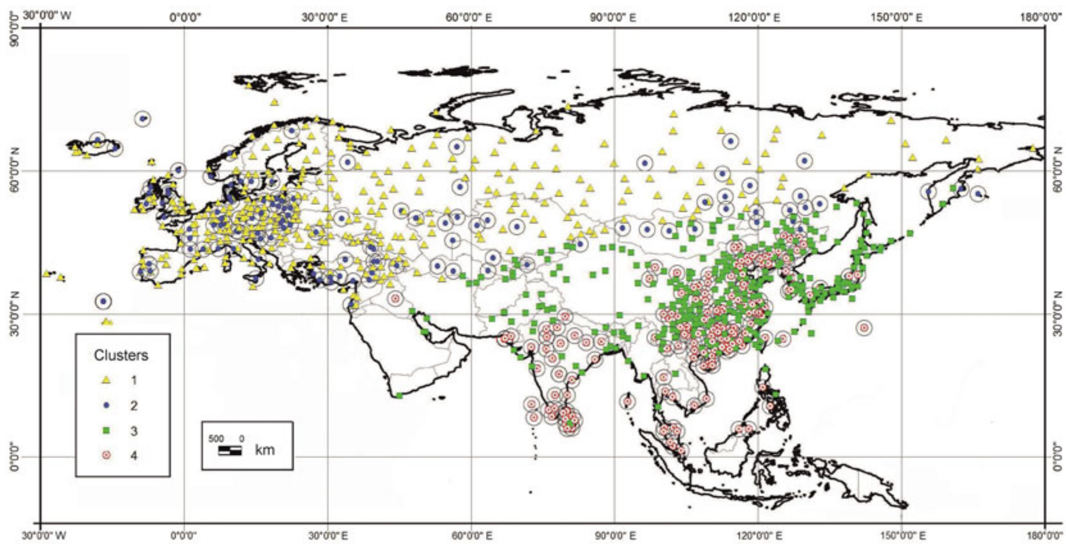

Fig. 7.2 Climate destabilization areas were established via spatial clustering of air temperature in Eurasia (see weather stations marked by a large circle) (Kirsta et al. 2014)

(1996), we would not describe the studied processes by means of differential equations that characterize mass flow, impulse, or different forms of energy.

SAM makes it possible to reveal and describe quantitatively a set of basic processes and their relations to environmental factors (i.e. structural–functional organization) for little-studied natural systems. For instance, SAM enabled to detect of short temperature-independent 1–3-day periods in plant annual development as well as to estimate quantitatively a vertical diffusion and condensation of vaporous water in soils throughout a year (Kirsta 2006a, b). SAM provides the construction of adequate models of complex natural systems and the achievement of the theoretically best accuracy of mathematical models. SAM is based on the system-hierarchical approach and executed as a specific mathematical analysis of equations, which simulate intra- and interannual dynamics of studied characteristics of natural systems (see more details in (Kirsta 2006a; Kirsta and Kirsta 2014)). In our case, it is intra-annual dynamics of river WR/HCR calculated and compared with experimental data for each year of the available long-term records.

We apply SAM method to identify and quantitatively characterize the functional relationships of river WR/HCR with meteorological factors, morphometry, and landscape structure of river basins. Similar to the methodological approach of hydrograph separation by Tardy et al. (2004), SAM allows to extract the information on these relationships from the experimental data series. The simulation balance models of WR/HCR are constructed from algebraic equations since the use of differential equations for the description of hydrological and hydrochemical processes in mountain conditions is hardly possible. We determine the character of functional relationships between the processes and factors by way of theoretically well-founded selection and adjustment of the combined equations to minimize the RMS discrepancy (quadratic residual) between the calculated and the observed dynamic characteristics. Using the observed water and hydrochemical discharge values as a left side of river discharge equations permits to evaluate both the equations parameters and quadratic residual for the test versions of the mathematical model via inverse problem solution by optimization methods. The model is considered to be constructed if it provides a minimal residual value.

In order to take into account a landscape structure of river basins, we have selected several groups of geosystems peculiar to the Altai-Sayan mountain country. Each group is characterized by its own values of hydrological regime parameters determined during SAM. Thus, the WR/HCR model development is performed by spatial division of the river basin into several typical areas with different types of hydrological and hydrochemical regimes jointly describing the overall regime of the basin.

Low sensitivity to an experimental data error is one of SAM features. The increase in data error brings to residual enhance without change in the target equations and values of model parameters. In our case, SAM makes it possible to use meteorological factors (monthly precipitation and air temperature), which are spatially generalized throughout the Altai-Sayan mountain country by regional climate model (Kirsta 2011b). The model performance is evaluated with criterion RSR (RMSE-observations standard deviation ratio) defined as the ratio of the standardized root mean square error to the observed standard deviation of the target variable (Singh et al. 2004; Moriasi et al. 2007). Such a spatial generalization has RSR exceeded 0.7, that is commonly inadmissible under the modeling of hydrological processes (Koch and Cherie 2013). Despite this, SAM makes the best use of these data because the mandatory requirement for a tenfold excess of experimental data over the number of developed model parameters in SAM does exist.

The second main feature of SAM is a fixation-free form of the sought-for dependence of model variables on the environmental factors. Note, in case of differential equations, this form is strictly fixed by equations' choice. To support this feature, we apply a universal match function H defined as follows (Kirsta 2006a):

$$H(X1, X2, Y1, Y2, Z1, Z2, X) = \begin{cases} Y1 + Z1(X - X1), & \text{if} \quad X < X1 \\ \dfrac{Y2 - Y1}{X2 - X1}(X - X1) + Y1, & \text{if} \quad X1 \le X \le X2 \\ & \quad X1 \ne X2 \\ Y2 + Z2(X - X2), & \text{if} \quad X \ge X2 \end{cases}, \tag{7.1}$$

where $X1$, $X2$, $Y1$, $Y2$, $Z1$, $Z2$ are parameters; X is a changing input factor or a model variable.

H represents a continuous piecewise linear function composed of three arbitrary segments.

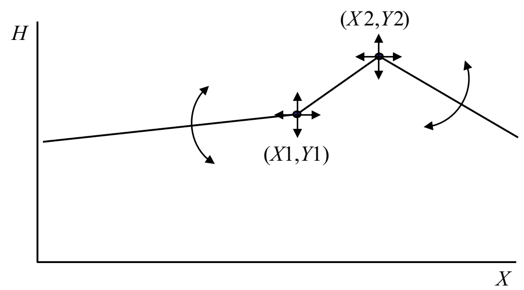

Fig. 7.3 A match continuous piecewise linear function *H (X1,X2,Y1,Y2,Z1,Z2,X)* composed of three arbitrary changeable segments (see Eq. 7.1)

As illustrated in Fig. 7.3, function *H* is usable for the approximation of different dependencies between variables via change of its parameters in Eq. (7.1). Methodologically, the application of *H* is close to the automated modeling method (Todorovski 2003).

The third peculiarity of SAM relates to the aforementioned lack of data on hydrological and hydrochemical process relationships as well as climatic, geological, edaphic, and other characteristics of the territory under study. Various natural climatic conditions of the Altai-Sayan mountain country are responsible for the marked temporal and spatial difference of WR/HCR formation. With a great number of analyzed river gauges (34), SAM enables to eliminate the unique features of individual basins and to find the common regularities of basin hydrological and hydrochemical processes.

Any mathematical model needs verification (Hauduc et al. 2011). To do that, we can use a criterion for assessing the adequacy of any calculation methods or models based on the comparison of the observed and the calculated data series (Kirsta et al. 2012):

$$A = S_{dif}/\sqrt{2}S_{obs} \quad (7.2)$$

where A is the criterion of model adequacy; S_{dif} is the standard (RMS) deviation for the difference between observed and calculated data patterns (i.e. for model residual); S_{obs} is the standard deviation for the observed pattern; $1/\sqrt{2}$ is the introduced multiplier.

According to Eq. (7.2), criterion A is actually a model error normalized to the standard deviation of the observed data. When assessing the model performance, A is similar to performance criterion RSR (Moriasi et al. 2007; Koch and Cherie 2013) and Nash–Sutcliffe model efficiency coefficient NSE (Koch and Cherie 2013) related to A by equations RSR = $A\sqrt{2}$, NSE = 1–RSR^2 = 1–2A^2.

Multiplier $1/\sqrt{2}$=0.71 is entered (7.2) to make up a standard range 0–1 involving two meaningful intervals of A values. Based on the variance sum law (applied for S_{dif}), values A can vary from 0 to 1 and more:

- interval 0–0.71 characterizes a different degree (the best is at A = 0) of the identity of compared patterns and model adequacy. This interval of the adequacy corresponds to a change of RSR between 0 and A/0.71 = 1. It includes RSR ~ 1 values that lie outside permissible limit RSR = 0.70 (Koch and Cherie 2013). At the same time, such RSR values did not prevent both the execution of SAM and the construction of an adequate river WR model of a good quality (Kirsta and Puzanov 2015). Thus, A provides more accurate model performance measure as compared with RSR;
- interval 0.71–1 implies that the adequacy of the model is low, and the regularities from the observed pattern are not taken into account properly. For predictions, the use of the mean value of hydrological characteristic with A = 0.71 is preferable;
- interval larger than 1 indicates that the calculated pattern has greater variance than the observed one. Sometimes it is essential to keep the observed pattern variance when employing the calculated data in other models/submodels. It is reasonable to substitute the calculated data with random variations of the analyzed characteristics. The variations should have the similar average and variance as the observed pattern has. In this case, A will be equal to 1.

Adequacy criterion *A* is also convenient to calculate another criterion that characterizes the model sensitivity to the natural variations of environmental factors (Kirsta and Puzanov 2015).

Any developed model should be validated through independent data not used for its development and identification. Such a verification is easily performed via excluding a part of river streamflow data from SAM and comparing this part as a testing dataset with the calculated pattern newly resulted from SAM. Then we exclude the next part of the data and again repeat the procedure of SAM. With more than a tenfold excess of the observed data over the model parameters' number, the elimination of some data has a negligible effect on the parameter values defined during SAM. Our experience of SAM execution (Kirsta 2006a; Kirsta and Kirsta 2014) shows that, generally, the RMS discrepancy (quadratic residual) in testing comparisons does not differ from the primarily derived one. Thus, the model verification on the independent testing dataset in SAM turns in a formal procedure.

7.3 Materials

SAM was based on observations of mid-size and small river streamflow and concentrations of seven HCR components. The latter includes three nitrogen mineral forms (NO_2^-, NO_3^-, and NH_4^+); phosphates (PO_4^{3-}); ions (cations of Ca, Mg, Na, K, and anions of hydrocarbonates, sulfates, chlorides) close in content to water mineralization; total dissolved iron (Fe); suspended matter. Ion concentration also accounts for ions of Fe, nitrates, etc., if their content exceeds 0.1 mg/dm^3. The observations were made by the Hydrometeorological Service of the former USSR and the Russian Federation in the Altai-Sayan mountain country in 1951–2003. We also used the data on monthly precipitation, average monthly temperature, landscape structure of river basins, area and altitude of landscapes, and some other cartographic characteristics. A total of 34 river gauges with parallel observations of streamflow and substance concentration were studied in SAM. As indicated above, a great number of river gauges analyzed simultaneously in SAM allow to characterize the patterns of WR/HCR formation, which are the same for the whole territory.

Taking into account the streamflow annual dynamics, we specified four hydrological periods/seasons: the first (winter low water—XII–III months), the second (spring–summer flood—IV–VI), the third (summer low water—VII–VIII) and the fourth (autumn low water with possible flood in case of heavy rains—IX–XI). The data on daily streamflow observations at each of 34 river gauges as well as concentrations of seven HCR components were averaged by seasons; thereafter only four season-average values of streamflow and analyte concentration for each year were employed in SAM. On average, the streamflow made up approximately 10, 140, 50, 30 m^3/s with standard deviation of streamflow time series for each basin 33, 27, 41, 40% for seasons 1, 2, 3, 4, correspondingly. In turn, the average annual analyte concentrations for NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}, ions, total dissolved Fe, and suspended matter were about 0.01, 0.4, 0.2, 0.02, 200, 0.1, 20 mg/dm^3, respectively.

Typification of landscapes of the Altai-Sayan mountain country, which reflects the conditions of WR formation including altitudinal-belt and structural-layering heterogeneity of the territory, was made to account for the landscape structure of river basins and for spatial separation of different types of a hydrological regime (Kirsta et al. 2011). A total of 12 typological geosystem groups including one extra for aquatic landscapes of the small area were selected (Table 7.1).

We established the boundaries of 34 basins (which have river gauges as outlets; see Fig. 7.4) and calculated areas and mean altitudes of geosystem groups in each basin. Basin square ranged from 177 to 21,000 km^2. Two maps "Landscapes of Altai (Altai Krai and Altai Republic)" (Chernykh and Samoilova 2011) and

Table 7.1 Mean altitude, relative area, and contribution of geosystem groups of the Altai-Sayan mountain country to the river runoff

Geosystem groups (landscapes)	Mean altitude, m a.s.l	Mean relative area, % *	Share of precipitation passed to the river flow in each of four hydrological seasons (XII–III, IV–VI, VII–VIII, IX–XI months) **			
			1	2	3	4
1. Glacial-nival high mountains with permafrost	2448	1.2	0.30	0.23	0.45	0.00
2. Goletz-alpine-type high and middle mountains, pseudogoletz low mountains with permafrost	1446	9.5	0.09	0.35	0.61	0.28
3. Tundra-steppe and cryophyte-steppe high mountains with permafrost	2329	0.4	0.30	0.56	0.02	0.00
4. Forest high, middle and low mountains	742	44.1	0.29	0.33	0.69	0.91
5. Exposure-forest-steppe and steppe high and middle mountains	1213	1.8	0.14	0.69	0.75	0.00
6. Forest-steppe, steppe low mountains and foothills	415	15.9	0.36	0.24	0.62	0.70
7. Intermountain depressions with different steppes and forest-steppes	720	5.2	0.33	0.31	0.85	0.44
8. Steppe and forest-steppe piedmont	268	8.8	0.06	0.31	0.42	0.31
9. Nondrainable and intrazonal landscapes with partial permafrost	1501	1.3	0.72	0.93	0.00	0.22
10. Mountain river valleys	563	9.0	0.22	0.00	0.63	0.52
11. Lowland river valleys	229	2.0	0.08	0.37	0.61	0.99
12. Forest high and piedmont plains	263	0.7	0.02	0.36	0.77	0.42
13. Aquatic landscapes	1400	< 0.1	0.58	0.69	0.01	1.00

*In percent of the total river basin area.
**Results of calculation of b_k in Eq. (7.3).

"Landscape map of Altai Krai" (Tsimbaley 2011) of 1:500,000 scale as well as topographical maps of 1:200,000 scale serve as a basic cartographic material processed in ArcGIS 9.2 to create digital versions of the maps. Landscape morphometry was calculated with TIN models constructed by 3D Analyst extension of ArcGIS.

The general climatic characteristics of the Altai-Sayan Mountains according to data from weather stations (Table 7.2) show that most of annual precipitation falls on the warm period lasted about half a year. In SAM, we use the long-term monthly dynamics of air temperature and precipitation, which are normalized and spatially generalized.

The created database to execute SAM of river water quality includes the following characteristics: hydrological (5300 normalized seasonal average values of streamflow for 34 selected river basins and four seasons for each year of the period 1951–2003), hydrochemical (1200–2000 seasonal average concentrations for each of seven analytes), meteorological (636 + 636 = 1272 normalized monthly values of air temperature and precipitation for 1951–2003 with the resulting 1272/4 = 318 seasonal values), and cartographic (the area and average altitude of each landscape in each basin, the area of arable land, lateral slope of the basin and altitude of its outlet, river length from source to outlet).

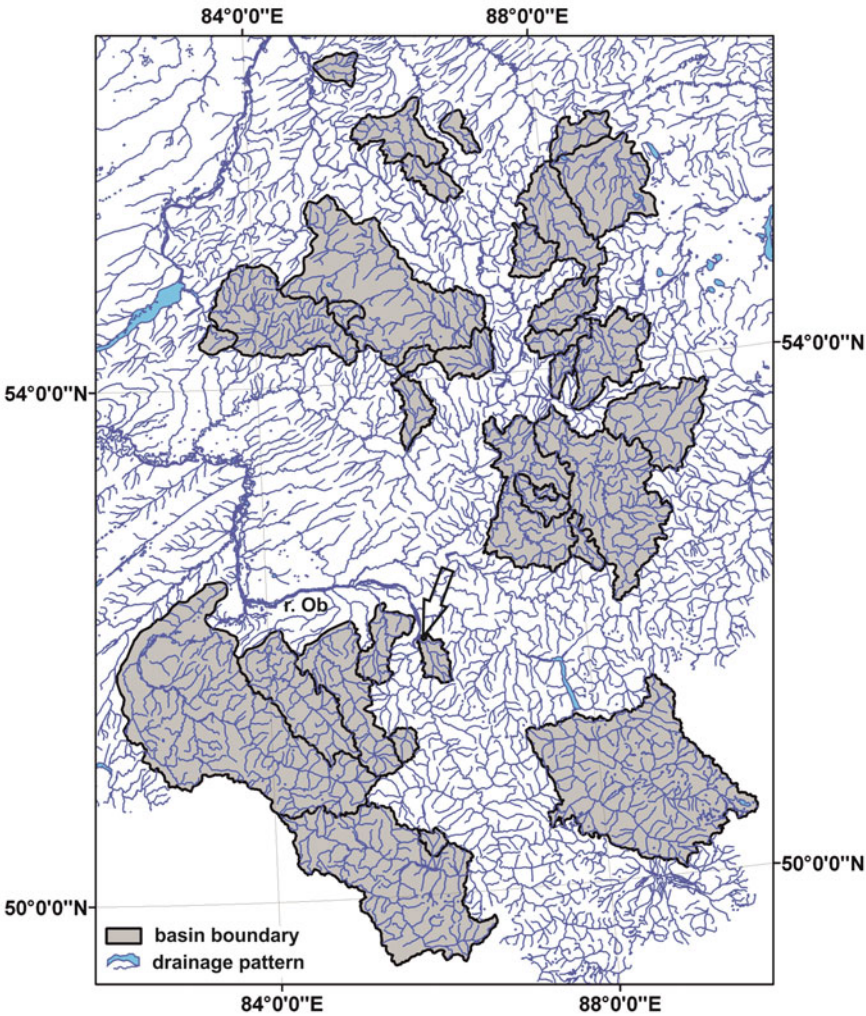

Fig. 7.4 Schematic map of 34 model river basins in the Altai-Sayan mountain country. The arrow points at the Maima river gauge (Sect. 7.5)

Table 7.2 Long-term (1951–2010) mean air temperature and precipitation in the Altai-Sayan mountain country

Climatic characteristics	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Temperature, °C	–16.0	–14.6	–8.0	2.2	10.5	15.7	17.8	15.3	9.6	2.1	–7.3	–13.3
Precipitation, mm	21.9	19.5	22.3	40.7	58.3	71.1	81.9	73.0	50.9	49.4	39.5	30.6

7.4 Development of Regional Climate Model

The meteorological observations in most of the basin territory associated with 34 river gauges under study were short term and, therefore, useless for SAM. SAM was used previously to prove the existence of air temperature and precipitation trends common to the vast space, e.g. for Russia or the USA (Kirsta 2006b, 2011a). These characteristics were expressed in a normalized form, i.e. in percent/fraction of their specified long-term averaged monthly values. As a result, we obtained the long-term monthly dynamics of normalized temperature and precipitation, that is the same throughout the Altai-Sayan mountain country (Kirsta 2011b).

The developed method of spatial generalization of climatic characteristics was applied to calculate their dynamics using the data from 11 reference weather stations for 1951–2010, and, thus, to work out the regional climate model. All stations were outside the considered river basins but had a continuous series of observations. The found dynamics was expressed in percent/fraction of three specified in situ long-term averaged monthly values (January temperature applied for X–IV months, July temperature for V–IX months, and July precipitation for all months of a year), and it does not depend on the site coordinates and altitude. Such an independence of the altitude changing across the territory allowed describing the dynamics of normalized temperature and precipitation throughout each basin with altitude difference as much as 2000 m, and this was of great importance. Moreover, this dynamics was identical for all river basins in the Altai-Sayan mountain country. In the subsequent SAM, the climate model is used for calculating both 636 normalized values of average monthly temperature and 636 normalized monthly precipitation over the period 1951–2003 as input factors for WR/HCR models.

The adequacy of calculations of normalized climatic characteristics in the climate model was also assessed (Kirsta 2011b). In the case of arbitrary (not reference) weather stations, a comparison of the observed and calculated long-term data series according to criterion A in Eq. (7.2) gave $A = 0.5$ for average monthly air temperature and $A = 0.66$ for monthly precipitation. Hereafter we shall use these values of A in evaluating the adequacy of WR/HCR models.

Note that in order to restore the long-term monthly dynamics of temperature and precipitation in terms of °C and mm, correspondingly, one should know only their monthly values observed at the study site for 1–2 years. First, the observed and normalized values are used to calculate the transition coefficients. Then, the calculated long-term monthly dynamics of both normalized temperature and precipitation, which is uniform throughout the Altai-Sayan mountain country, is multiplied by these coefficients.

It should be noted that a sufficiently large criterion $A = 0.66$ for spatial generalization of precipitation, the dynamics of which is influenced by many random factors, has not prevented the execution of SAM. This value of A corresponds to RSR = $A\sqrt{2}$=0.93 that usually is not allowed for hydrological models (Koch and Cherie 2013).

7.5 Development of Water Runoff Model

Since the normalized air temperature and precipitation are among the input factors of the WR model, the river streamflow values should be normalized as well. For this purpose, the observed streamflow values were divided by the corresponding long-term mean seasonal values for each basin. By this means, we passed from streamflow measurements in m^3/sec to dimensionless units of normalized streamflow. In a similar manner, geosystem group areas (km^2) in each basin were converted into percent/fraction via division by the basin area (Table 7.1).

Like regression analysis rules, to use SAM successfully, the array of actual data on the process dynamics should exceed the number of model equation parameters at least by a factor of 10 (Kirsta and Kirsta 2014). There are 5300 values of seasonal average river streamflow that theoretically allows entering up to $\sim$500 parameters to the model or 500/4 $\sim$100 for each of four hydrological seasons stated above. However, the number of river basins comes to 34 resulting in three allowed parameters if we describe the influence of the basin-specific characteristics (e.g. area or altitude of landscapes) on streamflow. For example, when describing (analytically or graphically) the relationship between WR and basin area or landscape altitude, we have only 34 pairs of dependent and independent variables, and, hence, cannot use more than three parameters for this relationship in SAM. The limitation to three parameters implies the presence of not three but two linear segments in piecewise linear function H (Fig. 7.3). This condition is implemented according to Eq. (7.1) as dependence $H(X1, X1, 1, 1, Z1, Z2, X)$.

The execution of SAM with the examination of different versions of equations, which describe the WR formation under environmental impact, permits to construct the model best in quadratic residual. The model takes into account the landscape structure of river basins and has 36 parameters for each of four hydrological seasons. Its block diagram is shown in Fig. 7.5.

In block 1, we arrange the model input factors and exclude from calculations all the data relating to the omissions in streamflow records or significant discrepancy between the calculated and observed streamflows. Such a discrepancy can arise for individual basins in any hydrological season of any year due to (a) considerable difference between spatially generalized value of meteorological factor and its natural fluctuation, (b) human errors in data record, etc. The mistakes are detected via comparison of the calculated and observed streamflows by means of a well-known “three-sigma rule” for normal distribution. Like in adequate mathematical models, the deviations of calculated characteristics from the experimental/observed values in SAM fit a normal distribution. Streamflow observations for specific basin, year, and season going beyond the bounds of triple sigma, i.e. triple S_{dif} (see Eq. 7.2), are formally considered false. Therefore, these data are sequentially eliminated. After each elimination (<1%), the determination of model parameters by the solution of inverse problem and the calculation of residual for the tested version of model equations is started afresh. We repeat such a data processing until all the “false” observations (2–4%) are revealed. Some of the eliminated data could describe the real random fluctuation of air temperature and precipitation in a basin, and, hence, be reliable. However, their elimination from the database has not influenced SAM execution because of their negligible number. In general, the described procedure of data processing has provided the reliable exclusion of significant technical errors from the streamflow data (e.g. change by one order or more if missing a decimal point). Such errors, which are inevitable if operating a vast amount of data, can influence the parameter values determined during SAM.

In block 2, the WR calculation for each basin, year, and hydrological season is executed in accordance with the following balance equation:

$$\begin{aligned} Q^i = & \sum_k \{a_k S_k^i P_1 H(c_1, c_1, 1, 1, c_2, c_3, T_1) \\ & \times H(c_4, c_4, 1, 1, c_5, c_6, h_k^i)\} \\ & + \sum_k \{b_k S_k^i P_2 H(c_7, c_7, 1, 1, c_8, c_9, T_2) \\ & \times H(c_4, c_4, 1, 1, c_5, c_6, h_k^i)\} + c_{10} \end{aligned} \quad (7.3)$$

where Q^i is the normalized seasonal average streamflow at the basin outlet i, i = 1–34; the first and second summands in Eq. (7.3) relate to

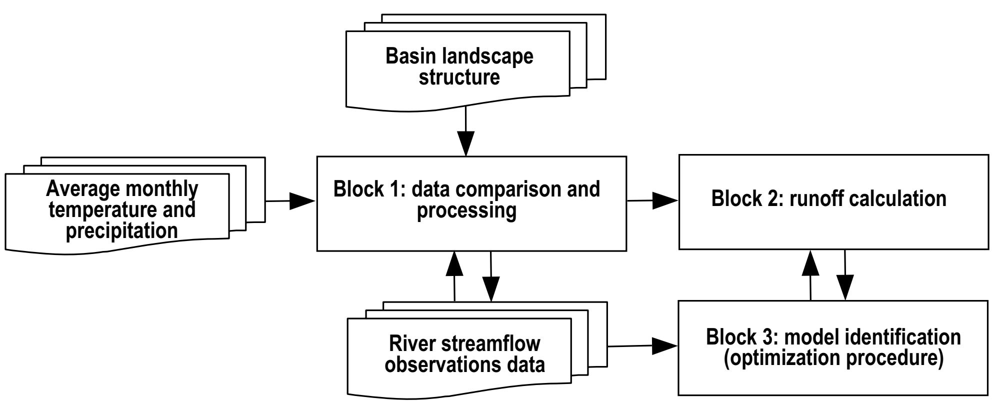

Fig. 7.5 Computation scheme in the river runoff model

contributions of the preceding and current seasons, correspondingly; but when calculating the streamflow for the first season (winter low water), these summands relate to the third and fourth seasons of the previous year because snow remains on the surface and does not affect the streamflow in winter; parameters a_k, b_k characterize the contribution of k-th geosystem group in relevant seasons, k = 1–13; S_k^i represents the relative area of k-th geosystem group in basin i; h_k^i is mean altitude of the same group in basin i, m a.s.l.; P_1, P_2 are normalized monthly precipitation averaged for a corresponding season; T_1, T_2 are deviations of normalized air temperature from 1 (1 is a long-term mean value of normalized characteristics) averaged for a corresponding season; H is a piecewise linear function (see Eq. 7.1); parameters $c_1,\ldots,c_9$ reflect the influence of temperature T_1, T_2 and altitude h_k^i upon the basin WR; parameter c_{10} characterizes constant replenishment ($c_{10} > 0$) or depletion ($c_{10} < 0$) of WR into both free groundwater and water of rock fracture zones. Thus, Eq. (7.3) includes 13 parameters a_k, 13 parameters b_k, and 10 parameters c_i, i.e. 36 parameters for each hydrological season are used to calculate WR.

On the right-hand side of Eq. (7.3), the individual contributions of geosystem groups into the seasonal average streamflow Q^i of the basin i are summed up. In the first summand, the contribution of k-th geosystem group refers to a delayed WR formed by precipitation P_1 of the preceding season. This process is specific to each group and depends on (a) the peculiarities of water movement in soils and various losses of water before it reaches a riverbed (parameter a_k), (b) the area S_k^i occupied by the group, (c) evapotranspiration features primarily dependent on temperature T_1, (d) and the altitude of geosystem location h_k^i. The contribution of k-th geosystem group in the second summand is provided by precipitation P_2 of the current hydrological season and depends on the above-listed factors, surface and subsurface flows (parameter b_k) and S_k^i, T_2, h_k^i. Thus, fairly simple Eq. (7.3) describes the formation of river WR under the influence of six important environmental factors: P_1, P_2, T_1, T_2, S_k^i and h_k^i.

In block 3, the inverse problem is solved to determine 36 parameters for each season separately that give minimal discrepancy between the calculated data according to Eq. (7.3) and the observed WR. The problem is implemented with the optimization procedures of a widely used software package MATLAB (procedures LSQNONNEG, LSQNONLIN are used to determine the initial and final values of parameters, correspondingly). All 36 parameters in Eq. (7.3) are computed simultaneously from the data sample of observed Q^i, which characterizes the individual season and includes 5300/4 $\sim$1300 normalized seasonal average values of river streamflow. Hence, to calculate streamflow for four seasons, the 36 × 4 = 144 parameters are identified. It is compatible with SAM requirement on tenfold excess of actual data (5300) over the number of model parameters (144). It should be noted that 36 model parameters define the seasonal runoff of 13 geosystem groups (Table 7.1), i.e. we use less than three (36/13 < 3) parameters to characterize the seasonal peculiarities of hydrological regime for each group/landscape. This minimal number of parameters allows for the impact of six environmental factors on hydrological processes. When describing these processes by differential equations with three parameters, the achievement of similar results will be extremely difficult.

Table 7.1 presents SAM-estimated values b_k in Eq. (7.3). They are related to the portion of seasonal precipitation, which comes to river streamflow from each geosystem group during the current season. Apart from the landscape features, the change of actual (not normalized) precipitation with altitude is also taken into account. For instance, rain precipitation increase at altitudes of 1600–1900 m (Selegey and Selegey 1978) will enlarge the contribution from geosystem groups peculiar to these altitudes to a streamflow. In Table 7.1, we can immediately see the small contribution of highlands into the river streamflow in autumn (geosystem groups 1–3, 5 in season 4), where precipitation remains on the surface as a snow cover. Besides, we see a considerable contribution of forest and forest-steppe high, middle and low mountains to the streamflow during summer and autumn low water (geosystem groups 4, 6 in seasons 3, 4). By and large values of b_k show that over half of precipitation enters the river streamflow in summer low water and slightly less than half—during autumn low water period.

In turn, values of c_{10} in Eq. (7.3) characterizing the continuous replenishment or leakage of streamflow into groundwater and/or into water of rock fracture zones are + 0.27; + 0.40; –0.02; –0.38 for 1–4 seasons, correspondingly, i.e. + 27%, + 40%, –2%, –38% of the long-term mean river basin runoff. Here one can see small water outflow into groundwater during summer (–2%); i.e. summer feeding of rivers in the Altai-Sayan mountain country is provided mainly by precipitation of previous and current hydrological seasons.

Using the calculated and observed streamflow patterns, we can estimate the adequacy of the developed simulation balance WR model (7.3) by criterion *A* in (7.2). *A* values calculated for each season are given in Table 7.3. From the table, we see that *A* is less than threshold level 0.71 for all seasons and, thus, allows practical application of the model.

Formal verification of the model with the help of independent data was performed according to the method described in Sect. 7.2. We sequentially excluded one of 34 river basins from the streamflow data. Execution of SAM for 33 basins instead of 34 hardly changed the values of sought-for model parameters. The comparison of newly calculated and observed WR for the excluded basins showed the primary discrepancy (for 34 basins) high-resolution and formally confirmed the adequacy of Eq. (7.3).

In using the differential equations to create WR models, one directly enters the physical regularities of hydrological processes in equations. In contrast, SAM reveals such regularities from the experimental data by match function (7.1). Hence, physical consistency of the developed WR model should be considered. As an illustration of the found relations between the river WR and environmental factors, we can take any gauge, for example, the Maima river gauge with a watershed of 780 km^2 (Fig. 7.4). The WR should be presented in a normalized form to reflect the general regularities of its formation in river basins of different catchment areas, different landscapes, and orography. Figure 7.6 demonstrates the derived dependences of seasonal average streamflow on two (P_2 and T_2) of six (P_1, P_2, T_1, T_2, S_k^i and h_k^i) model input factors in Eq. (7.3) for each of four hydrological periods/seasons. According to (7.3), P_2 and T_2 characterize precipitation and air temperature in the previous (Fig. 7.6a) or current (Fig. 7.6b, c, and d) season. For all river basins of the Altai-Sayan mountain country, the dependencies are similar (Fig. 7.6). Let us consider hydrological seasons separately.

- In a winter low water season (Fig. 7.6a), the river streamflow decreases when autumn air temperature falls. When temperature declines, more precipitation as a snow cover remains on mountain slopes; hence, the autumn soil moisture "charging" (essential for winter streamflow) reduces.
- During a spring–summer flood (Fig. 7.6b), the streamflow increases with temperature decrease due to less evaporation of precipitation. Evaporation is the main expenditure component of the WR formation in mountain river basins during a warm season. Incoming solar radiation does not vary over the years and controls snow melting and WR formation by 50–80% (Revyakin et al. 1979). Only evaporation and solar radiation form the received "extraordinary" temperature dependence of river streamflow. A noticeable

Table 7.3 The adequacy of water runoff model by criterion A in Eq. (7.2)

Hydrological seasons	1	2	3	4
Model adequacy assessment by criterion *A* in Eq. (7.2)	0.65	0.56	0.58	0.59

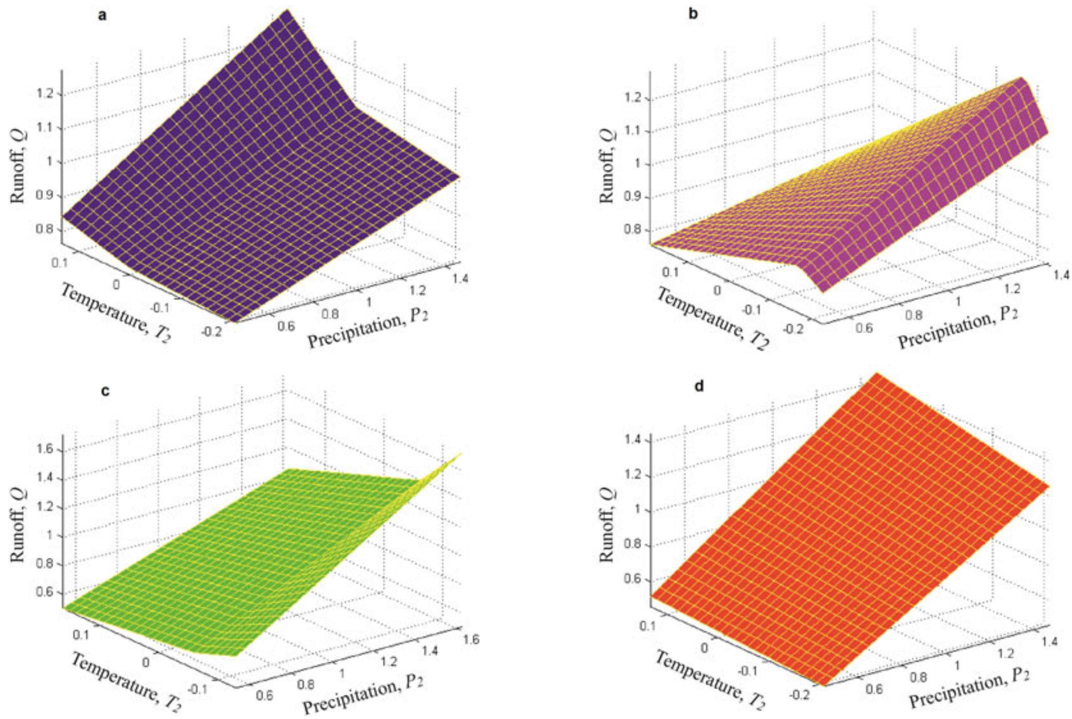

Fig. 7.6 Dependence of the Maima river runoff on temperature and precipitation at mean values of other factors: **a**—winter low water (XII–III months), temperature and precipitation for IX–XI of a preceding year; **b**—spring–summer flood (IV–VI), temperature and precipitation for IV–VI of a current year; **c**—summer low water (VII–VIII), temperature and precipitation for VII–VIII; **d**—autumn low water (IX–XI), temperature and precipitation for IX–XI

decrease in WR at a very low temperature is caused by late snow melting high in the mountains that results in shift of melting time and, therewith, a transition of some portion of streamflow to the third season (July).

- During a summer low water (Fig. 7.6c), the streamflow also increases with temperature decrease since the decreasing portion of precipitation again goes to evapotranspiration.
- In an autumn low water season (Fig. 7.6d), the streamflow decreases with temperature fall because similarly to the case in Fig. 7.6a the increasing amount of precipitation remains as snow on the mountain slopes.

The developed imitation balance model of mountain river WR provides the least quadratic discrepancy among 5300 observed and calculated streamflows in the basin outlets for each (out of 4) hydrological season. It includes 144 parameters found for a system of $\sim$1300 equations for each season. A total of 36 parameters fall on one season and 3 parameters on the description of a hydrological regime of an individual landscape. The model calculates the contribution of each landscape in each river basin for all years of experimental observations (more than 12.000 values for four hydrological seasons) to be used later in seven HCR models.

Spatially generalized monthly precipitation is the most important input factor of the developed river WR model. According to Eq. (7.3), WR varies in direct proportion with precipitation, thus greatly contributing to the calculation error of the model; therefore, the latter should be close to the error of spatial generalization of precipitation over the Altai-Sayan mountain country. Model adequacy criterion *A* (Table 7.3) averages 0.6, while criterion *A* for generalized precipitation approaches 0.66 (see Sect. 7.4). This means that the elaborated model has a small inherent error and adequately reflects the basic hydrological processes in river basins of the Altai-Sayan mountain country.

7.6 Development of Hydrochemical Runoff Model

In the same fashion as the balance WR model, we developed the HCR model to calculate the seasonal and long-term dynamics of seven HCR components (NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}, ions, total dissolved Fe, and suspended matter). The input factors and variables of the model are as follows: spatially generalized for the Altai-Sayan mountain country normalized monthly precipitation and mean monthly air temperature; WR estimated for individual landscapes in river basins with the WR model; the cartographic information on the area and average altitude of the basins, the altitude of the outlet, the length of river channels (between the river head and the outlet), and the area of arable lands. The same 13 typological geosystem groups/landscapes (Table 7.1) were applied to account for a landscape structure of river basins.

The target HCR is described by imitation balance equations with due regard for calculated WR, precipitation, lateral slope of the basin, and arable land area:

for the first season (winter low water),

$$HR^i = \sum\nolimits_k \{a_k Q_k^i H(c_1, c_1, 1, 1, c_2, c_3, P) \times H(c_4, c_4, 1, 1, c_5, c_6, K^i)\} + bq^i + dS^i Q^i \tag{7.4a}$$

and for each of the rest seasons,

$$HR^i = \sum\nolimits_k \{a_k Q_k^i H(c_1, c_1, 1, 1, c_2, c_3, P) \times H(c_4, c_4, 1, 1, c_5, c_6, K^i)\} + bq^i + d\sqrt{S^i} Q^i, \tag{7.4b}$$

where HR^i is the seasonal average hydrochemical runoff (HCR) from basin i; P is normalized monthly precipitation averaged for preceding IX-XI months (1st season) or for IV–VI, VII–VIII, IX–XI months (second, third, fourth seasons); Q_k^i is the calculated water runoff (WR) from k-th landscape in basin i, k = 1–13, i = 1–34; a_k are parameters corresponding to a permanent seasonal analyte concentration in the calculated WR for landscape k = 1–13; K^i is the average lateral slope of basin i; b is the parameter characterizing the permanent seasonal analyte concentration in the calculated inflow (or outflow) of mean seasonal groundwater runoff q^i in basin i; S^i is the relative area of arable land in basin i; d is the parameter characterizing the dependence of the analyte concentration on S^i in the calculated runoff Q^i in basin i.

In the right part of Eqs. (7.4a and b), a cumulative contribution provided by surface, subsurface, and groundwater runoff of each geosystem group to seasonal HCR is presented. Function $H(c_1, c_1, 1, 1, c_2, c_3, P)$ characterizes the influence of precipitation P of the current hydrological season, and $H(c_4, c_4, 1, 1, c_5, c_6, K^i)$—lateral slope K^i of river basin i. The influence of arable land is expressed as area S^i. Power n = 1 of S^i for the first hydrological season (winter low-water) means the analyte inflow from the whole area of arable land to groundwater and water in fractured rock zones feeding the streams in winter. Power n = 1/2 of S^i for the remaining hydrological seasons reflects the analyte inflow mostly due to the surface and subsurface interflow. The contribution bq^i reflects matter inflow or outflow under positive or negative q^i calculated by the WR model. Thus, seasonal and interannual dynamics of HCR for each landscape and the entire basin is calculated with the use of Eqs. (7.4a and b).

In Eqs. (7.4a and b), the average lateral slope K^i of basin i is defined as the tangent of inclination angle of slopes relative to the horizontal. To calculate it, we use the equation:

$$K^i = \frac{h}{1/2L} = \frac{(\text{average altitude of basin } i) - (\text{outlet altitude})}{1/2(\text{basin area})/(\text{river bed length})}, \tag{7.5}$$

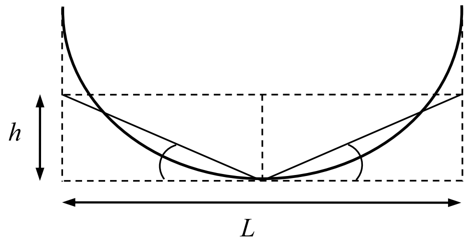

Fig. 7.7 Lateral section of river basin with average values of height (h) and width (L)

where h and L are the average height and width of basin i (Fig. 7.7). Such a calculation of K^i formally excludes the influence of geometrical slope of the river channel that should not affect the HCR from landscapes.

During SAM, the solution of the inverse problem for four hydrological seasons allowed to find all parameters a_1–a_{13}, b, c_1–c_6, d in Eqs. (7.4a and b). Each analyte (three nitrogen mineral forms, phosphates, ions, total dissolved iron, suspended solids) has its own parameters in each season. Values a_1–a_{13} characterize permanent seasonal analyte concentrations in water discharged from each of 13 landscapes into rivers of the Altai-Sayan mountain country. Estimated adequacy of HCR models is given in Table 7.4. Note that there were no experimental measurements of analyte concentrations in landscape water entered the river WR, and, therefore, parameters a_1–a_{13} characterize their theoretical values. Dividing the right-hand side of Eqs. (7.4a and b) to the water runoff Q^i, we get analyte concentrations present in the river water.

Figure 7.8 demonstrates typical dependencies of ion runoff on environmental factors. It shows the ion runoff as a function of different lateral slopes of river basin and normalized precipitation. Theoretical explanation of the obtained seasonal relations between seven analyte runoffs and environmental factors takes much time. It can be found in other papers (Kirsta and Puzanov 2016).

Thus, SAM of river HCR made it possible to construct seven models of water quality, which describe the dynamics of seven HCR components as well as the hydrochemical composition of landscape water entering the rivers. Every HCR model has 84 parameters: 21 for each season, including ~2 for each landscape. All the parameters were found via the solution of inverse problems carried out for systems of 1200–1500 imitation balance equations for every season, which describe the analyte flow for the selected years. The models allow to calculate the seasonal and long-term dynamics of the analyte runoff from each of 13 landscapes and arable land, total runoff from the basin, and the analyte concentration in the river streamflow.

7.7 Assessment of Model Sensitivity

To provide effective water quality management, the sensitivity of WR/HCR models to input factor variations was evaluated. We expressed the sensitivity as the contribution of a particular

Table 7.4 The adequacy of hydrochemical runoff models by criterion A in Eq. (7.2)

Hydrochemical runoff model	Hydrological seasons			
	1	**2**	**3**	**4**
Nitrite ions NO_2^-	0.61	0.62	0.64	0.61
Nitrate ions NO_3^-	0.61	0.60	0.60	0.60
Ammonium ions NH_4^+	0.59	0.66	0.55	0.56
Phosphate ions PO_4^{3-}	0.56	0.53	0.49	0.53
Ions (see details in Sect. 7.3)	0.38	0.38	0.32	0.34
Total dissolved iron	0.61	0.64	0.62	0.61
Suspended matter	0.57	0.60	0.56	0.67

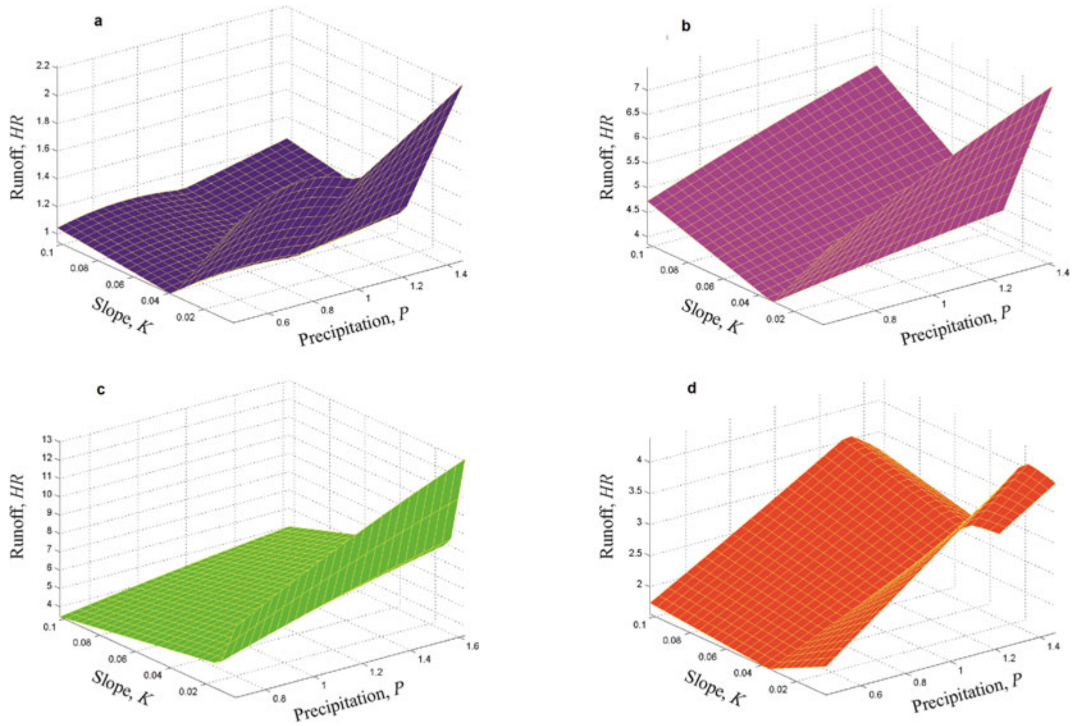

Fig. 7.8 The total ion runoff (g/s × 10^4) as a function of hypothetically different lateral slopes of the basin and precipitation (at mean values of other environmental factors) for the upper reaches of the Katun river: **a**, **b**, **c**, **d** are four hydrological seasons (see Fig. 7.6)

factor to the variance of the observed values of the output variable (WR and HCR).

A simple method for assessing the model sensitivity to natural variations of environmental factors used as input ones was developed. In Eq. (7.2), the criterion A is proposed to check the adequacy of calculation methods and/or models by comparing the patterns of the observed and calculated data. The heart of evaluating the sensitivity of mathematical models is criterion FS, which characterizes the sensitivity directly to natural variations of environmental factors. FS is close in meaning to the known "percentage of explained variance" and is calculated by the formula

$$FS = (A')^2 - (A)^2 = \frac{(S'_{\text{dif}})^2 - (S_{\text{dif}})^2}{2(S_{\text{obs}})^2} = \frac{2(S_{\text{fac}})^2}{2(S_{\text{obc}})^2} = \frac{(S_{\text{fac}})^2}{(S_{\text{obc}})^2} \quad (7.6)$$

where FS is the model sensitivity to the target input factor; A is calculated from (7.2); A' is A value obtained from (7.2) by using the randomly mixed values of the input factor instead of initially ordered ones; in this case, the randomly mixed pattern has a former statistical distribution and variance; $(S_{\text{dif}})^2$ is the variance for the difference between the calculated and observed data patterns (WR or HCR); $\left(S'_{\text{dif}}\right)^2$ is a similar variance for the difference between the calculated and observed output variable after the substitution the randomly mixed values of the input factor; $(S_{\text{fac}})^2$ is the contribution of input factor variations to the variance of the model output variable (calculated WR/HCR); $(S_{\text{obs}})^2$ is the variance of the observed output variable.

It should be pointed out that FS could be also expressed as a function of RSR. Taking into account the abovementioned equality, RSR = $A\sqrt{2}$, we have $FS = \left[(\text{RSR}')^2 - (\text{RSR})^2\right]/2$.

Similar to *A*' in (7.6), RSR' is equal to RSR obtained via using the randomly mixed values of the input factor instead of initially ordered ones.

Criterion *FS* is a close analog of determination coefficient R^2 known in the variance analysis. In accordance with the variance sum law, value $(S'_{\text{dif}})^2$ is greater by two variances $(S_{\text{fac}})^2$ than $(S_{\text{obs}})^2$. The first $(S_{\text{fac}})^2$ results from the contribution of real variations of the input factor to observed values of the output variable, and the second $(S_{\text{fac}})^2$ is due to the contribution of artificially created random variations of the input factor (by entangling its observed values) into the calculated output variable. For adequate models, $(S_{\text{dif}})^2$ will be free of both variances $(S_{\text{fac}})^2$ because of subtracting the calculated contribution of the input factor from the observed one. At the same time, the variance derived from observational errors of the input factor (or errors of spatial generalization of meteorological factors) will be present both in $(S'_{\text{dif}})^2$ and $(S_{\text{dif}})^2$ and, therefore, its values in (7.6) will be subtracted from each other. Thus, *FS* evaluates the model sensitivity solely *to input factor variations*, except for observational errors. Based on this sensitivity to individual environmental factors, one can assess their relative importance to the model. Since *FS* is expressed in proportion of $(S_{\text{obs}})^2$, it can be expressed in percent via multiplying by 100.

The estimated sensitivity of WR/HCR models to the input factors via the use of randomly mixed values of the target input factor and its original pattern is shown in Table 7.5. Take, for example, the second season (spring–summer flood). We see a consecutive reduction of WR sensitivity to precipitation (22%), temperature (16%), landscape structure of river basins (6%), and landscape altitude a.s.l. (0.2%). As expected, the WR model shows its maximum sensitivity to precipitation and air temperature, and the minor sensitivity to landscape altitude. The latter means the high adequacy of meteorological condition description for all 34 river basins by virtue of using the spatially generalized normalized precipitation and air temperature (see Sect. 7.4) in the model. Due to the normalization to the corresponding average long-term values, the dynamics of these factors is the same throughout the Altai-Sayan mountain country and properly accounts for their change with altitude. In Table 7.5, the *FS* abrupt jump >100% for PO_4^{3-} runoff is due to two-order difference of landscape areas in some river basins. During random mixing, such a difference leads to multiplying the large WR of certain landscapes by the large PO_4^{3-} concentrations in WR of other landscapes, and consequently in abrupt increase in $(S_{\text{fac}})^2$ in Eq. (7.6).

The series of factors with consecutive reduction of their importance for the runoff formation can be outlined from Table 7.5, thus ensuring efficient water quality management. These series are the same for 34 river basins and, therefore, for any basin of the Altai-Sayan mountain country.

7.8 Results and Discussion

The combined models of normalization and spatial generalization of mean monthly temperature and monthly precipitation, as well of WR and HCR, allow us to estimate seasonal and long-term dynamics of water and seven analyte runoff for any river basins of the Altai-Sayan mountain country. Values of model parameters are the same for 34 river basins in spite of their marked orographic and climatic diversity. Thus, the elaborated model package is universal and applicable to any river basin in the investigated mountainous area, including river basins, for which experimental hydrometeorological and/or hydrochemical data are not available.

Using the sensitivity data (Table 7.5), a comprehensive component analysis of residual variance $(S_{\text{dif}})^2$ of WR and HCR models (i.e. variance of difference between the calculated and observed runoff) was carried out (Kirsta 2016). This analysis made possible to estimate the contribution from the input factors of models and the errors of the model equations themselves to

Table 7.5 The sensitivity of water and hydrochemical runoff models by criterion *FS* in Eq. (7.6)

Target input factor	Sensitivity of water and hydrochemical runoff for first/second/third/fourth hydrological seasons, %*							
	Water	NO_2^-	NO_3^-	NH_4^+	PO_4^{3-}	Ions	Dissolved Fe	Suspended matter
Landscape structure of river basins**	4 6 11 4	52 9 88 19	22 19 46 31	41 3 55 9	>100 52 55 48	8 4 7 6	12 33 64 69	98 13 21 12
Landscape altitude**	0.3 0.2 ~0 0.6	–	–	–	–	–	–	–
Lateral slope of basins	–	6 5 2 10	14 9 0.5 15	9 2 9 19	15 14 5 7	18 5 7 2	10 4 6 9	5 3 0.8 2
Precipitation	17 22 16 34	5 0.3 3 5	1 1 0.4 1	3 2 6 11	9 0 5 16	2 1 6 6	11 ~0 6 8	5 2 2 5
Temperature	6 16 6 4	–	–	–	–	–	–	–
Arable land area**	–	4 5 0.3 3	2 0 0 0	0.1 5 0 0	4 16 16 16	12 33 7 9	~0 21 ~0 ~0	1 20 9 4

*Estimated by Eq. (7.6) and expressed in percent of variance $(S_{obs})^2$ for the observed output variable (WR or HCR). **The values of landscape area, altitude and arable land area were randomly mixed within the corresponding river basin.

the residual variance. The analysis allowed to characterize the model error without the influence of observation errors of input factors and output variable. Thus we received the model performance calculated in the best way in comparison with traditional RSR (RMSE-standard deviation ratio) and NSE (Nash–Sutcliffe model efficiency coefficient), which do not separate the model errors from observation errors of input factors and output variable.

Based on the received model error, the performance criteria RSR = S_{dif}/S_{obs} (sf. Equation 7.6) and NSE = 1–RSR^2 were calculated anew for each of WR/HCR models. The resulting values RSR < 0.60 and NSE > 0.65 represent good or very good performance of the developed models (Koch and Cherie 2013) that makes possible to calculate with good accuracy the seasonal and long-term dynamics of WR and HCR for all rivers in the Altai-Sayan mountain country.

Some conclusions directly follow from the adequacy of the developed WR/HCR models:

- The proposed approach and methodology for SAM of WR and HCR are universal and suitable for mountain regions. For the territories free of stable snow cover in winter, it is easy to identify other hydrological seasons and geosystem groups and redefine model parameters by means of SAM. Though climatic zones in the Altai-Sayan mountain country are diverse (from forests and steppes to glacial deserts in Table 7.1), each zone is adequately characterized during SAM.

- Spatially generalized precipitation adequately reflects the areal distribution of actual precipitation and provides more accurate river runoff computations as compared with point observations at some weather stations. Obviously, this conclusion holds significance in any hydrological calculations, which use areal meteorological characteristics.
- Model parameters correspond to average meteorological and hydrological characteristics of the mountain country, which significantly vary from one river basin to another. For a single basin, one can specify some parameters by using long-term river observations of WR/HCR and thereby considerably reduce the computation error.

The developed high-performance WR/HCR models have a large number of parameters that characterize the universal hydrophysical and hydrochemical features of river basins throughout the Altai-Sayan mountain country. In contrast, traditional runoff/streamflow models (Dingman and Sharma 1997; Moriasi et al. 2007; Sene 2008; Agal'tseva et al. 2011) have much fewer parameters. The reason is that bringing every additional parameter to these models does require special field investigations to determine its value. Additional parameters require studying climatic, orographic, hydrogeological and hydrochemical characteristics of a river basin, a soil-vegetation cover, a glacier, a hydrographic structure of river network, etc., that is costly and time-consuming. SAM does not face such a problem because it uses the implicit information contained in long data series on dynamics of the characteristic under study, namely, WR and HCR.

Most traditional runoff models are based on the data of a single river basin that makes the analysis and quantitative estimation of landscape structure influence on runoff extremely difficult. In fact, only one value of an area can be related to each landscape in the basin. It is hardly possible to establish runoff dependence upon a landscape area using one available value of an area. It is also impossible to exclude the individual features of the studied basin from the model that restricts the model applicability to other territories. It is obvious that SAM is devoid of both problems.

To apply the developed model package to any river basin of the Altai-Sayan mountain country, we just need landscape and topographic maps supplemented with normalized monthly air temperature and precipitation spatially generalized for the country. The calculated long-term dynamics of normalized WR and HCR for each hydrological season can be easily converted into real runoff dynamics (m^3/s and g/s). To do this, the value of long-term mean runoff should be determined via comparison of calculated normalized WR/HCR and the real one for 1–2 years of observations. Subsequently, using the right side of Eqs. (7.3 and 7.4), one can find the long-term dynamics of WR and HCR in m^3/s and g/s for each geosystem group (landscape) and the whole watershed.

Using the presented model package, it is easy to forecast the WR and HCR for the next hydrological season, i.e. for 3–4 months ahead. It demonstrates a significant improvement of forecast accuracy as compared with the long-term predictions using the long-term mean value of the observed river WR. In particular, the most probable seasonal WR can be forecasted with a twice-reduced variance as compared with the similar forecast based solely on the observed mean WR. The forecast of seasonal WR, for example, is particularly important for the regulation of water releases from mountain hydroelectric plant reservoirs in spring–summer flood season, during which the main volume of annual WR enters the reservoir. To do prediction, the actual values of normalized monthly air temperature and precipitation for the current season (first summand in Eqs. (7.3 and 7.4)), and their long-term mean values for the next one (second summand in Eqs. (7.3 and 7.4)) are substituted in the models. Incidentally, such a substitution is not required for winter low water season (XII–III months) because its WR has been already calculated from meteorological data of two previous seasons. It was found that original and predictive models have similar adequacy criterion $A < 0.7$ in Eq. (7.2) for all hydrological seasons. In predictive model, the accuracy of calculations is still affected by spatial generalization of precipitation ($A = 0.66$) and air temperature ($A = 0.50$). It is worth noting that generalization of these input factors for the Altai-Sayan mountain country was carried out due to the data from 11 weather stations located outside the analyzed 34 river basins.

In closing, we can sum up the following key results:

- The combined universal models of normalization and spatial generalization of average monthly temperature and monthly precipitation, water, and hydrochemical runoff allow us to estimate and manage the seasonal and long-term dynamics of water quality for any river basin of the Altai-Sayan mountain country, even if experimental hydrometeorological and hydrochemical data on the basin are unavailable.
- The proposed evaluation of model sensitivity to natural variations of environmental factors is achieved by random entangling the observed values of the target input factor. This method does not require any special mathematical procedures and can be applied to any mathematical models based on the observed data series.
- The developed balance models of water and hydrochemical runoff with anew selected landscapes and parameters updated via system-analytical modeling can be applied to any mountainous area.

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River Basin Councils: Evidence from Russia

8

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Abstract

Integrated water resource management is a process that promotes the comprehensive development and management of water, land and other resources to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. The water management system still requires improvement and further development. In particular, various usage conditions for the same water body in different Russian regions give rise to social conflicts and escalation of negative public sentiment. Moreover different Russian regions may establish various sanctions for same offense for the same water object, for example, violation of the human life protection rules on water or the rules for the use of small boats equipped with motors. Currently, basin agreements are concluded only for inter-regional water objects, i.e. catchment area, which is located within several subjects of the Russian Federation, it does not take into account the cross-border nature of the water objects, located in the territory of one subject of the Russian Federation, but covers the boundaries of several administrative areas.

Keywords

River · Basin · Management · Council · Russia

8.1 Introduction

Water resources are an essential part of Russia's natural resources. In spite of the abundant supply of freshwater, the size and quality of water resources are a vital issue, given the volume of untreated sewage contaminants. In this regard, small rivers make their important contribution to the formation of the water system.

The main national natural resource regulators are the government and the legislatures, who are able to set rules and control their fulfillment. Ecological politics in regard to natural resources, including water resources, can be implemented in many different ways: by administrative power, economic effect, or social motivation. But the achievement of efficient water resource usage is hampered by the fact that these resources are collective access ones. In microeconomic theory, this problem is called “the tragedy of commons”. The essence of this phenomenon is in that economic agents, maximizing their individual gains from natural resource usage, do not take into

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_8

account public interest of preservation and maintenance of this resource. Such behavior results in early resource depletion.

