Climate Change Management

Walter Leal Filho *Editor*

Handbook of Human and Planetary Health

Springer

Climate Change Management

The aim of this book series is to provide an authoritative source of information on climate change management, with an emphasis on projects, case studies and practical initiatives – all of which may help to address a problem with a global scope, but the impacts of which are mostly local. As the world actively seeks ways to cope with the effects of climate change and global warming, such as floods, droughts, rising sea levels and landscape changes, there is a vital need for reliable information and data to support the efforts pursued by local governments, NGOs and other organizations to address the problems associated with climate change. This series welcomes monographs and contributed volumes written for an academic and professional audience, as well as peer-reviewed conference proceedings. Relevant topics include but are not limited to water conservation, disaster prevention and management, and agriculture, as well as regional studies and documentation of trends. Thanks to its interdisciplinary focus, the series aims to concretely contribute to a better understanding of the state-of-the-art of climate change adaptation, and of the tools with which it can be implemented on the ground.

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Walter Leal Filho
Editor

Handbook of Human and Planetary Health

Springer

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FTZ-NK
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Hamburg, Hamburg, Germany

ISSN 1610-2002 ISSN 1610-2010 (electronic)
Climate Change Management
ISBN 978-3-031-09878-9 ISBN 978-3-031-09879-6 (eBook)
https://doi.org/10.1007/978-3-031-09879-6

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

Preface

In recent times, the increase in various human activities has caused a disarray in various natural systems. Such disruptions have intensified over the past decades and have caused changes in the climate, have led to the endangerment of many animals and plant species, and have led to a depletion in the quality of the air, water, and even soils. More so, these changes have adversely affected human health and livelihoods across the world.

Exponential increases in human activities such as in the use of fresh water resources, in motor vehicle use, increased consumption of crops and meat, in fertiliser use, the burning of fossil fuels and the production of non-biodegradable materials such as plastic, have been observed in the past decade. This is accompanied by increases in losses of biodiversity, increased carbon dioxide emissions, ocean acidification and loss of natural sources such as tropical forests, amongst others. Furthermore, pollution has reduced the air quality in many parts of the globe, posing major health threats.

Whereas the development model of continuous industrial growth followed in the past has led to an improvement in lives in rich countries, such improvements have been achieved with a continuous damage to the environment and, inter alia, to the health and wellbeing of humans. Such damages—including the emerging of new pandemics related to disruptions in natural systems—are likely to continue in the future.

The complexities of the inter-relations here outlined suggest that the concept of planetary health, being discussed today, needs to be complemented by the addition of the human component to it, hence the term “human and planetary health”, the subject of this book.

The concept of Human and Planetary Health departs from the view that whereas human activities have caused significant biophysical changes (e.g. climate change, pollution, loss of biodiversity, changes in the natural cycles, changes in land use and resource depletion), it is a mistake to believe that only the physical environment has suffered. On the contrary. Human health has also been negatively influenced by them. Indeed, the rapid deterioration of environmental conditions has substantially increased the burden on human health by affecting nutrition, fostering the spread of infectious disease and non-communicable diseases, increasing home displacement and conflict and affecting mental health, amongst others. This background serves to outline the need for a publication on Human and Planetary Health.

This book meets a perceived need for a publication on the topic. It demonstrates various means via which how planetary health may be pursued, with an emphasis on humans and on human influences.

It focuses on:

(a) Outlining which human activities influence or disturb natural systems
(b) Describing the health impacts of environmental problems to human health
(c) Illustrating some of the measures which may be deployed to change current trends (e.g. reductions in resource consumption)
(d) Showcasing tested solutions to reduce human influences on planetary health.

The book is structured around two parts. Part I presents a set of concepts and theoretical frameworks.

Part II entails a set of papers which present practical experiences and case studies showing various initiatives being implemented.

I thank the authors for sharing their knowledge and their experience by means of their chapters, and those colleagues who have contributed to it by assisting with the reviews. Thanks to its design and the contributions by experts from various areas, it provides a welcome contribution to the literature on planetary health, and it may inspire further works in this field.

Hamburg, Germany
Winter 2022-2023

Walter Leal Filho

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Part I
Concepts and Theoretical Frameworks

Chapter 1
Modelling of Human Activities on Planetary Systems for Sustainable Living

Tad Soroczynski

Abstract The paper presents integrated systems analysis (ISA) as a "tool" for modelling and for the development of decision support systems (DSS). ISA enhances understanding of the complex relationships between different systems in the form of inputs > transformations > outputs, and also facilitates an understanding of the term sustainable systems for sustainable living through human intervention. Further, the paper presents general and specific models of ISA for sustainable systems and sustainable living. The presented concept also facilitates an understanding of the linkage between human activities, planetary systems, and sustainable living.

Introduction

The term "sustainable development" (WCED 1987) created great confusion in the scientific community as soon as it entered general use. Due to the difficulties of explaining this term, the terms "sustainability" and "reducing a footprint" have also been used, also causing further confusion (Martens 2006; Kemp and Martens 2007). Environmental impact assessment (EIA) has not explained this complex issue (Glasson and Therivel 2019).

However, for decades, the term "sustainable development" has been postulated and accepted, worldwide, as a term which means "development" which can be "sustained" for an indefinite period. This implication has resulted in the acceptance of a "business as usual" political and public attitude throughout the industrial world, despite the fact that widely available scientific evidence postulates that a "business as usual" approach will not be possible into the indefinite future. In addition, the general concepts of sustainability, practical application and the related issue of how the relevant systems should be managed have never been explained.

On the basis of the above, it is, therefore, considered that the term "sustainable development" should be immediately replaced with the term "sustainable systems for

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_1

sustainable living". However, the term "sustainable development goals" is acceptable and could also be used. (IISD 2021; UN 2021a, b, c) A revised and broader explanation is essential because "sustainable development" as a term, or an idea, is leading the world community towards a totally unsustainable global future.

For example, the maintenance of sustainable living for all species currently living on our planet is universally acknowledged as impossible. "Sustainable development" which must, necessarily, strain current living standards even more is obviously and clearly impossible.

Further, on the basis of the above and in light of the climate change experienced in recent years, the terms "sustainable development", "sustainability" and "reducing a footprint" are simply hypocritical and illusory.

Due to the obvious impact of world-wide climatic change, it is probable that the world has now entered a new era of gradual "sustainable destruction" and this situation requires urgent and immediate explanation to the general public, including politicians and decision makers. The current inaction, or "business as usual" approach will lead us all to disaster. Major decisions must be made, if we are to break the impasses of unsustainable destruction as soon as possible. New paradigms for actions, strategies and implementations, including concepts which can be easily explained and have practical application need to be developed now.

It is considered that the greatest future impacts on the environment will be caused by two factors: population growth and human activities. The issue of population growth is clearly beyond the scope of this paper. However, it is obviously necessary to understand future population growth and the impact which it entails. The concept of time horizon has been researched for population growth in relation to growth of cities (Soroczynski 1999, 2001a, b). Demographers have been concerned about the inaccuracy and uncertainty of world population projections. The world population has been projected subject to uncertainties related to the next period of 50–100 years. On the basis of Lutz's (Lutz 1996; McDonald 2001) deliberations the following accuracies have been considered; (i) projections for the current period up to next 50 years, (ii) projections which include uncertainties for the next period of 50–100 years, and (iii) speculation for the period beyond 100 years. So, the next 50–100 years should be considered as an immediate input.

Human activities are impacting the climate, natural resources, biodiversity, air, soil, water availability, and quality.

The current practice is that a 20–25-year time horizon is used. A natural resource such as water is limited, so a time-line longer than 20–25 years should be adopted to allow for better management practice of this resource. This principle also applies to all renewable resources.

Currently, the rate of destruction of the environment is widely acknowledged as greater than the rate of replacement, and so the word's current population has been undermining our joint future livelihood at an ever-increasing pace. In plain terms, this means that our current actions are undermining our children's future existence.

Methodology—Integrated Systems Analysis

The concept of integrated systems analysis (ISA) was researched in relation to sustainable development in 2002 (Soroczynski 2002). The author of this paper developed the definition of ISA and two models, general and specific, were presented. However, the author of the paper has not explained that the world environmental systems consist of systems such as climate, oceans, rivers, forests, agriculture, etc. In turn these systems consist of component systems. The 2002 paper also did not describe or provide the definition of a component system, and did not consider human intervention.

A component system could be chemicals, chemical elements, bacteria, and distribution patterns (e.g., population distribution), as well as chemical/bacteriological processes, physical processes, population, as well as man-made components such as transport, power generation and mega cities. The fact that different component systems are performing different functions in different systems is a very important consideration, as performance of systems may, therefore, be altered. Human activities are also altering balance and performance of component systems and the consequential performance of systems. The above considerations mean that this overall issue is very complex.

It is considered that human intervention is required to keep systems within certain boundaries which would be capable of maintaining sustainable systems for sustainable living. On the basis of the above, it is postulated that the terms sustainable systems, sustainable living and human intervention should be adopted.

It is proposed that ISA definition (Soroczynski 2002) should be amended as follows:

> "Integrated systems analysis (ISA) is a "tool" for modelling and for the development of decision support systems (DSS). ISA enhances understanding of the complex relationships between different systems in the form of inputs > transformations > outputs, and also facilitates an understanding of the term sustainable systems for sustainable living and human intervention. Some component systems create constraints and impact other component systems which over time undergo transformations such as self-organisation and self-regulation. Some component systems may adopt a distribution pattern as an output. Therefore, behaviour of component systems or distribution patterns may be defined as growth, decline, stable conditions or oscillation. On the basis of the above it is possible to monitor behaviour and performance of relevant component systems. Further, the adoption of this approach promotes the conclusion that sustainable systems for sustainable living may be modelled, managed and maintained by control of the relevant component systems."

In order to maintain sustainable systems human intervention may be required, and the performance of such systems would, in this case, be changed. The perfect example of such systemic change is the climatic change currently experienced worldwide. It has, therefore, become necessary to amend the model of ISA presented in the paper published in 2002 (Soroczynski 2002) to now include human intervention into the model of sustainable systems for sustainable living in acknowledgement of this fact. (Please see: Fig. 1.1) The previous 2002 model was not clearly explained.

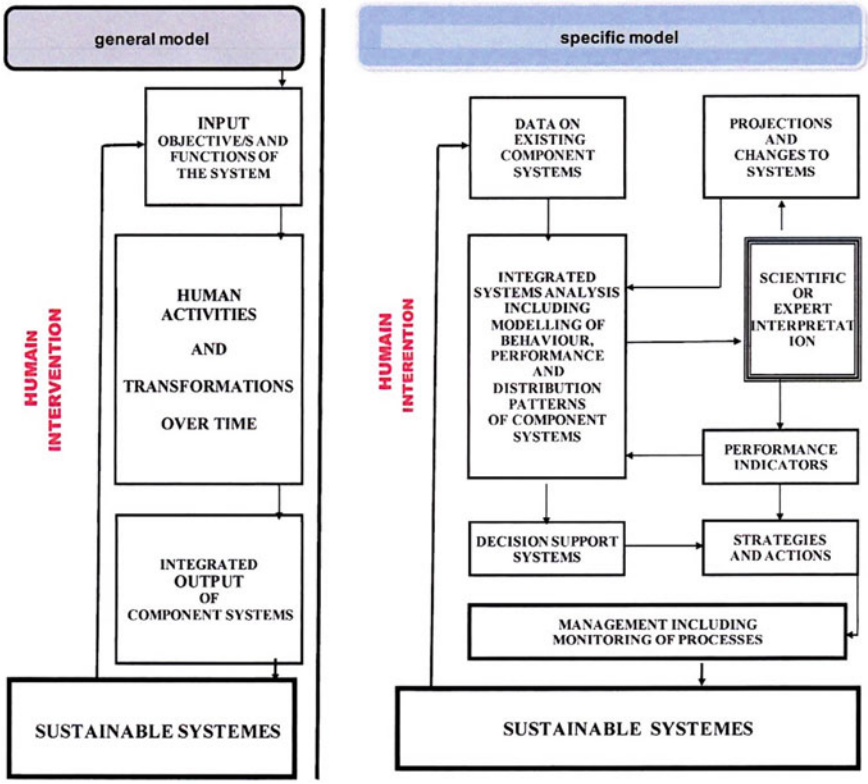

Fig. 1.1 Model of human activities on planetary systems for sustainable living

This new term sustainable systems for sustainable living explains the current situation much more clearly. Due to the fact that the world has entered a new era, the issue of sustainable living is becoming a very urgent political consideration. It is now, therefore, possible to conclude that the world has become an enormous chemical and biological plant in which many processes need to be controlled by human intervention. It is obvious that the world will need many more specialists to monitor and manage the sustainable systems of the future for sustainable living into the future.

It is also considered obvious that the world has entered a new era in which the performances of many natural systems have already been altered by human activities. Sustainable management of these systems requires an integrated approach by the application of ISA, and, as discussed, this is an extremely complex task. First, it is necessary to establish the objectives, function, behaviour and performance of such systems, including their interaction with other systems. It is also necessary to monitor the performance of components of such systems.

Analysis of the climatic system is a good example of the possible practical application of ISA and DSS. It is considered that this system requires urgent human intervention.

Such intervention is justified on the following grounds: that this system effects all areas of human activities, for example: availability of water, food production, and health, among others. Further, this system also underpins the actual future existence of humanity.

Whenever a system is overloaded, the system changes its performance and will, in the end, become unsustainable. Examples of change engendered by the overloading of systems are; wide spread changes in climate world-wide, changes in the water quality in oceans, changes in Australia's Murray Darling river systems and the salmon farming currently conducted in Tasmania which, at the time of writing, is rapidly becoming unsustainable. Similar changes are taking place in other parts of the world. All such systems require human intervention if they are to become sustainable. Further, such human intervention needs to be supported by all available technologies.

The issue of "sustainable destruction" is discussed above. It is strongly believed that the problems of sustainable destruction, which is, of course, actually unsustainable destruction, and the allied problem of unsustainable human intervention should be adopted as urgent political issues by all governments that consider themselves responsible for the future welfare of their people.

Generally, systems can be classified as closed and opened systems. Closed systems are, for example: water supply systems, electricity distribution systems and transport systems etc. These systems can be easier to manage as the relevant component systems can be easily identified. Open systems are large environmental systems such as the climatic system, long rivers and oceans etc. These systems are difficult to manage as a great number of component systems may impact the performance of a system and some of these components are difficult to quantify at the beginning of any project. Some components are only identified later as they impact human management of sustainable conditions.

Further, this issue should be politicized, and any proposal/project should be evaluated on the basis of possible future damage or destruction of the environment. New criteria need to be developed for evaluation of projects, and new bases for decision makers need to be developed in relation to future possible destruction of the environment. On the basis of such an approach, many past projects may well be rejected as causing unsustainable destruction.

Explanation of the Basis of the Methodology, Results and Limitations of Presented Model

The presented model is based on principles of controlling processes in chemical and biological plants (Control Systems 2021). Practically, this proposed model is much more complex due to the need of integration with other systems. This integration needs to be conducted via component systems. So, this integration requires understanding the behaviour and performance of component systems in different systems. A model of sustainable systems for sustainable living will present the successful output of management of component systems.

Such a model would apply to climatic, rivers and ocean systems. Application of this model must be tested for other systems.

The main objective of this model is to better understand the impact of human activities on planetary systems. The presented model has its own limitations because it is a static model. So, impact of population growth must be compensated by monitoring the performance of the component systems of all systems impacted by human activates. All existing or new technologies will need to be used to maintain those systems which are suitable for sustainable living.

The model provides a better understanding of the impact of population growth on planetary systems in relation to the need to develop appropriate long-term strategies.

It is possible to imagine sustainable systems for sustainable living. Natural systems such as water, air, soil, ocean etc., may be considered as sustainable systems when their performance, over time, is not impacted/altered by human activities or other systems.

However, it is obvious that, in practice, such a system has never existed in the modern era as human activities have universally impacted these systems.

Theoretically, sustainable systems supporting sustainable living are these which are not impacted by human activities, or by other systems, and are not causing negative impact on the performance of other systems. In practice such systems are systems which are not impacted by human activities but may still be impacted by climatic changes.

To maintain systems which are negatively impacted/altered by human activities or other systems, human action/intervention/technology is, therefore, clearly required.

Other limitations of this methodology are related to water resources systems, surface and groundwater, which are much more complex. These systems are impacted by human activities and climatic changes. Such changes are related to annual rainfall variation, distribution, increase in evaporation and overall climatic changes.

Sustainable Systems

It is considered that wastewater systems present very good examples of systems which are sustainable when new management practices and technologies are applied.

The following can be considered to be wastewater systems: domestic and industrial collection systems, (generally called wastewater), wastewater treatment plants, as well as the collection and use of rainwater, and the disposal of effluent.

Over a 100 years ago, combined sewage systems, which also collected wastewater and rainwater, were constructed in large cities (e.g., London, Warsaw). These systems resulted in the pollution of receiving waters.

Now, separated systems are used, one for wastewater and another for rainwater. Initially, rainwaters were not treated, while now, in many cities, impurities are routinely removed from rainwater.

Initially, a primary treatment was used (removal of solid). However, the next improvement to be utilised was a secondary biological treatment in order to reduce the oxygen demand in receiving waters such as rivers and lakes and control processes.

The next stage in the improvement of processes was the introduction of a tertiary treatment to remove phosphorus and nitrogen from wastewaters in order to control biological processes and also to reduce the load on receiving waters. Further examples of sustainable systems include the application of new technologies for the treatment of wastewater.

Such gradual changes to the wastewater systems outlined above have now been taking place for more than one hundred years.

The examples discussed above illustrate human intervention which is intended to maintain critical sustainable systems for sustainable living. On the basis of these examples, it is possible to conclude that similar sustainability principles may be applied to other critical systems.

Unsustainable System

The current global situation of climatic changes is a good example of an unsustainable system. This situation is related to a large planetary system. This system is out of control, and it’s behaviour is unpredictable and causing damage to humanity through unpredictable floods and fires, climatic changes also have a profound impact on the efficiency of agricultural production. Further increases in temperature will make some areas inhabitable. (IPCC 2021)

Conclusions

The main objective of the presented model is to promote better understanding of the impact of human activities on planetary systems. The presented model has its own limitations, because it is a static model. Therefore, impact of population growth must be compensated by monitoring the performance of component systems of all systems impacted by human activates. All existing or new technologies will have to be used to enable these systems to remain suitable for sustainable living.

The practical application of the concept of sustainable living should be based on the monitored performance of component systems for all planetary systems. The complexity of all systems is extensive, and the need for appropriate human intervention to maintain sustainable systems is not well understood by the general public and politicians. Due to this complexity the scientists can’t, quite often, provide straight answers on how to manage any system. The extreme complexity of this issue needs to be conveyed to both the general public and politicians so that this problem can be managed more effectively.

The practical applications of integrated systems analysis (ISA) should facilitate/enable the making of rational decisions (DSS) to maintain systems for sustainable living conditions. The identification and development of new technology is urgently needed to implement sustainable systems. This task appears to be the greatest challenge for all governments and for all inhabitants of our planet.

On the basis of the above deliberations it is concluded that the concept of sustainable systems for sustainable living appears to be an improved way to manage the impact of human activities on planetary systems i.e., it is an appropriate methodology which can be adopted world-wide. This is a general approach. More specific research is needed for any planetary system impacted by human activities. Sustainable development is only attainable through the concept and use of sustainable systems for sustainable living. It is considered that the concepts of integrated systems analysis and sustainable systems for sustainable living are vital tools for maintaining the future performance of all planetary systems.

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Chapter 2
Sustainable Management Model for Native Flora in the Face of Climate Change and Planetary Health

Ángel Eduardo Vázquez-Martin, Noé Aguilar-Rivera, Julio Díaz-José, Gerardo Torres-Cantú, Pablo Andrés-Meza, and Dora Angelica Avalos-de la Cruz

Abstract Vascular plants have shown the highest level of adaptability to climatic alterations. On the planet, it is estimated that there are 400,000 species of plants. In addition to, a third of the flora is in danger of extinction. The native flora is a biocultural resource harness by the indigenous agricultural communities of the planet. Currently, the flora is explored by science and used by industry for food, cosmetological and pharmaceutical purposes. So that, these activities has caused the increase of international trade of the native flora, which for 2020 was $ 6.38 billion dollars. Therefore, the model productive management is unsustainable. This is the reason why the incorporation of approaches on sustainability between ecosystems and productive systems is required. It is because of that the review presents a study framework based on a holistic approach, which can be used in the sustainable management of native flora. The proposal includes the documentation and systematization of the indigenous knowledge through information and communication technology. Also, ethnobotany is recognized as a means for the preservation and conservation of plant

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_2

species. As well as, it will could be used as a precedent for the elaboration of legal and political frameworks for the protection, use, preservation and conservation of natural resources.

Introduction

Ecosystems support life on the planet. In particular, humans are provided with resources for surving, such as water, food, clean air, and shelter (WHO 2005). It is because of that any alteration to the environment could mean a risk to the existence of humanity. Despite this situation, extinction rates of flora and fauna are currently at the highest levels in 66 million years; and an increase in these indicators is estimated as a result of climate change (Ceballos et al. 2015; Edie et al. 2018). Global warming alone causes serious consequences on the behavior of ecosystems. This could be related to the fact that, over the past 50 years, human activities have transformed the global ecosystem rapidly (Reid et al. 2005).

In addition to this, it is estimated that only 12% of the planet's surface belongs to arable land (Erb et al. 2007). It is for this reason that the growth of world food consumption for 2050 is limited (Erb et al. 2016), both by the increase in the world population and its relationship with the change in eating habits (Duro et al. 2020). Currently, other threats to human health and well-being are hunger and obesity (Swinburn et al. 2015). As well as diseases related to diet, which are considered serious public health problems (Valerino et al. 2020). Therefore, sustainable agricultural production systems are required, which allow the conservation of natural ecosystems (Röös et al. 2018). Since it has been studied that activities related to food production play an important role in keeping greenhouse gas and carbon dioxide emissions low (Roelfsema et al. 2020). In the case of flora, it has been observed directly in the redistribution of floristic species at various special scales (Pecl et al. 2017). These plant organisms have demonstrated a significant degree of adaptation to climatic alterations and have been key to human survival (Govaerts et al. 2021).

Overview of Native Flora

Vascular plants are the element of flora with the greatest presence within ecosystems (Richard et al. 2021). Nowadays, it is estimated that around 400,000 species of plants have been identified (Nic Lughadha et al. 2016; Brummitt et al. 2021). In addition, it is estimated that there is another 15% of species are to be identified (Joppa et al. 2011). In the studies of (Brummitt 2001) and (Brummitt and Lughadha 2003), the geographical areas with the highest concentration of vascular plant species on the planet were proposed. These areas correspond to the current territory between southern Mexico to Bolivia, southeastern and central Brazil in the neotropics; Thailand, Vietnam and South China in Asia, as well as the Southeast Asian archipelago. They were also included in Oceania, the territories of Queensland and New South Wales in Australia; and in Africa the region occupied by the countries of Kenya, Cameroon, Tanzania, Madagascar and South Africa. Other research recognizes that tropical regions are home to the largest number of plant species (Joppa et al. 2013).

Characteristics of Native Flora as a Biocultural Resource

Ethnobotany studies traditional knowledge related to plants, so it is considered a biocultural resource (Garibaldi and Turner 2004; Gaoue et al. 2017). Biocultural species constitute part of the cultural identity of a group of people, since they belong to the culturally recognized biological elements. Thus, their material or symbolic role in the different human activities is recognized by the population (Cristancho and Vining 2004; Nuñez and Simberloff 2005; Platten and Henfrey 2009).

There is an important body of knowledge related to the use and management of local native flora in agricultural communities around the world (Long et al. 2021). This kind of knowledge is used for the selection of basic foods, building materials, medicines, use of dyes. Which represents a source of economic income for the agricultural communities of the planet (Liu et al. 2021). Particularly in these collectivities, group-specific traditional knowledge has been generated and identified as unique hallmarks of each culture (Cao et al. 2020). It is because of that for the industry it has represented a source of information for the creation of different commercial products; such as medicines, insecticides, food, cosmetics, and fragrances (Oli 2009). Also in modern science, it is recognized that more than 75% of medicines have an origin based on ancestral knowledge or so-called indigenous knowledge (Sen and Chakraborty 2017).

Unfortunately, it is susceptible to multiple threats, including biopiracy. Because his study includes elements of polular wisdom in the public domain (Chambers and Richard 2000) and this is exacerbated by the weakness of legal frameworks for intellectual property rights (Volenzo et al. 2018). As a result of this situation, in several countries, their legislation has sought to include traditional knowledge in various legal instruments (Chakrabarty and Kaur 2021). Mainly through updating its existing laws on intellectual property rights and developing laws that protect and promote local knowledge (Dutfeld et al. 2020). However, these efforts have not been successful and a third of the vascular plants are endangered. These situations are mainly caused by the overexploitation of plant species, climate change and environmental pollution (Fazan et al. 2020). The objective of the paper is to denote the impact of the international commercialization of native flora, which involves describing the factors that intervene. This is the reason, a study framework based on an interdisciplinary approach is also proposed to serve as a reference for the sustainable management of native flora.

Methodology

This research belongs to the field of socio-technical transitions, whose objective is the search for solutions to understand the interactions between culture, industry, technology and industry, towards the search for the sustainability of the systems (Geels 2012). This study used the conceptual theory construction method (Meredith 1993). The method defines a strategy for the review, analysis and synthesis of the information based on the objectives (Meredith 1993). So, a literature search was conducted on the academic, web of science, and scopus digital platforms; as well as information related to the international trade of flora was collected in the database of the United Nations Department of Economic and Social Affairs. The design of the management model included a multidimensional understanding of the socio-technical systems that intervene in the commercialization processes of the flora (Markard et al. 2012). Therefore, for the creation of the conceptual framework, inductive content analysis was used. This process abstracted the main elements for a sustainable management model based on the literature review, through the open codification of the main aspects of the study phenomenon (Elo and Kyngäs 2008).

The first stage consisted of establishing the objectives of the study, including social, economic, technological and ecological aspects. Subsequently, using the databases, an exhaustive literature review was carried out. The next step consisted in defining the keywords which allowed the categorization of the information, abstracting the most relevant on the subject. As a result of this process, a content analysis was obtained with the critical aspects of greatest relevance to the subject of study. Finally, the information synthesis was obtained. This result helped to identify links and differences to design a general framework for the management of native flora (Fig. 2.1).

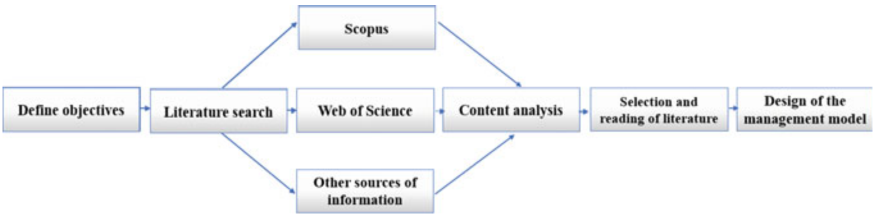

Fig. 2.1 Paper methodology process. Designed based on Meredith (1993) and Elo and Kyngäs (2008)

Results and Discussión

International Trade in Flora

Recently, the global market for the consumption of wild plants has intensified. In the last decade their consumption has been linked to the idea that they mean a healthy source of food (Sansanelli et al. 2017). The trade has been one of the causes that has caused the overexploitation of natural resources. For this reason, an analysis of international trade in flora was included, through the analysis of a report obtained from the Department of Economic and Social Affairs of the United Nations. The document includes the export and import of plants and parts of plants (including fruits and seeds), mainly used in perfumery and pharmacy. The international trade in 2020 includes exports were $ 3.20 trillion and imports were $ 3.17 trillion, representing a total of $ 6.38 trillion in the world economy (Fig. 2.2). These data could be related to the increase in demand for agricultural products. Thus, it is should consider an increase in the population of the planet, which by 2050 is expected to be 9.8 billion people and by the year 2100 around 10.9 billion people (UN 2017).

Trade in flora, in the period from 1990 to 2020, was $ 114 trillion dollars, which represented a cumulative growth of 231% (Fig. 2.3) (UN 2021). This could mean at this growth rate, that the native flora traded would be at risk of extinction. The impact of the production of native flora and other anthropogenic activities, have caused the increase in greenhouse gases. This is associated with climate change, so this activity could pose another threat to the global supply of agri-food and food security (WHO and UNEP 2014). In relation to the generation of greenhouse gases on the planet, it has been estimated that food systems contribute approximately 29% (Vermeulen et al. 2012). It is because of that agriculture represents one of the sectors with the

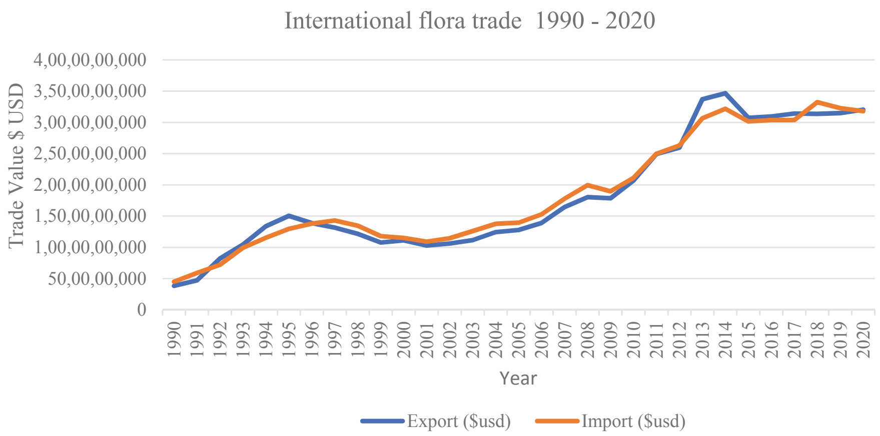

Fig. 2.2 International trade in plants and plant parts (1990 to 2020). World exports and imports report code 1211 (UN 2021) (Open Source, https://comtrade.un.org/data/)

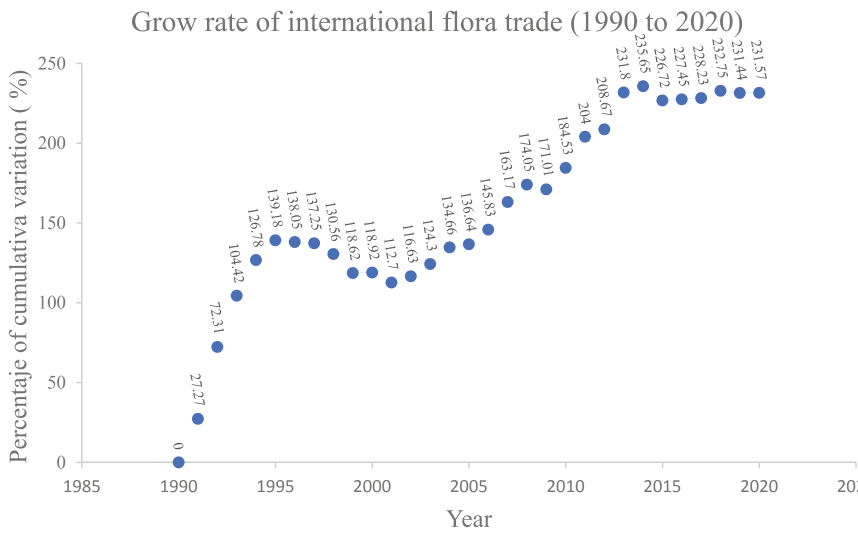

Fig. 2.3 Growth rate of international flora trade from 1990 to 2020. World exports and imports report code 1211 (UN 2021) (Open Source, https://comtrade.un.org/data/)

greatest impact on the generation of GHGs within food systems (FAO 2013) and is expected to continue to increase (Tilman and Clark 2014). In addition, it will be necessary to consider the effects on the change of diet of the world population, who are consuming a greater number of animals and a lower proportion of grains, legumes and other vegetables (Popkin et al. 2012).