In this chapter, the experience of the basin district's creation in Russia is highlighted. Basin councils working in the districts are aimed at developing recommendations in the field of use and protection of water objects.

8.2 Theoretical Basis

In fundamental economic works, Gordon (1954), Scott (1955) devoted to the public goods usage on the example of fishing, it is shown that in situations, when many individuals have unrestricted access to the scarce resources of fishing stocks, the factual amount of the fish caught is higher than the optimal level, which would ensure the maximum level of fishers' private benefit. Later Hardin (1968) called this phenomenon "the tragedy of commons". The reasons for this problem may lie in the absence of strictly defined and reliably protected property rights. Both nationalization and privatization of public good seem to be the obvious solution to this problem (Gordon 1954). This approach was motivated by the implicit assumption of the public goods users' incapability to self-organization and self-regulation.

The Nobel Prize winner Elinor Ostrom doubted the latter statement and gave numerous empirical counter-arguments (Hess and Ostrom 2003; Ostrom 1990). Ostrom showed that collective access resources can be used without depletion and depreciation and individuals are able to manage such resources by themselves (Ostrom 1990, 1992, 2005; Ostrom and Gardner, 1993).

Natural resources management carried out by groups of people became widely studied; see, for example, Pretty and Ward (2001), Mostert et al. (2007). It was shown that self-organized economic institutions can develop and establish resource access rules, monitor, and regulate its usage. As a result, they demonstrate higher effectiveness than government regulation.

Ostrom suggested to expand the traditional theory of public goods by creating a notion of common-pool resource (CPR). They are subtractable, orrivalrous, and non-excludable goods, i.e. people tend to compete for the consumption of that resource, since one consumer prevents simultaneous consumption by other consumers, but it is very hard to exclude those consumers who have not paid for that resource (Hess and Ostrom 2003). Both common-pool resource and public goods have low level of excludability, but, in contrast to CPR, public goods are non-subtractable, such as fresh air or national defense.

Due to the non-excludability, both CPR and public goods face the problem of underinvesting, because the individuals do not pay for the good, supposing that the others pay. This is called "free rider problem" and it was thoroughly investigated in classic economic literature (Grossman and Hart 1980; Groves and Ledyard 1977; Hampton 1987). The subtractability of CPR, in turn, leads to the problem of overuse, or congestion, when the individuals increase the level of CPR consumption until it is possible.

CPR became the basic concept in water resources analysis, because rivers, for example, are exactly such kind of resources; that is why one of the ways to solve the problem of water resource usage is to complement the government regulation by collective action of water resource consumers. Thus the alliance of two approaches to natural resources regulation: monocentric, implying the existence of special natural resources management state institutions, and polycentric, based on the active role of local communities—seems to be the most effective. The second approach involves managing water resource down up and government institutions are supposed to perform those functions, which cannot be performed by individuals or small groups of people.

8.3 Water Basin Councils in Russia

The Water Code of Russian Federation brought significant changes in the system of state management of water resource usage and protection (State Duma 2006). The changes affected the powers and the relationship between the federal authorities and the federal subjects of Russia authorities; the legal regulation of the access to water objects and water objects ownership; cardinally changed the protection regime of water objects and surrounding areas. In fact, the water resource state management system reform was conducted.

However, the water management system still requires improvement and further development. In particular, various usage conditions for the same water body in different Russian regions give rise to social conflicts and escalation of negative public sentiment. Moreover, different Russian regions may establish various sanctions for the same offense for the same water object, for example, violation of the human life protection rules on water or the rules for the use of small boats equipped with motors.

Besides, there is the water strategy of the Russian Federation up to 2020, which includes the development of principles for integrated water resource management system as main directions of state water protection system improvement (Government of Russia 2009). Integrated water resource management is a process that promotes the comprehensive development and management of water, land, and other resources to maximize economic and social welfare in an equitable manner without the sustainability of vital compromising ecosystems.

Adoption and implementation of management solutions provide the greatest social and economic benefit and allow exploiting the water resources most efficiently and without compromising its quality, possible only if the cooperation and interaction of all participants of water relations exist. Therefore, it seems reasonable to organize the water resource management system within the river basin boundaries and to give prerogative of making management decisions to basin councils, whose actions are coordinated with local authorities, water users, and public associations. Besides, integrated management should be based on regional (territorial) features and individual characteristics of water objects.

The entire territory of the Russian Federation is divided into hydrographic units on the basin level. The Water Code of the Russian Federation initially established 20 basin districts, delimited by the pools of the largest country's water arteries (Fig. 8.1). Subsequently, in 2016, an additional Crimean basin district was introduced.

Fig. 8.1 Basin districts in Russian Federation, introduced in 2006. *Source* Ministry of Natural Resources and Environment of the Russian Federation, https://www.mnr.gov.ru/english/)

The main river of the river basin (hydrographic basin level unit) is a large river. The basins of such rivers are located in several geographic zones, and the hydrological regime is not peculiar to the rivers of each geographical area separately. The large rivers are plain rivers with a basin of more than 50,000 km^2 as well as rivers that are predominantly mountainous with a catchment area of more than 30,000 km^2 (State Duma, 2006).

Each district has a river basin council, which is aimed at the development of recommendations on the use and protection of water bodies. Basin councils' recommendations are directed to the appropriate federal or subject executive authorities and local government. Further, the recommendations are taken into account in the development of schemes of complex use and protection of water bodies.

According to the State Duma (2006), basin councils carry out the development of recommendations, including:

- The procedure of establishing and determining the water quality in water objects;
- The formation of the list of measures for water bodies protection;
- Determination of water intake and relevant quality wastewater discharge limits;
- Ensuring the safe operation of water supply systems;
- Definition of the main targets for reducing the negative effects from floods and other adverse effects from water and the formation of a list of measures to achieve those targets;
- Financing of the planned actions from different sources and formation mechanisms to attract extra-budgetary funds for the implementation of water management activities.

Basin councils discuss the problems of water management within the entrusted river basin, work out an agreed program of joint action, and submit it to the relevant authorities. The resulted program is expected to be taken into account in the budgets of various levels.

The positive experience of basin agreements and councils accumulated in many countries (Sivakov 2010). In several European countries (for example, France, Spain), basin councils are key entities in the water sector management and possess the appropriate financial and administrative authorities. At the heart of this, democratic management system is equal basis engaging of representatives of all stakeholders, who are interested in the water resource protection and use, i.e. government agencies at various levels, water users, the business, the public.

In fact, the river basin, including groundwater, is a natural ecosystem, which has clear geographical boundaries within which the water management should be carried out. Rivers do not recognize administrative borders and political preferences; therefore, the river basin seems to be the perfect control unit. Integrated water resource management is directed to the prevention of conflicts between water users, reducing the negative externalities, and easy assessment of the relationship between water users located below and above the river.

Taking into account, the above-mentioned opportunity of small groups of people to develop effective strategies of natural resource usage, the basin management principles should be applied not only for the major river basins but also in the implementation of water relations at the level of small river basins at intermunicipal level. Small rivers are the source of water supply for settlements, industry, and agriculture. In some cases, small rivers partially dehydrate due to stalled streams and springs, siltation, waterlogging, and overgrowing of many shallow rivers.

We examine the problem of water resource management on the example of Nizhny Novgorod region. Rivers flowing through the territory of the region are presented in Table 8.1. We can see that only three rivers can be classified as large ones, basin area of the rest rivers is less than 50,000 km^2. Additionally, 13 rivers flow not only through the Nizhny Novgorod region but also through the territory of neighboring regions of the Russian Federation. Regulation of water use, in this case, requires transition to the interregional and intermunicipal levels.

Due to the complex nature of water usage, the same water body can be used for different

Table 8.1 The rivers of Nizhny Novgorod region (Dark cells mean rivers, the basins of which are located not only in the territory of the Nizhny Novgorod region but also in the territory of neighboring regions)

№	Name of the river	Area of the basin, 1000 km^2	The whole length, km	Length in the territory of the region, km
Large rivers				
1.	Volga	1380	3530	277
2.	Oka	245	1480	270
3.	Sura	65,4	840	164
Small rivers				
4.	Klyazma	42,5	728	35
5.	Vetluga	40,1	899	323
6.	Pizhma	15	300	127
7.	Alatyr	11	287	130
8.	P′yana	8,1	436	436
9.	Tesha	8	311	311
10.	Kerzhenets	6	290	290
11.	Usta	5,8	253	181
12.	Kudma	3,2	142	142
13.	Seryozha	2,7	196	196
14.	B.Kaksha	2,3	138	66
15.	Uzola	1,9	147	147
16.	Lunda	1,8	121	82
17.	Linda	1,6	122	122
18.	Vol	1,5	97	97
19.	Yuronga	1,5	81	42
20.	Rudnia	1,4	84	45
21.	Lapshanga	1,3	85	85
22.	Vaja	1,3	106	106
23.	M.Kaksha	1,2	91	91
24.	Sundovik	1,1	97	97
25.	Medyana	1,1	83	83
26.	Yezhat’	1,1	55	55
27.	Ozierka	1	74	74
28.	Oshma	0,9	74	58
29.	Kishma	0,7	71	71
30.	Urga	0,7	184	184
31.	Imza	0,7	75	75
32.	Seima	0,6	42	42
33.	Vatoma	0,6	56	56
34.	Checka	0,6	56	56
35.	Dorogucha	0,6	75	59
36.	Zheleznitsa	0,5	52	52

(continued)

Table 8.1 (continued)

№	Name of the river	Area of the basin, 1000 km^2	The whole length, km	Length in the territory of the region, km
37.	Velet'ma	0,5	99	99
38.	Kesa	0,4	52	52
39.	Vezloma	0,4	52	52

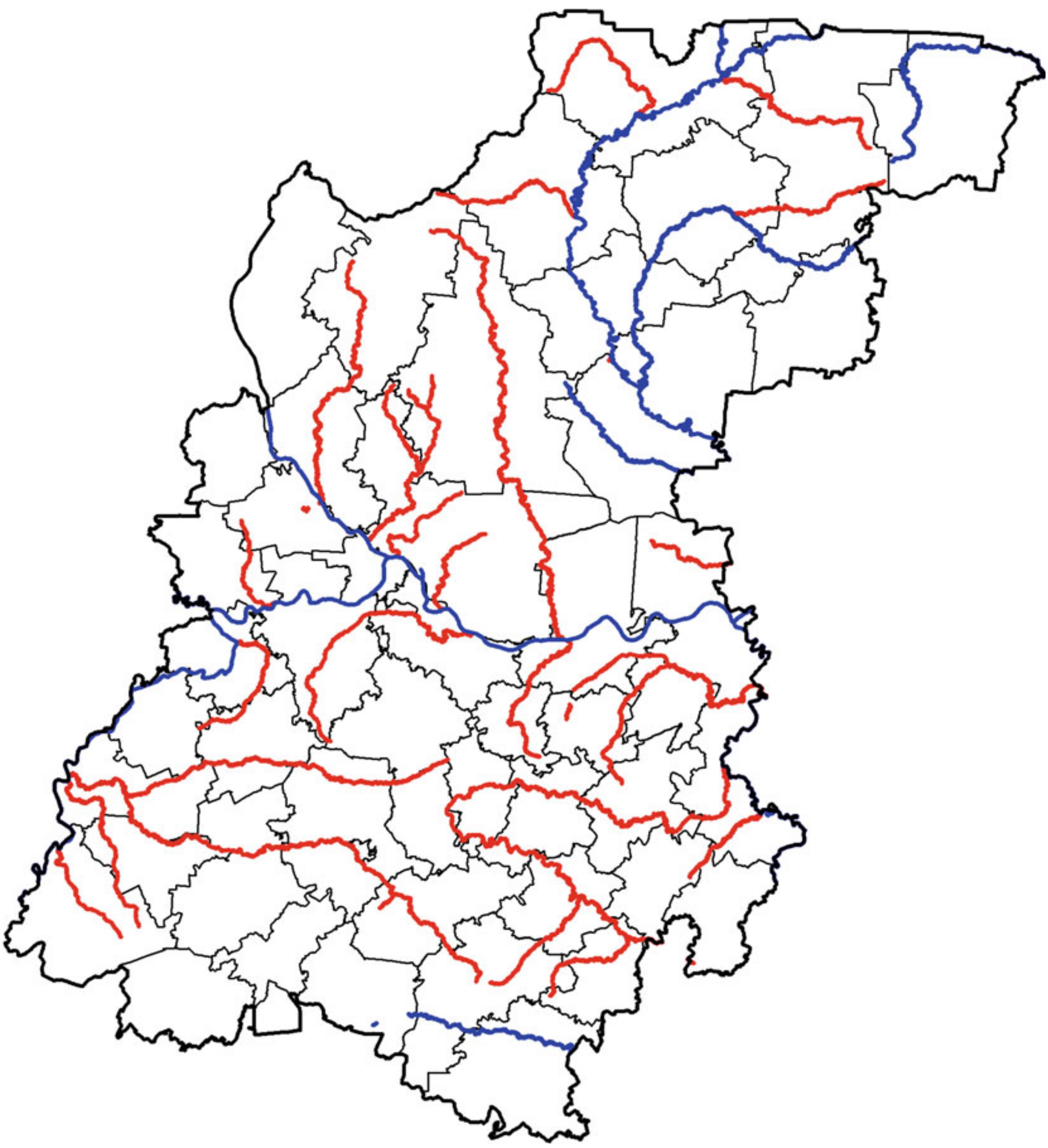

Fig. 8.2 The main rivers of the Nizhny Novgorod region

purposes (navigation, water supply, power generation, wastewater discharges, fishing, and hunting). Within a river basin or sub-basin, some water users (energy industries, industry) can objectively create problems for others (agriculture, fishing, hunting organization). In economic theory, this situation is labeled as negative externality. This can be expressed in lowering the water level, the deterioration of water quality, reducing stocks of fish and fowl, etc. Another problem is in fact that bordering subjects of Russian Federation set up different rules of water usage. For example, Klyaz'ma River, separating the Nizhny Novgorod and Vladimir regions, now has a different mode of the small boats equipped with motors usage: in the Nizhny Novgorod region is prohibited from 15 April to 31 May, and in the Vladimir region prohibition set until April 15 (Nizhny Novgorod Region Governor 2010; Vladimir Region Governor 2007).

Many rivers of the Nizhny Novgorod region flow through the territory of several adjacent municipalities, which makes the intermunicipal basin councils of small rivers especially important (Fig. 8.2). Figure 8.2 demonstrates the administrative structure of Nizhny Novgorod region, including the borders of municipal districts (in black), with the main hydrographic arteries according to Table 8.1 (in color). Blue color highlights rivers, which flow within and beyond the territory of Nizhny Novgorod region. Rivers, colored red, are situated in Nizhny Novgorod region entirely. In our opinion, the rivers under consideration can serve as a basis for the organization of intermunicipal basin councils in Nizhny Novgorod region and the neighboring regions.

Basin small river management principles allow to reconcile the interests of water users and to minimize the possibility of negative externalities. An important step in the Basin Council work is the development of the basin water management and protection program, which, after approval, should be given the status of interregional or intermunicipal target program. Basin program is a program of actions, which are aimed at achieving the appropriate water quality targets and the necessary volume of water simultaneously with the sustainable and environmentally safe development of the water complex. The program is the main activity of the basin councils (Zherelina 2005).

Another important task of intermunicipal basin councils is the formation and approval of the river basin budget. The budget of the river basin is cash used not only to finance the governments but also to solve the existing problems of water of the river basin and to provide co-financing of municipalities and water users, who contribute to the achievement of the basin council goals. In addition, the opinion of intermunicipal basin councils on the feasibility and priority of investment projects should be considered when deciding on the funding of such projects from the federal and regional budgets.

8.4 Conclusion

Intermunicipal basin councils can deal with the elaboration of agreed decisions on strategic issues and on the use and protection of water bodies within a river basin. Under the reduction of public services, which deals with the protection and management of water objects, involvement of the direct river resource consumers (local authorities, the public, which are directly interested in improving water quality and living conditions of the environment) seems to be the most effective. Increasing the autonomy and the significance of local authorities creates objective prerequisites for the improvement of approaches to water management. Thus, local initiatives and projects, aimed at solving water protection problems, require comprehensive support.

Currently, basin agreements are concluded only for interregional water objects, i.e. catchment area that is located within several subjects of the Russian Federation, it does not take into account the cross-border nature of the water objects, located in the territory of one subject of the Russian Federation, but covers the boundaries of several administrative areas. This group makes a significant portion of medium and small rivers of Russia.

As a result, the water protection legislation should change toward the empowerment of regional and local authorities, not forgetting about the financial security of these initiatives.

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9 Water Resources of Madhya Pradesh: Contemporary Issues and Challenges

S. K. Sharma

Abstract

Madhya Pradesh has vast surface water resources drained by the rivers radiating from this state toward all directions and being utilized by the bordering states much before this state could think of it. There is wide regional variation in potential as well as utilization of water resources within the state following the variations in hydro-geological aquifers, precipitation pattern, land use and cropping structure. Groundwater is resource in real sense because it is being utilized within the state for irrigating more than two-thirds of net irrigated area besides for domestic and other uses. Though slightly more than half of the groundwater potential could be utilized, 95 development blocks present symptoms of excessive exploitation. Most of them are confined in the Malwa region, which is deprived of any major river valley project. Besides lowering of water level and depletion of groundwater, certain other issues such as large scale displacement of people, their rehabilitation and resettlement in amicable way, Interstate River Water Disputes, rapid silting of reservoirs, water pollution, water logging and salinization have come on the way of proper management of water resources in the state.

Keywords

Aquifer · Water level · Potential water resource · Surface water · Groundwater · Safe · Semi-critical · Over exploitation

9.1 Introduction

Water is essential for the existence of the human being and his biotic world. It is required nearly for all activities of man and nurtures the socio-economic development. With the advancement of the society, awareness and requirements of water resources have been increasing phenomenally. List of uses of water has been expanding from traditional use for drinking, domestic and irrigation purposes to generation of power, industrial ingredients, and media of transport, waste remover and purifying agent as well as a recreational agent. People now emphasize on quality of water. Contrary to expanding demand, its supply is limited and is being depleted or made unusable by excessive utilization, pollution or careless management. Uneven distribution is another characteristic of water resources. Under such conditions, coordination between demand and supply as well as between different sources of water resources are imperative.

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
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In context of water resources, Madhya Pradesh has certain unique physical features. Dependent primarily on monsoon rainfall, the geological structure and physiography determine the condition of the water table, run-off and aquifers etc., which ultimately determine the feasibility of water resources. Structurally this state is predominantly composed of hard rocks, ranging in age from the Archaean to the recent period with limited potentiality of groundwater. Barring a few areas, most of the state is hilly and dissected plateau with sloppy land not congenial for water percolation. Climatically, western half of the state is semiarid region undergoing water strain throughout the year. At the same time, eastern and southeastern part is hilly and dissected increasing the velocity of running water and inhibiting percolation and therefore facing water scarcity.

9.2 Potential and Availability of Water Resources

The primary source of water supply on earth is precipitation. Much of it is lost as evaporation; a good deal of it goes as run-off and is called 'surface water' and a small amount penetrates into ground and is known as 'groundwater'. Availability of surface water depends on amount of rainfall, which varies widely in this state. In fact, major component in calculation of potential of surface and groundwater is the amount of rainfall. Precipitation decreases from southeast to northwest in the state (Fig. 9.1). Average annual rainfall is 62 cm at Gohad in Bhind district in the northwest and 78 cm at Jhabua in the west to 212 cm at Pachmarhi in Hoshangabad district in south. South of the Satpura-Kaimur line, annual rainfall is more than 130 cm but it is less than this amount north of this line. Along with low rainfall, it is highly variable in the Madhya Bharat, western Malwa and middle Narmada valley. Because of these characteristics, Indian Metrological Department has identified 27 drought-prone districts of this part of the state. This pattern is manifested in available potential of both surface and groundwater.

9.3 Surface Water

The surface water is feasible through ponds, tanks, rivers, streams and reservoirs. Rivers are major source of surface water in the state. Rivers of this state constitute part of the Ganga, Narmada, Tapi, Mahi and Godavari basins. The Ganga basin, comprising the sub-basins of Chambal and its tributaries, Betwa, Ken (all part of Yamuna basin), Tons and Son, drains the largest area of the state. The northern part of the state is drained by the rivers Chambal, Betwa, Ken and their tributaries, which flow northerly through Bundelkhand region and ultimately join River Yamuna. The Son River flows east–north-east and joins Ganga near Patna. The Narmada, flowing in a westerly direction, is a major river between Satpura and Vindhayan ranges draining to Arabian sea. Tapi is also westerly flowing river debouching its water in Arabian Sea. Wainganga and Pench are tributaries of Godavari river draining in south-eastern part of the state. Mahi covers small area of Dhar and Jhabua districts in the west.

The water resource department of the state has estimated the annual flow of rivers of the state at 81.7 billion cubic meters at 75% reliability. Out of this, 57.1 billion cubic meters can be utilized in this state and rest 24.6 billion cubic meters are allocated to the bordering states. Basin-wise distribution of this potential is very uneven (Table 9.1). Largest availability, more than two-fifths (41.4%) of the state is in the Yamuna sub-basin followed by the Narmada basin (39.5%). Godavari basin is at third place (36.4%). Remaining Ganga basin possesses only 15.3% of potential surface water of the state. The combined potential of the Ganga-Yamuna basin (57.6%) is largest in the state. However, this share in potential water resources is lower than their share in total catchment area of the state.

Besides rivers, there are a large number of tanks, ponds, lakes and reservoirs preserving surface water. Estimated area under these water bodies is about 60 thousand hectares. Along with this, about 2.27 lakh hectares are under large man-made reservoirs.

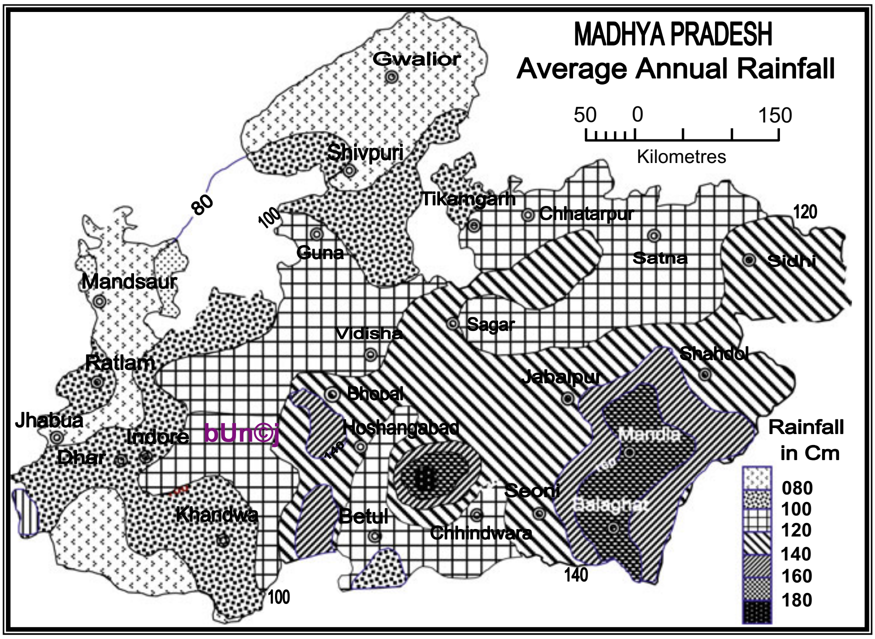

Fig. 9.1 .

9.4 Groundwater

Groundwater constitutes a major and widely used resource in the state. However, its distribution is very uneven because of varied hydrogeological characteristics. Central Groundwater Board, Government of India (2013) has divided this state into 12 Principal Aquifer Systems and 25 major aquifers based on hydrogeological characteristics. The replenishable groundwater potential is associated with unconsolidated formations, while semi-consolidated and consolidated geological formations have very limited potential. The unconsolidated rocks and soils are very limited in the Chambal valley in the north and the Narmada valley in the south which form excellent aquifers but constitute only 14.4% of total geographical area. The northern, eastern and southern parts are covered by hard rocks. These hard rock areas show wide variations and complexities in nature and composition of rocks, geological structures, geomorphological set up and hydrological conditions. The crystalline rocks of Archaean age like granite, gneiss, granulites, schist, quartzite and granitoids occupy about 14.7% of geographical area of the State. In these areas, groundwater occurs in upper weathered mantle and fractured zones underlying them. The consolidated sedimentary rocks of Vindhyan and Cuddapah Super Groups occupy about 19.1% of total geographical area and the semi consolidated Gondwana formation occupies about 6.7%. Gondawana formations are granular where tube wells are capable of yielding 100–500 cum/day for drawdown of 6–10 m. The basaltic rocks of Deccan lava flows are the predominant formations and occupy nearly 44.5% of western part of the state, separable into vesicular and massive units. The vesicular units, at various depths below ground, are moderately productive with wells capable of yielding 250–750 cu.m/day for drawdown of 3–6 meters.

As per 2011 reassessments made jointly by the Water Resource Department of the State and Central Groundwater Board (2015, pp 29–30), total recharge from rainfall in the state is 29.01 BCM (29, 00,686 ham), whereas from other sources is 6.03 BCM. Thus, total recharge from all sources is 35.04 BCM (Table 9.2). The

Table 9.1 Madhya Pradesh: basin-wise availability of surface water (Crore cubic metres)

Basin/Sub-basin	Catchment area in MP (sq km)	Av. flow at 75% dependability	Allocated to other states	Share of M.P
Ganga Basin				
a. Tons	11,974	224.4	–	224.4
b. Son	28,880	787	–	397
c. Yamuna Basin	142,250	2762.7	–	2364.2
Ken	24,785	570.3	104.8	465.5
Kuwari Sindh	26,999	507.9	–	507.9
Chambal	59,940	1059.2	197.9	861.3
Jamani	1235	22	(-) 1.3	23.3
Paisuni-Badhain	1920	8.9	4.8	4.1
Dhasan	8291	172.3	–	172.3
Betwa	19,365	385.7	92.3	293.4
Bagain	1500	36.4	–	36.4
Godavari	23,388	7630	ND	ND
Narmada Basin	85,149	3454.2	1203.1	2251.1
Tapti Basin	9800	240.1	75.5	164.6
Mahanadi Basin	154	ND	ND	ND
Mahi Basin	6700	195.2	161.4	33.8
Total	**308,245**	**8171.9**	–	**5705.1**

Source Water Resource Department, M.P. and updated using India WRIS river wise data

Table 9.2 Madhya Pradesh: availability and utilization of groundwater (BCM) 2011

Recharge from rains	29.01
Recharge from other sources	6.03
Gross recharge	**35.04**
Natural discharge	1.75
Net annual availability	33.29
Present draft for irrigation	17.48
Draft of domestic and industrial uses	1.35
Gross draft at present	18.83
Allocation for domestic and industrial uses	1.91
Future availability for irrigation	**13.90**

Source Central Ground Water Board, Dynamic Ground Water Resources of India, (as on 31st March, 2011)

natural discharge during non-monsoon season is 1.75 BCM. The net groundwater availability in the state is 33.29 BCM.

Distribution of groundwater potential is also very uneven in the state. It is as low as 0.216 BCM (21,648 ham) in Alirajpur and 0.232 BCM (23,214 ham) Jhabua districts and as high as 2.13 BCM (2, 13,837 ham) in Hoshangabad district. District-wise potential of groundwater is depicted diagrammatically in Fig. 9.2. Out of 50 districts of the state, only seven districts, viz. Hoshangabad, Betul, Chhindwara, Sagar, Narsinghpur, Shajapur and Dhar have groundwater potential above 1.0 billion cubic meters. These districts are located in south-central part of the state and have developed canal irrigation resulting in higher recharge from other sources than rainfall. Other 44 districts have availability below 1.0 BCM per annum and 17 out of them have potential even below 0.5 BCM. These are non-command areas and some of them, such as Dindori, Jhabua, Barwani, Sidhi and Singrauli, are dominated by the hilly and dissected terrain unsuitable for rapid recharge of groundwater and others are small in size such as Harda, Ashoknagar, Datia, Bhopal and Neemuch. As such, uneven distribution of groundwater is mainly due to geological structure, characteristics of soil, nature of terrain and slope, amount of rainfall and its characteristics, vegetative cover and size of the district.

The effect of size of the district can be eliminated by calculating the replenisable groundwater per unit of area. In calculating recharge of groundwater, hilly area of the district/block is deducted from the total area and hence per unit replenishable groundwater is per unit of replenishable area only. Areal unit used is hectare. The annual replenishable groundwater resource is highest in Hoshangabad (0.38 m/ha) district followed by Narsinghpur (0.26 m/ha). It is as low as 0.07 m/ha in Alirajpur followed by Sheopur, Damoh and Singrauli, all 0.08 m/ha. In 15 districts, the annual replenishable groundwater resource is between 0.07 and 0.10 m/ha, whereas in 25 districts, it is between 0.10 and 0.15 m/ha and 8 districts have 0.16–0.20 m/ha (Fig. 9.2). The average annual replenishable groundwater resource of the state is 0.13 m/ ha. Replenishable of groundwater is above 0.15 m/ha in districts of eastern Malwa and middle Narmada valley. Contrary to it, districts with replenishable rate lower than 0.01 are concentrated in three areas. First major tract extends from Chhatarpur in the Bundelkhand region to Rewa and Singrauli in the Baghelkhand region in the northeastern part to Mandla and Dindori districts in southeast. Second tract extends from Sheopur to Ashoknagar in the Madhya Bharat plateau region in the northwest and third tract encompasses Alirajpur and Jhabua districts in the southwest.

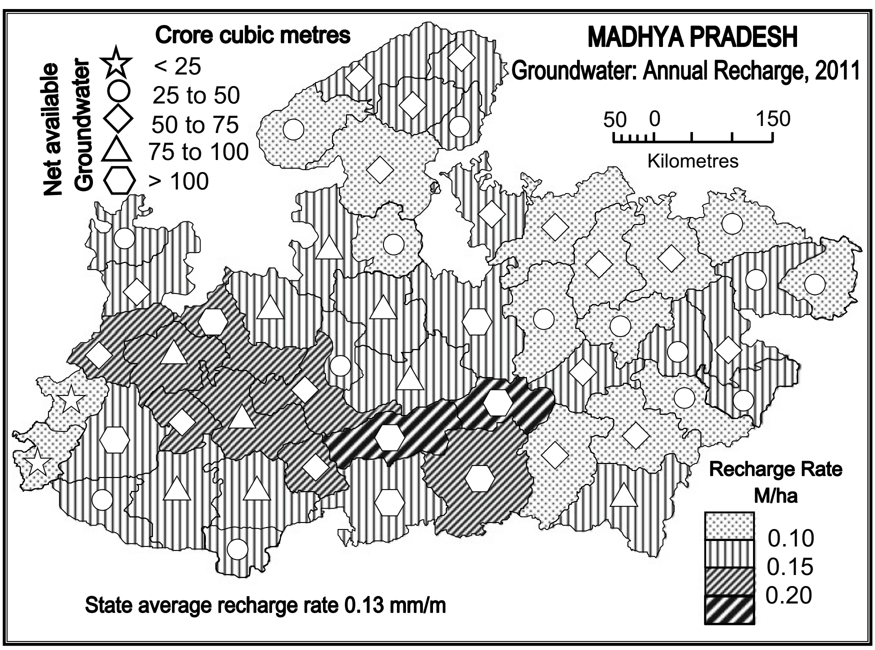

Fig. 9.2 .

The annual replenishable groundwater resource has increased from 33.95 BCM in 2009 to 35.04 BCM in 2011. The reason being localized improvement in rainfall pattern, increased activity on rainwater harvesting and water conservation measures etc. In addition, management practices like efficient water use practices with community participation, increased awareness also helped in improving water use efficiency of groundwater resources in stressed areas. In majority of the cases, it is the combination of the above-mentioned reasons which have brought in the changes in category.

9.5 Gross Water Resources

Summing surface water 56.8 billion cubic meters and groundwater 33.95 BCM, total potential water resources arrives at 90.75 BCM annually. It can provide water for irrigating more than 112.9 lakh hectares. As per estimation of National Agriculture Commission only 91 lakh hectares can be irrigated. In 2014–2015, gross-irrigated area is 10.3 million hectares which is just two-thirds of the total potential.

9.5.1 Utilization of Water Resources

Major economic use of water in the state is for irrigation. Irrigated area increased from only 4.7 lakh hectares in 1950–1951 to more than 103.0 lakh hectares in 2014–2015, recording average annual growth rate of 4.9%. Consequently proportion of gross irrigated area also rose from 4.4% to 42.3% during the this period. Spatial and temporal variation in growth of irrigated area has been very wide (Sharma and Jain 1994).

Gross irrigated area ranges from only 1.26% of gross cropped area in Dindori district to 75.64% in Datia district in 2014–2015. However, net irrigated area varies from 1.8% in Dindori to 99.3% in Raisen district in the same year (Fig. 9.3). Areas with higher intensity of irrigation than the state average are (i) Madhya Bharat plateau including upper and lower Chambal basin, (ii) Narmada valley-Nimar plain-Dhar upland, (iii) eastern Malwa, (iv) Western Bundelkhand upland, and (v) Wainganga valley. Contrary to them, proportion of irrigated area is low and very low in the northwestern Malwa, Satpura region, Rewa plateau and Baghelkhand plateau. Potential of groundwater is limited in districts of these regions. Reasons behind low development of irrigation in these areas are dissected and hilly terrain, shallow and comparatively low fertile soils, dense forest, dominance of tribal population, marginal and small landholdings and predominance of coarse grains in crop structure. These regions are deprived of such basic facility essential for improving farming. In certain districts such as in Dindori (1.3%), Anuppur (3.3%) and Singrauli (9.0%), Mandla (14.8%), Shahdol (15.0%) and Alirajpur (17.8%) irrigation could not be started in real sense.

9.5.2 Sources of Irrigation

There are three major sources of irrigation. These are canals, wells and tube-wells and tanks. Besides them, some other sources are used for irrigation. Relative significance of these sources has changed. For example, canals irrigated 26.0% of net irrigated area in 1950–51 but only 17.2% in 2014–2015. On the other hand, significance of wells and tube wells increased enormously with the introduction of diesel and electric pumping-sets. Net irrigated area by them increased from 241 thousand hectares in 1950–1951 to 6403 thousand hectares in 2014–2015, recording more than 26-fold growth. Consequently, proportion of well and tube well-irrigated area rose from 53.2% to 66.8 during this period. Out of this, more than half (34.2%) is irrigated by tube wells and remaining 32.6% by dug wells. There are 1623.1 thousand irrigation wells and 665.6 thousand tube wells in the state in 2014–15. Out of them only 2.45% wells and 0.58% tube wells are under government control and remaining of them are owned by farmers. It means most of the area is irrigated by non-governmental sources in the state. It involves the issue of the ownership and management of water resources. Other sources also gained significance, by raising their share in

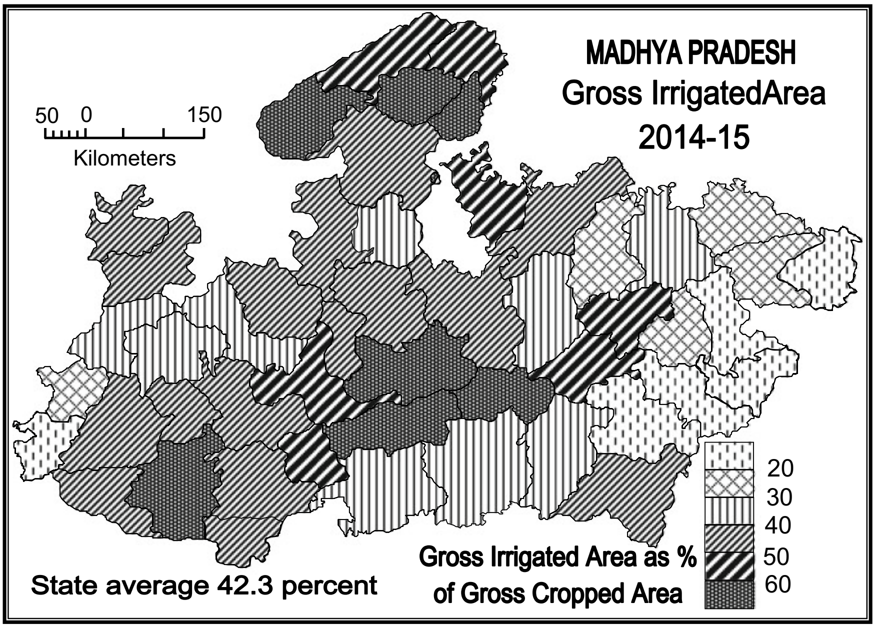

Fig. 9.3 .

net irrigated area from only 3.9% in 1950–1951 to 13.2% in 2014–2015.

9.5.3 Issues of Water Resources

Utilization of water resources for different purposes has created certain problems (Sharma 2016). Irrigation has largest share in water utilization. The spatial variation in availability of irrigation facilities has given birth to conflicts of interest in several forms. At the same time, several problems such as land degradation, salinization, water logging have crept in the irrigated areas. The rapid development of groundwater-based irrigation in most parts of the state has caused lowering of the water table and depletion of groundwater resources. To meet the irrigational necessity inter-basin water transfer is proposed and practiced, causing disputes. There has been emphasis on the construction of big dams. They have caused large-scale submergence and displacement of people from their original habitat. Low efficiency of water use and water pollution cost are other serious problems. Some of these issues are reviewed below.

9.6 Declining Trend of Rainfall

The base of the water resources itself is dwindling in the state. Rathore et al. (2013) have recently analyzed the trends of average annual rainfall for the period 1961–2002. Though there is an inter-annual variability of average monsoon rainfall in the 41-year period, the rainfall is also decreasing. Further a study carried out by Goswami et al. (2006), for observations spanning 50 years in the Central Indian region including Madhya Pradesh, indicates that the extreme precipitation events which are above 100 mm are increasing in terms of their intensity and frequency, with low and moderate events becoming more and more infrequent. On the basis of rainfall data for 1951–2013, Mishra and others (Mishra et al. 2016) have concluded that most part of the state of Madhya Pradesh experienced a significant decline in the monsoon season precipitation during this period. The monsoon season precipitation is projected to decline in the near future (2016–2045). Further, they also indicated that the frequency of severe, extreme, and exceptional droughts has increased in the state. Droughts in the recent years were severe and wide-spread. The number of hot days has increased significantly in the state. It will increase the need of water. This is just an indication that the present potential of water resources is likely to decline in future which must be taken into account while planning for their development in the state.

9.7 Groundwater Draft

The most serious problem is of rapid lowering of water level and depletion of groundwater in the state. It can be sensed from the fact that per sq km of net sown area there are 14.53 dug wells and 4.31 tube wells in the state in 2014–2015. Groundwater draft for various uses has been calculated separately for command and non-command areas by the state Water resource Department (2015). Total draft of groundwater for all uses in state is calculated as 18, 83,352 ham (18.83 BCM). It is seen that maximum groundwater drawl for all uses is 96,822 ham in Shajapur district and minimum draft of groundwater for all uses is 2,180 ham in Annupur district in the eastern part of the state. Districts and blocks of high groundwater development concentrate mainly in the western (Malwa region), central (Narsinghpur district), Budelkhand region and part of Bagkhelkhand region of the state (Fig. 9.4). Other parts of the state have developed low and very low proportion of their groundwater potential. Sixteen districts have developed between 60 and 90% and another five districts between 90% and 100% of their net groundwater potentials in the state. Among them, Indore and Ratlam districts have reached at highest level of groundwater development of 120% and 126% respectively. Shajapur (98%), Mandsaur (96%) and Ujjain (95%) are very close to over exploitation. Contrary to them, 29 districts have groundwater development index below 60%. Most of the districts of eastern and northern parts are in this class. Raisen, Ashoknagar, Harda, Jhabua and Alirajpur are other such districts. Anuppur (6%), Shahdol (7%) and Dindori (8%) could develop less than 10% of their potentials. The overall development of groundwater in Madhya Pradesh is 57%, which is in safe category of utilization.

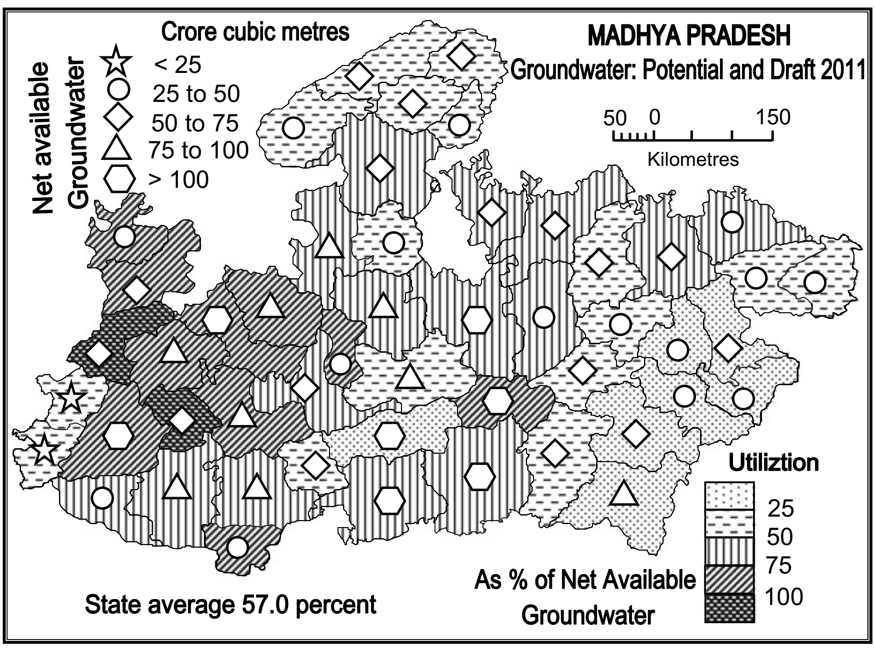

Fig. 9.4 .

9.8 Over Exploitation of Groundwater

The development blocks are categorized for groundwater development by the state Water Resource Department (2015, pp 34–35) based on two criteria—stage of groundwater development determined on the basis of the proportion of draft of groundwater in net replenishable groundwater of the block, and by long term trend of pre- and postmonsoon water levels. Four categories of development blocks/districts thus identified. They are:

1. Safe areas (proportion of draft below 70% of net rechargeable resource) which have groundwater potential for future development,
2. Semi-critical areas (proportion of draft between 70 and 90% of net rechargeable resource) where cautious groundwater development is recommended,
3. Critical area (proportion of draft between 90 and 100% of net rechargeable resource) where regular monitoring and evaluation is required for future groundwater development,
4. Over exploited areas (proportion of draft above 100% of net rechargeable resource) where intensive monitoring and evaluation linked with water conservation measures are essential for future groundwater development.

Out of 313 blocks of the state, the entire command areas of 218 blocks fall under safe category of utilization. Non-command areas of 67 blocks are in semi-critical, 4 blocks are in critical, and 24 blocks are in over-exploited category. Almost all over-exploited blocks are falling in western part of Madhya Pradesh, known as "Malwa" where groundwater draft has increased many folds during past decades (Table 9.3). District-wise analysis of data of groundwater availability and annual groundwater drafts indicate that two districts namely Indore and Ratlam fall in "Over-Exploited" category where more than 100% net potential of groundwater is already developed. Middle Narmada valley and north-eastern districts are also approaching to this level. These areas particularly the Malwa region is deprived of any medium or large irrigation projects, and therefore farmers heavily depend on tube wells for irrigation. It caused high density of tube wells in these districts. Density of tube wells per square kilometer of net sown area in 2014–2015 is more than 10 in

Table 9.3 Madhya Pradesh: list of over-exploited development blocks, 2011

S N	District	Block	% Potential developed	S N	District	Block	% Potential developed
1	Barwani-1	1. Pansemal	115	13	Ratlam-4	1. Alot	113
2	Dewas-2	1.Dewas	109	14		2. Jaora	167
3		2.Sonkutch	104	15		3. Piploda	168
4	Dhar-4	1.Badnawar	103	16		4. Ratlam	106
5		2.Dhar	136	17	Satna-1	1. Rampur	102
6		3. Dharampuri	108	18	Shajapur-4	1.Mohan Barodia	134
7		4. Nalcha	107	19		2. Nalkhera	117
8	Indore-3	1. Depalpur	123	20		3.Shujalpur	103
9		2. Indore	148	21		4.Susner	102
10		3. Sanwer	134	22	Ujjain-3	1.Badnagar	117
11	Mandsaur-2	1. Mandsaur	116	23		2.Ghatia	102
12		2. Sitamau	104	24		3.Ujjain	125

Source CWC and State Water Resource Department: Dynamics of Groundwater Resources of M. P. 2010–2011

Indore, Ratlam, Ujjain and Bhopal; and between 5 and 10 in Dewas, Dhar, Narsinghpur, Satna, Shajapur, Sehore, Vidisha, Raisen, Burhanpur, Rewa and Sheopur district as against the average of 4.34 for the state.

District-wise balance groundwater for future irrigation is estimated by deducting groundwater draft for irrigation and allocation for next 25 years (upto year 2035) for drinking and industrial water supply from net groundwater availability. About 13, 46,522 ham (13.47 BCM) groundwater is available for future irrigation at present (2010), which can irrigate additional area of 33, 66,305 hectares. In two districts namely Indore and Ratlam balance of groundwater is estimated as nil for future irrigation, while Ujjain will have minimum irrigation potential as it is very close to 100% development projecting the domestic and industrial draft for the year 2035.

9.9 Water Level Fluctuation

Groundwater level refers to underground surface below which the ground is wholly saturated with water. The upper surface of the zone of saturation is the water table. Groundwater is a dynamic system and groundwater level varies significantly over time and space. The groundwater level is subject to change due to natural and man-made causes. Groundwater level is an important indicator for the recharge of the aquifer, groundwater abstraction and the discharge from the aquifer to surface waters and to some extent groundwater quantity. Decline in groundwater levels can occur as a result of natural climatic conditions (low rainfall), changes in land use, or as a result of over abstraction. Rise in groundwater levels can occur as a result of natural climatic conditions (heavy rainfall), changes in land use, or as a result of artificial recharge to groundwater by rainwater harvesting. The average depth of water level during the decade 2003–2012 in pre and postmonsoon periods (CGWB 2013, Pts III and IV), derived from data of 1246 observation wells of the state, is discussed below succinctly.

9.10 Depth to Water Level in Pre-Monsoon Level: May

The decadal mean depth of water level for 2003–2013 varies from 2 to 41 m bgl in the state. In general, the depth to water level ranged between 5 and 20 meter below ground level (m bgl), except in small localized patches. Groundwater level, ranging between 2 and 5 m bgl, was observed in isolated patches, mostly in a belt from northern Betul-Chhindwara districts to part of Narsinghpur, Jabalpur, Mandla and Dindori districts. More than 43.0% of monitoring network wells had depth of water level ranging between 5 and 10 m bgl, which are widely distributed in the state, spreading over major part of Jhabua, Barwani, Khargone, Khandwa, Harda, Hoshangabad; northern parts of Betul and Chhindwara district to Jabalpur district; parts of Umaria, Shahdol, Sidhi and Sigrauli districts; Sehore, Vidisha, Ashoknagar and major portion of Sagar district; and part of Morena, Gwalior, northern Chhatatpur and Panna districts. Depth to water level ranging between 10 and 20 m bgl was observed in 45.0% of monitoring network wells. Such areas are particularly covering major part of the Malwa, Madhya Bharat, Rewa plateau, middle Satpura and Dindori district. Very deep water levels more than 20 m.bgl were seen in some small pockets spread in alluvium aquifer covering parts of Bhind, Morena, Datia, Gwalior and Sheopur in the north; and basalt-sandstone areas of Indore, Dewas, Barwani, Burhanpur, Sagar and Damoh districts.

9.11 Depth to Water Level in Post-Monsoon Period: November

Mean depth of water level for 2002–2012 for postmonsoon period ranges from 0.61 to 41 meters below ground level (mbgl) in the state. Very shallow water levels up to 2 mbgl are seen as a continuous patch in southern parts of the state covering mainly Chhindwara, Betul, Seoni, northern Balaghat, Mandla, Dindori, southern

Anuppur and Jabalpur districts and isolated patches in central part of state. About 29% of wells have recorded a depth of 2–5 mbgl which are spreading over the Nimar plain, middle and upper Narmada valley and adjoining middle and eastern Satpura region. Such wells are also seen in major part of Sagar, Damoh, Katni, Panna and southern Chhatarpur districts. Depth to water level ranging 5–10 mbgl is noticed prominently in major part of the Malwa plateau, Shivpuri and Ashoknagar of the Madhya Bharat plateau and major part of the Bundelkhand region of the state. Deeper groundwater levels ranging 10–20 mbgl are seen in a narrow continuous patch in northern parts and in isolated patches in western and eastern parts (Panna, Damoh, Rewa, Sidhi and Singrauli districts) of the state. About 18% of wells fall in this category. Groundwater level more than 20 m are exception and are seen in pockets in Morean, Bhind and Gwalior districts.

9.12 Trend of Groundwater Level

Groundwater is replenished from precipitation and from surface water, but the rate of abstraction (withdrawal by humans) exceeds the rate of natural recharge, leading to reduction of the resource indicated by declining trend of water level. Rising trend in groundwater levels can occur as a result of natural climatic conditions (heavy rainfall), changes in land use, construction of pond or reservoir or as a result of artificial recharge to groundwater by rainwater harvesting.

Water level of November 2010 was compared with the average water level of November (2001–2009). In general, there was rise/fall in groundwater level of ±2 m in entire state during November 2010 as compared to decadal average. About 49% of wells showed a rise in water level. Rise up to 2 m in groundwater level was noted in 39.8% of monitoring wells and between 2 and 4 m in 6.4% of monitoring wells. Rise more than 4 m in groundwater level was observed in 2.9% of monitoring wells distributed in isolated manner.

Out of total monitoring wells fall is found in 51% of wells scattered throughout the state, covering mainly parts of northern districts of Morena, Bhind, Gwalior and Sheopur. Fall in groundwater level up to 2 m was observed in 31.3% of monitoring wells and between 2 and 4 m in 10.5% of monitoring wells. Fall more than 4 m in was observed in pockets in northern half of the state, comprises 10.42% of monitoring wells. Such a declining trend of water level of dug wells is indication of declining water level as a result of excessive extraction apart from poor saturation of aquifers. In fact, problem is accentuated by the tube well with high yield of water. In 2014–2015, total 6,65,658 tube wells as against 2.01 million dug wells were used for irrigation in this state. Therefore, regular monitoring of these tube wells should be mandatory.

9.13 Groundwater Quality

The groundwater quality in shallow aquifers of Madhya Pradesh collected from National Monitoring Wells reveals that quality is generally good for drinking purposes with Electrical Conductivity, and Residual Sodium Bicarbonate parameters showing low range of corresponding values, except for high nitrate concentration recorded at many places. The distribution of EC in groundwater shows that in most parts of the area it is in the range of 750–1500 s/cm. Moderate to high EC in the range of 1500 s/cm to 3000 s/cm is found in pockets of north, central and western parts of the state; while it is high to very high EC, more than 3000 s/cm in a few localized pockets in parts of Bhind, Ratlam Indore, Gwalior, Sheopur, Khargone and Jhabua districts.

Nitrate is a non-essential constituent of groundwater and concentration of nitrate in excess of 45 mg/l in water is harmful for human consumption. In about 38.5% water samples, nitrate concentration is above 45 mg/l and in about 104 water samples, nitrate concentration is above 100 mg/l. Very high nitrate concentration of 546 mg/l was found in the groundwater sample from Khargone district followed by 380 mg/l in groundwater of Dewas district.

Fluoride concentration is generally low except in some samples. The fluoride in excess of

1.5 mg/l is harmful and causes fluorosis. High fluoride problem is encountered in Jhabua, Mandla, Chhindwara and Shivpuri and in isolated pockets in Shajapur, Satna, Guna, Jabalpur, Vidisha, Sehore, Ujjain, Seoni, Datia, Gwalior, Rajgarh, Shahdol, Bhind, Dhar and Morena districts. Sulfate contents are generally low except in few places. Maximum 900 mg/l SO_4 is found in Bhind district. At Chhindwara, Dewas, Indore, Rewa and Satna district SO_4 contents are around 300–400 mg/l.

9.14 Rehabilitation and Resettlement of the Affected Population

By 2015, there are 22 major, 90 minor and 4804 minor completed/under construction irrigation projects in Madhya Pradesh. Most of the major projects are located in the Narmada valley and the Chambal valley. Most of these projects are fraught with serious issues related to massive displacement, forest submergence, poor rehabilitation and resettlement, tribal issues and forest rights, reservoir fishing leases, legal and procedural issues etc. As an example, situation of rehabilitation and resettlement of the families displaced in the Narmada Valley Development Project, one of the world's largest multipurpose projects, is presented. For almost three decades now agitations have been going on against Madhya Pradesh government's poor rehabilitation and resettlement. In one of the latest episodes, in August 2012, several affected people from Omakareshwar and Indira Sagar Dams undertook a Jal Satyagrah for 17 days together against absence of rehabilitation. The Supreme Court issued a show cause notice to MP Government. The Sardar Sarovar is one of the 30 dam-based projects of the valley. Over last 30 years, the project has been in the news due to the controversy over the enormous social, cultural and environmental costs and displacement and dislocation in large scales. It is said to be one of the most ambitious river valley projects in modern Indian history. The height of Sardar Sarovar dam, located in the rift valley, was raised in phases from 95 to 100 m in May 2003, 110 to 110.64 m in March, 2004, later to 119 m in March 2006 and up to 121.92 m by end of 2006, where it stood, before fresh construction started in late 2014 to take the height to 138.68 m. At its final height of 138.68 m, the reservoir itself is supposed to submerge over 37,500 hectares of land (20,822 ha in M.P., 9590 ha in Maharashtra and 7112 ha in Gujarat) in 245 villages in Gujarat (19), Maharashtra (33) and Madhya Pradesh (193), including over 13,300 hectares of biodiversity rich forest land, as per official estimates. As a result of the increased height, the backwater levels have also gone up, inundating many villages and hamlets. The number of displaced families from these 245 villages has been conservatively estimated at over 48,000 in the three states who are yet to be settled as per guidelines of the Narmada Water Disputes Tribunal.

The Central Fact Finding Committee (CFFC 2015) after visiting the Narmada Valley presented its report regarding this issue and highlights the gravity of the situation and concerns of the affected people. As per report, many of the villages submerged/being submerged are adivasi/tribal villages. For example, out of the 193 villages affected by SSP in Madhya Pradesh, 70 are fully tribal villages. Thousands of families, especially the tribals, fisher folk, landless poor who are under the threat of imminent inundation and thus forcible displacement, are not being given any alternative place to live, as also, alternative land and livelihood sources, in many cases. The essential components of land-based rehabilitation for even those recognized as project-affected are not being implemented. Cultivable, irrigable lands are not located nor purchased by the Governments. Several thousands of people, whose houses and lands are in reality getting submerged during high flood levels, are not even recognized as project affected families/ persons. The rehabilitation sites chosen/ identified by the governments are in extremely poor conditions, having no adequate facilities for people to live there as per the NWDT norms, with poor water supply, broken roads, no electricity, and nonexistent or pathetic education and health facilities.

9.15 Inter-State River Water Disputes

Inter-state water disputes are also one of the major issues with the management of water resources of the state. Major rivers of the state are shared by two or more states. Madhya Pradesh is located in the center of the country and rivers flow almost in all directions and drain huge water from the state. As soon as they cross the boundary of Madhya Pradesh, they are dammed in such a manner that the submerged area confines in this state but water goes to the states of lower reaches. The Rihand, Betwa, Ken, Chambal, Narmada, Wainganga are some of the rivers to be mentioned. Sometimes even dams are located within the state and water is passed to other states. Bansagar located on the Sone in Shahdol district and Gangau Dam in Chhatarpur district are glaring examples. Such a situation has created water conflicts between Madhya Pradesh and the bordering states. With the increasing demand for water which largely falls under the authority of the states, and with the states increasingly asserting their legal and political power, inter-state water disputes are in the rise and are getting more complex and contentious. At present, this state has water disputes with Andhra Pradesh, Chhattisgarh, Odisha and Karnataka for water of Wainganga and its tributaries; with Rajasthan for Chambal water, with Gujarat, Maharashtra and Rajasthan for Narmada water; with Gujarat and Rajasthan for Mahi water; with Maharashtra for Tapti water; and with Uttar Pradesh and Bihar for Son and Rihand water. On the behest of the central government agreements for the sharing of river waters have been reached several times between Madhya Pradesh and concerned states. In spite of this, dispute triggers almost every year particularly in lean years or lean season.

Under the Inter-State Water Disputes Act, 1956, the Central Government constituted Narmada Water Disputes Tribunal (NWDT) on 6th October 1969 to adjudicate upon the sharing of Narmada waters and for the Narmada River Valley Development. The Tribunal gave its Award on 7th December 1979. The Award specified a quantum of utilizable waters at 75% dependability to be shared by the four States of Gujarat, Madhya Pradesh, Maharashtra and Rajasthan. The Narmada Control Authority is an interstate high level administrative authority, set up by the Government of India, in 1980 for the purpose of securing compliance with the implementation of the decisions of the Narmada Water Disputes Tribunal by the basin States. Agreements between riparian states of Narmada were made in 1972, 1974, 1975 and 1978 besides Tribunal awards and judgments of Supreme Court of India. Similar agreements were made with Uttar Pradesh regarding Matatila dam, Rangawn dam, Jamni dam Bhander canal complex in 1965; regarding projects of Bundelkhand in 1972, Rajghat project in 1973; and regarding Rajghat, Paisuni, Ken Canal, Kanhar, Urmil, Bansagar, and (vii) Bhander Canal in 1977. Similar agreements were made between Madhya Pradesh, Uttar Pradesh and Bihar regarding Bansagar in 1973 and regarding Kanhar waters in 1982. Disputes of the Tapti basin and Godavari basin were discussed and agreed upon several times between concerned states. These agreements are most often violated particularly in lean seasons and dry years.

9.16 Issue of Drinking Water Facility

The use of water for drinking and domestic purposes is practiced since time immemorial. But even today it is not easy to get sufficient drinking water from improved sources in this state. The NSSO Survey conducted during 2012 (2013) shows that while in rural 83.2% of households got drinking water from 'improved sources', the proportion was 97.1% in the urban areas of Madhya Pradesh. The averages for the country are 88.5% and 93.5% respectively. It means the rural households of the state are far behind the country average to get water from improved sources. In this survey, it has been ascertained that in the state 76.2% of rural and also urban households get sufficient drinking water throughout the year. These figures are much lower from the national averages (85.8% rural and 89.6% in urban).

In terms of travel distance to reach the principal source of water, the rural households are at a disadvantage compared to the urban households. The Census 2011 data on water access point out that 35.0% rural households (HHs) have access to a water source within the premises as against 71.2% of urban HHs. Contrary to this, 20.7% urban and 42.9% rural HH have water sources near their premises, and 8.1% urban and 22.1% rural HH have to fetch water from far away sources. With regard to source of water, 70.6% of urban and 30.8% rural HHs use tap water, 20.8% urban and 51.9% rural HH use hand pumps, tube wells and bores, 6.2% urban and 13.3% rural HH use wells, and the remaining 2.5% urban and 4.0% rural HH use other sources. It is also pertinent to mention that nearly two-thirds (62.0%) of urban and one-sixth (17.9%) rural HHs get treated tap water. Water supply in urban Madhya Pradesh is extremely dissatisfactory. In the urban areas, 182 towns receive daily water supply, 115 towns on alternate days, 50 towns once in 2 days, and 24 towns once in 3 days.

9.17 Pollution of Water

Pollution of water of rivers, ponds and groundwater is reaching to a point of crisis particularly near urban and industrial centers due to unplanned urbanization, rapid growth of industrialization and increasing use of fertilizers and other chemicals in farming. The quality of river water is deteriorating mainly due to human activities such as discharge of industrial and municipal sewage wastes and agricultural runoff, causing ecological damage and posing serious health hazards. Shraddha et al. (2011) concluded that due to discharge of untreated sewage at Hoshangabad into the Narmada along with industrial effluents from Security paper Mill, the water quality of Narmada has been severely deteriorated and the potable nature of water is being lost. The Kshipra, one of the sacred rivers of Malwa holding Simhasth Kumha, carries untreated wastes and effluents from Ujjain, Dewas and Indore cities which have not only affected the quality of the river water but also has aggravated the water crisis in the region. Its waters, which once quenched the city's thirst, are not even fit for bathing any longer, and government has to bring Narmada water to keep is glory during Singhstha. The River Betwa plays a significant role in the human life of the villages located on its bank. It is being polluted at Mandideep due to industrial activities and the confluence of sewage, domestic wastes and industrial effluents of many big and small enterprises with various types of organic compounds and heavy metals. The water quality in the stretch of the River Betwa extending from its origin near Mandideep industrial area up to Bhojpur remains poor because of the regular inflow of domestic waste of the Bhopal city through the Kaliyasot river and industrial/domestic waters from Mandideep. The untreated sewage of the human habitations in Mandideep is directly flown into the Kaliasot river which flows on the one side of the town while untreated chemical waste directly mixes into river Betwa which flows on the other side of the town (Margade 2009; Vishwakarma et al. 2013).