Study Framework for the Design of a Model for the Management of Native Flora

The different agricultural production systems are fundamental to maintain the supply of food, materials and raw materials (Herliana et al. 2019). The production of native flora involves agricultural production systems adapted to local socio-cultural aspects. Trade in these agricultural systems represents relative economic source importance for the large agricultural regions of the planet, where indigenous communities live. This is one of the reasons why it is necessary to incorporate its processes with a sustainable vision, through the integration of the relationships that are generated inside and outside the production systems (Orozco et al. 2021). These complex production relationships are expected to connect, interpret and incorporate the needs and interests of producers, retailers and consumers (Katchova and Enlow 2013). The implementation of sustainable models in all low-trade agriculture processes could increase their productivity (Montuori 2013). Therefore, it is reflected in a

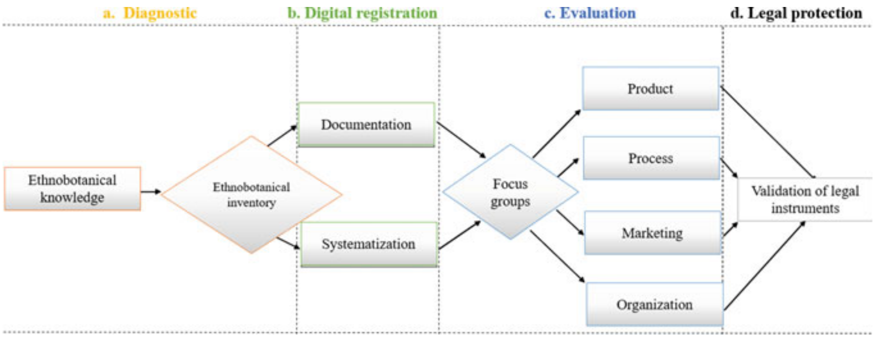

Fig. 2.4 Stages of the sustainable management model for native flora. Elements of the conceptual framework

high degree of complexity between the relationships between small-scale agricultural production societies and prevailing commercial frameworks (Brycenson and Ross 2019). Because small-scale societies are characterized by their social interference (Viswanathan et al. 2012). Next, the elements for a study framework based on a holistic approach are described (Fig. 2.4). The proposal derives from traditional knowledge related to native plants. The first phase consists of the diagnosis of resources, then their digital registration, through evaluation processes and finally the integration of legal protection. In such a way, that it serves as a precedent for the creation of productive strategies and public policy for the sustainable management of native flora.

The model proposes to incorporate bioethics, with the purpose of balancing all aspects of economic, ecological and social processes. Environmental bioethics intervenes in the search for just social arrangements that seek the human well being, while preserving environmental resources (Caicedo et al. 2021). Furthermore, its understanding allows to recognize and conceptualize the environmental role of native flora in ecosystems (Urker et al. 2012). This model proposes the incorporation of different interdisciplinary approaches including fair trade, bioeconomy, circular economy and green economy (D'Amato et al. 2017). It is essential to search for mechanisms that reconcile economic growth through environmentally responsible actions in the agricultural sector (Barañano et al. 2021).

a. *Diagnostic based on ethnobotany*

Traditional knowledge about the use of native plants in many cultures has been passed on orally from generation to generation. Current social dynamics and environmental problems have accelerated the loss of this information (Asif et al. 2021). The first to use the term "ethnobotany" in research was John William Harshberger in 1896, in an article entitled "The purposes of ethnobotany." This discipline allows studying the relationships that are established between humans and plants. The process consists of documenting information, using different data collection methods (Pardo de Santayana and Gómez 2002). As a result, it is possible to identify various

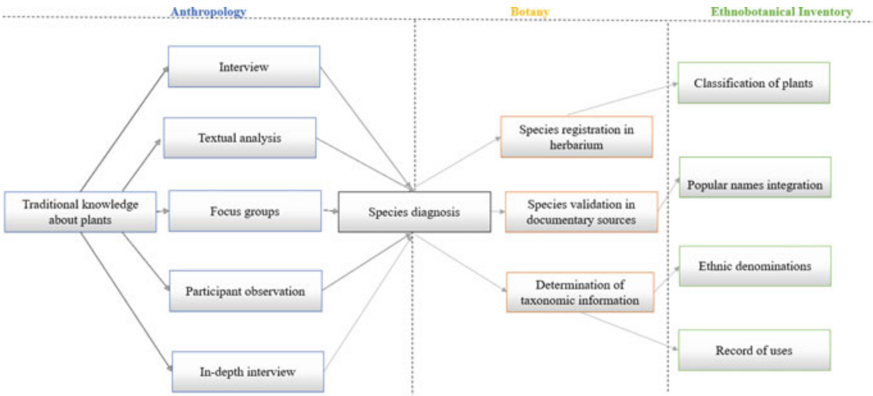

Fig. 2.5 Methodological framework used by ethnobotany. Preparation of an ethnobotanical inventory (Albuquerque et al. 2017)

forms of use of plant resources; both in agriculture, as in medicine, in food, in ceremonial uses, in construction, etc. (Khan et al. 2013).

Ethnobotanical studies use the interdisciplinary approach and are supported by anthropology and botany. The discipline used mainly data collection techniques based on the interview, textual analysis, focus groups, in-depth observation and participant observation (Fig. 2.5) (Albuquerque et al. 2017). Botany discipline facilitates the identification and classification of biocultural information related to plants. Therefore, it allows to classify plant species by their plant taxonomy and through an ethnobotanical classification records the biocultural knowledge of the flora (Abbas et al. 2017). Ethnobotany as a source of knowledge recovery could define local strategies for the preservation, conservation and sustainable use of native flora. Which represents a methodology to identify local phylogenetic resources through local knowledge.

b. *Digital registration using ICTS*

It is an area of interest for research, the insertion of small-scale commercial agriculture within technological information systems (Marinchenko 2021). The most recognized definitions regarding Information and Communication Technologies (ICTS), we find that UNESCO determines that they result from the combination mainly between information and communication technologies (UNESCO 2002). In turn, the World Bank (WB) proposes that consist of the software, hardware, media and networks for the storage, collection, processing, presentation and transmission of information (WB 2002). The used ICTS management of native flora, are a oportunity innovative for agriculture. Its incorporation into the distribution and commercialization processes could contribute to increasing the productivity of the resources that are used, improving the coordination between actors and processes the productive chains (El Bilali, and Allahyari 2018). There are different mechanisms for digital technological innovation in the global agricultural sector. This includes, from electronic devices for data collection, virtual storage of information, instruments for monitoring based on precision mechanisms, to big data (linked open data, web data) (Bronson, and Knezevic 2016). It is an opportunity to generate innovation in hardware and software for the agricultural sector adapted to each of the needs of the processes that integrate the native flora production systems. So, as a premise for future facilitators of these technologies in agriculture, critical adverse socio-productive factors (Fig. 2.6) should be considered to guarantee access for farmers and rural communities (FAO 2015).

iii. *Evaluation of ethnobotanical knowledge through open collective innovation processes*

The demand for agricultural products requires the need to incorporate with a sustainable approach, without excluding any sector of farmers (Brun et al. 2021). This fact encourages the management of local agricultural resources, including vascular plants that are marketed as a biocultural resource. It is because of that implementing processes based on innovation on ethnobotanical knowledge results of opportunity area for research, industry and the development of public policies.

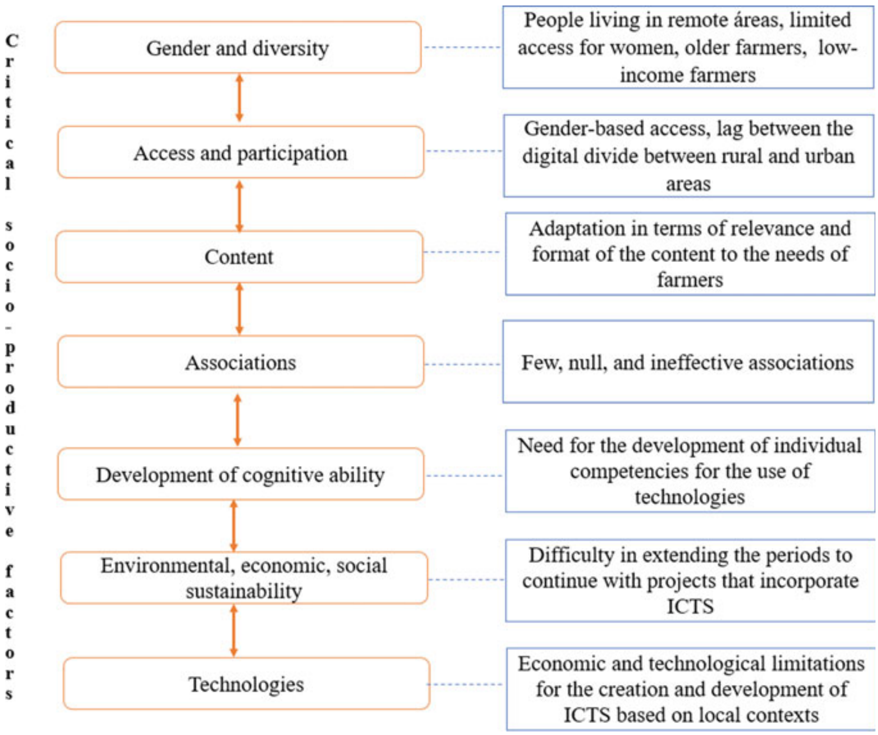

Fig. 2.6 Critical socio-productive factors for the availability and accessibility of ICTS in rural communities. Oslo manual (FAO 2015)

About this subject, the Organization for Economic Cooperation and Development (OECD) proposes one of the most widely recognized classifications. This classification includes 4 different types of innovation oriented to products, processes, organization and marketing (Fig. 2.4) (OECD/Eurostat 2018). Its implementation in groups will be achieved with the application of open innovation models. This it is could facilitate the use, conservation, preservation and commercialization of native flora (Freire et al. 2016). The participation of internal and external actors in each of the production processes; as a result promotes the collective intelligence of human groups (Álvarez and Bernal 2017). The model proposes to develop a structured and permanent innovation process. Supported by the contribution of each of the members, with first-hand information about their field experiences, their perceptions and permanent feedback (Molina et al. 2021). Collective participation projects can lead to social awareness, strengthen social capital, strengthen social networks and, consequently, promote innovation (Cofré et al. 2019) (Fig. 2.7).

iv. *Legal protection and considerations on intellectual property rights*

Property rights are one of the greatest weaknesses in the management of biocultural resources. This represents the main problem due to the lack of technical resources for the systematization and registration of traditional knowledge (Rodrigues 2012).

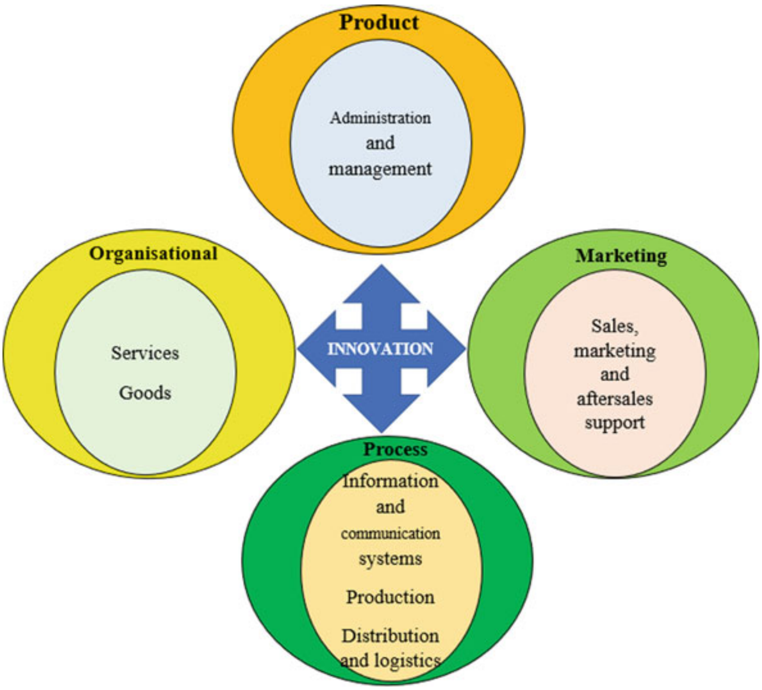

Fig. 2.7 Classification of types of innovation. Oslo manual of the organization for economic cooperation and development (OECD/Eurostat 2018)

In this regard, the United Nations Organization since 2010, through the Nagoya Protocol, provides a clear legal framework for the equitable and fair sharing of the benefits obtained from the use of genetic resources (UN 2011). This international agreement was signed by 92 countries; it is complementary to the 1992 Convention on Biological Diversity. Nagoya Protocol was created to prevent biopiracy, establishing measures to guarantee the prior and fair consent of the communities where these resources are part of indigenous knowledge (Dörr 2018). Biopiracy understood as a lucrative practice, without the permission of the holders of the right to use and exploit and with little or no compensation or recognition from indigenous peoples (Rabitz 2015).

In addition, the World Industrial Property Organization makes legal protection instruments available, through the creation of patents, trademarks, copyrights, integrated circuit designs, breeder's rights (plant varieties), industrial designs, trade secrets and indications geographic (WIPO 2004). However, the efforts have not been sufficient, so in each country the appropriate legal instruments must be generated to ensure the protection for use, management and enjoyment of these plant resources.

Conclusions

This management model integrates each of the actors and processes of production, distribution, supply and commercialization of native flora. One of its main characteristics is that it adjusts to the characteristics and conditions of each process. Therefore, the proposal could allow registering, classifying and documenting indigenous knowledge. To achieve the systematization of the information, the innovation represented by the information and communication systems was included. Which represent a means of conservation of ethnobotanical knowledge. What would facilitate inclusion and access for the planet's rural population located in remote populations. For this reason, it could help to conserve the biocultural heritage of the planet. In such a way, it is possible to create active communication channels to determine actions for the use, management and protection of natural plant resources. This to bioprospecting suggests the creation of a mechanism de evaluation for the sustainable use of native flora. In addition, this model could serve as a legal instrument for the protection of intellectual property rights.

The accelerated growth of the commercialization of plant resources, as well as the adverse effects of climate change on the planet's ecosystems, are considered as the main risks to the subsistence of native flora. Therefore, this management model based on a holistic study framework could facilitate the design of legal instruments of public policy and multidisciplinary research for the protection of native flora. This means designing innovative strategies for the conservation and preservation of plant phytogenic resources. Because of this, the biocultural character of natural resources must be recognized. Ethnobotanical knowledge at every site on the planet represents an unlimited source of information for multiple scientific disciplines.

Limitations

The revision of the document was based on a qualitative judgment of how to design a model of sustainable flora management. Since the concept of native flora has not been broadly defined, the interpretation provided could be argued. The approach that was used to design the study framework may include limitations on how it is understood. The design of the flora management model was based on 38 articles. The literature review was done exhaustively, however there is the possibility that some information was not included. For future research, a more detailed analysis of the concepts of open innovation processes, information and communication technologies, legal protection of plant resources and bioethics is recommended.

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Chapter 3
Entomophagy and the Nexus Between Human and Planetary Health

Bruno Borsari

Abstract Insect consumption complements the daily diet of about two billion people in the tropic regions of the world, while the idea of employing insects as food is getting traction also in areas of the global north. Entomologists identified more than two thousand species of insects as edible. Others pointed out that raising insects possesses distinctive environmental benefits, including getting potential for contributing to human nutrition and health. For example, insects can be grown on various organic substrates, from livestock manure to food and crop residues thus, adding value to agricultural waste, while reducing pollution from disposal of the same, and contamination risks for soil, air and water. Also, insects generate less greenhouse gases (GHGs), they are high feed converters and require less water than typical farm animals, while posing minimal risks of transmitting zoonotic illnesses. The purpose of this study consisted in reviewing the status of insect foods safety and nutritional power for their inclusion in the human diet, while assessing their health potential, extensible to a planetary scale, should entomophagy expand further and get established, worldwide. Also, this work was framed within the urgent need of achieving the sustainable development goals (SDGs) of agenda 2030, with a special focus on SGD#2 (zero hunger) and SDG#3 (good health and well-being).

Introduction

Consuming insects is a dietary habit that played an essential role in the nutrition, growth, and health of our early hominin ancestors (Lesnik 2018; DeFoliart 2002; Morris 2006). The relevance of edible insects was pointed out also by Raubenheimer et al. (2014), who estimated that entomophagy is still being practiced by circa two billion people around the world. Although many insects are notorious enemies of cultivated crops and ectoparasites of humans and livestock (Eggleton 2020), or vectors of life-threatening infections, many of these species remain valuable as food sources for large segments of humanity (van Huis et al. 2013), or feed for

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_3

farm animals (Glover and Sexton 2015; Belluco et al. 2015). Moreover, insects serve as distinctive indicators of environmental quality, ensuring a plethora of ecological services (da Rocha et al. 2010). For example, the pollination of fruit and vegetable crops embodies an essential ecological service offered by insects to agriculture, which has been estimated to be in the billions of US dollars every year (Porto et al. 2020), in addition to protecting cultivated crops from insect pests through biological control strategies such as predation and/or parasitoidism (Pickett and Bugg 1998).

Regarding edible insects, Lesnik (2018) explained that their consumption has been declining together with a decreasing emphasis about gathering food from the wild, since the discovery of agriculture, 10,000 years ago thus, reducing to a great extent, the diversity of human diets. This pattern was amplified by an industrialization of farming in recent decades, and it has been linked to teeth decay and a weakening of health that began already among early farming communities, in Neolithic times. More evidence from the study of human fossils indicated that the cultivation of agronomic crops became a prominent cause that lessened food variety in the human diet, leading eventually, to nutritional shortcomings (Larsen 1995). On the other hand, Selaledi et al. (2021) discovered that in human cultures where entomophagy persists, is because this practice has become an emblem for community identity, health, food security and sovereignty. Also, in some western cultures of industrialized countries entomophagy is beginning to develop into a form of creative gastronomy that is starting to get traction in local, culinary tradition (van Huis et al. 2014).

The environmental impacts of industrial agriculture on land, energy and water resource use, pollution and public health constitute tangible examples that the agribusiness model of agriculture is amplifying the perils of exhausting Earth's natural capital, while putting at risk its recovery capability (Union of Concerned Scientists 2008). More sustainable alternatives for remediating to this extractive approach in agriculture are urgently needed to avert predictable consequences posed by global climate change as these are caused by industrial farming, its purported intensification needs and ongoing expansions. Despite pragmatic wants that continue to justify an upscaling of agriculture, food production could veer toward agroecology to become more sustainable, although the necessity of doubling food output to feed a population of about 10 billion by 2050 remains as a convincing fact to many stakeholders for conserving the present, agricultural *status quo* (Borsari 2021b). However, the fact that insects generate less greenhouse gas emissions (GHGs), that they are high feed converters and need less water to be raised than typical farm animals, are persuasive points to consider their employment as food products, or feeds (van Huis et al. 2013). Additional facts are supportive about the idea of growing insects as food (Fig. 3.1). Thus, it could be speculated that employing edible insects in human and livestock nutrition contribute effectively, to decrease the heavy carbon footprint of agriculture. According to Rockström and Gaffney (2021), this effort is necessary to stabilize global climate, while assisting society to harness all human activities within planetary boundaries.

To public health officials the Covid-19 pandemic of 2020 epitomized a clear sign of planetary homeostasis loss, whose restoration is now an imperative mandate to avoid the possibility of an occurrence of future pandemics (Pachauri et al. 2021). On

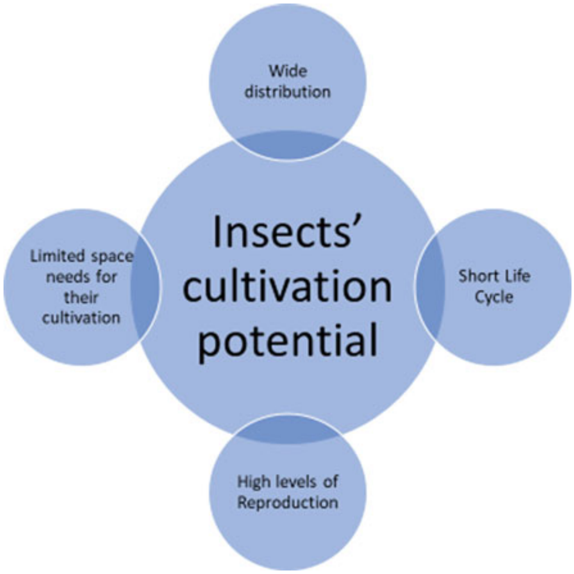

Fig. 3.1 Favorable reasons that legitimize feasibility and great potential for insects farming

a similar trajectory, Atwoli et al. (2021) have been urging humanity to respond to the current climate crisis with effective actions focused on stabilizing global temperature, preserve biodiversity, while safeguarding and improving human health.

The nonexperimental nature of this work constituted an inevitable limitation for this study. Another constraint consisted in focusing only on the health of consuming insects and potential safety aspects derived from these foods. The planetary diet concept that was proposed by the EAT-Lancet Commission as a mean to improve human and global health (Willett et al. 2019) was inspirational for this review. However, it did not consider edible insects among its dietary recommendations hence, this effort aimed at building a persuasive case to employ these arthropods in the human diet, as a vehicle and opportunity to restore human and planetary heath. Finally, this work attempted to respond with urgency to specific sustainable development goals (SDG#2—zero hunger) and (SDG#3—good health and well-being) of agenda 2030, as proposed by the United Nations in 2015.

Methodology

This study updated the present status of knowledge about edible insects and their consumption as food, to build an appreciation and understanding of entomophagy. According to Patten (2004) literature reviews can be helpful to identify trends, relationships, and/or research gaps in any, field of study. Thus, the work presented here discussed selected studies in entomophagy and their implications for achieving planetary health. It considered a two-pronged approach, that focused on human dieting and the safety of consuming insects because these topics were considered most relevant in addressing the queries posed by the purpose statement of this research. Through this work, recent data were assessed to understand the long-time legacy that humanity has had with the practice of entomophagy, as presented by Lesnik (2018) and others (Ramos-Elorduy 2009; Morris 2006). This review was necessary to summarize the complex dynamics of expanding the use of insect foods in human nutrition, while appraising historical evidence that served the purpose of developing a new model and hypotheses supportive of food security for a growing population, in pursuit of a sustainable development.

Results

Entomophagy and Human Healthy Dieting

Eating insects has been touted as a healthy practice that since the dawn of human civilization, has been ensuring nutritious food at specific times of the year, for many of our predecessors (Borsari 2021a). Relying on entomophagy to complement dieting habits is becoming persuasive especially when this practice has potential in aiding with the ill effects of malnutrition and its consequences on human development and health. It is important to point out that the former condition is not only caused by an insufficient ingestion of calories but also by an inadequate intake of nutrients (macro and micronutrients), that consumed in sufficient amounts should fulfill the dietary requirements of all men and women (Lesnik 2018).

Industrial agriculture can be successful in providing large quantities of high-calorie foods that are also quite low-priced yet, these often are depleted of their nutritional value because they have been highly processed prior to being sold at supermarkets (Borsari et al. 2014). Additional treatments of these foods after being harvested may include bleaching, dyeing or, adding artificial flavors to enhance palatability and/or to extend their shelf-life, at the sacrifice of their nutritional load. On the other hand, edible insects are a food resource, which is stuffed with unadulterated nutrients that since the start of human evolution have been providing good nutrition to our early, hominin ancestors especially, those inhabiting geographic areas where insects grow in abundance from the wild (Imathiu 2020).

Recovering from the loss of dietary diversity that was amplified by industrial agriculture remains a priority goal to be achieved in public health yet, its pursuit and associated benefits are envisioned more as a log-term strategy rather than an easy achievable, short-term goal (Kohler et al. 2019). Unfortunately, concerns about diversifying the human diet to enhance health remain of negligible relevance within the agroindustry, as this continues to respond to the pressure exerted by an increasing population, through further intensification plans and investments focused at maximizing the yields of a handful of ubiquitous plant and animal species. Thus, agriculture has become mostly a global, highly subsidized, economic enterprise dominated by a handful of gigantic, agribusiness companies whose priority seeks to deliver high-caloric foods, that despite their questionable nutrient content and residues of agrichemicals, remain relatively inexpensive to buy, for most consumers (Borsari and Kunnas 2019).

Instead, the contribution of edible insects to food security and sustainable nutrition remains evident from their broad-spectrum content of macro and micronutrients and the health benefits that these can pass to people who eat them (Imathiu 2020). For example, lipids (fats), proteins, and minerals constitute keystone nutrients for which edible insects are valued as nutritious foods (Ramos-Elorduy 2009). Their nutritional composition differs across species and this variance depends also on other factors such as their developmental stage (from egg to larva, from pupa to adult), their diet, as well as preparatory treatments (e.g., boiling, smoking, frying), before these can be sold, or consumed (Rumpold and Schluter 2013). Proteins derived from insects are keystone nutrients when considering food security for two thousand million people, who inhabit tropical and sub-tropical regions around the world. Therefore, insects are much appreciated in these contexts because they can produce proteins expeditiously, when compared to the much longer time needed by farm animals to yield the same nutrients. Their high biotic potential and short life cycle are additional, cherished attributes that make insect species prized for ensuring a relatively easy availability of food, or feed. Although more than two thousand species have been classified as edible (Takov et al. 2021), the global consumption of insects relies upon groups that belong to a much more limited number of insect taxa (Table 3.1).

It has been estimated that insects can provide more than 50% of dietary protein in equatorial countries in Africa and that their market price is often higher than most of animal-derived protein sources (Raubenheimer et al. 2014). Similarly, insects being considered for consumption in the countries of the global north such as crickets and/or mealworms were found having as many proteins as those found in common livestock (van Huis et al. 2013). Also, it has been known for decades that insects'

Table 3.1 Insect taxa that are most used in human nutrition. Adapted from: van Huis et al. (2013)

Order	Common name	Percent of all insects consumed
Coleoptera	Beetles	31
Lepidoptera	Butterflies and moths	17
Hymenoptera	Bees, wasps and ants	15
Orthoptera	Grasshoppers and locusts	13
Hemiptera	True bugs	11
Isoptera	Termites	
Diptera	Flies	<3
Odonata	Dragonflies	

protein quality is similar, or even superior to the quality of the same derived from plants such as pulses crops, like soybean (Finke et al. 1989).

A recent review by Takov et al. (2021) showed that the content of essential amino acids among insects commonly consumed is outstanding for the typical size of these invertebrates, thus reiterating their excellent nutrition potential, when these are employed in the human diet. In addition to this, DeFoliart (1992) had already pointed out that some insects possess more essential amino acids like linoleic acid, than the same measurable in foods from domesticated animals. For these reasons, insects as food could be particularly cherished by vegetarians and/or vegans to satisfy their proteins requirements, without the hassle of having to combine a multitude of plants derived foods, to fulfill their dietary needs for essential amino acids (Lesnik 2018).

The fat content in edible insects oscillates between10 and 50% and it varies for the same factors such as: species, environment, diet, developmental status, time of the year, insects' age, and sexual category, that regulate proteins content (Takov et al. 2021). Insects embed high quality fat in their tissues as essential fatty acids, like α-linoleic acid and omega-3 fatty acids, that are needed for a healthy development and maintenance of the brain and more organs of the nervous system (Carlson and Kingston 2007). More nutrients from insects comprise chitin, which is the keystone polysaccharide (carbohydrate) of arthropods' exoskeleton, which contributes to the 5–20% of insects' dry biomass and fosters bacterial growth in people's intestinal tract (Mlcek et al. 2014). DeFoliart (1992) discovered that prokaryotes ingested with insects are also a good source of zinc, which is considered essential for enhancing humans' immunity responses, while facilitating metabolic processes that could be implicated in reducing risks of developing obesity, or diabetes (Geurts et al. 2013). Macro minerals such as calcium, potassium, phosphorus and microminerals such as: manganese, sodium, iron, copper, zinc, originate mainly from the food that insects eat (Ayensu et al. 2019). Insects add also important hydro soluble vitamins (ß-carotene, vitamins B1, B2, B6, C) and liposoluble vitamins (D, E, K) to people's diet (Mlcek et al. 2014). In sum, edible insects offer remarkable benefits to human health due to their distinctive concentration and variety of nutrients that are necessary to ensure the health of consumers' intestinal microflora (Graf et al. 2015). Therefore, edible insects can contribute effectively to a diversification of the human diet, as this will continue to enhance healthy digestive systems and thus, remain a pivotal factor in strengthening public health (Ercolini and Fogliano 2018).

Are Insect Foods Safe to Eat?

Despite an increasing enthusiasm for employing edible insects in the human diet, many concerns persist in adopting them for consumption. For example, major worries about the presence of heavy metals (Zagrobelny et al. 2009; Arif Tasleem Jan et al. 2015), or pesticide residues persist (Selaledi et al. 2021), although some experts have been explaining that the idea of eating insects is feasible and should pose negligible risks (Bellucco et al. 2015; Borsari 2021a; DeFoliart 2002). Others made the case that, also risks of contracting diseases spread by insects is insignificant because we humans (including domesticated animals), are separated from these invertebrates by hundred million years of evolution (van Huis et al. 2013; Payne 2018). Nonetheless, hesitations to consume insects remain robust in western cultures, together with feelings of disgust and repugnance to the idea of eating them (Moruzzo et al. 2021). Concerns regarding the hazardous effects of insect foods due to a presence of biological, chemical, or allergenic compounds continue to persist as major challenges for an employment of these foods, or food ingredients that derive from insects in the diet of many western societies (Murefu et al. 2019). A summary of these potentially harmful causes, or sources of insect-derived food contaminants is reported (Table 3.2).