Most of the water bodies in and around Bhopal are presently under great environmental stress due to pollution from point and nonpoint sources, eutrophication, fast growth of aquatic macrophytes, enrichment of nutrients, and human encroachments. Due to the joining of untreated domestic sewage, washing activities, and so forth, the water quality of these water bodies has deteriorated to a great extent thereby reducing the carrying capacity of the system. The sewage disposal system in the state capital covers only 40% of the city’s area. Everyday more than lakh liters of waste water and sewage are being discharged to the Upper Lake water and Patra, Halali and Betwa rivers. Water of water-bodies of the city is highly polluted. These domestic and industrial waste waters have polluted not only the surface and lake waters but groundwater also. Irrigation reservoirs constructed near Bhopal city

—Hathaikheda, Kaliasot, Kerwan and Laharpur—are also in grip of sewage pollution. Sonam (2012) found that highly polluted water of Shahpura lake percolates downwards and makes well, hand pump and tube well water polluted.

In Indore, 202.2 million liters sewage is generated every day and most of it disposed of in the Khan River without treating it. Textile and chemical industries of the city leave their wastes in the Khan River which ultimately poisons the Kshipra River. Sohani and Sanjeeda (2012) investigated the quality of surface water of Indore and concluded that surface water is full of pathogens which are percolating in the groundwater. They emphasized to save surface water from sewages. Gwalior drains its 50 million liters after treating and remaining 66 million liters untreated sewage to the Swarnarekha River. Morar River receives sewage of the Morar town. Similarly, effluents of the Orient Paper Mills, Amlai, have polluted the Son river for long distance (Shrivatava et al. 1988) and of News Print Paper mill of Nepanagar pollutes Tapti. In this context, the statement of Sunita Narain from the Centre of Science and Environment made at the occasion of opening of the 7th State of India's Environment Report at Bhopal, that 'we are killing our rivers and water bodies', is turning to be true.

9.18 Other Emerging Issues

Sedimentation of reservoirs is also a severe problem. Sedimentation is the process by which larger sediments in water entering a reservoir are deposited at its upper end forming a delta and steadily raising level of the upper reaches of the reservoir. This process shortens the utility, capacity and life span of the dam. In case of Sardar Sarovar dam, there is the possibility of premature siltation (Alvares and Billorey 1987). Central Water Commission (2015) in its report has surveyed the status of siltation in the Gandhi Sagar dam constructed on Chambal and found that the dam has lost capacity of 519.85 million cubic meters during 41 years from 1960 to 2001. Average rate of siltation thus arrives at 12.679 M cum per year. It is slightly lower in the Rana Pratap Sagar below the Gandhi Sagar. The Halali dam in Raisen district lost 16.91% live storage capacity, from 226.940 M cum in 1976 to 188.583 M cum in 2003, yielding annual rate of siltation of 1.42 M cum. Because of loose soil present in most of the state problem of siltation exists in every project area.

Waterlogging is another serious problem, which can be easily witnessed in command areas of Tawa, Chambal, Barna, Harsi projects. About one-third of the command area of Tawa is suffering from waterlogging. The Indian Institute of Social Science estimates that 40% of the command area of the Sardar Sarovar dam will become waterlogged. This area contains black soils, which are particularly prone to waterlogging under perennial irrigation due to high water retentive capacity. Rich soils in Punjab and Haryana have been robbed of their use because of waterlogging. Salinity is also in filtering in the canal irrigated area. It is estimated that 4410 hectares are salt affected. Irrigation water unlike rainwater contains considerable amount of salt in solution which is deposited on soils to make them salty. Again in Tawa dam command a large tract of good quality cultivable land has been affected by salinity and became infertile.

9.19 Suggestions

In the background of the emerging problems and issues of the water resource situation in the state and as a response to the demands of the challenges that lie ahead, fundamental changes are required in the management of water system. The National Water Policy 2002 accepts these challenges. At present, a new conceptual framework for the water resource management, known as 'Integrated Water Resources Management (IWRM)' is postulated. This integrated water resource management concept emphasizes on 'all physical aspects of water resources' and 'environmental considerations.

At the moment emphasis is laid on the management of demand rather than the supply. The central point of water resource management is to match supply and demand imbalance through structural facilities of storage, conveyance, processing and their operations. Construction of storage should be planned in such a fashion that it's social, cultural, and environmental cost and displacement should be least. Groundwater and surface water are in hydraulic continuity and their development should therefore involve the conjunctive uses of surface and groundwater resources. Nevertheless, issue of the ownership of the groundwater should be taken care of. At the same time, recharge of aquifer needs special attention. Fortunately, different methods of water harvesting are being popularized.

Modern water conservation techniques should be applied. They are 'multiple use' and 'priority of use'. Multiple approaches ensure stability in water resources. For instance, technical measures can be applied to increase resources, for purification of discharges and reduction of water damage and for increasing water use efficiency. Water resource can be increased by regularization over a period of time, intra basin and inter basin transfer of resources, conjunctive use of surface and groundwater, recycling of water after first use and by reducing demand for water. Technical means can also minimize the damage caused by floods, which is major natural hazard. Further, the water resources management should pay attention to the intricate linkages water has with other aspects of environmental resources. For example, since sewage has polluted almost all local sources of water in Bhopal and Indore, they have to draw drinking water from the Narmada, of course at very high cost.

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10 Industrial Operation of the Biological Early Warning System BioArgus for Water Quality Control Using Crayfish as a Biosensor

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Abstract

The quality of the natural water incoming on water intakes of water supply in certain European countries since the beginning of the 1970s at the drinking water supply Early Warning Systems (EWS). The use of high level of chemical in drinking water is danger and economic losses in such cases depend on speed of acceptance of the management decisions directed to their prevention and elimination. The aim of EWSs is to support of the management decisions directed to minimization of environmental risks in the case of dangerous water quality changes at water supply. The BioArgus-W is a science-based, multi-parameter, multi-level biomonitoring system comprising several building blocks. Even a failure in one of them can reduce partly or entirely a whole system efficiency. The main distinctive features of the BioArgus-W system are test-organisms (crayfish and fish) used as the sensors. The measuring system allows carrying out a long-term continuous biomonitoring of a surface water quality and quality of biologically treated wastewaters on the basis of the analysis of heart rate variability in the freshwater crayfish.

Keywords

Real-time biological early warning systems · Surface and sewage water monitoring · Crayfish as a biosensor · Heart rate variability

10.1 Introduction

Environmental policy of all countries of the world is directed to water supply of the population by drinking water of high quality and preserving the rivers, lakes and seas, suitable for people and wildlife. However, now freshwater reservoirs and water bodies, as well as community centralized drinking water supply systems, have been exposed to continuous and escalating anthropogenic loading, and also cases of sudden emergency pollution. Besides, the problem of ecological safety of the population and prevention of threats of ecological crime and terrorism in a zone of drinking water intakes is urgent for many countries. Level of chemical

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_10

danger and economic losses in such cases depends on speed of acceptance of the management decisions directed to their prevention and elimination.

To control quality of the natural water incoming on water intakes of water supply in some European countries since the beginning of the 1970s at the drinking water supply (WS) Early Warning Systems (EWS) were started to use. The systems are based on continuous real-time measurements of integrated water physical-chemical characteristics. In the case of intensive accidental pollution of water source, the intake can be stopped for several days or weeks, that lead to decrease in necessary amount of drinking water supply for the population.

The fire case in stock of the Sandoz pharmaceutical plant near Basel in 1986, when many toxic substances were dumped to Rhine together with firefighting water, that led to death of almost all live organisms in the river up to 100 km downstream. The result was a forced stop of a number of waterworks for a period of up to 9 days. This became a milestone event for paradigm shift of the EWSs. This case most visually has designated for all European companies managing water resources a problem of drinking WS of the population in the case of similar emergency pollution of water of sources and stimulated development of biological early warning systems—BEWSs. The main BEWS requirements are:

– Assessment of chemical danger of surface water, and in particular, sources of community drinking WS is to be based on reliable and operative information.
– Careful selection of real-time water quality control methods and technologies.

At the same time, it is not known in advance what kind and origin of pollutants (or their mixture) will cause threats for ecological safety of the population. Besides, modern physical–chemical characteristics monitoring systems do not give the possibility to determine toxicity level for live organisms due to cumulative effects. Thus, nowadays, it is strongly recommended to use biological methods of monitoring, taking into account synergism of the operating factors, to reveal changes in environmental quality negative for a biota (Borcherding 2006; Depledge et al. 1995; Hagger et al. 2009; Kholodkevich et al. 2008).

Biological methods are recommended as an additional method (Directive 2000/60/EC) and as a tool for integrated environmental monitoring. Methods “work well” at the level of an organism and indicate the biological pollution effects (Depledge and Andersen 1990; Depledge et al. 1995; Handy and Depledge 1999; Kholodkevich and Kuznetsova 2014; Kuznetsova and Kholodkevich 2015). In this regard, biological methods are useful to develop science-based methods of environmental risk assessment (Moore et al. 2004).

Main objectives of chemical and toxicological monitoring systems for surface water bodies for centralized drinking water supply by means of EWSs are the following:

– ensuring work of water supply station in the presence in surface natural water of high toxicity.

Thus, the aim of EWSs is to support of the management decisions directed to minimization of environmental risks in the case of dangerous water quality changes at WS.

In EWSs, living organisms are universal sensors, able to respond to wide range of toxicants negative action. The International Organization for Standardization (ISO) has approved the list of biosensor organisms and test reactions in which benthic invertebrates, in particular bivalves, take the important place (ISO standards). The list of relevant species of organisms and their response reactions are presented in a number of papers (Baldwin and Kramer 1994; Gerhardt 2000; Kholodkevich and Kuznetsova 2014). Bacteria, algae, fishes, plankton invertebrates, freshwater mollusks and other species of the invertebrates are used as test-organisms in the EWSs.

Now a number of BEWSs types are known (see reviews: Kramer and Foekema 2001; Kuklina et al. 2013). Modern BEWSs allow revealing at early stages possible threatening for ecological safety of water supply in time scale from minutes up to an hour.

In the recent paper, the results of successful long-term operation of two types of original automated systems of BEWS developed in SRCES RAS and are installed at State Unitary Enterprises "Vodokanal of St. Petersburg" are presented. In such automated systems, freshwater crayfish as a biosensor is used with the stress as ecotoxicological biomarkers indicative parameters.

10.2 Experience of Bioelectronic System BioArgus for Water Toxicity Monitoring for the Water Supply Stations Intakes

The following specific requirements for all BEWS systems to make management decisions concerned with the community drinking water supply (WS) are:

1. Time of water exchange at inlet chamber of intake works of WS stations and in aquariums with biosensors in BEWSs has to be similar.
2. Time of detection and the subsequent elaboration of management decision for stop of a water intake and interruption in supply of natural water of a source for further treatment facilities of waterworks shall be less, than time for which water reaches them from the inlet chamber. Otherwise, there can be a situation it will be necessary to stop waterworks for a long time to carry out expensive works on the recovery.
3. Time for management decision to stop treatment facilities of the WS shall not exceed the time demanded for emptying of the tank of clear water at usual daily water consumption by population in the certain region (usually about 5–7 h). Therefore, it imposes special requirements to the rapidity of detection and identification in laboratory of the toxicant chemical nature in incoming water of source. The results of the analysis shall give the answer to a question: whether it is possible to receive water of drinking quality.

Other important factors are the choice of suitable test organisms and the maintenance of comfortable conditions for their long-time keeping and functioning in the industrial BEWS.

10.2.1 Requirements to Organisms for Bioindication of Surface Water Quality

Requirements to test organisms for bioindication and bioassay of the environmental components, in general, are reported in numerous scientific studies (Zaitseva et al. 1994).

The requirements to test organisms in real-time BEWSs can be formulated as follows:

1. To use reference group of test organisms in which animals shall be genetically uniform individuals not only of one species, but also the same population (or micropopulations), which is cultivated and maintained in the same conditions in which biomonitoring is carried out. Also, selected animals shall be functionally healthy and their physiotypes shall provide likeness of sensitivity and tolerance, and also uniformity of responses to toxic treatment. It promotes high reproducibility of responses that is necessary for biotesting method standardization.
2. Test organisms shall have rather high level of their metabolism what promotes rapid responses to toxicant and, as a result, can provide a rapid water quality assessment.
3. It is desirable to use native (local) species, which are key species in studied biocenosis. It is possible to take also invasive species, which adapted to life in a new environmental condition, forming steady population.
4. The information arriving from the selected biosensor organism shall be read out

continuously or with such a frequency, that provides a reliable assessment of its functional state.

5. The organisms used shall be characterized by rather long life cycle, for example, several years.
6. Biosensor organisms shall have sensitivity to changes of physical–chemical factors of the environment, rather well studied from the point of view of functioning their vital systems (e.g. cardiac, respiratory, excretory systems and locomotor behavior), to be convenient for application of ecophysiological evaluation methods of the physiological state assessment status and to be suitable for non-invasive fixing measuring sensors on their bodies.
7. For more objective assessment of environment quality, it is desirable to use not one but several organisms of different taxonomic origin, which are characterized by a different level of sensitivity to toxicants. It will increase reliability of assessment of quality of environmental components and improve a testing scale for possible contaminants.

The necessity of choice of representatives of various species among specified classes and types (Decapoda and Mollusca) was caused by their difference in adaptive capacities and cardiac responses to disturbances (both chemical and physical modalities). It expanded a possibility of application of developed noninvasive method for the analysis of a physiological condition of animals and allowed to estimate water quality in various natural, laboratory and industrial conditions.

Mostly suitable organisms for the application in such monitoring systems are freshwater and marine bivalves and freshwater crayfish (Brown et al. 2004; Depledge and Galloway 2005; Füreder and Reynolds 2003; Reynolds and Souty-Grosset 2012; Kholodkevich 2007). Parameters of locomotor activity (valve movement of bivalves) and/or cardiac activity, for the both types of the invertebrates, are usually used. Significant variations in mentioned above parameters can indicate negative changes in ecological state (health) of an ecosystem the animals live in.

In the case of surface water quality control, in water supply stations in State Unitary Enterprises “Vodokanal of Saint-Petersburg” we are faced a problem of a very soft water of water source—the Neva River (the water containing not enough amount of calcium, magnesium and other substances for their well-being), only a few of the invertebrates can survive and function sustainably in such a condition for a long time. Besides, the water of the Neva River, as well as of the Ladoga Lake, from which it runs out, contains fewer amounts of phytoplankton and detritus that needs for the existence of these bivalve species. As a result, mussels as Dreissena cannot live in that water, and Unio and Anodonta do not exist normally in the Neva River water flow for a long time. For example, being exposed to the system, Anodonta exhibited abnormal patterns in their activity after 8 day of their keeping in industrial system conditions. The character of the valve movements is sharply changed, with the periods of shells opening that are replaced by the periods of fully closed ones. So, a mollusk’s normal functioning is appeared to be disrupted and it cannot be used as biosensor.

Therefore, it was decided to use other aquatic test organisms (bio-indicators), namely, representatives of crustaceans (Crustacea, Decapoda): crayfish *Astacus astacus* and *Astacus leptodactylus*. Both of these species are found in the rivers and lakes of the Russian North-West, in particular, in the basin of the Neva River. Comparative studies of these two species of crayfish have shown that *Astacus leptodactylus* are more suitable to be used as test organisms, as more adaptive (Cucerzis 1968; Holdich 2002). It is characterized by faster acclimation to the individual aquarium-keeping, rapid recovery after a short-term stress and high tolerance range to temperature changes. The simplicity of keeping crayfish in industrial conditions includes 1 per 3 days feeding and cleaning of the aquariums with animals.

In 1999 in SRCES RAS, an original fiber-optic method for recording cardiac activity of *Crustacea* (Decapoda) was developed (Fedotov et al. 2000). On the basis of the proposed method, the automatic system of non-invasive measurement of cardiac activity of invertebrate animals with a rigid external skeleton has been developed (Kholodkevich et al. 2007a, b, 2008, 2013).

Figure 10.1 presents a block-scheme for cardiac activity registration, signal transformation and automatic data processing in real time.

The infra-red light beam initially formed in the laser fiber-optic photoplethysmograph (FP) is transmitted to the animal by a thin optical fiber with a small sensor (weight less than 2 g) attached to the carapace, thus illuminating the heart area with a scattered light. The optical signal modulated by the heart of an animal contains information on cardiac contractile activity. After appropriate amplification and filtration in the FP, the analog signal is then transmitted to analog–digital converter (ADC), where it is converted to digital form by 14-bit 16-channel and then it is sent to the personal computer (PC) via USB port. As a result, of such measurements one obtains a photoplethysmogram, which can be further analyzed by various mathematical and statistical methods. An original software program, VarPulse® (Kholodkevich et al. 2008), automatically reads data from the ADC, determines the duration of each cardiac interval in real time (block 1) and then calculates a set of heart rhythm variability characteristics (block 2).

10.2.2 System for Industrial Biological Water Quality Monitoring—BioArgus-W

Since 2005 a System for Industrial Biological Water Quality Monitoring (BioArgus-W) based on this method to provide real-time monitoring of toxicity level changes at the Neva River water intakes has been operating at the St. Petersburg drinking Water Supply Stations (WSS) (Fig. 10.2). Up to the present, 10 of such automatic systems were set up at all 10 WSSs of St. Petersburg and have been used in industrial operation for more than 15 years.

Heart rate (HR) and the stress-index SI (Bayevsky 1988; Kholodkevich et al. 2008) were proposed as indicative parameters. To measure these physiological parameters continuously and regularly, a special flow 6-aquarium system was used with one adult male crayfish in each aquarium.

The following indicative parameters are used in the case of acute toxicity detection in controlled water, what leads further to production of an alarm signal:

$$\Delta HR - \text{heart rate change } (\%).$$

$$dHR/dt - \text{derivative of HR}.$$

$$SI = 1/\left(2CI_m * SD^2\right) - \text{stress - index},$$

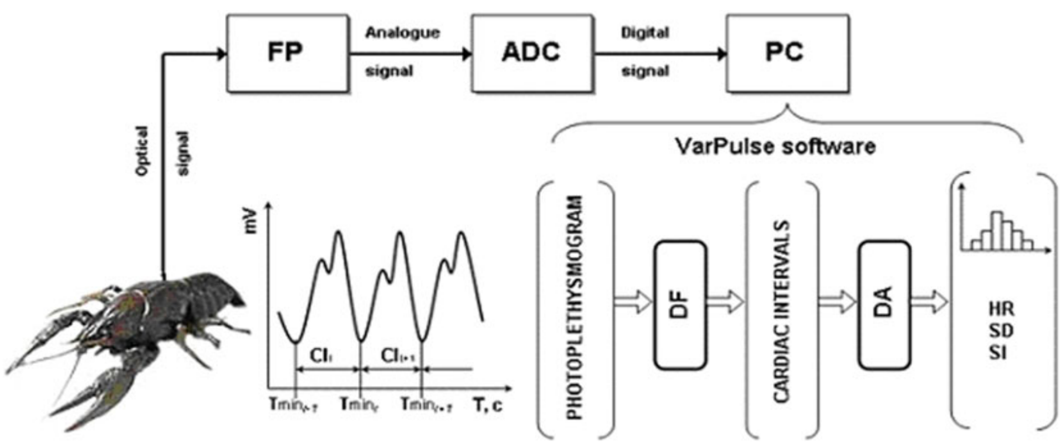

Fig. 10.1 FP—fiber-optic photoplethysmograph, ADC—analog-to-digital converter, PC—portable computer, CI—cardiac interval, DF—digital filter, DA—distribution analysis, HR—heart rate, SD—standard deviation, SI—stress index

Fig. 10.2 A picture of a System for Industrial Biological Water Quality Monitoring (BioArgus-W) set up at one of water intakes of St. Petersburg. The lightproof doors (usually closed) are opened for demonstration. 1–6—numbering of flowing aquariums with crayfish; 7—a flowing aquarium with a few fishes

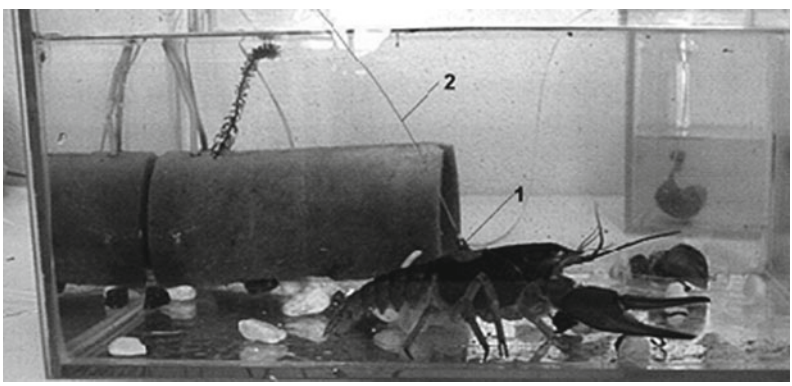

Fig. 10.3 A freshwater crayfish A*stacus leptodactylus* with attached fiber-optic sensor (1) and fiber-optic cable (2) Changes in the state of biological system caused by a long-term environmental stressor

where CI_m stands for mean cardiac interval which is related to HR as HR = $60/CI_m$, and SD—standard deviation.

An alarm signal is produced only if not less than four of the six crayfish and fish simultaneously show significant reactions.

Integral indicating qualitative measures of water toxicity level are formed as a "traffic lights" system. The suggested system for the production of "traffic lights" is as follows:

"the green"—the data is updated and in it is within the norm set limit, "the blue"—parameters are not updated or are in condition that definitely indicates that the channel or sensor are not in the ready to work position;

and "the red"—is produced in case of simultaneous transition of no less than 4 from 6 crayfish "on duty" from normal state to the disturbed state. In that case, the sharp and simultaneous increase of some of the mentioned above parameters: HR, SI and/or dHR/dt, can indicate possible toxicity of the incoming water. The later requires measurements for further detailed clarification of the origin and reasons of such an increase with support of water analysis in specialized laboratories.

Waterworks operation algorithm in case of toxic substances detection in the water at water supply stations:

– real-time detection of the toxic substance in the water of water supply facilities using bioelectronic system for permanent automatic bioindication of the water quality;
– automatic water sampling in fist lift pumping stations when a signal on the toxicological hazard in the water source is received;
– emergency delivery and analysis of the samples in the chemical and bacteriological laboratories of waterworks and authorized organizations to determine the origin and approximate concentration of toxic substances in the water of the first lift pumping station;
– water supply interruption from the first lift pumping station to the treatment facilities while simultaneous feeding powder sorbent into the wells at first lift pumping stations to remove toxic substances as well as making decision for the possibility to supply city from the reservoirs of treated water;
– water sampling and analysis of toxic substances in the chemical and bacteriological laboratories of waterworks and authorized organizations for the above-mentioned locations with 1 h periodicity for each sampling point;
– in case of negative result of the water samples analysis for the detected substance at least in two successive samples—the resumption of the water supply from the first intake of pumping station to the treatment facilities.

10.3 Typical Cardiac Responses of Crayfish *Astacus Leptodactylus* to Various Stressors

The factors causing a stress (stressor) induce similar biological reaction of an organism to a stress (Selje 1979). Stressor imposes requirement to change the organism's systems. This requirement is not specific and it consists of adaptation processes. In other words, except specific effect, all agents influencing organism cause as well the non-specific reaction following by the restore the normal (undisturbed) state.

In Fig. 10.4, the typical course of adaptation in organismal level is presented under influence of extreme factor of the environment.

The dotted circle in Fig. 10.4 indicates the alarm (arousal) reaction of the organism to disturbance, which serves as indicative point for the production of alarm signal in the suggested monitoring system.

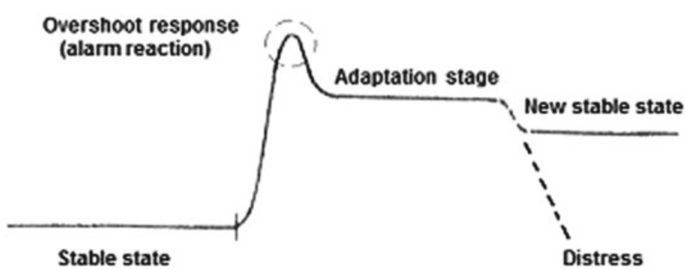

Fig. 10.4 Changes in the state of biological system caused by a long-term environmental stressor

Testing of crayfish in case of "suspension test" was performed as lifting of crayfish over the bottom of the tank (by the optical cable attached to its carapace), but within a water column. At the same time, the contact of tarsus of legs (proximal part of leg) with substrate was lost.

Such a test has been used by us as functional loading. Loss of contact with an aquarium bottom makes crayfish move legs, trying to find a substrate contact. Typical response of crayfish in a good condition in such suspended position is expressed in rapid and sharp increase in HR and maintenance of this level along all time of suspended state (Kuznetsova 2015). Such reaction was shown by all selected crayfish *Astacus leptodactylus* before their usage in toxic treatment (Fig. 10.5a, b) (Kuklina et al. 2014).

To investigate different stressors action, the crayfish were subjected to acute influence of the following stress factors: handling, oil exposure, biocide chloramine-T and the addition of some military agent. It appears that one of the most stressful actions on crayfish is handling (taking crayfish in hands by experimenter) (Kuznetsova et al. 2010).

Figures 10.5 and 10.6 illustrate typical cardiac responses to chosen model stressors in *Astacus leptodactylus*. During experimentation (Fig. 10.6) on simulation of oil pollution the oil emulsion 33 mg/l was added to the tank with

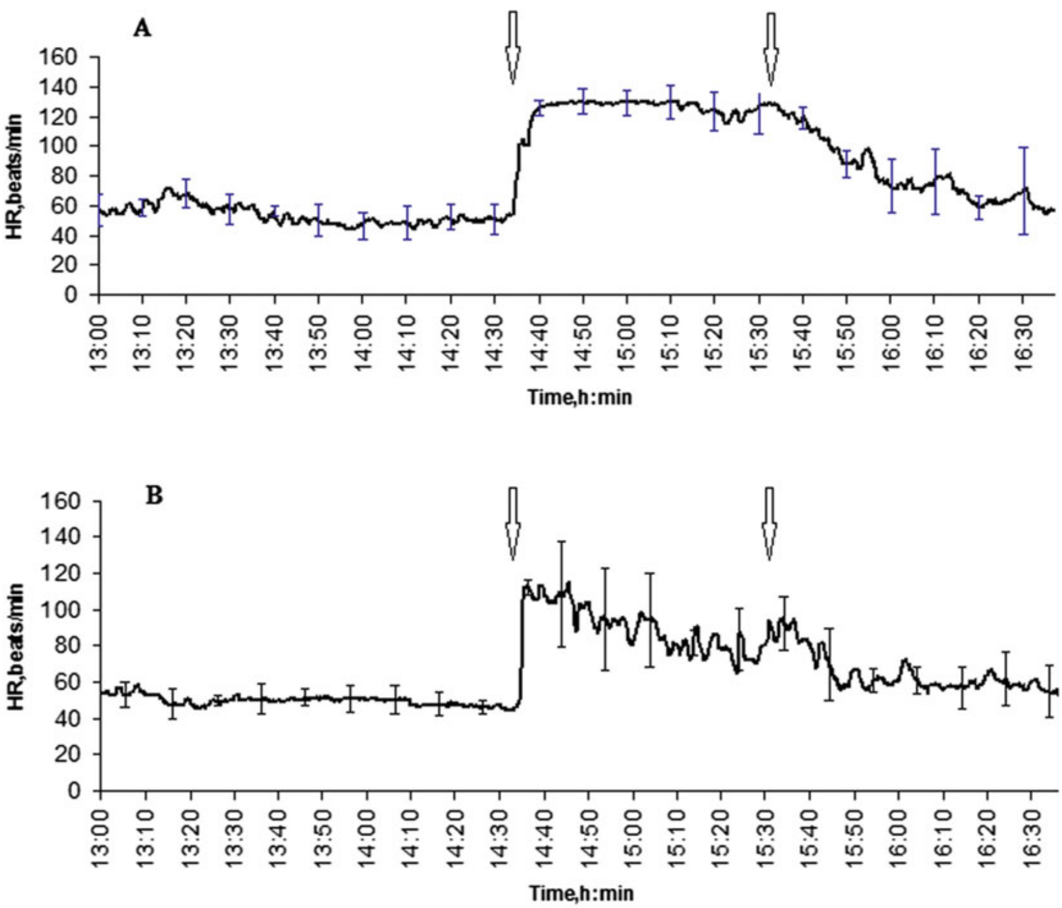

Fig. 10.5 Testing of crayfish before (**a**) and after (**b**) a 1-day exposure in water solution of chloramine 50 mg/l (Kuklina et al. 2014)

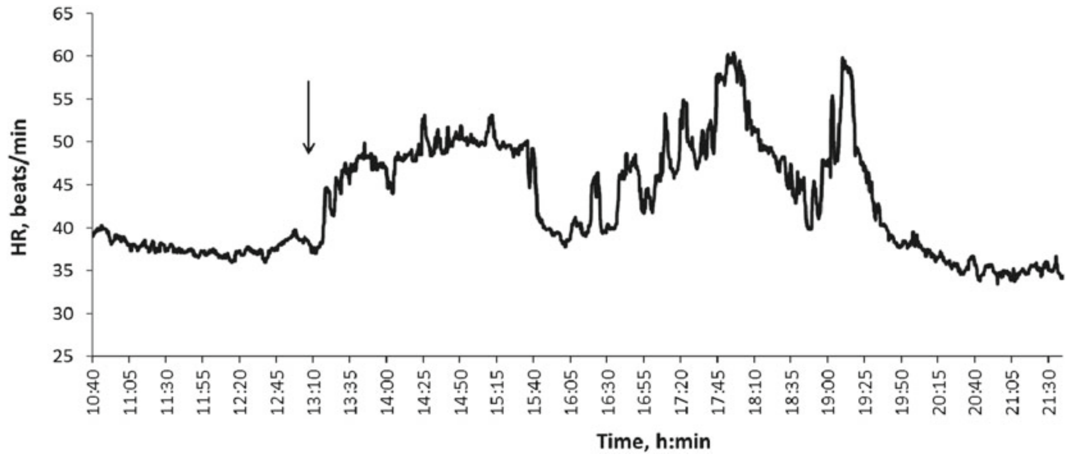

Fig. 10.6 Chemical stress in crayfish exposed to oil emulsion. Effect of 0.033% (33 mg/l) of crude oil emulsion in water on HR of crayfish. The arrow indicates the moment oil addition. Axis Y corresponds to HR (beats/min); axis X—real time of experimentation (h: min). Typical response to toxic treatment—the presence of the second wave in fluctuations of HR as an indicative sign of toxic stress

crayfish (Kholodkevich et al. 2012). The water pumping system was used for mixing oil suspension in the tank. As in the previous experiment, the HR shows evident increase in 2–3 min after oil addition. The period of initial reaction is short, 10–12 min. Such a reaction presents the primary response to disturbance caused by a chemical. Second HR increase was observed later as a typical toxic reaction.

In Fig. 10.7, the response of crayfish to 25 mg/l of chloramine-T is shown. The agent is often used as biocide in industrial use and in aquacultural farms.

The effect of chloramine-T is expressed in a sharp increase of the HR in 2–3 min, temporary decrease of the HR after 5–7 min of alarm reaction, followed by unstable cardiac rhythm with increased values of the HR, characterizing cardiac response to toxic effect.

Figure 10.8 demonstrates the response of crayfish to the addition of one of a military chemical agent inhibiting cholinesterase activity.

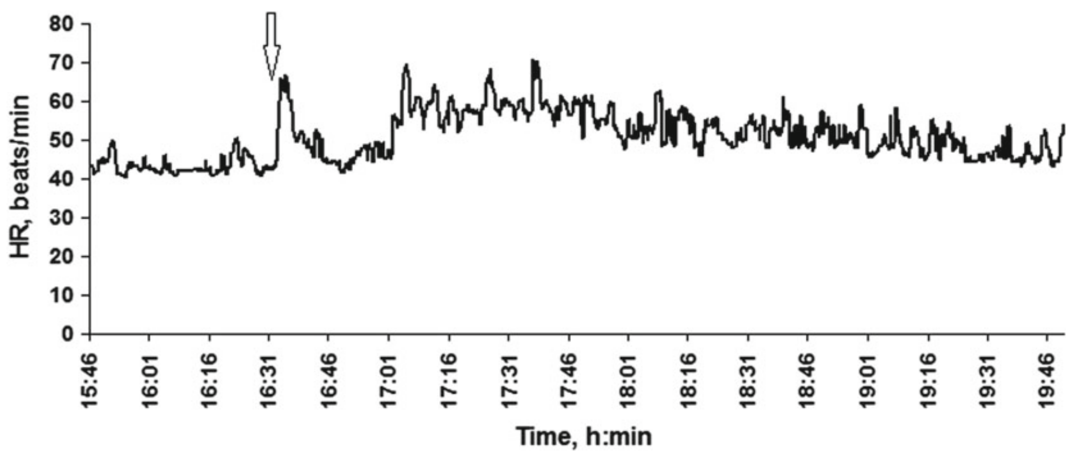

Fig. 10.7 HR changes in the presence of 25 mg/l chloramine-T in water. The arrow indicates the moment of agent addition

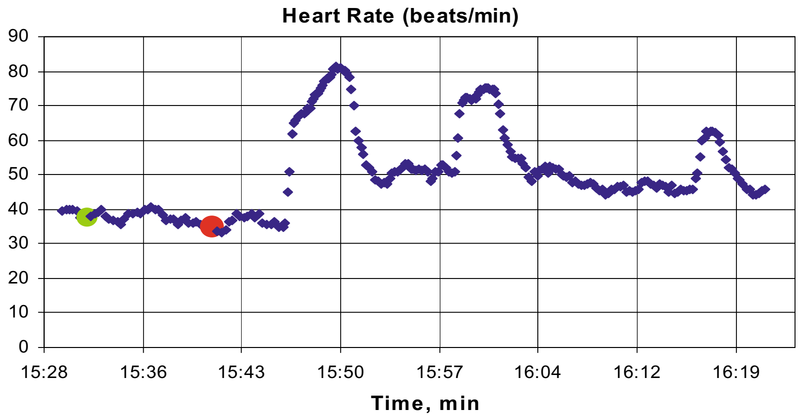

Fig. 10.8 Stress induced by chemical agent evoking inhibition of cholinesterase activity in crayfish (modified from Kholodkevich et al. 2008). Green dot—the addition of control water to the tank with crayfish, red dot—addition of chemical agent

Concentration of the agent corresponded to LC_{50}. The first spot on the graph indicates the control addition (green spot) of natural water and the second one (red spot) the addition of the agent. One may see a fast reaction of both HR and SI; the latent period is approximately 3–4 min. It is visible that at first chemosensory reaction of crayfish, primary by the origin, is alarm response to the presence in the environment of toxic agent. Developing, the response triggers the cardiac response—short-term increase in the HR. Later, it is followed by organismal reaction on toxicant, which is expressed in fluctuations in the HR and at manifestation of the steady increased HR values.

Figure 10.9 shows a typical example of BioArgus-W operation when a "human factor" initiated the danger alarm signal in water intake, although it was caused by occasional chlorinated water running through the aquarium with animals. Figure ure8 clarifies that "on duty" crayfish showed almost synchronic reaction to the staff action error.

As a result, in one minute, the alarm signal caused by chlorine toxicity passed to the control office. In comparison, the fish monitoring system produced the alarm signal in only 6 h when the fishes died.

10.4 Experience of Further Development and Operation of Bioelectronic System BioArgus-W for Monitoring of Toxicity of the Incoming Water on Intakes of Water Supply Stations

The BioArgus-W is a science-based, multi-parameter, multi-level biomonitoring system comprising several building blocks. Even a failure in one of them can reduce partly or entirely a whole system efficiency. The main distinctive features of the BioArgus-W system are test organisms (crayfish and fish) used as the sensors. Their reliable interaction with the other system components is a complicated task from the viewpoint of system efficiency. Development and operating stages have revealed the false alarm problem of the system. False alarms are not related to the water quality changes that are dangerous for municipal water supply and treatment technologies. They are typically caused by the rapid changes in physiological condition of test organisms due to chemical compound of water or stressful industrial factors like noise, vibration, temperature and light. To prevent

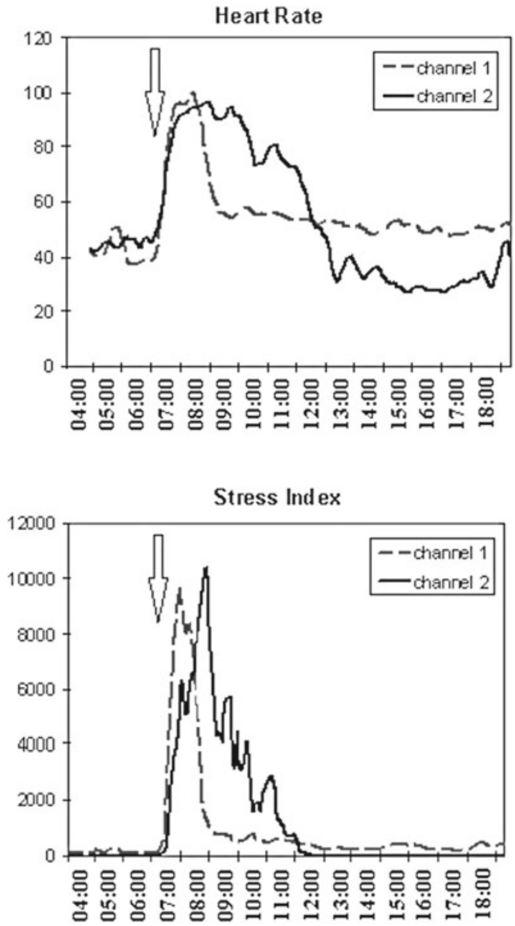

Fig. 10.9 An example of cardiac response of crayfish when a "human factor" initiated an alarm signal. Channels 1 and 2—HR trends and SI in crayfish 1 and crayfish 2, respectively

some false alarms of the potential water toxicity, the BioArgus-W is equipped with the water quality monitoring module to measure some physical–chemical parameters of water. The module provides control for selected integral physical–chemical parameters of incoming water as well as noise and vibration with a specially designed decision-making algorithm to block alarm signals.

For each crayfish biomarker of effect and exposure, the threshold level is adjusted to produce alarm signal if exceeded the values considered to be the reference values for crayfish cardiac activity. To set up a threshold value, it is necessary to consider the following assumption. High threshold levels decrease system sensitivity, as the animal stress has to be rather high to exceed the threshold for alarm signal. On the contrary, low threshold levels induce alarm signals for any insignificant excitation of the biosensor even not related to the dangerous change of water quality. Thus, there is a problem to determine optimal threshold values for measuring parameters and develop algorithms for information processing: on the one hand, sensitivity of the system has to be sufficient to identify dangerous pollution, but, the frequency of false alarms has to be minimal. Operating the biomonitoring stations and saved-up database analysis have allowed us to approach the solution of this problem in the following way.

HR analysis of each test organisms is made independently. For each biomarker of the animal physiological condition, the threshold level (L_B) is set up to specify a stress state. An alarm signal of possible pollution arises in case when test organisms change their state to stress during rather short operating time (T_o). T_o is set up in the settings of the BioArgus-W software. The main biomarkers for the system to make decision about stress state are SI and dHR:

$$\mathrm{dHR(t)} = \frac{\mathrm{HR(t)} - \mathrm{HR(t - T_d)}}{\mathrm{HR(t - T_d)}} \cdot 100\% \quad (10.1)$$

where HR(t)—heart rate for the time *t*; T_d—delay time.

Thus, the decision-making procedure to alarm emergency includes three parameters: L_B, T_o and T_d. The analysis of influence of each of these parameters on biomonitoring station sensitivity showed the following (Kinebas et al. 2012):

1. Decrease in L_B involves increase in station sensitivity, as in this case a smaller stressful impact on the bioindicator is necessary for corresponding parameter to exceed L_B. At the same time, the system reliability decreases as the probability of false alarms increases in

result of natural fluctuations of the corresponding parameter exceeding L_B caused by changes in a physiological state.

2. Increase in T_o, on the one hand, improves reliability for bioindicators reaction detection as the temporary difference of responses for two test organisms can exceed T_o, and on the other hand, the probability of false alarms increases as two independent transitions of bioindicators to the excited state (especially at low values L_B) can lead to emergency alarms. The similar can be stated for parameter T_d. When increased T_d, both the fast and slow processes leading to increase of HR will be taking into account, i.e. reliability to detect the transition to stress increase. However, such slow transitions, most likely, are connected with natural changes of bioindicators physiological state, and not associated with the toxicity. In this case, the temporary delay between the onset of toxic deposition and alarm in the BioArgus-W system increases.

Based on the data analysis for some previous years for each of the main parametrs (SI and dHR), three values (1000, 5000 and 10,000 s^{-3} for SI and 50, 75 and 100% for dHR) were chosen as a threshold levels. Besides it, the dHR was calculated for three values of T_d: 2, 10 and 30 min (Kinebas et al. 2012).

In processing data on daily cardiac activity of bioindicators, irregularly excesses of threshold level L_B were detected. Thus, mentioned values do not exceed L_B within a day at all, or exceed it from time to time. If the dHR values 50, 75 and 100% were chosen as a threshold levels L_B, the average periods of false alarms (T_e) for a 24-hour interval were calculated for three values of T_d: 2, 10 and 30 minutes (Kinebas et al. 2012), based on the BioArgus-W crayfish HR data analysis for the time of conventional water quality and the false alarms probability per day (T_e/1440 min) were calculated. So, if L_B = 100% − T_e = 9, 4 and 2 min (for T_d = 30, 10 and 2 min), if L_B = 75% − T_e = 18, 8 and 3 min (for T_d= 30, 10 and 2 min) and if L_B = 50% − T_e = 43, 22 and 4 min (for T_d = 30, 10 and 2 min).

Having calculated for each of the installed system BioArgus-W channel, the probability of an event when parameters exceeds L_B levels within a day, and also average values for T_e, it is possible to decrease the probability of false alarm generation. P(A) could be calculated by the followed formula:

$$P(A) = P(A/B) \cdot P(B), \qquad (10.2)$$

where P(A)—probability of false alarms; P(B)—probability of an event when a biomarker excesses L_B level within a day; P(A|B)—probability of a false alarm given event B has occurred.

The probability of P(A|B) is a ratio of time T_e (in minutes), when HR exceeds L_B and a total minutes in one day (1440 min). So, for two bioindicator $P_2(2)$ = 0.030−0.015 (T_e = 40–20 min, if L_B = 50% T_d = 30–10 min) and false alarm may take place 1 time a 30 day.

Results of the toxicological experiments showed that the response times of biosensors to high concentration of toxic substance were from 1 till 5–10 min, as at Fig. 8 (Kholodkevich et al. 2008; Kinebas et al. 2012) and the typical dHR values are 100–150%. Considering these results, it is possible to recommend the values of the BioArgus-W setup parameters to be chosen by the following algorithm:

1. Taking into account technological, regulation and economic requirements, the maximum operating time of station (i.e. a temporary delay between the beginning of influence and the system alarm – $T_{o.max}$ is chosen as well as the optimal (or maximum) number of the predicted false alarms per year. (Usually To = 10–20 min and T_d = 10 min as a biosensor response time is less, than 10 min and the stress- induced HR high value is conserved for more, then 10 min after the primary rise).
2. It was shown in Karmazinov et al. (2007) that the values of the corresponding parameters (L_B, T_o for SI and L_B, T_o, T_d for dHR) which correspond to the required number of false alarms per year with the assumption: $T_o < T_{o.max}$.
3. The minimum L_B values and the maximum values of parameters T_o and T_d have to be

chosen as providing the most sensitive detection of stress transition for test animals. But it lead to the maximal probability of false alarms (usually L_B = 50% is optimal).

The most effective way to decrease the probability of false alarms is to increase the number of crayfish-biosensors used in the water quality assessment.

The probabilistic assessment of false alarms was obtained for N crayfish in the case, when M of them synchronously (within T_o) alarm a potential danger of pollution.

Considering p as the alarm probability for one crayfish as a response to water quality change, the alarm probability $P_N(M)$ for whole system for the fixed N and M values is described by a formula:

$$P_N(M) = \sum_{k=M}^{N} C_N^k p^k (1-p)^{N-k} \tag{10.3}$$

As the probability p depends on the water quality changes, and also considering that detection of this influence has to be rather reliable, it is possible to consider only those changes of water quality (high toxicity), for which $p > 0.5$. If the N = 6 and M = 4 the $P_6(4) > P_4(3)$, when $p > 0.4$. From the above, it was established that the high sensitivity of system is high at N = 6 and M = 4. But the false alarm probability of biomonitoring system is $P_6(4)$ = 0.0001, i.e. is the lowest one (Kinebas et al. 2012), compared with the $P_2(2)$ = 0.03.

The previous experiments have shown that only healthy animals, characterized by the emotionally steady state, are to be selected as bioindicators. Therefore, healthy mature males of a certain size without visible injuries of a carapace and legs are selected for the BioArgus-W system use. The crayfish adaptation for aquarium keeping (to reach typical for a steady rest state of crayfish to the normal level: 35–50 beats/min at the 20–22 °C) is to be done. It usually takes from 0.5 to 1 h for healthy animals to adapt for industrial noise in place of installation.

Our experience shows that the content of the total protein in hemolymph for healthy crayfish has to be more than 20 mg/ml (Kuznetsova et al. 2010). Crayfish with low values are in unsatisfactory physiological condition (Kuznetsova et al. 2010; Sladkova and Kholodkevich 2011). To investigate deterioration of physiological state of crayfish, one could perform additional "suspension test" (Kuznetsova 2015; Sladkova et al. 2015). In sick or weakened crayfish with the total protein content is less than 10 mg/ml, the suspension test reveals a deviation of HR more than 20%. Cardiac rhythm of sick or weakened crayfish is characterized by the expressed arrhythmia and unstable HR, and SI does not exceed 1000 s^{-3}. Such crayfish are to be rejected at a stage of primary selection.

When selecting animals by means of testing procedures for use in the BioArgus-W system, no more than 5–10% of crayfish have appeared to be suitable for usage. Operating experience with the BioArgus-W system showed that the reference groups of crayfish selected in such a way, along with a correct feeding regime and aquarium maintenance, at least, within a year, can keep the normal functional state of crayfish suitable for their use as test organisms (except a molting period). Regular and successful molting in crayfish is also a good indicator of crayfish normal functioning.

One of the important problems is to be solved during the development and operation of any complex technical systems is how to control the reliability of its individual units/channels and the system as a whole. The BioArgus-W operating has revealed the need for developing a system of continuous automated control of functional state (health) of crayfish. Weakened or sick animals cannot adequately respond to the change in their habitat quality.

Under natural conditions, crayfish show the near diurnal (circadian) rhythm in HR variation associated with higher locomotor and feeding activity in nighttime. Figure 10.9 shows an example of typical dynamics of HR for crayfish from reference group within 3 weeks of functioning as a part of the BioArgus-W station. Night-time increase of physical activity of crayfish is followed by the increase of HR (Styrishave et al. 2007; Kuznetsova et al. 2010;

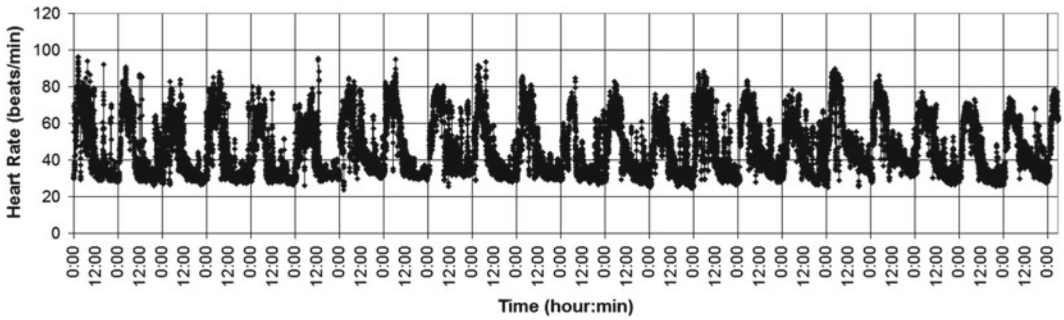

Fig. 10.10 A typical example of the 3-week HR dynamics of a healthy crayfish

Udalova et al. 2009). Numerous studies of various aquatic animal species indicate the relationship between their functional state and the presence of circadian activity (Bojsen et al. 1998; Udalova et al. 2009; Kuznetsova et al. 2010; Sladkova et al. 2016). Our studies on crayfish confirmed existence of such relationship and also revealed differences in responses of crayfish with well-expressed (Fig. 10.10) and absence of the circadian rhythms to the external influences (Fedotov et al. 2002; Udalova et al. 2009; Kuznetsova et al. 2010). In particular, it was shown that circadian HR rhythms can be disturbed (Fig. 10.11) in crayfish with deteriorated physiological state as a result of prenosological state (early signs of disease) and/or during premolt period.

Well-expressed circadian HR rhythm is typical for the species with nocturnal activity, as well as oxygen consumption and other periodical physiological functions of an organism, testifies to the steady adaptation of an animal to its habitat. This criterion can also be used for assessment of physiological condition and thus has to be considered when using animals as test organisms in biomonitoring systems (Udalova et al. 2009; Kuznetsova et al. 2010; Kuznetsova 2013).

The method for automatic registration of a circadian (near diurnal) rhythm of HR in crayfish used in the BioArgus-W system (Ivanov et al. 2012) was developed as a solution for this crayfish testing.

For practical realization of the above criterion, the BioArgus-W system was equipped with the artificial illumination regime (16L:8D). This module uses the timer to control luminescent lamps above aquariums with crayfish for providing a stable day–night regime. Besides, the BioArgus-W rack in equipped with additional shading covering to isolate crayfish from external light and protect them against undesirable mechanical influences.

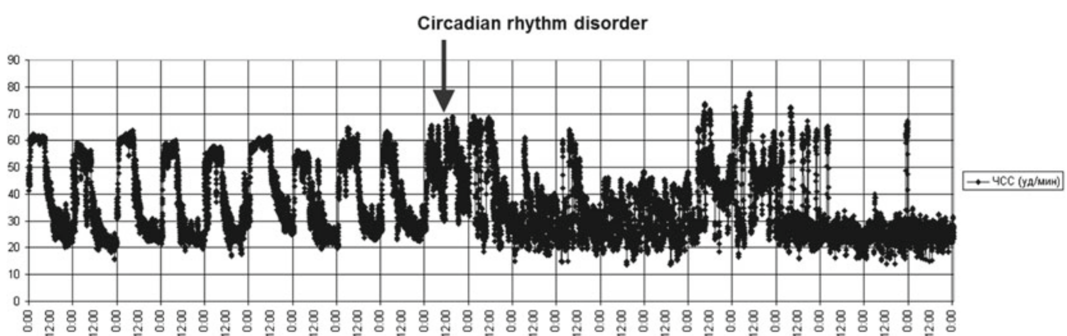

Fig. 10.11 A typical example of disorder in circadian rhythm in HR during transition of crayfish from healthy to sick state (12 days before death after circadian rhythm disorder)

Scheduled maintenance of a modern BioArgus-W system of water source toxicity monitoring at water supply station of St. Petersburg is carried out twice a week.

Existence of automatic module of the day-night light regime together with the additional shading covering gave us a chance to develop algorithm for automatic analysis of circadian HR rhythms. A new mathematical approach and algorithm for the self-diagnosis to use for BioArgus-W animals were further developed including VarPulse® software with a new self-diagnosis module (Ivanov et al. 2012). Such modernization of the system utilizing a real-time analysis of circadian rhythms in crayfish has significantly increased the accuracy of the total toxicity estimation at the water intakes of water supply stations along with a significant simplification of its operation (Ivanov et al. 2012; Kurakin et al. 2015).

For ensuring ecological safety of drinking water supply of the population, the following recommendation complex was developed (Makhnev et al. 2006):

- Regulations of work of waterworks of St. Petersburg in the case of toxic substances detection in water.
- System of ensuring safe water supply in the case of toxic substances detection in water of water intake.

10.5 The Bioelectronic System for the Control of Toxicological Safety of Biologically Treated Effluents Dumped by South-West Waste Treatment Plant (SWWTP) SUE Vodokanal of St. Petersburg into the Neva Bay

SWWTP discharges biologically treated effluent (BTE) into the Neva Bay, which refers to commercial fishing waters of the I category. That imposes extra requirements to the city wastewater treatment plants operation; in particular, to production monitoring methods and the company self-inspection, as the effluents discharged into natural water bodies. In the SWWTP, crayfish could serve for the chronic effects diagnostics as a kind of prognostic assessment of the environment quality for the biota. SUE “Vodokanal of St. Petersburg” jointly with the Saint-Petersburg Scientific Research Centre for Ecological Safety Russian Academy of Sciences has setup biomonitoring system for Wastewaters (BioArgus-WW) to provide the function of the BEWS for quality control of biologically treated effluents.

The main purpose of such system development is a real-time monitoring of toxicological safety of BTE discharged by SWWTP for the Neva Bay aquatic organisms.

The practical significance of this biomonitoring system based on BioArgus-WW is the possibility of its application at SWWTP:

- as the information basis of an automated system for continuous displaying objective data on safety of BTE discharged into the Neva Bay (for example, via Internet) to interested state authorities and the public;
- as an efficient information and measuring system for preparing decision-making on wastewater treatment process;
- as a tool for the accumulation and storage of objective data showing how to improve the existing regulatory requirements to BTE quality both in terms of the nomenclature and contaminant level.

The structure and main principles of the functioning of the automatic biomonitoring system BioArgus-WW are the similar to those discussed above the BioArgus-W system, but has some differences in the species of crayfish used as test organisms.

BioArgus-WW uses six male crayfish and two to three fishes (carassius). The quality of treated effluent at SWWTP is checked by the fish health condition and crayfish heartbeat. The crayfish live in aquaria with treated effluents flows through.

If the quality of water where the crayfish live greatly deteriorates, BioArgus-WW generates an alarm (red) signal, which is transferred to the SWWTP's controller's office via the computer network.

Since 2010, the crayfish of *Astacus leptodactylus* (Esch., 1823) and Australian crayfish *Cherax quadricarinatus* (Von Martens, 1868) at SWWTP control the quality of treated effluents. High sensitivity of both crayfish species to xenobiotics, in particular, to heavy metals (Cu, Zn) and pesticides was mentioned in some ecotoxicology studies (Anderson et al. 1978, Nakayama et al. 2010).

The temperature of biologically treated effluent (BTE) at South-West WWTP fluctuates in the range of 15–32 °C throughout the year that stands specific requirements to the bioindicator species. It is known (Holdich 2002) that for *Astacus leptodactylus* (local for the Neva River), the optimal temperature for the best growth is 15–22 °C.

Given the above data on sewage water temperature and the well-known resistibility of thermophilic (optimal temperature 25–30 ºC) Australian crayfish to higher nitrate concentrations in water, we have selected this species as test organisms for BTE quality monitoring in summer (Melnik et al. 2013).

In BioArgus-WW the Continuous Ecological Monitoring Automatic System (CEMAS-3), which records and transmits the real-time data on physical–chemical characteristics of water in aquaria with test organisms to the SWWTP control office of is also included. The following parameters are recorded and transmitted:

- temperature of water,
- electrical conduction of water,
- water pH,
- ammonia nitrogen concentration in water,
- nitrate ions concentration in water,
- chloride ions concentration in water,
- water optical density, wavelength 254 nm,
- water turbidity (FTU units).

Functional purpose of CEMAS of BioArgus-WW is the same as in BioArgus-W in general. Analysis of crayfish stress and/or fish death is performed in comparison with the real-time information from CEMAS.

Integral qualitative assessment for the water toxicity is formed as a "traffic lights" system: the red—"danger", the blue—"technical errors", and the green—"no danger". This procedure is performed automatically within the software "Data Admin" on the basis of signals from individual animals (crayfish and fish) taking into account the CEMAS data.

The BioArgus-WW system was installed at SWWTP 6 years ago as the substantial addition to the conventional laboratory control regulated by the state supervisory authorities. The system enables to correct the SWWTP treatment stages. The most important feature of the BioArgus-WW is that it enables to control synergistic result of simultaneous exposure of a number of water-dissolved toxicants affecting aquatic organisms in real time. Only living organisms can simultaneously assess water toxicity and this is a difference from the physical–chemical water quality analysis.

10.6 Conclusion

The developed innovative system and technology of biological monitoring of water quality is unique from the point of view both scientific and technical decisions.

The measuring system allows carrying out a long-term real-time biomonitoring of incoming surface water quality and quality of biologically treated wastewaters on the basis of the analysis of heart rate variability in the freshwater crayfish.

The automatic system of bioindication can be used as BEWS for ensuring ecological safety of drinking water supply of the population.

BioArgus-WW, in addition to monitoring the acute toxicity of BTE, can also be used to monitor the chronic impact of biologically treated wastewater on aquatic organisms. Bioelectronic system BioArgus-WW can be used, in particular, as information basis for automatic system of continuous demonstration (for example, by means of a special board and/or on the Internet) to the interested public services and the population of the most objective information on ecological safety of BTE as it completely answers criterion of departmental "independence" of monitoring of BTE quality.

The study was partly performed using equipment of Research Center for Environmental Safety Observatory of Saint-Petersburg State University.

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11 Water in Cultural Perspective with Special Reference to Islam

Ravi S. Singh and Sarah Ahmad

Abstract

Water is regarded as the ultimate source of life in all the world religions including Hinduism, Christianity, Islam, Judaism, and Zoroastrianism. Apart from being considered as a major source of survival, the religious perspectives on the water are diverse and unique and play an important part in religious traditions and rituals. The most common characteristic of water to be found common in all religions is the source of purity and is reflected in most of the Hindu rituals as well as Baptism (Christianity), ablution (Islam), Mikvah (Judaism). Majority of the known works on the water are from economic and technological perspectives, whereas fundamentally it is the culture which defines water usage. The present chapter provides a run-through of water symbolism of world religions followed by focusing on the various facets of water in Islam. It explains the numerous themes of water, which prevail in the Islamic world on the basis of the two major relatable sources: the holy Quran and the hadiths.

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Keywords

Water · Symbolism · Religion · Islam

11.1 Introduction

Water is an essential element for the survival of living creatures on the globe. Our dependency on the water can be seen from the daily chores to economic activities such as agriculture, industries, or public health, safety, and recreation (Singh 2015). In almost every religion, water signifies and acts as a symbol of purity. It is used for cleansing and purification of the physical and spiritual bodies. In Islam as well, we see the relevance of water in various perspectives. Water is referred to as a gift from the almighty and as a source of blessing which should be appreciated and used sustainably. The Quran which is the holy scripture for Muslims and hadiths, which are the records of Prophet Muhammad (the founder and the last Prophet in Islam) are the two reliable sources for Muslims all over the world. The Quran reminds the significance of water, as a sign of mercy for living creatures, its significance can be clearly seen as it has been mentioned in the text 63 times. The Quran and hadiths refer to various facets of water from the biological world dealing with water being an important element as the source of life and food for various living

B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_11

creatures, they also contain description about the water cycle and water stratification, classification of water as pure, salty and bitter, water as a form of charity, relevance in pilgrimage as well as water conservation.

This chapter aims to outline different roles of water in the Islamic teachings and its applicability in today's world for instance, in water conservation. Following the overview of the relevance of water in different religions, the following sections provide the conceptual account of the place of water in Islam based on Quranic verses and hadiths. The hadiths have been retrieved from the website (sunnah.com) which has a multilingual database of the hadiths for non-Arabic speakers.

11.2 Religious Use of Water and Symbolism

In the words of Eliade (1958, p. 188) "Water symbolizes the whole of potentiality; it is *fons et origo*, the source of all possible existence. Water thou art the source of all things and of all existence! Says one Indian text, summing up the long Vedic tradition." Every religion has an association with water, or it has a central role to play in it. Water is used in the ritual practices, some water designated as sacred is used to treat the ailments through its miraculous properties, it also holds the notion of washing away the sins, purifying the soul and cleansing the body, and designated as an important element of life and its continuity. For different faiths and cultures, water inherits different roles and purposes, which will become clearer in the following discussion.