A correct approach for handling insects in human consumption necessitates conformity with specific protocols that ensure the safety of these foods, like those employed for the safety and quality of foods derived from farm animals (Dickel et al. 2020; Ng'ang'a et al. 2018). Additional issues for the safety of insect-derived foods relate to the quality of the substrates and feed resources that are used for raising them, especially when these are employed for large scales of production. Discarded vegetables, fruits, or grains can serve as insect feed, however, concerns remain for the risk that insects grown on these diets may amass mycotoxins (Gong et al. 2004). Testa et al. (2016) warned that a malabsorption of nutrients, growth alteration, or chemical and microbiological contamination, constitute more plausible risks presented by food, often leading toward allergic reactions, and edible insects are no exception. Nevertheless, a recent study from Tanzania where grasshoppers (*Ruspolia differens*) were eaten did not pose risks to consumers when the insects were fried, smoked, or boiled (Ng'ang'a et al. 2018).

Table 3.2 Main hazardous chemicals, allergens and organisms detected in edible insects

Food hazard	Group	Species/compound	References
Biological	Bacteria	*Shigella, Micrococcus, Staphylococcus, Bacillus, Clostridium, Salmonella*	Mezes (2018)
	Mycotoxins	Aflatoxins (*Aspergillus*)	Gong et al. (2004)
	Parasites	*Dicrocoelium dendriticum, Entamoeba histolytica, Giardia lamblia Toxoplasma spp.*	Boye et al. (2012)
Chemical	Heavy metals	Lead, mercury, arsenic cadmium	Arif Tasleem Jan et al. (2015)
	Antinutrients	Tannin, oxalate, hydrocyanide, phytate saponins and alkaloids	Ekop et al. (2010)
	Pesticides	Chlorinated and organophosphorus insecticides	Saeed et al. (1993)
Allergens	Proteins	Arginine kinase, α-amylase and tropomyosine	Murefu et al. (2019)

Even without knowing safety preparation processes (including roasting), these precautionary measures are commonly adopted by street-food vendors in Africa and more world regions, to prevent often unknowingly, food contamination from bacteria-like organisms, but not from their endospores. Consequently, great care is necessary when insects and insect-derived foods are processed. Their handling and preparation prior to packaging, or consumption become prioritizing aspects for guaranteeing safety and thus, increasing marketing opportunities while gaining consumers' satisfaction and trust.

The management employed in raising insects, their harvesting and post-harvest technologies remain keystone processes to guarantee food safety and quality (Testa et al. 2016). Also, Belluco et al. (2013) suggested that eating certain insect species is safe for people yet, these should be properly processed and prepared, in compliance with specific standards protective of environmental and public health. For these reasons the European Union has been evaluating the safety of insect foods since 2015 to regulate trading agreements with producers in foreign countries thus, aiming at responding to the increasing demand for insect foods in Europe (Takov et al. 2021). The Netherlands is at the top of the insect food market in the European community where it has been offering insect products to its consumers since 2014 (Collins et al. 2019). In North America the largest insect farm is in Canada, in Norwood, Ontario. It produces cricket and/or, mealworm powders, including roasted snack bars from these two insect species. Many other farms (about 20 all together) have become established in the rest of the country and in the U.S. (Borsari 2021a). Continue researching on rearing, harvesting practices, as well as post-harvest technologies and processing, including the automation for extracting proteins, fatty acids, and micronutrients from insects, while retaining the qualitative attributes of insect-derived food is an imperative trajectory to be followed by this emerging segment of the agroindustry, to make their mass production attractive and acceptable to consumers in the industrialized world (FAO 2010). While there is an on-going interest in studying further consumers' attitudes about insect foods and their safety, there are also needs such as how to cook with insects. To this end, van Huis et al. (2014) published a book with many recipes, suggesting that demonstrations accompanied by degustation and sampling should be offered at public events to continue educating all consumers about entomophagy.

Discussion: Connecting Public and Planetary Health Through Edible Insects

Insects' employment as food, or livestock feed is opening new possibilities in the nutrition arena, with promising opportunities to diversify the human diet. Insects can feasibly become established across cultures and gastronomies (Vermeulen et al. 2019) as their consumption and use are being amplified also by the cultures of different peoples migrating across continents. In the meantime, insects continue to play an important role for the nutrition of large segments of the human population (Tiencheu and Womeni 2017). Although these are not fully considered as food in societies of the global north, it is important to recognize their role in human, evolutionary history (Lesnik 2018). Studies abound about consumers' attitudes and likelihood to include insects as food in their diet. From Australia (Sogari et al. 2019), to Europe (Moruzzo et al. 2021; Orkusz et al. 2010; Yüksel and Canhilal 2018) and in more countries of the western world (Collins et al. 2019), these reports indicated that a generalized hesitancy persists in including insects, or insect ingredients in the human diet.

Concurrently, pressures to intensify agricultural production outputs to fulfill the food demands for a population estimated to reach the 10 billion marks by mid-century remain consistent, whereas van Huis et al. (2015) predicted that by that time, meat production will have increased 75% since the onset of this century, at the sacrifice of additional biodiversity loss and land degradation. Foods from the meat and dairy industries continue to remain extremely costly to the environment making a further expansion of these systems a major risk for spreading zoonoses, with possibilities of evolving into dangerous pandemics, like the one prompted by Covid-19 (Borsari 2021b). Willet et al. (2019) proposed the 'planetary diet' as a roadmap to ensure adequate, healthy food that should reduce the ill effects of malnutrition, while constraining farming to operate within the confines set by the planetary boundaries (Rockström et al. 2009). Although entomophagy was not included among the recommendations in adopting the planetary diet, eating insects should find a viable niche in these conjunct efforts aimed at restoring human and planetary health.

It is important to understand that a desire for establishing insect foods across cultures is not a capricious impulse aiming at expanding entrepreneurial opportunities for the agroindustry, but rather it is a re-discovery of a renewable food resource, capable of ensuring quality food and adequate nutrition for all. This vision is substantiated by the fact that eating insects is becoming more common around the world (Collins et al. 2019) and that plans of introducing insects to dietary regimens remain effective as their nutrient loads are outstanding (Selaledi et al. 2021).

Also, when compared to growing domestic animals, insects' growth rates, yield potential and reduced carbon footprint make them desirable to be farmed. Gahukar (2011) and more recently, van Huis and Oonincx (2017) predicted that insects farming is a feasible practice to alleviate effectively, the foreseeable, increasing demands of food occurring at present and in future years. In addition to this, insects grant pollination services for agronomic crops and biological pest control in agriculture (Nicholls and Altieri 2012). Many more insect species inhabit the soil ecosystem where they decompose organic detritus that replenishes the topsoil with humus (stable carbon), thus enhancing synergies with soil biota that improve lands' ecological fertility and health (Lavelle et al. 2016). To this end, Seibold et al. (2021) calculated that soil insects' decomposition processes account for 29% of the carbon flow, which substantiates their valuable role in the global carbon cycle and in fostering soil health.

Thus, increasing a consciousness for conservation through education and restoration endeavors, could expand further across cultures and make most persuasive the case that we humans have an obligation to operate in agriculture and in other economic activities, within the constraints set by the ecosphere, if we wish to leave Earth as biologically productive as we inherited it from our ancestors. In this context,

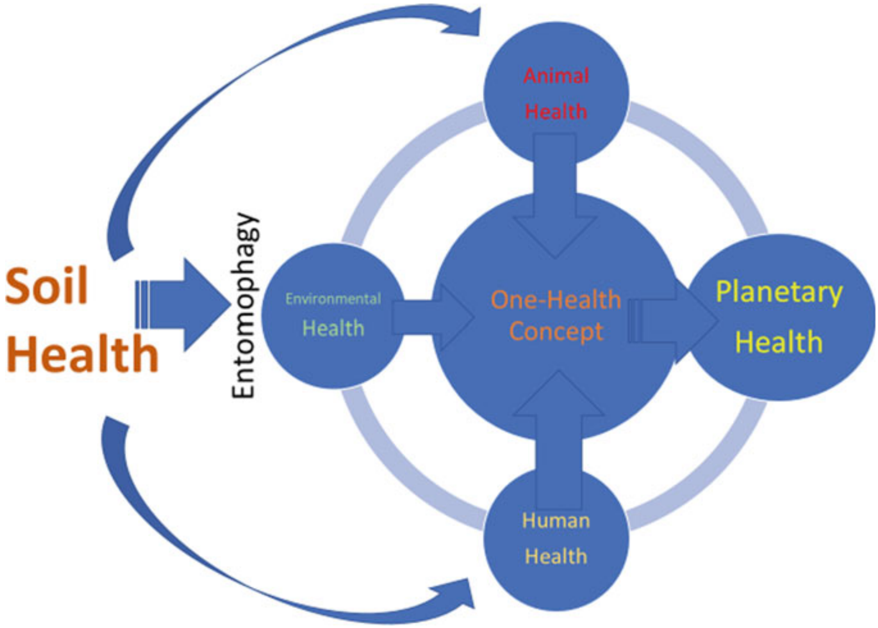

Fig. 3.2 Soil health as pivotal domain that through entomophagy expands health to a planetary scale

entomophagy becomes complementary to agendas for sustainable development, contributing further to the one-health concept (Xie et al. 2017), and acquires wider acceptability by modern society because from the soil up, insects can truly ameliorate the human diet, people, and planetary health (Fig. 3.2). The model here proposed is cyclical and inclusive of entomophagy that becomes a keystone feature of this new paradigm, extending its benefits to Earth's health.

Soil microbial diversity and metabolisms drive the health of the soil (Borsari 2020), which remains a keystone resource together with water, to ensure food production for the human population, plants, and animal communities. Health from all these domains depends on the soil and when its health is conserved through agroecological farming practices, including insects farming, then humanity can strive for achieving planetary health.

Conclusion and Final Reflections

Entomophagy as part of the human diet has potential to benefit planetary health because insects conceived as food (instead of foes) would amplify global awareness for conservation efforts to protect entomofauna from extinction (Cardoso et al. 2020;

Wagner 2020), while also fostering enthusiasm for a preservation of natural habitats and restoration, or reconstruction of wildlife refugia. Edible insects have been consumed for millennia and considered as appropriate food that as substitutes to meat, fish, or dairy foods have been playing a pivotal role in decreasing undernourishment in countries of the developing world, where nutrition instability remains a constant challenge for many (Feng 2018; Gahukar 2011). This review study suggested that growing insects for food can benefit efforts directed toward sustainability by closing loops in the cycling of nutrients at reduced energy levels. The same extend also to enhance food access and security with minimal environmental impacts thus, aiding in fulfilling several goals for sustainable development (SDGs), that were set by the United Nations in 2015 (Moruzzo et al. 2021).

Certainly, efforts for an establishment of insect foods and entomophagy will also entail a stronger commitment for transitioning present agribusiness models of food production toward agroecology. This change will amplify environmental benefits in agriculture and ecosystems, consisting in tangible reductions in the use of agrichemical products (from synthetic fertilizers to insecticides and more biocides), from food production. Such a transition will facilitate also shifts from energy derived from the combustion of non-renewable fossil fuels to a wider establishment of on-farm, renewable-energy sources. The socioeconomic benefits of these changes will spur a decentralization of food systems and food supply chains into more sustainable, local food systems, that can be much more effective and reliable in preserving the livelihood of farmers, while granting easy access to food for all. More benefits should include a vanishing of inequalities for accessing food and risk reductions of food-borne diseases, contamination and zoonoses. Farmers and consumers education efforts about the health effects of converting farming systems to sustainable agroecosystems, where insect farming is included has potential to amplify the benefits of a 'cleaner' agriculture in pursuit of human and planetary health. To do this, a transparent cooperation with scientific communities of different countries will remain necessary to amplify ongoing efforts for insects' conservation from remnant wildlife areas (Harvey et al. 2020). In addition to this, indigenous, traditional knowledge should be included in an agenda for employing insect as foods successfully, and in pursuit of most SDGs (Selaledi et al. 2021), because indigenous people have often maintained a legacy and knowledge to consume insects and utilize natural resources more sustainably, than most people in industrialized cultures.

Food sovereignty as a keystone principle advocated by agroecology as a social movement sounds also as a compelling need to restore the rights and opportunities for human communities to produce and consume their own food, instead of depending from gigantic supply chains that maintain disparities in food access and delivery. The latter is inflated by transportation costs that further exacerbate demands for high energy use in agriculture, caused by a high centralization of the food system. Thus, an incorporation of insects in human nutrition has potential to increase food security, diminish the ill effects of malnutrition (Kewuyemi et al. 2020), while adding diversity to eating with achievable benefits for human health and well-being. Growing insects as food is scalable and adaptable to rural contexts as well as urban environments, making an expansion of insect farming potentially capable of responding to rising food needs with nutritious foods that can be consumed in the vicinity of their production sites and easily traceable for quality and safety (van Huis et al. 2013).

A decentralization of the food system remains the necessary step for moving toward sustainability in production agriculture (Borsari and Kunnas 2019) to lessen the risks of lurking infections that adulterate food quality and compromise its safety. Sogari et al. (2019) conceded that sustainability and climate change issues related to food production enhanced awareness among youth for making entomophagy acceptable, envisioning its higher acceptance, if the food industry will be innovative and creative enough, to promote positive sensory experiences about insects as food. Tangible efforts are already taking place in various European countries especially in The Netherlands where an introduction of entomophagy is occurring rapidly, through creative gastronomies that employ insect-derived flours as ingredients in bread and for a variety of bakery and dessert products (van Huis et al. 2014). Therefore, strategic marketing approaches to enhance a consumption of foods containing insects will continue to play a very important role for these to become established. An expanding environmental awareness aimed at spurring urgency to abate climate change has been spreading among millennials and youth of generation z. Activist Greta Thunberg's slogan:" Our Home is on Fire!" was effective in catalyzing large youth masses in the demonstrations and rallies of 2019 that quickly spread around the world. On a similar note, "Eat Bugs instead of Beef!" could become the new catchphrase capable of enthusing more western consumers as DeFoliart (1999) envisioned, while strengthening the links between environmental sustainability and edible insects for a pursuit of human and planetary health. This is the auspice and the desired outcome for a multilateral adoption of entomophagy in the human diet.

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Chapter 4
Future of Flood Control Projects in Bangladesh Considering the Health of Its Floodplain and Inhabitants

Md. Rezaur Rahman

Abstract Bangladesh is one of the most flood prone countries in the world, with almost 80% of its area being floodplain of three mighty rivers—the Ganges, Brahmaputra and Meghna. Over the years, many flood control projects have been built to safeguard its paddy crop from repeated floods in order to ensure food security for its ever increasing population. Large scale intervention in the fragile floodplain environment has however resulted in unintended consequences for physical and human environment, causing concerns for the long-term sustainability of such interventions. Physical consequences include silting up of surrounding rivers and waterlogging within the projects. Deterioration of water quality and loss of fish which is the major sources of animal protein in the country have direct consequences on human health. Recently two feasibility studies related to flood control projects have been carried out at the Institute of Water and Flood Management. The first study was on resuscitation of a river which became almost dead due to a regulator built about thirty years back at its mouth for flood control and the second study was on feasibility of a new flood control project. The lessons learnt in the first flood control project along with other flood control projects in the country were utilized in advocating and undertaking a fresher approach to flood control project focusing on sustainability issues. This new approach was accepted by the implementing agency—Bangladesh Water Development Board, opening up a newer direction regarding the future of flood control projects in the country.

Introduction

Exponential growth in population and economy during the last century required enormous jump in production of various commodities including food. This was largely achieved by harnessing various ecosystems through numerous hydraulic

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_4

interventions such as dams, barrages, embankments and regulators. Such interventions however, have caused large scale disruption to natural ecosystems. Unless addressed, this will substantially diminish the benefits that future generations obtain from ecosystems (MEA 2005). Characterising and addressing these threats require a paradigm shift (Meyer 2017).

Over the years, Bangladesh has constructed many flood control projects with the basic objective of ensuring food security in a flood prone country. The projects while contributing to their objectives have shown to have many repercussions on floodplain environment. A necessity for a paradigm shift in order to recuperate the health of floodplain and its inhabitants has gradually gained traction. This shift in approach has recently been embedded in feasibility studies of two projects—one of reviving a river system within an old flood control project and one of new flood control project—which is narrated in this chapter.

The narration is based on synthesis of systematic review of literatures, insight of the author from working in the water resources sector of Bangladesh for last 30 years and then experience of leading the abovementioned feasibility studies. The important limitation is that the suggested approach for future of flood control is not based on rigorous quantitative assessment of trade-offs between feasible approaches but rather on the basis of qualitative assessment of the situation and observed trends.

Floodplain Country—Productive but Fragile

Bangladesh is located at the confluence of three large rivers—Ganges, Brahmaputra and Meghna (GBM). Almost 80% of the country with an area of around 147,000 km^2, belongs to the floodplain of these three rivers (Fig. 4.1). The rest of the area are terraces or hills in the south-eastern region. The average peak discharge of these three rivers during the flood season are about 51,000, 66,000 and 14,000 cumecs respectively (Chowdhury et al. 1997a).

Flood is a regular phenomenon in this country. Bangladesh experiences floods almost every year due to the huge flow of the rivers during monsoon which passes through a single outlet into the Bay of Bengal. The combined average flow through the river system in a year is enough to inundate the entire country up to 6 m depth. The internal rainfall will add another 2 m (ibid). On an average, 20–30% of the land area is flooded every year while large floods may cover more than 60% of the country (Rahman and Salehin 2013).

Regular floods have brought silt, built delta, recharged aquifers and made the floodplain extra-ordinarily productive. Globally, Bangladesh is currently 4th in rice production, 3rd in capture fish production, 6th in vegetable production and so on (Prothom Alo 2021) despite the fact that land per capita is one of the lowest in the world. In general, floodplains are known for their high productivity (Rahman and Anik 2020).

This floodplain, however, can be considered fragile since the GBM river system has been building this newest and biggest delta namely Bengal Delta, by bringing

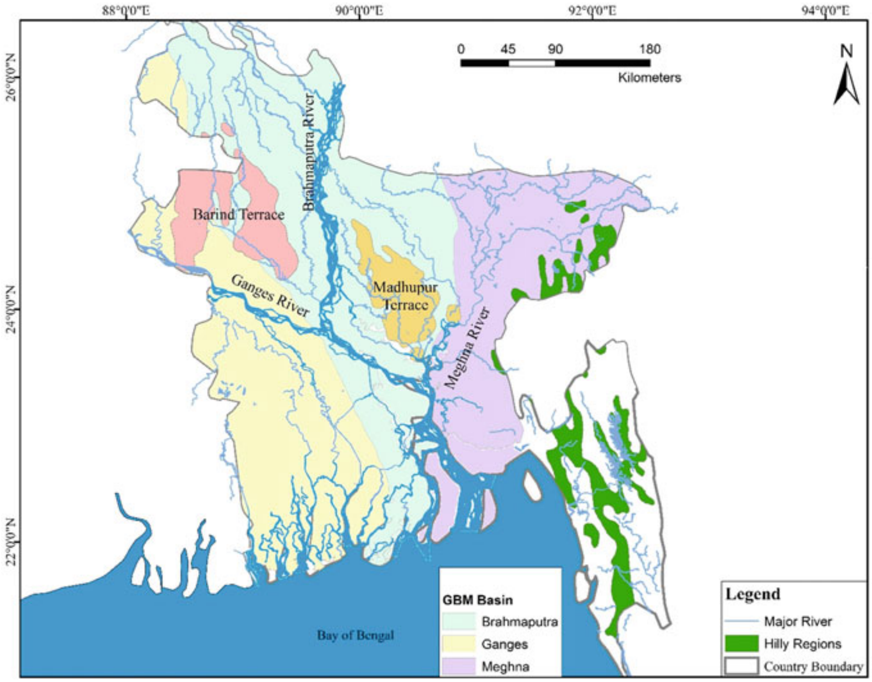

Fig. 4.1 The GBM basin in Bangladesh

huge loads of sediment from Himalayas and depositing those on the floodplain. Every year this river system carries about 1 billion tons of sediment which if spread uniformly over the country will be 1 cm thick (Chowdhury et al. 1997a). However, interventions in the floodplain such as embankments disrupts this delta building process. The floodplain is deprived not only of sediments but also the associated nutrients. As a result, the floodplain gradually becomes lower than the surrounding river level causing drainage congestion and loss of productivity.

Food Security in an Overpopulated Country

Bangladesh is heavily populated with a current population hovering over 160 million. Population density at 1127 persons/km^2 is one of the highest among non-city states. This immense pressure of high population has been sustained by the floodplain by producing a variety of crops in abundance. Principal components of a typical Bengali diet are rice and fish, two major produces of the floodplain. Rice contributes to more than 90% of cereal intake and fish supplies more than half of protein intake of a typical Bengali diet (Rahman and Mondal 2015).

Favourable agro-climatic conditions prevailing in the floodplain supports hundreds of crops, rice being the dominant one. Rice is produced in more than 80% of the cropped area. Abundance of water during rainy season, dietary habit and socio-economic preferences have made rice a dominant crop (Chowdhury et al. 1997b). Major rice production has switched from monsoon rice to winter rice due to propagation of irrigation facilities since the 1980s.

Fish is also produced in abundance in the floodplain. The monsoon floods link up the different components (rivers, floodplains, wetlands, and estuaries) of the inland open waters, creating a single integrated biological production system where the fish and prawn populations breed and grow in numbers.

Although the country now produces abundant food to feed its people, it was not the case much long ago. Rice production was dependent only on monsoon rice which when affected by flood, severely imperilled food security of the population. Such a crisis arose after consecutive floods in 1954 and 1955. The-then government became concerned and felt an urgent need to protect crops from repetitive floods in order to ensure food security for the fast-growing population.

Raising Flood Control Projects

Several studies were undertaken after these floods which eventually led to the formulation of a 20-year Master Plan for Water Resources Development (IECO 1964) in early 1960s. The basic objective of the Master Plan was to achieve self-sufficiency in food grain (principally rice) production for the growing population (Rashid and Rahman 2010). Its proposal centered on large scale public works involving embankments for flood control, gravity irrigation through canal system and pumping stations for drainage and irrigation. Right now, a total of 6.5 million ha of land is provided with flood protection by 16,000 km of embankment. The protected area constitutes almost 60% of the potential area for flood protection at 11 million ha (BWDB 2020).

Some of the large projects protect their command areas from riverine floods during monsoon. Such projects include Brahmaputra Right embankment (BRE) on Brahmaputra, Ganges-Kobodak (G-K) project on the Ganges, and Meghna-Dhonagoda Irrigation Project (MDIP), Chandpur Irrigation Project (CIP), and Bhola irrigation Project on the Meghna (Fig. 4.2). Some projects are named as irrigation projects as they have surface water irrigation components in them.

As noted by Chowdhury et al. (1997b), the flood control projects, despite occasional failures, have in general been able to protect their command areas and increase crop production but their overall impact on the country's crop production is ambiguous. Rahman and Chowdhury (1999) posit that external impacts of flood control projects have compromised the overall gain in monsoon rice production. Rahman and Mondal (2015) showed that in Bangladesh, raising winter rice production by developing irrigation facilities has been more successful than raising monsoon rice production by flood control.

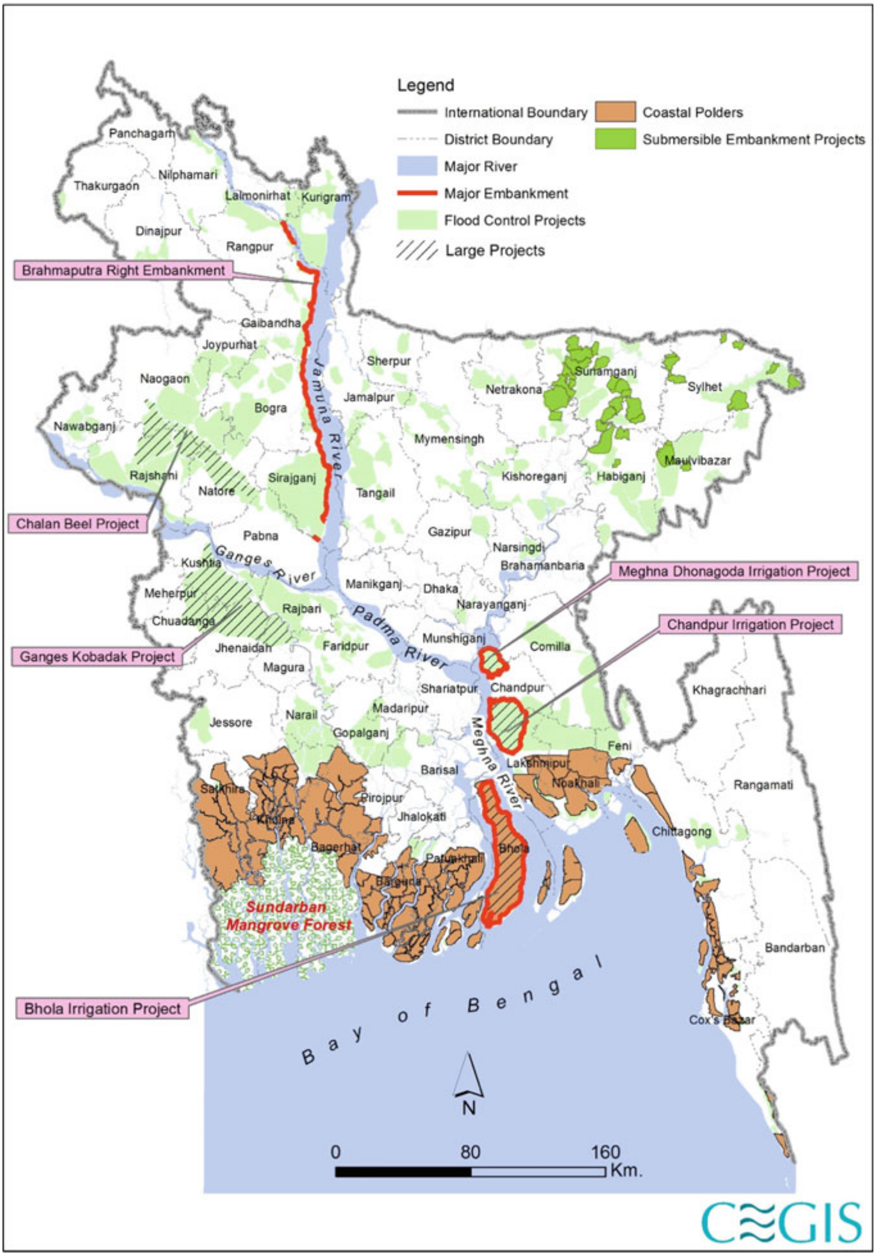

Fig. 4.2 Spread of flood control projects over the country (Figure courtesy of Center for Environmental and Geographic Information Services, Dhaka, Bangladesh)

In the coastal areas subject to regular tidal inundation, polders have been constructed to save crops from damage from salinity. Right now, there are 139 polders spread over the entire coastal zone. The polders have initially improved crop production but later on started to suffer from drainage congestion due to sedimentation of the rivers (Rahman et al. 2021).

Submersible embankment projects in the north-east are designed to protect standing winter crops from flash floods in the pre-monsoon period. The embankments get submerged during monsoon that is why they are so named. During monsoon the river water level is so high, that it is impractical to provide protection against monsoon flood. Submersible projects therefore are also known as partial flood control projects. Submersible projects have been found to be successful in raising rice production (Saleh and Mondal 2009).

Most of the flood control projects in the country are old, some of them are more than 50 years old. Since the embankments are earthen, therefore these are at poor state at present. Furthermore, the embankments along the major rivers have been weakened by erosion, breaching and overtopping during major floods. The coastal polders have been battered by frequent cyclones most recently in 2007 (Sidr), 2009 (Aila), Amphan (2020) and Yaas (2021). Required rehabilitation of some of the projects have started in recent times.

Impact on Health of Floodplain and Its Inhabitants

After another two consecutive big floods in 1987 and 1988, the Government initiated another planning exercise called Flood Action Plan (FAP). FAP considered embanking both sides of major rivers (Brammer 2010). However, by that time social and environmental issues with earlier large scale interventions became apparent and further embanking of the major rivers faced criticism (Parvin et al. 2018). FAP commissioned multiple studies to review the past performances of flood control projects. Various impacts assessed by the Agriculture study (HTSL 1992) are as follows:

The most common positive direct environmental impacts were:

- Reduced flooding, in terms of level, timing, rate of rise, duration and extent of floods;
- Improved soil moisture status at critical periods, due to reduced wetness in the monsoon and, in some cases, to irrigation of water retention for post-monsoon and dry season use;
- Improved land capability through the reduction of flood hazard and increased cropping severity and flexibility;
- Increased land availability due to reduced extent of wetlands;
- Improved opportunities for culture fisheries;
- Greater opportunities for afforestation and other tree planting.

These in turn provided significant benefits to the human populations including:

- Substantial rises in human carrying capacity;
- Some improvement in human health and nutrition;
- Greater protection for infrastructure, with increased human safety and diminished disruption;
- Improved access and communications, if only via the embankments themselves;
- Substantial, if somewhat inequitable, economic benefits to the people in terms of incomes, employment, land values and credit worthiness;
- Generally favourable social attitudes to the projects, despite many complaints;
- Overall improvements in the quality of life due to these positive physical and socio-economic impacts.

The most common negative environmental impacts were:

- Cumulative influences in the external areas in increasing river flows, bank erosion and bed scouring, siltation and flooding levels;
- Drainage congestion due to inadequate design, operation and maintenance of drainage structures and channels;
- High risk in specific areas of certain projects of future catastrophic flooding, with associated hazards to infrastructure, life and property;
- Possible decline in the quality of subsurface, river and wetland waters, and thereby domestic water supplies;
- Reduced extent of wetlands, which is ecologically negative;
- Decline in soil fertility due to diminished aquatic vegetation and micro-biota;
- Contribution to the general decline in fish ecology and capture fisheries;
- In one or two study areas, contribution to a continuing decline in bird communities and habitats;
- Some decrease and deterioration in the livestock sector;
- Loss of land to embankments and other project works, often with inadequate compensation;
- Disproportionate distribution of project benefits and disbenefits, causing some strains on social cohesion.

The loss of fisheries from obstruction by embankments de-linking the floodplains from the rivers have been substantial. The FAP Fisheries Study (ODA 1995) reported a decline of 81% in catch per unit area in case of BRE Project. If this loss is considered in calculation of project benefit, then the net benefit of increased crop production and loss of fish production becomes zero (HTSL 1992).

The Fisheries study (ODA 1995) also noted a clear impact on fish bio-diversity due to flood control projects. Flood control resulted in a reduction of 33% in the total number of species recorded annually. A reduction of 95% was found for migratory species in full flood control projects.

In case of Pabna Irrigation and Rural Development Project (Fig. 4.3), farmers reported up to 80% more agricultural production inside the schemes than outside (Halls et al. 2008). The study however, found that fish production and species richness is typically lowered by these structures. Fish yields inside a typical flood control compartment can be 50% lower than outside, with up to 25 species of fish absent

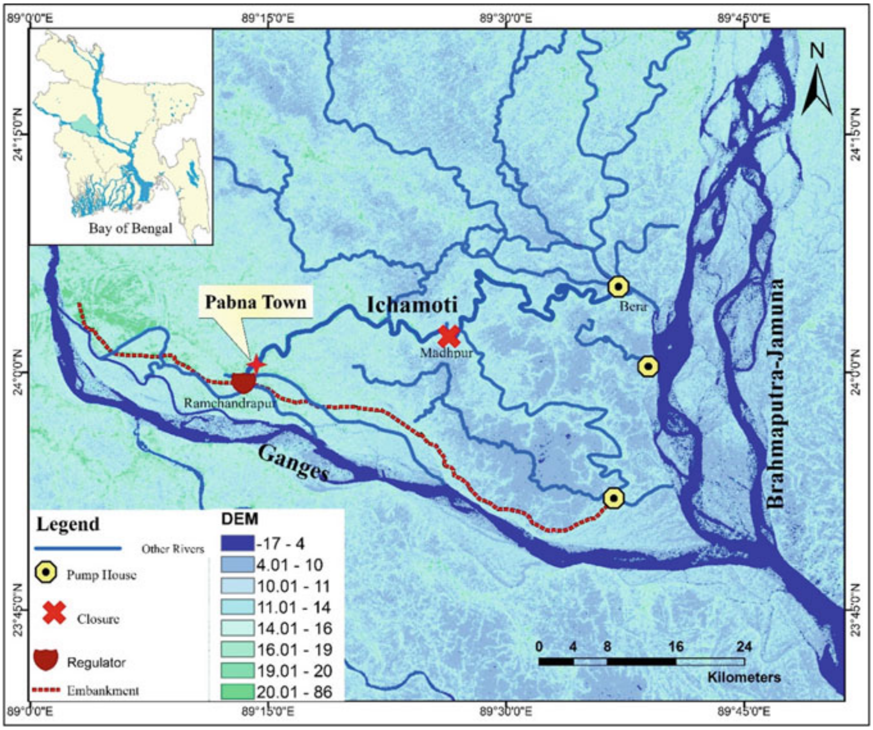

Fig. 4.3 Location and important features of PIRDP

or less abundant. Lower rates of recruitment of migratory whitefish species, whose lateral migrations are obstructed by the embankments, were found to be largely responsible for these differences.

Shawanigan Lavalin (1994) determined a 90% decline inside full flood control projects and 50% decline inside partial flood control projects (or submersible projects) in the north-east region. Since the submersible projects do not inhibit fish migration during monsoon, the impact on fisheries has also been less. Mirza and Ericksen (1996) report a net loss of 5343 tons/year of capture fisheries in case of Chandpur Irrigation Project, a net loss of 83% compared to pre-project condition.

In an evaluation of MDIP, the study (BRAC and ICDDR,B 1997) found that the embankment area had already achieved substantially higher agricultural yields than the outside area. The use of high yielding varieties (HYV) rice certainly tends to significantly increase harvests, but the practice of monoculture, which is usually an outcome of this form of cultivation, can have negative impacts on the environment as well as on human health. One manifestation of this is a decline in the availability of other important foodstuffs. It appears that a number of items of important nutritional value are being given low priority within the embankment and are being replaced by those which contribute towards increasing earnings, regardless of health implications. Not only did the villagers inside the embankment suffer a decline of fish in their diets, but they also experienced deficiencies in nutritional value from lack of fruits and vegetables. Indeed, according to a study called 'Potential Impacts of Flood Control on the Biological Diversity and Nutritional Value of Subsistence Fisheries in Bangladesh' (ISPAN 1995), found that fish consumption was overall lower by 43% inside the MDIP compared to the outside.

Respondents for a perception survey in the BRAC and ICDDR,B (1997) study said that water quality and quantity for agricultural and household use had declined. Respondents said that the floods were beneficial in "washing away all the dirty things" and replenishing water bodies. The low level of water in still water bodies led to stagnant situations and associated problems. For instance, respondents said that water stagnation led to increased mosquito populations, high levels of agro-chemicals and more ill health, including skin diseases and stomach disorders. Water for bathing, clothes washing and other household needs was also limited by the reduction in water quality.

While investigating cholera incidences in MDIP area, results of Carrel et al. (2010) indicate that the construction of a flood control structure in rural Bangladesh is correlated with an increase in cholera cases for residents protected from annual monsoon flooding. Emch (2000) also found out that individuals living in flood-controlled areas were more likely to be hospitalized with cholera than those living outside flood-controlled areas. He additionally found that incidence of kala-azar (Black fever) in embanked areas of northwest Bangladesh was significantly higher than the incidence in non-embanked areas.

In a study by IWFM, BUET for UN-ESCAP, Chowdhury et al. (1997b) carried out a diagnosis of success and failure of flood control, drainage and irrigation (FCDI) projects in the country. The broad lessons which can be deduced from the case studies are that projects are successful when.

- Projects face no serious threat from morphological process in alluvial floodplain (e.g., river erosion);
- There are no severe adverse hydraulic impacts (e.g., higher water level in fluvial environment) and morphologic impacts (e.g., siltation in tidal environment) outside the projects;
- Interaction between morphological process and project intervention is small, and as a result embankment can perform its intended function;
- Impact on fisheries is minimal;
- Irrigation component is present;
- Project is accepted by the people.

The study recommended that planning studies of future flood control projects should cover the followings:

- Better understanding of floodplain environment including hydraulic, morphological and ecological aspects;
- Appropriate accounting of environmental consequences;

- Round-the-year water management rather than planning for flood season alone; and
- Ensuring people's participation.

Parvin et al. (2018) identifies a post FAP phase during 1996–2004 terming it as Integrated Water Resources Management (IWRM) phase where focus shifted towards management of water resources of Bangladesh in a comprehensive, integrated, equitable, and environmentally sustainable manner. During this phase National Water Policy was prepared in 1999 and subsequently the National Water Management Plan in 2001. Gain et al. (2017) states that the IWRM dimensions are in general reflected in recent policies, institutional reforms and project formulation in Bangladesh. However, such reflections gradually weaken as we move from policies to institutions to projects.

New Projects—Shift of Paradigm

Recently, Bangladesh Water Development Board (BWDB) who is the implementing agency for construction of large FCDI projects, commissioned two feasibility studies—one for the revival of river within an old FCDI project and another for a new FCDI project. Instead of engaging any engineering consultancy house, which has been the usual practice, BWDB entrusted Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET) to bring in multi-disciplinary approach in project planning and design. This itself showed a shift in approach of the implementing agency recognizing the need to bring newer approach for the sake of sustainability of projects.

IWFM carried out these studies during 2018–2019 period and BWDB approved and accepted their final reports. IWFM took these opportunities to utilize the lessons learnt over the years to make a paradigm shift in approach related to FCDI projects in Bangladesh—a floodplain country. The main features of the feasibility studies (IWFM 2019a, b) are discussed as follows.

Resuscitation of Ichamoti River (IWFM 2019a)

The Pabna Irrigation and Rural Development Project (PIRDP) was constructed in early 1980s to protect 185,000 ha of land at the confluence of Jamuna and Ganges (see Fig. 4.3). The area used to be flooded by both of these big rivers. Ichamoti river, a medium sized river, was a connecting river between the Ganges and the Brahmaputra and conveyed their flood water into the area. PIRDP was part of the IECO Master plan and the project plan was developed in late 1970s.

Under the plan, the main features were a regulator (Ramchandrapur) at the mouth of the Ichamoti river, 120 km of embankment along the Ganges and the Brahmaputra, three pump houses for supplying irrigation water to the project area, and a closure (Madhpur) separating mainly flood control area (Ganges dominated) from mainly irrigated area (Brahmaputra dominated). The project was successful in keeping the area flood free even during large floods. Agricultural production increased fulfilling the main objective of the project. The cropping intensity increased from 154% in pre-project condition to 246% mainly due to improved irrigation facilities.

The PIRDP area was well known for its rich fisheries resources as noted in its feasibility report (ADC 1978) because of its connection to the two major rivers. While assessing the impact of PIRDP on fish, Hall et al. (1999) found that catch per unit area was 38–51% lower inside the PIRDP (51–81 kg/ha/year), than that in floodplain lands of similar elevation outside the FCDI embankment (104–130 kg/ha/year). It was concluded that the 38–51% reduction in observed productivity at the PIRDP was mainly caused by its reduced accessibility to migrant floodplain.

In the meantime, the Ichamoti river due to lack of flow from the main rivers started declining. The river degraded and took the appearance of a dirty, narrow canal within the Pabna Town. The mosquitos and the foul smell endangered the health of its inhabitants. A vigorous civic movement to revive the river gradually took shape. At one stage, in 2017 people forced the opening of the Ramchandrapur regulator during flood and massively celebrated the flood flow on seeing flood water after so many years.

When IWFM started the study, it first dig out the history of the river from old literature and maps so that the river could be restored to its original size and flow to the extent possible. This historical information was checked with older people living in the area. Several rounds of participatory exercise were carried out with local and national stakeholders and overwhelming support for the revival of the river could be gauged. The proposed interventions were endorsed through dissemination workshops.

The study focused on re-establishment of linkage with the Ganges as Pabna Town needed immediate attention. Linkage with Jamuna was left alone because of the irrigation benefit accruing to the project area. This was the trade-off made between full restoration and partial restoration and was done in consultation with BWDB and the local people. They agreed with this trade-off between environmental benefit of river restoration and the economic benefit of keeping the irrigation facilities operational.

A three-stage plan for resuscitation was developed. In the first phase called No-regret phase (1st five years) the original linkage with the Ganges is to be restored (Fig. 4.4). All encroachers will be removed, and the river will be re-excavated to its original cross-section. The sill-level of Ramchandrapur regulator will be lowered and widened and it will be made fit for fish and navigation passage. The gate operation rule has been changed. Previously the gate remained closed all the time. It was opened only occasionally to drain out internal rainfall flood. Under the new rule, which can be considered a paradigm shift, the gate will remain open all the time. It will be closed only during instances of extreme floods to protect Pabna town from flooding.

A research center on river resuscitation has been proposed in the nearby regional university namely Pabna University of Science and Technology. The research center will monitor the revival of the river and carry out research on river restoration. The

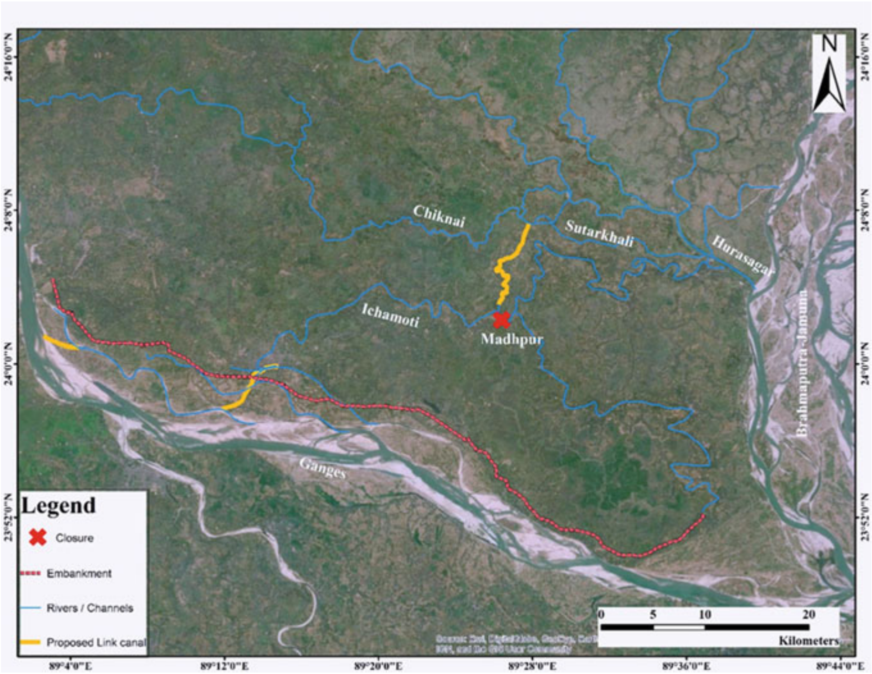

Fig. 4.4 Proposed hydrological interventions in PIRDP (IWFM 2019a)

knowledge gathered through this research center will be used in the river restoration. Such research and integration of the findings in project planning and operation is vital as river restoration is a new concept in the country.

In the second phase (2nd five-year period), which is being called as New Hydraulic Connectivity (NHC) of the system, more linkage will be made by canals with Ganges, establishing link between floodplain and river, and removal of a closure before Pabna Town are proposed. Establishment of these new connectivity will boost the hydraulic situation (See Table 4.1). The proposed link canals with the Ganges have been assessed to be morphologically stable. The activities under these two phases will not interfere in any way with the present irrigation facilities and activities of PIRDP.

The main objective of Master Plan (10–20 years) is to resuscitate the whole Ichamoti system into its near-original state. This phase will have all the components of No Regret and NHC phases. In addition, the following components need to be added to implement the Master Plan phase:

1. Removal of closure of Ichamoti near Hurasagar outfall
2. Removal/Re-modelling of Madhpur closure
3. Link canal is excavated inside Pabna town
4. Connectivity with Chiknai river is closed.

Table 4.1 Improvement of water flow situation in different phases of Ichamoti river restoration

Ichamoti at Pabna town			
Flow parameters	2017 flood	No regret phase	NHC phase
Maximum discharge (m^3/s)	20	210	300
Average discharge (m^3/s)	5	40	100
Maximum water depth (m)	4	8	9
Minimum water depth (m)	0.4	1.5	3
Average water depth (m)	1	5.0	5.5

Closure at Madhpur (Fig. 4.3) has divided Ichamoti into two separate hydraulic systems. To resuscitate Ichamoti to its near-original state, this closure needs to be removed or remodeled as a gated structure. This will ensure direct connectivity of Ichamoti with Jamuna. It is a likely scenario that after several years of operation of NHC phase, irrigation system that needs closure at Madhpur will not be required as it was seen during field visits that the agricultural system is moving from an irrigation intensive crop like rice to less irrigation intensive horticulture as an inevitable consequence of the country's economic progress.

Like Ichamoti, there are many rivers which are dying in similar conditions that is, due to regulators at the mouths of the rivers. There needs to be a systematic effort to free up the rivers, as it has been proven that complete flood control is not desirable in a floodplain country. Rather accepting certain levels of flood is healthy and sustainable. This lesson was incorporated in the feasibility study for a new FCDI project described next.

Gowainghat FCDI Project (IWFM 2019b)

The proposed project area is located in the flash flood prone area in the north-eastern part of the country (Fig. 4.5). It is located at the Khasia-Jaintia foothill, a very high precipitation zone, and is a wetland dominated area. The Om river carries water from the hill area and distributes to the project area through Dawki and Piyan river. Other major rivers are Sari, Sari-Gowain and Kapna river. These rivers are medium sized rivers. For example, peak discharge in Sari river was around 600 cumecs in 2017.

In the project area, one rice crop is grown during winter, harvested during premonsoon time. Flash flood may occur during pre-monsoon causing damage to standing winter rice crop. During monsoon, most of the area goes under water and remains so for 5–6 months. Little agricultural activity is carried out during that time. Fish becomes abundant during this time.

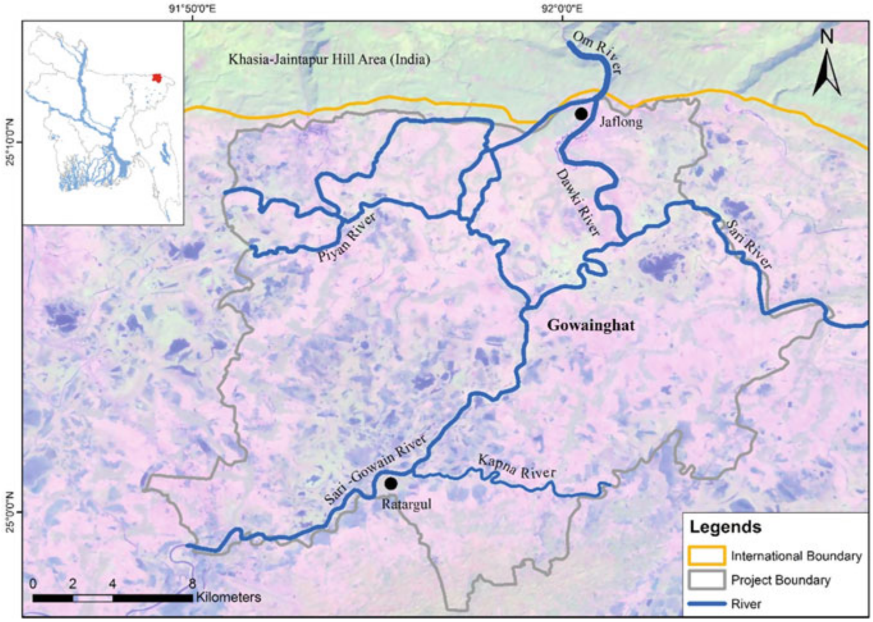

Fig. 4.5 Proposed FCDI project area and the major rivers at Gowainghat

The wetlands in the project area are ecologically resourceful. The wetlands are under tremendous anthropogenic pressure and most of the original swamp forests no longer exist. Some remnants can still be found in the forest area and needs urgent protection. One such area—Ratargul swamp forest has been declared a special biodiversity zone, the only one in the country. Jaflong with its impressive natural beauty is declared as an ecologically critical area (ECA).

The project proposal included embanking the main rivers as shown in Fig. 4.6 in order to reduce flood damage to rice crops. However, it was found that flood water does not stay for more than 2–3 days and flood damage to rice crop is not high. On the other hand, potential for fisheries and livestock is high. Actually, in these wetland dominated areas, the traditional cultivation practice is a rotation between rice, fish and livestock.

Since, the project area is located in an ecologically resourceful (e.g., number of haors, lowland forest etc.) and sensitive area (e.g., Ratargul Biodiversity Special Area, Jaflong ECA), therefore a minimum intervention approach is undertaken to develop the proposed interventions. The planned interventions put more emphasis on non-structural options rather than structural options of flood management. Interventions (Fig. 4.7) include partial flood control, strengthening flood forecasting, strategic dredging of the rivers, erosion protection at important locations, maintaining open connectivity between haors and rivers, protection of remaining natural features of haor basin in Gowainghat, and sustainable land use management.

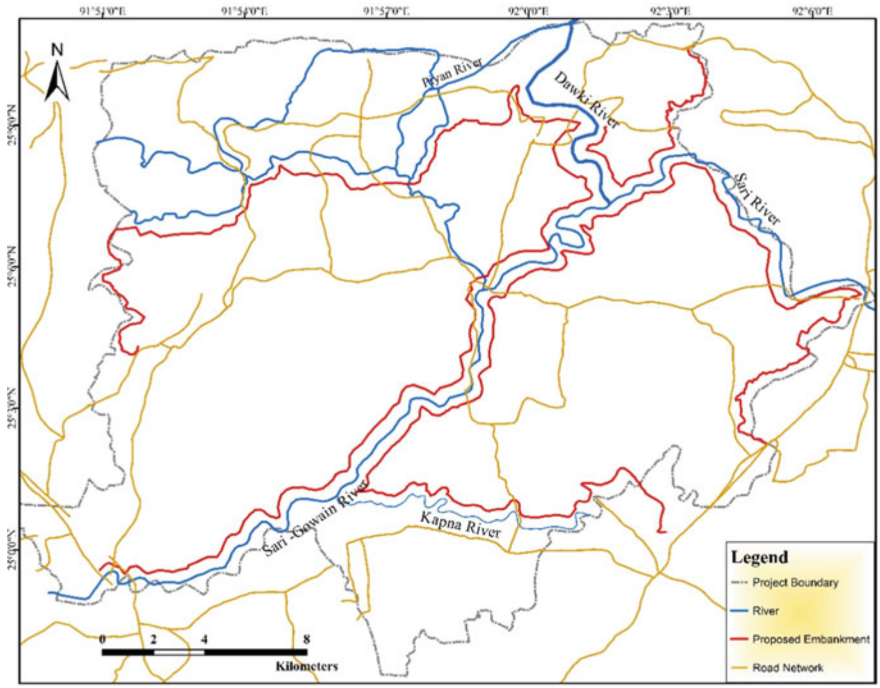

Fig. 4.6 Field level proposal of interventions at Gowainghat

The haor basin has the potential to optimize production of rice, fish and livestock. This feasibility study proposes to take maximum advantage of this potential for the sake of sustainable development of the project area instead of focusing only on production of rice. Protection of its immensely valuable natural resources such as Ratargul swamp forest and Jaflong are also critical for such development.

Conclusion

The impacts of flood control projects in Bangladesh on the health of floodplain and its inhabitants have been consequential. Protection from flood by structural interventions has proven to be challenging on account of social and environmental impacts. This realization is now setting in and newer approach is being looked for. More environment friendly infrastructures are now being considered to reclaim the health of the floodplain.

Most of the flood control projects of the country are very old and at rehabilitation stage. So, there is a golden opportunity to adopt a more sustainable approach during this rehabilitation phase. The sustainable approach needs to recognize that Bangladesh is a floodplain country. These floodplains are productive but fragile and

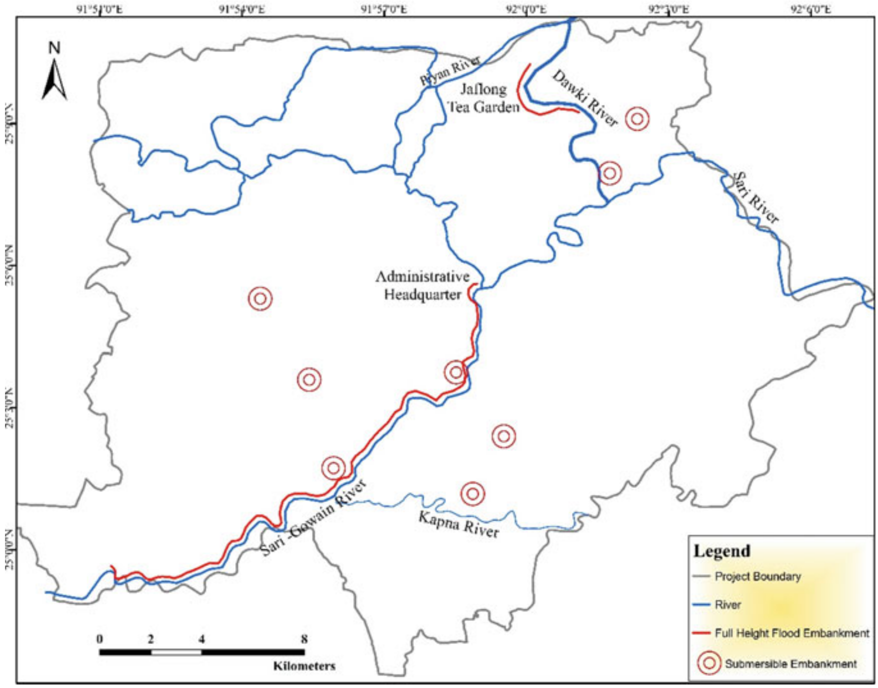

Fig. 4.7 Interventions at Gowainghat as per feasibility study (IWFM 2019b)

needs careful and holistic management. Such an approach has been demonstrated through two recently carried out feasibility studies—one on a reclamation of a river of an old FCDI project and another one on a new FCDI project.

Acknowledgements The author served as Team Leader of the two feasibility studies carried out for BWDB—(i) Feasibility Study with ESIA for Resuscitation of Ichamoti River in Pabna District and (ii) Feasibility Study for Flood Control, Drainage and Irrigation System at Gowainghat in Sylhet District. These studies formed the basis of this chapter. The support of BWDB towards adoption of newer approach in planning and design of FCDI projects in a floodplain context, propagated in these two studies is gratefully acknowledged.

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Chapter 5
Ways to Protect and Preserve Human and Planetary Health Through the Water, Sanitation and Hygiene Sector in Schools

Alua Omarova

Abstract Access to safe drinking water is the first aspect of public health that significantly reduces morbidity and mortality, increases life expectancy, school attendance and gender equality, as well as decreases poverty and ensures the economic and social development of the country. At the same time, the advantage of access to adequate drinking water sources can only be fully exploited with access to improved sanitation and personal hygiene. The objective of the paper is to suggest some environmentally sustainable and cost-effective ways to improve access to safe WASH facilities in schools and to enhance the existing hygiene skills of students. The study was conducted in Karaganda city from September to October 2021. It included students between the ages of 11 and 18. The total number of respondents was 1030, which is 50.32% of the total population. The WASH concept implies both the availability of technical means (drinking water, toilet, washbasin and soap) and development of human potential to improve the hygiene skills of the population. This may be one of the reasons why improving WASH services in schools does not always affect the hygiene skills of students. Consequently, building the capacity of students to transfer knowledge and develop their skills in WASH is critical to achieving sustainable results.

Introduction

Access to safe drinking water is the first aspect of public health that significantly reduces morbidity and mortality, increases life expectancy, school attendance and gender equality, as well as decreases poverty and ensures the economic and social development of the country. At the same time, the advantage of access to adequate drinking water sources can only be fully exploited with access to improved sanitation and personal hygiene. The burden of disease associated with water, sanitation and hygiene (WASH) accounts for 4% of all deaths and 5.7% of the total burden of

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_5

disease in the world (Andrew et al. 2019; Kristie et al. 2020; Maya and Amy 2020; Mbah et al. 2019; Omarova 2021; Omarova 2020; UN Water).

According to United Nations Resolution 64/292: "The right to water is the right of everyone to sufficient, safe, physically accessible and affordable water for personal and domestic uses" (Shaheed et al. 2014; UNDESA). Therefore, according to Sustainable Development Goal 6 (SDG 6), it is necessary to ensure the availability and rational use of safe water supply and sanitation for all by 2030. Achieving SDG 6 will also provide a basis for achieving SDG 3, which aims to ensure healthy lives and promote well-being for all at all ages, and SDG 4, which aims to ensure inclusive and quality education for all and promote lifelong learning (UN Deployment Programme). However, the COVID-19 pandemic has made its own adjustments to the plans for implementation of the above SDGs, especially in low- and middle-income countries.

The adequate WASH is a paramount aspect in protecting public health during infectious disease outbreaks, including the current COVID-19 pandemic. It is also of great importance in building resistance to potentially pandemic infections. Proper WASH practices that applied consistently preclude human-to-human transmission of COVID-19, both in households and in organized communities, such as educational, healthcare and others (Omarova and Tussupova 2018; (Omarova et al. 2018, 2019; UNICEF 2011; Yang et al. 2012).

The COVID-19 pandemic has caused the largest educational disruption ever, affecting nearly 1.6 billion students in 190 countries, which represents 94% of students globally and 99% in low- and middle-income countries. Never before have so many children been deprived of the opportunity to attend school, which disrupts the learning process and completely changes lives, especially in the most vulnerable and marginalized social groups. The global pandemic has long-term implications that may jeopardize the hard-earned achievements in improving global education (Cronk et al. 2015; UN Deployment Programme). Therefore, to date, achieving sustainable results in creating safe conditions for students and educators during the COVID-19 pandemic is the most important task in protecting human and planetary health.

The objective of the paper is to suggest some environmentally sustainable and cost-effective ways to improve access to safe WASH facilities in schools and to enhance the existing hygiene skills of students. To achieve this goal, we analyzed the coverage of WASH services in schools around the world, assessed the availability and status of current WASH services in the schools being studied, and examined the student awareness of WASH there.

Methodology

Area Description

The study was conducted in Karaganda city (49° 48′ N 73° 07′ E), which is the largest industrial zone in Central Kazakhstan, located on the Eurasian continent. The climate here is sharply continental with an average temperature of +20.4 °C in July and −12.9 °C in January and mean annual rainfall of 332 mm. As of 2020, the population of Karaganda is 497,777 people (Akimat of Karaganda city).

The city of Karaganda has two inner districts: Kazybek bi and Oktyabrsky. In order to build a complete picture of the main advantages and disadvantages of WASH in schools in this region, the following three secondary schools of Karaganda were selected for further research:

- Seifullin School and Al-Farabi School, both located in Kazybek bi district and mainly populated by people with good and middle levels of income;
- School No. 9, located in the Oktyabrsky district and mainly populated by people with a low level of income.

Questionnaire Development

A student questionnaire was developed based on the WHO and UNICEF "Core Questions and Indicators for Monitoring WASH in Schools in the Sustainable Development Goals" taking into account local conditions (UNICEF and WHO 2016). The purpose of this questionnaire was to study the students' awareness of WASH. The questionnaires covered the following topics: hygiene of body, mouth and genitals; hand washing with soap; hand treatment with an alcohol-based antiseptic; and proper drinking regime.

The questionnaire was approved at a meeting of the Scientific and Expert Commission of the Karaganda Medical University, Karaganda, Kazakhstan (Minutes No. 12 of 05/18/2021). This study was approved by the Regional Department of Education. The collected data were daily checked for completeness and entered into the Microsoft Excel database in a coded form. The respondents knew that participation in the study is voluntary and their right to refuse it was respected. Identification of a respondent is possible only by an identification number. In addition, the school administration obtained permission to participate in this study from the respondents' parents.

Table 5.1 Distribution of respondents by study bases

	Seifullin School (n_1)	Al-Farabi School (n_2)	School No. 9 (n_3)	Total
Total number of students between the ages of 11 and 18	461	1155	431	2047
Number of respondents surveyed	236	578	216	1030
Coverage (%)	51.19	50.04	50.12	50.32

Calculation of Sample Size

The study was conducted from September to October 2021. It included students between the ages of 11 and 18. The total number of respondents was 1030, which is 50.32% of the total population. Of them, the students from Seifullin School, Al-Farabi School and School No. 9 accounted for 236, 578 and 216 respondents respectively (Table 5.1).