11.2.1 Hinduism

Water holds a prominent role in Hinduism, which is known to be the oldest religion of the world dating back to 5000–6000 BC. According to Singh (1994, p. 210) "In ancient Hindu mythology (about 800 BCE) water is described as the foundation of the whole world, the basis for life and the elixir of immortality… Metaphorically and metaphysically the ancient mythologies refer to water as the container of life, strength, and eternity. More commonly water is perceived as a purifying medium. However, to reach the source and receive the merit of living water involves a series of consecrations, rituals, and religious activities like a pilgrimage and sacred baths." We find a strong association of Hindu religious sites with water. In the Hindu religious beliefs, all the river bodies are revered as pure and have the spiritual power of cleansing. However, there are few rivers designated with special status such as Ganges, Yamuna, Kaveri, Sarasvati, Narmada, Godavari. The Ganges is the sacred of all attract millions of devotees throughout the year from all the parts of the country and abroad. The water of river Ganga is revered as the holiest water for Hindus and is used on several occasions because of its sacrality. The rituals associated with the poojas (prayers) involve the use of water such as the *Tarpana* (a gesture of pleasing the Gods by pouring the water with hands). Water also holds an important significance in death. Manikarnika ghat which is "mythologically known as "the great cremation ground" situated in the banks of river Ganga in Varanasi (India) is one of the most important cremation grounds for Hindus (Singh 1994, p. 215). One of the major pilgrimages and festivals in Hinduism "the Kumbh Mela" invites millions of adherents in every 12 years. It is marked as one of the largest gatherings of people at a time on the globe.

11.2.2 Christianity

In Christianity, we see water as a "sign of God's favor and goodness" (Flemming 2008, p. 6). Fletcher (2018, p. 1) states "the ancient Israelites and early Christians understood water's value-there are at least ten words for rain in biblical Hebrew, eight for cloud, and numerous terms for springs, wells, cisterns, and aqueducts. The people of the ancient Near East developed and depended on these technologies for collecting as much water as possible: wells, cisterns for rainwater, tunnels that allowed access to springs in wartime, aqueducts to bring water into the cities, and terrace farming to maximize the benefits of rainfall on hilly areas." The relevance of water still holds a strong value among Christians. Indicating the significance of water in Christianity Fletcher (2018) identifies different themes on the water which the bible represents such as the origin of life, water as a sign of compassion, purification, and restoration. The dependency on the water can be divided into physical sense and spiritual sense. While talking about spiritual sense, the prominent role of water in Christianity is seen in the tradition of baptism. Finneran (2009, p. 168) mentions "Baptism is one of the most important Christian rites, deriving directly from Jesus' own immersion in the River Jordan, itself, at the simplest level, a rite that confers life membership of a religious group." In the water baptism ritual, the person is partially or fully immersed underwater, which signifies the official admission of that person into the fellowship of the church. Thus, in the context of purification water holds an important value in Christianity.

11.2.3 Judaism

In Judaism, water symbolizes life. It represents the primordial element of the world. In Judaism as well, we see water playing an important part in religious rituals. Jewish lives are associated with an important ritual of water immersion known as Mikvah. Mikvah or Mikveh is a Hebrew word meaning "collection" or "gathering" which has a pool-like structure having clean and pure water in which a person takes immersion to spiritually clean themselves.

There are specific rules that need to be followed that designates a pool as Mikvah such as the water should be clean and not be discolored, and a mix of natural sources of water is essential such as rainwater, melted snow or spring water. The depth of Mikvah should be enough to immerse the entire body. The ritual is usually performed by the women on various occasions such as after the end of each menstrual cycle, before getting married, before giving birth or following the birth. Men go to Mikvah as well, on various occasions such as illness or divorce.

11.2.4 Zoroastrianism

Zoroastrianism is one of the ancient religions on the globe being originated from Iran. The followers of this religion are considerably low compared with other ancient religions. Albeit, "Considering the small number of followers of this particular religion, the impact that it has made on the world is relatively large" (Varte 2017, p. 38). In mostly all religions water signifies as the primary purifying agent. In the case of Zoroastrianism water is looked from a different perspective. Oestigaard (2005, pp. 35–36) argues "Zoroastrianism sees water as a secondary purifying agent. It is possible to use only after ablutions have been performed with unconsecrated bull's urine. The use of water to wash away dirt and impurities is seen as a heinous sin because then water is exposed to demonic impurities (Choksy 1989:11). Consequently, nothing impure is allowed to be in contact with a natural source of water such as a lake, stream, or river. If anything ritually unclean was to be washed, water should be drawn off for this purpose, and even then, this was not to be used directly, but the impure objects should first be cleaned with cattle-urine, and then dried with sand or in sunlight before water was allowed to touch it for the final washing (Boyce 1979:44)." Thus, polluting the water bodies is considered a major sin, and the punishments for the same are severe (Varte 2017).

11.3 The Relevance of Water in Islam

The presence or absence of resources shapes the culture and society. The Islamic teachings reflected by verses of the Quran and hadiths provide an impression of the desert setting. Thus, the absence of water and its value are engraved in the religion. And if we look closely, we find several themes that deal with water rituals and symbols.

11.3.1 Water as a Source of Life and Food for Living Beings

Every living entity is made up of water or has a major proportion of water in their body. Although it is now after the development of modern science, we are known to this fact. However, 1440 years ago people living in the scarce water region of Saudi Arabia would not have thought about it in the same way. However, the Quran provides an ample amount of verses, which deals with water being the major element of life creation:

> God created every living creature from water. Some of them crawl on their bellies, and some walk on two feet, and others walk on four. God creates whatever He wills. God is Capable of everything (The Quran, 24.45).
>
> Do the disbelievers not see that the heavens and the earth were one mass, and We tore them apart? And We made from water every living thing. Will they not believe? (The Quran, 21.30).
>
> And it is He who, from fluid, created the human being. Then He made relationships through marriage and mating. Your Lord is Omnipotent (The Quran, 25.54).

Thus, the Quran signifies the origin of every creature on earth with water. The Quranic verses also give an account of the importance of water for the survival of living creatures. It talks about water as an important element for the development of plants and crops, which is necessary for the human and animal survival.

Considering the following verses, one may see the relevance of water in the holy book:

> Do they not see how We conduct the water to a dry land, and with it We produce vegetation, from which their livestock eat, and themselves? Do they not see? (The Quran, 32.27).
>
> Have you not seen that God sends down water from the sky? With it We produce fruits of various colors. And in the mountains are streaks of white and red, varying in their hue, and pitch-black (The Quran, 35.27).
>
> And We brought down from the sky blessed water, and produced with it gardens and grain to harvest (The Quran, 50.9).
>
> He who made the earth a habitat for you, and the sky a structure, and sends water down from the sky, and brings out fruits thereby, as a sustenance for you (The Quran, 2.22).
>
> And it is He who sends down water from the sky. With it We produce vegetation of all kinds, from which We bring greenery, from which We produce grains in clusters. And palm-trees with hanging clusters, and vineyards, and olives, and pomegranates—similar and dissimilar. Watch their fruits as they grow and ripen. Surely in this are signs for people who believe (The Quran, 6.99).
>
> It is He who sends the wind ahead of His mercy. Then, when they have gathered up heavy clouds, we drive them to a dead land, where We make water come down, and with it We bring out all kinds of fruits. Thus, we bring out the dead—perhaps you will reflect (The Quran, 7.57).
>
> It is He Who sends down for you from the sky water. From it is drink, and with it grows vegetation for grazing (The Quran, 16.65).
>
> Do you not see that God sends down water from the sky, and the land becomes green? (The Quran, 22.63).
>
> Or, who created the heavens and the earth, and rains down water from the sky for you? With it We produce gardens full of beauty, whose trees you could not have produced (The Quran, 27.60).
>
> And if you asked them, Who sends water down from the sky, with which He revives the earth after it had died? They would say, God. Say, Praise be to God. But most of them do not understand (The Quran, 29.63).
>
> And of His signs is that He shows you the lightning, causing fear and hope. And He brings down water from the sky, and with it He revives the earth after it was dead. In this are signs for people who understand (The Quran, 30.24).
>
> And of His signs is that you see the land still. But when We send down water upon it, it stirs and grows. Surely, He Who revived it will revive the dead. He is Able to do all things (The Quran, 41.39).
>
> In the creation of the heavens and the earth; in the alternation of night and day; in the ships that sail the oceans for the benefit of mankind; in the water that God sends down from the sky, and revives the earth with it after it had died, and scatters in it all

> kinds of creatures; in the changing of the winds, and the clouds disposed between the sky and the earth; are signs for people who understand (The Quran, 2.164).

> The likeness of the present life is this: water that We send down from the sky is absorbed by the plants of the earth, from which the people and the animals eat. Until, when the earth puts on its fine appearance, and is beautified, and its inhabitants think that they have mastered it, our command descends upon it by night or by day, and We turn it into stubble, as if it had not flourished the day before. We thus clarify he revelations for people who reflect (The Quran, 10.24).

Therefore, all these above-mentioned verses point out the potential of water as the basic element of production of crops, greeneries, and vegetation.

11.3.2 Classification and Stratification of Water

Cleanliness and purification are an important matter for Muslims to the extent that Abu Malik at-Ash'ari reported*:* "The Messenger of Allah (Prophet Muhammad (peace be upon him)) said: Cleanliness is half of faith" (Muslim, 2.432). It is essential to be in a pure state for a Muslim and mostly before performing the prayers or touching the Quran. The purification processes are mainly of two types: minor ablution known as *wudu* which is performed before the *Salat* (daily prayers) as a preliminary ritual and the *ghusl* which is the major ablution performed for various other purification reasons. However, for carrying out the ablution, there are certain water requirements, which are needed to be fulfilled to make ablution valid such as in the case of *Mikvah* (in Judaism). It is essential to perform the ablution with clean water. The Quran distinct or classify water as pure, sweet and bitter. The verses of Quran supporting the statements are:

> And it is He who sends the winds, bringing advance news of His mercy, and We send down from the sky pure water (The Quran, 25.48).

> And set on its lofty mountains, and given you pure water to drink? (The Quran, 77.27).

> The two seas are not the same. One is fresh, sweet, good to drink, while the other is salty and bitter (The Quran, 35.12).

Apart from the distinction of water as sweet and salty. Quran also provides an understanding of water stratification. The difference in salinity is one of the factors that separate the water into layers. Whenever two different seas meet there is a barrier between them. The Quran talks about this water barrier in the following verse:

> He merged the two seas, converging together. Between them is a barrier, which they do not overrun (The Quran, 55.19–20).

> And it is He who merged the two seas; this one fresh and sweet, and that one salty and bitter; and He placed between them a barrier, and an impassable boundary (The Quran, 25.53).

Modern science explains the meaning of this verse in a better way today. The verse is quite accurate about the water separation caused by the difference in salinity and thus the formation of a halocline.

11.3.3 Water Cycle

It is quite astonishing to us that what we called today as the "water cycle" or "hydrological cycle" and the source of underground water was discussed 1440 years ago in the lands of Arabia and thus mentioned the holy text Al-Qur'an. Some of the Quranic verses provide the idea of the water cycle. For instance,

> Have you not considered how God sends down water from the sky, then He makes it flow into underground wells, then He produces with it plants of various colors, then they wither and you see them yellowing, then He turns them into debris? Surely in this is a reminder for those with understanding (The Quran, 39.21).

> And of His signs is that He shows you the lightning, causing fear and hope. And He brings down water from the sky, and with it He revives the earth after it was dead. In this are signs for people who understand (The Quran, 30.24).

> And We sent down water from the sky in proper quantity, and settled it in the ground, and We are Able to take it away (The Quran, 23.18).

And We send the fertilizing winds; and send down water from the sky, and give it to you to drink; and you are not the ones who store it (The Quran, 15.22).

Have you not seen how God propels the clouds, then brings them together, then piles them into a heap, and you see the rain drops emerging from its midst? How He brings down loads of hail from the sky, striking with it whomever He wills, and diverting it from whomever He wills? The flash of its lightening almost snatches the sight away (The Quran, 24.43).

God is He who sends the winds. They stir up clouds. Then He spreads them in the sky as He wills. And He breaks them apart. Then you see rain drops issuing from their midst. Then, when He makes it fall upon whom He wills of His servants, behold, they rejoice (The Quran, 30.48).

It is He who sends the wind ahead of His mercy. Then, when they have gathered up heavy clouds, we drive them to a dead land, where We make water come down, and with it We bring out all kinds of fruits. Thus, we bring out the dead—perhaps you will reflect (The Quran, 7.57).

He sends down water from the sky, and riverbeds flow according to their capacity. The current carries swelling froth. And from what they heat in fire of ornaments or utensils comes a similar froth. Thus, God exemplifies truth and falsehood. As for the froth, it is swept away, but what benefits the people remains in the ground. Thus, God presents the analogies (The Quran, 13.17).

And it is He who sends the winds, bringing advance news of His mercy, and We send down from the sky pure water. To revive dead lands thereby, and to provide drink for the multitude of animals and humans We created (The Quran, 25.48–49).

God is He who sends the winds, which agitate clouds, which We drive to a dead land, and thereby revive the ground after it had died. Likewise, is the Resurrection (The Quran, 35.9).

And in the alternation of night and day, and in the sustenance, God sends down from the sky, with which He revives the earth after its death, and in the circulation of the winds, are marvels for people who reason (The Quran, 45.5).

And We brought down from the sky blessed water, and produced with it gardens and grain to harvest. And the soaring palm trees, with clustered dates (The Quran, 50.9–10).

No, we are being deprived." Have you seen the water you drink? Is it you who sent it down from the clouds, or are We the Sender? If We will, we can make it salty. Will you not be thankful? (The Quran, 56.67–70).

In Islam, rainwater is revered as a blessing from God, a sign of mercy, a reviver of the earth, a source of freshwater. If we look into these verses of the Quran, it provides an abundance of knowledge on the water cycle and underground water which was not known to the people in the earlier times.

11.3.4 Water in Pilgrimage Rituals

The importance of water and its relevance can be seen in one of the most important rituals of Hajj and Umrah *Sai*, which is performed in the Hajj and Umrah. The ritual commemorates the struggle of Hajar (wife of Prophet Abraham) and his son Ishmael. God commanded Prophet Abraham to leave his wife and son in the valley of Becca (now Mecca, Saudi Arabia), as a test of his faith in Allah. Following the command of God, he left them in this inhabited valley, with no source of food and water. As soon as the saved water and food ran out, his wife was unable to feed her baby. So, she went alone looking for help and ran back and forth between the two hills—Safa and Marwa. Ahmad (2015, pp. 8–9), with the assistance of hadith of Sahih Bukhari, states "Ibn Abbas (May Allah be pleased with him) narrates the Prophet Muhammad (peace be upon him) as saying:

This is the source of the tradition of the walking of people between them (i.e., Safa and Marwa). When she reached the Marwa (for the last time) she heard a voice and she asked herself to be quiet and listened attentively. She heard the voice again and said, 'O, (whoever you may be)! You have made me hear your voice; have you got something to help me? And behold! She saw an angel at the place of Zam-Zam, digging the earth with his heel (or his wing), till water flowed from that place. She started to make something like a basin around it, using her hand in this way, and started filling her water-skin with water with her hands, and the water was flowing out after she had scooped some of it."

Now the Muslims all over the world while performing the pilgrimage to Mecca commemorate the ritual. The water source is still present in the masjid al-Haram in Mecca, Saudi Arabia called "well of Zamzam". Every year millions of Muslims perform Hajj and Umrah and consume the water of the holy well of Zamzam.

11.3.5 Relevance of Water in Charity

Sadaqah is the term used in Islam to signify the voluntary charity. It is non-obligatory although it is highly recommended. "Abu Hurairah (May Allah be pleased with him) reported:

The Messenger of Allah (Peace be upon him) said, When a man dies, his deeds come to an end except for three things: Sadaqah Jariyah (ceaseless charity); a knowledge which is beneficial, or a virtuous descendant who prays for him for the deceased)" (as-Salihin, 12.1383).

In Islam offering water is considered as a charitable deed. "It was narrated by Sa'd bin 'Ubadah that his mother died. He said: O Messenger of Allah, my mother has died; can I give charity on her behalf? He said: Yes. He said: What kind of charity is best? He said: Providing drinking water. And that is the drinking-fountain of Sa'd in Al-Madinah" (an-Nasa'i, 4.30.3696).

Offering water is regarded as a rewardable action and it is highly recommended and not just mentioned in the hadiths but also the Holy Quran:

> Do you consider giving water to pilgrims and maintaining the Sacred Mosque the same as believing in God and the Last Day and striving in God's path? They are not equal in God's sight. God does not guide the unjust people (The Quran, 9.19).

11.4 Water Conservation

It is a well-known fact that "culture, including religion, clearly influences how people perceive and manage a resource such as water" (Faruqui 2001, p. 9). Water is a scarce and precious resource in the lands of Arabia, and Islam being originated from the same depicts the importance of conserving this resource. Here the absence of the water resource led to shaping the thoughts and perception of people and it is well represented in the Islamic teachings. In the verses of the Quran and narratives of the hadith, it is constantly discussed about water as a source of blessing from God and should be used sustainably. Both of these sources clearly state the two aspects of water "Firstly, the supply of water is fixed, and second, it should not be wasted" (ibid, p. 19). The following verses explain the two points more explicitly:

> Say, "Have you considered? If your water drains away, who will bring you pure running water?" (The Quran, 67.30).

> And We sent down water from the sky in proper quantity, and settled it in the ground, and We are able to take it away (The Quran, 23.18).

Muslims are instructed to perform *salat* which is an obligatory ritual prayer performed five times a day. Before performing these prayers, one should be in a pure state and follow the Islamic procedure of *wudu* or ablution:

> you who believe! When you rise to pray, wash your faces, and your hands and arms to the elbows, and wipe your heads, and your feet to the ankles. If you had intercourse, then purify yourselves. If you are ill, or travelling, or one of you returns from the toilet, or you had contact with women, and could not find water, then use some clean sand and wipe your faces and hands with it. God does not intend to burden you, but He intends to purify you, and to complete His blessing upon you, that you may be thankful (The Quran, 5.6).

The above-mentioned verse of the Quran also provides a substitute for water and a secondary purifying agent for Muslims in the absence of water or when they are incapable of performing ablution by water, for instance, if they are wounded. So that they do not get to be burdened and get into the state of purity. The historical records of the Prophet Muhammad also bring the concept of water conservation in Islam to the forefront:

> It was Narrated by 'Abdullah bin' Amr:
>
> The Messenger of Allah passed by Sa'd when he was performing ablution, and he said: 'What is this extravagance?' He said: 'Can there be any extravagance in ablution?' He said: 'Yes, even if you are on the bank of a flowing river. (Ibn Majah, 1.1.425).

Thus, the above hadith exemplifies the sustainable use of water and explains even if we have an abundant amount of water for usage one should have a logical approach to its uses. This knowledge of water conservation provided by the qur'anic verses and hadiths need to be brought into the light. Atallah et al. (2001) in their study talk about raising the awareness of water conservation through mosques. They describe the role of *imams* (Muslim leaders) in spreading the awareness and reaching out to the people through *Khutbah Juma* (preaching of Islamic teachings on Friday noon prayers). The congregational prayer invites several people and is a good platform for spreading the knowledge of water conservation and can be an effective source of changing human behavior and attitudes towards water conservation.

11.5 Conclusion

From the above discussion, it may be aptly concluded that water is just not an essential element of survival in the Islamic tradition, it is also regarded as a blessing from the almighty which needs to be cherished and taken care of. As noted in the verses of the Quran too, it has been reminded quite a few times about respecting the water resource as it is scarce and can be taken back. The Qur'anic verses present the understanding of water being the source of life of living creatures and also how water plays an essential role in the growth of food crops and livestock. The Quranic verses are also a source of knowledge of various hydrological and oceanographic phenomena such as water cycle and water stratification. The story of Hajar depicts the notion of water being a precious resource. Her struggle to find the water and later saving it for the future portrays the sustainable usage of water. From the Islamic religious perspective providing someone clean drinking water is regarded as the best form of charity and rewardable action. The usage of water in religious practices such as ablution teaches the basic principles of saving water and minimizing its usage. Islamic teaching on water conservation through formal or informal discussions can play an effective role in adapting new perspectives of water usage.

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12 Water Resource Management Through Ecological Restoration in Garhwal Himalaya, Uttarakhand, India

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Abstract

Water is considered as the most vital natural resource of Garhwal Himalaya and is also an important asset to the state population. The state is richly endowed with hilly terrain having an enormous volume of water from the catchment areas of Garhwal Himalaya that consists of Alaknanda river, Bhagirathi, Yamuna, Tons, and Nayar. Among them, Alaknanda river basin is the biggest one, which occupies around one-third area of whole Garhwal region. This paper presents a methodological approach through ecological restoration for the water resource management, integration of extreme events, climatic vulnerability, land use/land use cover changes, and natural resource for sustainable development planning. Climate change and anthropogenic activities are continuously disturbing the natural system of the Garhwal Himalaya and its impact on sustainable development and water potential. Himalayan geosystem is highly vulnerable and susceptible to various kinds of geo-hydrological vulnerability and its impact on socio-economic capacity. The study areas which are a part of fragile Garhwal ecosystem are isolated with its difficult topography and need immediate consideration for water resource management. Better legislative frameworks are necessary to protect water resources and prevent water pollution. The study has been based on the primary and secondary data. Primary data has been collected from field observation, interview techniques, informal interviews, interaction, and discussion with local people. The main technique of primary data collection was done through questionnaire and participatory rural appraisal (PRA) approaches. This parameter is important in building resilience capacity and ensuring sustainable development pathways and provides water resource management. This research paper has suggested a policy to improve the transfer of scientific knowledge, and to increase mutual understanding, partnership, and cooperation for better policy outputs in Sustainable Development Goal 06 (Clean water and Sanitation), Sustainable Development Goal 13 (Climate Action), and SDG 15 (Life on Land). These approaches

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_12

will be useful in building collaborative arrangements across political and administrative barriers and boundaries to govern at the scale of sustainability challenge to achieve way toward the SDG 06.

Keywords

Water resource management · Garhwal himalaya · Ecological restoration · Sustainable Development Goals

12.1 Introduction

Water resource, mainly the water for drinking and sanitation purposes (Sustainable Development Goal 6: Clean Water and Sanitation), to the people is a prime concern. Mountains are fragile ecosystems which are globally important as water tower of the earth, reservoirs of rich biodiversity, and popular destinations for recreation, tourism, and cultural heritage. Mountains provide direct life support base for human kind (Roy and Singh 2002). The unique geo-climatic condition of Garhwal Himalaya in Uttarakhand makes it one of the most vulnerable regions in India. Garhwal Himalaya, Uttarakhand is highly vulnerable to many man-made and natural disasters such as cloud burst, glacial lake outburst flood (GLOF), flash flood, landslide, soil erosion, and avalanches. In this situation, the normal patterns of life and livelihood are disrupted and extraordinary emergency interventions are required to save and preserve human lives, properties, and environment (Prasad and Pandey 2017). Water and forests are constantly interacting to produce healthy and productive ecosystems (Alford 1992).

This study examines and suggests the methodology framework to determine the management of forest plantation for water conservation in Garhwal Himalaya. The spatial and temporal variability of human-induced hydrological changes in a river basin could affect quality and quantity of water (Negi et al. 2017). The growth of population has an increasing pressure on renewable and non-renewable resources to meet the basic needs of food, water, and raw materials. The resultant environmental degradation and serious ecological imbalances are posing threat to the survival of mankind. Water is the vital natural resource for all life on earth surface. The economics importance of water in a country where agriculture is the mainstay can hardly be exaggerated. Indian history is full of example of indigenous water harvesting systems showing enormous variation in their design, structure, and size. Owing to the seasonal nature of rains, numerous types of water harvesting practices are developed to meet the water-related needs round the years (Plate 12.1).

Through crude by present-day standards, these were nonetheless complex and required enormous skill to construct. Many of these structures continue to meet the needs of the people even today. State management of irrigation was not unknown in the past, but community management was widespread. It was the people's participation in the management of these resources that made it a success (Rautela 2000). The land around each Indian village had been transformed over the centuries into a complex ecosystem of croplands, grazing lands, forest and trees lands, thus constituting an interactive, multi-components biological system that responded not only to the region's sharp seasonal rhythms but also reduced risk by keeping the social and economic impact of rainfall variations down to a minimum (Gupta and Katiyar 1982). When no options were available people learnt to rely on rainwater for survival. For irrigations purposes they would build rain-fed tank to provide irrigation water for a downstream channel areas (Plate 12.2).

Agriculture in the mountainous regions needed carefully fine-turned systems of water supply, distribution, and management. And so, did the towns and cities of the region that could not develop or survive without good water management. Wherever there were streams, people developed techniques to divert its water, with the help of simple engineering structures, into artificial channels that would feed the agricultural fields. In areas of good ground water regime, people harvested water with the help of specially designed structures (naulas), local variations of which are encountered throughout the terrain (Pandey 2017).

Plate 12.1 Water harvesting practices, Pauri Tehsil, Garhwal Himalaya. *Source* Primary Survey, 2015

Plate 12.2 Water supply, distribution and management, Dhansali, 2015. *Source* Primary Survey, 2015

Mountains have been considered as the planet's water towers, by receiving much of its precipitation. Some natural factors like steep slopes, barren land, lack of soils, and so on are responsible for rapid flow of waters in hills. But the vegetative blanket of the forests serves as the natural harvester and keeper of the raining downpour. In early 1990, Doodhatoli Lok Vikas Sansthan (DLVS), community participation groups had started to make small intervention to sustain and conserve the ample water reserve of the mountains (Bandooni 1999). This time due to deforestation the mountain Gad and Gadhera (small rivers and drain etc.), which in earlier times had sustained its flow throughout the year, had begun to run dry during the summer months. It required extra input of water to run its full course all the year round. To solve this problem, after successful planting of trees the DLVS workers and locals of Gadkharak village, Garhwal Himalaya made small Jal Talais (water ponds), in the upper parts of the village forest, to stall the immense surface runoff, which otherwise rapidly meander down hills (Bandooni et al. 2017). The vast, top ground tree cover facilitated the natural process infiltration and increases the water holding capacity of the land. Uttis (elder) is known to give out roots that almost spread like a network, reaching far into the soil, serving almost like capillaries supplying nourishment and water into the deep recesses of the earth. In the present research an attempt has been made to evaluate, examine, and understand the problems of water and forest resources and participation of community, social worker, and NGOs to manage them in Garhwal Himalaya, Uttarakhand.

12.2 Study Area

Uttarakhand state is characterized by high altitudinal mountains and deep valley. There are 13 districts in this mountain-dominated state which accounts for more than 80% characterized by hilly regions. The coordinate of Uttarakhand is at 28°43'N to 31°27'N, 77°34'E to 81°02'E. The total geographical area of Uttarakhand is 53,483 sq. km (Bandooni 2004), out of which 46,035 sq. km is hilly area and remaining are plain area. In Garhwal Himalaya, Alaknanda river basin is characterized by hilly terrain, deep gorges and river valleys. The region is broadly divided into four major divisions: (i) The Great Himalayan Ranges (snow-covered regions), (ii) Alpine and pasture land (covered by snow during the four months of winter season), (iii) Middle Himalaya (characterized by high concentration of population) and (iv) river valleys (characterized by mushrooming service centers and institutions) (Fig. 12.1). Among the major rivers of India, the Alaknanda river and its tributaries (Dauli Ganga, Vishnu Ganga, Nandakini, Pindar, Mandakini and other numerous perennial streams) originate and flow here.

The western part of Uttaranchal is known as Garhwal. Culturally, the Garhwal is divided into about 15 sub-regions. Among them, Raath is one of the most important regions. Raath is in the central-eastern part of the Garhwal and is the core of massive Doodhatoli range of Lesser

Fig. 12.1 The different basins in Alaknanda river basin, Uttarakhand. *Source* LANDSAT TM, 2017

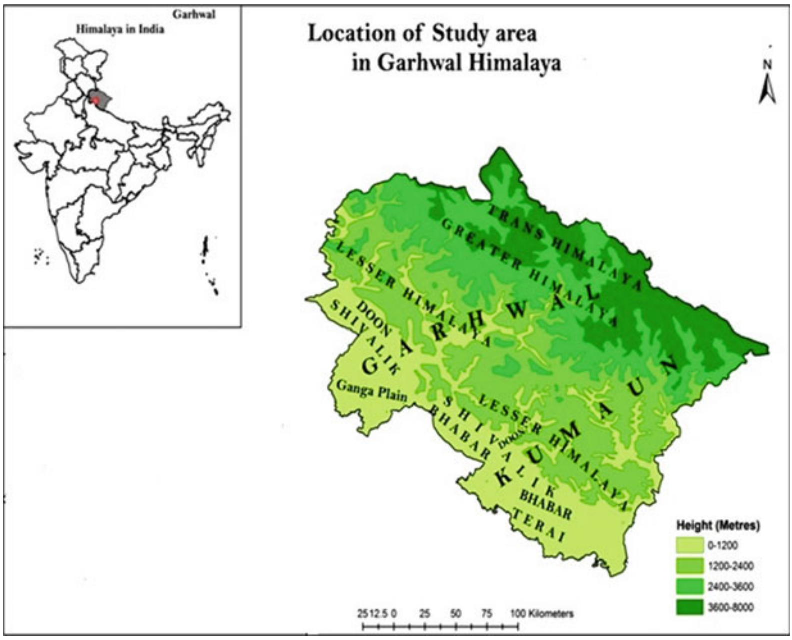

Fig. 12.2 The Garhwal Himalaya, Uttarakhand

Himalaya (Fig. 12.2), where elevation from mean sea level ranges between 1100 and 3100 m (Bandooni et al. 2017).

Lower and middle parts of the region are famous for cultivation, horticulture, and settlement mainly due to availability of water. But the irony is that in spite of this, some areas of Raath are facing the problem of availability of water, particularly in summer season. At present, locals of Uffrainkhal, Gadkharak, and Dulmoth are trying to conserve the forest and water resources. Of these, the most important are the Dhanpur (north-west), Devitonk and Ameli (south-west), Gabni, Seela, and Khatli (south). Doodhatoli (Raath) is known for dense and virgin forests, which capture huge amount of surface water resource.

12.3 Research Methodology

The study has been based on the qualitative and quantitative data. Primary data has been collected from field observation, interview techniques, informal interviews, interaction, and discussion with local people. The main technique of primary data collection was done through questionnaire. A questionnaire was set up according to the fieldwork survey. All questions were designed to specific topics related to water problems, scarcity, and its sustainability approaches. With the help of the interview, precise information regarding the local perspectives on development of water sustainability was received. Arranging it into tabular form first processed the outcome of the data generated through the questionnaire, and then it was analyzed thoroughly before further interpretation. Finally, the result of the data tables was converted into different graphs and the pictorial form of presentation including the representation of bar diagram, pie charts, column, and line graphs clearly depicted the analysis of the data.

12.4 Results and Discussion

12.4.1 Status of Water Resources and Its Sustainability

Garhwal Himalaya, Uttarakhand is located in Himalaya region which is best endowed with mighty glacier from which rivers like Ganga and Yamuna originated. The state is also fortunate because of rainfall, and this state receives rainfall from monsoonal winds as well as from western disturbances (Singh 2004). It receives 1700 mm/year. The average volume of water received per year from rainfall is about 94.62 BCM; out of which 17.5% is evaporation loss, 29.55% is absorbed by soil, and 15.45% is infiltrated into ground water and the remaining 37.50% returns into river (Table 12.1).

According to the state policy of Uttarakhand, only 3% of annual rainfall in the state will suffice to meet the state's total water needs for all the purpose. But presently shortage of water is felt in Garhwal region due to the growing population and rising living standard. Presently, the greatest threat is faced by agriculture by this adverse condition. Shortage of water is noticed both for irrigation and drinking purposes.

The demand of water to fulfill the requirement of farming and livestock production is increasing day-by-day in Garhwal Himalaya. Population of people and livestock is increasing rapidly and it pressurized the water resources. It is not possible to reduce the production of agricultural crop. The new high-yielding variety of crops required more water as compared to traditional crop. There is a great consensus among the scientist community that with the increasing of food diversification, requirement of water is increased (Recdlift 1990). Agriculture, domestic water use, animal husbandry all is dependent on ground water resources. Ground water resource is depleting rapidly. According to villagers of Rudraprayag district, Chamoli, Northwestern Pauri Garhwal, and Northeastern Tehri Garhwal district, the level of ground water is depleting. Twenty years ago any person digs the ground below 20 feet found water, but in the present time there is decline of ground water table (Bandooni 2004). You have to dig more than 50 feet to get fresh water. There is change in the qualitative and quantitative aspect of water. Quantity of water is decreasing as well as quality of water is also decreasing. The ground water is contaminated, may be due to the natural reason because the effect of industrial activity is not pronounced here. Shortage of water is noticed at both for irrigation and drinking purposes. Canal irrigation is not a suitable option for irrigation purpose because it requires flat land and the topography of village is not permitted to such type of infrastructure. The main reason for the scarcity of water is mismanagement of water resource (Singh et al. 2009). Villagers are not using any water harvesting as practiced in other parts of Uttarakhand. There are many techniques of water harvesting like Khal. All the water which are received by rainfall in this village goes to vain due to the absence of any water harvesting technology.

Water is also one import resource of the Garhwal Himalaya, Uttarakhand and most part of the Himalaya receives heavy rainfall during the monsoon from July to September (Bandooni 2004). The average volume of water received annually from rainfall is approximately 9.46 Mha-m (94.62 bcm). Of this, 17.5% is lost as evaporation, 29.55% is absorbed into the soils, 15.46% infiltrates into the ground water, and 37.5% ends up in rivers (Bandooni 2004). Because of the steep slopes, runoff is very heavy and the holding capacity of water is very low in deforested and other land. Any improper development in the watershed changes the land use/land cover patterns which reduces the base flow by changing the ground water flow path ways to surface water bodies. This water mostly goes in runoff. However, rain-event-runoff

Table 12.1 Water balance of Uttarakhand

Water loss	In percent (%)
Evaporation loss	17.5
Absorption in soil	29.55
Infiltration as a ground water	15.45
Flow in river	37.50
Total	100

Source Planning Commission Report on Development Report of Uttarakhand, 2016 increased by 60% after forested land converted to agricultural land at farm level. Moreover, water for household activities and animals are obtained from springs or flowing mountain streams. Because of heavy runoff, there is increasingly shortage of drinking water. But there is a potential for improving water quality and quantity with proper land use management practices in the study area. Therefore, watershed conservation is an important step in Garhwal Himalaya, and Alaknanda river basin, Uttarakhand to manage water, forest and other natural resources. The main purpose of this study is to establish the relationships between the forest plantation and water conservation for agricultural and domestic use such as for animals and household. This is done by relating land use/land cover (LULC) patterns and soil erosion rate in sub-watershed, using a computer-based GIS software system. The need for understanding forest and water relationship is necessary especially in the areas where the runoff is very high and source of income is only agriculture. The study shows opportunities for increasing water conservation in forest plantation and for improving fast-growing plantation management which meet the goals for productivity. The results suggest that soil erosion is more prone to the area where the plantation is very less and possibilities of very high runoff. Local communities have undertaken plantation of forest with the local leaders, in order to develop the management strategies for effective water conservation in forest plantation. However, limitations associated with the availability of hydrological data are difficult to increase the accuracy and reliability of results.

12.4.2 Community Participation and Water Resources Management in Garhwal Himalaya

By 1990–1991, the Doodhatoli Lok Vikas Sansthan (DLVS) in Garhwal Himalaya becomes connected with another critical problem in the hills. Many hilly districts in Alaknanda river basin such as Rudraprayag, Pauri Garhwal, and Tehri Garhwal were in the grip of acute water scarcity. The land of heavy rainfall was fast becoming a case of water-thirsty region. In the early 1990s, the neighboring district of Almora, once considered a water content region had about 85% of the area, facing severe water shortage. The situation was more serious in upper slopes and deforested areas (Pandey et al. 2004).

The small water bodies help to maintain the moisture in the soil and became the source of replenishing the drying watercourse. Within 2 years the dry Gadhera became alive with the splash of rolling water for the entire year. The water management system adopted by Doodhatoli Lok Vikas Sansthan (DLVS) in Garhwal Himalaya is typically unique to their home in mountain watersheds. In the past l0 years the people of Gadharak and Dulmoth in Garhwal Himalaya have developed an indigenous network of water ponds, along the face of the hillside, to tap the rainwater. The size of rectangular earthen pits is generally 2 m in length, 1 m in width, and 1 m in depth. The excavated soil serves to line the periphery in raised earthen mounds, planted with indigenous species of grasses like Chamliu and Munj. Another smaller earthen pits of about 2 feet × 2 feet and a depth of 1 m mark the distance between two water ponds, to anchor indigenous trees. In Garhwal Himalaya, Dulmoth, these water ponds are found in about 30 ha of a large tract of a hillside, from upper hill to the river valley Pasol. Total water ponds are about 1500, and there are about 1000 walnut trees grown. Unlike government estimates, the total cost of water ponds comes around only Rs 55 excluding labor donation. This area of hillside has been harnessed, to curb the surface drainage and the rampant soil erosion, which has washed away much of the topsoil, in the absence of adequate vegetative cover. The erosion of soils into the Pasol river of Garhwal Himalaya has also checked. Besides this water pond also offers good quality of fodders to animals. In Gadkharak village of Pasol Gad, Garhwal Himalaya most of the water ponds have been built in the village forestland within dense vegetative outgrowth. About 500 water ponds are found in this village. Therefore, the water seeping into the watercourse by water ponds has recharged Gadkharak Gadhera. From its source in the forest at the head of Gadkharak, it has been recharged by the water seeping into the watercourse, by the numerous Jal Talais that retard the excess surface drainage and nourish the land with moisture throughout the year. The presence of Jal Talais in the upper reaches of the landscape has nourished the impoverished land back to health and raised the moisture level, in the singularly barren slope, thus making it arable again. Hence the process of upland losses having immense downhill ramifications has been reversed. Taking advantage of the close proximity of the river Pasol, the people constructed a Gul, to help irrigate the restored fields. On an average each household owns about 40 Nali (20 Nali = 1 acre) of farm holdings. Of these about 10–15 Nali are Panchar or irrigated fields (Bandooni et al. 2017). In Dulmoth, the people have been able to recover a tract of about 50 nali, in the lower reaches of the hillside, served with Jal Talais.

Water for irrigation comes from either ground water or surface water, raising concerns that heavy uses could deplete water supplies in a region to the extent that non-agricultural users are negatively affected. Irrigation has been linked to the increasing soil salinity and contamination of ground water with chemicals fertilizers through run-off. Recreational water use is mostly tied to reservoirs. If a reservoir is kept fuller than it would otherwise be for recreation, then the water received could be categorized as recreational usage. Water release from a few reservoirs is also timed to enhance white water boating, which could also consign a recreational usage, and some other examples are anglers, water skiers, nature swimmers, and enthusiasts. Recreational usage of water is usually non-consumptive.

12.4.3 Water Potential: Availability, Need, and Storage and Its Sustainability

Water potential quantifies the trend of water to move from one area to another due to gravity, mechanical, pressure, osmosis, or matrix effects such as capillary actions. Water potential integrates a variety of different potential drivers of water movement, which may conduct in the same or different way. Within biological systems, it is prevalent for many potential factors to be important such as the addition of solutes to water lowers the water potential, just as the increase in pressure increases its potential. If there is no provision on flow, water will move from an area of higher water potential to an area that has lower water potential (Pandey and Mishra 2013).

On an average, India receives about 4000 cubic km (1 cubic km is the same as one billion cubic meters, abbreviated as bcm) of precipitation every year. Precipitation means rainfall and snowfall together. The rainfall is distributed unevenly not only in space but also in time. Almost 80% of rainfall occurs in the four monsoon months of June to September. Within these four months also, most of the rainfall comes in a few spells of intense rain. It is estimated that in Himalayan rivers, where there is some flow due to snowmelt also, about 80% of the total annual flow takes place within these four monsoon months. In peninsular rivers, where there is no contribution from snowmelt, monsoon flow accounts for more than 90% of the annual flow. Owing to this uneven distribution of flow in time and space, it is possible to utilize only a small part of it. It is estimated that out of this 400 bcm of precipitation, the annual flow in the rivers is only 1869 bcm, out of which only 690 bcm can be put to use. Another 432 bcm can be used from ground water. Thus, total utilizable quantity of water is 690 + 432 = 1122 bcm per year. Trans-basin transfer of water, also called interlinking of rivers, will enable utilization of an additional 200 bcm of water (IWRS 2015).

Water is essential for human life, development, and environment, but it is a finite and vulnerable resource which has quantitative limitations and qualitative vulnerability. Water is a regional resource, but water shortage is becoming a global issue due to increasing population, economic growth, and climate change. Development of new sources of water besides its efficient use, together with conservation measures, should be an important component of any country's national water plan (Pandey et al. 2017). Many reasons have been put forth to explain the depleting water resource of the Garhwal Himalaya, some of these are such as increasing population, engineering activity, deforestation, vanishing pasture lands, recurring forest fires, pollutions, change in lifestyle, change in cropping pattern, industrializations, neglect to traditional sources, disruption of the social mechanism of resource conservation, and change in the hydrology of the watersheds by tapping of water at higher elevations. Rapid population growth and increasing water consumption for agriculture, industry, and municipalities have too heavily stressed on freshwater resources (Sati 2014).

Water resource management is the activity of planning, development, distribution, and management of optimum use of water resource. It is a subset of water cycle management. Ideally, water resource management planning has regard to all the competing demands for water and seeks to allocate water on an equitable basis to satisfy all uses and demands (Global Water Partnership 2000). Without better water management in any country the Sustainable Development Goals (SDGs) for poverty, hunger, and a sustainable environment cannot be met. In some places water is abundant, but getting it to people is difficult because of lack of infrastructure and because of restricted access as a result of political and socio-cultural issues. Integrated river basin management (IRBM) is a relatively new concept for the developing countries. The most important feature of this concept is that it explicitly recognizes the inter-linkages between land use and sustainable water resource management (Singh and Prasad 2013). Furthermore, it takes the entire ecosystem, including its terrestrial aspects, as the basic reference for sustainable management. Integrated water resources management (IWRM) is an empirical concept which was built up from the on-the-ground experience of practitioners. This is the rationale for the integrated water resources management (IWRM) approach that has now been accepted internationally as the way forward for efficient, equitable, and sustainable development and management and for coping with conflicting demands (Mitchell 1990).

It becomes important to understand the interrelationship between spring yield and the recharge. Spring yield in any area is a function of recharge that is dependent upon the time duration for which the water stays at higher elevations. The longer this time period, the higher would be the recharge. Planting of barren areas, especially on slopes, is an important component of integrated watershed management programme. Grazing needs to be restricted in selected patches which are possible only when people are involved in these programmes. Water resources management for diverse uses should incorporate a participatory approach by involving not only the various governmental agencies but also participation of local communities and other stakeholders, in an effective and decisive manner, in various aspects of planning, design, development, and management of the water resources (Planning Commission Report on Development Report of Uttarakhand 2009).

At present, on the basis of experience, the size of water harvesting pits has been decided to smaller than old ones. The shape of new pits is like a bucket, that is, more width at the top and decreasing toward the bottom. The work to conserve water resource is still a continuous process. The main target is to replicate the system in different village at Pasolgad (like Dulmoth and Khaitoli), Lachigad, Khatalgad, and Benuganga watershed in Pauri Garhwal and Naugura watershed in Tehri Garhwal districts.

During 2013 around 300 pits have been digged in Mohllya and Onal villages of Naugar gad watershed. In the same watershed 500 pits have been digged in Herwal village and there is a plan to dig around 500 pits in the deforested area of Deengaon village in 2015. During the rainy season in the same year (2015) digging of water harvesting pits along with grass, tree, and fruit tree plantation has also been started in Ghodiyana village of Khatagad watershed. In near future the work will be started in different village of Lachi, Pasol and Benganga watershed.

12.5 Conclusion

The struggle of the people of Garhwal Himalaya is not just a part of environmental concerns but finds its essence in the fulfillment of human needs. It is good for interdependence and interaction between human and natural resources. At last we can say that the objective of forest and water conservation is not only to manage these resources, but active involvement and participation of local communities to sustain their environment means sustainable development without destruction. It is not only soil and land management, but also magnify the sustained endeavors of the mountain communities of Garhwal Himalaya to nourish and reuse the thinning headwaters of the Himalayan rivers and recharge and increase their volume in the upper and lower watersheds. Their sizes are small but the water of hundreds of Jal Talais along the hillsides evokes a powerful image of small water bowls, emptying out their pockets in the humble tribute, to the large vessel of milk, their benefactor, their native place, that is, Raath (Doodhatoli) through ecological restoration. Ecologically sustainable development is the basic prerequisite for disaster mitigation and sustainable development. Equitable development will reduce the vulnerable populations through livelihood diversification. We strongly believe that if all national governments and NGOs took collective and coordinated action to implement these three goals, Sustainable Development Goal 13 (Climate Action), SDG 11 (Sustainable Cities and Communities), and SDG 15 (Life on Land), it would significantly increase human health and quality of life around the world, and would slow the progression of global warming.

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13 Changing Rainfall Patterns and Their Linkage to Floods in Bhagirathi-Hooghly Basin, India: Implications for Water Resource Management

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Abstract

The present study provides a synoptic view of recent changes in the patterns of rainfall and their linkages to extreme floods in Bhagirathi-Hooghly Basin (BHB). The objectives are: (a) to obtain a better understanding of long-term and short-term trends and variations in rainfall; and (b) to ascertain whether the extreme floods were coincided with multi-decade excess monsoon rainfall epochs at the basin level. To fulfill the above objectives, we use district-wise long-term (1901–2000) monthly rainfall data and annual maximum flood series in BHB. The data are mostly obtained from Indian Meteorological Department (IMD), Irrigation and Waterways Department, Government of West Bengal, numerous research articles, published and unpublished reports. The methodology includes various statistical approaches and simple techniques, such as the Mann–Kendall (MK) test with Sen's slope estimator, Cramer's t-statistic and linear regression in order to evaluate the trends and patterns of the rainfall series. The analyses revealed a long-term insignificant declining trend of annual as well as pre-monsoon rainfall, whereas increasing trend in monsoon and post-monsoon season over BHB. Rainfall during winter seasons showed a decreasing trend. Statistically monsoon rainfall can be considered as very dependable as the coefficient of variation is 17.31%. However, there is decreasing monthly rainfall trend in June and August, whereas increasing trend in July and September. On the other hand, the shorter period of recent data showing higher significance may have better practical utility and correlatable with major floods in the basin. This changing rainfall trends during monsoon months is a major concern for the rain-fed agriculture. The results of this study therefore would be of immense help to the reservoir managers and policymakers in planning and management of water resources of the BHB.

Keywords

Climatic variability · Rainfall trends · Extreme floods · Monsoon rainfall periods · Water resources

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_13

13.1 Introduction

The ever-growing population and fast urbanization is leading to over-utilization of the water resources, exerting pressure on these commonalities which are on the brink of collapse. Consequently, the world climate is changing more rapidly in recent years (Vijaya et al. 2011) and causes difficulty in appropriate water management including storage plans. As the water resources are inextricably linked with climate, the global climate change has serious implications on them (Bates et al. 2008; Ghosh and Misra 2010) and therefore, it has led to the vulnerable state of the water resources worldwide. The *Intergovernmental Panel on Climate Change* (IPCC) has projected rising trend of Earth's surface temperature of about 0.2 °C per decade for the next two decades due to increasing concentration of greenhouse gases in the atmosphere (IPCC 2007). Increased temperature leads to irregular frequency and intensity of rainfall that significantly increases the intra-annual variability of stream flow; in turn will have an impact on water availability. The impact of climate change in future would be quite severe for India including Gangetic West Bengal (GWB) because the IPCC recently reported that there is a high confidence in a projected rise in temperature and medium confidence in a summer monsoon precipitation increase in the future over South Asia (IPCC 2013). It is also projected that the number of rainy days may decrease by 20–30%, which implies that the intensity of rainfall is likely to increase. Consequently, it produces more frequent floods and has rendered millions vulnerable to their impacts as the intensity of monsoon rainfall and large floods has been strongly associated. Although the subject area of climate variability is vast, the changing pattern of rainfall deserves urgent and regular attention as it affects the socio-economic conditions especially food production of India and the occurrence of water-related disasters triggered by extreme events (Dore 2005; Kumar et al. 2010; Kumar and Jain 2010). The data of the Central Water Commission (CWC), New Delhi demonstrated that on an annual average, 7.21 million ha of land is inundated and nearly 32 million people are affected by floods in India (Kale 2014). Therefore, it is important to study the trend and pattern of the distribution of rainfall where the growth of an agro-based economy is linked to the rainfall of the region in concern.

In recent decade, a great emphasis has been given on the studies of trend in monsoon rainfall pattern of India. Earlier, Lal (2001) reported large fluctuations in Indian rainfall with no systematic change on either an annual or a seasonal scale. However, areas of increasing trend in the seasonal rainfall have been found along the West Coast, north Andhra Pradesh and northwest India and decreasing trend over east Madhya Pradesh, Orissa and northeast India during recent years. Guhathakurta and Rajeevan (2007) found the significant decreasing trend in the three subdivisions (Jharkhand, Chhattisgarh and Kerala) and significant increasing trend in monsoon rainfall in eight subdivisions (Gangetic West Bengal, West Uttar Pradesh, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra subdivision, Coastal AP and North Interior Karnataka) during the period of 1901–2003. Decreasing tendency in the summer monsoon rainfall over Indian landmass and increasing trend in the rainfall during pre-monsoon and post-monsoon months have been reported by Dash et al. (2007). Kumar et al. (2010) examined the monthly, seasonal and annual trends in rainfall for 30 subdivisions in India during the period of 1871–2005. They reported that half of the subdivision showed increasing trends and half showed decreasing trend in annual rainfall. The fluctuations of rainfall amount for the Indo-Gangetic region have been studied by Singh and Sontakke (2002) using the data of 1829–1999. Their study indicated a significant increasing trend from 1939 over the Central part, and a significant decreasing trend over eastern parts of the country. Sen Roy and Balling (2004) analyzed the trends in the patterns of extreme precipitation events from 1910 to 2000 and showed an increasing trend over most of western India including Deccan Plateau and a decreasing to a neutral trend over the eastern half of the country except the north-eastern corner. Singh et al. (2008) indicated the increasing trends in annual rainfall and relative humidity during the period of 1901–2000 in North Indian river basins. The temporal variation in monthly, seasonal and annual rainfall during the period of 1871–2005 was examined by Krishnakumar et al. (2009) in Kerala. They found the decreasing trend in southwest monsoon while increasing trend in post-monsoon season. The study conducted by Kumar and Jain (2010) indicated the decrease in rainfall at four stations and increase at one station in the Kashmir Valley. Recently, Patra et al. (2012) have also detected rainfall trends in twentieth century over Orissa state. They found no trend in annual series as well as monsoon rainfall for the period of 1871–2006, whereas increasing trend in post-monsoon season of Orissa.

However, so far there is no comprehensive study on long-term and short-term behavior of rainfall in Bhagirathi-Hooghly Basin (BHB) which falls in the direct path of monsoon disturbances originating from the Bay of Bengal. Actually, the monsoon disturbances are known to be one of the major synoptic weather systems that are responsible for heavy rainfall and large floods on the rivers of BHB. So, rainfall trend analysis within the basin is important and the outcomes of this study will be highly useful for the planning and management of water resources in the basin. Keeping the above in background, the present research is aimed at analyzing trends in rainfall data series (1901–2000) of BHB and to probe into the linkage between flood-rich periods and excess monsoon rainfall. The BHB was selected for this study as it is one of the important river basins in West Bengal, India where agriculture plays a vital role in the economy. It is a part of western Ganga–Brahmaputra deltaic plain and one of the recognized climatically vulnerable regions of India. Recent occurrences of the extreme floods in this basin underscore the importance of evaluating the trend and variability of rainfall in order to understand the potential impact of future change. In this context, this study will not only improve our understanding of the large-scale global atmospheric dynamics (monsoons), but will also provide insight for understanding future changes in large floods vis-à-vis monsoon intensity.

13.2 Study Area

This portion of West Bengal, south of the Padma, together with a good chunk of the Chotanagpur plateau, over which extends the catchments of the western tributaries, comprise the hydrological basin of the Bhagirathi-Hooghly (Bagchi 1972b). It is one of the most important feeder rivers of the Ganges Delta which takes off on the right bank of the River Ganga at Mithipur in the district of Murshidabad and after traversing a distance of 570 km falls into the Bay of Bengal (Fig. 13.1). It drains an area of ~17,350 km^2 between 85°45′ E and 89° E longitude and 21°33′ N to 24°51′30” N latitude (Basu 1967, 2005; Mukhopadhyay and Dasgupta 2010). The non-tidal part of the river extending from the off-take to Nabadwip, a distance of about 248 km, is known as the Bhagirathi while the tidal reach from Nabadwip to the Bay, a length of about 322 km, is known as the Hooghly. It is distinct from the others in that it is not merely a spill channel but carries an independent supply of water from its western tributaries such as the Bansloi, the Pagla, the Mayurakshi-Babla, the Ajay and the Khari join the upstream of Bhagirathi-Hooghly while the Damodar, the Silabati-Rupanarayan, the Kangsabati-Haldi and Rasulpur join the downstream of it (Rudra 2010). The western tributaries bring in a considerable amount of sediment load along with their freshets from the upper catchments and this huge detritus load plays a significant role on the regime of basin (Bagchi 1972a). The hydrological basin of this river including the old alluvial flood plains of its tributaries is recognized as climatic vulnerable

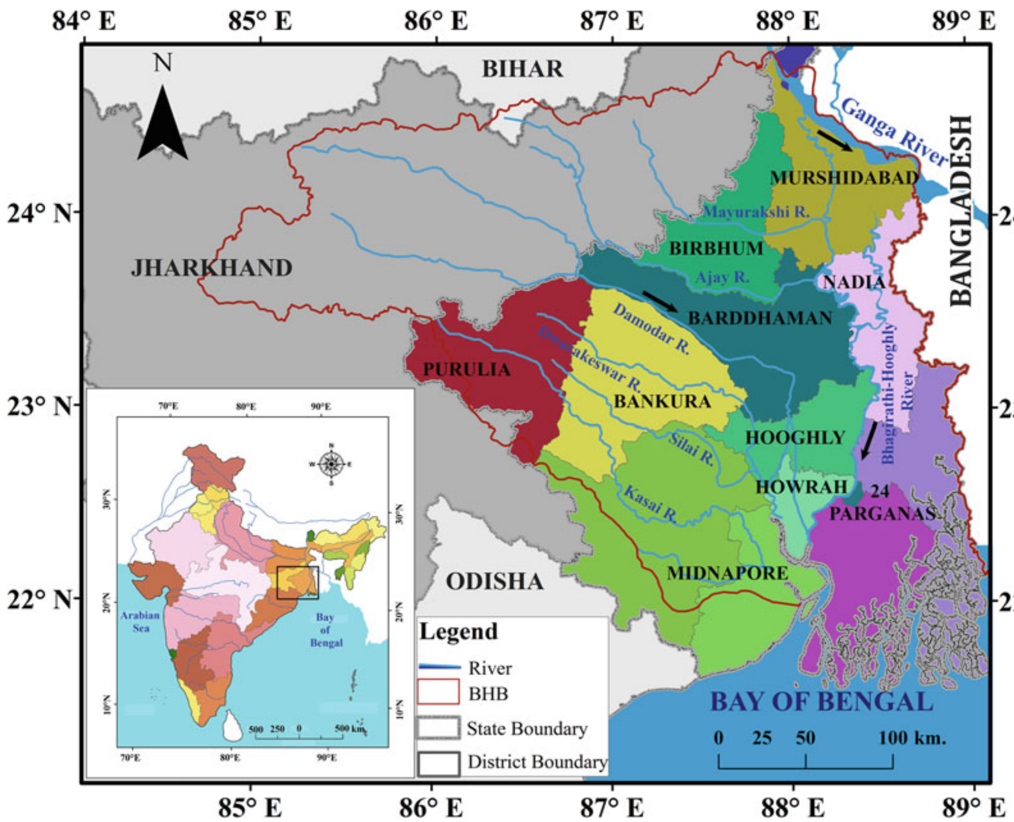

Fig. 13.1 Location of Bhagirathi-Hooghly Basin (BHB) in West Bengal, India

region of India where climate change and variability would adversely affect the water and food security of the densely populated basin.

Administratively, the basin covers Dhanbad, Hazaribagh, Ranchi and Singhbhum of southern Bihar and Murshidabad, Nadia, 24-Parganas, Calcutta, Birbhum, Barddhaman, Purulia, Bankura, Midnapore (East Midnapore and West Midnapore), Hooghly and Howrah of southern West Bengal. The basin starts on the north in the district of Murshidabad near Farakka where the Bhagirathi-Hooghly branches out from the River Ganga and extends south-westward that includes the Ganga–Brahmaputra Delta and the old alluvial flood plains of the Ganga tributaries. The overall climate of the region is characterized by hot summers and mild winters. The agricultural activities of this region mainly depend on the rainfall as most of the crop land is under rain-fed condition with limited irrigation facilities. The annual rainfall varies from 1000 to 2200 mm across the basin. Floods, droughts and cyclones occur almost every year with varying intensity. Due to frequent occurrence of these natural calamities, kharif rice yield is lower compared to normal possible yield. Winter rains, usually caused by western depressions, decreases moving east, and are only a fraction of the total rainfall. The winters rainfall, if occurs timely, are very important for the Rabi crops in the plains. There is great seasonal variability in the total amount of rainfall and its areal distribution in the basin. Consequently, some areas in the basin suffer from severe drought in the dry months, while floods inundate large area during the monsoon season. In this paper, the following rainfall studies have been carried out for an area comprising eight districts, viz., Murshidabad, Barddhaman, Birbhum, East Midnapore, West Midnapore, Bankura, Hugli and Howrah.

13.3 Description of Data and Methodology

13.3.1 Data Set

The monthly 100 years rainfall series of eight districts located in BHB covering period of 1901 to 2000 were obtained from the Hydrometeorology Division (Office of the Additional Director General of Meteorology) of Indian Meteorological Department (IMD), Pune. For the BHB, mean monthly rainfall values of eight districts were summed to obtain annual, seasonal and mean values of rainfall.

13.3.2 Method of Analysis

To study the intra-annual variations (seasonal analysis) of rainfall over BHB, the year was divided into four seasons, namely pre-monsoon (March–May), southwest monsoon (June–October), post-monsoon (November–December) and winter season (January–February), depending upon climatic conditions prevailing over the northeast India, including Gangetic West Bengal (Rao 1981; Jain et al. 2013). Rainfall characteristics like mean, standard deviation (σ), coefficient of variation (CV) and percentage contribution to annual were computed for annually, monthly and season-wise to find out the variability during the study period.

The rank-based non-parametric Mann–Kendall (MK) technique (Mann 1945; Kendall 1975) has been employed in this study to detect the long-term changing trends of annual, seasonal and monthly rainfall. The null hypothesis H_0 for this test is that there is no trend in the series. The alternative hypothesis is that the trend is either negative or positive. The MK test is based on the calculation of Kendall's tau (τ) measure of association between two samples, which itself are based on the ranks with the samples. A major advantage of Mann–Kendall test is that it allows missing data and can tolerate outliers. Several researchers from India have used MK test to identify rainfall trends due to climate change. The test does not quantify the trend magnitude. The linear slope (β) using Sen's slope estimator was calculated to estimate true slope (magnitude) of an existing trend (change $year^{-1}$) (Sen 1968). Positive values of Z correspond to a positive β, which indicate an 'upward trend', while a negative Z value corresponds to a negative β, and indicates a 'downward trend'. To achieve these analyses the following software were used: XLSTAT (https://www.xlstat.com/) for homogeneity test, for MK test and Sen's slope estimator. Further, a linear trend was added as parametric test to the series for identifying the trends. Linear trends represented by the slope (b) of the simple least-square regression line provided the rate of rise/fall in the variable.

The short-term decadal climate fluctuations have been studied by applying Cramer's t test for the 10-year running means (moving average) to examine the stability of climate and to establish climatic variability (WMO 1966; Kale 2012). The computational procedure is explained by WMO (1966) and Kripalani et al. (2003). This method was applied to the monthly rainfall series to detect decadal changes and to identify multi-decade epochs of above- and below-average rainfall.

13.4 Results

13.4.1 Features of Rainfall

The rainfall characteristics of BHB for the period of 1901–2000 are presented in Table 13.1. Considerable variability was observed between the different seasons with a standard deviation of 288.54 mm, while average annual rainfall was 1417.85 mm. The coefficient of variation (CV) of mean annual rainfall is 16.12%. Monsoon contributes 83.2% of the annual rainfall in this basin, whereas rainfall in the winter is least (2.4%). Looking at the amount of rainfall in different seasons (Table 13.1), it is evident that the BHB receives maximum rainfall in southwest monsoon season. The high amount of rainfall in the southwest monsoon season in the BHB is due

Table 13.1 Rainfall characteristics over part of Bhagirathi-Hooghly Basin: 1901–2000

Month	Rainfall (mm)			
	Mean	SD (σ)	CV (%)	% Contribution to annual
January	11.97	13.91	116.19	0.80
February	23.39	25.10	107.27	1.70
March	28.02	29.04	103.63	1.90
April	43.29	32.93	76.070	3.20
May	107.00	50.21	46.920	7.60
June	236.39	99.62	42.140	16.7
July	307.57	88.05	28.630	21.6
August	299.76	92.77	30.950	21.1
September	231.15	87.74	37.960	16.3
October	103.48	66.69	64.450	7.30
November	20.62	33.61	163.04	1.40
December	5.21	11.81	226.93	0.40
Annual	1417.85	228.54	16.120	100
Pre-monsoon	178.32	69.44	38.940	12.6
Southwest monsoon	1178.34	204.01	17.310	83.2
Post-monsoon	25.82	34.33	132.96	1.80
Winter	35.37	29.50	83.400	2.40

to the presence of monsoon disturbances. The southwest monsoon normally advances over the basin and adjoining areas by around end of June and establishes firmly over the entire region by the middle of July. It withdraws from the region by about second week of October comprising 80–150 days of rainy season with the normal duration of 120 days. The basin receives heavy to very heavy rainfall when different low-pressure systems like depressions, cyclonic storms, and so on originating in the Bay of Bengal, cross the Indian Coast and move in a north to northeasterly direction. During the monsoon season the coefficient of variation is very low (17.31%) compared to other seasons which shows a dependable monsoon rainfall. The post-monsoon season is the season of minimum rainfall. Monthly rainfall of July, August and September may also be considered as dependable. However, the spatial distribution of seasonal rainfall during monsoon season (Fig. 13.2b) is very much uneven and creating floods and droughts in different parts of the basin though showing a dependable nature when summed for whole season. The variation was studied for the basin with the help of isoheytal map (Fig. 13.2) which was created through interpolation techniques in Arc GIS (v. 9.3) platform. The analysis showed that highest rainfall is mostly concentrated in the south-eastern part of the basin in southwest monsoon season. Some patches over the basin receive moderately higher rainfall. The lowest maximum (<1050 mm) during this season was recorded by Bankura and Nadia districts while 24 Parganas district recorded highest seasonal maximum rainfall (>1200 mm). It is observed from these figures (Fig. 13.2) that the highest winter rainfall has been recorded by Midnapore, Hooghly, Howrah and Purulia districts.

13.4.2 Annual Rainfall Trends

The mean annual rainfall over BHB showed a long-term insignificant declining ($b = -0.042$) trend. However, a statistically significant trend may not be practically significant and vice versa

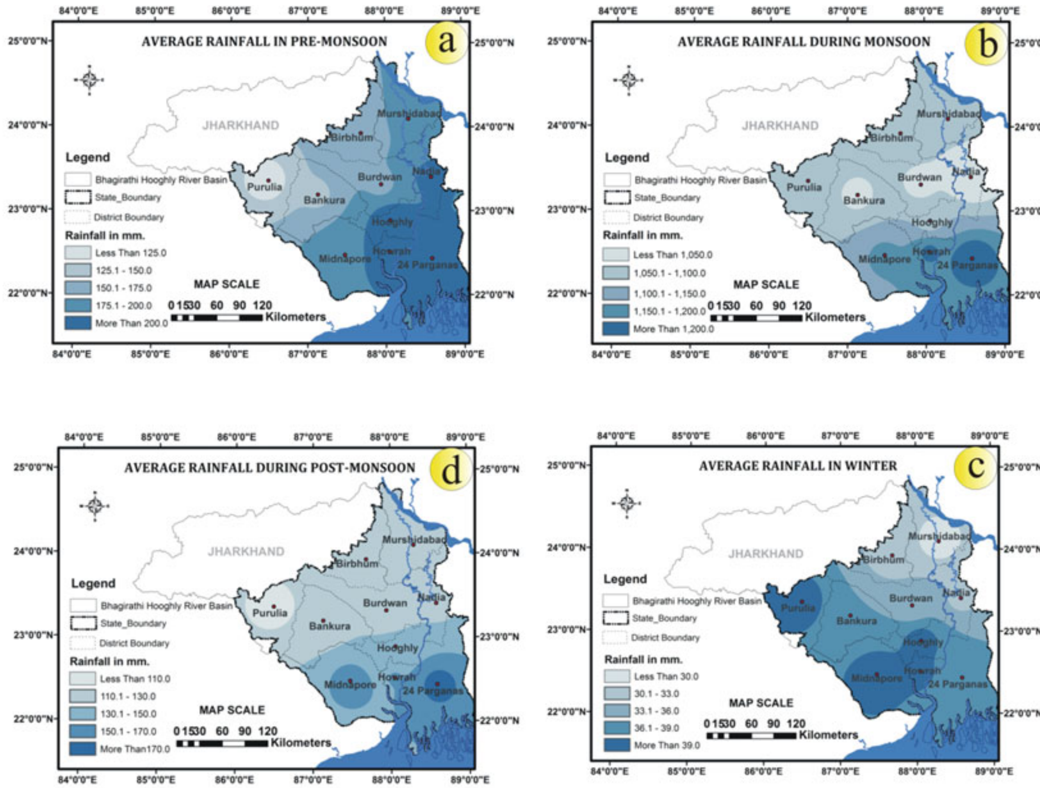

Fig. 13.2 Spatial distribution of seasonal rainfall over Bhagirathi-Hooghly Basin (BHB). **a** Average rainfall in pre-monsoon (March–May) period. **b** Monsoon (June–October) average rainfall. **c** Average rainfall in post-monsoon (November–December) period. **d** Winter (January–February) rainfall

(Daniel 1978). The annual rainfall has a high declining trend from 1950 to 1970s (Fig. 13.3). During this period there were two severe (1951 and 1960) drought years (Chanda and Dhar 1976). A relatively dry period (deficit rainfall) was also seen in earlier decades from 1923 to 1935 and during this period another two moderate droughts (1925 and 1927) occurred. The annual rainfall in recent years from 1990 is increased. On the other hand, the MK test was employed on the annual rainfall series and the results are presented in Table 13.2. Annual rainfall showed a decreasing trend ($\beta = -0.227$) on overall basis, although it was not statistically significant. The decrease in annual rainfall magnitude varied between 0.22 and 0.33 mm per annum.

13.4.3 Trends in Seasonal Rainfall

The seasons in BHB can be broadly classified as pre-monsoon (March–May), monsoon (June–October), post-monsoon (November–December) and winter (January–February) (Table 13.2). It was found that the pre-monsoon rainfall has overall decreasing trend ($b = 0.314$) during the study period analyzed from regression analysis. However, the MK test suggests decreasing trends and its magnitude is 0.24 (β) mm. The monsoon rainfall has an overall increasing trend ($b = +0.317$) in the last 100 years. Significant increasing trend was also detected in southwest monsoon rainfall over the entire BHB with the help of MK test. The increase in magnitude was 0.409 mm/year. Similar results were obtained for

Fig. 13.3 Annual rainfall trend over BHB (1901–2000). A linear trend with 10-year running mean

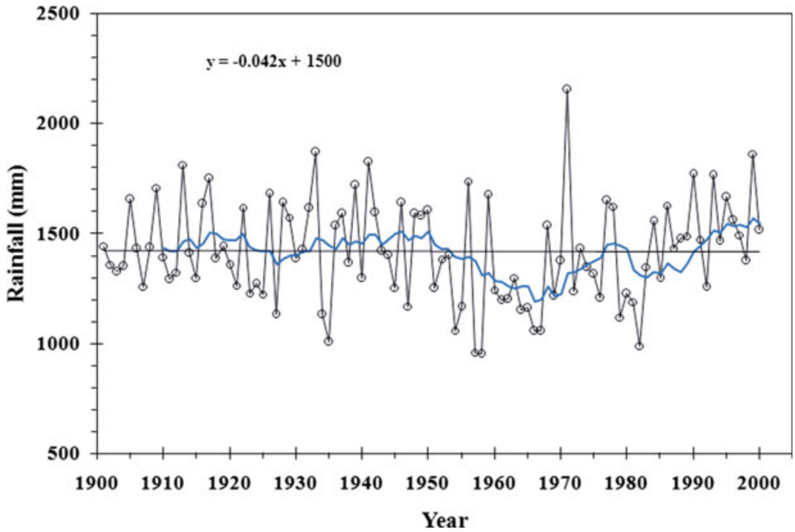

Table 13.2 Results of trend analyses of rainfall in the Bhagirathi-Hooghly Basin (BHB)

Month	Linear regression coefficient (*b*)	Kendall's τ	Mann-–Kendall statistic (*S*)	Normalized test statistics z	Sen's slope (*β*)
January	0.028 (−)	0.010 (+)	49	0.143 (+)	0.000
February	0.096 (−)	0.000	1	0.000	0.000
March	0.083 (−)	0.032 (−)	156 (−)	0.462 (−)	0.025 (−)
April	0.014 (−)	0.007 (+)	36	0.104 (+)	0.011 (+)
May	0.216 (−)	0.072 (−)	358 (−)	1.063 (−)	0.185 (−)
June	0.251 (−)	0.034 (−)	168 (−)	0.497 (−)	0.173 (−)
July	0.073 (+)	0.037 (+)	182	0.539 (+)	0.148(+)
August	0.153 (−)	0.039 (−)	194 (−)	0.575 (−)	0.184 (−)
September	0.756 (+)	0.130 (+)	641	1.906 (+)	0.455 (+)
October	0.107 (−)	0.013 (+)	62	0.182 (+)	0.041 (+)
November	0.012 (+)	0.084 (+)	414	1.231 (+)	0.016 (+)
December	0.067 (+)	0.067 (+)	304	0.936 (+)	0.000
Annual	0.042 (−)	0.019 (−)	96 (−)	0.283 (−)	0.227 (−)
Pre-monsoon	0.314 (−)	0.063 (−)	312 (−)	0.926 (−)	0.240 (−)
Southwest Monsoon	0.317 (+)	0.036 (+)	178	0.527 (+)	0.409 (+)
Post-monsoon	0.079 (+)	0.056 (+)	275	0.816 (+)	0.027 (+)
Winter	0.125 (−)	0.012 (−)	61 (−)	0.179 (−)	0.011 (−)

Gangetic West Bengal by Kumar et al. (2010). The rainfall during this season is high which contributes to major floods across the basin. The post-monsoon rainfall has an overall increasing trend over the study period (0.079 mm/year) and highly variable to the long-term normal. The MK test indicates that the seasonal rainfall during the post-monsoon has shown an increasing trend. Therefore, it can be inferred from the analysis that the post-monsoon rainfall was increasing. Rainfall during winter season has also shown decreasing trend.

13.4.4 Monthly Rainfall Trends

Behavior of monthly rainfall has been studied for individual months by the MK test and the results are presented in Table 13.2. It is interesting to note that rainfall in June and August showed a decreasing trend. Similar decreasing trends were noticed during May and March for rainfall contribution to the annual. Rainfall of March, September and November showed an increasing trend. Rainfall during March, July, September, October and November showed an increasing trend while remaining months showed no particular significant trend. There was a decline in rainfall contribution of June to the annual rainfall over a period of time. Unlike in June, the contribution of rainfall during July is stable though variations were noticed. In contrast, the contribution of rainfall during September and October is increasing. As a whole, the percentage rainfall contribution during the southwest monsoon was increasing while decreasing during pre-monsoon and winter season over BHB. The above phenomenon was more significant in recent decades. However, rainfall during the monsoon season is stable while instable in remaining months. These two contrasting phenomena in monthly rainfall trends are the major concern across the basin.

13.4.5 Decadal Monthly Rainfall: Short-Term Fluctuations

Since the rainfall series of BHB show annual and seasonal variations, there is every possibility that the monthly rainfall over the BHB is also characterized by multi-decade periods of excess (above-average) and deficient (below-average) rainfall. The decade-scale variability of monthly rainfall based on Cramer's t-statistic for BHB is depicted in Fig. 13.4. Several interesting features can be observed. First, the graphs are not exactly parallel and indicate month-to-month variations in the rainfall. Second, another remarkable feature that is evident from the plot is a striking change in monsoon regime at the end of nineth decade of the twentieth century and a prominent period of excess rainfall in last decade of the twentieth century in BHB. Third, the signatures of southwest monsoon rainfall pattern are less evident in the month of October. Four, the pattern displayed by Cramer's t-statistic between 1920 and 1970s is multifaceted and it is not possible to detect any systematic pattern, as during the other decades. The recent decadal change is attributed due to climate change associated with global warming. But clearly more work is required before any positive conclusion is drawn. In addition, the sub-period analysis (Cramer's test) also revealed a recent increase in the post-monsoon rainfall series in the last decade. The rainfall of winter months was below the overall mean during the three decades (1961–1970, 1971–1980 and 1981–1990). There is one 10-year period, 1921–1930 which showed positive anomaly from the overall mean in winter rainfall.

13.5 Discussion

The outcome of the study revealed various facts about the spatial–temporal variation of rainfall in this basin. The variations observed in different data series such as mean annual, onset of monsoon, rainfall in the month of winter and in the monsoon season. The overall characteristics of the long term and decadal annual as well as monsoon rainfall over the region are declining in nature. But in the last decade of twentieth century, the monsoonal rainfall has been increased (Fig. 13.4). However, it did not explain anything specific about the recent changes in climatic conditions. An undisputable fact about large floods in BHB is that they occur during the southwest monsoon months and are generated by heavy to exceptionally heavy rainfall in the catchment area. However, neither the exceptional

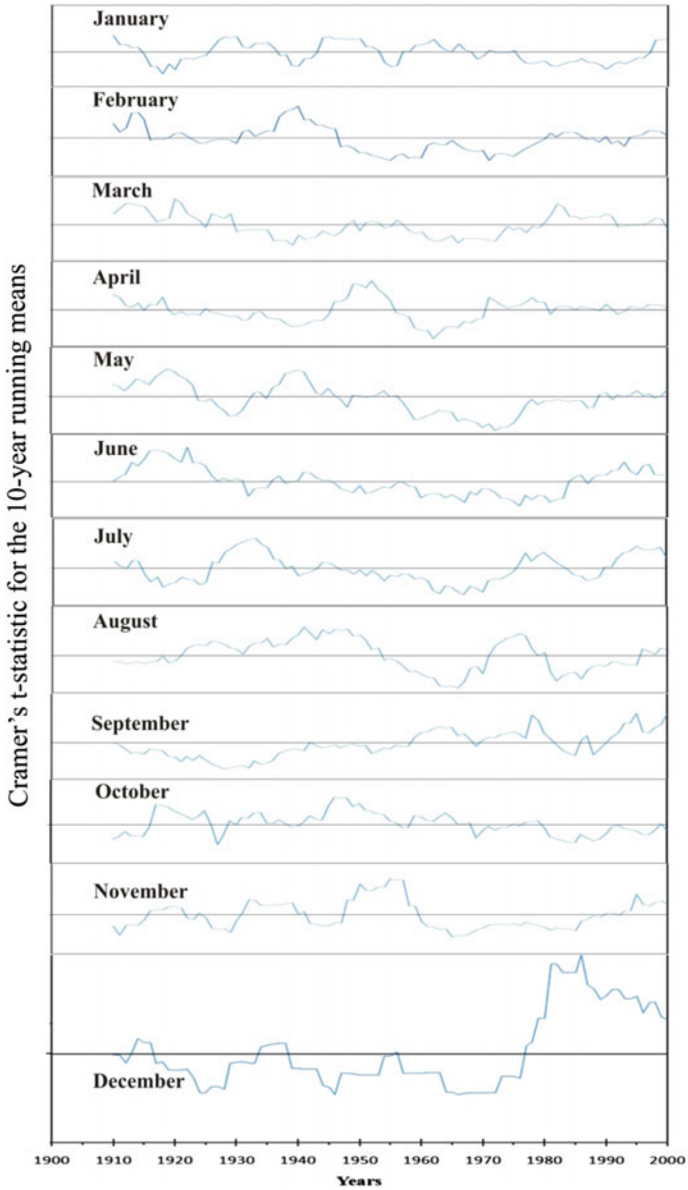

Fig. 13.4 Multiple time series plots of Cramer's t statistic for the 10-year running means, depicting decadal fluctuations in the basin's monthly rainfall for eight major districts of West Bengal

rainfall events nor the extraordinary floods occur every year in the same basin. In order to determine whether the frequency of large floods has increased in the last few decades of the twentieth century, the largest floods were considered and the decadal frequency was calculated. Hence, all the floods on the rivers of BHB during the twentieth century are not adequately represented in Fig. 13.5.

Notwithstanding these limitations, it is quite clear that the frequency of large and extreme floods was higher during the five discrete decades in general (1900s, 1940s, 1950s, 1970s and 1990s). A significant link between the Indian monsoon rainfall and 1970s and 1990s decade floods is observed. But on the other hand, there is no relation between excess flood occurrences and rainfall events in the 1900s, 1940s and 1950s

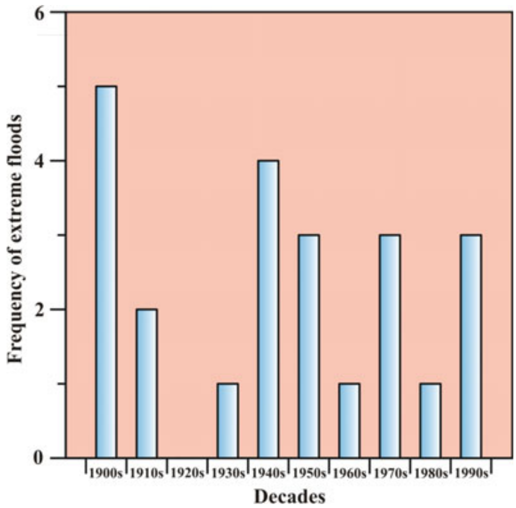

Fig. 13.5 Decadal variations in the frequency of extreme floods in Bhagirathi-Hooghly Basin (BHB). The plot is based on 23 largest floods on all the major BHB rivers in twentieth century

decades. As there is a decreasing trend in the annual rainfall in BHB, the correlation between monsoon flood and rainfall may be insignificant in the long term. Further, based on long-period average (LPA) and percent deviation from long-period average, the distribution of rainfall in monsoon months is classified as deficit, normal and excess events to probe into the relationship. The southwest monsoon rainfall was classified as deficit when the actual rainfall was <LPA ± CV; normal when actual rainfall was within LPA ± CV, and excess when actual rainfall was >LPA ± CV of the corresponding year. Analysis of 100 years of (1901–2000) monsoon rainfall revealed that the basin received only 23 normal monsoon years (< LPA ± CV >), while 77 years received either deficit (<LPA-CV: 73 years) or excess (>LPA + CV: 4 years) monsoon rainfall (Fig. 13.6). The link between monsoon flood and excess rainfall is reflected in the year 1941, 1971 and 1999. But the other large floods during this century in this basin may have occurred due to some other reasons or the excessive rainfall of the adjacent region (state of Jharkhand and Bihar). Because most of the rivers in this basin are cratonic, their origins are from Jharkhand and Bihar.

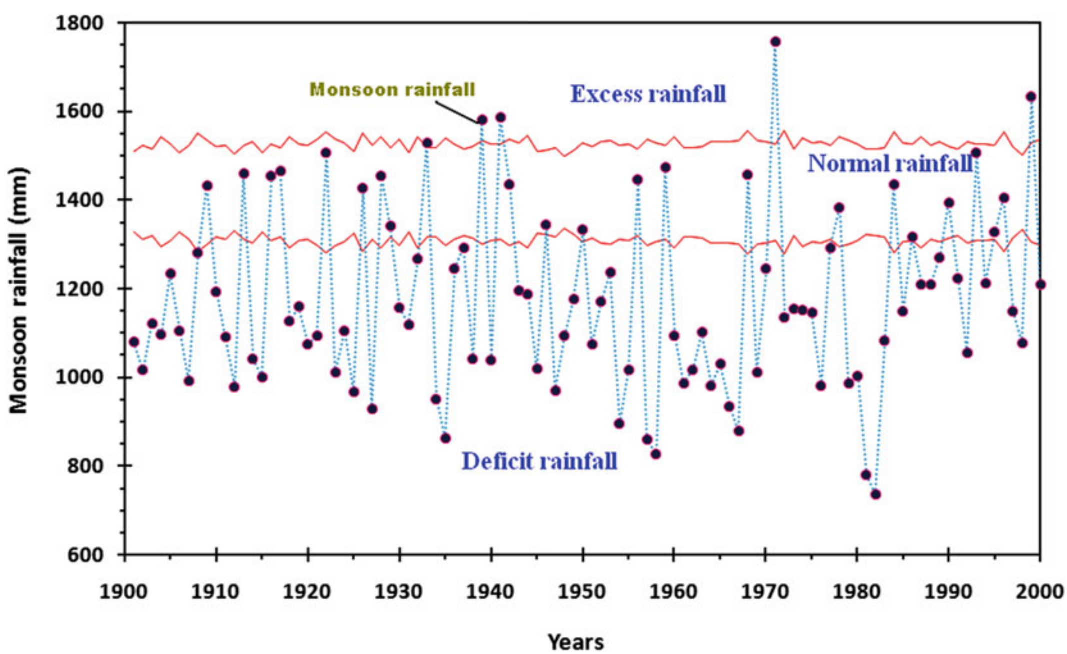

Fig. 13.6 Categorization of long-period (1901–2000) monsoon rainfall as deficit, normal and surplus at BHB

13.6 Conclusion

An understanding of temporal distribution and changing patterns in rainfall is a basic and important requirement for the planning and management of water resources. The present study examines the variability and trends in annual and seasonal rainfall for the eight districts of BHB, West Bengal. The investigation showed a long-term insignificant decline trend of annual as well as pre-monsoon and winter rainfall, whereas an increasing trend in southwest and post-monsoon season. During monsoon season the monthly rainfall in June and August were found to be in decreasing trend, but there was increasing trend in the month of July and September. There was a major shift in rainfall pattern temporarily during recent years as seasonal rainfall during the pre-monsoon was declining while increasing in post-monsoon season. Analysis of 100 years of (1901–2000) monsoon rainfall also revealed that the basin received 23 normal monsoon years, while 4 years received excess and 73 years received deficit monsoon rainfall. In the present study, the long term data set though has shown statistically insignificant trend at 95% level, it may not explain problems of real fact. However, the shorter period of recent database showing higher significance may have better practical utility. This has an implication in water resource development projects that depend on water from rivers. The trends and variability of rainfall clearly indicate the climatic impact that can have adverse impact on economic development of the basin. To minimize the climatic impacts, proper adoption and mitigation measures are required to be taken, but we cannot have control on natural factors causing climate change, while the anthropogenic activities can be controlled. As anthropogenic forcing should have caused a small increase in global mean precipitation (Zhang et al. 2007), it is recommended that people should overcome the problem by reducing interventions. The other way of coping with this problem is to diversify the economic base of the populace with emphasis on reducing over dependence on rain-fed agriculture. Finally, the assessment of rainfall trend in temporal and spatial scales is necessary for BHB including West Bengal state to have a detailed information at district level for better understanding and control over disasters and management of water resources. The results from the study would be useful for proper management of water resources as well as economic development of the basin with special reference to agriculture. Accordingly, the formulation of government policies for development in this area should essentially be based on recent rainfall trends.

Acknowledgements The authors wish to express their gratitude toward Department of Geography, The University of Burdwan for providing all the facilities needed for preparing this manuscript. Indian Meteorological Department (IMD), Government of India and Irrigation and Waterways Department, Government of West Bengal are thankfully acknowledged for providing the district rainfall data sets and flood event occurrences for this research, respectively. Indian Council of Social Science Research (ICSSR) is duly acknowledged for study grant (Ref. No. ICSSR-ERC/2014-15/15) to visit and consult libraries for collecting research materials. Author (S.B.) acknowledges the financial support in the form of grants provided by International Association for Mathematical Geosciences (IAMG) for carrying out part of this research. The present research work is a contribution to the thrust areas of UGC-SAP-DRS Programme.

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Impacts of Beach Placer Mineral Mining in the Shallow Coastal Aquifers of Southern Tamil Nadu Coast, India

14

S. Selvakumar and N. Chandrasekar

Abstract

Groundwater in the coastal area is relatively vulnerable to the contamination by seawater intrusion, which makes it unsuitable for drinking or irrigation. This study was carried out along the coastal aquifer of southern Tamil Nadu, India. To access the impact of mining, the coast was divided into three sites, namely (i) non-placer sand area, (ii) active mining area and (iii) inland dune area. The non-placer sand area is assumed to be undisturbed and is considered as reference site. The inland dunes sand area is the area with no active mining but within the impact of the mining activity. Hydrogeochemical and groundwater table characteristics of shallow coastal aquifer system in the mining and non-mining area were investigated to identify the salinization process. The Na/Cl ratio, correlation matrix and ionic relationship between major ions showed a marked increase in salinization in the active mining area and nearby wells. The reverse ion exchange and seawater intrusion control the groundwater chemistry along the active mining aquifers. The spatial visualization of electrical conductivity, salinity, chloride and groundwater quality index map (GWQI) that reflects active mining areas are exhibiting poor water quality and are comparatively low in non-placer mining areas. Gibb's diagram representing evaporation is the dominant process more than the rock water interaction and precipitation. The groundwater level fluctuation in both inland dune and non-placer sand area aquifers blocks a little variation due to lack of rainfall, irrespective of volumes of water recharge and over pumping of groundwater for irrigational purposes. In the active mining region, the groundwater level shows high fluctuation of ±3 to ±5 m below the ground level. Depth profile study indicates the highly depleted groundwater level in the active mining region that has induced higher EC value and salinity. The process might, therefore, be related to the saltwater encroachments. Tidal induces changes in water level in the Karamaniyar river estuary and near the active mining wells around 1.03 m and the Vembar river estuary water level increased in the wells around 0.68 m.

Keywords

Groundwater salinity · Seawater intrusion · Beach placer mining · Southern Tamil nadu coast

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_14

14.1 Introduction

Salinization of potable water resources is an emerging issue in India and it may damage agricultural productivity and health. Continued groundwater withdrawals, compounded by a decrease in groundwater recharge, can trigger the seawater/freshwater interface to move inland resulting in additional salinization of the coastal aquifer (Blanco et al. 2013). The seawater intrusion phenomenon can be attributed to a variety of conditions like gentle coastal hydraulic gradients, tidal and estuarine activity, excessive and heavy withdrawals of groundwater from coastal plain aquifers, depletion of groundwater level, low infiltration and local hydrogeological conditions. Sea-level rise associated with climate change is a potentially significant process that is expected to play a role in seawater intrusion. Where sea-level fluctuations are retained within the intertidal zone (i.e., coastal barriers are not overtopped), their influence on seawater intrusion is more ambiguous (Werner et al. 2013).

The coastline of southern Tamil Nadu has witnessed largest beach placer mineral extractions for more than several decades. One of the most serious and subtle but ignored negative consequences of sand mining is on groundwater recharge and quality as a result of the extraction process. For instance, some of the characteristics that make sand a valuable resource also makes it very good aquifer and recharge material. Sand mining within an aquifer recharge will increase the vulnerability of the aquifer in the coastal region, because it decreases the distance between the water level, land surface and sea level. Impact of mining on the land environment gets reflected in land-use pattern of the respective areas, because the land gets more exposed to erosion by losing its green cover or by getting disturbed otherwise due to mining (excavation, overburden dumping etc.) and related activities. Water resources get damaged, soils get contaminated, and part or total of flora and fauna get lost. Air and water get polluted and more damages go on proceeding in accelerated rates and the cumulative effects push the land toward degradation. The coastal sand excavation in this region has actually penetrated into the shallow aquifer, leading to a direct access to groundwater. Despite, there have been no studies on the extent of coastal placer mining operation or of the impact in shallow coastal aquifers. Yet, minimization of the negative effects of sand mining requires a detailed understanding of the nature and sources of the impact groundwater resources. The aim of this study is therefore, on shallow coastal aquifer of the coastal areas, to provide proper resource management and utilization. Salinization occurrence has been recognized by groundwater quality measurements, depth to groundwater level measurements and tidal level fluctuation. Avoiding saltwater intrusion is particularly important because once contamination has occurred it is often very difficult and expensive to remediate (Dominico and Schwartz 1990). Hence it is important to realize that seawater intrusion is a dynamic not a static process that depends on the periodic changes in the recharge and discharge balance of the aquifer. Any influence direct, or interaction, on the aquifer in water balance affects the position and movement of the seawater interface and chemistry of the groundwater (Elena Gimanezforcada 2010). Seawater intrusion into coastal fresh groundwater aquifers depends on surface and underground topography, hydraulic characteristics of aquifer, change in precipitation volume, groundwater flow patterns, infiltration rate, tidal and estuarine activity, overexploitation of groundwater and anthropogenic contamination of soil and water (Mondal et al. 2011; Singaraja et al. 2016). In the context of current status, a detailed study to determine the hydrogeology of the coastal mining area and the nature as well as extent of saltwater intrusion is a prerequisite in the prevention of further saltwater intrusion and is urgently required. Further, it is predicted that water abstraction will increase by 50% in the region, as population growth and development drive result in upward demand by the year 2025. In recent years, the availability of water and its quality have emerged as the major constraints to economic development and quality of life.

Therefore, the main objective of the present study is to assess the impact of sand mining based on the hydrochemical characteristics of groundwater emphasizing on the spatial extend of salinity of groundwater, water-level fluctuation and tidal-level activities of shallow coastal aquifer.

14.1.1 Study Area

14.1.1.1 Geographical Location

The present study area extends from south of Vembar to the north of Kanyakumari, which lies between latitude 8°08′ to 9°09′N and longitude 77°55′ to 78°35′E covering the districts of Tuticorin, Tirunelveli and Kanyakumari, Tamil Nadu, India (Fig. 14.1). The study area has many rivers such as Vembar, Vaippar, Tamiraparani, Karamaniyar and Nambiyar, which drain into Bay of Bengal.

14.1.1.2 Geomorphology and Hydrogeological Settings

The coastal area is mainly underlain by the geological formations comprising crystalline Archaean complex, tertiary and sub-recent to recent groups (GSI 1995). The crystalline rocks of late quaternary deposits and sandy materials are present along the study area. The coastal areas of Navaladi, Uvari and Periyathalai consist of red color sand sheets and dunes which are locally known as "Teri" that lies at some distance away from the shore. The red "Teri" formation is mainly composed of red-stained quartz with an admixture of fine red clayey dust and fine grains of iron ore. The coastal areas around Tuticorin and Tiruchendur are mainly used by the salt industry. The total coastal length of 223 km in the area has been the most intensively mined shoreline. The sandy shoreline is backed by extensive dunes having the maximum height of 15 m. These sites are mined for placer minerals such as garnet, ilmenite, zircon, sillimanite and rutile which are of high commercial value. The primary dunes and secondary dunes are exposed to wave runup. The mining is mainly between the primary dunes and mean water high level up to a depth of maximum 6 to 10 m. High tide and storm waves allow swash to undercut the dune with sand sliding into the beach and causes the seawater intrusion into the coastal aquifer.

The aquifer in the coast is shallow at −5 to −8 m in MSL. The average thickness of non-confining material is 3 to 12 m. Potentiometer change across the coastal sand dunes −0.3 to −0.6 m. The storage capacity of the coastal aquifer generally increases with depth with the increase in the grain size of aquifer material. Vertical hydraulic gradient is −0.85 to +1 m. The amount of seawater recharge in the mining area and other area depends upon the non-confining material is 0.02 to 0.08 m^2/day. The susceptibility to intrusion in a particular location is directly dependent on the vertical thickness of the aquitard and permeability of the sand. In all sites the wells are located between 10 and 5000 m from mining operations. Large and deep pit as a result of deep excavation from the mean high water level to the dunal area, the water tables drops, quantity and quality of water are affected especially during the dry season when there is no rainfall. (Annual rainfall amount ranges from 500 to 900 mm.) Due to lack of rainfall in these regions, the water table is also lowered in the mining site.

14.1.2 Materials and Methods

14.1.2.1 Sampling and Analysis

In order to evaluate the impact of sand mining, open wells are fixed within a 5 km radius. Groundwater samples in each of three sites at various flow levels were collected for analysis. The groundwater is mainly used for drinking, domestic, irrigation or for blending with desalinated and recreational purposes. The groundwater samples were collected in a HDPE bottles with a capacity of 500 ml, in minimally anthropogenically impacted. Before water sample collection, the bottles were thoroughly cleaned by rinsing with HNO_3 and deionized water. At the time of sampling, the bottles were rinsed three times using the groundwater to be sampled. The

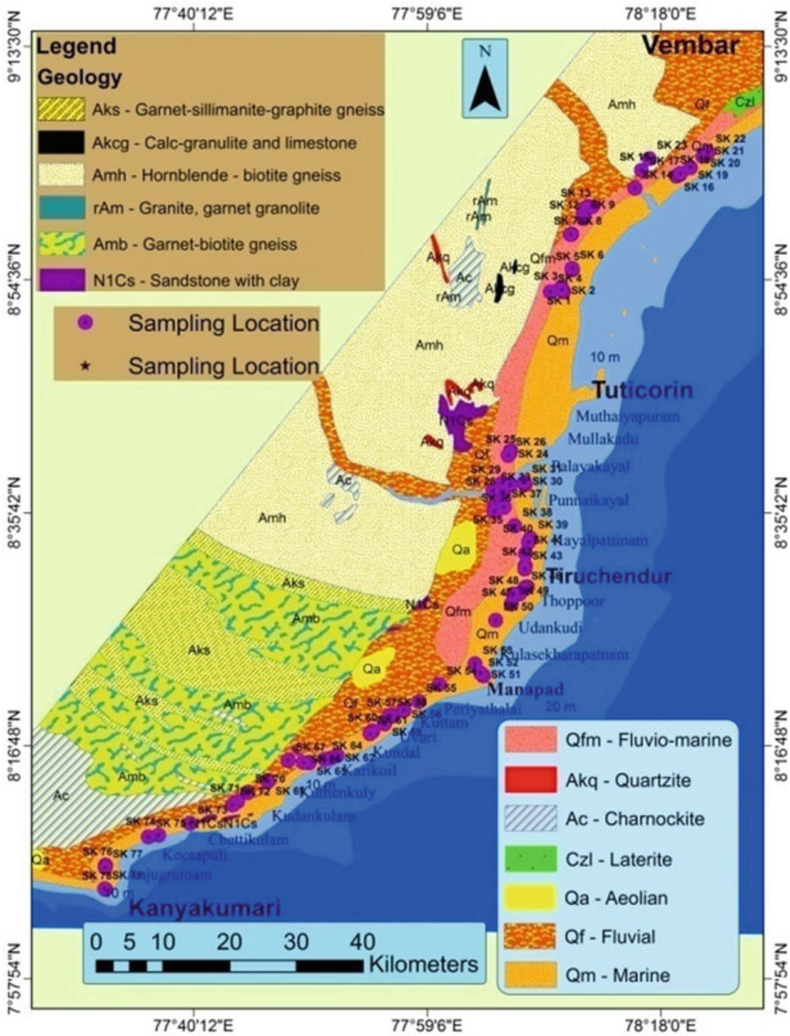

Fig. 14.1 Geology map of the study area with sampling point's location

bottled samples were immediately transported to the laboratory. Field parameters pH, electrical conductivity corrected to 25 °C (EC), total dissolved solids (TDS) were measured in the field, with previously calibrated instruments. On-site testing was necessary for these parameters since they are likely to change during transport. These variables were measured by using Hanna portable water quality meter (HI-9828, USA). Salinity was measured using sodium chloride refractrometer by using HANNA. The chemical parameters such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and HCO_3^{-}, Cl^{-}, SO_4^{2-} were determined in the laboratory following the methods of APHA (1995). The accuracy of the chemical analysis has been verified by calculating ionic balance error which is generally with 5%. The chemical data were utilized to evaluate the water quality; ionic concentrations were calculated to characterize the hydrochemical processes, correlation matrix, ionic relationship, were performed. Various factors controlling groundwater chemistry were analyzed by Gibb's diagram to identify the water quality. The Water Quality Index (WQI) map was prepared by computing the individual point data and then plotted in GIS.

14.1.2.2 Groundwater Level and Tidal Level Measurements

The groundwater levels in the sampling wells were recorded using a water level recorder. Tidal water levels were measured at estuary mouth of nearby beaches and inland dug wells. The influence of tide on the estuarine water level was measured using a Schlumberger data logger. Monitoring wells consisting of 3.2 cm diameter PVC pipe with a 7.6 cm screen at the bottom were installed in shore and river banks for tidal level and temperature measurement (Urish and McKenna 2004). The pressure transducers include atmospheric pressure compensation and were connected to a data logger for continuous data recording on hourly basis. The location of the sampling stations, elevation and distance from the coast was measured using Garmin E-trex 12-channel global positioning system (GPS).

14.1.3 Results and Discussion

14.1.3.1 Groundwater Chemistry

The quality of groundwater has equal importance as the quantity and this has been recognized only a couple of decades ago. The characteristic of groundwater (hard or soft; mineralized or non-mineralized) depends on extend of reactions with the country rock (Edmunds 1994). The identification of major controlling mechanisms of groundwater chemical composition and dynamics of flow systems are necessary for optimal management of coastal aquifers (Amiri et al. 2016). Salinization of groundwater due to seawater intrusion can be precisely examined using the water chemistry data along with hydrogeological assessments (Han et al., 2014). The result of hydrochemical analysis and field measurements for 79 groundwater samples for three years and its statistical parameters (i.e., minimum, maximum and mean) with drinking water specification are summarized in Table 14.1. Hydrogeochemical characteristics and preliminary investigation of groundwater quality analysis was performed (Selvakumar et al. 2012; Chandrasekar et al. 2013).

The pH of the analyzed samples that are alkaline in range varies from 6.17 to 8.9 (average 7.66). The electrical conductivity values vary from 276 to 14,523 µS/cm with an average value of 3,563.7 µS/cm in the year 2012. On examining the EC (Saxena et al. 2004 and Mondal et al. 2009) the groundwater was classified into three categories such as freshwater (<1,500 µS/cm), brackish water (1500–3000 µS/cm) and saline water (>3000). Based on the classification, 44% of the samples are found in saline water and 18% of the samples have brackish water, and the remaining 38% samples are fresh in nature. Abnormal high value of EC indicates the possibility of seawater intrusion. The electrical conductivity of water is an easy indicator of its salinity or total dissolved content. The spatial distribution map of TDS in the groundwater samples are shown in Fig. 14.2.

The maximum values of TDS are reported from Manapad to Navaladi zones and Chettikulam area where intensive beach placer mining is noticed and hence making the groundwater unsuitable for drinking. Moreover, the excavation of beach placer minerals from these sites disturbs the hydrologic conditions of these aquifers, which in turn results in seawater intrusion. The higher TDS concentration is due to other sources like saltpan activities, irrigation return flow and seepage from untreated domestic sewages. However, low TDS values are observed (<1000 mg/l) in villages of Pattinamaruthur, Veppalodai, Mettupanaiyur, Palayakayal, Punnakayal, Keeranur and Leepuram, which indicates the availability of fresh groundwater.

The cation and anion concentrations confirm most of the groundwater samples belong to the order of $Na^{+} > Mg^{2+} > Ca^{2+} > K^{+}$ and $Cl^{-} > SO_4^{2-} > HCO^{-}_3$ for cations and anions, respectively. The calcium and magnesium concentration varied from 24.1 to 1864.8 mg/l and 28.8 to 1174 mg/l. Sodium, the dominant cation, ranged between 104.1 and 804.2 mg/l. Most of the groundwater samples (82%) exceed the maximum permissible limit (200 mg/l) of WHO (2004). Spatial distribution of sodium (Fig. 14.3) indicates that the high concentration was noted

Table 14.1 Drinking water specification of the study area in comparison with WHO (2004) and BIS (1991), minimum, maximum and average ion concentration in all the three years

Parameters (mg/l)	2011			2012			2013			WHO (2004)	BIS (1991)
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg		
pH	6.79	8.50	7.64	6.9	8.3	7.59	6.17	8.9	7.75	6.5–8.5	6.5–9.2
EC (µS/cm)	288	12,540	3317	276	1452.3	3574	307	13,840	3800.4	1500	–
TDS	184.3	8026	2123	176.6	9294.7	2287	196.5	8857.6	2432	1500	1500
Ca	26.4	1311.3	157.6	29	1062	162.5	241	1864.8	181.3	200	200
Mg	28.8	1120.4	236.3	34.1	1094.6	243	31.3	1174.4	259.7	150	100
TH	249.7	6812.7	1366.4	240.3	6644.5	1407.4	210.3	9650	1593	500	600
Na	88.1	582	281.5	81.5	715	307	78.4	842.1	333.4	200	–
K	1.24	164.8	38.9	2	181	44.7	2	167	48.7	12	–
HCO_3	22.2	196.6	73.6	18.3	146.4	74.1	24.4	167.1	73.2	500	–
Cl	306.5	5876.4	1271.3	202.6	5978.2	1313.9	216.5	5982.6	1419.6	600	1000
SO_4	27.1	188.2	108.4	21.3	197.4	109.4	28.9	264.8	126.4	250	400

between Manapad and Koodankulam zone. Sodium is found to be associated with high concentration of chloride resulting in salinity. Water with high sodium content is not suitable for agricultural use as it tends to deteriorate the soils.

Chloride content in the groundwater samples shows a wide range in concentration, ranging between 202.6 and 5978 mg/l and with a mean value of 1355.0 mg/l. According to WHO (2004), the maximum permissible limit of chloride in the groundwater is 600 mg/l. Based on this limit 58% of the groundwater samples are within the permissible limit and the rest exceeds the permissible limit. The spatial distribution map (Fig. 14.4) indicates the high concentration of chloride noted between Manapad and Koodankulam zone (>2000 mg/l), and it is particularly derived from seawater entrapped in aquifers, solution of halite and related minerals in evaporated deposits. Chloride is the most commonly ion used as an indicator of seawater intrusion (Tibbott 1992).

The bicarbonate and sulphate anions varied in the range of 18.3–296.6 and 21.3–264.8 mg/l, respectively. From a careful examination of these data, it was clear that the sodium, magnesium, chloride and sulphate ions showed a wide range of distributions and high standard deviations. This suggests a possible incursion of nearby saline water, which has comparatively higher concentrations of sodium, magnesium, chloride and sulphate.

The groundwater quality index map of the coastal area is shown in Fig. 14.5 and it highlights the spatial distribution of overall groundwater quality in terms of drinking purpose. The results reveal that out of 79 groundwater samples, 42 samples in the study area fall under poor water quality zone, which is attributed to the depletion of water table and incursion of seawater in the active mining nearer to the sampling stations. Non-placer sand area and inland dune area groundwater falls under marginal to good water quality zone.

14.1.3.2 Ion-Exchange Reactions

Numerous hydrochemical process may take place in the freshwater/seawater contact zone of a coastal aquifer, which alter the mixture of freshwater/seawater away from the theoretical composition (Appelo and Postma 2005). When saline/saltwater encroaches on fresh coastal groundwater aquifers, Na^+ substitutes part of the Ca^{2+} on the surface of solid particles, and the following reaction takes place:

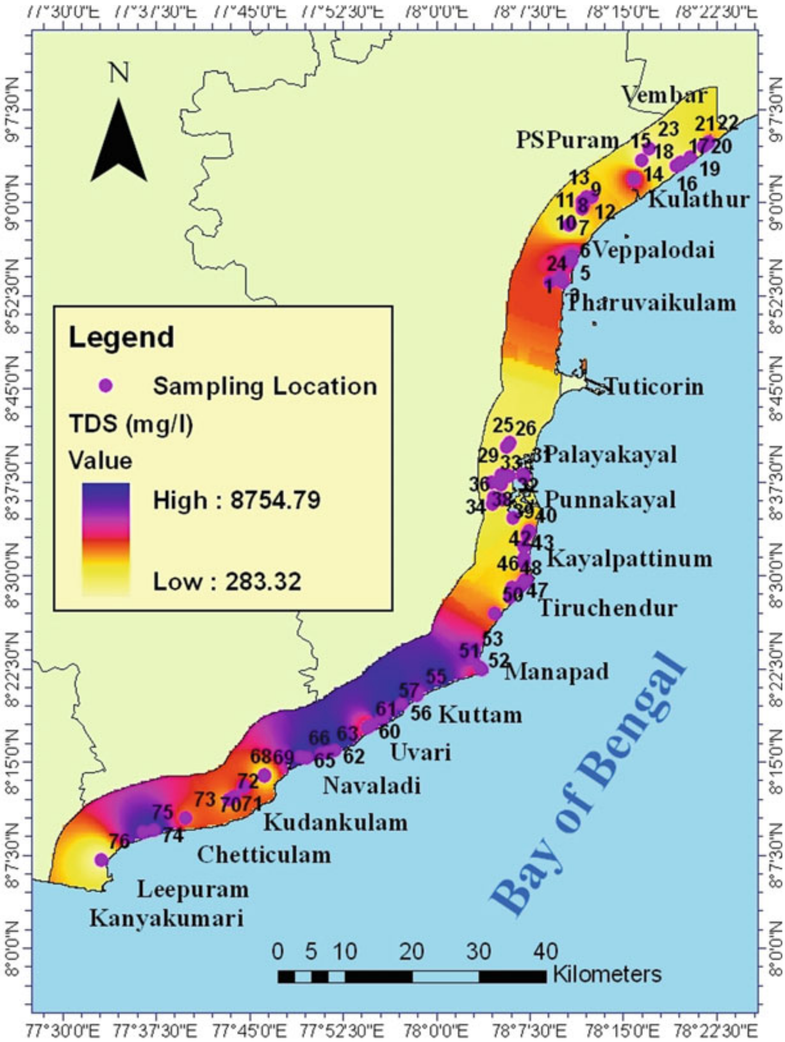

Fig. 14.2 Spatial distribution map of total dissolved solids

$$Na^{+} + 1/2Ca^{2+} - X_2 \rightarrow 1/2Ca^{2+} + Na - X$$

where X is the natural ion exchange. For this reaction, Na^+ is taken up by the exchange, while Ca^{2+} is released into the water for the reason that the chloride remains the same, a depletion of Na^+ relatively to chloride in groundwater is therefore observed when seawater intrudes the previously fresh groundwater aquifer. On the other hand, if seawater intrusion is stopped for some reason and the fresh groundwater flushes the aquifer, the reverse cation exchange reaction takes place as follows, resulting in enrichment of Na^+ relative to Cl^-

$$½Ca^{2+} + Na^{+} - X \rightarrow 1/2Ca - X_2 + Na^{+}$$

The freshwater intrusion into mixing zone leads to absorption of Ca^{2+} and Mg^{2+} by the ion exchangers with simultaneous release of Na^+. This reaction can increase the Na^+/Cl^- value and reduce the $(Ca^{2+}/Mg^{2+})/Cl^-$ ratio. In general, the Cl^- does not remove from the system because of its more solubility and high residence time. A depletion of sodium relative to chloride indicated in the coastal groundwater aquifer in the area is contaminated by saline intrusion; enrichment of sodium ion indicated gradual freshening.

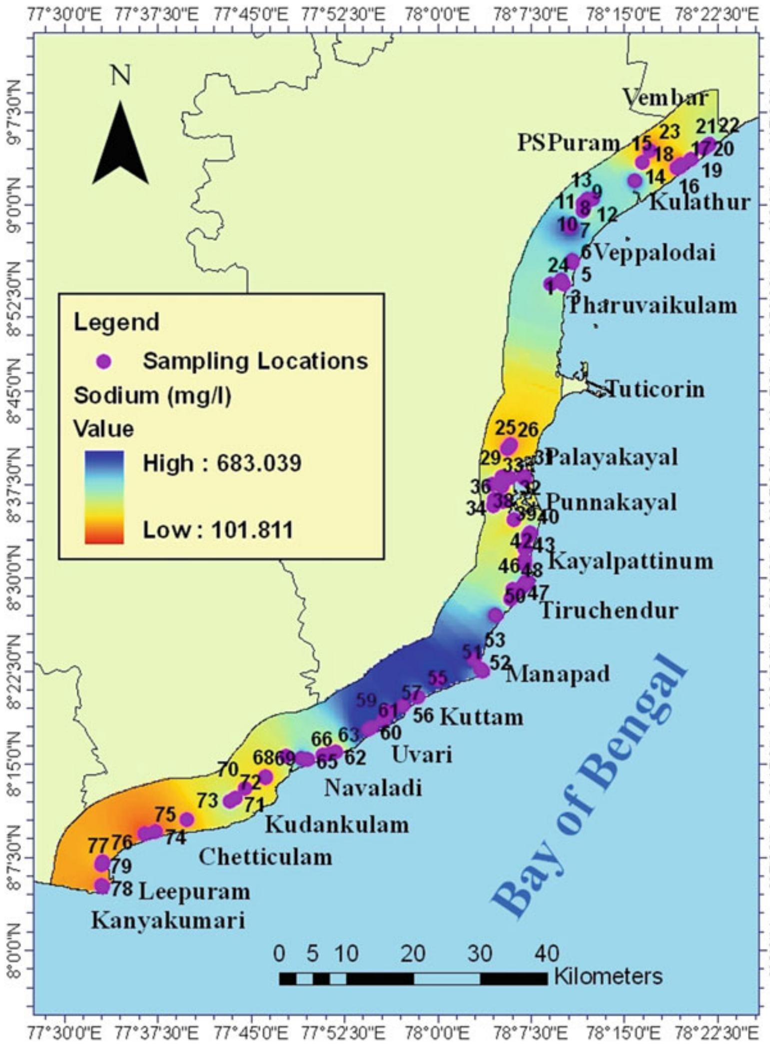

Fig. 14.3 Spatial distribution map of sodium

Appelo and Postma (2005) have described when saline/saltwater encroaches into fresh coastal aquifers, and so an exchange of cations occurs. It is indicated by the relationship between Na^+ and Ca^{2+}, particularly in samples with negative Na_{change}. Such a process is highly influenced by the seawater signature whereas when more seawater intrudes into the aquifer, the negative value of Na_{change} increases. In order to interpret the dynamic characteristics of saltwater encroachment, some bivariate diagrams and the relationship between EC with Ca^{2+}, Mg^{2+}, and Cl^- are assessed. The EC versus Mg^{2+} and Cl^- shows a relatively linear correlation (Fig. 14.6). It reveals that admixture with seawater intrusion is one of the potential processes responsible for the groundwater salinization. The relationship between EC versus Ca^{2+} and SO_4^{2-} indicates that concentration of SO_4^{2-} is generally determined by the presence of saltwater encroachment into coastal aquifers and is also associated with redox conditions along the seawater/freshwater interface.

14.1.3.3 Statistical Screening of Groundwater Data for Correlation Analysis

To understand the relation between different ionic concentrations, inter-elemental correlation was made. Table 14.2 presents the correlation of coefficient matrix for all physicochemical

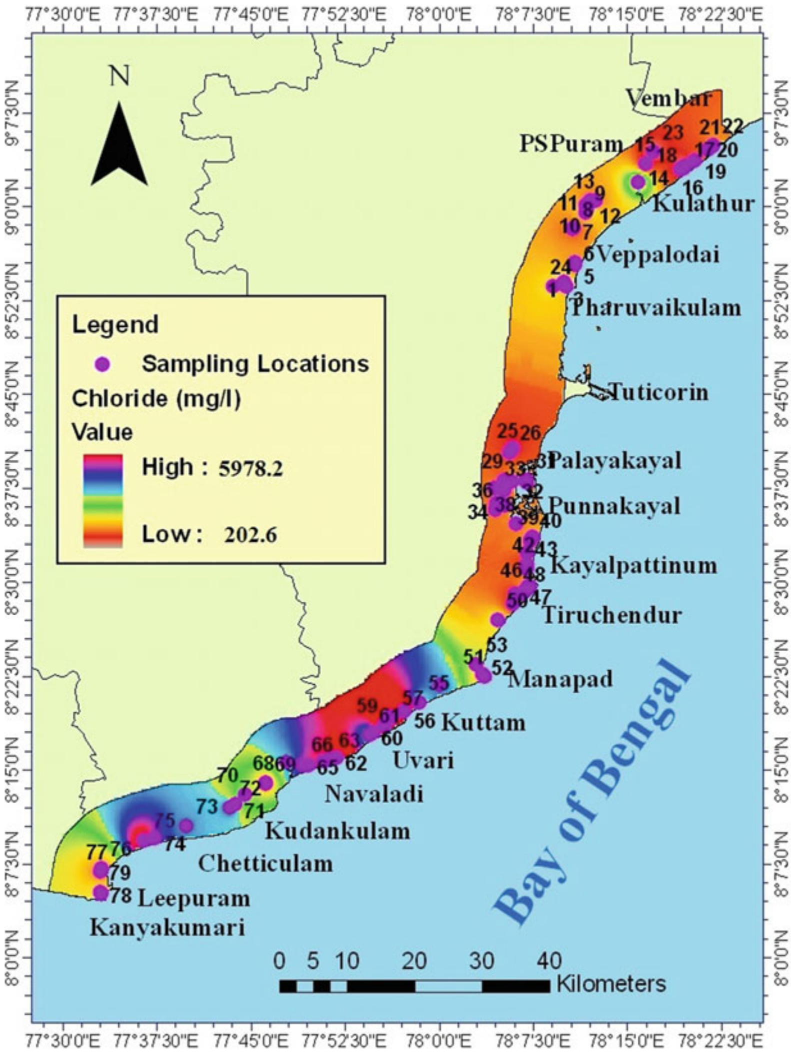

Fig. 14.4 Spatial distribution map of chloride

parameters. If the correlation coefficient (r) is greater than 0.7 and between 0.5 and 0.7, it indicates strong and moderate correlation of two parameters, respectively. Based on Spearman's correlation, it was found that the correlation between EC (salinity) and TDS with the major components of seawater (Na^+, Mg^{2+}, Cl^-, SO_4^{2-}) showed significant positive correlation (TDS and Mg^{2+} ($r = 0.774$); TDS and Na^+($r = 0.594$); TDS and Cl^- ($r = 0.825$) and TDS and SO_4^{2-} ($r = 0.602$)) that reflects signs of seawater influence on the groundwater salinity. The significant correlation of Cl^- ion with Na^+ and Mg^{2+} (Cl^- and Na^+($r = 0.659$); Cl^- and Mg^{2+} ($r = 0.872$)) reflects the significance of seawater intrusion into groundwater in the active mining area. The main contributors to the groundwater salinity are Na^+, Mg^{2+}, Cl^- and SO_4^{2-}, which show significant correlation with EC similar to TDS.

14.1.3.4 Mechanism Controlling the Groundwater Chemistry (Gibbs Plot)

Gibbs (1970) established the mechanism controlling the chemical composition of groundwater to find out a close relationship between chemical composition of water and aquifer lithological

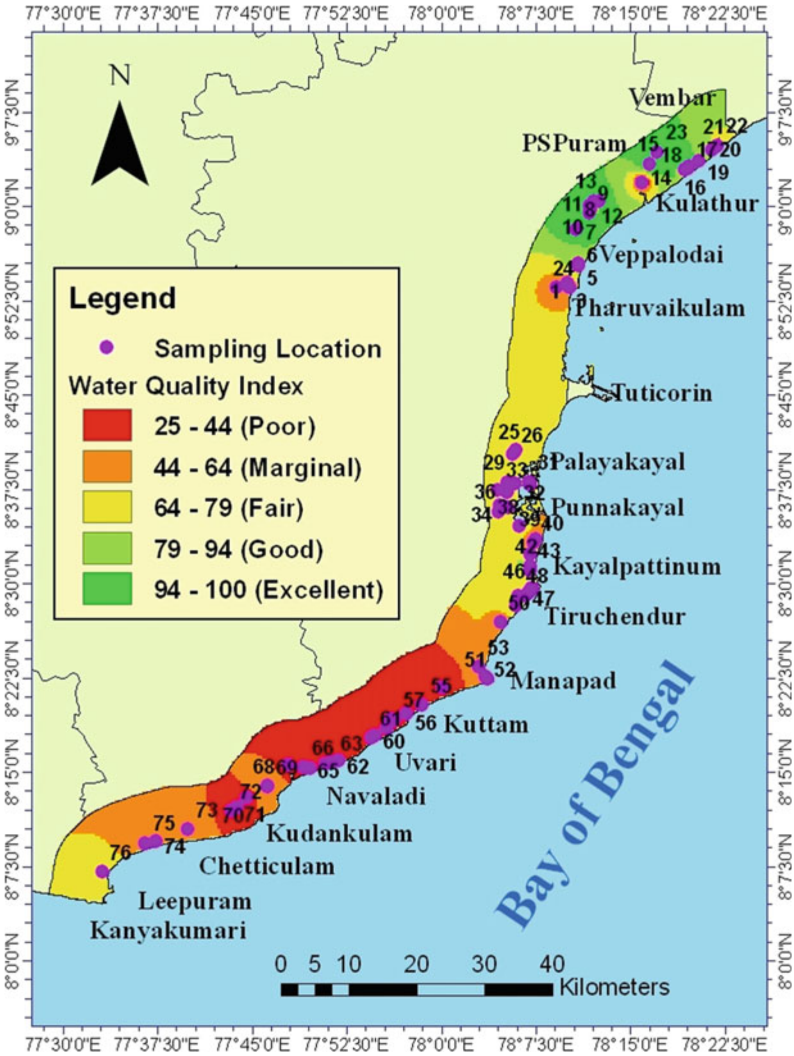

Fig. 14.5 Ground Water Quality Index (GWQI) map of the study area

characters. In this diagram, three distinct fields are recognized, such as evaporation dominance, rainfall dominance and rock water interaction on water chemistry. Gibb's plots were created from ratio I (for anion) $Cl/(Cl + HCO_3)$ and ratio II (for cation) $Na/(Na + Ca)$ of the groundwater samples which are plotted separately against the respective values of TDS. Figure 14.7 indicates that most of the groundwater samples fall under evaporation zone and few samples are placed under rock/water interaction field. Evaporation process is not only a common phenomenon in surface water but also in groundwater system (Jankowski and Acworth 1997). The result reveals that evaporation is the dominant process due to dry and arid condition prevailing throughout the region. Na/Cl ratio tends to be constant when EC rises up to certain extent in the non-mining areas.