Results and Discussion

Worldwide WASH Coverage in Schools

Schools water supply is one of highly effective methods for increasing access to education and improving educational outcomes (Bowen et al. 2007; Jasper et al. 2012; Lopez-Quintero et al. 2009). Water is essential to maintain personal and environmental hygiene, as well as to reduce student dehydration, which in turn improves their cognitive abilities (Edmonds and Burford 2009; Fadda et al. 2012). According data from the WHO/UNICEF Global Report (UNICEF and WHO 2020), in 2019 nearly 31% of children all over the world (584 million) did not have access to basic drinking water in schools. More than 15% of children among them (287 million) had no access to drinking water at all (Fig. 5.1). From 2015 to 2019, global school coverage of basic drinking water services increased by 0.4% per year. Achieving universal access by 2030 will require a sevenfold increase in the current rate of progress. Coverage of basic drinking water services was lower in rural schools (61.33% vs. 68.97% worldwide) and in primary schools (66.18% vs. 73.57% in secondary schools) (Figs. 5.2 and 5.3).

Having functioning and private restrooms in schools can have a positive impact on children's health and their educational outcomes, especially for girls (Bowen et al. 2007; Jasper et al. 2012; Lopez-Quintero et al. 2009). According to WHO/UNICEF Global Report (UNICEF and WHO 2020), in 2019, nearly 37% of children worldwide (698 million) did not have basic sanitation in schools, of which more than

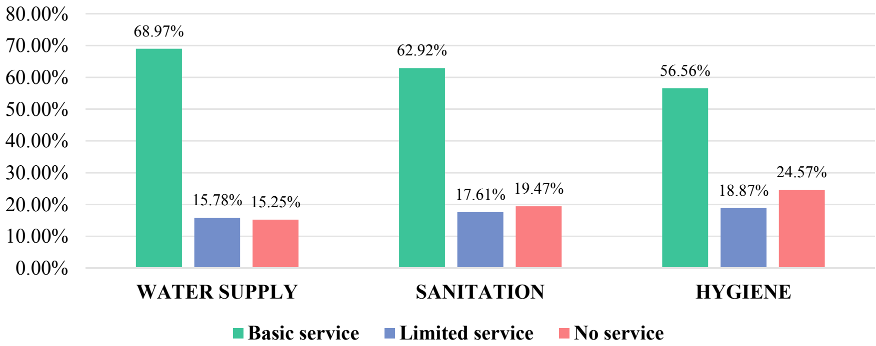

Fig. 5.1 Worldwide WASH coverage in schools (UNICEF and WHO 2020)

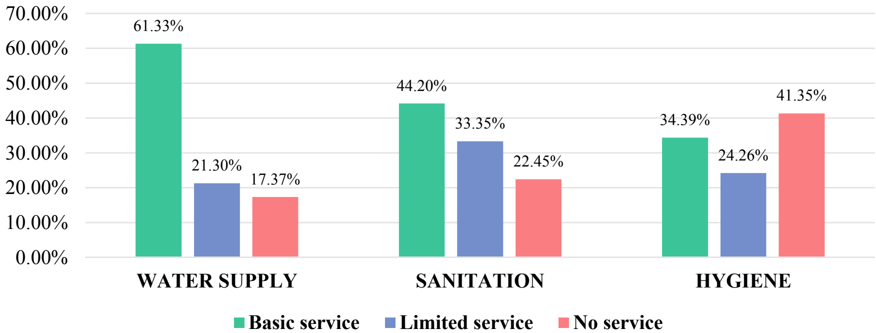

Fig. 5.2 WASH coverage in rural schools (UNICEF and WHO 2020)

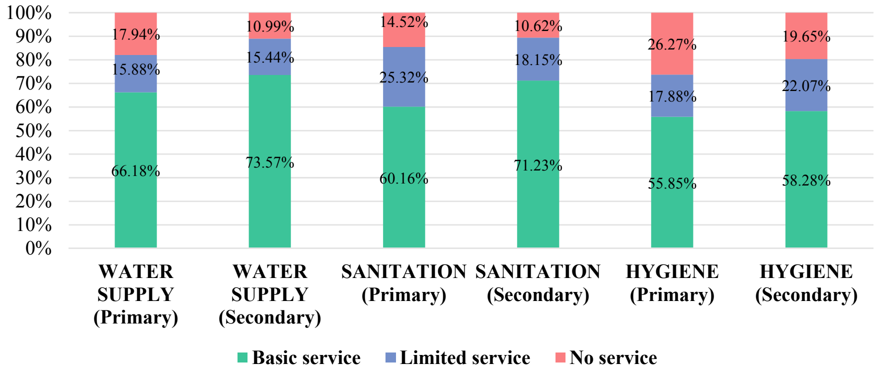

Fig. 5.3 WASH coverage in primary and secondary schools (UNICEF and WHO 2020)

19% (367 million) had no access to any sanitation (Fig. 5.1). From 2015 to 2019, global coverage of basic school sanitation increased by 0.7% per year. Achieving universal access by 2030 will require a fivefold increase in the current rate of progress. Coverage of basic sanitation was lower in rural schools (44.2% vs. 62.92% worldwide) and in primary schools (60.16% vs. 71.23% in secondary schools) (Figs. 5.2 and 5.3).

Hand washing is inextricably linked with human health, especially in a social or institutional environment (Bowen et al. 2007; Jasper et al. 2012; Lopez-Quintero et al. 2009). According to data from the WHO/UNICEF Global Report (UNICEF and WHO 2020), despite the importance of washing hands with soap, in 2019 nearly 43% of children (818 million) in schools did not have basic hygiene services, of which almost 25% (462 million) of children had no access to any hygiene services (Fig. 5.1). From 2015 to 2019, global coverage of basic hygiene services in schools increased by 1% per year. Achieving universal access by 2030 will require a fourfold increase in the current rate of progress. Coverage of basic hygiene services was lower in rural schools (34.39% vs. 56.56% worldwide) and in primary schools (55.85% vs. 58.28% in secondary schools) (Figs. 5.2 and 5.3).

This WHO/UNICEF Global Report lacks sufficient data to report on essential WASH services in schools in most countries of the world, including Kazakhstan. Therefore, filling the information gaps and setting baselines should be the top priority for these countries today.

Assessment of the Availability and Status of Current WASH Services in Schools

The assessment of the availability and status of current WASH services was carried out at three secondary schools of Karaganda city: Seifullin School, Al-Farabi School and School No. 9.

According to the data obtained, Seifullin School is located in a detached three-floored building built in 1962 (Fig. 5.4). The total number of students is 804 at the time of the study. The water supply in the school is centralized through the municipal networks; the water pipe goes inside the buildings. At the time of the study, tap water was available. The building has six restrooms, two of which are for girls (Fig. 5.5) on the 2nd floor, two are for boys (Fig. 5.6) on the 1st floor, and two are for employees on the 1st and 2nd floors. However, girls' restrooms have no facilities for hygiene during menstruation. The restrooms are available at all times, are functional and provide privacy. They are also equipped for handwashing with water and soap at the time of the study.

Al-Farabi School is located in a detached three-floored building built in 2017 (Fig. 5.7), and have 1900 students at the time of the study. The water supply in the school is centralized through the municipal networks; the water pipe goes inside the buildings. At the time of the study, tap water was available. The building includes 24

Fig. 5.4 Seifullin School

Fig. 5.5 Girls' restroom

restrooms, of which there are two restrooms for girls, two for boys, two for female employees and two for male employees on each floor respectively.

Restrooms for girls provide some facilities for hygiene during menstruation (Fig. 5.8). The restrooms are available at all times, are functional and provide privacy. They are also equipped for hand washing with water and soap at the time of the study (Fig. 5.9). In addition, schools have a dispenser to provide children with drinking

Fig. 5.6 Boys' restroom

Fig. 5.7 Al-Farabi School

water.

School No. 9 is located in a detached three-floored building built in 1966 (Fig. 5.10) and have 908 students at the time of the study. The water supply in the school is centralized through the municipal networks; the water pipe goes inside the buildings. At the time of the study, tap water was available. There are six restrooms in the building: one for boys and one for girls on each floor. However, girls' restrooms

Fig. 5.8 Facilities for hygiene during menstruation in girls' restrooms

Fig. 5.9 Place for handwashing in the restroom

have no facilities for hygiene during menstruation. The restrooms are available at all times, are functional and provide privacy. At the time of the survey, there was no soap, and staff restrooms were not available.

Thus, according to the Joint Monitoring Programme ladders for WASH in schools, Seifullin School has basic WASH services, Al-Farabi School has advanced WASH services, and School No. 9 has basic water supply and limited sanitation and hygiene

Fig. 5.10 School No. 9

services. It should be noted that hot water supply is another important aspect in practicing personal hygiene. However, hot water supply throughout the city of Karaganda is available only during the heating season (from late October to early May of each year). Consequently, during its absence, students from all three schools have to wash their hands with cold water, which is not always comfortable.

WASH Awareness Among Students

The findings revealed that the majority of students are aware of the importance of washing their hands with water and soap to prevent infectious diseases: Seifullin School—87.7% of students, Al-Farabi School—90.8%, and School No. 9—86.6% (Fig. 5.11).

However, only 47.5% of students from Seifullin School wash their hands with water and soap after using the toilet and 63.1% before eating. This indicator in Al-Farabi School was 55.5% and 66.4%, respectively, and in School No. 9, 45.8% and 56%, respectively (Fig. 5.12).

Compliance with the correct drinking regime is vital for the growing body of children. However, 56.8% of students from Seifullin School and 63.4% of students from School No. 9 experience dehydration during their stay at schools (Fig. 5.13). This value among students from Al-Farabi School was much lower (17.3%). The reason is a free dispenser with drinking water there.

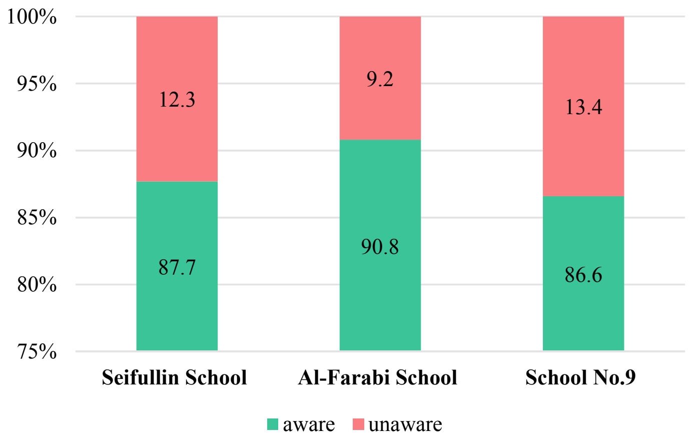

Fig. 5.11 Student awareness of the importance of washing hands with soap and water

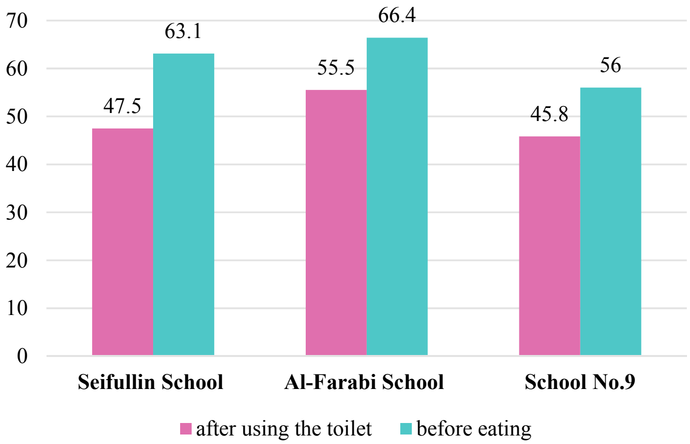

Fig. 5.12 Washing hands with water and soap among students

To meet students' needs, the toilet must be available at all times, functional and provide privacy. However, 12.7% of students from Seifullin School, 3.6% from Al-Farabi School and 7.4% from School No. 9 stated that the restrooms they used did not meet the above criteria (Fig. 5.14).

Water, soap and alcohol-based hand sanitizer are essential to maintain hygiene. According to the results of the survey, 28% of the students from Seifullin School, 13.5% from Al-Farabi School and 41.2% from School No. 9 stated that they did not have any hygiene products in restrooms (Fig. 5.15).

Thus, despite the fairly good awareness of students in WASH, they have a low level of hand hygiene and dehydration while in school, which in turn leads to negative

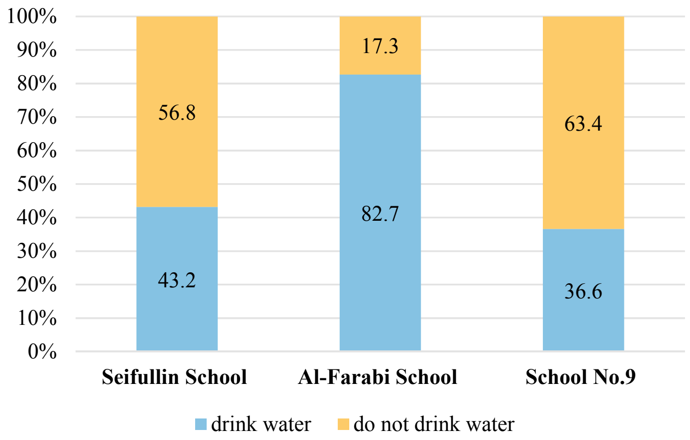

Fig. 5.13 Compliance with the drinking regime by students during their stay at schools

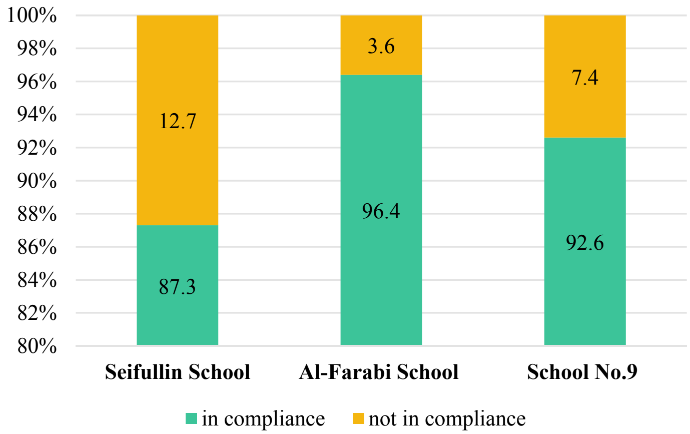

Fig. 5.14 Students' subjective assessment of compliance of the restrooms with "available", "functional" and "provides privacy" criteria

health outcomes and adversely affects their learning. They are also dissatisfied with the existing WASH conditions in schools, which stem from infrastructure problems and insufficient funding for the WASH sector in schools.

Conclusions

In conclusion, despite the measures taken in Kazakhstan to provide schools with adequate WASH conditions, no sustainable solutions have been found due to various problems in this area. They include the lack of reliable data on school coverage with

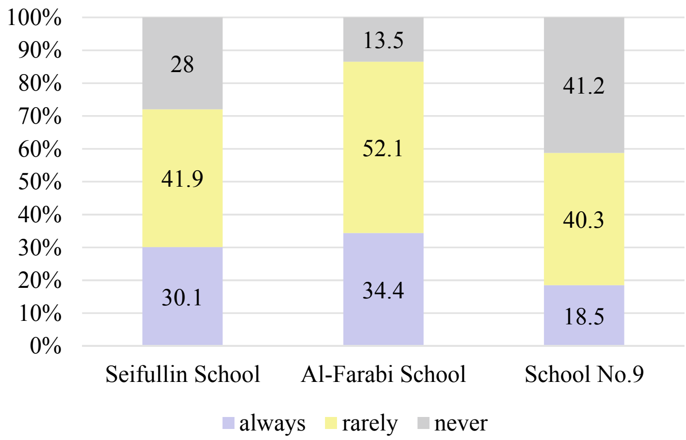

Fig. 5.15 Availability of handwashing/hand sanitizing products in restrooms

WASH services; poor quality of WASH infrastructure due to deterioration or initial non-compliance with safety requirements, especially in old-style schools built in the 60–70 s; insufficient funding for WASH services; lack of motivation to improve the available WASH services from those in charge; and lack of hygiene skills and knowledge among students.

The WASH concept implies both the availability of technical means (drinking water, toilet, washbasin and soap) and development of human potential to improve the hygiene skills of the population. This may be one of the reasons why improving WASH services in schools does not always affect the hygiene skills of students. Consequently, building the capacity of students to transfer knowledge and develop their skills in WASH is critical to achieving sustainable results. In turn, it will lead to behavioral change in the use of quality water sources and hygiene practices. Only such behavior will contribute to breaking the transmission paths of COVID-19, increasing the resistance of students' organisms to pathogens of various infectious diseases, which will improve their attendance and learning efficiency, as well as health and life quality.

Improving access to safe WASH in schools and hygiene skills of students is an environmentally sustainable and cost-effective way to protect and preserve the human and planetary health of today's children.

Limitation of the Research

In this research, there was no observation the hygiene skills of students during the presence and absence of water and soap in toilets. It will be the part of our further research.

Acknowledgements This research was funded by the "This Is Public Health" Global Grant Program of the Association of Schools and Programs of Public Health, Washington, USA.

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Chapter 6
The Power of Gender Equality to Accelerate Planetary Health and Prevent Pandemics: Evidence and Practice

Nicole de Paula, Sabine Baunach, Kathleen Mar, Sophie Gepp, Laura Jung, and Melvine Anyango Otieno

Abstract The COVID-19 pandemic has made global inequalities significantly worse, with women being disproportionately affected. It has also urgently demonstrated the need to rethink how we respond to global health threats, including the planetary emergency, notably climate change, biodiversity loss, and pollution. To be genuinely transformative, preventing pandemics requires addressing three systemic problems directly related to the UN Sustainable Development Goals (SDGs). First, the under-representation of women in leadership and, second, the dominance of sectoral policy decisions, which do not allow for systems-based responses. A third challenge to address is those and current dominant economic systems that disregard externalities causing dangerous environmental degradation and increasing risks of pandemics. These problems undermine critical development and human health progress achieved in previous decades, with a disproportionate impact on women in

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_6

low-income countries. Recognizing the urgency to develop actionable ways to translate research into practice, this chapter explores how gender equality accelerates the implementation of the UN Sustainable Development Goals. The analysis concludes by showcasing pragmatic and holistic approaches to enhance gender equality while strengthening the health-environment nexus.

Introduction

The COVID-19 pandemic exposed deep inequalities in our societies. It has also set back crucial development targets encapsulated by the UN 17 Sustainable Development Goals. The exact long-term effects of the pandemic remain to be understood. However, Dellink et al. (2021) show that, from 2021, emissions are projected to increase again after being reduced during the global lockdowns. They note that they will gradually get closer to the pre-COVID baseline projection levels as economic growth rates recover fully. Thus, there is a chance to observe a reduced impact on the levels of environmental pressures of 1–3% in the long term. And yet, the COVID-19 pandemic created multiple crises, which can be called a "syndemic" (Horton 2020). These associated crises have traumatized people's psychological wellbeing, as their social, economic, environmental peace got disturbed (Keshky et al. 2020). Although environmental pressure in the short term has been reduced, waste has been exponentially growing, which brings new challenges for sustainable development and health (Benson et al. 2021).

These impacts are unequal, with developing countries being left far behind. Vaccine inequity has been the most recent and symbolic example of these disadvantages (de Paula; Brown 2021). Moreover, people living in rural areas, the elderly, women, and children, are undergoing significant stresses and life changes due to the pandemic (Keshky et al. 2020).

This chapter focuses on how women worldwide have been disproportionately impacted by this global tragedy and argues that, more than victims, women hold untapped potential to overcome this crisis to the benefit of society. While violations of women's fundamental human rights have been observed for decades, the unfolding planetary crisis adds a new dimension to the picture. The gendered burden of COVID-19 is undeniable (Inno et al. 2020). Previous research has shed light on how past outbreaks resulted in similar impacts on women, suggesting that these burdens are not adequately considered in pandemic response systems (Simba and Ngcobo 2020).

In pre-COVID times, women were already disadvantaged when it came to their position in society. But with the pandemic, the pressures on women skyrocketed. As a result, more than half of women leaders who manage teams say they have felt burned out at work "often" or "almost always," and almost 40% of them have considered downshifting their careers or leaving the workforce over the last few months altogether (Cooper 2021). A gender pay gap can be another indicator of a gender crisis. For example, in Northern Africa and Western Asia, the gender pay gap is even higher than the global average. Moreover, women spend more than seven times as much time as men on non-remunerated tasks (UN 2020a, b). It is worrisome that the contributions of their essential work remain mostly invisible and non-remunerated. Moreover, women face structural barriers to participating in the labor market and accessing quality education and health care services. Even if paid, salary discrepancies between men and women mirror social inequalities and social norms that perpetuate these inequalities.

At the same time, many societies hold women as the pillars of their families and the backbones of communities. They are at the heart of the caring economy but lack fair opportunities to join the labor market equally (Biekert 2021). Despite women being at the core of our most fundamental societal roles, they face barriers to accessing leadership positions in all sectors. As we will show, the lack of diversity in decision-making has negative impacts on the whole of society.

With an ambition to do more than explain these challenges, our chapter underscores that gender equality accelerates the implementation of policies that support planetary health mainstreaming in public policies. We argue that gender equality is a win–win strategy to promote a healthier and more sustainable future for all. This analysis is timely and relevant, given that gender analysis in the field of planetary health studies remains overlooked (de Paula et al. 2021). Although many studies and projects are dedicated to gender issues, little is found on the cross-cutting themes of health, environment, and gender. The absence of direct discussions about gender equality in landmark planetary health books illustrates this point (see: Haines and Frumkin 2021; Myers and Frumkin 2020).

Our research aims to fill this gap by synthesizing evidence and providing examples of these synergies. It also explores ways to overcome three main challenges for combatting inequalities. First, the under-representation of women in leadership in all sectors. Second, the dominance of sectoral policy decisions that do not allow for systems-based responses necessary for planetary health. And third, the fact that current dominant economic systems disregard externalities, causing dangerous environmental degradation and impacting vulnerable populations, especially in low-and middle-income countries (LMICs).

This chapter has three parts. The first part provides an overview of the regression on progress towards the UN Sustainable Development Goals (SDGs) during the pandemic, focusing on gender. The second describes women's health on a changing planet, capturing new risks from rising environmental and social threats. It also extends this reflection in the context of the COVID-19 crisis, giving examples of how global lockdowns disproportionately impacted women, with costs to the whole society. The analysis also provides examples of how women can accelerate solutions for planetary health. The chapter concludes by showing the urgency of closing the gender gap for collective benefits. Finally, it outlines the limitations of the analysis and some recommendations for transformative gender policies that impact planetary health.

According to the International Labour Organization, the concept of gender equity refers to "fairness of treatment for women and men, according to their respective needs. This may include equal treatment or treatment that is different, but which is considered equivalent in terms of rights, benefits, obligations and opportunities" (International Labour Office [ILO] 2000). It is distinct and different from the concept of gender equality, which is the effective equality between men and women, which entails the concept that all human beings, both men and women, are free to develop their personal abilities and make choices without the limitations set by stereotypical views, rigid gender roles, and prejudices. Gender equality means that the different behavior, aspirations, and needs of women and men are considered, valued, and favored equally. It does not mean that women and men must become the same but that their rights, responsibilities, and opportunities will not depend on whether they are born male or female (ILO 2000).

Women's Health on a Changing Planet

> "Gender equality and women's empowerment are matters of fundamental human rights and social justice, as well as a prerequisite for sustainable development and achieving the SDGs and other global agendas."
>
> (IUCN 2020a, b)

We live in extraordinary times. Although COVID-19 paralyzed the world and brought a sense of collective grief, there is a relevant window of opportunity to transform global development and investment rationale. Concretely, the most urgent task that lies ahead of humanity is to achieve net-zero emissions by 2050 (Guterres 2020). This is no easy work, and a just transition has been considered necessary by those concerned with the social dimensions of climate change policies (Haines and Ebi 2019). More than costs, well-designed climate policies could bring significant health benefits, reducing the health risks of climate change and delivering multiple ancillary benefits to human health and development (co-benefits) (Haines 2017).

Our planet is rapidly changing, and the notion of planetary health encapsulates not only the climate crisis but all other interconnected human-caused disruptions of Earth's systems (Myers and Frumkin 2020). To safeguard human health in the Anthropocene, it is urgent to understand these growing challenges and act in a collaborative and transdisciplinary manner. It is thus imperative to find practical solutions for environmental threats and global inequalities at the same time. One key lesson from the pandemic is that diversity and equity are vital to promoting inclusive and effective policies for planetary health. In a nutshell, no one is safe until everyone is safe- as vaccine inequity proves- and women must be equally engaged in local, regional, and global decision-making to ensure a healthier, cleaner, and more resilient planet.

A Snapshot of Gender Inequality Worldwide with a Focus on Health

Gender equality is a fundamental human right and a necessary foundation for a peaceful, prosperous, and sustainable world. This is how the UN frames SDG 5, achieves gender equality, and empowers all women and girls (United Nations n.d.). Indeed, the Agenda 2030 explicitly states that realizing gender equality will make a crucial contribution to addressing all the global challenges embodied by the 17 SDGs and that "the achievement of full human potential and of sustainable development is not possible if one half of humanity continues to be denied its full human rights and opportunities" (UNGA Resolution 70/1 2015).

A look at the progress on SDG 5 is sobering. Despite some advances, progress remains slow and insufficient. A recent report by the World Economic Forum estimates that it will take another 135.6 years to reach gender parity worldwide (World Economic Forum 2021). On top of this, the COVID-19 pandemic has exacerbated pre-existing gender disparities and threatened to reverse the gains made thus far. School closures have led to lost opportunities for girls and an increased risk of violence, early marriage, and early childbearing (UN Women 2021). The UN Women also reports that school closures have also meant disruptions in school-based nutrition programs. Indeed, the COVID-19 pandemic has increased food insecurity globally, with women and girls disproportionately affected (UN Women 2020, 2021). Women have been hit harder by the economic impacts of the pandemic, while at the same time disproportionately bearing the direct implications of the pandemic, as they were majoritarian at the frontlines of the response, as health care workers and caregivers at home (United Nations n.d.).

The SARS-CoV-2 virus—a pathogen that most likely crossed over from animals to humans—has been an unpleasant reminder that human health and the health of natural ecosystems are inextricably intertwined—and that our social and economic systems also depend on both (IPBES 2020). In this way, the pandemic has served to underscore the principles already embodied by the SDGs, which shows that current global challenges, including poverty, inequality, climate change, biodiversity loss, transboundary pollution, and pandemics, cannot be addressed in isolation. Instead, we need to design interventions that solve multiple problems at once.

Women's Health in Times of Planetary Crisis

In times of crisis, such as natural disasters, violent conflict, or forced migration, environmental and socioeconomic determinants of health change for the worse, and existing inequalities exacerbate (WHO. Regional Office for the Eastern Mediterranean 2008). Physiological constitution, biological factors, and social determinants of health increase female vulnerabilities and susceptibility to often preventable illness (Vlassoff and Moreno 2002). Biologically, women's health needs differ from men's, and women are more susceptible to certain diseases, including auto-immune diseases and certain types of cancer (Sohn 2021). However, women's health and specific needs remain overlooked and excluded from public health planning and policies on many occasions instead of being studied and cared for with equitable attention (PMNCH 2019). Therefore, we must protect and promote the health of women and girls—focusing on availability, accessibility, affordability, quality, and equity of services—for the wellbeing and development of both current and future generations.

One aspect of women's health is particularly politicized and a victim of social power structures: Sexual and reproductive health and rights (SRHR). Defined as a state of complete physical, mental, and social wellbeing in all matters relating to the reproductive system, services are often not available, accessible, or affordable to women ignoring their equal rights and equitable needs beyond their sex and gender. Consequently, sexual, and reproductive health problems continue to be a leading cause of death and disability for women, especially in the Global South (WHO, Regional Office for Africa 2021). Approximately 810 women worldwide die every day from preventable causes related to pregnancy and childbirth.[1]

Family planning, which is central to gender equality and women's empowerment while improving maternal and newborn health outcomes, remains unavailable in many parts of the world. More than 214 million women who want to plan their births or avoid childbearing do not have access to contraceptive services (Darroch 2018). This results in unplanned pregnancies, often unsafe abortion, complicated childbirth, and negative socioeconomic and ecological consequences for women, communities, and ecosystems (e.g., school dropouts, missed professional opportunities, population pressure on natural resources, etc.). Granting women their right to health and fully meeting the unmet need for voluntary contraception would result in an estimated 76,000 fewer maternal deaths each year while reducing population pressure on ecosystems and natural resources (Darroch 2018). This idea, however, would not be complete without observing that the "overpopulation" argument risks being misused by developed countries. It is crucial to notice that overconsumption is what significantly impacts our environment.

Yet annually, 21 million adolescent girls (15–19 years) get pregnant and face an increased risk of obstetric complications for themselves and the newborn. Increasing their access to contraceptive services and creating a youth-supportive health care

[1] According to the WHO, maternal mortality is unacceptably high. About 295 000 women died during and following pregnancy and childbirth in 2017. Most of these deaths (94%) occurred in low-resource settings, and most could have been prevented (WHO 2019a, b).

system would prevent an additional 79,000 maternal deaths each year (Darroch 2018). While maternal mortality is disproportionally occurring in less developed countries, violence against women and girls remains a global concern on a pandemic scale. Over their lifetime, 1 in 3 women (ca. 736 million) experiences physical or sexual violence by an intimate partner or sexual violence from a non-partner (WHO 2021). This number has remained largely stable over the past decade, except for the exacerbation of the COVID-19 pandemic (Shalini and Singh 2020). Unfortunately, the observed rise in gender-based violence during the pandemic does not come as a surprise.

The case of pandemics is emblematic, as the COVID-19 pandemic, along with other zoonotic diseases, has revealed. For example, studies on outbreaks of Zika and Ebola have documented declines in facility-based deliveries, contraceptive use, and antenatal and institutional care (Azmat et al. 2021). Similarly, extreme weather events, post-disaster contexts, and climate-induced migration are linked to increasing gender-based violence and specific challenges for women's sexual and reproductive health (van Daalen et al. 2021). Therefore, the planetary crisis poses a relevant risk to the overall gains in gender equality and women's health in the past decades. In sum, the planetary crisis cannot be separated from a gender crisis, posing a disproportionate risk to women's health and delaying the implementation of the SDGs.

In LMICs, these challenges accumulate to an even more complex dimension. For local communities, poverty, access to education, and lack of awareness are critical socioeconomic determinants contributing to poor access to sexual and reproductive health services, perpetuating females' disadvantaged socio-economical position (WHO 2010). Moreover, while women represent approximately half of the global population and are often the caretakers of the families and the backbones of societies, their physiological needs, and human rights remain overlooked and deprioritized, especially in developing countries (WHO, Regional Office for Africa 2021).