14.1.4 Groundwater-Level Fluctuation

Groundwater elevation is significant parameters for monitoring the groundwater aquifer system. The water table of an area is mainly controlled by variations in groundwater recharge, discharge

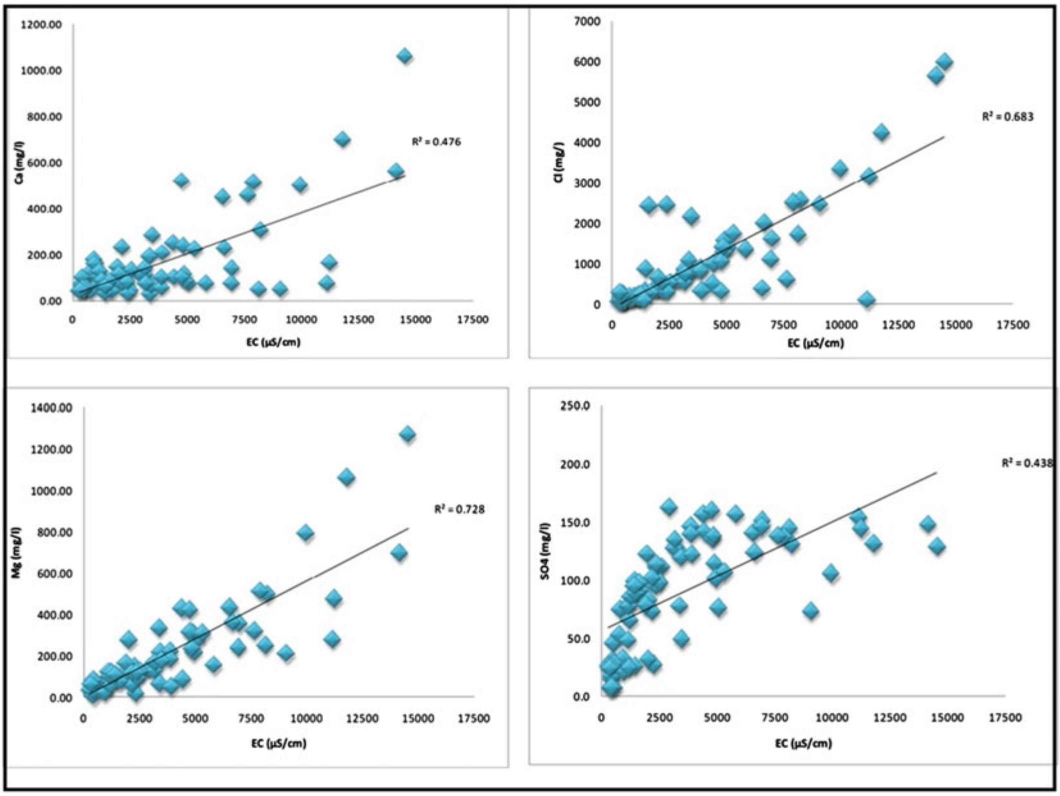

Fig. 14.6 Bivariate diagrams and relation between EC with major ions

Table 14.2 Spearman's correlation analysis for the groundwater samples

Parameters	pH	EC	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO4
pH	1									
EC	−0.336	1								
TDS	−0.336	**0.999**	1							
Ca	−0.447	0.505	0.505	1						
Mg	−0.441	**0.774**	**0.774**	0.7	1					
Na	0.027	**0.594**	**0.594**	0.206	0.39	1				
K	−0.371	0.612	0.612	0.303	0.511	0.413	1			
HCO3	0.11	−0.121	−0.121	−0.347	−0.271	0.009	0.018	1		
CL	−0.377	**0.825**	**0.825**	**0.717**	**0.892**	**0.629**	0.579	−0.332	1	
SO4	−0.034	**0.602**	**0.602**	0.385	0.539	0.372	0.458	0.077	0.531	1

and rainfall. If groundwater levels decline with time, this is an indication of an imbalance between recharge and discharge, and a groundwater table below MSL is an indication of seawater intrusion in the coastal aquifer. The data recorded on water table fluctuation in the observation wells indicated that the depth to water table below ground level was increased from

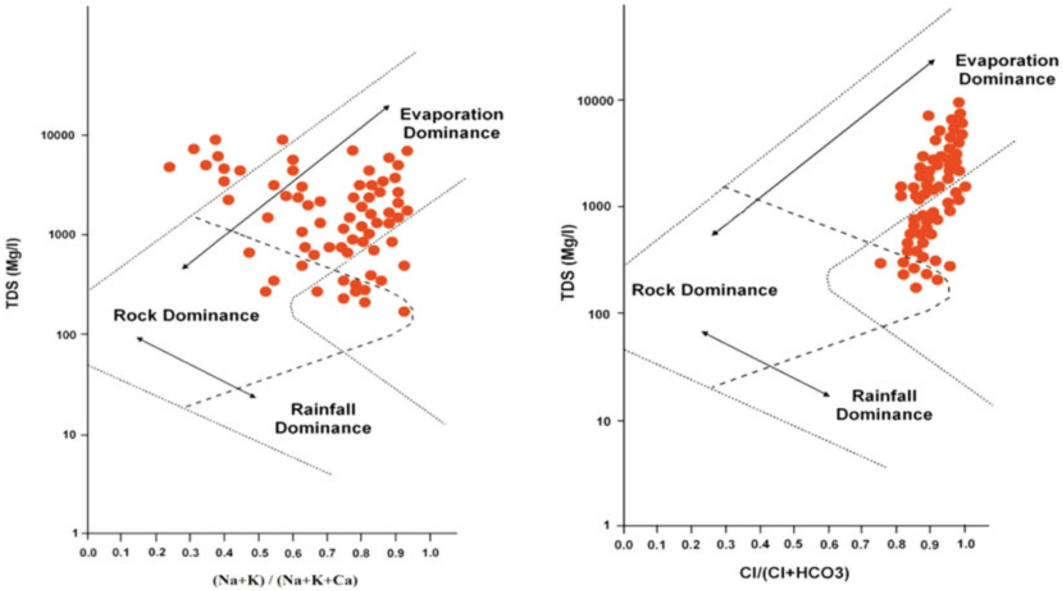

Fig. 14.7 Gibb's diagram illustrating the mechanism controlling the groundwater chemistry of coastal aquifer in the study area

May to August in all the regions. That is, the water level was found to be very near to the ground level during monsoon period and gradually lowered during dry period. Table 14.3 shows the average depth to water table below the ground level recorded in meters from January 2012 to November 2013. In all the regions, water level was found to be increased gradually in the month of January due to the effect of heavy rainfall received during the monsoon seasons.

14.1.4.1 Groundwater Level Fluctuation in Non-Placer and Inland Dune Region

In the non-placer sand region, the average depth to water level was minimum 0.86 m to maximum 1.45 m below ground level, resulting in the average groundwater level fluctuation as 1.02 m in the year 2012. In the same region the average groundwater level fluctuation was recorded as

Table 14.3 Groundwater level fluctuation (minimum, maximum and average) during 2012 and 2013 and yearly mean groundwater level fluctuation of the coastal aquifer

S.No	Sites	Region	Groundwater level fluctuation (mts)						Yearly mean groundwater level fluctuation (mts)
			2012			2013			
			Min	Max	Avg	Min	Max	Avg	
1	Non-placer sand area	Tiruchendur to Manappad	0.86	1.45	1.02	1.14	2.64	1.89	1.46
2	Active mining area	Kuttam to Navaladi	1.78	4.79	2.94	3.36	7.92	5.52	4.23
3	Inland dune area	Vallavanvillai to Kanyakumari (NE)	0.65	1.95	1.23	1.12	4.52	3.21	2.22

1.89 m in 2013. The yearly mean groundwater level fluctuation recorded in the region was found to be 1.46 m. It is formed due to dependence on the natural recharge and utilization of water in using domestic and irrigation purposes. The average depth to water level was varying between 0.65 m and 1.95 m with an average fluctuation of 1.23 m in 2012 in the inland dune regions. In the same region the groundwater table level was depleted (1.12–4.52 m) with an average fluctuation 3.21 in the year of 2013. The yearly mean groundwater level fluctuation is 2.22 m. Groundwater levels in both inland dune area and non-placer sand area aquifer blocks show little variation from summer to summer, irrespective of the volumes of winter recharge.

14.1.4.2 Groundwater Level Fluctuation in Active Mining Region

In the active mining region, the average depth of meters below ground level was found to be increased from 2.94 to 5.52 in January 2012–January 2013 and this gradually decreased till the starting of next monsoon. The average groundwater level fluctuation recorded in the active mining region was 2.94 m in 2012 and 5.52 in 2013. The groundwater level was found to be lowered from 1.78 to 4.79 m below ground level in 2012 and then increased up to 3.36 to 7.92 m below ground level in 2013. In this mining region (Uvari, Kuttam, Karikoil, Navaladi) the yearly mean groundwater level fluctuation recorded the highest fall of groundwater table (4.23 m) in 2012 to 2013 among all the ten monitoring wells. For that reason the wave runup on the swash zone and backshore will induce seawater infiltration into the coastal aquifer during the water table lowered. The infiltration is favored based on the permeability and grain size. This variation formed due to continuous scrapping of dunes along the coastal stretch, thus declines the storage capacity of groundwater into the freshwater aquifers apart from normal groundwater recharge. In the mining sites, more water is required to use for mineral washing and other purposes. Therefore, these areas have pumped more groundwater than limits, and water table was highly depleted. Over pumping of groundwater wells located near the shoreline is a major cause of encroachment of saline water into the aquifers and may lead to seawater intrusion. Because of its high density, saltwater goes inland under the freshwater. Figure 14.8 depth profile indicates that the water level highly declined into the below ground level, and the electrical

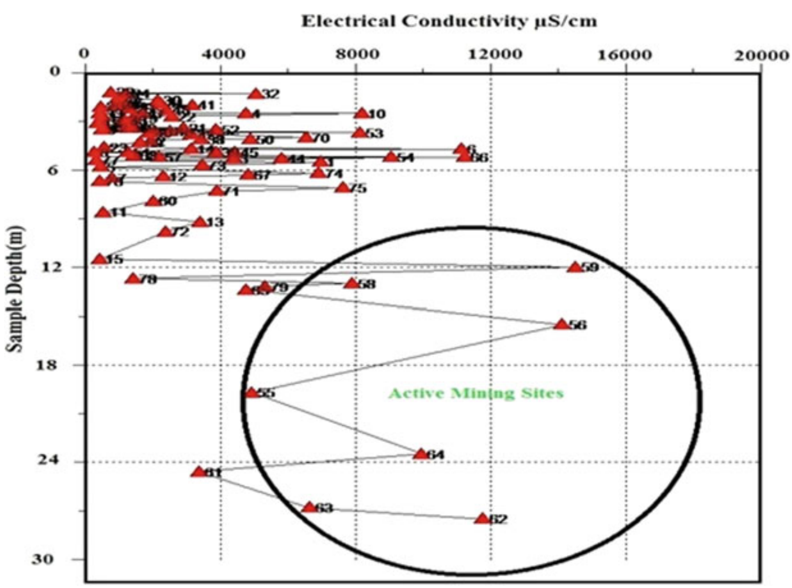

Fig. 14.8 Depth profile map (EC versus sample depth)

conductivity values also increased. The change might therefore be related to the saltwater encroachment into the aquifer. Further, the drastic changes on water level in the active mining region are observed in all seasons, which may be influenced by the transmissivity in dunal aquifers, and the ocean tides in the mining sites located nearer to the backshore has enhanced the effect of water table variation (Kim et al. 2008).

Groundwater extraction is the primary cause of seawater intrusion (Tibbott 1992). In the coastal regions, successive pumping will also cause seawater intrusion, consequently leading to the possibility of polluting the groundwater and corroding subsurface structures. As freshwater resources are depleted, results show an accompanying reduction in the height of the freshwater table, and the saltwater interface begins an upward and inland encroachment. It is important to have a detailed understanding of the spatial distribution of the coastal groundwater level and temporal resolution of the processes that control changes in water table height, and therefore it is essential to monitor groundwater levels continuously throughout the coastal zone in mining sites.

14.1.5 Tidal Level Fluctuation

Tidal activity can often induce a fluctuating water table as well as infiltration of surface water into sediments, forming a surficial mixing zone with groundwater discharging from the adjacent aquifer (Robinson et al. 1998; Ataie-Ashtiani et al. 1999; Zhou et al. 2006). The groundwater behavior in an unconfined aquifer with a mild sloping face in response to a tide is affected by two factors that do not exist in a confined aquifer. These factors are the infiltration of saltwater from the top of the beach slope into the aquifer at high tide and tidal pumping with a free water table. The latter effect is intensive by a mild sloping beach and the existence of a seepage-face at the sea boundary of the groundwater.

The tidal level and groundwater water level fluctuation measurements are studied in Vembar river estuaries, Karamaniyar river estuaries and dug wells near to coastal mining (Fig. 14.9).

14.1.5.1 Vembar River Estuary

The experimental setup was deployed in two selected sites along the Vembar estuary (from 8 am to 5 pm in a day). The minute wise fluctuation was recorded using an automatic data logger device. This device has the capability to monitor the pressure difference and the temperature change. The results reveal that high tide exhibits around 8 am and 5 pm and low tide is noticed around 2 pm in the estuarine mouth monitoring well. This fluctuation is barely because of the medium of water transport. The sediment texture of this site is 99% sand, which allows seawater to easily pass through. However, in other sites (site no. 2, 3, 4) the fluctuations vary with respect to high tide and the level becomes almost stable. This may be due to the presence of clay as it is a poor medium for water transmittance. The hourly tidal fluctuations are shown in Fig. 14.10. The distribution of temperature in the study area is dependent on the temperature of the incoming river and seawater, the mixing processes and on the exchange of heat through the surface. The effect of temperature is to increase the density difference between river and seawater. The study area experiences the tidal-induced water table motion in the phreatic aquifer of the shoreline. The water table range varies between 4.25 and 3.38 mbgl during 2011–2013. In the monitoring well the water table is observed as 2.78 mbgl. This reveals that the tide-induced change in water level is around 0.68 m (Simon Peter et al. 2014).

14.1.5.2 Karamaniyar River Estuary

In the Karamaniyar river estuary, it is seen that the distribution is controlled mostly by the local weather conditions. Surface temperature of the water chiefly depends on the incoming solar radiation; the estuary being a shallow one, the distribution appeared to be dominated by the diurnal effect rather than tidal effect. The study area experiences the tidal-induced water table motion in the phreatic aquifer of the coastal

Fig. 14.9 Tidal level and groundwater level measurements

mining area (Fig. 14.11). The water table range varies between 6.28 and 3.06 mbgl during 2011–2013. In the monitoring well the water table is observed as 3.16 mbgl. It reveals that the tide-induced change in water level is around 1.03 m. A tidal tracer study was conducted by Acworth et al. (2007); it revealed greater vertical fluctuations are relative to horizontal movements in response to tides, which enhanced mixing zone thickness.

14.1.6 Conclusion

The result of geochemical analysis indicates that the groundwater in the study area is slightly alkaline with moderate saline water. The cation and anion concentrations confirm most of the groundwater samples belong to the order of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ and $Cl^- > SO_4^{2-} > HCO^-_3$ for cations and anions, respectively. The increasing of EC, TDS, Na, Mg and Cl concentrations, correlation matrix and ionic relationship shows a marked increase in salinization in the active mining area and nearby wells. Spatial distribution map and water quality index map indicates the poor quality in the active mining regions. Alteration of the hydrologic budget due to anthropogenic and mining of dunal sands has resulted in changes of both the chemical and physical properties of groundwater discharge, and in many cases severely compromises with the groundwater quality in the coastal aquifer. The evaporation process is a dominant responsibility in the present coastal aquifer more than the rock water interaction and precipitation. The groundwater fluctuation level in the active mining sites shows significant variation (±3 to ± 5 m below ground level). This variation is due to continuous scrapping of dunes along the coastal stretch, thus declining the storage capacity of groundwater in the shallow aquifer apart

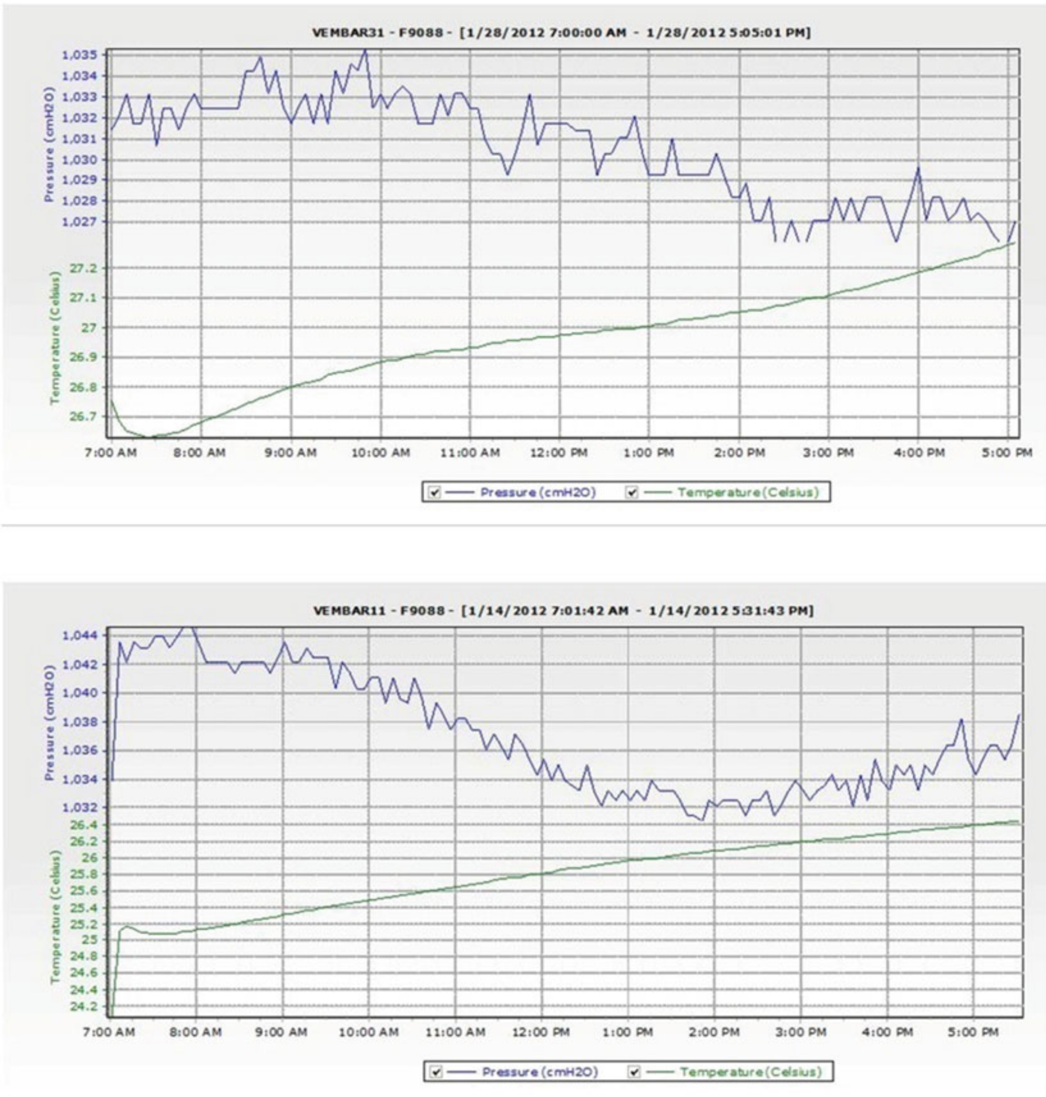

Fig. 14.10 Tidal-induced pressure and temperature fluctuation in Vembar estuary

from normal groundwater recharge. During the dry periods, the volume of seawater into the mining pit exceeds the groundwater table with leads to significant increase in the salinity. When the beach and coastal dune becomes flat, the infiltration of seawater is increasing and rising of water to the surface in the mining region. Most of the water infiltrates rapidly into inland sand above the water table causes high salinity. Extensive exploitation of coastal aquifers that are hydraulically linked to the sea usually results in deterioration of groundwater quality due to seawater intrusion. In the mining process freshwater being used for mineral extraction in the region between Kuttam and Navaladi. Mineral free sand in these regions will be dumped back in the form of slurry to the mined-out pits along with the freshwater which will be about 40–50% of total volume and it is a continuous daily process. Thus, the loose sand is filling the mined pits and pumped water percolating the sand and reaches the water table. Requirement of water for mining

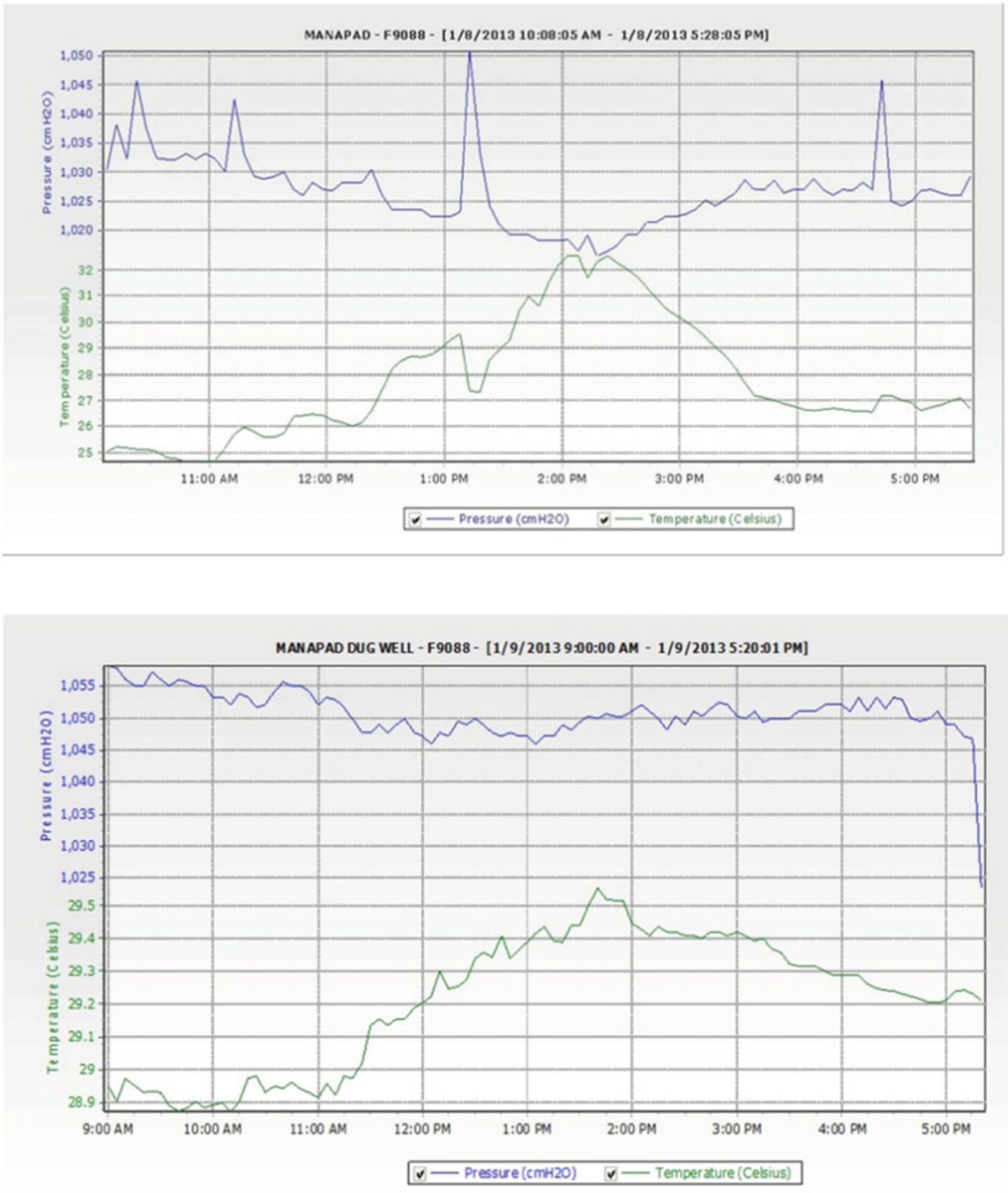

Fig. 14.11 Tidal-induced pressure and temperature fluctuation in Karamaniyar river estuary and dug well

and mineral separation by the industry is more. At this stage, groundwater is more extracted in the mining area for mineral separation. The excessive pumping and over extraction of sand in shoreline to meet the export demand is the main reason of saltwater intrusion in mining sites. In the active mining region depth profile indicates that the water level highly declined into the below ground level and the electrical conductivity values also increased. The change might therefore be related to the saltwater encroachment into the aquifer. There is an ongoing problem of saltwater intrusion in active mining sites. The high salinity and the continuous decline in groundwater elevations below MSL are the main indicators of this problem. Unregulated mining of coastal dune sands have to be controlled. The findings of this study are very useful for integrated coastal zone management and processing of mining lease in the future.

Acknowledgements The authors gratefully acknowledge the Department of Science and Technology (DST-Government of India), New Delhi for the financial assistances provided for the Project (Ref. No.DST/WAR-W/WSI/10/2010, Date: 10.01.2011).

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Flood Simulation Modelling and Disaster Risk Reduction of West Tripura District, Tripura, North-East India

15

Moujuri Bhowmik and Nibedita Das (Pan)

Abstract

Flood is a common fluvial hazard in the plain areas of West Tripura District during almost every monsoon season, where the gradient is very gentle (1:1461) and is drained by numerous drainage systems. About 40 percent area and 41 percent population of this district are flood affected which also includes Agartala, the capital of Tripura. This hazard causes tremendous loss in terms of property, standing crops, roads and houses. The objective of this study is to assess flood risk and disaster risk reduction using flood simulation model for 50 and 100 years return period. A study of 46 years' water level of the Haora River indicates 11 m a.m.s.l as the highest water level and 8 m a.m.s.l for the Lohar Nala. For this modelling, contour at 1 m interval has been generated on DEM which was downloaded from Bhuban Cartosat, the flood inundation data have been entered in Animation Manager Table in ArcMap and the layer thus generated has been overlaid on 3D map of West Tripura District in ArcScene. From this model, it has been estimated that during 50 and 100 years return period, the flood inundation depth was found to be 1–4 and 1–5 m, respectively; about 180 and 300 km^2 area of this district, respectively, will be affected; about 1,99,530 and 4,51,263 people will be affected, respectively. It means flood can be disastrous in the district when water level of the Haora River and Lohar Nala will be equal to or exceed 1.5–2 and 1–1.4 m above the river bank, respectively. Therefore, it is necessary to reduce the flood risk through proper flood plain land use planning and changing the cropping system.

Keywords

Flood simulation model · Flood hazard · Haora river · West tripura district

15.1 Introduction

Generally, after a spell of heavy rain (due to depression) which may last for a period of several hours to several days, a large volume of runoff is generated in the upper catchment and the river experiences floods (Kale 2003). Flood hazard is the probability of occurrence of a potentially damaging flood event of a certain magnitude within a given time period and area (Brooks 2003). Efficient flood protection measures require a good

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_15

knowledge about flood frequencies at different points in a catchment. The classical approach to obtain design flows is to carry out local or regional flood frequency analysis using long records of observed discharge data (e.g. Hosking and Wallis 1997; Stedinger et al. 1993). Other models for synthetic rainfall generation which can be applied for derived flood frequency analysis include different disaggregation approaches (Koutsoyiannis et al. 2003; Lu and Yamamoto 2008; Olsson 1998) and various re-sampling methods (Bardossy 1998; Lall and Sharma 1996).

In West Tripura District two rivers, namely, the Haora River and the Lohar Nala experience flood and these basins also experience flash flood. Flow reaches to peak discharge in a few minutes or a few hours and they often have a steep bore front (Leopold and Miller 1956; Renard and Keppel 1966; Sharon 1972; Schick 1988; Hassan 1990; Abrahams et al. 1995; Reid and Frostick 1997). About 40 percent mouza and 41 percent population of West Tripura District are severely affected by flood. Piedmont plains (areas of flash flood) and the alluvial plains cover about 70 percent of the district out of which 60 percent experiences flood hazard and 55 percent population are affected which also includes Agartala, the capital of Tripura. This hazard causes tremendous loss in terms of property, standing crops, roads and houses.

15.2 Study Area

West Tripura District extends from 23°40′N to 24°07′N latitude and 91°12′E to 91°32′E longitude (Fig. 15.1). Geologically, the study area falls under Dupitilla series and Tipam group of rocks which is characterized by sand rocks. Surma group and alluvium deposition are also found in this district. Tropical monsoon type of climate prevails here. Physiography of the study area is characterized by (i) hill range, (ii) piedmont slopes and uplands, (iii) terraces and tillas and (iv) flood plains. In this district (i) reddish yellow brown sandy soil, (ii) red loam and sandy loam soils, (iii) younger and older alluvial soils and (iv) lateritic soils are found. The total population of this district is 988,192 (30% of the state) out of which about 189,998 population live in Agartala, that is, 20 percent of this district and about 256,930 (26%) population are engaged in agricultural activities.

15.3 Aims and Objectives

The aim of this research work is to reduce the flood risk, as well as disaster risk in West Tripura District. To fulfil this aim, the main objective is to prepare flood simulation model of West Tripura District for 50 and 100 years return period.

15.4 Materials and Method

In order to carry out this study, Geomatica V 10.1, ArcGIS, MS Excel, Adobe Photoshop, GPS tool, SOI topographical maps (Ref. No. 79 M/1, 2, 5, 6, 9, 10, 78 P/8 and 12), Land sat Imagery (ETM PAN and MSS) (2015) and Google Earth Imagery (2015) have been used.

Flood simulation map has been prepared using ArcMap 10.1 and ArcScene 10.1. For this purpose, digital elevation model, contour map at 1 m interval, rainfall data, water level and flood inundation data have been considered. In ArcMap, contours at 1 m interval have been generated on DEM which was downloaded from Bhuban Cartosat website. In ArcScene, 3D map of West Tripura District has been prepared; flood inundation data and water level have been entered in Animation Manager Table, and the simulation layer, thus generated, has been overlaid on 3D map of West Tripura District. For this modelling, discharge and water level of the Haora River for 50 and 100 years return period have been measured from the flood frequency curve and rating curve. On the basis of those water level data, the flood simulation model of the Haora River for those return periods has been prepared. In case of the Lohar Nala, no hydrological data was available. Therefore, the flood simulation model of the Lohar Nala has been prepared on the basis of collected information on flood inundation depth and water level.

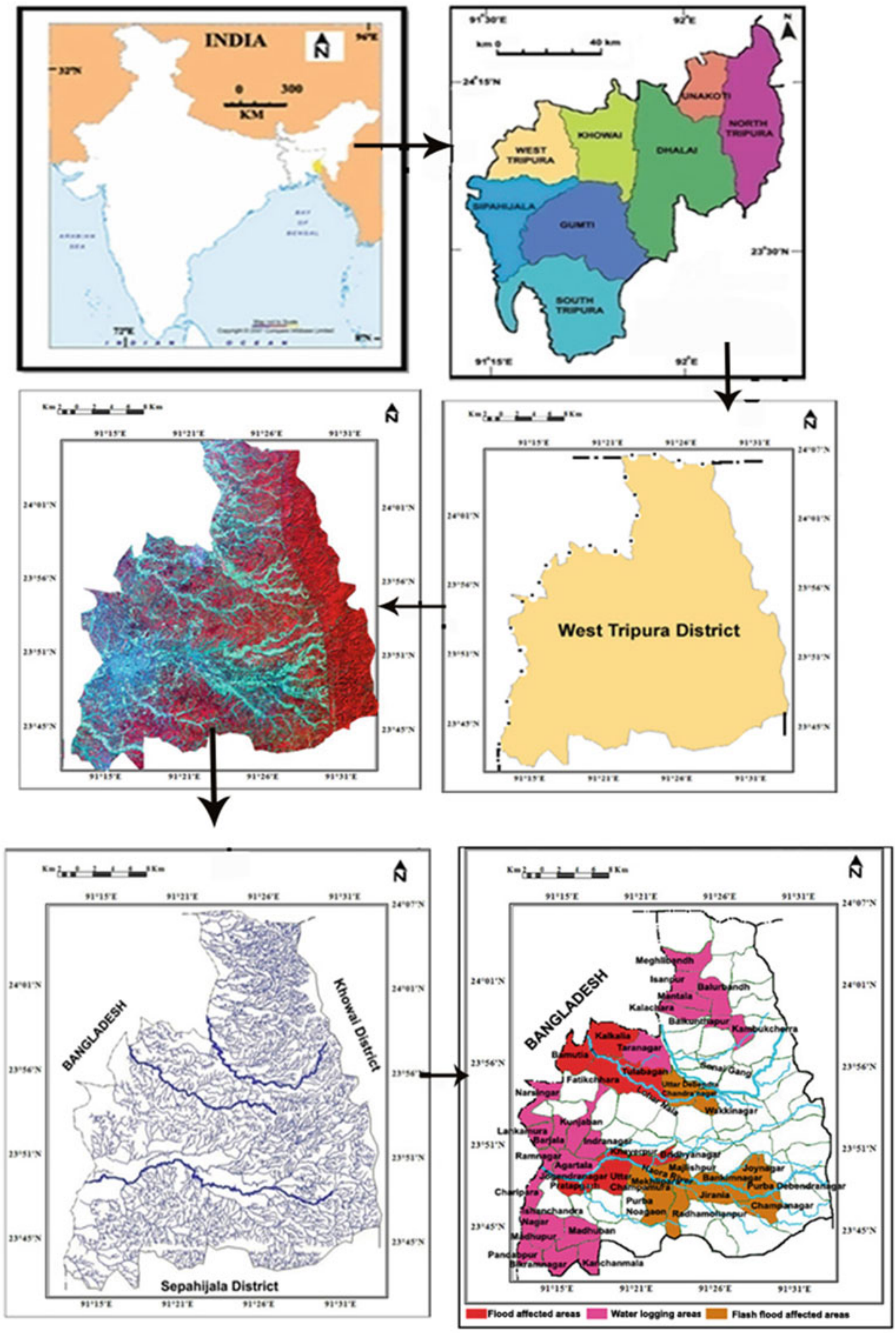


Fig. 15.1 Location map of the study area. *Source* Prepared by the researcher

15.5 Results and Discussion

Simulation and modelling for flood estimation is a rapidly developing field in hydrology (Boughton and Droop 2003). The results are a good way of providing relevant information on how the flood is going to behave at the location where people live and how the flood will affect them (Shaviraachin 2005). Flood simulation model gives a clear picture about the extent of flood water in respect of water levels of the river. This model has been prepared on the basis of flood frequency curve and rating curve of the rivers.

15.5.1 Flood Frequency Analysis

To identify discharge for the 50 and 100 years return period, flood frequency curve of the Haora River has been prepared where flood recurrence and associated discharge have been plotted on log–log graph along the abscissa and ordinate, respectively (Fig. 15.2). Then, the frequency curve has been extrapolated graphically along the upper trend, so as to include 50 and 100 year flood event. From the graph, it can be predicted that in every 10, 50 and 100 years the River Haora would have a flood discharge of 290, 400 and 470 cumec or more, respectively. Again, by extrapolating the rating curve along the upper trend, the water levels associated with each of these discharge of different return periods have been determined (Fig. 15.3 and Table 15.1).

The *Lohar Nala* is an ungauged river and therefore, no hydrological data is available. On the basis of field observation and interaction with the local people it was noted that, during last 100 years, highest inundation depth was observed as 2.5–3 m above the river bank (where the contour height is 0–2 m) with 9 m water level a.m.s.l. It indicates that the chances of occurrence of this much inundation depth or more are expected within the next 100 years period. In the Lohar flood plain the recent inundation depth is 1.5–2.5 m from the river bank with 8 m water level of the river from the mean sea level. Thus, the flood simulation model of the Lohar Nala has been prepared on the basis of 8 and 9 m water level for 50 years and 100 years return period, respectively. After that, those layers of simulation have been overlaid on West Tripura District and flood simulation model of West Tripura District for 50 and 100 years return periods has been prepared (Fig. 15.4).

15.5.2 Outcome of the Flood Simulation Model

This model gives the clear picture about the extent of flood water and also the flood affected areas in the West Tripura District, which may occur in the next 50 and 100 years. Government may take necessary steps to reduce its effects on the flood plain dwellers on the basis of this model. The model indicates that about 180 and 300 km^2 areas, situated at 1–26 m contour height, will be affected in the 50 and 100 years return period, respectively (Table 15.2).

From this model it is found that, if the water level of the Haora River and the Lohar Nala increase up to 11 and 8 m, respectively, in 50 years return period, then inundation depth will also increase up to 4 m in different affected mouzas of this district (Fig. 15.5). On the other hand, in 100 years return period, the inundation depth will increase up to 5 m when the water level will reach up to 12 m in case of the Haora River and 9 m in case of the Lohar Nala (Fig. 15.6 and Table 15.3). During the flood of 50 years return period about six mouzas, namely Pratapgarh, Bridhyanagar, Khayerpur, Jogendranagar along the Haora River and Kalkalia, Bamutia along the Lohar Nala, will be highly vulnerable to flood hazard due to high inundation depth of 2.5–4 m, and large number of affected population (Table 15.3) leads to the high risk of flood.

But, in the flood of 100 years return period about 11 mouzas, namely Pratapgarh, Bridhyanagar, Khayerpur, Jogendranagar, Agartala (capital city of the state), Ramnagar, Uttar Champamura, Mekhlipara along the Haora River

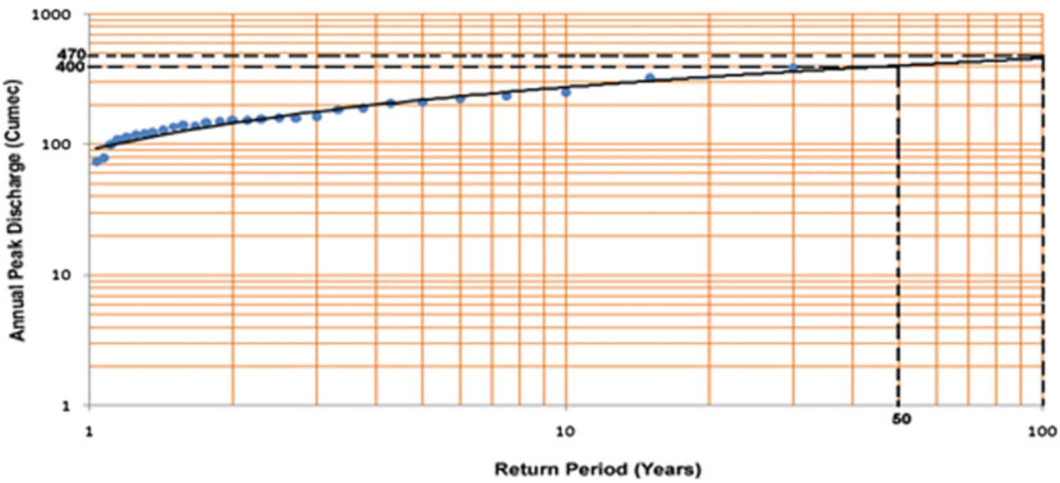


Fig. 15.2 Flood frequency curve of the Haora River showing discharge of 50 and 100 years return periods. *Source* Prepared by the researcher on the basis of restricted discharge data provided by the CWC

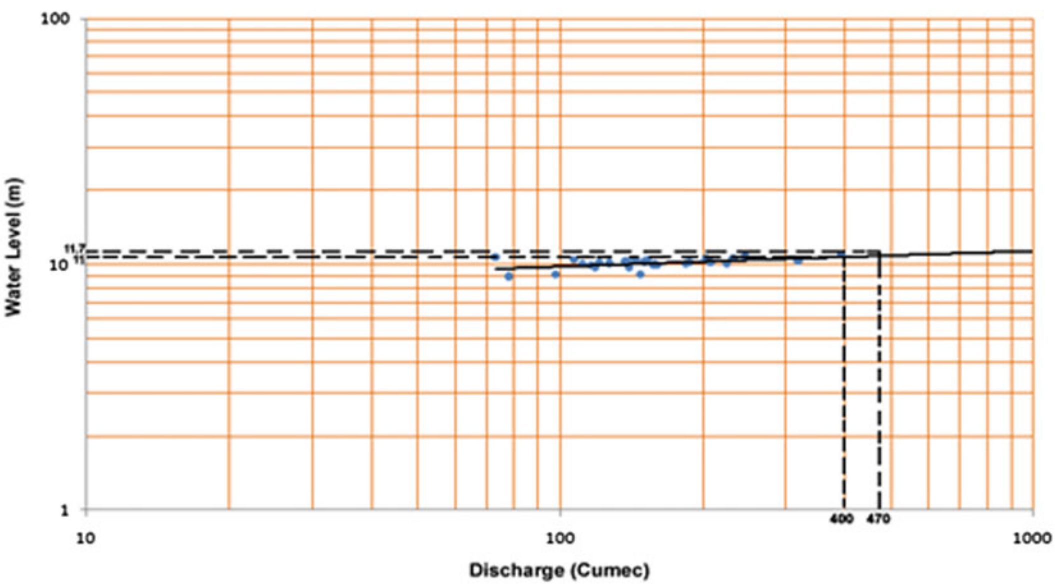
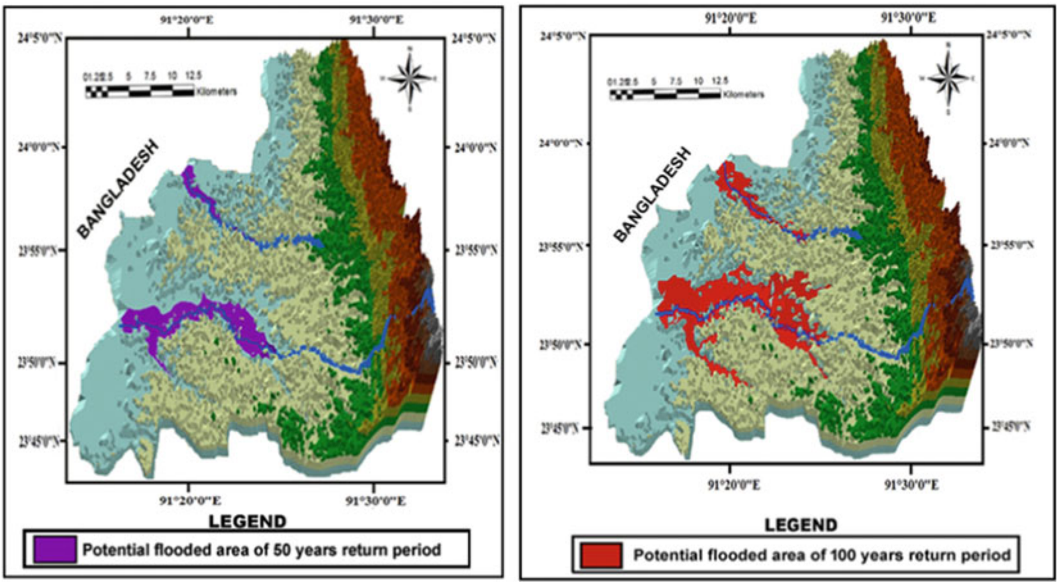


Fig. 15.3 Rating curve of the Haora River for calculating water level against discharge for 50 and 100 years return periods (400 and 470 m^3/s, respectively). *Source* Prepared by the researcher on the basis of the restricted gauge height data of the Haora River provided by the CWC

Table 15.1 Discharge and water level associated with different return periods of the Haora River

Return Period (Years)	Discharge (Cumec)	Water Level (m)
100	470	11.7
50	400	11

Source Measured by the researcher



(a) (b)

Fig. 15.4 Flood simulation model of the West Tripura District for **a** 50 years return period and **b** 100 years return period

Table 15.2 Area affected from flood in different return periods

Return periods (years)	Affected areas (km^2)	Settled areas including viti (km^2)	Agricultural area (km^2)	Land elevation (m)
50	180	100	83	1–20
100	300	257	181	1–26

Source Calculated and measured by the researcher

and Kalkalia, Bamutia, Fatikcherra along the Lohar Nala will be highly vulnerable to flood hazard. At that time the inundation depth will increase up to 5 m which will affect 17–100 percent population of these mouzas (Table 15.3). This level of inundation depth will overtop the embankment of the right bank of the Haora River and will spread in the Agartala town. Therefore, the flood risk is high in these mouzas as well as in Agartala in the 100 years return period.

This flood water level may take some days to recede and after receding it will leave many effects. Due to the damage of standing crops, as well as agricultural land, it may cause food crisis for many days and the price of the stored food will be raised so much that it will become beyond the ability of the people to purchase. On the other hand, the people, whose houses will be fully damaged, will become homeless for many days and they will require more financial help to rebuild their houses, as most of them belong to extremely poor or poor category. They will suffer from mental stress as well as financial crisis because, on the one hand, they will lose their standing crops which are their only source of income, and on the other hand, flood water will severely damage their houses which are their only property. The owners of partly damaged houses also require money to restore the damaged portions and thus, they will also remain homeless until the renovation will be completed. Due to the damage of roads, transport system will be disrupted. So, it will be impossible to bring necessary commodities from other states. There

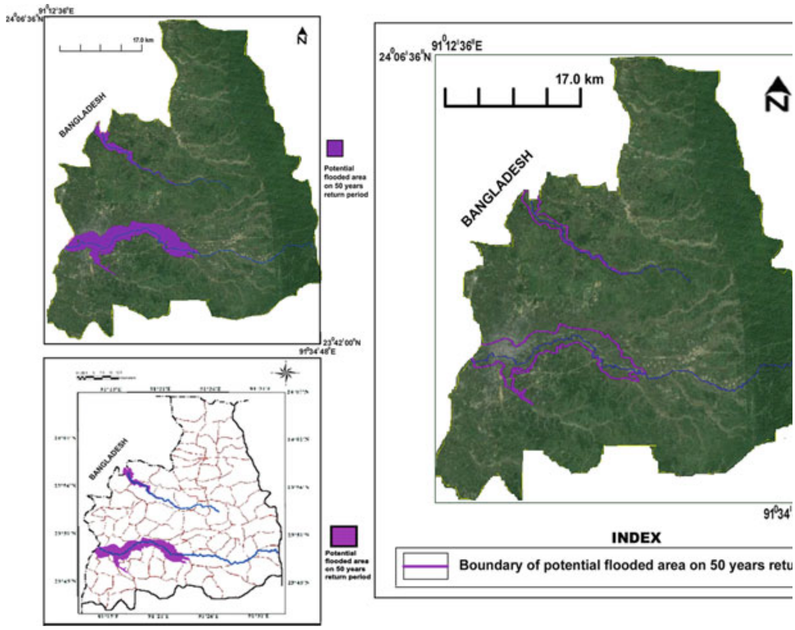


Fig. 15.5 Flood simulation layer of 50 years return period (on the basis of 11 and 8 m water level for the Haora River and the Lohar Nala, respectively) on Google Earth Imagery of West Tripura District for identifying the flood affected areas. A total of 16 mouzas have been identified as partially affected; there is no fully affected mouzas

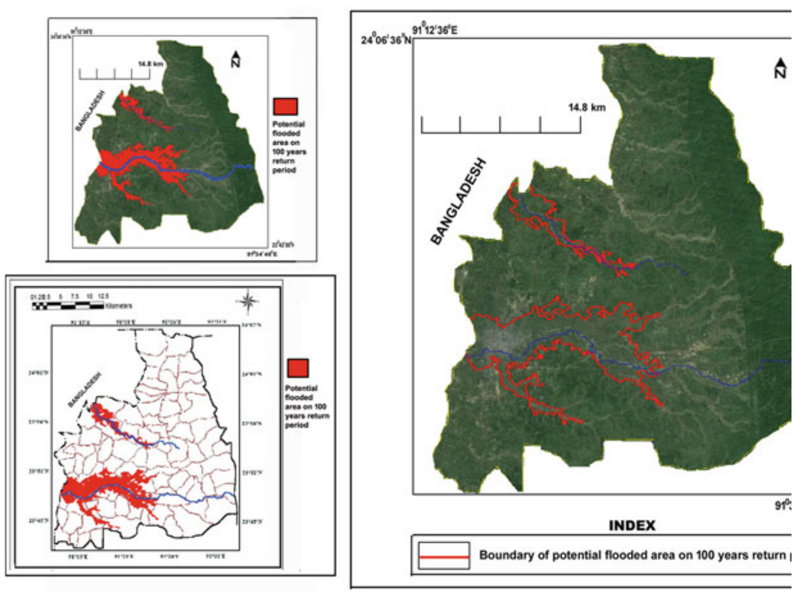


Fig. 15.6 Flood simulation layer of 100 years return period (based on 12 and 9 m water level for the Haora River and the Lohar Nala, respectively) on Google Earth Imagery of the West Tripura District for identifying the flood affected areas of this district. Total and partially affected mouzas are identified as 4 and 15, respectively

Table 15.3 Mouza-wise flood inundation depth and number of affected population during 50 and 100 years return period

Rivers	50 Years return period			100 Years return period		
	Mouzas	Inundation depth (m)	Affected population	Mouzas	Inundation Depth (m)	Affected population
HAORA RIVER	Ramnagar (Southern part)	1.5	400	Ramnagar a. Southern part b. Central part	2 1	700
	Agartala (Southern part)	1.5	1,00,000	Agartala a. Southern part b. Central part	2 1	2,00,000
	Khayerpur (Southern part)	3	25,420	Khayerpur a. Southern part b. Central part	2.5 1.5	41,140
	Briddhyanagar (South-western part)	2.5	3,000	Briddhyanagar a. South-western part b. Central part	3 2	7,041
	Majlishpur (South-western part)	2.5	3,200	Indranagar a. South -eastern part b. Southern part	1.5 1.5	41,500
	Charipara (Northern part)	2	3,150	Laxmipur (Southern part)	2	3,000
	Pratapgarh (Northern part)	4	30,150	Radhakishore Nagar (South-western part)	1	6,000
	Jogendranagar (North-western part)	4	18,900	Majlishpur a. South-western part b. Central part	3 2	9,000
	Uttar Champamura (Northern part)	2.5	3,000	Charipara a. Northern part b. Central part	2.5 2	9,700
	Mekhlipara (North-eastern part)	2.5	1,500	Pratapgarh a. Northern part b. Central part	5 3.5	48,765
	Purba Noagaon (Northern part)	2	1,760	Badharghat (Northern part)	2.5	2,500
	Badharghat (Northern part)	2	700	Dukli a. Southern part b. Central part	1 1.5	8,000
	Dukli (Central part)	1	2,500	Srinagar (North-western part)	1	1,500
				Jogendranagar a. North-western part	5 3.5	35,000

(continued)

Table 15.3 (continued)

Rivers	50 Years return period			100 Years return period		
	Mouzas	Inundation depth (m)	Affected population	Mouzas	Inundation Depth (m)	Affected population
				b. Central part		
				Radhamohanpur a. Northern part b. Central part	2.5 1	1,500
				Uttar Champamura a. Northern part b. Central part	3 2	6,000
				Mekhlipara a. Northern part b. Central part	3 1.5	4,367
				Purba Noagaon a. Northern part b. Central part	2.5 1.5	3,700
				Radhapur (Western part)	1	3,250
LOHAR NALA	Kalkalia (South-western part)	2.5	2,000	Kalkalia a. South-western part b. Central part	3.5 2.5	4,900
	Bamutia (North-eastern part)	2.5	1,850	Bamutia a. North-eastern part b. Central part	3.5 2	4,900
	Fatikcherra (Northern part)	2.5	2,000	Fatikchhara a. Northern part b. Southern part c. Central part	4 1.5 2.5	6,300
				Uttar Debendra Chandra Nagar (Southern part)	1.5	1,500
				Tulabagan (Central part)	1.5	1,000

Source Measured by the researcher on the basis of contour height, flood simulation model and village-wise population data (modified)

will be scarcity of drinking water during and after flood. Thus, food crisis and polluted water will cause many diseases like cholera, typhoid, dysentery and so on. Therefore, proper risk management is necessary to mitigate the adverse effects of flood in this district by proper flood plain management.

15.5.3 Flood Plain Management

Firstly, it is necessary to save the houses, which are the property of any people and the standing crops, which are the sources of income of most of people of this district. To protect the roads from flood in the Haora flood plain, all the roads

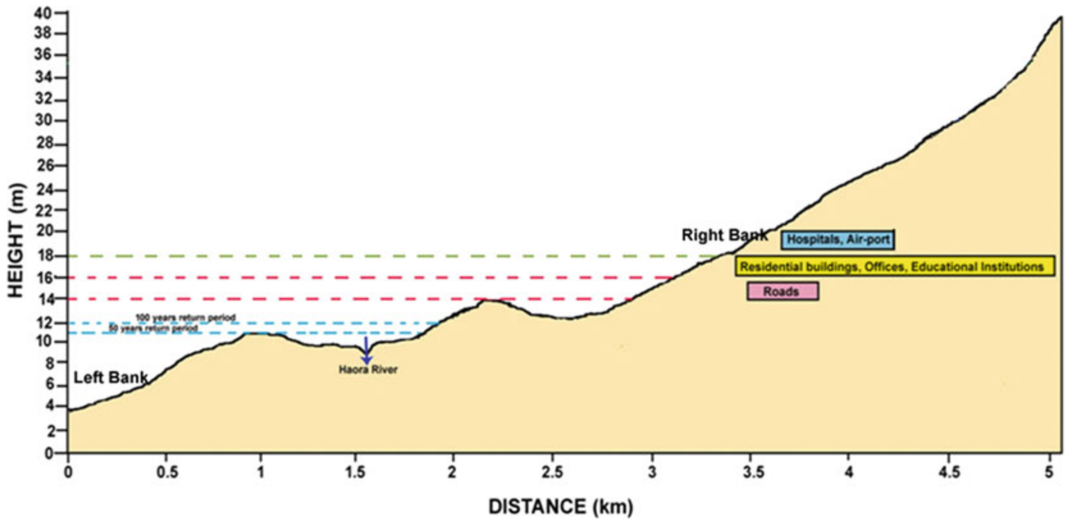


Fig. 15.7 Land use planning of the Haora flood plain [Cross profile prepared from north-east to south-west of the Haora flood plain on the basis of contour map]. *Source* Prepared by the researcher

may be constructed at the height of 14–16 m a.m.s.l.; offices, educational institutions at 16–18 m a.m.s.l. and hospitals and airport at a height of 18 m a.m.s.l. (Fig. 15.7). The areas susceptible to flood are densely populated and it is very difficult to shift all people to the safer places during emergency. So, the researcher has suggested the construction of houses, nearest to the river bank, about 16–18 m height above mean sea level, that is 6–8 m above the ground level, otherwise they will have to accept the losses from flood. It has also been suggested to train the local people through different workshops on how they can fight against flood, so that they can prepare themselves to save their lives and properties during flood time.

In case of the Lohar Nala flood plain, the roads may be constructed at an elevation of 12–14 m a.m.s.l.; residential buildings, offices, educational institutions at 14–16 m a.m.s.l. and hospitals and airport at the height of 16 m a.m.s.l. (Fig. 15.8).

Moreover, to save agricultural land, the cropping pattern has to be changed. Agricultural activities can be performed in flood plains that are suitable for cultivation but the varieties resistant to submergence should be planted or cropping pattern to be changed.

15.6 Conclusion

Flood simulation model gives the clear picture about the extent of flood water in the flood plain areas such as Pratapgarh, Jogendranagar, Khayerpur and Uttar Champamura through which government may take necessary steps to reduce the adverse effects of flood on the flood plain dwellers. It is found that in 50 and 100 years return period, it will not be possible to save Agartala, if the water level of the Haora River increase up to 11 and 12 m, respectively. About 180 and 300 km^2 area of this district will be affected in 50 and 100 years return period, due to the excessive water of the Haora River and the Lohar Nala, respectively which will become disaster in this district. Therefore, proper risk management is necessary to mitigate the adverse effects of flood in this district by proper flood plain management and changing the cropping pattern.

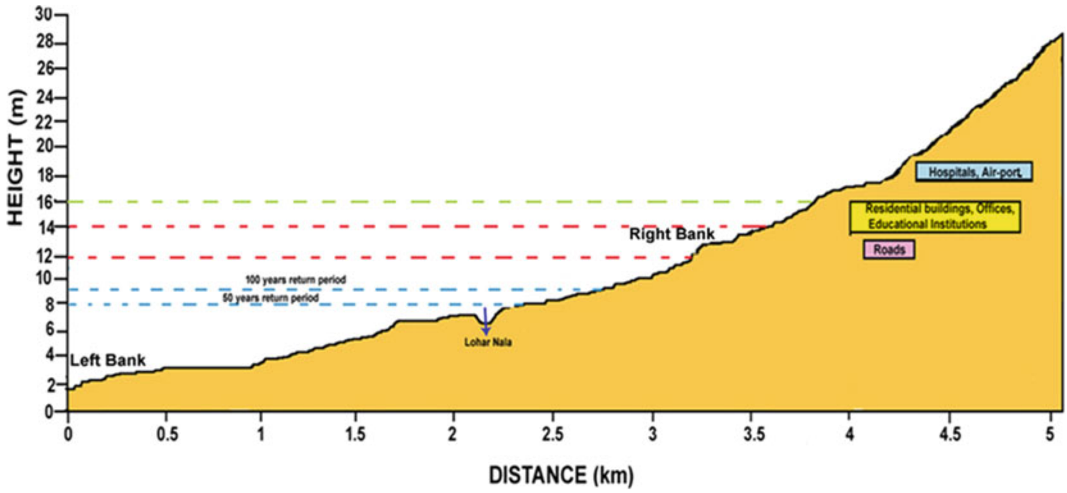


Fig. 15.8 Land use planning of the Lohar flood plain [Cross profile prepared from north-east to south-west of the Lohar flood plain on the basis of contour map]. *Source* Prepared by the researcher

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16 Remote Sensing and GIS-Based Morphometric Analysis of Spiti River Basin

Arif Husain and Pankaj Kumar

Abstract

Spiti river basin is located in the north-eastern part of Himachal Pradesh, India. The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER), 2011 has been used in the present study. Three different basins have been delineated by using hydrological tool given in the ArcGIS 10.1. They are named as Spiti, Tsarap Chu and Parechu basins with an area of 5419, 781 and 651 sq. km, respectively. The morphometric parameters of all the three sub-basins have been calculated. ArcGIS 10.1 software was used for delineation and computation of drainage parameters and also for generating map layout. All the morphometric parameters of Spiti river basin provide an important information about drainage density, stream frequency, soil texture, slope aspect, drainage pattern, type of relief, stream order and the total number of streams. Morphometric analysis of the study area of all the three sub-basins represents sub-dendritic to dendritic drainage pattern with moderate to very fine drainage texture. The bifurcation ratio of all three basins indicates normal basin category and presence of low drainage density suggesting that the region has highly permeable sub-soil.

Keywords

Morphometry · Digital elevation model · Spiti river basin · Remote sensing and GIS

16.1 Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the earth surface, shape and dimensions of its landforms (Clark 1966). The morphometric analysis of a river basin and drainage network plays a significant role in understanding the hydrogeological behavior of the basin and expresses the prevailing climate, geology, geomorphology and structure. The relationship between various drainage parameters and the above factors is now almost well established (Horton 1945). Morphometric analysis using remote sensing technique has emerged as a powerful tool in recent years. Remote sensing has the ability to obtain the synoptic view of the large area at one time and is very useful in analyzing the drainage morphometry (Rudraiah et al. 2008). So far, no detailed work on the morphometry of the Spiti valley has been done. The study area covers an area of 7,589 sq. km and comprises three river

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_16

sub-basins, Spiti, Parechu and Tsarap Chu. The searching literature on the study area indicates that there is no published data on the morphometry based on remote sensing and GIS techniques. Therefore, the present study aims at morphometric analysis on basin level by using remote sensing and GIS techniques. The Spiti river originates from Kunzum range, and Tegpo and Kabzian streams are its tributaries. Water draining the famous Pin valley area is also a part of the Spiti river system. Its position across the main Himalayan range deprives it from the benefit of the South-West monsoon that causes widespread rain in most parts of India from June to September. Most of the rivers in the area are perennial rivers, originating from glaciers and snow fields (Singh and Kumar 2014a).

The river attains peak discharge in late summers due to glacier melting. Owing to faster rate of snow and ice melting, the accumulation of water in the newly formed glacial lakes has been increasing rapidly and resulted in sudden discharge of large volume of water and debris, causing flooding in the downstream (Singh and Kumar 2014b). The present study will further help in assessing flood vulnerability to downstream dwellers. After flowing through Spiti valley, the Spiti river meets Satluj at Namgia in Kinnaur district traversing a length of about 150 km from the north-west; beyond that it flows in the south-west direction in Himachal Pradesh. The larger tributaries of the Spiti flow through valleys resembling much that of the main river but toward their junctions with it have to force their way in deep narrow chasms through the rocky walls that rise on either side of the main valley. The main tributaries are the Pin on the right bank and the Sampa, Shila and Lingti on the left. The Pin which rises in south-west corner of the Spiti and drains fully one-quarter of its total area is almost equal to the Spiti river in volume at their point of junction.

16.2 The Study Area

Spiti river basin is located between 31°42′ and 32°58′ N latitude and 77°21′ and 78°35′ E longitude with an area of 7,589 sq. km. It is bordered by Ladakh in the north, Tibet in the east, Kinnaur and Kullu in the south and Lahaul in the west (Fig. 16.1). Owing to its location on the leeward side of the greater Himalayan ranges, the lack of precipitation and minimum elevations of over 3350 m, Spiti has a bleak, awe-inspiring terrain, seemingly devoid of vegetative cover and one of the harshest climates in the world (Gazetteer of the Kangra District, 1897). Spiti is home of lofty mountain ranges of an average elevation of 18,000 feet. The carrying capacity of Spiti valley is low due to harsh climatic condition and rugged topography. Population is mainly concentrated in a few favorable pockets which are confined to valley. Therefore, large area of Spiti, especially with steep slopes and higher altitude, is uninhabited (Pankaj et al. 2018).

16.3 Data Set and Methodology

Drainage map and spilt drainage map of the Spiti river basin has been prepared by using Global Digital Elevation (GDEM) with 30 m resolution. The tiles of the Global Digital Elevation Model (GDEM) have been merged using image processing software Erdas Imagine 14. Then, flow direction, flow accumulation, stream order and watershed and so on have been simulated using hydrological tools such as ArcGIS 10.1. The morphometric parameters of all the three sub-basins have been calculated using ArcGIS 10.1 software for digitizing and computation purposes and to generate the output. The study analyzed 14 morphometric parameters of the Spiti river basin (Table 16.1).