The Health Care's Bias Problem

Female health conditions and outcomes are worsened by receiving delayed care, stigmatization, and a male-biased healthcare system (Pacagnella et al. 2012). When symptoms differ from the "norm" (men's symptoms), women are at greater risk of receiving a delayed diagnosis or misdirected care, with heart attacks being a prominent example (Martinez-Nadal et al. 2021). Sometimes the same symptoms, e.g., chronic pain, are also perceived differently due to gendered perceptions of health care providers (Samulowitz et al. 2018). Women and girls are suffering from a male bias when receiving care, as well as in research and the pharmaceutical industry. Due to the perceived complexity and higher costs of including female animals and participants in pharmaceutical studies, they are still underrepresented in pharmaceutical research (Ravindran et al. 2020). Especially gender diverse, older, or pregnant and lactating women are often excluded, meaning women in their most critical stages of life are being overlooked. Where white men are the default, race and socioeconomic determinants often intersect with gender inequalities as well, seriously limiting the generalizability of results (Duma et al. 2018). This means drug efficacy can differ for women, especially women of color, and there might be higher risks for adverse drug reactions due to gaps in evidence collection and reporting.

While the influence of sex and gender on pharmaceutical outcomes is increasingly recognized, it is still routinely ignored even in recent studies. Less than 20% of clinical trials on treatments and vaccines for COVID19 published until January 2021 report gender-disaggregated data (Brady et al. 2021). And yet, women are known to develop higher antibody responses and experience more side effects (Vijayasingham et al. 2021). This is just one example where a lack of gender-responsive policy and regulation combined with gender inequality in decision-making leads to worse health outcomes for women and girls.

The Impact of Poverty on Women's Health

Undeniably, poverty is the driving force behind struggles around workloads, poor nutrition, and stress amongst many women, especially in low-and-middle-income countries (LMICs) (Fasogbon et al. 2020). Economists define poverty as a condition within a community, a family, or a person. They lack the financial resources for a minimum standard of living. In this case, the essential requirement for ownership of resources cannot be met. According to research, poor people have disproportionately serious health consequences and have less healthcare access than those who are not (Woolf 2015). Poverty-stricken neighborhoods affect women in most cases. They are more likely to have poor health facilities, less access to education, and lack of access to affordable and nutritional meals and recreation areas that encourage physical exercise (Barnett and Vornovitsky 2016).

Low-income neighborhoods are further subjected to poor sanitary conditions, including lack of clean drinking water, inadequate housing, and living conditions. This scenario increases diseases and results in physical and psychological stress to women and children. Breaking the cycle of intergenerational poverty is difficult as children are more vulnerable to the negative consequences of poverty than adults (Wagmiller and Adelman 2009).

Poverty also leads to food-insecure families. Sometimes women must work with their children under the scorching sun, which can influence a child's health and cognitive development (Von Grebmer et al. 2013). This has been shown to increase vulnerability to poor nutrition and health problems such as stroke, heart diseases, obesity, hypertension, certain cancers, and even a shorter life expectancy (Duncan et al. 2010). In addition, poverty is associated with inadequate household vital resources, under-resourced communities coping with stress, anxiety, and depression, fewer opportunities, discrimination, and class wars (Nackerman et al. 2016).

Furthermore, agriculture is the principal source of income for 1.4 billion rural women worldwide, with women accounting for 43% of the farmworkers and 66% of livestock keepers in the Global South (Glazebrook and Opoku 2020). In sub-Saharan Africa, the farmworkers are approximately 60% women. Workloads in rural areas in the LMICs are demanding in terms of time and energy (Johnston et al. 2018). Farming, preserving, preparing, and cooking meals, managing animals, harvesting crops, pasture, and firewood, handling the domestic water supply, and contributing most of the work for post-harvest chores are all responsibilities of rural women (Upadhyay 2005). This phenomenon of women's increasing role in growing food, which is attributed to family income diversification that draws men away from farming, is referred to as the 'feminization of agriculture,' where women increasingly work as small-scale, subsistence farmers in the global South. The 'feminization of agriculture' is exacerbated by the 'feminization of poverty,' first recognized at the UN Fourth World Conference on Women in Beijing in 1995.

Despite their significant contribution to that process, women are not being given their share of development benefits (Chen and Yeh 2020). Women's responsibilities have likely increased dramatically further due to economic recession and efforts to alleviate it through comparative economic purposes. With the elimination and restriction of government funding, impoverished and rural populations have less access to health care and education, the increased burden of care is being transferred to households (Yaron et al. 1997). Gender-sensitive development policies that fully recognize women's multiple roles and needs are vital for a resilient sub-Saharan Africa and other LMICs (Barette and Browne 1993).

For a great transition and proper recovery to a more resilient global society, planetary health concepts can be adopted to reduce social and gender inequalities (de Paula and Mar 2020). This is embodied by the São Paulo Declaration on Planetary Health, an emblematic initiative calling for the global planetary health community to support a more equitable and resilient post-pandemic world (Myers et al. 2021).

In sum, many social determinants of female health stem from patriarchal structures in our societies. These structures lead to the normalization and undervaluing of unpaid care work and the gender pay gap. This situation creates invisible barriers to women's engagement in the formal economy, causing stress and negatively impacting women's mental health (Seedat and Rondon 2021). Therefore, we argue that only gender-transformative policies towards more gender equity will prevent further harm to women's health and reduce their high burden of care work in the future. Furthermore, such liberation could positively impact planetary health, as we will show next.

Gender-Transformative Policies to Accelerate Planetary Health and Enhance Pandemic Prevention

Social and economic determinants of health are aggravated and reinforced in times of crisis. This was true in the COVID-19 pandemic and is valid for the climate crisis (de Paula et al. 2021). Therefore, we need to address these underlying inequities and injustices to prepare for the future - be it for the consequences of the climate, biodiversity, and pollution crises that are already inevitable, or be it for the next pandemic.

When addressing the COVID-19 pandemic, decision-makers have a window of opportunity to build back better or to build forward. The SDGs highlight that those challenges interlink and that we need to think about these together instead of in silos (Griggs et al. 2017; United Nations 2015, de Paula 2021a). As the next steps, decision-makers must ensure that sustainable development pathways within the nine planetary boundaries are followed to reach all SDGs by avoiding discriminatory policies and systems (Soergel et al. 2021). The concept of planetary boundaries, proposed by Rockström et al. in 2009 defines nine boundaries of the planetary system (Rockström et al. 2009). These boundaries "define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes" (Rockström et al. 2009).

Amidst the pandemic chaos, the World Health Organization (WHO) showed signs of taking these boundaries to heart. In 2020, the WHO published a manifesto for a green & healthy recovery (World Health Organization 2020). The prescriptions clearly outline the connection between health and the environment and show win–win solutions for both moving forward after the pandemic. They included investing in essential services, such as water and sanitation and clean energy in healthcare facilities. They also urge shifting away from fossil fuels (and subsidizing these) to clean energy, healthy, sustainable food systems, healthy and livable cities to protect nature as an essential antidote against pandemics (World Health Organization 2020). 70% of emerging diseases are zoonoses, and the risks of these spilling over are increased by humans coming into close contact with animals (Daszak et al. 2020). Therefore, deforestation, wildlife trade, and other forms of human ecological disruption increase the risk for a spillover with epidemic and pandemic potential (Daszak et al. 2020).

The WHO manifesto also explicitly highlights the urgency for taking into account the needs of different population groups in the cross-cutting actions: "Monitor and track risks to health and wellbeing of different population groups; monitor the adoption and health impacts of policies and investments using timely data and targeted indicators; disaggregate by income, gender, age, race, ethnicity, migratory status, geographic location and other characteristics relevant in national contexts" (World Health Organization 2020). However, as outlined above, the lack of disaggregated data is often the basis for the needs of population groups being overlooked when it comes to the design and implementation of policies.

We need to rethink the societal, economic, and political status quo to move from constantly overstepping planetary boundaries to living within ecological limits. In 2011, the German Advisory Council for Global Change (WBGU) published a flagship report (Nakicenovic and Schulz 2011) outlining that we need a "Great Transition" to move to societies within planetary boundaries. In its report, the WBGU "defines a comprehensive transition to take the planetary guard rails into account as a Great Transformation requiring the modification of both the national and the global economy within these guard rails to avoid irreversible damages to the Earth system and its ecosystems, and the impact of these damages on humankind" (Nakicenovic and Schulz 2011: 393).

To achieve such a transformation, we must consider tipping points regarding climate and social tipping elements. Otto et al. (2020) identified such potential social tipping elements, defined as "subdomains of the planetary socioeconomic system where the required disruptive change may take place and lead to a sufficiently fast reduction in anthropogenic greenhouse gas emissions" (Otto et al. 2020). They considered interventions regarding financial systems, norms and value systems, the education systems, and many other areas (Otto et al. 2020). All these tipping points need to be achieved within a just manner for all the population. Therefore, policies need to be gender-transformative and sustainable at the same time.

It is important to note that discrimination based on sex and gender is not the only factor to consider in policymaking. Other forms of discrimination cannot be ignored. Race, age, physical ability, religion, place of origin, and many others should be monitored and mapped out when deciding on policy options to ensure these policies do not perpetuate or worsen inequality or inequity. Moving forward, we have the urgent duty to opt for ecologically and socially just policies and programs. As de Paula and Mar argue, "we don't have the luxury of addressing one crisis at a time" (de Paula and Mar 2020). These challenges are interdependent and cannot be solved by ignoring others.

Nature Protection and Diverse Leadership as Secret Ingredients for Transformative Action

So far, we have underscored several reasons for addressing gender inequality as imperative for successfully mainstreaming planetary health in public policies. Women make up 50% of our global population, yet many analysts and advocates remain concentrated on *why* women are influential in sustainability and health. We consider it more appropriate to understand the main conditions that allow success stories to blossom instead of justifying empowering women. That is, one must consider *how* and expand solution-oriented research.

The UN Women shows that only 6% of elected national leaders are female, reminding us how flagrant the political leadership gap is. However, it is worth noting that countries led by women during the pandemic demonstrated some positive skills to navigate this invisible threat. Although more research is needed, some analyses point to the positive trend of having women leaders as prompt responders during health crises, which results in lower death rates (Mavisakalyan and Tarverdi 2019). Factors that influence these could be both unique characteristics of women leadership or the features of the countries with women leaders, which might be more equitable and healthier (Soares and Sidnun 2021). The same can be said in the field of sustainability (de Paula 2021b). The following part makes these links more explicit through concrete examples by sharing the potential of women leaders for planetary health as incubators and accelerators of planetary health policies.

Gender Equality and Planetary Health: Pathways to Positive Change

Many vital multilateral agreements have been guiding decision-makers towards a more sustainable and healthier planet. The SDGs and the Paris Agreement on Climate Change are the most high-profile universal agreements calling for deep transformations in every country as well as all aspects of society. These transformations cannot occur without the meaningful involvement of governments, civil society, science, business, and inclusive policies.

Despite theoretical guidance, clear pathways to operationalize the implementation of the 17 SDGs, especially in a synergistic manner, are still lacking. One attempt to bridge this gap between theory and practice highlights six SDG Transformations that would work as building blocks. They are: (1) education, gender, and inequality; (2) health, wellbeing and demography; (3) energy decarbonization and sustainable industry; (4) sustainable food, land, water and oceans; (5) sustainable cities and communities; and (6) digital revolution for sustainable development (Sachs et al. 2019). The synergies among these pathways are clear and the following examples illustrate why women in positions of leadership enhance our chances to achieve planetary health. Below, we discuss some of the attributes and behaviors that might differ by gender. In line with the UN, we reiterate that these attributes are socially constructed and are learned through socialization processes and, therefore context-specific, have the possibility to be transformed (UN Women 2002).

One should highlight that consumption patterns differ by gender with women being appointed as more sustainable consumers and more sensitive to ecological, environmental and health concerns (UNEP 2016). In addition, women are more likely to support a circular economy by recycling, minimizing waste. Women also support the market of organic food and eco-labeled products, despite men being more willing to pay higher prices for organic food (Ureña et al. 2007). This suggests that consumption decisions are gendered and that behaviorally informed policy solutions could be a tool to enhance sustainable choices benefiting the whole of society (OECD 2017). However, women's roles have been downplayed (UNIDO 2021). Considering the efficiency argument, promoting gender equality means positive economic gains (Woetzel et al. 2015). Although more research is needed, studies are showing that women could improve the quality of institutions and organizations by promoting sustainability and health policies on the public agenda and demonstrating reduced levels of corruption (Profeta 2017).

Transforming our food systems plays a fundamental role in the Great Transition for Planetary Health. There are several areas in which women contribute positively but do not earn the same benefits, delaying positive transformations for all. For example, as noted by the Rockefeller Foundation, about 62% of dairy farmers are women (Rockefeller Foundation 2021). Moreover, male dairy farmers still earn 64% more in total than females, even though milk sales are more likely to make up the bulk of women farmers' total income when compared to men. This is one example of significant disparities in terms of asset ownership and control, such as cow ownership

(72% of women dairy farmers do not own cattle), access to land, access to credit and capital, access to transportation, and participation in the formal dairy sector (Rockefeller Foundation 2021). Women are also crucial in agriculture. In sub-Sahara African and the Caribbean, women produce 80% of basic foodstuffs, in Asia they provide fifty to ninety percent of the labor force for rice cultivation. In Nigeria, for example, 60% are involved in farming in Adamawa State Nigeria (Olalekan et al. 2019).

Fisheries and coastal resource management also illustrate how gender dimensions are often overlooked, despite signs of positive contributions (IUCN 2020a, b). This can be primarily attributed to the lack of documentation of these contributions, making them invisible for policymakers (Torres et al. 2019). Moreover, overfishing and swift coastal development negatively impact groups of women and men in local communities, as marine resource depletion and coastline degradation degrade their quality of life and health. However, efforts to address these problems often target technical and economical solutions, ignoring the drivers of inequality and vulnerability. Torre et al. (2019) note examples of economic growth strategies that prioritize industrialized fishing practices, ignoring the needs of small-scale fish catches and the importance of household food security. To overcome these, they suggest five entry-points for transformative pathways in fisheries that are valid for other areas: (1) Inform and sensitize communities on gender issues to ensure that decision-making is more equal at the community and organizational level; (2) Develop a common approach to address gender inequality, while systematically mainstreaming inclusive practices; (3) Recognize women's ability to question and support them by identifying potential for change (4) Strengthen girls and women's self-esteem; (5) Promote integrated approaches to gender and coastal resource management at the national level (Torre et al. 2019).

The water sector is another relevant area that deserves attention. For decades experts have demonstrated the positive role of women in sustainable water management. When women's access to safe water increases, many areas show positive effects: social inclusion, poverty alleviation, health, environmental sustainability, and food security (OECD 2018). The involvement of women in water and sanitation has great potential to benefit communities. However, their talents remain underused. In technical and managerial positions, they are underrepresented. According to the World Bank, on average only 23% of licensed engineers are women, and the figure is the same for female managers. In addition, some utilities have no women in technical and managerial positions at all—one in three (32%) utilities in the sample have no female engineers and 12% of utilities have no female managers (World Bank 2019). For example, among 122 projects studied by the World Bank, those that involved women were six to seven times more effective than others. And yet, women comprise less than 17% of the hygiene, sanitation, and water force globally. Based on these findings, Thompson et al. argue that women's leadership nationally and internationally would likely result in even more significant benefits. Even more relevant is the conclusion that women are vital contributors to formal and informal peace processes. They influence how people perceive and experience conflict (Polk 2011).

They are thus mighty peace messengers and could reduce the increasing threats of water-related risks and conflicts (Trivedi 2018).

In addition, the health of our ocean holds immense potential to safeguard human wellbeing on this planet. And yet, ocean-gendered biases still influence our interaction with the ocean (Gissi et al. 2018). Ocean experts at the Commonwealth Blue Charter argue that ocean governance needs to acknowledge women's role for its effectiveness, calling for reducing the structural, and systemically embedded hurdles that continue to lead to gendered decision-taking concerning the ocean. This Charter is a commitment by 54 Commonwealth countries to work together to solve ocean-related challenges. Under the Blue Charter, ten action groups coordinate around key ocean issues, led by "champion countries," with Canada championing the Commonwealth Blue Charter Action Group on Ocean Observation (Black 2020). Key recommendations from these groups include ensuring gender equality in decision-making, building capacity, creating leadership and mentorship opportunities, and collecting gender-disaggregated data in the ocean sector. According to these action groups, promoting sustainable and inclusive oceans management through women and science is a promising avenue for change (Michalena et al. 2020).

Overall, women in conservation have demonstrated meaningful contributions to biodiversity protection (The Nature Conservancy 2021). Given that nature protection is a crucial ingredient to prevent pandemics in the long term, scaling their contribution suggests collective benefits. Practice indicates that women are promising players in natural resource management, contributing to environmental conservation, sustainable development, and adaptation to climate change. To illustrate this, especially in rural areas, women are involved in household activities like collecting food, water, fodder, and fuel. These activities enhance their knowledge of the environment and implement the appropriate conservation practices and technologies. Unfortunately, there has been a history of denial when it comes to the role of the global South. As Raimi et al. argue, "people in Western countries think they originated the environmental movements without knowing that the villagers in mostly poor and developing countries initiated these movements" (Raimi et al. 2019: 8).

Finally, one should note that everybody is vulnerable to COVID-19. But women and girls are not a homogeneous group, and forms of discrimination may vary. For example, young women face a disparate impact of job losses, particularly in informal markets, while indigenous women might require information in their languages (UNAIDS 2020). The same can be said about planetary health. Despite being a global approach, its operationalization remains highly local and contextualized. Overall, this chapter is a powerful reminder of the utmost importance of combatting inequalities of all sorts to advance the Great Transition and secure global peace (UN 2020a, b).

Conclusion

In a pre-COVID world, achieving the UN SDGs already seemed a difficult task. Currently, it is known that such goals are even further out of reach. The burden of this implementation gap will be carried mainly by the most vulnerable populations, especially in LMICs. Gender equality is not a nice-to-have but an intelligent way to achieve multiple goals at once while allowing the benefits to be shared across the whole society.

We are living in one of the unique periods of contemporary history. Building forward from the COVID-19 pandemic is an unmissable opportunity for planetary health knowledge and practice. This chapter has argued that gender equality means faster recovery and preventive measures against future pandemics. We have also suggested how policies that are gender transformative represent a fundamental step towards enhanced solutions for global challenges aggravated by environmental degradation, which hinders human health. We showed that there are higher chances to accelerate planetary health mainstreaming in public policy when women can lead.

This chapter is an attempt to overcome fragmented research in planetary health, which has overlooked the link between sustainable development, health, and gender. The analysis evaluates the synergies between policies related to planetary health and the untapped potential of gender equality to spur positive transformation for all.

Our approach, however, is not a systematic review of the literature. Instead, our analysis concentrates on the work of vital players in this field, the most updated data, and demonstrates the gap in the planetary health literature regarding gender. The chapter suffers from this limited available literature but opens a new area of inquiry for future researchers. In particular, future studies could concentrate on quantitative analysis of neglecting the contributions of the "caring economy" for the health of people and the planet. More research is needed to understand the negative impact on women's health after the pandemic and the costs of inequitable inclusion of women in decision making, which potentially delays the effective implementation of the UN SDGs. These evaluations pose methodological challenges, and other researchers could clarify new ways to conduct this work, as well as policymakers and institutions ensure that gender-disaggregated analysis is scaled up when formulating policy plans in the field of public health and sustainable development.

Moreover, our analysis provides a comprehensive insight into the gender dynamics within the broader framework of Planetary Health and provides a compilation of recent and relevant literature with multiple examples. Nonetheless, the content is not the result of a formalized literature review. Perhaps even more challenging is the lack of studies designed to evaluate how gender-transformative policies can improve outcomes for planetary health and women's health at scale. How can the pathways to positive change highlighted above be scaled up? What lessons learned are widely applicable, and where is it most important to take local context into account? To effectively answer these questions will require collaborative inter-and transdisciplinary efforts from the research community in cooperation with the communities of study, which is certainly no simple (or inexpensive) task. As a first step, more rigorously designed, social scientific case studies on the role of gender in social and ecological transformation within specific communities would be valuable.

Continued research should help support the development and implementation of gender-transformative, climate-smart planetary health solutions. The collection of gender-disaggregated data will be vital for illuminating the best policy options to ensure gender equality and planetary health. And while we should strive for win–win solutions, conflicts are bound to arise. In these instances, policymakers will have to evaluate these options to arrive at the best compromise carefully. Moving from knowledge to action also requires support. Awareness-raising, also among men, will be necessary for this, as well as new funding schemes that support cross-cutting research.

Time is not on our side. According to the UN, if nothing is done, achieving gender equality could take more than 130 years. From this perspective, we highlighted an urgency to move beyond awareness in favor of "consciousness." Instead of *why,* stakeholders must further explore *how* to scale success stories that demonstrate the power of gender-transformative policies for implementing the SDGs. It is thus fundamental to focus on the underlying causes of discrimination and inequalities, targeting longer-term planning and enhancing understanding of how these affect different groups of women. The effects of the COVID-19 pandemic on the world's development will be felt for generations to come. Although more research could improve our understanding of the benefits of investing in women as leaders, there is already clear evidence that diversity leads to better outcomes (Brown 2021). Moreover, they serve as role models for more equal societies. Broader planetary health positive impacts are thus at stake when investing in gender equality.

In sum, inequality reduces the ability of girls and women to ensure good health and essential access to services, such as health care and education. This chapter is thus a call to action. It urges researchers and practitioners to combat stigmas and value diversity, especially related to leadership. We must move from words towards deeds. There are concrete steps that could be taken to scale opportunities for combatting historical, social, and environmental injustices, certainly the right step towards planetary health. Making women's contributions and talents more visible is crucial for a healthy recovery and a resilient post-COVID world.

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Chapter 7
Energy, and Human and Planetary Health: Is the Mutual Link Inevitable?

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Abstract Energy is crucial for human life. By many metrics, the combined effects of increasing energy use on human well-being have been more positive than negative, and energy has contributed positively to improvements in global human health. At the same time, the effects of human energy use on the biosphere have been usually adverse—the well-known byproducts of energy generation, mainly from fossil and nuclear fuel, are pollution, change of biogeochemical cycles, disruption of the global climate system, and biodiversity loss. These changes, in turn, affect not only planetary but also human health. The chapter focuses on these mutual relationships between energy and human and planetary health and possible solutions to the issue, such as energy conservation and alternative energy sources.

Introduction

Energy is one of the most fundamental and universal concepts in natural science. Yet, it is not easy to define what energy is because humans cannot sense and, therefore, visualize energy in any direct way. Although energy does not exist by itself, humans can perceive energy only as its effects, such as motion or heat. Therefore, energy is usually defined as the ability to do work or to produce/transfer heat. Although heat is often viewed as just kinetic energy of the internal motion of molecules, sometimes it is discussed as a separate energy category.

Energy can take on many forms. However, living organisms use only one energy source to power their metabolism and growth—from biochemical reactions. Without any doubt, energy is fundamental for life. From a biological standpoint, any living organism can preserve its internal order only by taking free energy from the surroundings, either from sunlight or nutrients, and later returning an equal amount of energy to surroundings as heat and entropy (Nelson and Cox 2005). Living organisms cannot store a significant amount of free energy because it would result in overheating

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_7

and damaging the organisms. Instead, living organisms can store energy safely in energy-rich molecules and release it for use only as needed. In any case, energy for living organisms comes from the sun and keeps them alive through a series of complex biochemical transformations. Solar energy also fuels life on earth indirectly by keeping the air and water temperature within acceptable ranges. Although life can grow and reproduce in a relatively large range, the temperature is always crucial because it influences liquid water—a crucial part of life.

Human life, as the life of any living organism on earth, depends on energy too. Humans, similar to all other living organisms, need energy for metabolism in their cells. However, being unable to utilize free solar energy directly, humans have to rely on solar energy transformed by other organisms into nutrients such as proteins, lipids, and carbohydrates. Therefore, despite tremendous progress in agriculture and food technologies, hunger, which is essentially a deficit of energy stored in food, remains a life-threatening issue for millions worldwide. In contrast to almost all other living organisms, however, humans use other energy forms than biological metabolism. Although some plants and animals use the kinetic energy of wind or water for movements, the degree to which humans have been able to utilize and transform various forms of energy—from firewood to nuclear power is just incredible. In this regard, humans are unique among all other biological structures.

By using different energy sources, human beings have been improved their life drastically—the combined effects of increasing energy use on global human health have always been positive by all metrics. At the same time, the effects of human energy use on the biosphere have been usually adverse—the well-known byproducts of energy generation are pollution, alteration of geochemical cycles, disruption of the global climate system, and biodiversity loss.

It is argued that historically the concept of public health did not include whether health benefits were achieved in an environmentally friendly manner or not. Only recently the global community started to acknowledge that human and planetary health are essentially two sides of the same coin. The idea of planetary health is based on the assumption that global human health depends on healthy natural systems and adequately managing these complex natural systems (Demaio and Rockström 2015; Whitmee et al. 2015). If a particular group of people improves its health at the cost of destroying natural systems, it is likely to be doing so at the expense of other groups—now or in the future. Therefore, the global health model concept should include all dimensions of public health—biological, economic, environmental, social, cultural, and political (Lang and Rayner 2012; Whitmee et al. 2015).

Energy services have contributed significantly to both public and planetary health, both positively and negatively. However, their relationships are relatively less investigated in the current literature (Haines 2001; Pillarisetti and Smith 2020). Recognizing the positive effects of energy services on public health and the immense burden on natural systems, this chapter offers an overview of complex relationships between energy, health, and the environment. This review summarizes the existing literature on the topic rather than analyzes primary data, which is the study's major limitation.

The chapter is structured as follows. First, it discusses the complex relationships between energy and human health. Second, it describes how energy affects planetary health. The final part of the chapter discusses possible solutions and concludes.

Energy and Human Health

Although humans, like many other animals, can maintain a stable internal body temperature, the body can only compensate for a relatively narrow range where the use of energy is minimal. Therefore, the temperature of the environment is quite essential for human health. Unlike other animals, however, humans have learned how to change the environment's temperature around them.

The first form of energy that humans learned to use was fire—the primary source of energy that separated them from the rest of the animal kingdom and has become an inevitable part of human life since prehistoric times. The exact time when early hominids started to control fire for their purposes regularly is not very well known. According to some estimates, it happened approximately 1.5 million years ago in Africa. Although thermal comfort was not a severe issue in that part of the world, early humans possibly used fire for protection, predominantly nocturnal, roasting plants and animal meat, and lighting. All these possible helped to survive early human groups (Clark and Harris 1985). The role of fire for the health and survival of early humans is more evident for times of the second half of the Middle Pleistocene approximately 400,000 years ago when it helped to survive in the cold regions of Eurasia during its colonization (Roebroeks and Villa 2011; Smil 2017).

From that time on, energy remains one of the fundamental mechanisms for keeping thermal comfort—either through heating or cooling air, which is especially important for places with extreme hot or cold temperatures. The temperature of thermal comfort is relatively narrow and usually ranges from 18 to 24 C. This range is even smaller for sensitive groups such as very young, elderly, and individuals with chronic diseases. Very low and high temperature poses a severe risk to their health, especially individuals with chronic illnesses. For example, cold homes often explain excess winter deaths, especially among the elderly. As a result, the World Health Organization recommends minimum temperature thresholds of 18 C for the general population and 20–21 C for the elderly (Ormandy and Ezratty 2012; Hughes et al. 2019). Historically, because of its Eurocentric focus, the issue of thermal comfort focused on preventing low temperature. Yet extreme hot temperature has adverse effects on human health as well. Billions of people live in permanently hot and humid places, especially in sub-Saharan Africa and Southeast Asia. Yet even in Europe, due to the increasing number of heatwaves, access to indoor cooling technologies such as air conditioning is usually needed to avoid heat-related stress (Mazzone 2020). Most importantly, both heating and cooling require enormous amounts of energy. Throughout centuries, the lion's share of energy has been used to maintain thermal comfort, so crucial for human health.

Quite similarly, improving lighting condition increase quality of life—it improves people's mood, job performance, and safety. Thus, energy used for lighting positively affects human health (Sörensen and Brunnström 1995; Dianat et al. 2013).

Because their ability to move their bodies and things is quite limited, humans have always tried to utilize other forms of energy for transportation. From ancient times humans used the energy of water and wind, and animals for transportation. However, the real revolution in transportation was when humans started using mechanical engines and fossil fuels as a source of energy. The invention of the steam engine and its use in railways and steamships has changed the quality of life of people worldwide. Later, automobiles and airplanes, first gasoline and diesel, some currently electric, have helped travel previously insurmountable distances. Technological innovation in transportation has even expanded to the point that space travel has started to be viewed as a real possibility.

The transformation from a human- and animal-based economy to one based on machines during the eighteenth century is known as the Industrial Revolution. It began with wind-powered and water-powered technologies, gradually replaced by fossil hydrocarbons: coal in the nineteenth century, oil in the twentieth century, and recently, natural gas (Hall et al. 2003). Because of the progress in transportation, it has become possible to transport goods and services across previously insurmountable distances. Access to goods and services that were expensive or not available has dramatically improved the quality of life of millions. For instance, electric devices are currently used in all areas of human life and thus, improve the quality of life. The progress in electric energy made advanced forms of communication possible, beginning from the telegraph and telephone to emails and instant messaging, enabling instantaneous communication over long distances and fostering economic growth (Chernotsky and Hobbs 2018). It is estimated that by 2050, the number of electric devices will increase by 80% in developed countries and by a factor of 3 in developing countries (Grubler et al. 2018).

Naturally, the choice of energy sources has radically expanded from firewood to other burning fuels such as coal, oil, natural gas, peat, water, wind, sun, and geothermal and nuclear energy with some possibilities of thermonuclear synthesis in the future.

The use of energy increases not only in the number of ways how humans receive and use energy but also in the amount of energy used. The annual energy use of late-Paleolithic time is estimated to have been around 5 GJ per capita. By the middle of the nineteenth century, the primary energy consumption rose to 20 GJ per capita. Today, after 150 years of industrial development and fossil fuel use, it has reached 80 GJ per capita (Rao et al. 2019; Millward-Hopkins et al. 2020). Energy consumption usually correlates highly with the quality of life. Because of the importance of energy for human well-being, an adequate amount of energy is needed for a healthy life. Insufficient use of energy usually negatively affects people's living standards. Yet energy is not free, and to have adequate energy service, people should spend a part of their income. In strict budgets, an energy consumer faces a difficult choice to consume less energy or spend less on other services. One of the first estimates set 10% as a maximum share of income to be paid for having "adequate energy services" (Boardman 1991). The affordability of energy, poor thermal comfort, and inefficient cooking appliances have become a problem in both developing and developed countries (Wilkinson et al. 2007). There is significant inequality in energy consumption among nations and households. The gap in energy consumption among households is vast in developed countries. Currently, 15% of the world's population consumes about half of the total energy generated in the world. In contrast, 6% of the global population, mostly in developing countries lives without or with minimal essential energy services that inevitably affect their health (Pachauri 2010; Pasten and Santamarina 2012).

At the same time, although the improving quality of life usually requires increasing energy use, the relationships between human health and energy consumption are not so straightforward. Although the increased energy consumption is essential for improving human health in developing countries (Ahmad et al. 2014), the tremendous energy use in industrialized countries seems to have no benefit for their citizens' well-being because they often consume energy unnecessarily and ineffectively. Therefore, meeting everyone's needs at sustainable levels of energy use is theoretically feasible even with today's technology (Mazur 2011; Millward-Hopkins et al. 2020).

Although energy is required for a healthy life, paradoxically, it can also damage human health. Considering cases when energy use caused fire burns or electric trauma, more critical factors resulted in indirect adverse effects caused by generation and use of energy. Each type of energy generation has its own, sometimes unique, war to affect human health negatively.

The current global energy balance depends enormously on the combustion of carbohydrates fuels, such as coal, oil, and natural gas. The world's use of fossil fuels has increased approximately 800-fold since the middle of the eighteenth century and 12-fold during the twentieth century (Hall et al. 2003).

Energy starts affecting human health beginning from extractions. Deep mining of coal is highly harmful and dangerous to those who work in the mines. Miners often suffer from lung diseases. Mine shafts can collapse or explode, killing miners (Moan and Smith 2007).

Although extraction and transportation of energy resources affect a relatively small share of the human population, adverse effects of energy caused by its transformation and use affect everybody. The combustion of fossil fuels is required to release chemical energy stored in the fuel is into useable forms, such as electricity or heat. The contribution of energy generation to pollution is especially evident in pollution (Moan and Smith 2007). Pollution remains one of the critical factors affecting human health, and energy-related air pollution is one of the most important sources of pollution that has been a long-lasting environmental issue that has plagued the world since the Industrial Revolution. The United States Environmental Protection Agency (EPA) identifies six common air pollutants (also known as "criteria air pollutants")—carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ground-level ozone (O_3), and particulate matter (PM) (EPA 2021).

The effects of polluted air on human health are vast, but it primarily affects the body's respiratory system and cardiovascular system. The health effects caused by air pollution depend on the type of pollutant but often include coughing, asthma, and aggravation of existing respiratory and cardiac conditions (EPA 2021). One of the earliest well-known examples in history of how air pollution can affect human health happened in London in 1952, known as the "Killer Fog" or "The Great Smog." The fog and the pollutants from fossil fuel combustion, primarily coal, caused a thick layer of smog that lasted for about a week. An anticyclone resided over the capital and created a very thick fog. Due to the heaviness of the fog, public transportation ceased except for its underground system, setting the city on lockdown. A total of 4000 deaths happened from the Killer Fog, and another 10,000 had respiratory health issues. This death toll would awaken the dangers and risks that air pollution could bring to not only human beings but the environment it surrounded, calling for a new approach to be put in place. London chose to use financial incentives to make it so that its residents would move away from coal for heating and instead use central heating to protect themselves against another disaster. However, the tragedy was not diverted, and many individuals still decided to use coal, causing another incident just ten years later (Davis, et al. 2002). The World Health Organization estimates that each year fine particle air pollution in urban areas causes 800,000 premature deaths, mainly in Asia, from acute respiratory infections, lung cancer, and cardiovascular diseases (Wilkinson et al. 2007). In China, where 16 out of 20 cities with the most polluted air are located, it is estimated that particulates have contributed to 1.2 million premature deaths (Yang et al. 2013).

When nuclear energy was first discovered, it was viewed as a clean and inexpensive alternative to fossil fuels. In the aftermath of the oil crises of the 1970s, nuclear energy was considered positively as a solution for national energy independence for countries with poor fossil fuel energy reserves. However, accidents at nuclear power plants such as Three Miles Island, Chernobyl, and Fukushima in 1979, 1986, and 2011, respectively, which release high radiation levels into the environment, demonstrated that nuclear energy could be dangerous for human and environmental health. Although the immediate casualties from the accidents accounted for hundreds, hundreds of thousands suffered from delayed health effects, displacement, and economic losses (Novikau 2017). Even without significant accidents, nuclear fuel waste disposal and storage are difficult because high-level radioactive materials are harmful to human health (Moan and Smith 2007).

Although renewable energy sources are usually viewed as having a less negative impact on human health, they are not free from the adverse effects. For instance, biofuels can contribute to air and water pollution without appropriate sewage treatment and, therefore, negatively affect human health. Living close to a hydroelectric dam could increase the risk of contracting malaria, especially in areas of unstable malaria transmission, because reservoirs become the breeding grounds for mosquitoes (Utzinger et al. 2005; Lautze et al. 2007; Kibret et al. 2019). The construction of large dams can also cause the displacement of millions of people (Moan and Smith 2007).

Energy can cause political instability and armed conflicts and thus can affect human health. Because of the threats to energy security, states can use military force to prevent energy sources from reaching the end-user, either by controlling energy resources or their transit routes, potentially resulting in full-scale military conflict (Kelanic 2016). There are several pathways through which concerns about energy security can result in international disputes. First, vulnerable energy supplies make states' militaries vulnerable; when states already have incentives for conflict, oil vulnerability can influence the assessment of adversaries' military capabilities and, therefore, provoke an interstate conflict. Second, energy reserves, or perceived energy reserves, increase the value of territory and encourage countries to engage in territorial conquests since the rewards of such resource wars are perceived as higher than the risks associated with them (Glaser 2013).

Energy resources can create economic inequality, bad institutions, and political instability (Elhefnawy 2008; Colgan 2013). Because of the collapse of energy prices, reducing incomes from energy sources can result in the desire of leaders of energy countries to start wars (Bremmer and Johnston 2009). Similarly, energy can create conditions for domestic conflicts that lead to foreign or state failure.

Although the threat of energy resource wars is often exaggerated (Jaffe et al. 2008; Noël 2014), many experts view the political effects generated by the energy industry as a primary cause of conflicts in the twenty-first century, either directly or indirectly (Salameh 2001; Ciută 2010; Colgan 2013).

Energy and Planetary Health

By many metrics, the combined effects of increasing energy use on human health have been more positive than negative. Energy indeed contributed positively to improvements in global human well-being. At the same time, the effects of increasing energy use on the biosphere have been almost always highly adverse. As Moan and Smith (2007) put it, "There are no energy sources that are completely environmentally friendly, but some are more damaging than others." Indeed, almost every step associated with energy use can be harmful to human health and the environment.

Fossil fuel extraction and transportation inevitably result in land and water pollution harmful for all organisms. When a crude oil spill occurs, the amount of land and water affected by oil spills usually extends for hundreds and even thousands of miles, usually takes decades to recover from the incident fully, and most importantly, they occur way too often. Marine oil spills are damaging to aquatic ecosystems (Moan and Smith 2007).

The process of energy generation and use usually result in air, land, and water pollution. Sulfur and nitrogen oxides contribute to acid rains that harm sensitive ecosystems, and nitrogen oxides contribute to nutrient pollution in coastal waters. Ground-level ozone pollution can affect sensitive ecosystems, such as forests and parks. Its damaging effects are especially harmful during the vegetation season because ozone reduces photosynthesis in plants. High lead levels can harm the growth and reproduction of plants and animals. Sulfur and nitrogen oxides and fine particles cause reduced visibility (EPA 2021).

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) that are released into the atmosphere during combustion can trap heat in the atmosphere and are therefore called greenhouse gases. Because heat is customarily reflected from the earth's surface, the molecules of these gases trap the heat, causing warming (EPA 2021). Since most of the ecosystems are extremely sensitive to temperature fluctuations, the increase of temperature had a marked influence on many species and, therefore, can result in a loss of biodiversity (Moan and Smith 2007).

It is important to note that global climate change affects not only planetary but also human health. Global climate change's direct and indirect effects include more frequent and severe temperature extremes, weather events such as severe floods, storms, and droughts, sea-level rise, and disease outbreaks. Even though all countries are vulnerable to extreme events associated with global climate change, developing countries are affected disproportionally (Leal Filho et al. 2016, 2018). World Health Organization estimated that the total cost of climate change had reached about 0.4% of the global burden of disease, including malaria, protein-energy malnutrition, and dengue fever. Thus, climate change is already responsible for about 150,000 deaths, mostly in developing countries and children under age 5. Although the effects of global climate change on human health are now not significant compared to other factors, the main concern is that it will likely become a considerable factor affecting human health in the nearer future (Wilkinson et al. 2007).

The energy use often damages the structure of the land cover. For example, the infrastructure and heavy equipment needed to extract fossil fuels result in massive land erosion. The mining industry often strips away the land to reach fossil fuel beds, and the ground can sink or collapse into abandoned mine shafts (Moan and Smith 2007). Wind power has been criticized for its danger to birds. Large wind farms consisting of many wind turbines displace large amounts of air and therefore can affect climate. Photovoltaic energy can be harmful to the environment because solar panels contain toxic material, solar plants require large areas, preempting other land uses (Smith 2013). If done on a large scale, like creating dams, hydropower can negatively affect planetary health—it can alter the oxygen concentration and temperature of downstream waters and affect dwelling animals (Moan and Smith 2007).

The final issue is related to the scarcity of energy resources. Even though a physical shortage of fossil fuels in the world is rarely a real issue, there has always been a concern over whether adequate amounts of energy will be available to end-users, in all circumstances, and most importantly, at reasonable prices (Akins 1973). The diminishing energy resources affect not only energy generation but also other areas of human life. The problem is that all the resources used for energy generation can be used in different industries contributing to a better life. For instance, carbohydrates are crucial for the chemical industry; the reduction in available oil and natural gas because of their use as fuel inevitably affects the prices of other goods. Not surprisingly, a Russian chemist Dmitri Mendeleev once said that the combustion of oil products is equal to using banknotes as fuel. This is true not only for fossil fuels. For instance, wood, crops used as a fuel, naturally affect food affordability and human health.

Discussion and Conclusion

The history of energy use represents a classic paradox of simultaneous global health and the deterioration of ecosystems. While humanity is experiencing significant and steady improvements in quality of life, natural systems are degrading at an enormous rate (Whitmee et al. 2015). Considering the effects of energy on both human and planetary health, both positive and negative, it is vital to improve access to affordable, clean energy for everybody while minimizing such use's health and environmental effects (Wilkinson et al. 2007).

Unfortunately, the polysemic nature of energy services poses severe difficulties in achieving these goals simultaneously. An increase in energy supply, an immediate solution to energy poverty, often damages human health and the environment. Thus, improving one could often compromise the other. Analogously, an improvement of environmental metrics may jeopardize the affordability of energy for end-users. Therefore, the decrease in energy consumption should be very careful not to harm positive effects associated with energy use. Two main strategies can help to achieve the goal mentioned above.

First, although energy is essential for human health, much of it is used in ineffective ways and is lost during extrication, transportation, transformation, and end-use of energy. About a third of global energy use is lost as waste heat (Whitmee et al. 2015). Energy use by end-users is the least efficient part of the global energy system, and therefore, it has the most considerable potential for improvement (Grubler et al. 2018). Energy efficiency, or the delivery of more services for the same energy input or the same services for less energy input, is an ideal solution for the issue. Advances in energy management in industrial, transport, services, and the residential sectors decrease energy consumption and reduce harm to human and planetary health. However, technological innovations must always be supplemented by public policies, such as fuel-efficiency standards, building energy codes, and fiscal and financial incentives, such as tax reliefs on energy-efficient actions (Novikau and Novikau 2020). For instance, because of energy conservation, energy efficiency, and transition from more energy-intensive to less energy-intensive sectors of economy 1990 and 2015, the energy intensity of economy fell by 28% in OECD countries, by 40% non-OECD countries, and by 32% the world (Engelman et al. 2020).

Second, although any energy use harm or can potentially harm human and planetary health, different types of energy resources harm them to another degree. Coal use for electricity generation is already being replaced by natural gas in many countries, resulting in a decline in air pollution and CO_2 emissions. The next step is to replace fossil fuels, most harmful for human and planetary health, with low- and no-carbon alternatives such as hydro, solar, and wind power. Access to clean household energy can reduce exposure to outdoor pollution and greenhouse gas emissions while not jeopardizing access to affordable and reliable energy services (Whitmee et al. 2015; Jackson et al. 2019).

Most importantly, the present systems of governance and organization of human energy systems are inadequate to address the threats caused by energy use to planetary health. Better governance aiming to integrate energy, environmental, economic, and social public policies is crucial for achieving these goals.

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Chapter 8
Possible Role of Positive Stratospheric Ozone Anomalies and Adaptation to Climate Change

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Abstract It becomes more apparent that physical processes throughout the atmosphere, as vertically and horizontally, are correlated on different spatial and time scales. The total ozone has various concentrations over the whole Earth's atmosphere. A sharp correlation between total ozone, stratosphere profile, and tropospheric circulation was observed. Last experiments have shown that positive stratospheric ozone anomalies can lead to more dangerous effects on weather-climate change. The study of specific anomalous phenomena in the regional climate experimentally and by the method of mathematical modelling demonstrates the severe influence of an increase in the concentration of stratospheric ozone, including Sudden Stratospheric Warming (S.S.W.), on the features of not only local weather changes but also on variations in the climate of the hemispheres in a global scale. Climate change adaptation is adapting native, social, or economic systems in response to actual or anticipated climate changes and their consequences. Adaptation to Sudden

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_8

Stratospheric Warming is often impossible and therefore it is necessary to develop theoretical aspects of forecasting such phenomena.

Introduction

Modern climate change appears as global warming caused by natural and anthropogenic factors. Since the middle of the twentieth century, humans have significantly increased their impact on the Earth's climate system, resulting in changes on a global scale. Suppose little to no action is taken to reduce our influence on climate change before the end of the twenty-first century; global warming will be subject to irreversible consequences. Warming mitigation and climate adaptation are complementary methods for identifying risk, even on different time scales (high confidence). Climate change mitigation could significantly reduce the impact of climate change in the last years of the twenty-first century. The benefits of adaptation can already be realised when risks may be realised in the future when risks are removed (IPCC 2014, 2018; UNFCCC n.d.).

When examing the atmosphere, it should be noted that any local changes in the structure or composition of the atmosphere, in height or horizontally above any point on the Earth, could lead to changes above other points. Such changes are apparent when considering relatively stationary processes associated, for example, with cyclones and anticyclones. At the same time, there are rapid changes, such as Sudden Stratospheric Warming (S.S.W.), which are difficult to compare with changes in other parts of the atmosphere. An S.S.W. phenomenon of rapid warming (sometimes more than 50 °C in one to two days) in the stratosphere at high latitudes can break down stratospheric polar vortices (WMO 1992). Rapid warming in the stratosphere and decreasing the tropopause height affected weather conditions in the troposphere, displacement of jet currents, and cyclone trajectories, causing severe frosts over North America and Eurasia.

Moreover, S.S.W.s affect the atmosphere above the stratosphere, having a widespread effect on the atmosphere's chemistry, temperature, wind, and electric fields. These effects cover both hemispheres. Given their decisive role in the entire atmosphere, S.S.W.s are considered an important phenomenon for analysing climate change and long-term forecasts for the future (Baldwin et al. 2021).

It is well known now that future variations in stratospheric ozone will depend on decreasing ozone-depleting substances (ODS) concentrations and the effect of climate on stratospheric temperatures and circulation. Past changes in stratospheric ozone have influenced the climate of the surface layer; future ozone changes are projected to affect the climate system. Because of the vital link between ozone depletion and climate change, observations of climate and ozone variables should, whenever possible, be undertaken and analysed together. There is growing recognition that the inclusion of ozone in atmospheric models improves the quality of long-term climate change predictions and creates new opportunities for seasonal predictions. Accordingly, investigations are needed in order to better understand climatic processes on the Earth's surface associated with changes in the stratosphere, including effects on such areas as tropospheric circulation, sea ice and our oceans (Report 2014).

The impact of ozone on climate is primarily temperature change. The more ozone concentration, the more heat. Ozone produces heat in the stratosphere by absorbing solar U.V. radiation. Consequently, a decrease in stratospheric ozone concentration leads to lower temperatures. Satellite observations and model calculations show that over the past decades, the lower, middle, and upper stratosphere (from 20 to 50 km above the Earth's surface) has cooled by 0.1–0.6 K / decade over the period 1979–2015 (Maycock et al. 2018; Randel et al. 2016). This stratospheric cooling occurred with an increasing number of greenhouse gases in the troposphere (WMO 2018).

In the late 1980s, attention was turned to negative ozone anomalies. For example, ozone holes above the poles or mini-holes in extratropical latitudes lead to increased solar U.V. radiation, climate change, and dangerous effects on all living organisms. To prevent the consequences of decreasing stratospheric ozone, the world community united around international agreements such as the Vienna Convection (1985), and the Montreal Protocol (1987). Krasouski and Zenchanka (2018) discussed some aspects of adaptation to climate change and ozone depletion. Numerous studies show how a decrease in total ozone concentration affects surface climate change (Calvo et al. 2015; Ivy et al. 2017; Xia et al. 2018). The risks associated with ozone depletion and climate change affect human health, changes in biodiversity, agriculture, and energy consumption. Therefore, adaptation measures should be appropriate.

Liu et al. (2020) showed a clear relationship between stratospheric-tropospheric fluxes and changes in stratospheric ozone in the upper and lower troposphere over North America, while over Europe, the stratospheric influence is limited to the middle and upper troposphere. Longitudinal variations of meteorological parameters in the Northern Hemisphere's middle latitudes are associated with a lower height of the tropopause and changes in tropospheric stationary fronts (jets) over North America than over Europe. These variations cause the longitudinal change in stratospheric ozone in the middle latitudes of the Northern Hemisphere, which manifests itself in an increase in the frequency of stratospheric folds close to jets.

On the other hand, positive stratospheric ozone anomalies are also a severe challenge for adaptation to climate change. It was shown (Rind et al. 2009; Wang et al. 2020) that positive stratospheric ozone anomalies were observed over Europe and North America during the ice ages. Positive stratospheric ozone anomalies pose a significant danger to people and national economies both in summer (by the development of destructive cyclones) and in winter (by the formation of S.S.W. and severe frosts) (Krasouski et al. 2020). The development of S.S.W. in one hemisphere affects the climate in the other hemisphere, creating anomalous arid conditions, for example, wildfires in Siberia or Australia (Krasouski et al. 2021a, b).

According to Schoeberl (1978), an increase in temperature during S.S.W., on the contrary, begins in the upper stratosphere-lower mesosphere. It has been shown that cooling is observed in the mesosphere above the warming zone in the stratosphere (Labitzke 1972). Ageeva et al. (2017) determined, that large S.S.W.s (with a change in wind direction, a significant increase in air temperature, and a displacement of the polar vortex) are observed during the eastern phase of the quasi-biennial oscillation (Q.B.O., and the maximum of the 11th solar cycle; and small S.S.W.s (having only a change in wind direction) are observed at the western phase of the Q.B.O. and the minimum of the 11th summer solar cycle.

King et al. (2019), analysing the ground-based observations during the development of the S.S.W., concluded that the mean monthly below zero air temperature anomalies in winter in Northern Europe precede S.S.W. events, and short-period extreme cold snaps are observed more often after S.S.W. events. Kidston et al. (2015) showed that significant disturbances in the stratospheric circulation could change the troposphere over several days and weeks. In particular, S.S.W.s are often accompanied by a shift in the trajectories of the North Atlantic cyclones and the formation of a negative phase of the North Atlantic Oscillation (NAO). This leads to positive temperature anomalies above Greenland, eastern Canada, and northern Africa, and below zero temperature anomalies over northern Eurasia and the eastern United States. Blume et al (2012), using the reanalysis data from National Center for Atmospheric Research (NCAR/NCAR) for 1958–2010, noted that large S.S.W.s are observed approximately every two years. The highest repetition rate of such events is typical for January, less for December and February. In March, warming began to be observed over the past decades and is associated with the destruction of the circumpolar stratospheric vortex.

Brönnimann et al. (2004) reconstructed the fields of geopotential and air temperatures of the upper troposphere and lower stratosphere in the period of the mid-40s of the twentieth century for the territory of Europe using ground-based and model data. They identified warming in the upper atmosphere and a decrease in geopotential throughout the troposphere over northern Europe. It was concluded that there was an S.S.W. and a weakening of the polar stratospheric vortex, which led to a cooling in Europe, a warming in the Arctic and Alaska, a negative phase in the Arctic Oscillation (A.O.), and a positive phase in the North A.O.

Zhang et al. (2017) established a link between the Arctic Oscillation, the Brewer-Dobson Circulation (BDC), and stratospheric ozone in the Northern hemisphere during winter. During the positive phase A.O., positive ozone anomalies between 0° and 30° N at 50–150 hPa were associated with weakening the meridional transport of the Brewer-Dobson circulation (BDC). Negative ozone anomalies in the Arctic middle stratosphere are also due to the weakening of the B.D.S. Negative ozone anomalies in the Arctic upper troposphere-lower stratosphere (UTLS) are due to an increase in the height of the tropopause, a weakening of the vertical transport of the B.D.S., and a weaker exchange between the middle latitudes and the Arctic. The strongest negative correlations are observed in the mid-latitude UTLS, where correlation coefficients can reach about −0.6. At the same time, the most significant ozone variations due to A.O. variability are found in the Arctic UTLS due to significant high-latitude ozone variations. Differences in percentage anomalies of ozone between the two phases of A.O. in the Arctic UTLS in winter can overtop 30%.

Another article (Zhang et al. 2018) shows that the shift of the polar vortex towards Eurasia can affect the decrease in stratospheric ozone concentration and increase in U.V. radiation. Such changes are formed under the influence of dynamic (polar vortex) and chemical processes (the presence of active chlorine in the polar vortex, which destroys ozone), which will affect the recovery of ozone at the end of the winter of the Northern Hemisphere.

Thus, not only does a decrease in total column ozone (TCO) entail a change in the near-ground climate, but; conversely, an increase in TCO from the norm will lead to dangerous meteorological phenomena and new challenges for society to adapt to this kind of atmospheric phenomena.

Aims and Objectives

This article investigates the role of positive stratospheric ozone anomalies in the Northern Hemisphere. In particular, the article will consider some cases of cut-off cyclones with very large TCO gradients, the development of S.S.W.s by the method of superimposed epochs, and an unusual local increase in TCO which led to dangerous meteorological events, where people and infrastructure were ultimately damaged.

Methods and Data

The T.O.C. data, the dynamic of tropopause at an altitude of 300 hPa, and the surface minimum air temperature from the MERRA-2 Reanalysis (https://acd-ext.gsfc.nasa.gov/) and AIRS satellite observations (https://airs.jpl.nasa.gov/), OMI/TOMS (http://www.esrl.noaa.gov/gmd/grad/neubrew/SatO3DataTimeSeries.jsp) were used. The instrumental data of the surface air temperature from Belhydromet (https://pogoda.by/) and the QGIS software package were used to build the maps.

Based on the results of previous studies on the statistical relationship between the deviation of total ozone and surface air temperature (Schlender et al. 2018), a model of stratospheric-tropospheric interaction was created, which describes the physical mechanism of the obtained statistical relationship between T.O.C. and surface temperature. It considers such atmospheric values as total ozone concentration, thermal and dynamic tropopause heights, high-altitude stationary front, jet streams, and surface weather. These values are integrated on one map using satellite observations and reanalysis data.

The Potential Vorticity Unit (P.V.U.) reflects the thermodynamic characteristics of air. It is usually used in meteorology to denote the dynamic tropopause, separation of stratospheric and tropospheric air, and the origin of cyclones (Kunz et al. 2011). One P.V.U. value, equal to $10^{-6}K * m^2/kg * s$, is the unit for describing potential vorticity (Hoskins et al. 1985). Values above 2–3 P.V.U. represent the boundary of the dynamic tropopause and the presence of stratospheric air with higher potential energy.

This model is a special case of the manifestation of the ozone mechanism of solar-terrestrial bonds, which describes the transformation of solar energy in the Earth's atmosphere and focuses on the formation and destruction of ozone molecules as the main absorbing element of the middle atmosphere and subsequent changes in tropospheric weather (Krasovski et al. 2016; Shalamyanski 2013).

Ozone Mechanism Theory

The ozone mechanism is one of the mechanisms of the effect of solar energy on small components of various layers of the atmosphere. The ozone mechanism can be represented as follows:

- The sun's rays ionise the upper layers (from 60 km and above) of the atmosphere due to positive NO+ ions, which create electrical disturbances in the lower ionosphere (Mitra 1974);
- In the stratopause area (60–70 km), the formation of ozone is determined by the local height of the lower belt of the ionisation layer. A decrease in the number of NO+ ions in the lower ionosphere, in the stratopause region, leads to a local increase in the concentration of stratospheric ozone (Lunin et al. 1998);
- Moving downward vertically under the action of the gravitational settling process, ozone (since the ozone molecule is heavier than oxygen and nitrogen) experiences mainly a relaxation decrease in local concentration due to collisions with destructive molecules. In the upper stratosphere, due to the extended free path, ozone diffusion both downward and horizontally occurs at a higher rate than in the lower stratosphere, where the concentration of molecules increases sharply. This determines the vertical position of the maximum partial pressure of the ozone layer, which is measured instrumentally (Zvyagintsev 2013). A set of dynamic processes such as advection and vortex air systems distribute ozone molecules horizontally in the stratosphere. The thermal properties of ozone determine the thermal field of the lower stratosphere, which leads to expansion of air mass, lowering or raising of the tropopause height (Manney and Coy 2014; Rakipova and Vishnyakova 1978);
- A change in the position of the tropopause height affects the position of high-altitude stationary fronts and jet streams;
- High-rise stationary fronts, which are the boundaries of the global circulation cells: Headley, Ferrel, and polar, determine the trajectories of movement of baric formations in the troposphere (Baldwin and Dunkerton 2001; Hoinka et al. 1996; Hudson et al. 2003; Shalamyanski 2013).

Thus, TCO plays an intermediate role in accumulating and converting solar energy in the middle atmosphere and can determine the weather and climate in the troposphere.

Statistical methods (Pearson correlations and epoch overlays) and cartographic methods (QGIS and Python) were used to study the influence of the S.S.W. on the climate and weather in the territory of Belarus. The method of superimposed epochs is used when certain events do not have a constant time of occurrence. It is usually used to study solar proton flares. In addition, since the S.S.W. has extremely high TCO values, in this case, we compared the average deviations of the TCO and the surface air temperature (minimum air temperatures and deviations of the daily mean air temperatures from the norm) over Minsk, depending on the geographic location of large (major) S.S.W.s in Northern Hemisphere. There were 19 such large S.S.W.s in 40 years, for the period 1980–2021, divided into three groups depending on the location of the S.S.W. concerning the territory of Belarus. The essence of the superimposed epochs method is that all cases of TCO and surface air temperature deviations during large S.S.W.s are averaged over a local point (in our case, the coordinates of the city of Minsk) for 25 days from the beginning of S.S.W. formation over Eastern Siberia. Thus, we have obtained the predicted time for the appearance of high TCO values associated with the S.S.W. over Eastern Europe, in particular over Belarus. Complex averaged maps of TCO, P.V.U., and surface air temperature for each S.S.W. group for Europe were obtained using the Python and QGIS algorithm.

To study the spatial location of ozone stratospheric positive anomalies over the territory of Europe, data from ERA-Interim reanalysis (https://www.ecmwf.int) for the period 1991–2016 were used. The rate from which the positive ozone anomalies were calculated was analysed from 1979-to 1990 with a 30-day smoothing.

Results

Positive Ozone Anomalies

The most significant number of positive stratospheric ozone anomalies characterise the winter season. In particular, in January, the number of anomalies reached 160. In summer, their number is either absent or has a value of no more than ten pieces. In the autumn period, positive anomalies gradually increased to 100 in December (see Fig. 8.1).

On a spatial scale, over the territory of Europe, the most significant number of occurrences of positive ozone deviations from the norm are characteristic of the regions of Scandinavia, the Norwegian Sea, and Iceland (see Fig. 8.2). Still, this is an average picture of positive ozone deviations. However, if taken into consideration a shorter time frame, such ozone anomalies can spread far to the south, up to 40° N, and have a different shape. Sharp TCO drops above normal can be observed during cut-off cyclones, S.S.W. formation, and substantial displacement of the high-altitude stationary front far to the south. Thus, the frequency of occurrence of positive ozone anomalies is typical for Northern Europe, from 50° to 75° N.

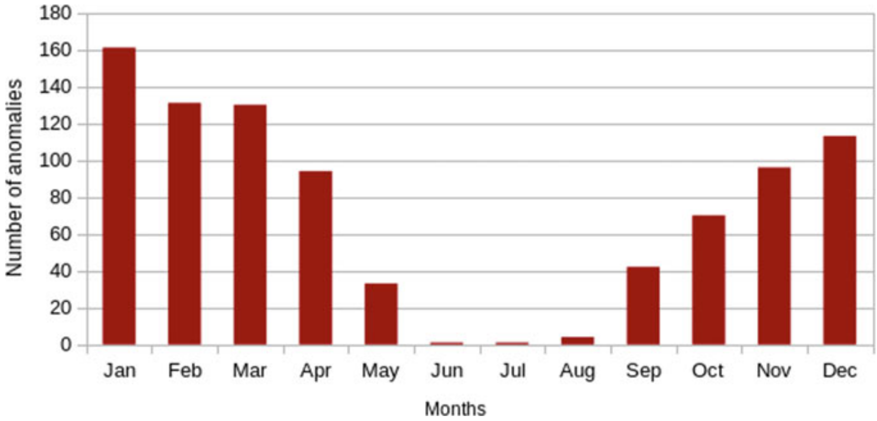

Fig. 8.1 Seasonal distributions of positive ozone anomalies for the Europe region by ERA-Interim Reanalysis for the period 1991–2016 (Barodka et al. 2016)

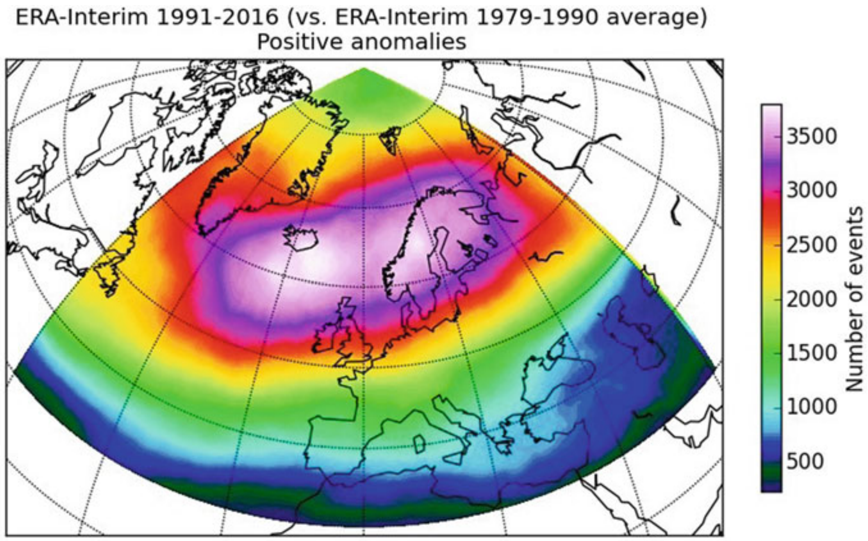

Fig. 8.2 Spatial distribution of positive ozone anomalies for Europe region according to ERA-Interim reanalysis data for 1991–2016 (TCO norm is average of 1979–1990 from the ERA-Interim with a 30-day smoothing)

Positive Ozone Anomalies and Stratospheric Intrusions

Consider the case of a severe cyclone that formed in October 2018, when heavy rains hit Spain, France, and Italy, resulting in severe flooding. According to official data, up to 69 people died. The characteristic of this mini-cyclone is that it formed in the tropopause region in the jet stream zone (Polar Jets), which was located north of the U.K. in the period from October 6 to October 11, 2018,

According to the Potential Vorticity criterion for October 6, 2018 (see Fig. 8.3) at an altitude of 300 hPa, it is seen how the dynamic tropopause was formed to a considerable distance, the potential vorticity increased above 10 P.V.U., and, as a result, stratospheric air from the zone of jet streams began to spread into the troposphere in a short period.