16.4 Flow Direction and Accumulation

The flow direction tool is used to determine the direction of flow from every cell in the raster image. This tool takes a surface as input and outputs a raster showing the direction of flow out of each cell. The direction of flow is determined by the direction of steepest descent, or maximum drop, from each cell. This has been calculated as follows:

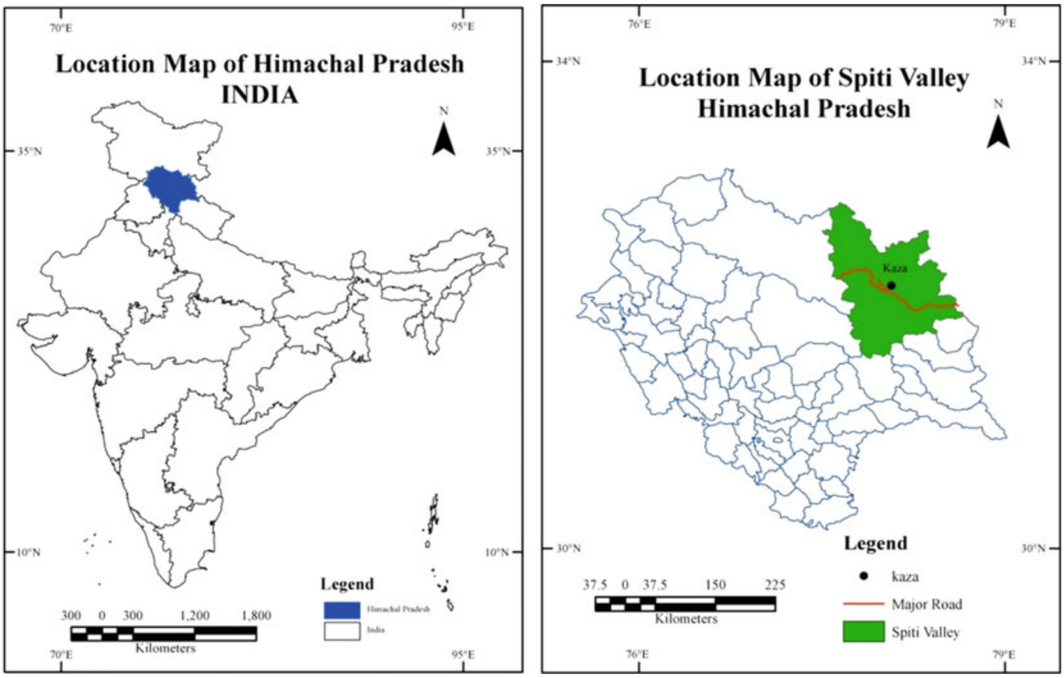

Fig. 16.1 Location map of the study area. *Source* Author

$$\text{Maximum Drop} = \text{Change in Z Value}/\text{Distance} * 100$$

The flow direction determines the natural direction of drainage for every pixel in a digital elevation model (DEM). Based on the output flow direction map, the flow accumulation operation counts the total number of pixels that will drain into outlets (Fig. 16.2). The flow accumulation tool calculates accumulated flow as the accumulated weight of all cells flowing into each down slope cell in the output raster.

16.5 Basin Delineation

In the present study, three different basins have been delineated by using hydrological tool in the ArcGIS 10.1. The three basins are named as Spiti, Tsarap Chu and Parechu basins with an area 5419, 781 and 651 sq. km, respectively. All the three river basins, Spiti, Parechu and Tsarap Chu, flow in the south-east, north-east and north-west direction, respectively (Fig. 16.3).

16.6 Results and Discussion

16.6.1 Linear Aspect

The linear aspects include stream order, stream length, mean stream length, stream length ratio and bifurcation ratio, and the results of the analysis are given in Tables 16.2, 16.3 and 16.4.

16.6.1.1 Stream Order

The stream classification system developed by Strahler (1964) has been adopted in the present study. In the Strahler scheme for ordering the network, all the "fingertips" tributaries are designated as first-order streams, and where two of them join, they form a second-order stream. Likewise, two second-order streams join to form a third-order stream and so on, to the streams of

Table 16.1 Formulae incorporated for computation of morphometric parameters

S. no	Morphometric parameters	Formula	References
1	Stream order	Hierarchical rank	Strahler (1964)
2	Stream length (Lu)	Length of the stream	Horton (1945)
3	Mean stream length (Lsm)	Lsm = Lu/Nu, where Lsm = Mean stream length Lu = Total stream length of order "u" Nu = Total no. of stream segments of order "u"	Strahler (1964)
4	Stream length ratio (RL)	RL = Lu/Lu-1, where RL = Stream length ratio Lu = The total stream length of the order "u" Lu-1 = The total stream length of its next lower order	Horton (1945)
5	Bifurcation ratio (Rb)	Rb = Nu/Nu + 1, where Rb = Bifurcation ratio Nu = Total no. of stream segments of order "u Nu + 1 = No. of segments of the next higher order	Schumm (1956)
6	Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
7	Relief ratio (Rh)	Rh = H/Lb, where Rh = Relief ratio H = Total relief (Relative relief) of the basin (Km) Lb = Basin length	Schumm (1956)
8	Drainage density (D)	D = Lu/A, where D = Drainage density Lu = Total stream length of all orders A = Area of the basin (km^2)	Horton (1932)
9	Stream frequency (Fs)	Fs = Nu/A, where Fs = Stream frequency Nu = Total no. of streams of all orders A = Area of the basin (km^2)	Horton (1932)
10	Drainage texture (Rt)	Rt = Nu/P, where Rt = Drainage texture Nu = Total no. of streams of all orders P = Perimeter (km)	Horton (1945)
11	Form factor (Rf)	Rf = A/Lb 2, where Rf = Form factor A = Area of the basin (km^2) Lb 2 = Square of basin length	Horton (1932)
12	Circulatory ratio (Rc)	Rc = 4*Pi*A/P2, where Rc = Circulatory ratio Pi = "Pi" value, i.e., 3.14 A = Area of the basin (km^2) P2 = Square of the perimeter (km^2)	Miller (1953)
13	Elongation ratio (Re)	Re = 2$\sqrt{}$(A/Pi)/Lb, where Re = Elongation ratio A = Area of the basin (km^2) Pi = "Pi" value, i.e., 3.14 Lb = Basin length	Schumm (1956)
14	Length of overland flow (Lg)	Lg = 1/D*2, where Lg = Length of overland flow D = Drainage density	Horton (1945)

fourth, fifth and higher order. The stream networks vary from first to seventh order (Fig. 16.4), and further study area has been divided into three river basins: Spiti, Parechu and Tsarap Chu. Stream order in Spiti basin indicated 3265 of first order, 1442 of second, 802 of third, 490 of fourth, 284 of fifth, 140 of sixth order and 74 of seventh-order streams. The order of stream network in Parechu basin indicated 439 of first order, 196 of second, 106 of third, 77 of fourth and 53 of fifth-order streams. Stream network in Tsarap Chu basin indicated 651 of first order, 226 of second, 215 of third, 102 of fourth and 83 of fifth-order streams (Fig. 16.5).

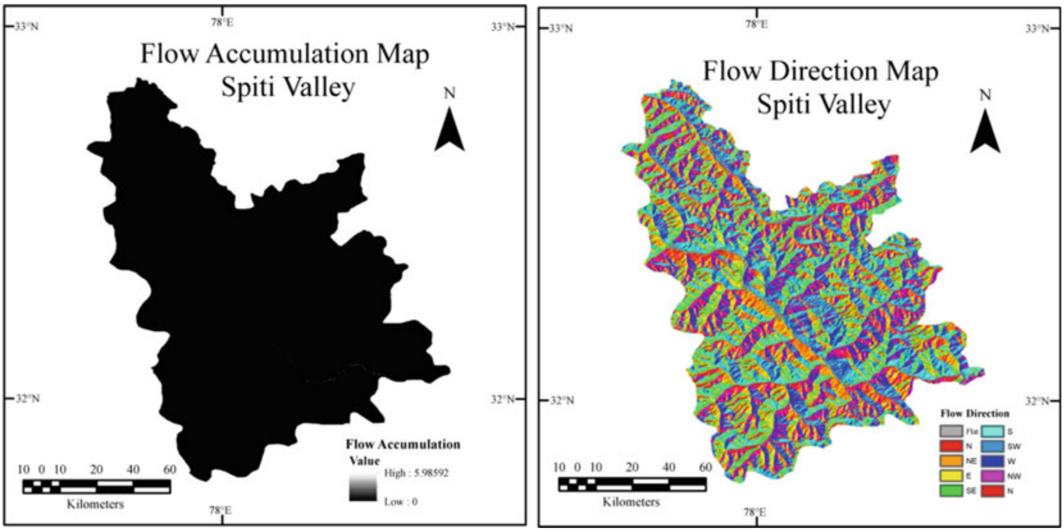

Fig. 16.2 Flow accumulation and flow direction map, Spiti Valley. *Source* Computed from SRTM

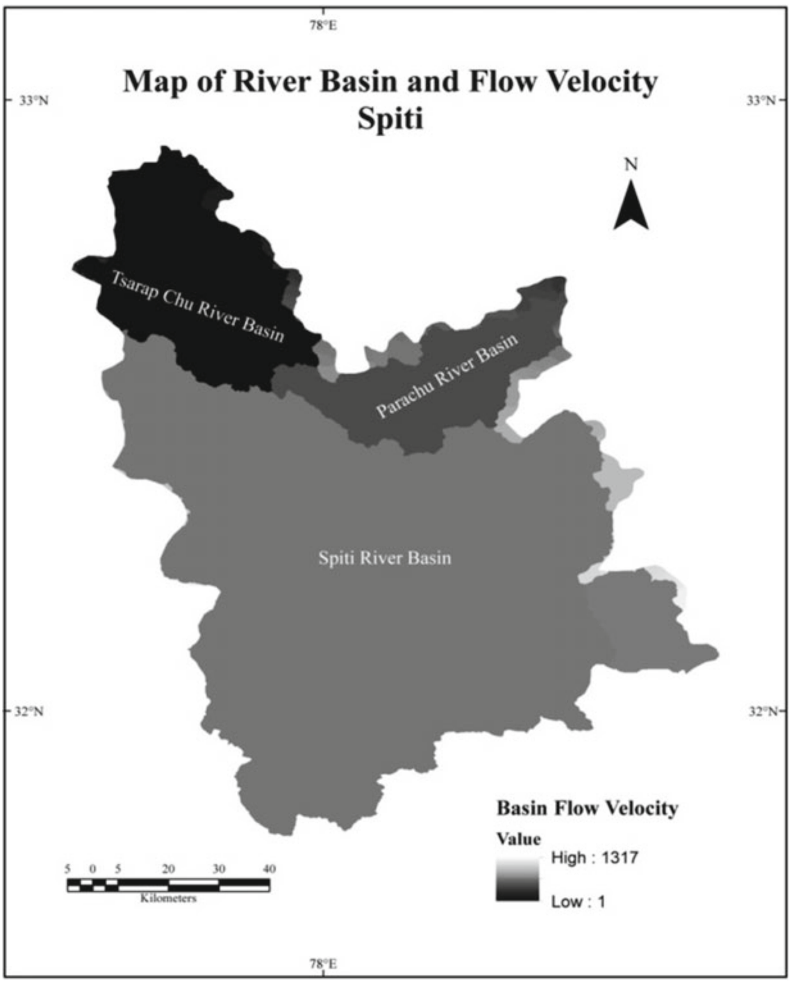

Fig. 16.3 Map of river basins and flow velocity. *Source* Computed from SRTM

Table 16.2 Linear aspects of the drainage network of the Spiti river basin

Basin name	Basin area (km^2)	Stream order	Stream number	Stream length in km (Lu)	Mean stream length in km (Lsm)	Stream length ratio (Rl)	Bifurcation ratio (Rb)	Mean bifurcation ratio (Rbm)
Spiti	5419	I	3265	2645	0.81	0	2.26	1.61
		II	1442	1221	0.84	0.46	1.79	
		III	802	581	0.72	0.47	1.63	
		IV	490	297	0.60	0.51	1.72	
		V	284	164	0.57	0.55	2.02	
		VI	140	64	0.46	0.39	1.89	
		VII	74	37	0.50	0.57	0	
Tsarap Chu	781	I	651	541	0.83	0	2.88	1.45
		II	226	180	0.79	0.33	1.05	
		III	215	161	0.75	0.89	2.10	
		IV	102	51	0.61	0.85	1.22	
		V	83	59	0.57	0.36	0	
Parechu	651	I	439	353	0.80	0	2.23	1.37
		II	196	154	0.78	0.43	1.84	
		III	106	32	0.59	0.62	1.37	
		IV	77	72	0.67	0.46	1.45	
		V	53	51	0.66	0.71	0	

Source Compiled by author

Table 16.3 Aerial aspects of the drainage network of the Spiti river basin

Basin name	Drainage density (D)	Drainage texture (Rt)	Stream frequency (Fs)	Form factor (Rf)	Circularity ratio (Rc)	Elongation ratio (Re)	Length of overland flow (Lg)
Spiti	0.92	17.51	1.19	0.38	0.49	0.70	2.16
Tsarap Chu	1.27	6.32	1.63	0.28	0.24	0.60	1.57
Parechu	1.01	5.17	1.33	0.21	0.28	0.51	1.96

Source Compiled by author

Table 16.4 Relief aspects of the drainage network of the study area

S. no	Basin name	Perimeter (km)	Basin length (km)	Total relief (m)	Relief ratio (Rh)
1	Spiti	371	118	3605	0.30
2	Tsarap Chu	202	52	1937	0.37
3	Parechu	168	55.52	2121	0.38

Source Compiled by Author

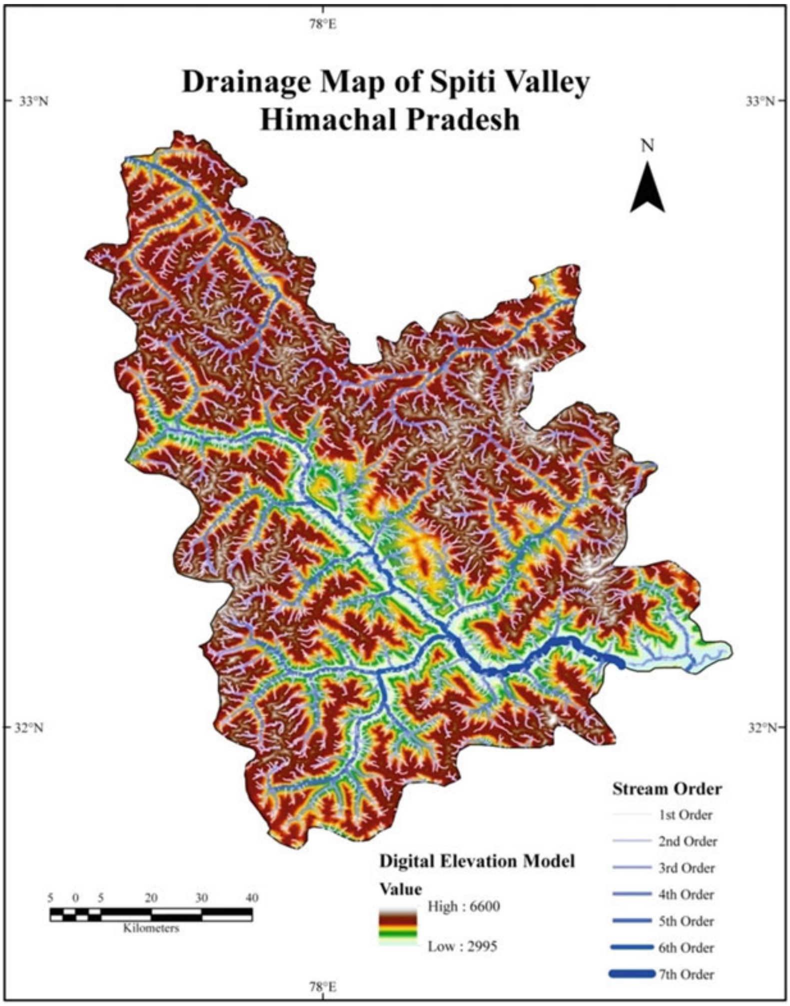

Fig. 16.4 Drainage network of Spiti Valley. *Source* Computed from SRTM

16.6.1.2 Stream Number (Nu)

According to Horton's (1945) law, it states that the "number of stream segments of each order forms an inverse geometric sequence with order number". This geometric relationship has been shown graphically in the form of line graph where the values of these variables (stream order Versus stream number and stream order Versus stream length) are plotted (Figs. 16.6 and 16.7). Spiti river basin has the highest number of first-order streams among all the basins. The total number of streams of all orders in Spiti, Tsarap Chu and Parechu basins are 6497, 1277 and 871, respectively.

16.6.1.3 Stream Length (Lu)

Stream length has been measured by the law proposed by Horton (1945) for all three basins by raster calculator in ArcGIS 10.1. The number of streams of various orders in the basins has been counted, and their lengths have been measured. In all the three basins, the stream segments of various orders vary considerably. The total length of the stream of all orders of Spiti, Tsarap

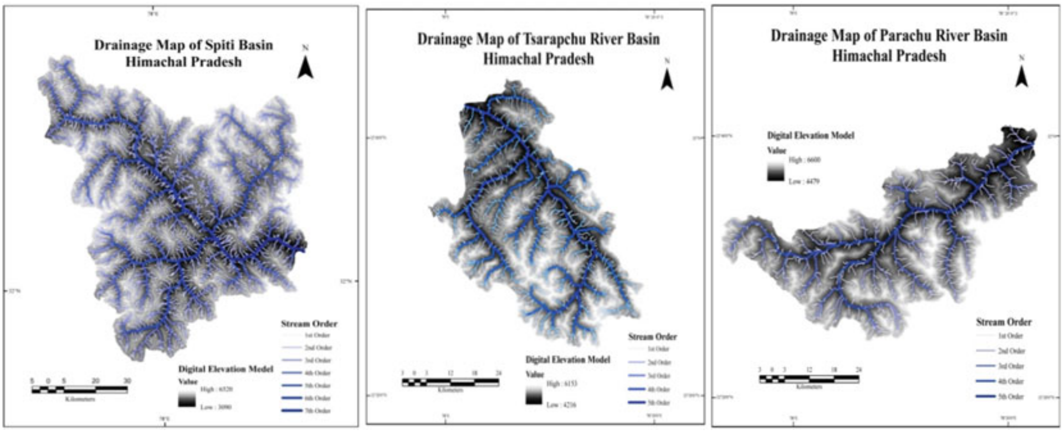

Fig. 16.5 Split drainage of Spiti river basin. *Source* Computed from SRTM

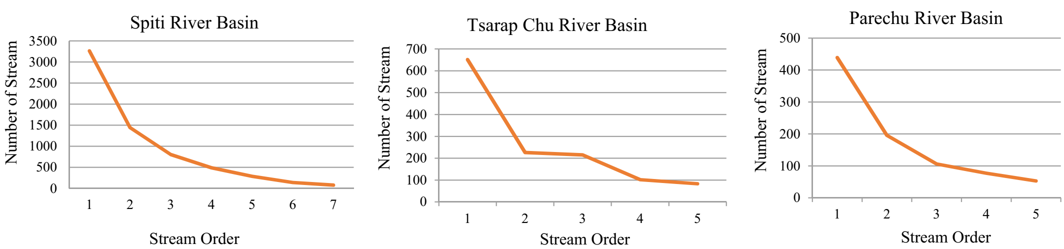

Fig. 16.6 Stream order versus stream number. *Source* Compiled by author

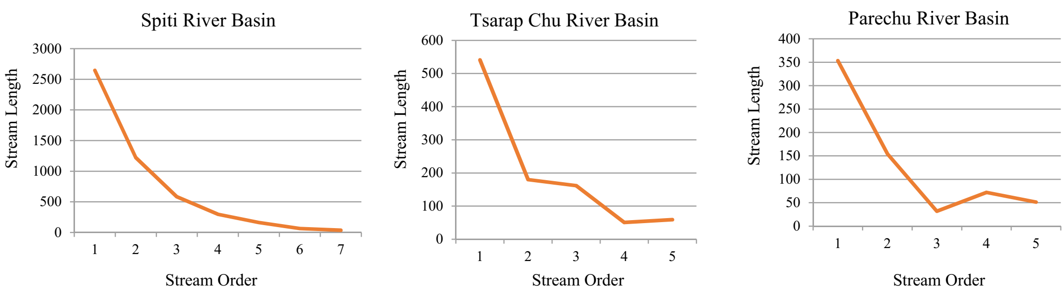

Fig. 16.7 Stream order versus stream length. *Source* Compiled by author

Chu and Parechu basins are 5009, 992 and 663 km, respectively (Table 16.2).

16.6.1.4 Mean Stream Length (Lsm)

The mean stream length is calculated as the ratio of total stream length of particular order with a number of streams of a segment of that order (Strahler 1964). The Lsm ranges from 0.50 to 0.84 km within the study area (Table 16.2). Lsm of any given order is greater than that of the lower order and less than that of its next higher order up except first order of Spiti and fourth order of Tsarap Chu and Parechu.

16.6.1.5 Bifurcation Ratio (Rb)

The ratio of the number of stream segments of given orders to the number of segments of next higher order is known as bifurcation ratio (Schumn 1956). Bifurcation ratio for different basins of the study area for different stream orders has been calculated (Table 16.2). The Rb values are not the same from one order to next order and they range from 1.63 to 2.26. The difference in Rb values depends on the geological development of the drainage basin. "The lower value of Rb indicates that the basin has suffered less structural disturbances and the drainage pattern is not distorted" (Strahler 1964). The mean bifurcation ratio, which is the average of bifurcation ratios of all orders, varies from 1.37 to 1.61, indicating that the area is not much influenced by the geological structure and undisturbed drainage pattern.

16.6.1.6 Stream Length Ratio (RL)

Stream length ratio is defined as the ratio of the mean length of the one order to the next lower order of the stream segments. The stream length ratio between the streams of different orders of the study area shows change in each basin. This change may be attributed to variation in slope and topography (Vittala et al. 2004). The RL values have been presented in Table 16.2.

16.6.2 Aerial Aspects

The aerial aspects include drainage density, drainage texture, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow. The results of aerial aspects are given in Table 16.3.

16.6.2.1 Drainage Density (D)

The drainage density is a ratio of the total length of the stream of all orders and drainage. It indicates the closeness of spacing of channels (Horton 1932). All factors related to drainage density are also related to the climate, surface roughness and runoff in the area. High rainfall results in more runoff with more drainage lines, whereas runoff is reduced at places where subsurface is permeable and vegetation covers increase the infiltration capacity. The drainage density of the study area is low and varies from 0.92 to 1.27 per km^2, indicating that the area has highly permeable soil and low vegetation cover. The drainage densities of all three basins have been given in Table 16.3.

16.6.2.2 Drainage Texture (Rt)

Drainage texture is a ratio of the total number of stream segments of all orders and perimeter of the basin (Horton 1945). It is an important concept of geomorphology which means the relative spacing of drainage lines. Drainage lines are numerous over impermeable areas than permeable areas. There are five different types of drainage texture that have been classified based on drainage density (Smith 1950). The drainage density less than 2 indicates very coarse, between 2 and 4 are related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine, and greater than 8 is very fine drainage texture. The value of drainage texture ratio of the study area varies from 5.17 to 17.51 (Table 16.3), which indicates moderate to very fine drainage texture.

16.6.2.3 Stream Frequency (Fs)

The total number of stream segments of all order per unit area is known as stream frequency (Horton 1932). The Fs value of the study area is presented in Table 16.3. The value of Fs varies from 1.19 to 1.33. The value of drainage density shows a positive relation with the stream frequency suggesting that the number of stream increases with increasing drainage density.

16.6.2.4 Form Factor (Rf)

Form factor can be defined as the ratio of the area of the basin and square of basin length. The form factor value varies from 0 to 1, where 0 indicates highly elongated basin and 1 is perfectly circular basin. The value of form factor more than 0.78 indicates perfectly circular basin. The smaller the value of form factor, more elongated will be the basin (Horton 1932). The Rf value of the study area varies from 0.21 to 0.38. The Rf values in Spiti, Tsarap Chu and Parechu river basins are 0.38, 0.28 and 0.21, respectively (Table 16.3).

The Rf value of the study area indicates that basins are sub-circular and elongated in shape.

16.6.2.5 Circulatory Ratio (Rc)

The circulatory ratio is mainly concerned with the length and frequency of streams, geological structure, land use/land cover, climate, relief and slope of the basin. A circulatory ratio is the ratio of the area of the circle having the same circumference as the perimeter of the basin (Miller 1953). The Rc values of the study area vary from 0.24 to 0.49. The Rc values of Spiti, Tsarap Chu and Parechu river basin are 0.49, 0.24 and 0.28, respectively. The Rc value of Spiti river basin indicates that it is sub-circular in shape, while the Rc value of Tsarap Chu and Parechu basins indicate that it is elongated in shape. The Rc values of the study area are given in Table 16.3. A circular basin appears to be more efficient in the discharge of runoff than that of an elongated basin (Singh and Singh 1997).

16.6.2.6 Elongation Ratio (Re)

Elongation ratio is the ratio of diameter of a circle of the same area as the drainage basin and the maximum length of the basin (Schumm 1956). The values of elongation ratio generally vary from 0.6 to 1.0 over a wide variety of climatic condition and geologic types. The elongation ratio value near to 1 indicates region of very low relief, whereas values between 0.6 and 0.8 are generally associated with strong relief and steep ground slope (Strahler 1964). The Re values of study area vary from 0.51 to 0.70. The Rc values of Spiti, Tsarap Chu and Parechu are 0.51, 0.60 and 0.70 indicating high relief and steep slope.

16.6.2.7 Length of Overland Flow (Lg)

The length of overland flow is the length of water over the ground surface before it gets concentrated into definite stream channel (Horton 1945). The Lg values of Spiti, Tsarap Chu and Parechu are 2.16, 1.57 and 1.96 km. The length of overland flow is approximately equal to the half of the reciprocal of drainage density. This factor is related inversely to the average slope of the channel and is quiet synonymous with the length of sheet flow to a large degree.

16.6.3 Relief Aspects

The elevation difference between the highest and lowest point on the valley floor of the region is known as relief. The relief measurement includes perimeter, basin length, relative relief and relief ratio. The values of the perimeter, basin length, total relief and relief ratio of all the three basins are given in Table 16.4.

16.6.3.1 Total Relief

Total relief is the difference between the maximum and minimum elevations in the basin. The maximum height of the Spiti basin is 6600 m and the lowest is 2995 m. Therefore, the total relief of the basin is 3605 m. The maximum height of the Tsarap Chu basin is 6153 m and the lowest is 4216 m. Thus, the total relief of the basin is 1937 m. The maximum height of the Parechu basin is 6600 m and the lowest is 4479 m. Therefore, the total relief of the basin is 2121 m.

16.6.3.2 Basin Length (L)

Basin length is the longest length of the basin, from the catchment to the point of confluence. The length of the Spiti, Tsarap Chu and Parechu basins are 118, 52 and 55 km, respectively.

16.6.3.3 Relief Ratio (Rh)

The relief ratio is the ratio of maximum relief to the horizontal distance of the basin parallel to the principal drainage line is termed as relief ratio. "Relief ratio measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on the slope of the basin" (Schumm 1956). The relief ratio normally decreases with the increasing area and size of sub-basin of a given drainage basin (Gottschalk 1964). The values of relief ratio (Rh) of the study area vary from 0.30 to 0.38 indicating high relief and steep slope (Table 16.4).

16.7 Conclusion

Remote sensing and GIS techniques constitute as an efficient tool in delineation and analysis of drainage basin. The morphometric analysis has been carried out with measurement of linear, areal and relief aspects of basins. All the morphometric parameters of Spiti river basin provides an important information about drainage density, stream frequency, soil texture, slope aspect, drainage pattern, type of relief, stream order and total number of streams. Morphometric analysis of the study area of all three sub-basins represents sub-dendritic to dendritic drainage pattern with moderate to very fine drainage texture. The variation in stream length ratio may be due to change in slope and topography. The bifurcation ratio of all three basins indicates normal basin category and presence of low drainage density suggests that the region has highly permeable sub-soil. Stream frequency indicates that all basins show the positive relation with increasing stream number concerning increasing drainage density. The values of form factor and circulatory ratio suggest that the Spiti river basin is sub-circular in shape, whereas Tsarap Chu and Parechu basins indicate that it is elongated in shape. Elongation ratio indicates that all the three basins are region of very high relief and steep slope.

Analysis of drainage basin parameters of Spiti river will further help in assessing flood vulnerability to downstream dwellers. It can be used in prioritization of suitable sites for water harvesting in the region because people are facing problem of water scarcity despites of its location in glaciated region.

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17 Demarcation of Hyper-Arid Land in the Indian Desert: An Environmental Analysis

Sahila Salahuddin

Abstract

Hyper-arid deserts bear extremely fragile environment of acute water scarcity with very low floral, faunal and human sustainability. The ecological diversity is meagre and marginal in the hyper-arid conditions. Hyper-arid lands with less than 100 mm mean annual rainfall globally comprise 5.86 million sq. km. Hyper-arid deserts along with very scanty rainfall also experience a very high rainfall uncertainty and recurrent drought frequency. In the Indian Desert, as we advance towards the west, it is noticed that the monsoon becomes feeble and rainfall consequently becomes erratic. As the predominantly rangeland economy and subsistence agriculture are directly related to the amount and variability of rainfall, the socio-economic conditions also hinge upon this variability. The intensity of the problem can be ascertained by the fact that the arid lands of the Indian Desert experience 60 percent rainfall variability, while the extreme water scarcity hyper-arid lands experience up to 80 percent rainfall variability.

Macro-level studies have generated a widespread perception amongst the scholars that Indian Desert is a mild desert in comparison to the Arabian Desert, Atacama Desert and the Great Sahara Desert. Most parts of the Indian Desert are admittedly mild but there are small remote patches which qualify themselves to be extreme desert. Central Arid Zone Research Institute delineated the semi-arid and arid lands in the Indian Desert. Semi-arid lands depicted a greater half of the desert and arid lands comprised lesser half of the Indian Desert. However, a micro-level analysis of the western frontier of the Indian Desert has revealed a narrow strip of hyper-arid conditions in the Indian Desert adjacent to Cholistan Desert in Pakistan. The enquiry reveals meteorological, hydrographic and botanic evidences to this effect. The hyper-arid conditions would become even more intense and further challenging in the wake of global and regional climate change.

Keywords

Hyper-arid · Indian desert · Environment · Aridity · Evapotranspiration

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_17

17.1 Concept and Measurement of Aridity

The concept of aridity is centred around inadequate rainfall and absence of adequate vegetation cover. It is not of practical utility to define aridity in terms of rainfall inadequacy alone. Aridity is the cumulative climatological characteristic of continued moisture deficiency when rainfall is unable to meet the evaporative demands of a region. The modern systems for defining aridity are based on the concept of water balance. Water balance is largely an equation between the precipitation and evapotranspiration. By definition, there is an overall deficit in water balance in the deserts. The amount of that deficit determines the degree of aridity. The concept and delimitation of hyper-arid zone is based on the largest gap between water availability (rainfall) and the atmospheric water need (potential evapotranspiration). When mean annual rainfall (water availability) of a place is only around 5 percent of the mean annual potential evapotranspiration (atmospheric water need) it would be a hyper-arid condition. For example, if the mean annual potential evapotranspiration of a place is 2000 mm and the mean annual rainfall is only around 100 mm, it would be a climatic condition of hyper-aridity.

17.2 Evapotranspiration and Climatic Demarcation

The concept of evapotranspiration is integrally indispensable to climatic classification and demarcation of environmental regions. One of the most important factors related to water management in the hyper-arid lands is evapotranspiration. Evapotranspiration is considered a major factor in the water loss. It plays an important role in the hydrological cycle (Jensen et al. 1990). Evapotranspiration is a combined term representing the transport of water to the atmosphere in the form of evaporation from the soil surfaces and from the plant tissue as a result of transpiration (Allen et al. 1998). Evapotranspiration is expressed in two forms: potential evapotranspiration and actual evapotranspiration.

Potential evapotranspiration (PET) is defined as "the maximum water demand of the atmosphere if it was available for evapotranspiration". The reference evapotranspiration (ET_0) is the rate of evapotranspiration from a well-defined reference environment. In most cases, limited water is available for evapotranspiration which is the actual rate of water loss. Actual evapotranspiration is defined as the rate at which water is actually removed by evapotranspiration to the atmosphere. Transpiration helps the plants to assimilate and transport mineral nutrients. It also cools the leaves surface due to the removal of latent heat for vaporisation. However, too much transpiration can lead to plant stress in the hyper-arid rangelands. The term "potential" is equivalent to the maximum possible level of water loss under given climatic conditions. As soil water depletes, evapotranspiration decreases and reduces from potential and actual evapotranspiration in hyper-arid regions where the potential evapotranspiration is extremely high and the available water is very limited.

There is a popular notion that the arid environment is monotonous in the western part of the Indian Desert. Owing to inaccessibility and scanty research in these extreme areas, the geographical variations within a broad range of arid lands were often underestimated. In view of this scientific tradition, arid condition was considered the last limit of environmental degradation in the Indian Desert. At macro- and meso-level enquiries, the aridity index in the Indian Desert has been measured from 85 to 94 percent. However, an environment is admitted to be hyper-arid if the aridity index is measured as 95 percent or more.

There was an educated guess that the environment of the Indian Desert, on its last frontiers, could be more than arid. The available literature at Central Arid Zone Research Institute (CAZRI), Arid Forest Research Institute (AFRI), Central Research Institute for Dryland Agriculture (CRIDA) and International Crop Research Institute for Semi-Arid Tropics (ICRISAT) does not seem to have made an attempt on the identification of hyper-arid areas in the Indian Desert.

17.3 Demarcation Bases of Hyper-Arid Land

The present demarcation of hyper-arid zone in the Indian Desert is largely based on the latest criterion of climatic classification by Kafle and Bruins (2009). Kafle and Bruins attempted a classification of semi-arid, arid and hyper-arid environments as evident from Table 17.1. The other significant bases for identification of hyper-arid environment in the Indian Desert are botanical basis and hydrographic basis.

17.3.1 Meteorological Basis

The following maps of precipitation and potential evapotranspiration have been considered as the bases of climatic demarcation of hyper-arid lands. On this basis, the author has made an attempt to scientifically demarcate the hyper-arid lands of the Indian Desert. The identification and analysis have been based on the meteorological data from the years 2004 to 2009. Figure 17.1 depicts the geographical extent covered by 100 mm isohyet at the end of the monsoon rains. The 100 mm isohyet of 2004 extended up to the areas which on an average received 150–250 mm annual rainfall. It means that 2004 was the year of severe and widespread drought. In the arid zone 22 tehsils experienced severe drought and 25 tehsils recorded a moderate drought. Even Jodhpur which has an average annual rainfall of 360 mm received only 139.5 mm rain in the year 2004.

This situation has been examined in view of the corresponding geographical distribution of potential evapotranspiration. Figure 17.2 depicts the geographical extent covered by 2400 mm annual potential evapotranspiration in the year 2004. Most of these arid areas have an average annual potential evapotranspiration of less than 2300 mm in the years of normal rainfall. But, as 2004 was a year of severe drought with considerably below average rainfall, the potential evapotranspiration was conversely much higher than its average.

Hence, the lower rainfall coupled with higher potential evapotranspiration led to a higher aridity index than in the normal years. In the equation of very low rainfall and very high potential evapotranspiration, the aridity index was 97.08. Thus, the year 2004 notably experienced the hyper-arid conditions.

Likewise Fig. 17.3 shows the geographical extent covered by 100 mm isohyet by the end of monsoon rains in the arid western Rajasthan. The given isohyet represents total annual rainfall for the year 2005. This 100 mm particular isohyet covers sporadic and non-contiguous areas in western Ganganagar, western Jaisalmer, western Jodhpur and the adjoining Barmer district.

In the year 2005, when the areas of 200–250 mm average annual rainfall received only 100 mm rainfall, then it is quite obvious that the areas of acute rainfall scarcity of average 100 mm would have received nearly 75 mm rainfall. The very low 75 mm rainfall would have considerably raised the aridity index of the year 2005 to easily qualify it as a year of hyper-arid conditions.

Figure 17.4 illustrates the geographical extent of 2400 mm annual potential evapotranspiration for the year 2005. Most of these arid areas have an average annual potential evapotranspiration

Table 17.1 Climatic classification by Kafle and Bruins (2009)

Climatic classification	Aridity index
Hyper-arid	<0.05
Arid	0.05 to <0.20
Semi-arid	0.20 to <0.50

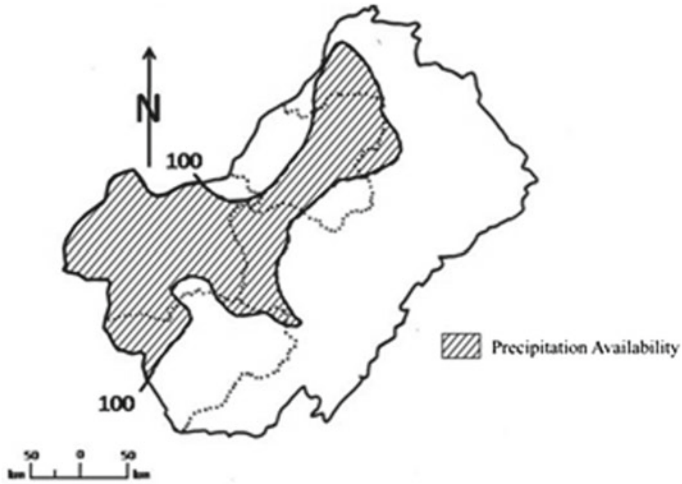

Fig. 17.1 Indian Desert: 100 mm isohyet at 2004 monsoon end. (*Source* Adapted from Annual Report 2004, CAZRI)

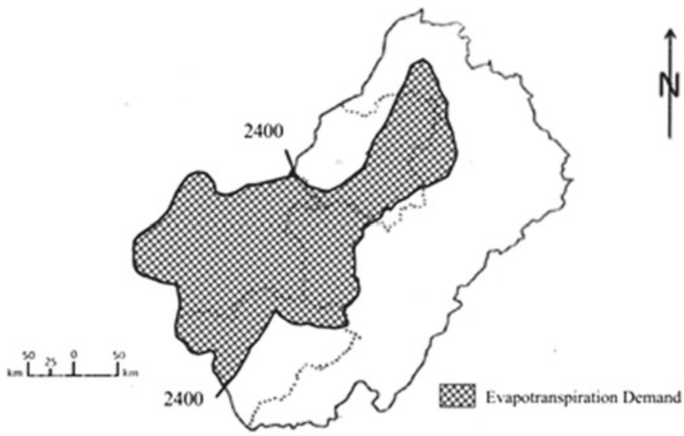

Fig. 17.2 Indian Desert: Above 2400 mm annual potential evapotranspiration, 2004. (*Source* Prepared by researcher)

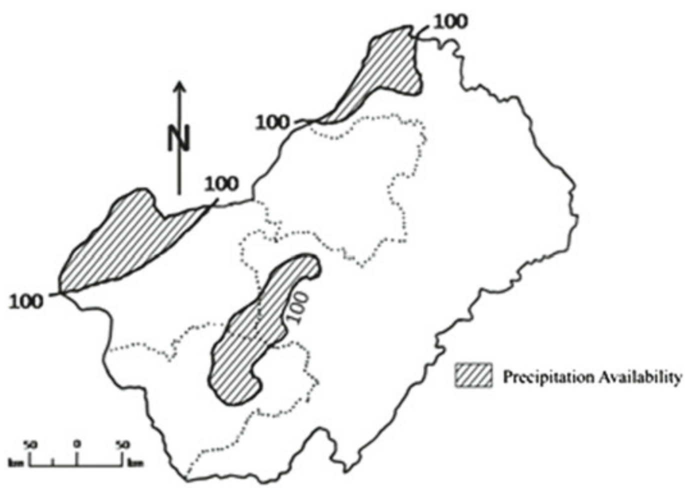

Fig. 17.3 Indian Desert: 100 mm isohyet at 2005 monsoon end. (*Source* Adapted from Annual Report 2005, CAZRI)

ranging between 2200 and 2300 mm in the years of normal rainfall. However, as 2005 was a year of pronounced drought conditions of severe nature with lower rainfall, the potential evapotranspiration was conversely much higher than its average atmospheric demand.

Consequently, the lower rainfall coupled with higher potential evapotranspiration led to a higher aridity index than the average annual normal rainfall years. In the equation of very low rainfall and exceptionally high potential evapotranspiration, the annual aridity index was 96.875. Hence, the year 2005 also experienced hyper-arid conditions for the consecutive second year.

Figure 17.5 demonstrates the geographical area covered by 100 mm rainfall at the end of the monsoon period. The isohyet represents the total amount of rainfall of the year 2006. The 100 mm isohyet covers a small area of Pokaran tehsil in Jaisalmer district, Kolayat tehsil in Bikaner district, Bikaner tehsil and south-western parts of Anupgarh tehsil of district Ganganagar.

The isohyet of 2006 is equal to the average annual rainfall of the western strip of land along Pokaran and Kolayat tehsils. In its northern half, it depicts the below average rainfall. Hence, there was a drought condition. Parts of Bikaner and Anupgarh tehsils have an average annual rainfall of 175 mm, but in the year 2000, these areas had considerable drought with only 100 mm rainfall. The southern half of the 100 mm isohyet area has a normal rainfall. In the year 2006, the areas depicted normal rainfall. No drought conditions were noticed.

Figure 17.6 shows the geographical extent covered by 2300 mm annual potential evapotranspiration for the year 2006. Most of these arid areas have an average annual potential evapotranspiration of less than 2300 mm in the normal seasonal conditions.

Hence, potential evapotranspiration in the year 2006 was slightly above its average. The resultant aridity index was 95.652 in the year 2006. It means that even the year 2006, with almost normal rainfall just experienced the hyper-arid conditions.

Figure 17.7 shows the geographical area covered by 100 mm rainfall at the end of the monsoon period. The isohyet represents total annual rainfall of the year 2007. This 100 mm low rainfall isohyet covers a small area of the arid zone. It is confined to the western limit of Jaisalmer. A very small area of lowest rainfall indicates that rest of the Rajasthan had experienced good rainfall. Hence, the year 2007 was not a scarcity rainfall or drought year.

Figure 17.8 illustrates the geographical extent of potential evapotranspiration for the year 2007. The most western extent of Jaisalmer records a mean annual potential evapotranspiration of slightly less than 2300 mm. The resultant aridity index was again 95.652 in the year 2007 also. It indicates that 2007 was also a just hyper-arid year in this small area.

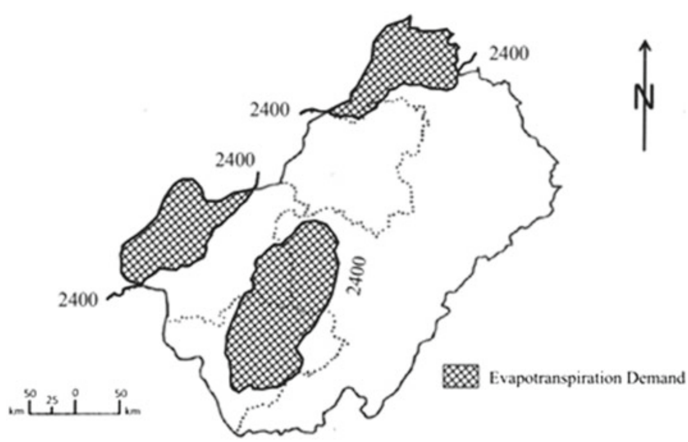

Fig. 17.4 Indian Desert: About 2400 mm annual potential evapotranspiration, 2005. (*Source* Prepared by researcher)

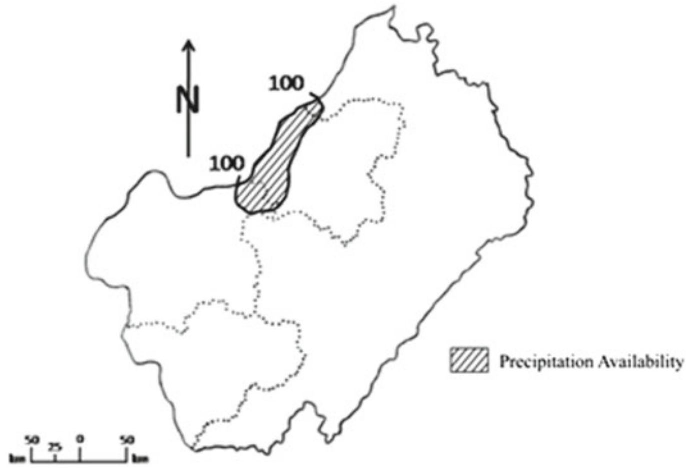

Fig. 17.5 Indian Desert: 100 mm isohyet at 2006 monsoon end. (*Source* Adapted from Annual Report 2006, CAZRI)

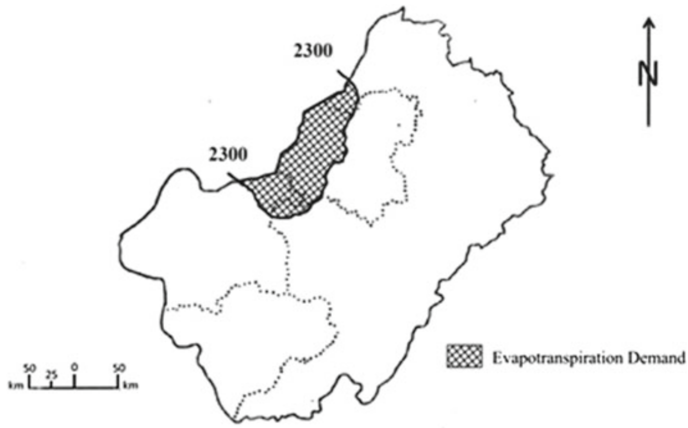

Fig. 17.6 Indian Desert: Nearly 2300 mm annual potential evapotranspiration, 2006. (*Source* Prepared by researcher)

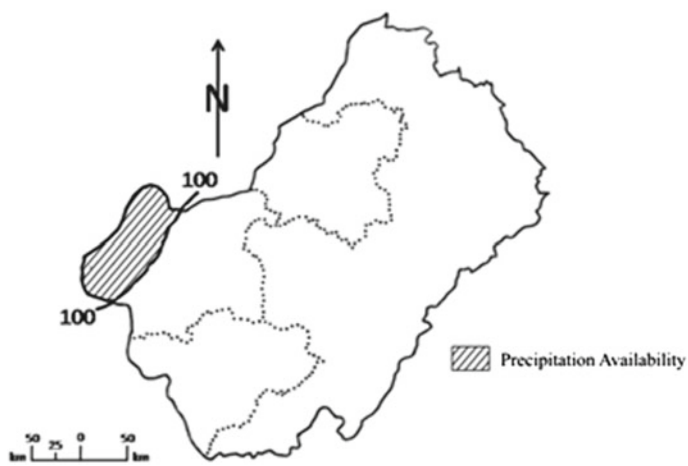

Fig. 17.7 Indian Desert: 100 mm isohyet at 2007 monsoon end. (*Source* Adapted from Annual Report 2007, CAZRI)

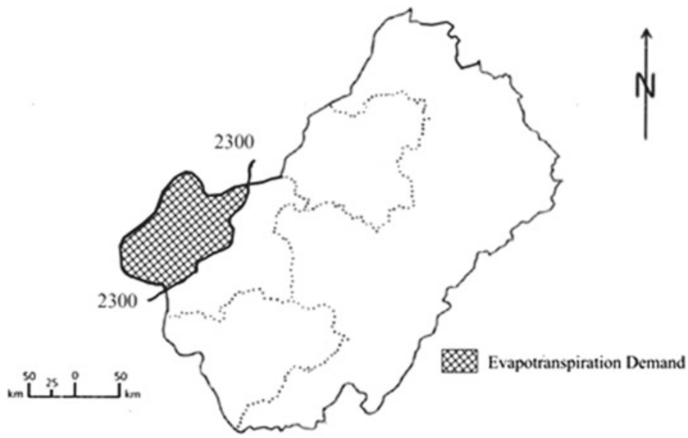

Fig. 17.8 Indian Desert: Nearly 2300 mm annual potential evapotranspiration, 2007. (*Source* Prepared by researcher)

Figure 17.9 depicts the geographical expanse of 100 mm isohyet by the end of monsoon rains in the arid western Rajasthan. This particular isohyet represents the total annual rainfall of the year 2009. This 100 mm specific isohyet covers a much larger contiguous area than the area covered by the normal average annual rainfall. The very low 100 mm isohyet rainfall of 2009 extended up to the areas which on an average received 150–300 mm annual rainfall.

When areas of 150–300 mm average annual rainfall received only 100 mm rainfall in the year 2009, then one can estimate the acute scarcity areas of 100 mm rainfall would have received even less than 70 mm rainfall. Year 2009 depicted a much larger contiguous area of severe drought. This severe drought year has considerably increased the aridity index of 2009 to qualify it as a year of hyper-arid conditions.

Figure 17.10 illustrates the geographical area covered by 2400 mm annual potential evapotranspiration in the year 2009. Most of these arid areas have an average annual potential evapotranspiration of less than 2300 mm in the years of normal meteorological conditions. However, because 2009 was a year of severe and extensive drought with considerably below average rainfall, the potential evapotranspiration was conversely much higher than its average. Consequently, the lower rainfall coupled with higher potential evapotranspiration led to a higher aridity index than would be the case in normal years. In the equation of low rainfall and high potential evapotranspiration, the aridity

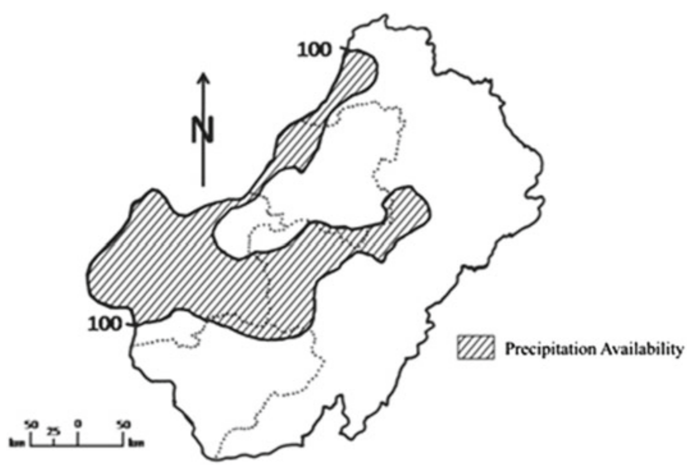

Fig. 17.9 Indian Desert: 100 mm isohyet at 2009 monsoon end. (*Source* Adapted from Annual Report 2009, CAZRI)

Fig. 17.10 Indian Desert: Above 2400 mm annual potential evapotranspiration, 2009. (*Source* Prepared by researcher)

index was 97.083. Hence, 2009 was a year of distinct hyper-arid conditions.

The actual annual precipitation and potential evapotranspiration analysis for the period 2004 to 2009 helped to identify and demarcate the hyper-arid areas of the Indian Desert. The meteorological analysis verified that all the years recorded the annual aridity index ranging from 95.652 expressed as percentage of 97.083. Hence, all the years recorded an annual aridity index of 95 or higher as per the climatic classification scheme of Kafle and Bruins. The analysis reveals a regularly occurring hyper-arid condition along the narrow western margin of the Indian Desert. The hyper-aridity of the study area has been validated.

17.3.2 Botanical Basis

For the identification and demarcation of the hyper-arid areas in the Indian Desert, the researcher has additionally employed the Koppen's eternal botanical index for the demarcation of hyper-arid areas. As per the present demarcation, the hyper-arid areas of the Indian Desert have two unique identification features.

Botanically, the drastic floral changes in the form of disappearance of the tree line are another basis of the identification and demarcation of hyper-arid zone in the Indian Desert. All the areas of Indian Desert are dotted with versatile and robust *Prosopis cineraria*—a tree locally called *Khejri.* A sudden disappearance of this tree including the shrubs is a botanical evidence of the encroaching hyper-arid conditions. There is no tree growth or shrubs in the hyper-arid areas of the Indian Desert. Only extremely drought-resistant annuals, biennials, ephemerals and grasses sustain. Drought-resistant grasses have been acknowledged as hyper-arid.

17.3.3 Hydrographic Basis

There are a number of evidences to support the view that the genesis of hyper-arid lands in the Indian Desert lies to the hydrographic changes in the form of shift and disappearance of the palaeo drainage systems. A network of palaeochannels is testimony to the organised drainage system in the areas where the hyper-arid lands lie as well as other arid lands of the Thar desert.

A large part of the region is covered by Aeolian sand and alluvium and is devoid of any other perennial drainage system. Late quaternary climatic changes and neotectonics have significantly modified the drainage courses in the region to form a large number of palaeochannels. Palaeochannels are remnants of stream channels cut in older rocks/sediments and filled by younger overlying sediments. The palaeochannels of Saraswati coincide with the dry bed of present-day Ghaggar.

The Luni was a tributary to the Himalayan river Saraswati and the confluence of these two rivers was at Pachpadra, where Luni takes a sharp right angular bend towards the south. It was suggested that the Saraswati river system was forced to shift its course westwards at least four times by Aeolian sand advance from the southwest.

The courses of the Saraswati river in the western part of the Jaisalmer district using Landsat imagery and field observations were identified. The signature and migration of Saraswati river in Thar desert were delineated and the archaeological, ground water and other field evidences were utilised to confirm the traced palaeochannels.

The sand advance from the southwest has additionally contributed to the gradual anti-clockwise migration of Saraswati till its ultimate burial in the Anupgarh plains. The palaeochannels pattern of Saraswati river system in Great Indian Desert was classified as:

(1) Organised near rectilinear palaeochannels
(2) Disorganised convergent palaeochannels and
(3) Sprayed palaeochannels.

The course of the river Saraswati close to Indo-Pak border in the Jaisalmer district of Rajasthan could be identified. The Ground water Department, Government of Rajasthan, carried out eight exploratory drillings in the Kishangarh-Ghotaru region of Jaisalmer district and the results have been encouraging. These results are significant in view of the extreme arid terrain (less than 100 mm average annual rainfall).

Figure 17.11 depicts an eventual demarcation of hyper-arid zone in the Indian Desert. The area has been demarcated on the basis of meteorological data. These areas experience a meagre mean annual precipitation of less than 100 mm with a high rainfall variability of up to 80 percent which renders acute scarcity of water.

The mean annual potential evapotranspiration exceeds 2300 mm. It further exceeds to 2400 mm in the years of drought. The drought frequency is very high in these areas. Hence, the aridity index exceeds 95 percent to render them hyper-arid. In the years of severe drought the rainfall is reduced to 70 mm or even less up to 50 mm. This increases the aridity index to 97 percent or more. Figures 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9 and 3.10 depict geographical extent of the annual variations in the dwindling precipitation and potential evapotranspiration from 2004 to 2009.

17.4 Conclusion

The years with larger extent of 100 mm rainfall experienced a widespread and severe drought and were prone to hyper-arid conditions. The rainfall was reduced by 70 mm to 50 mm in such years, rendering them distinctly hyper-arid. Out of 5 years of depiction, 3 years experienced very severe droughts due to high rainfall variability. Accordingly, the hyper-arid areas have been demarcated in consonance with the lowest rainfall and highest potential evapotranspiration.

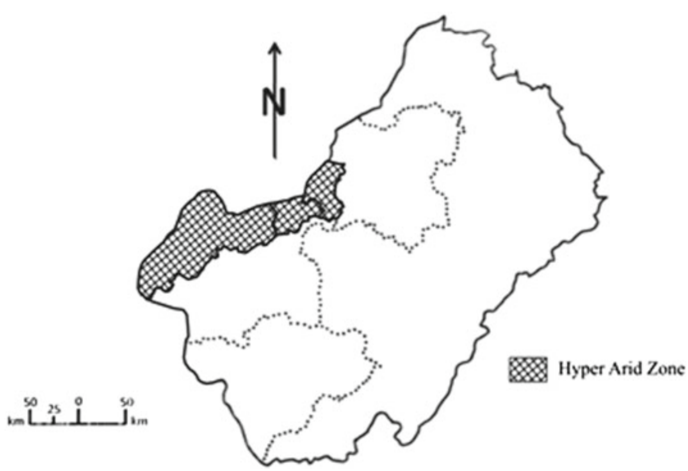

Fig. 17.11 Indian Desert: Demarcation of hyper-arid zone. (*Source* Prepared by researcher on the basis of meteorological data)

This area is relegated to western limits of the desert along the International Border of India with Pakistan. The area covers parts of Jaisalmer tehsil, Pokaran tehsil and Kolayat tehsil of Bikaner district. It encompasses a total area of 16,369 sq. km. Its largest extent is in Jaisalmer tehsil, spanning over 11,824 sq. km, which covers 72.234 percent of the area. In Pokaran, it extends over 2,511 sq. km with 15.340 percent area. In Kolayat, it spreads over 2,034 sq. km with 12.426 percent of the total hyper-arid area. The entire hyper-arid zone includes 175 villages. Out of which, 102 villages lie in Jaisalmer tehsil, 43 villages in Pokaran tehsil and 20 villages in parts of Kolayat tehsil. The hyper-arid areas affect a considerable population which lives under extremely precarious environment.

Acknowledgements The author acknowledges the UGC–CSIR for the joint research fellowship.

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Development of the Approach for the Complex Prediction of Spring Floods

18

A. A. Volchak, D. A. Kostiuk, D. O. Petrov, and N. N. Sheshko

Abstract

Snow storage influence on the flood situation and the contemporary approaches to determine water content in a snow cover are discussed. An artificial neural network application is proposed and tested to improve the accuracy of snow water equivalent retrieval from the satellite microwave radiometer-based measurements and to predict the water discharge in a river flow control point. A method of inundation zone outline calculation in case of river flood situation is proposed and evaluated.

Keywords

Flood · River · Snow · Radio-temperature · Forecast

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18.1 Snow Storage Influence on the Flood Situation

Prediction of the flood evolution is a complicated task, which makes it necessary to take into account a lot of factors. Particularly, long spring flood is typical for water regime of some rivers, having nourishment of a mixed type with prevailing snow one. Therefore, taking into account the dynamics of snow storage accumulation allows to increase the prediction accuracy and to make more effective organizational and technical measures to level out flood consequences.

Snow storage in the beginning of the active melting period is the main source of the maximal discharges causing material and social damage. Besides the amount of snow, weather also makes substantial influence on the spring flood formation. Therefore, it is possible to predict the volume of the spring river flow based on the estimation of water, stored in the form of a snow over the watershed. Temperatures and rainfalls mid-term prediction allows in their turn to estimate the snow melting intensity and the corresponding maximum discharge of the river, which is possible in the flood time.

B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_18

18.2 Contemporary Approaches to Determine Water Content in a Snow Cover

Traditional and most labor-consuming method for snow water equivalent determination on the explored area involves weighting of the snow samples taken with snow-measuring cylinder at the observation sites and linear snow courses, both on forest and field lands.

In addition, there are methods to measure snow cover characteristics by placing autonomous snow-measuring devices based on different operation principles.

Snow pillow is an example of such devices, targeted at weight measuring of the snow placed above it. Pillow of the most used type looks like a round container of the 3.7 m diameter, made of some rubberized material and filled with no-frost liquid. Hydrostatic pressure inside of the pillow is a measure of the snow weight upon it. Water equivalent measurements done with snow pillows can produce 5–10% difference compared with traditional snow samples weighting.

Vertical radioactive snow gauges are another type of autonomous devices. Their operation is based on gamma-ray attenuation while passing through some medium. Such attenuation depends on the ray's initial energy, stuff density and thickness. High-energy gamma-rays source is needed for this method. Cobalt-60 is often used due to its high gamma energy and long half-life period (5.25 years).

Lead protective container with the radiation source is placed into the ground in such a way that upper surface of the container is on the same level with the ground surface, and gamma ray beam is directed toward the radiation detector, placed above the snow cover. Either Geiger-Muller counter or scintiometer can be used as a detector. Pulses from the counter are transferred to the integrating and registering device.

Relatively expensive and complex equipment is needed for such radioisotope devices. Also there are special safety precautions, especially when strong radiation source is used.

Gamma-radiation survey done from an aircraft is useful to estimate snow water equivalent on the area up to several thousands of square kilometers. Gamma-radiation survey uses the fact that snow cover attenuates gamma rays radiated by natural radioactive elements contained in the soil upper layer. Water storage in a snow cover can be calculated by using the gamma radiation intensity measured over the surface of the snow cover and the intensity measured in the same route before the snowfall. Aircraft survey produces integral area estimation of the snow cover water equivalent, as series of point measurements are done along the fragments of a flight. This method is recommended not only to map water storage in the snow on lowlands, but also can be used on hilled areas with heights difference up to 400 m.

Accuracy of the aircraft gamma survey of the snow cover depends on the measuring equipment quality, oscillations of the space radiation and the ground air radioactivity, oscillations of the humidity on upper 15 cm layer of the ground, homogeneity of the snow deposit, absence of long thaw periods, and so on. Supposed errors are ± 10% with the low limit of approximately 10 mm of the water equivalent. Detailed experimental research has shown that standard deviation of the snow water equivalent measurements done by an aircraft survey on a 10–20 km route is about 8 mm and has random pattern.

The main disadvantage of listed at-ground methods of the snow cover water equivalent determination is the point nature of the carried out measurements, which causes the necessity of data interpolation to find out area characteristics, and may cause substantial errors of the snow water storage on large areas in case of non-homogeneity of the snow cover forming conditions. From the other side, remote gamma survey of the snow cover done from an aircraft does not allow to make measurements at arbitrary weather conditions.

Starting from 70th year of the last century, remote sensing of the Earth surface is actively used to carry on the express tests of the snow storage in regions not covered by meteorological stations. Such sensing is based on the Earth thermal radio radiation measurement with the use of such satellite platforms as SSMR, SSM/I, AMSR-E (Mitnik and Mitnik 2005; Hollinger et al. 1990; Sharkov 2004). Snow cover is able to attenuate thermal radio radiation from the substrate. This fact allows calculating the snow depth and its water equivalent based on the snow density and grain size.

An empiric regression formula is used to calculate the snow cover water equivalent *S*, taking into account the difference between the brightness temperatures of 18 and 37 GHz frequency channels of the SSMR sensor horizontal polarization (Chang et al. 1985; Kitaev and Titkova 2010):

$$S = 4.8\,(\mathrm{T}_{18\mathrm{h}} - \mathrm{T}_{37\mathrm{h}}) \qquad (1)$$

Here T_{18h} and T_{37h} are the brightness temperatures of the horizontal polarization at 18 and 37 GHz frequency channels, respectively, and the 4.8 coefficient characterizes the snow cover density of 0.30 g/sm^3 for the grain size of 0.3 mm.

The SSM/I scanner operates on a different set of frequencies, and therefore Eq. (1) is changed in the following way:

$$S = 4.8\,(\mathrm{T}_{19\mathrm{h}} - 5 - \mathrm{T}_{37\mathrm{h}})$$

Fraction of the surface covered with forest is taken into account in estimating water equivalent by introducing an additional *c* coefficient for the equation (Chang et al. 1987):

$$c = 1/(1 - f)$$

where *f* is the percentage of the surface covered with forest.

Substantial disadvantage of such snow storage estimation method is its low space resolution, which is from 12 to 25 km. Besides that, the calculated parameters accuracy is substantially influenced by such factors as terrain complexity, vegetation and snow cover specifics (Nosenko et al. 2005). Particularly, microwave scanning does not allow finding out snow cover with depth less than 15 mm (Global snow monitoring 2010). In addition, it is discovered that Chang model does not allow estimating water equivalent with values higher than 120 mm (Chang et al. 1987). Finally, free water presence in the snow cover causes substantial errors of the water equivalent determination due to its microwave transparency decrease (Stiles and Ulaby 1980).

That is why additional measures targeted at timely detection of the liquid water layer on the snow surface are used to increase the accuracy of the obtained results. For example, as it is proposed in (Semmens et al. 2013), combined usage of passive and active remote microwave sensing can be used.

18.3 Evaluation of Artificial Neural Network Application for Improving the Accuracy of Snow Water Equivalent Retrieval from Satellite Microwave Radiometer-Based Measurements

The range of scientific research papers (Gan et al. 2009; Tedesco et al. 2004; Tong et al. 2010) reviews the positive experience of artificial neural network (ANN) application for retrieval of snow water equivalent (SWE) from satellite radiometer-based measurements, but the study sites were located in the relatively small areas, ranging from 120,000 to 338,430 km^2 and having 3–12 meteorological stations. The training datasets for the ANN consisted of measurements performed by orbital SSM/I and AMSR-E radiometers and ground-based test sites, screened for the effects of wet snow (average daily temperature is less than 0 °C) (Gan et al. 2009). The application of trained neural networks showed quite high correlation coefficient values up to 0.8–0.9 for AMSRE and 0.7–0.8 for SSM/I. It must be said that different nonlinear regression techniques had provided considerable less correlation coefficients: 0.2–0.3 (Tong et al. 2010).

The task of SWE retrieval from passive microwave sensor measurements for large land areas is a difficult task because of high spatio-temporal variability of snowpack cover and low quality of ground observations, leading to poor territorial zoning by snow cover constitution parameterization. As described in Nosenko et al. (2005), these factors determine the futility of obtaining sufficient accuracy of snow cover depth and SWE retrieval for hydrological applications on the whole territory of the Russian Federation. At the same time, the regression formula (2) gives poor quality of SWE retrieval in the deforested central and polar regions of the European part of the Russia, with the situation becoming even worse at a thaw period, especially when it is followed by rains, which leads to formation of impervious for microwave radiation ice layer above the show. The more favorable conditions for SWE retrieval arise when the percentage of the forest cover comes to 40% (Nosenko and Nosenko 2007). To overcome the described problems, it is proposed to find new regression relations for extended range of microwave radiation frequencies, which are more reliable for the territories of sufficient climatic and landscape conditions uniformity (Nosenko et al. 2005; Nosenko and Nosenko 2007).

The Special Sensor Microwave Imager (SSM/I), as described by National Snow & Ice Data Center (https://nsidc.org/data/docs/daac/ssmi_instrument.gd.html), was carried aboard Defence Meteorological Satellite Program (DMSP) satellites F8 (launched on June 19, 1987), F10, F11, F12, F13 and F15 (launched in December 1999). The SSM/I is a seven-channel, four-frequency, orthogonally polarized, passive microwave radiometric system that measures atmospheric, ocean and terrain microwave brightness temperatures at 19.35, 37.0, 85.5 GHz (vertical/horizontal polarization with spatial resolution of 25 km) and 22.2 GHz (vertical polarization only with spatial resolution of 12.5 km). The data for all frequencies, organized in the Level-3 Equal-Area Scalable Earth-Grid (EASE-Grid) for both Northern and Southern Earth Hemispheres, with spatial resolution of 25 km and collected on daily basis by SSM/I radiometer is freely available from the National Snow & Ice Data Center (ftp://sidads.colorado.edu/pub/DATASETS/nsidc0032_ease_grid_tbs/).

For the purpose of research, the daily observed snow cover characteristic data at 117 in situ meteorological observation stations that widely cover the territory of the Russian Federation (see Fig. 18.1) were selected from the dataset, freely available from All-Russian Research Institute of Hydrometeorological Information–World Data Center (RIHMI-WDC). All the selected meteorological stations are located within 12.5 km radius relative to the centers EASE-Grid cells.

The artificial neural network (ANN) is used as a mathematical model. In fact, neural approach supposes settling the mathematical relationship between a set of input parameters X_i and a set of output parameters Y_i which is established by training on a certain group of samples. One of the most popular ANN architectures is a multilayer feed forward artificial neural network, which consists of a set of interconnected processing unit groups called layers (Fig. 18.2).

In the first experiment, the following six artificial neural networks were constructed and trained for retrieval of snow water equivalent from SSM/I measurements of brightness temperatures for channels 19.35, 37.0 and 85.5 GHz of different polarizations over subset of EASE-Grid cells, containing snow observation courses located in terrain, which share common characteristics:

(a) Artificial neural networks for horizontal, vertical and both orthogonal polarizations on the all forested snow courses;
(b) Artificial neural networks for horizontal, vertical and both orthogonal polarizations on all open terrain snow courses.

The multilayer perceptron (MLP) architecture was chosen for every constructed artificial neural network. Depending on the actual combination of selected channel polarizations, each MLP had the number of neurons in the input layer ranging from 3 (horizontal or vertical polarization) to 6 (polarization in both directions). The hidden layer had 10 neurons with sigmoid activation

Fig. 18.1 Location of meteorological observation stations

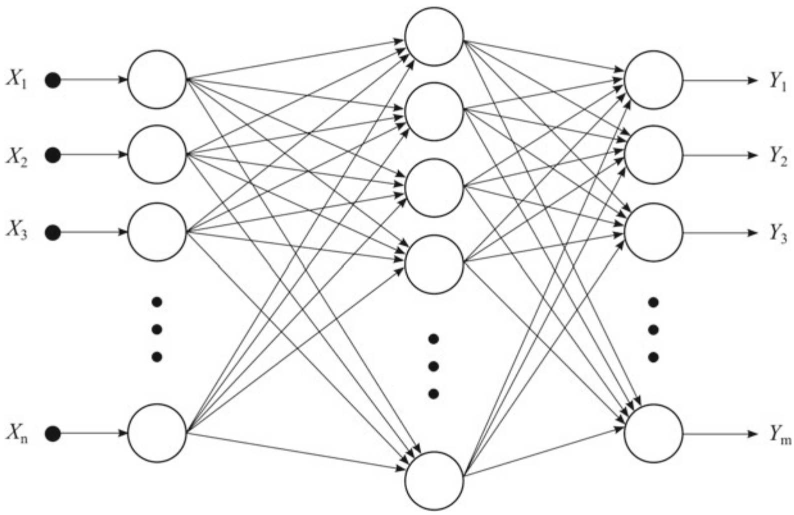

Fig. 18.2 Multilayer feed forward artificial neural network

function and the output layer had only one neuron to give computed SWE value.

All the artificial neural networks were trained by back-propagation learning rule (Rumelhart et al. 1986), using the set of recorded SSM/I radiometer-based remote measurements and direct SWE measurements, collected from nearby snow courses that are selected as study observation stations during the time period from January 1, 1988 to December 31, 1988. This time period was selected for study because it was the first year since DMSP F-08 launch, when all 366 daily SSM/I measurements were collected.

To improve the SWE retrieval, the training datasets were screened from cases when ice or water cover was detected atop the snow cover (Chang et al. 1987; Nosenko et al. 2005). The SWE retrieval capability of the trained artificial neural networks was tested against the respective snow courses observation data, collected through the time period, beginning from 1992 to 1998. In order to judge neural network performance, the following statistical parameters were used: root mean square error (RMSE) and the Pearson correlation coefficient r (Table 18.1).

The goal of the second experiment was to test the ANN performance for SWE retrieval from SSM/I measurements of brightness temperatures over all EASE-Grid cells without differentiation between underlying terrain type. The artificial neural network architecture and the training/testing datasets constitution were as in the first experiment. Three different neural networks were constructed and trained for SWE retrieval from brightness temperatures for channels at 19.35, 37.0 and 85.5 GHz of different polarizations:

(a) ANN for brightness temperatures of horizontal channel polarization;
(b) ANN for brightness temperatures of vertical channel polarization;
(c) ANN for brightness temperatures of both orthogonal channel polarizations.

Performance tests for brightness temperatures of horizontal channel polarization gave very low value of $r = 0.11 \pm 0.01$, and use of vertical channel polarization had risen the correlation coefficient value to 0.12 ± 0.01. The input data consisting of both orthogonal channel polarizations gave a r value equal to 0.39 ± 0.01 and the RMSE = 24.9 mm (Fig. 3c). Excluding the channel of 85.5 GHz with both polarizations has lowered the value of correlation coefficient r to 0.32 ± 0.01 with RMSE value of 25.8 mm (Fig. 3d).

As it is obvious from the latter experiments, the correlation coefficient values are mostly

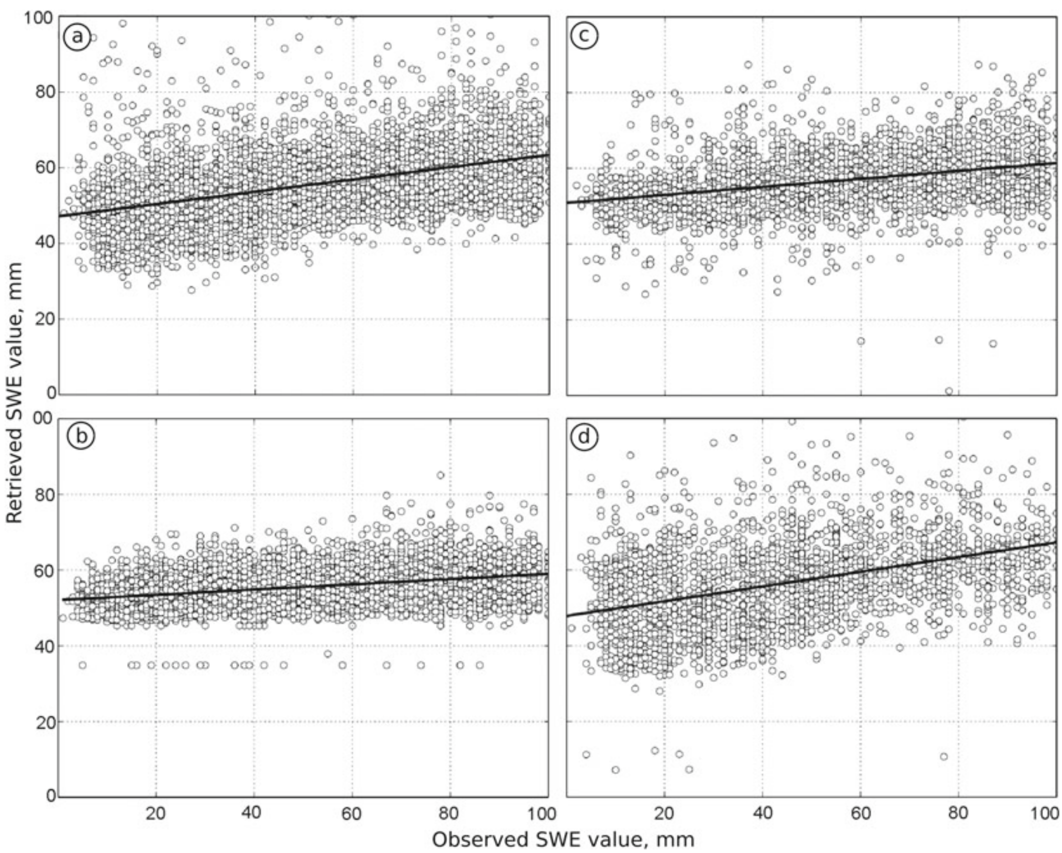

Fig. 18.3 ANN snow water equivalent retrieval test results: **a** snow observation courses in the forested terrain, 19.35; 37.0; 85.5 GHz channels of horizontal polarization: RMSE = 24.65 mm, r = 0.317 ± 0.02; **b** snow observation courses in the open terrain, 19.35; 37.0; 85.5 GHz channels of both orthogonal polarizations: RMSE = 28.8 mm, r = 0.32 ± 0.02; **c** snow observation courses in the forested and open terrain, 19.35; 37.0; 85.5 GHz channels of both orthogonal polarizations: RMSE = 24.9 mm, r = 0.39 ± 0.01; **d** snow observation courses in the forested and open terrain, 19.35; 37.0 GHz channels of both orthogonal polarizations: RMSE = 25.8 mm, r = 0.32 ± 0.01

lower than those given in the published research papers (Gan et al. 2009; Tedesco et al. 2004; Tong et al. 2010). To further investigate the reason behind the low obtained *r* values, third experiment was carried out to test SWE retrieval performance for ANNs constructed and trained for every individual EASE-Grid cell with distinct snow course terrain features. The results obtained from testing of neural networks which were trained to retrieve snow water equivalent from brightness temperatures for channels 19.35, 37.0 and 85.5 GHz of horizontal polarization for open terrain snow courses had given the highest correlation coefficient values up to 0.79 (Fig. 4b). The input data consisting of temperatures of both orthogonal polarized channels for the forested terrain allowed reaching the value of *r* up to maximum value of 0.7. For the meteorological observation stations that have both forested and open terrain snow courses nearby, the best correlation coefficient value of SWE retrieval from channels of horizontal polarization reached 0.55.

Therefore, the obtained statistical criterion values confirmed the possibility of reaching ANN retrieval performance comparable with the ones published by Gan et al. (2009), Tedesco et al. (2004) and Tong et al. (2010). It must be noted that the increase of neuron count in the hidden layer nor the increase of hidden layer count for the employed MLP ANN did not give any boost to SWE retrieval capability.

According to the opinion given by Nosenko et al. (2005), the low *r* values could be explained because of frequent thaws leading to wetting of

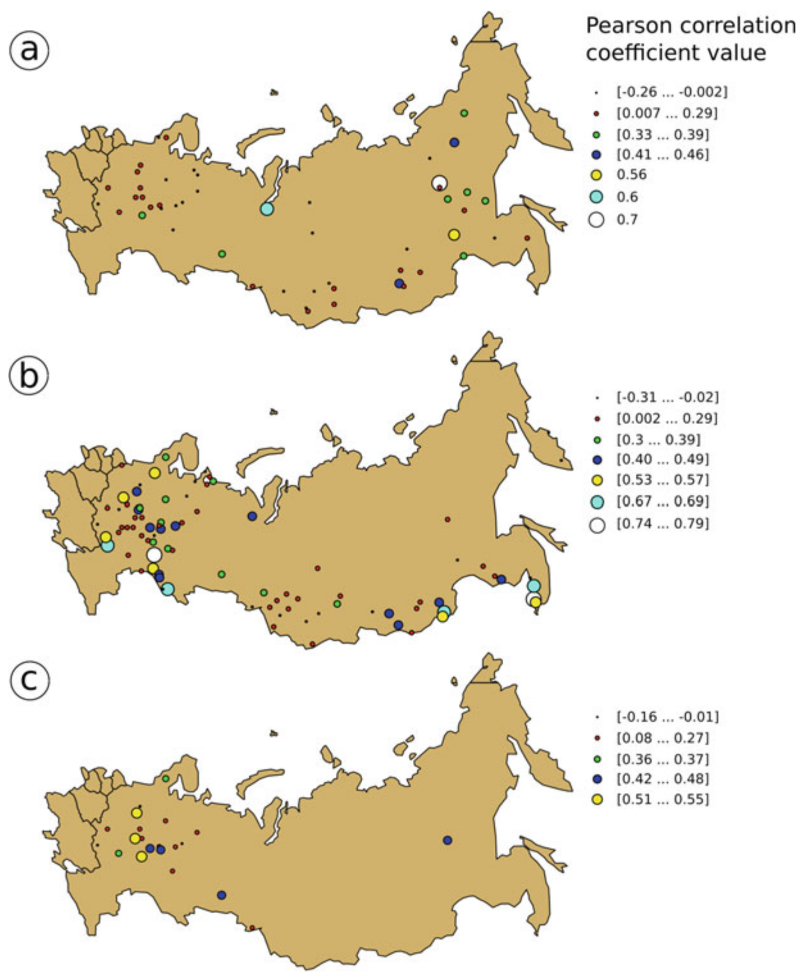

Fig. 18.4 Meteorological station locations where forested (**a**), open (**b**) or both forested and open terrain snow course observations are conducted (**c**), along with the Pearson correlation coefficient values obtained in the ANN testing process

the snow, which is impervious for microwave radiation ant thus indiscernible from snow-free terrain. At present, it is no more than one meteorological observation station per EASE-Grid cell of 25 × 25 km size on the territory of the Russian Federation, which can lead to poor representation of snow cover characteristics due to “bad” placement of observation within a cell bound.

From the result of completed study (Volckak et al. 2016) and based on the obtained values of root mean square error and Pearson correlation coefficient (RMSE = 24.9 mm, $r = 0.39 \pm 0.01$), we have come to the conclusion that the best SWE retrieval performance has the artificial neural network which takes the results of SSM/I measurements of brightness temperatures for channels at 19.35, 37.0 and 85.5 GHz for both orthogonal polarizations with distinct differentiation of terrain cover features within EASE-Grid cells as input data. It is shown that the low obtained values of correlation coefficient (lower than 0.5) in contrast with the published result of studies over relatively small territories come from specific features of the completed experiments which are the significant diversity of climatic and terrain characteristics and irregular meteorological observation station coverage of the studied territory.

It must be noted that the forest cover density, the forest cover type and the air temperature at the ground level were not taken into consideration in the presented research. There is a probability that taking into account the forest cover density will improve the accuracy of the SWE value retrieval, because the vegetation cover significantly scatters the microwave radiation, and on the other hand, the snow cover characteristics depend on the forest cover type. The consideration of the air temperature at the ground level will help to detect the thaw conditions more precisely. To further improve the accuracy of the snow cover retrieval, it seems to be practical to employ the artificial neural network ensemble, which is trained on the samples collected from the set of territories organized by climatic and land cover similarity.

18.4 Estimating How the Snow Water Equivalent Dynamics Influences the Water Discharge in a River Flow Control Point

An open access archive of the snow water equivalent dynamics data was used as a source data for the research. The archive contains observations carried out in bounds of the GlobSnow project on the Northern Hemisphere of Earth and is covering years of the 1979–2011 range. Archive data are obtained by combining land meteorological station observations with SMMR and SSM/I sensors measurements (Luojus et al. 2010). Measurements of the satellite passive sensors are performed on daily basis, while snow-gauging surveys have 5–10 days interval. The archive itself is a set of matrices of 721 × 721 size, with elements containing values of averaged thickness of the snow cover water equivalent in millimeters. Area of each cell is equal to 625 km^2.

A preselection of the matrix cells belonging to the Pripyat river watershed was done, with an outlet near the Mozyr hydrological station, based on data from the 1979 to 2004 years range, and the volume of water in the snow for each day from November to March was calculated for this territory.

Primary evaluation of the calculation results and their connection to the flood specifics was done by measuring average daily water discharge of the Pripyat river, on the Mozyr hydrological station.

Typical case can be seen in Fig. 18.5, which illustrates the dynamics of 2003–2004 years and for 2004–2005 years. Winter of 2003–2004 was marked by a strong thaw, which results in two peaks as shown in Fig. 5a. Next year had no significant winter thaw, which is clearly seen by the only peak in Fig. 5c.

Therefore, the approach to evaluate dynamics of the snow cover water storage illustrated by Fig. 18.5 allows in carrying out the qualitative prediction of the spring water discharge dynamics at specific hydrological station. Meanwhile,

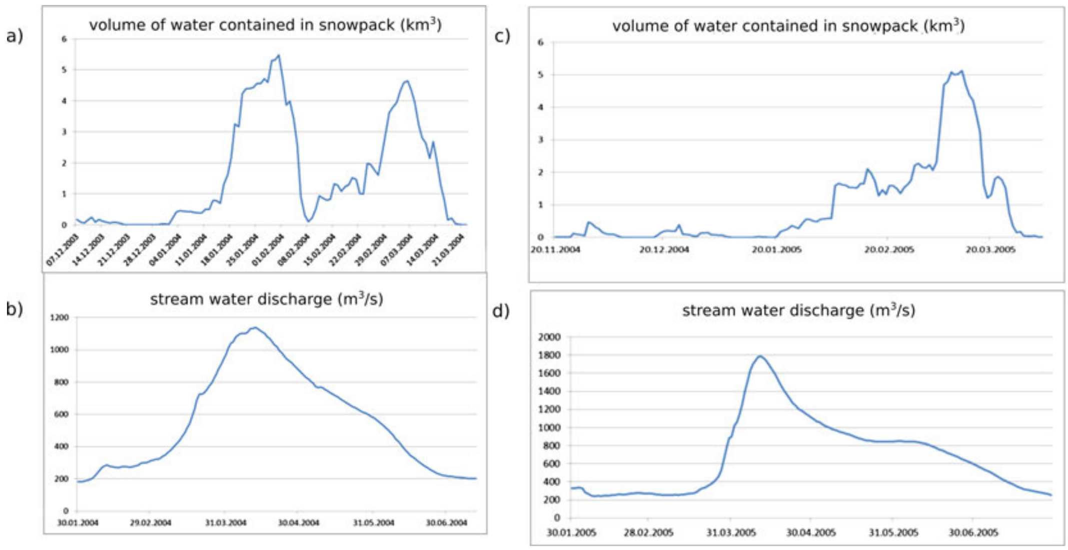

Fig. 18.5 Water equivalent accumulation dynamics during a 2003–2004 winter period (**a**), 2004–2005 (**c**) and hydrographs on the Mozyr hydrological station at winter-summer period of 2004 (**b**), and 2005 (**d**)

quantitative restoration of the water discharge depends on such important factors as the presence and the amount of rainfalls during the spring melting period, and also precipitation of snow-originated water into the ground.

Good illustration of the possibility to have non-adequate prediction of the water discharge because of ignoring these factors can be seen on relatively snow-free winter in the years 1989–1990, and calculations for which are shown in Fig. 18.6. One can notice that despite the water equivalent volume reaching 5 km^3 several times, the hydrological station has not registered any proportional increase of the water discharge.

Visible difference in this and similar cases cannot be corrected by a simple adjustment coefficient. Additional integrated accounting of the above spoken factor is a necessary condition to increase the prediction accuracy.

Results of the research show that remote microwave scanning can be used to quickly control the daily dynamics of the snow cover water equivalent value on large territories, which is sufficient to provide qualitative prediction of the water discharge spring dynamics on a hydrological station. Quantitative restoration of the water discharge, nevertheless, demands accounting of important factors such as rainfall during the spring thaw and amount of rainfall, as well as precipitation of the snow-originated water by the ground.

18.5 Applying Artificial Neural Networks to Predict the Water Discharge in a River Flow Control Point

Using ANN mathematical apparatus allows us to take into account the whole complex of parameters while making the hydrological forecast for the river flow control points, such as air average daily temperature, water discharge on the hydrological station, level of the snow cover and rainfall on the watershed (Vladimirov et al. 2012).

Owing to substantial time gaps between traditional snow cover measurements and rather sparse network of meteorological stations, it is reasonable to use the results of daily estimates of the water content in a snow cover made by passive microwave sensing done by a satellite.

Source data to carry on such research in our case were water discharge observations done on

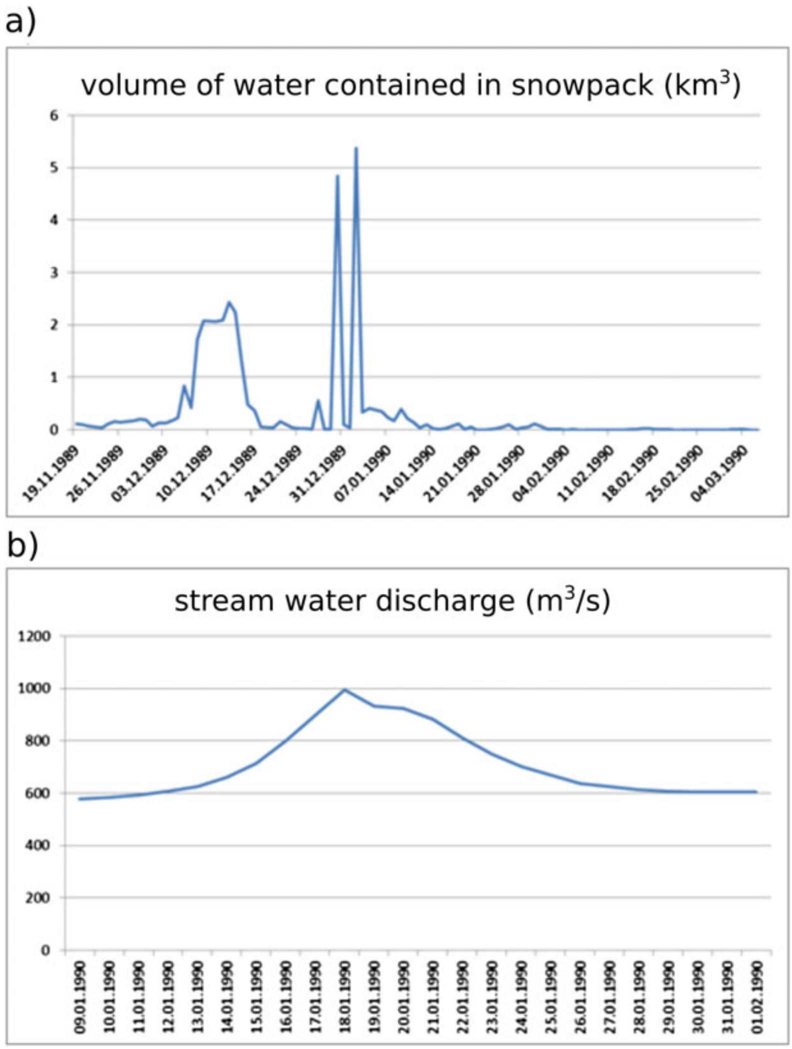

Fig. 18.6 Water equivalent accumulation dynamics during winter for the period 1989–1990 years (**a**) and hydrographs on the Mozyr hydrological station during winter of the year 1990 (**b**)

the Mozyr hydrological station residing on the Pripyat river (these data have been collected on daily basis from January to April during the 1980–2005 years range), as far as ground air temperature and rainfall on the meteorological stations of the watershed, residing upper than Mozyr hydrological station, and also the snow cover water equivalent data taken from the microwave SMMR and SSM/I satellite passive sensors.

Source data analysis has shown two remarkable years, 1996 and 1999. Year 1996 has maximal water accumulation in the snow cover in the Pripyat watershed, which was 14.3 km^3 (Fig. 7a). Year 1999 has distinguished flood with maximal water discharge on the Mozyr hydrological station, equal to 3270 m^3/s. Year 1999 is characterized by a long snow-melting period with practically constant speed of the snow cover water loss during 51 days. Also, one can notice (Fig. 7b) that winter/spring period of the year 1999 has substantially higher liquid rainfall amount than the year 1996.

Years 1996 and 1999 were used to train ANN and reveal the quality of prediction in case of highly probable hydrological hazards, based on correlated data of the ground air temperature, rainfalls, water content in snow cover over the

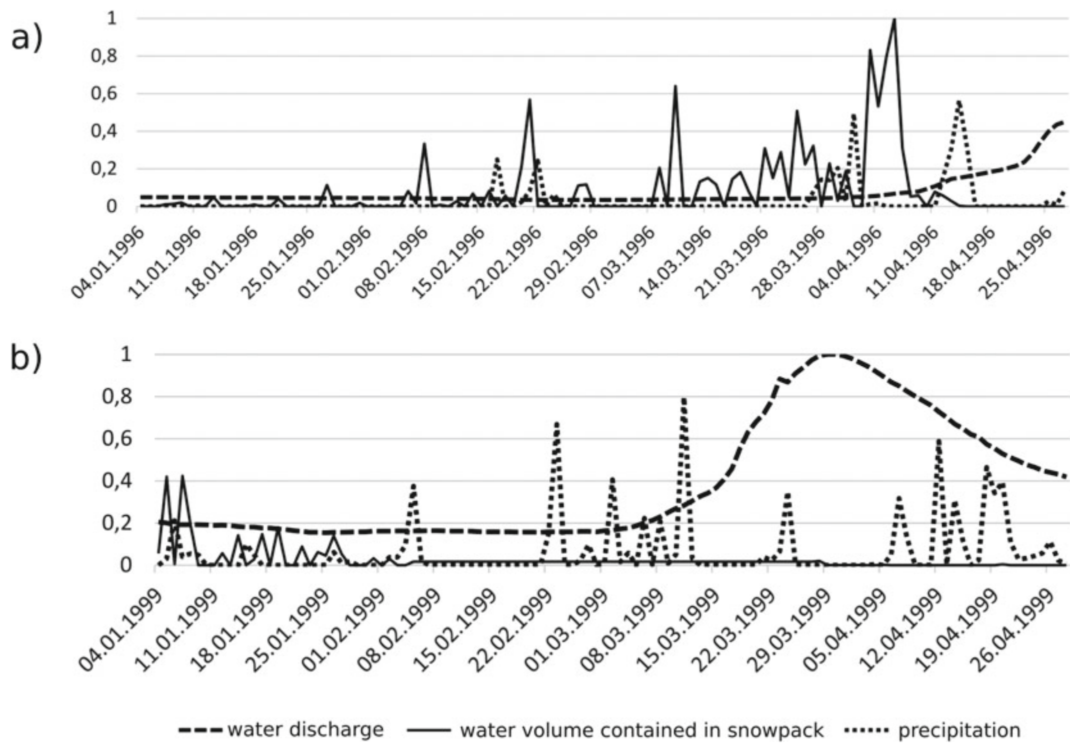

Fig. 18.7 Water discharge on the Mozyr hydrological station and water stored in a snow cover (a, b), the snow cover water equivalent dynamics and liquid rainfalls on the watershed for the years 1996 (**a**) and 1999 (**b**)

watershed and the water discharge on the hydrological station.

An MLP with one hidden layer was used as a predicting ANN architecture. Taking into account that the time gap between beginning of the snow water content stable decrease and the increase of water discharge on the hydrological station was 28 days, we have used the sliding window method (Golovko, 2001) for the ANN, with the window size equal to 28 and step equal to 1.

Quality of the 3, 5 and 7-day prediction was investigated while carrying out digital experiments with the data of snow melting and rainfall at positive average daily air temperature, so without these factors. Best results were obtained for the year 1999 while making 5 days of forecast with snow cover water equivalent dynamics and taking into account rainfall at positive average daily air temperature (Fig. 8b).

The numerical evaluation of the prediction quality was based on the Pearson's correlation test (Table 18.2).

Figure 9 shows correlation of the water discharge prediction quality at the hydrological station for different cases. Upper row of plots corresponds to 7 days window size, while the bottom row is for the 5 days window. The prediction results without snow melting and rainfall are on the left. Central column shows results with snow melting, and the rightmost column is about taking into account both snow melting and rainfall.

Using both climate factors as input data gave the most accurate prediction at different forecast horizon of the ANN. Results confirm that all the data included into the testing sample are describing the interconnected natural system, and also that this correlation is stably revealed by the neural network, and steadily increases the effectiveness of this forecasting approach.

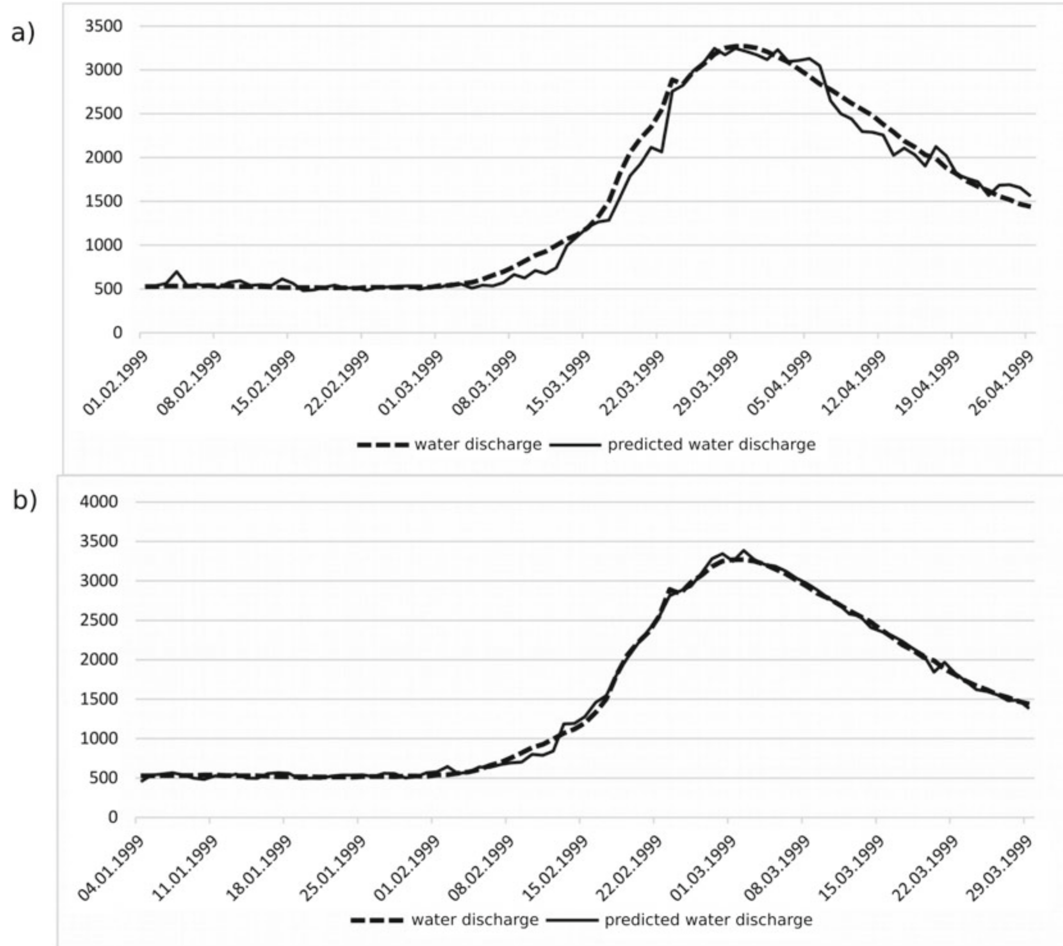

Fig. 18.8 Time series prediction of the water discharge on the hydrological station (**a**) same prediction with snow melting and rainfalls taken into account (**b**)

Table 18.2 Evaluation of the water discharge prediction quality on the Mozyr hydrological station during the year 1999

Prediction window	Water content in snow accounting	Rainfall accounting	Correlation factor values
7 days	−	−	0.986
	+	−	0.988
	+	+	0.990
5 days	−	−	0.990
	+	−	0.992
	+	+	0.998
3 days	+	+	0.997

Table 18.1 Statistical parameter values obtained in the ANN snow water equivalent retrieval performance testing process for the first completed experiment

Polarization direction	Forested snow courses		Open field snow courses	
	RMSE (mm)	r	RMSE (mm)	r
Horizontal	24.65	0.317 ± 0.02	–	0.13 ± 0.02
Vertical	–	0.13 ± 0.02	–	0.30 ± 0.02
Horizontal/Vertical	–	0.31 ± 0.02	28.8	0.32 ± 0.02

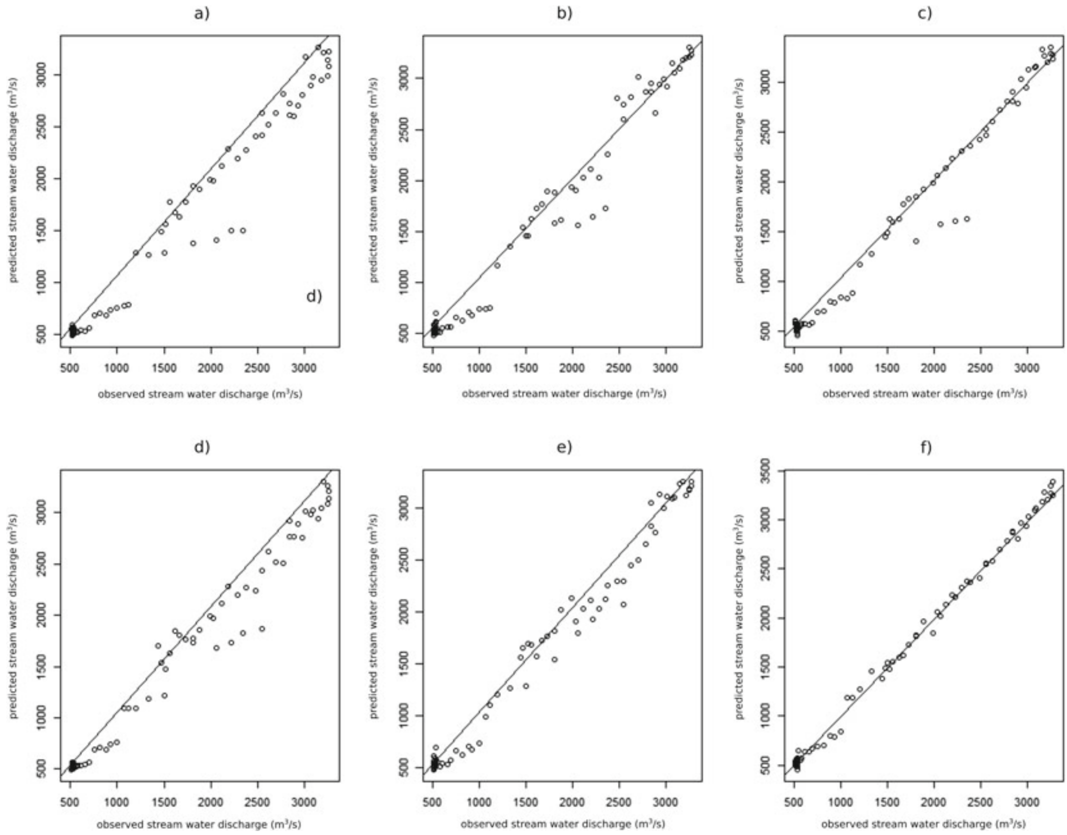

Fig. 18.9 correlation of the predicted water discharge prediction on the Mozyr hydrological station, year 1999

18.6 Method of Inundation Zone Outline Calculation in Case of River Flood Situation

Under the development of the integrated approach for spring time river flood forecast, the new geometric algorithm of inundation zone outline calculation was proposed, which simulates the flood water spread from the river directly over the terrain digital elevation model (DEM) raster elements.

The proposed algorithm includes three phases:

(a) The river center line is projected over the DEM;
(b) The water elevation in the river center line pixels is calculated as a result of linear interpolation between the water elevations registered by the neighboring stream flow measuring stations;

(c) The calculated water elevations are propagated over the DEM elements by the 2D cellular automaton.

The first proof of the algorithm concept was carried out using the data from the flood event of June 2013 in the Central Europe.

Because of the open access to the water elevation monitoring of the German river network, the 181 km long Elbe river section that resides between stream flow measuring stations of Schöna, Dresden, Meißen, Riesa, Torgau and Pretzch-Mauken was selected for inundation zone outline modeling at June 3, 2013. The calculated outline was then validated against the actual one, as it was registered at Dresden, Riesa and Torgau sites (Fig. 18.10). For the purpose of modeling the SRTM v4.1 DEM with 3 arc second (90 m) horizontal resolution and the reported absolute height error of less than 16 m was used.

For each of the inundation test sites the following area characteristics were calculated: the number of DEM pixels reported as wet by actual observation (A), the number of pixels reported as wet by the model (B), the number of pixels reported as wet by actual observation and by the model ($A \cap B$), the number of pixels reported as wet by actual observation but reported as dry by the model ($A \setminus B$), the number of pixels reported as dry by actual observation but reported as wet by the model ($B \setminus A$).

The following measures of model fitness were used: $F_1 = \frac{A \cap B}{A}$ (Borshch et al. 2013), and $F_2 = \frac{A \cap B - B \setminus A}{A \cap B + A \setminus B + B \setminus A}$ (Horritt, 2006). All the inundation

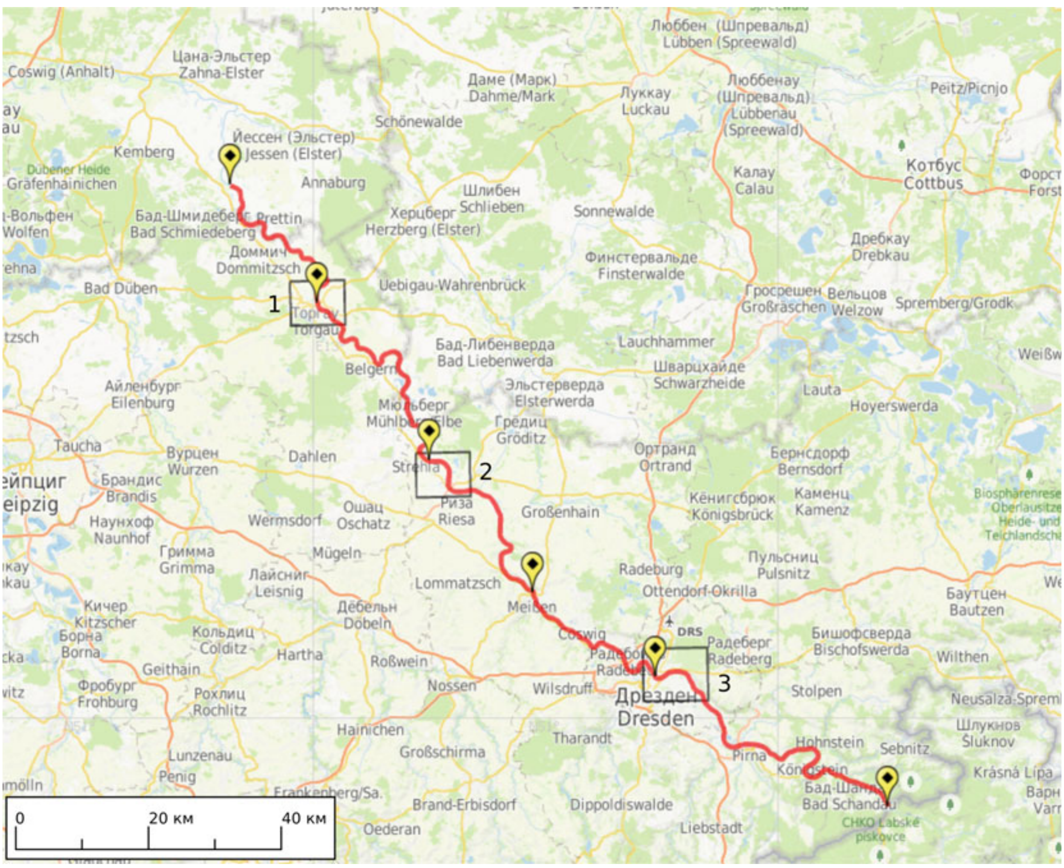

Fig. 18.10 The Elbe River section with the inundation test sites location: Torgau (1), Riesa (2), Dresden (3)

Table 18.3 The characteristics of the observed and the modeled inundation areas for three Elbe river test sites

Region number	A	B	$A \cap B$	A\B	B\A	F_1	F_2
1	972	492	448	524	44	0.46	0.4
2	1523	1124	810	314	713	0.72	0.05
3	629	842	571	271	58	0.68	0.57

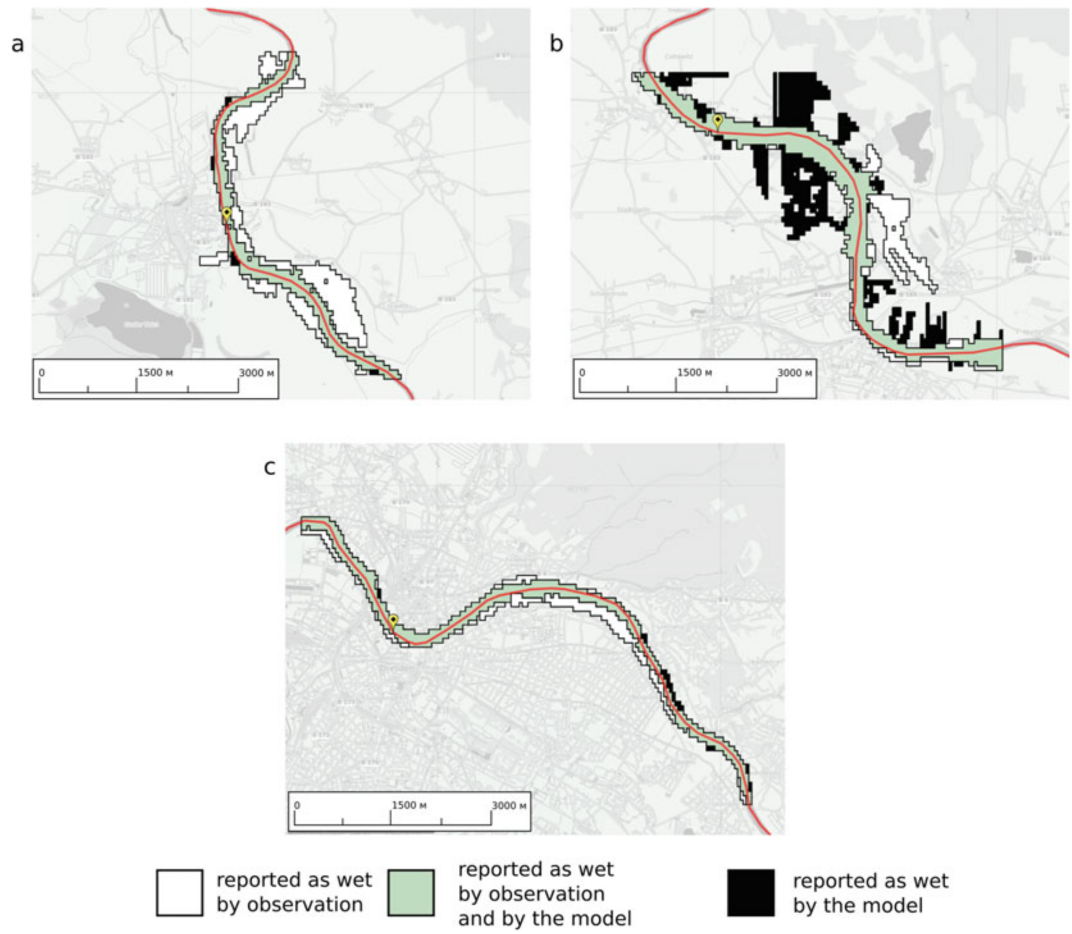

Fig. 18.11 The integral composition of the areas reported as inundated by the actual observation and by the model with the nearest stream flow stations location marks: a – Torgau, b – Riesa, c – Dresden

area characteristics and the values of model fitness are presented in Table 18.3.

The visual representation of the inundated areas is shown in Fig. 18.11. The most bold difference from the observed inundation area is visible in Fig. 18.11, which corresponds to the second row of Table 18.3. The reason behind so distinct difference is inadequate height errors of the DEM used for the modeling of the inundation area.

Despite significant height errors of the SRTM DEM (Karionov 2010, Volchak et al. 2013) used for the inundation modeling, the best model fitness value is up to 57%.

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19 Conclusion

Bindhy Wasini Pandey and Subhash Anand

Water is one of the basic resources for mankind and essential to all forms of life. It is a vital substance which plays a crucial role in the existence of life on the earth surface. It forms the living mass, together with the soil and air, and represents the living environment. Water is the most important component of the biosphere. It is abundantly found on the earth which links the three components of the geosystem by means of an endless circulatory movement called the hydrological cycle.

Water is not only vital for sustenance of life but also essential for socio-economic development. The ecological balance maintained by the quality of water available to a large extent determines the way of life of the people. Existence of man has always been associated with water; it is well known that the earlier Paleolithic implements of human existence have been traced in the river graved. This situation clarifies the essential needs of water even for the most primitive man. In ancient times towns and villages were invariably situated near water bodies, preferably at the banks of streams from which they conveniently get water. But in a time span since population increased and extended inside the country, there was lack of natural supplies, and artificial methods of securing the requisite supply became necessary.

Of the three essential requirements of human life, air, water and food, water plays the most important role to maintain the tissues of the body for healthy functioning. Without supply of potable water, all the function suffers as the body degenerates and also air cannot clean the blood sufficiently and food is imperfectly assimilated. The continuous working of human body is a function of constant rotation of release and replacement of water. At any stage, disturbance in the cycle will result in damage of various tissues. However, if the supply is impure it endangers the lives of consumers and may also create water-borne diseases. Food, clothing and shelter are called the basic minimum needs of human beings, but this directly depends on population growth and development of land, water and energy resources. In a developing country, it requires optimum development and utilization of water resources. Demand and supply have become a matter of great concern today for the societal wellbeing. But to save ecological crisis due to imbalance of above resources, a serious thought has already begun.

Out of vital resources, water is life and safe water means a better life. In the recent year increasing emphasis has been justifiably laid on the key issues of the water supply problems. While the provision of adequate water supply remains the key to general development in many countries, both old and new, it is now recognized that the development of water resources may be planned in relation to national requirements and strategy in which the proper use of land and other important factors are fully taken into account. Furthermore, a spatial study of water in relation to man is essentially to be conceived as a geographical problem, which involve the roll of such

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B. W. Pandey and S. Anand (eds.), *Water Science and Sustainability*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-57488-8_19

factors as climate, geology, relief, drainage, rainwater absorption, vegetation and soil, which generally examines the man–environment relationship. All these aspects are more directly related to the water supply problems of rural areas where man is primarily in contact with his environment than the urban areas.

The objective of providing safe water supply to the rural masses is of paramount importance because it is a minimum need and without this no improvement can take place in the living standards of rural people. In spite of concerted effort, it requires more to be achieved toward the objective of providing safe drinking water to each and every segment of rural population. It must also be borne in mind that the available statistics relating to the status of rural water supply does not fully reflect the hardship and inconvenience that is encountered by the poor, particularly the women and the children. Water is scarce, inadequate or polluted. It is needless to say, this gigantic task of active cooperation of the local people, voluntary agencies, economists, scientists and engineers are to be enlisted. It also requires to ensure that the facilities of potable water supply that are already available in the rural areas are made actually available to rural people in large measure.

The access to safe water is an essential condition for the realization of economic, social and cultural rights. UN Committee on Economic, Social and Cultural Rights indicated the following relevant remarks:

> Water is required for a range of different purposes, besides personal and domestic uses, to realize many of the [rights contained in the International Covenant on Economic, Social and Cultural Rights]. For instance, water is necessary to produce food (right to adequate food) and ensure environmental hygiene (right to health). Water is essential for securing livelihoods (right to gain a living by work) and enjoying certain cultural practices (right to take part in cultural life). Nevertheless, priority in the allocation of water must be given to the right to water for personal and domestic uses. Priority should also be given to the water resources required to prevent starvation and disease, as well as water required to meet the core obligations of each of the Covenant rights (CESCR 2003: p.3).

1992 *International Conference on Water and the Environment*, dubbed the Dublin Conference, had come and gone water problems remained critical across the globe, and to this day many human communities still do not have access to clean water despite the noble promises that were made at the conference. Since then Integrated Water Resources Management (IWRM) has increasingly become an important rallying theme for addressing the governance and management of water resources. The IWRM has become the most preferred framework for attaining water resources management (Manyanhaire and Nyaruwata 2014). IWRM is an important tool to water resources management in which water-related ecological/ environmental, social and economic needs within an area (which could be a water basin, hydrological zone or an entire country) are met simultaneously. Integrated water resource management is a process that promotes the comprehensive development and management of water, land and other resources to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

Gallego-Ayala and Juizo (2011) define IWRM as an approach to water development management that seeks a balance among the three dimensions of sustainable development, namely economic efficiency, social equity and environmental sustainability. Economic development can influence the protection and use of water resource directly or indirectly (Shengwu 2010). First of all, because of different ways, styles and speed from economic development can directly influence the water resource protection. Secondly, economic development can indirectly influence environmental consciousness, social custom, environmental policy to the water resource protection and use. Therefore, except the qualitative analysis of regional economic development and water resource protection, it also needs quantitative analysis to them.

Rivers constitute the main inland water resources for domestic, industrial and irrigation purpose and they play a major role in assimilation or carrying off municipal, industrial wastewater and runoff from agricultural lands ultimately ended up in estuaries (Edmunds 2003). The municipal and industrial wastewater discharges a constant polluting source. Non-urban land uses, particularly agricultural areas, are the dominant sources of nutrient (nitrogen and phosphorus) pollution but urban areas contribute the majority of the heavy metal pollution. However, both sources have an influence on water quality and quantity over a range of temporal and spatial scales (Bhaduri 2000). Therefore, water scarcity and water pollution have become a global issue (Liu Cheng et al. 2012; Li et al. 2014).

Water quality management of river runoff calls for adequate mathematical models to assess quantitatively the hydrological and hydro-chemical processes in river basins. The models should take into account both temporal and spatial effects of natural and anthropogenic (if any) factors on hydrological and hydro-chemical regimes of rivers. The complicated orographic structure of mountainous areas and space–time composition of climatic fields impede the task solution greatly. A system approach with appropriate methods for modeling of complex natural systems can be feasible solution of the problem. One of such methods is the application of single-valued functions with multiple arguments analytically defined on specified time intervals. The system approach and these functions were used as a basis for a proposed system-analytical modeling of water quality and mountain river hydrochemical runoff.

Water resource, mainly the water for drinking and sanitation purposes (Sustainable Development Goals-6: Clean Water and Sanitation) to the people is prime concern. Mountains are fragile ecosystems which are globally important as water tower of the earth, reservoirs of rich biodiversity, and popular destinations for recreation, tourism and cultural heritage. Mountains provide direct life support base for human-kind (Roy and Singh 2002). The ever-growing population and fast urbanization are leading to over-utilization of the water resources, and exerting pressure on these commonalities which are on the brink of collapse. Consequently, the world climate is changing more rapidly in recent years (Vijaya et al. 2011) and causes difficulty in appropriate water management including storage plans. As the water resources are inextricably linked with climate, the global climate change has serious implications on them (Bates et al. 2008; Ghosh and Mishra 2010), and therefore has led to the vulnerable state of the water resources worldwide. The *Intergovernmental Panel on Climate Change* (IPCC) has projected rising trend of Earth's surface temperature of about 0.2 °C per decade for the next two decades due to increasing concentration of greenhouse gases in the atmosphere (IPCC 2007). Increased temperature leads to irregular frequency and intensity of rainfall that significantly increases the intra-annual variability of stream flow; in turn will have an impact on water availability. The impact of climate change in future would be quite severe for India.

Salinization of potable water resources is an emerging issue in India and it may damage agricultural productivity and health. Continued groundwater withdrawals, compounded by a decrease in groundwater recharge, can trigger the seawater/freshwater interface to move inland resulting in additional salinization of the coastal aquifer (Blanco et al. 2013). The sea water intrusion phenomenon can be attributed to a variety of conditions like gentle coastal hydraulic gradients, tidal and estuarine activity, excessive and heavy withdrawals of groundwater from coastal plain aquifers, depletion of groundwater level, low infiltration and local hydrogeological conditions. Climate change-induced sea-level rise is one potentially significant process that is expected to play a role in sea water intrusion. Where sea level fluctuations are retained within the intertidal zone (i.e. coastal barriers are not overtopped), their influence on sea water intrusion is more ambiguous (Werner et al. 2013).

The water supply was so far treated as main development of an exploitative delivery system. Now, the thrust has to change toward an integrated approach of the subject through a large number of disciplines which would include geologists, hydrologists, geophysicists, irrigation engineers, agricultural scientists and above all social scientists. Water supply is not a mere hardware-oriented program but a massive social awareness campaign for the development of the people as well as water as a scarce commodity. The necessity of having safe water for health and other purposes should be launched. No doubt, those developmental resources have been initiated in the past but the needs of the future give a new dimension to all activities in this field.

It may be emphasized that the distribution of water is becoming more and more inequitable. Non-availability of water is one of the main reasons for migration of people from rural to urban areas. This is also creating problems for small marginal farmers to bare burden of development and livelihood on agricultural land. In the long run, this inequitable distribution can completely damage our economy unless we take certain measures immediately. The measures may be bitter today but will bear sweet fruits tomorrow.

Water resources utilization and management as a discipline involves the interests, perspectives and methodologies of a number of biological, physical and social sciences. These interests co-exist toward enhancing its status as an academic discipline with enormous planning-oriented implications. Water being a fundamental value for the basic organic survival, its role as a vital ecological component is further high-lightened in the biological and social life-support systems of increasing complexity. Water resource management in the context of both theory and practice is an attempt to successfully make use of the hydrological potential available in a system toward catering the demands exerted by the system. The disciplinary fragmentation of interest involved in water resource management can be broadly outlined in terms of the three major scientific groupings of the physical, biological and social sciences. The primary relationship of a discipline to water is a function of its utility value, as envisaged by the broad scientific perspectives on water resource management.

The contribution of National Environmental Engineering Research Institute (NEERI), Nagpur is most significant in this field. National Institute of Hydrology (NIH) Roorkee has a great contribution in water resource potential, management, spatial distribution, monitoring, conservation and management. In order to promote and coordinate research and development policies for rural water supply and sanitation, meeting was held at Montreal in April 1974 with the participation of the U.N. Secretariat, U.N.D.P., W.H.O., IBRD, FAD, UNICEF, OECD and IDRC. The group recommended a substantial reinforcement of the international reference center for community water supply in Voorbugh, Netherlands to promote and coordinate research and development activity throughout the world.

Water resource management studies have, therefore, been pursued with varying objectives under different physical and social environments. The fundamental concerns of all such studies have been toward the provision of adequate quantity and quality of water supply for the sustenance, growth and development of rural and urban systems. Future research should involve more elaborate assessments of inputs from the consumers and also at the managers that goes into the decision-making calculus of the people in their consumption behavior and attitude toward water as an ecological social overhead facility of the rural/urban systems.

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