Further development of the mini-cyclone was characterised by an unusual movement trajectory from northwest to southeast, then to the west, and finally to the north. An even more interesting point was that the TCO values in the mini-cyclone development zone had very large gradients (up to 100 DU) over a small area. The absolute TCO values exceeded 430 DU. It is seen that TCO and P.V.U. coincide in isolines. P.V.U. values above 2–3 correspond to 370–380 DU, and values above 4–5 correspond to 390–410 DU. As a result, due to the prevailing specific atmospheric conditions on October 9, 2018, over Sardinia, southern France, Mallorca, Spain, and Portugal, heavy rainfalls of the cut-off cyclone were observed, which led to floods. Such cut-off cyclones are best identified by changes in TCO and P.V.U. on 300 hPa (Dynamical Tropopause) because they form from the upper troposphere and develop to the surface. Something like a tornado.

Another case of positive ozone anomalies is associated with the crash of a Boeing 737 airliner. On March 19, 2016, the air crash took place at about 00:30 UTC near Rostov-on-Don. After two attempts to land during unfavourable weather conditions, the plane crashed onto the runway. All passengers have died. At the time of the plane crash, the Rostov-on-Don region was located in the gradient zone of TO and tropopause altitude, where unfavourable meteorological conditions were observed for aircraft takeoff. The peculiarity of this case is that the positive ozone anomaly was formed in the polar region of the Northern Hemisphere on March 15, 2016. In a couple of days, it shifted, in an unusual position, meridionally southward, towards the Black Sea (see Fig. 8.4). The absolute T.O.C. values exceeded 450–500 DU, P.V.U. values were above 4 in the plane crash zone. The polar and tropical high-altitude fronts were located relatively close to each other. The southern part of the high-altitude polar front passed over the north of the Black Sea, and the northern part of the tropical front over Turkey. Such conditions form dangerous meteorological

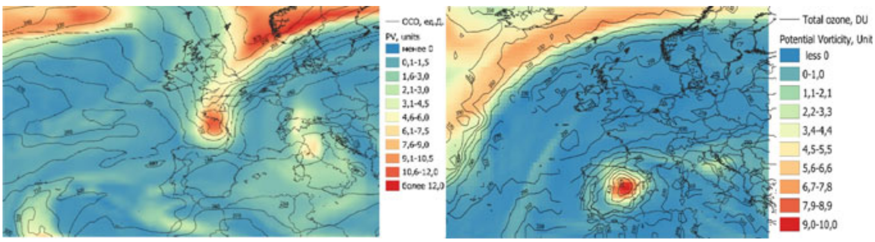

Fig. 8.3 Potential Vorticity (MERRA-2, PVU on 300 hPa, color), TO (AIRS, contour, DU), on 15:00–18:00 UTC 06 October (left) and 06:00–09:00 UTC 09 October 2018 (right)

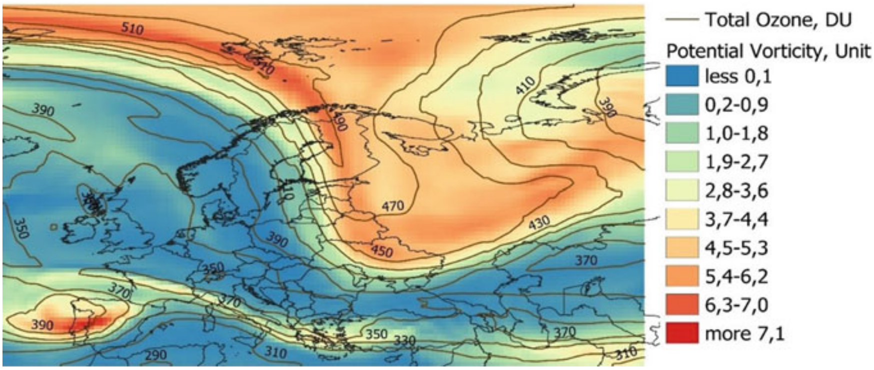

Fig. 8.4 Potential Vorticity (MERRA-2, P.V.U. on 300 hPa, color), TO (AIRS, D.U., contour) on 00:00 UTC March 19 2016

phenomena at altitude and in the surface layer, affecting the entire thickness of the troposphere, tropopause, and even the lower stratosphere. Other plane crash cases under the influence of positive ozone anomalies were considered (Krasovsky et al. 2021b; Schlender et al. 2020).

There are many such cases. For example, Ott et al. (2016), Langford et al. (2012) describe the frequency of manifestation of stratospheric intrusions in the summer season over the United States and their effect on the gas composition of the surface layer. Stratospheric intrusions, which rapidly transport air from the stratosphere deep into the troposphere, are usually associated with the development of low-pressure systems and cold fronts at the surface (Reed 1955; Shapiro and Keyser 1990). It is shown by Appenzeller and Davies (1992) that these intrusions turn into elongated (about 2000 km) and thin (about 200 km) streamers and are divided into several eddies in the stage of their destruction. According to aircraft experiments and studies of mid-latitudes (extratropical regions), the stratospheric air has a lower concentration of moisture, hydrocarbon, methane, and a higher concentration of ozone and potential vorticity, which occurs more often in winter (Škerlak et al. 2015; Sullivan et al. 2015; Tilmes et al. 2010).

> Thus, with an increase in TCO above its latitudinal and seasonal norm, the dynamics of stratospheric-tropospheric processes lead to certain complex and dangerous weather conditions, both in winter and in summer, in the surface layer.

Positive Ozone Anomalies and Sudden Stratospheric Warming

S.S.W. research over 40 years from 1980 to 2021 for the Northern Hemisphere identified the 19 largest S.S.W.s. These 19 warmings were divided into three conditional territorial groups of the S.S.W. development. Since all S.S.W.s are accompanied by a sharp local increase in temperature in the middle atmosphere and wind change to the opposite direction, the TCO and P.V.U. values can indirectly estimate the trajectory of S.S.W. movement in the Northern Hemisphere. After analysing the cases of S.S.W. with a positive deviation of the mean monthly surface air temperature over the city of Minsk (Belarus), it became obvious that these warmings were located outside the European region—over Canada and the North Pole. Accordingly, over the territory of Belarus at this time, there was a decreased TCO value or small local positive ozone anomalies. The first group includes SSW 1987 (1), 1987 (2), 1998, 2001, 2004, 2008, 2019, 2021. The second group includes S.S.W.s that affected the territory of Eastern Europe, in particular Belarus. During their development, there were significant ten-day negative deviations of the surface air temperature from the norm—S.S.W. 2001, 2006, 2009, 2010, and 2018. At last, the third group—when the S.S.W. did not enter the territory of Belarus, but large positive ozone anomalies were observed over Eastern Europe—S.S.W. 1980, 1984, 1989, 1999, 2013, 2016.

Since these are different time events of the S.S.W., different years, and dates of the beginning of the S.S.W., they were combined using the method of superimposed epochs. As a result, for all three S.S.W. groups, the averaged values of the absolute TCO values, average daily surface air temperature, and their deviations from the multiyear norm for the coordinates of Minsk were obtained for 25 days from the beginning of the S.S.W. formation date. After that, Pearson's correlation coefficients were calculated for the relationship between the TCO and surface air temperature over the city of Minsk (Belarus). In addition, the spatial maps of TCO, P.V.U., and minimum surface air temperature for the territory of Europe were built for the second group of S.S.W., which affects the territory of Belarus.

As a result, Fig. 8.5 shows the graphs of the relationship between TCO and surface air temperature for three groups of S.S.W. The sizeable negative correlation is typical for the second and third groups when the S.S.W.s are over the territory of Belarus ($R = -0.7$, with a P-level value less than 0.05; $R = -0.6$, if the P-level is less than 0.05). These groups are characterised by a decrease in TO (by 20–30 D.U.) during 5–10 days after the start of the S.S.W. date and an increase in the surface air temperature (by 2–5° C). This is followed by a gradual increase in TO and a decrease in the surface air temperature. In the interval from 13 to 18 days, the TO reaches maximum values above 400 DU (deviations up to 50–60 D.U.). The surface air temperature has reached its minimum; for the second group, the minimum air temperature is up to −12° C, and the average daily deviation from the norm is up to −6° C; for the third group, the minimum air temperature is up to −9° C, the average daily deviation from the norm is up to −3° C.

For the first group, when the S.S.W. is located over Canada and the North Pole, the correlation was positive and very small ($R = +0.1$, with a P-level less than 0.05).

Thus, in 11 cases of S.S.W. (58% of all large cases of S.S.W. in the Northern Hemisphere), the territory of Belarus and Eastern Europe is characterised by negative deviations in the surface temperature and a significant increase in TCO 13 days after the start of the S.S.W. date.

Figures 8.6, 8.7 and 8.8 present averaged complex maps of TCO, P.V.U., and minimum surface air temperature for the second group of S.S.W. (where $R = -0.7$)

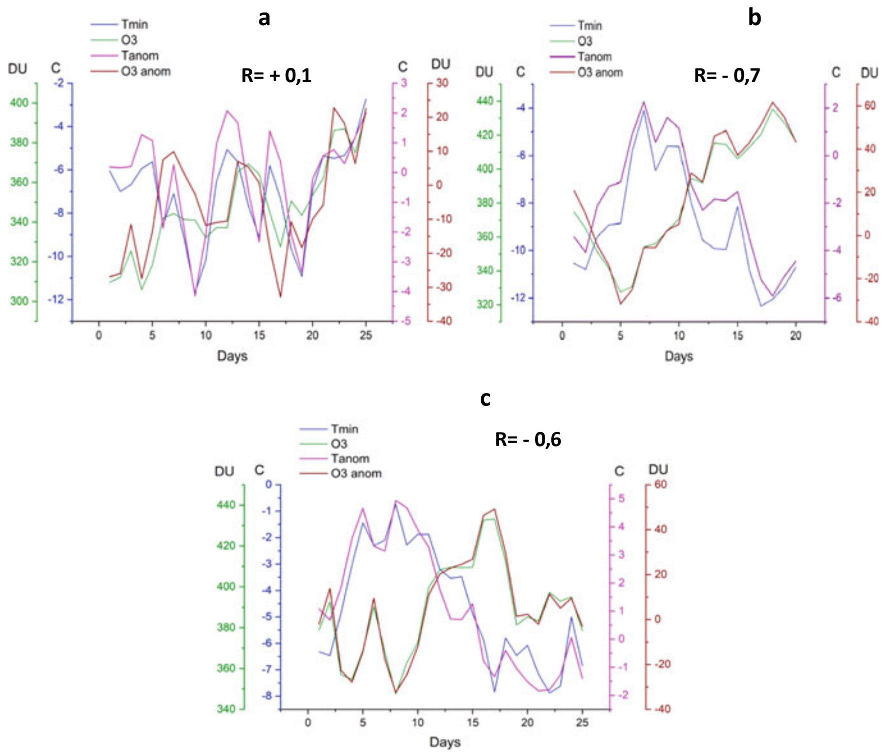

Fig. 8.5 Correlation (R) of TCO (data from O.M.I., D.U., in the picture—O_3—daily average ozone, O_3 anom—deviation of the average daily ozone value from the norm) and surface air temperature (data from Belhydrometeocenter, °C, in the picture—Tmin—absolute minimum surface air temperature and Tanom—deviation of the average daily surface air temperature from the norm) for threes group of locations of S.S.W. by the method of superimposed epochs: over Canada and Pole (A, 8 cases), over Belarus (B, 5 cases), with positive anomalies TCO over Belarus (C, 6 cases)

by 1–12 days, 13–18 days, 19–25 days after the beginning of the development of the S.S.W. for the territory of Europe (according to the obtained graphs, see Fig. 8.5).

For the first daily interval (1–12 days), when the S.S.W. is not yet over the territory of Eastern Europe, the range of surface minimum air temperatures for the territory of Belarus is from −9° to −12° C. T.O.C. is less than 350 DU, and P.V.U. is less than 1.5. Almost the entire territory of Europe, except for the extreme north of Scandinavia, is in the zone of low TCO and P.V.U. values (see Fig. 8.6).

For the second daily interval (13–18 days), when the S.S.W. is already over Eastern or Northern Europe, the range of minimum surface air temperatures for the territory of Belarus is from −13° to −21° C, TCO is above 440 DU, and P.V.U. is above 3–4 (see Fig. 8.7). Northern, Eastern, and Central Europe are in the zone of high TCO (above 420 DU) and P.V.U. (above four units). Typically, this interval is characterised by severe cold and frost in Eastern, Central, and Northern Europe and floods, snowfalls, and hurricane winds in Southern Europe, which claim lives and disrupt the

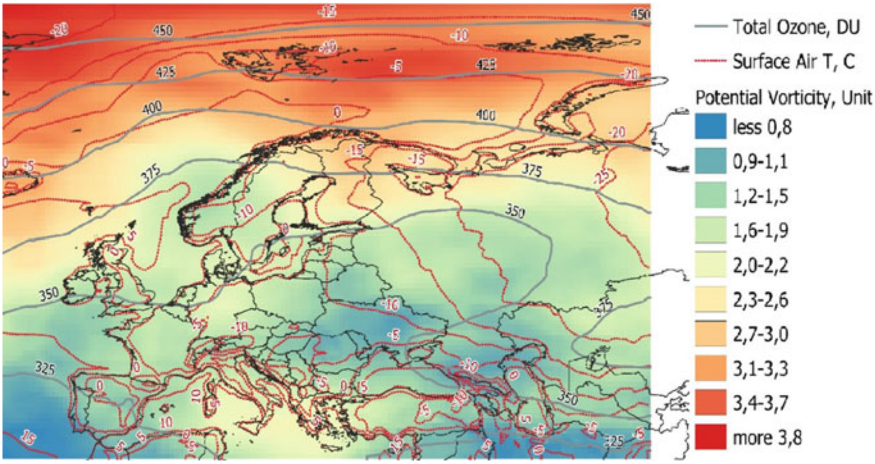

Fig. 8.6 Second group (S.S.W. over Belarus—5 cases) 1–12 days from the day of start S.S.W.: TCO (from MERRA-2, grey line), Minimum surface air temperature (from MERRA-2, red line), P.V.U. on 300 hPa (from MERRA-2, colour)

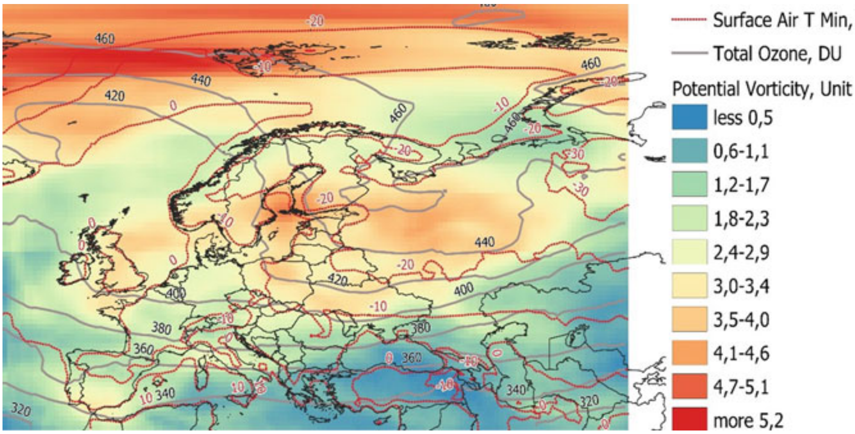

Fig. 8.7 Second group (S.S.W. over Belarus—5 cases) 13–18 days from the day of start S.S.W.: TCO (from MERRA-2, grey line), Minimum surface air temperature (from MERRA-2, red line), P.V.U. on 300 hPa (from MERRA-2, colour)

functioning of the infrastructure (Domeisen and Butler 2020; Karpechko et al. 2018; King et al. 2019; Krasouski et al. 2020; Vargin and Kiryushov 2019).

For the third day interval (13–18 days), when the S.S.W. is only over Northern Europe, the range of minimum surface air temperatures for the territory of Belarus is from −6° to −10° C, and the TCO values are also high—about 400 DU and P.V.U. is already lower—from 2 to 3 (see Fig. 8.8).

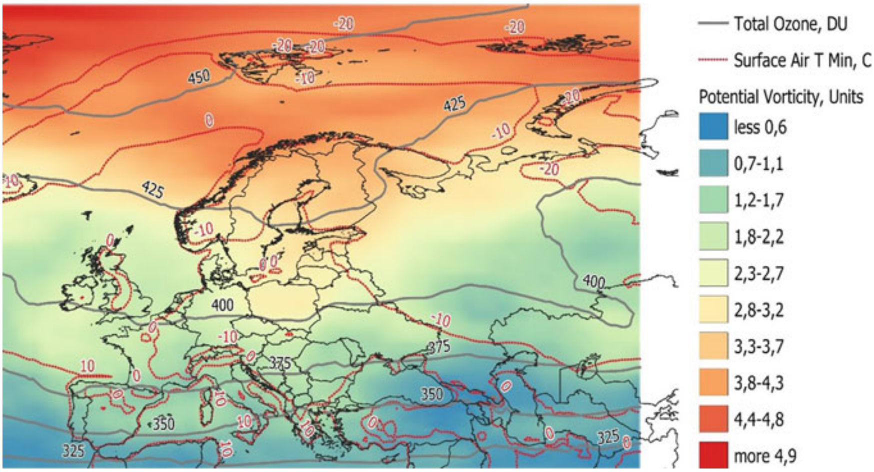

Fig. 8.8 Second group (S.S.W. over Belarus—5 cases) 19–25 days from the day of start S.S.W.: TCO (from MERRA-2, grey line), Minimum surface air temperature (from MERRA-2, red line), P.V.U. on 300 hPa (from MERRA-2, colour)

All cases of S.S.W. development for the period 1980–2021 had a common and similar pattern of impact on surface weather in Belarus and the regional climate of Eastern Europe. Usually, S.S.W. formation occurs in the region of Eastern Siberia, the Far East, and Alaska, accompanied by a significant increase in the local TCO values and displacement (depending on the location of the stratospheric polar vortex (Limpasuvan et al. 2005; Waugh et al. 2017) positive TCO anomaly (over 420 DU) towards Europe for several days. The high concentration of ozone in the lower stratosphere, due to its energy characteristics, lowers the tropopause height to a level of 450–500 hPa, thus increasing the role of stratospheric air in the formation of surface weather conditions, which is consistent with the obtained data on potential vorticity values (values above 3–4 P.V.U.). A decrease in the tropopause height, in turn, shifts the trajectory of the high-altitude stationary front to the south, up to the Black Sea and the Caucasus, where, due to jet currents, cut off mini-cyclones are formed, in which the surface wind speed increases to hurricane values.

The complexity of the orography of North-Eastern Europe, where the Scandinavian and Ural Mountains are present, creates a distinct corridor for cold, dense air masses. Considering the lower stratosphere's thermal heating, the isentropic surfaces in the layer above the mountains will converge. Such conditions represent a kind of barrier to further latitudinal air movement. Thus, certain conditions are created for the stratospheric impact on the blocking processes in the troposphere during the development of S.S.W.s in the Northern Hemisphere in winter.

Thus, the dynamics of the development of large S.S.W.s in the Northern Hemisphere leads to significant positive TCO deviations over Belarus and the corresponding negative deviations of surface air temperatures from the norm.

Conclusions

The main result of the work is that positive ozone anomalies are no less dangerous for creating dangerous meteorological phenomena and mini ozone holes. Dynamic processes in the lower stratosphere-upper troposphere and positive ozone anomalies contribute to developing hurricane winds, showers, and powerful cut-off cyclones like a tornado during the warm period. Heavy snowfall is observed in winter. The appearance of S.S.W. (or positive TCO anomalies) over Europe always contributes to the development of severe frosts near the Earth's surface (up to −25° and −30° C). The impact of large S.S.W.s on surface weather over Eastern Europe (including Belarus) is 58% of all stratospheric warming events for the period 1980–2021. Such conclusions must be taken into account with timely adaptation:

- short-term forecast of dangerous meteorological phenomena for 2–3 days;
- medium-term weather forecast for two weeks.
  That is why the main extreme criteria in forecasting are:

  – TCO over 400 DU;
  – P.V.U. at 300 hPa (dynamic tropopause) over 3–4 units;
  – Location of the tropospheric stationary front (Polar jets).

Thus, as a result of the statistical analysis of satellite, numerical, ground-based, and reanalysis observations, it was shown that in summer (less) and in winter, a stratospheric effect on surface weather and regional climate could be observed. By monitoring TCO, tropopause altitude (P.V.U.), and Polar Jets trajectory, it is possible to timely predict various dangerous climatic and weather events in a particular region of the Northern Hemisphere.

The work does not consider the chemical reactions associated with the destruction of TCO, and also does not focus on a detailed consideration of the formation of the S.S.W., but only on its presence. Among other things, vertical ozone profiles in stratospheric folds were not taken into account. The peculiarity of the study is that a statistically significant negative relationship and the impact of TCO, variations of potential vorticity on the surface air temperature over the territory of Eastern Europe, in particular for Belarus, was established both for individual cases and for those averaged over a long period (climatically).

Acknowledgements We would like to acknowledge the submission of data for this study to Giovanni's online portal for the provision of MERRA-2 Reanalysis data, AIRS, and OMI/TOMS satellite observations, and the ECMWF reanalysis and Belhydrometeocenter, data submission team. We also want to thank the QGIS team and Anton Gladkevich for their help in writing the algorithm in Python.

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Chapter 9
Handbook and Human and Planetary Health. Sustaining Planetary Health: Putting a Stop to Ecosystem Decline, Unsustainable Practices and Associated Human Suffering

George Atisa and Parita Shah

Abstract The natural environment is considered a free resource for humans to utilize, but doing so comes with costs associated with how it is used, e.g., degraded ecosystems, fragmented landscapes, pollution and climate change. These negative effects make humans' place on Earth inhospitable. The inherent challenge is the inability to connect or simply deny the association of the poor health currently experienced by people to the cumulative degradation of various ecosystems. A degraded ecosystem is not just a loss to a diverse planetary system or a waste in its own right, but because of the complex relationships involved, it becomes a health threat to other ecosystems. Studies have shown that there is interdependence between the quality of ecosystems and human health. Initiatives to protect environmental resources are being made, but they continue to fail at the adoption and implementation stages, and thus, the expected outcomes are not obtained. While there are many ways to restore and maintain planetary health, putting a stop to activities that cause ecosystem decline in regions that have deficits and unsustainable practices is the most viable way to restore and maintain a healthy planet. This chapter attempts to make this connection through detailed qualitative and quantitative data analyses of reports showing the cumulative depletion of ecological resources, initiatives designed to protect the environment, case studies and peer-reviewed literature. The findings show that the rates of use of ecological resources and the waste dumped on this planet are higher than those that the Earth is able to process and renew itself. It is therefore safe to conclude that humans are suffering from poor health due to poor environmental quality. The study recommends that countries that are facing ecological deficits start to reduce consumption, give back to nature an equivalent of their cumulative ecological deficits,

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_9

and increase investments in compensation schemes to offset their ecological deficits. Regions with a surplus of resources should develop modern and targeted sustainable use practices to avoid going into ecological deficits and to develop policy tools and management processes that can stop ecosystem decline. The global community should create relationships and a culture that recognizes the cumulative effects of ecological decline, work together to reverse the trend, and keep the planet healthy for current and future generations.

Introduction

The natural environment is considered a free resource for humans to utilize, but doing so comes with costs associated with how it is used and can lead to environmental conditions that make humans' place on earth inhospitable. The framing of the costs associated with the intensive and unsustainable use of natural resources has not created sufficient urgency in terms of the threats these costs pose to the health of the planet and the health of human beings. As a result, threats that compromise the planet's capacity to support human health and wellbeing, the sustainability of the global civilization, and the quality of natural and human-made systems have intensified over the years (Myers 2017; Horton et al. 2014). From 1950 to date, human activities globally have driven the use of natural resources into what has come to be known as the "Great Acceleration", leading to an exponential degradation of ecosystems (Myers 2017). The impact of such activities is felt in the atmosphere through climate change, as well as in deforestation, pollution and land-use changes.

Lessons from responses to recent environmental disasters, such as the increased intensity and more frequent wildfires and floods and the effects of biodiversity decline, show that apocalyptic themes and fatalistic slogans are drowned out by political and economic priorities (Bradshaw et al. 2021). Prescott and Bland (2020) defined planetary health as "*the interdependent vitality of all natural and anthropogenic ecosystems* (*social, political and economic*)". Current global political priorities and economic models are moving in directions that are constantly eroding natural systems with little regard for or inadequate understanding of how large-scale environmental changes affect planetary systems and long-term economic and human health outcomes. An improved understanding of the linkages among human health, human civilization and natural systems at the individual, societal and planet levels can help uncover the vulnerabilities of the natural world in the face of rising human activity intensity (Prescott and Bland 2020).

This chapter discusses the reality of the adverse effects of the intensive and unsustainable use of natural resources and the declining biodiversity and takes these effects beyond policy conversations to show evidence of a planet whose health is under pressure and has been declining. Evidence of depleted resources rather than the use of only strong language or powerful slogans can be more effective at creating strong and long-term commitments to protecting ecosystems and hence planetary health. For a long time, how much clean water, clean air, forests and mineral deposits humans took from nature and how much waste they generated were not issues of concern. The assumption was that the planet's capacity to supply humans with natural resources was endless, and the capacity of the planet to renew itself has always been taken for granted. The planet's limitations in terms of continuously supplying humans with resources as demanded, taking in waste and continuing to renew itself are now obvious (Wackernagel and Beyers 2019). In her book, "*River of Grass*" (page 392), Marjory Stoneman Douglas stated that "*the capacity of the earth for compensation and forgiveness after repeated abuses has kept the planet alive, but it has encouraged more abuse*" (Atisa 2020).

Although not so evident in the eyes and in the lives of most stakeholders, this abuse can be seen in the demand that is placed on the planet's resources, such as forests, fisheries and water, to meet the needs of humans. Overall, the cumulative demand for resources and waste generation has rendered the planet incapable of compensating for overconsumption to sustain planetary health and reverse the negative effects caused by humanity. Humans have begun to feel the effects of such abuse in the form of poor health, as life depends on materials supplied by nature, and by extension, the quality of those materials determines the quality of human life. The capacity of the earth to "*regenerate and provide natural resources and other services that support life*" on Earth is known as biocapacity (GFN 2021).

The erosion of the planet's biocapacity through intense human activities has brought about a phase known as the Anthropocene in the planet's history. *"Planetary health is the total well-being of humans and the integrity of the natural environment*" (Al-Delaimy et al. 2020). The integrity of the natural environment is dependent on ecological functions, which in turn depend on biological variety and the variability of life on the planet, otherwise known as biodiversity. The linkage between declining biodiversity and planetary health has not been clearly established across all stakeholder interests. Therefore, actionable solutions that focus on the benefits of a healthy planet, which require stopping activities that lead to ecosystem decline and the erosion of biodiversity, are diminished in many policy discussions and implementation.

Ecosystems and Sustainability Practices

An ecosystem is the natural capital comprised of the biophysical patterns and relations among humans, plants, animals, water, organisms, the climate and the sun. Ecosystems provide ecological services that benefit and maintain the entire planet and human health. The benefits provided by ecosystems are referred to as ecosystem services and fall into four classifications: provisional services (the ability to provide fish, water, air and forests), regulatory services (such as the control of floods, storms, soil erosion and climate regulation), cultural services (including recreation and aesthetics), and supporting services (such as soil formation, primary productivity and habitats) (Day et al. 2014). The ability of ecosystems to continue providing these services is threatened by human activities that include the unsustainable use of, for example, fish, water, and forests; the destruction of natural habitats; and waste production and dumping (Day et al. 2014).

For a long time, neoclassical economic (NCE) theory has guided economic development and resource use decisions by the government and private sectors in major economies. NCE theory advocates for the free market allocation of resources based on the needs of economic actors (Editorial 2014). This approach would be appropriate if natural resources were still abundant, but as economies have started to consume more resources than the planet can support, it is critical that economic models and the use of natural resources be subjected to the biophysical limitations of the planet. However, with difficulties in clearly understanding the tradeoffs between ecological decline and economic development, setting limitations on the use of ecological resources is often perceived as an underserving loss to economic development goals. The concept of sustainable use has also been presented as the best path out of this difficult decision-making environment, but how sustainable use can bring resource use to a level that the planet can support has not been clearly established. In regard to planetary health, the model of sustainable use should include resource-use limitations curbed on the boundaries of overexploitation to "stop to use" or start to "scale back".

Evidence of Declining Planetary Health

Global ecosystems are constantly being threatened, shaped and transformed by anthropogenic activities (WHO and CBD 2015). An ecosystem is the interaction between "physical (plants, animals and humans) and chemical biotics (light, air, temperature, soil texture and chemistry and nutrients)" (WHO and the CBD 2015). "*An ecosystem that performs its various functions well and where equilibrium is maintained depends on the quality and quantity of biodiversity, often referred to as ecosystem integrity, ecosystem stability or ecosystem health*" (WHO and the CBD 2015). The increasing global health challenges, including poverty, infectious diseases and the growing burden of noncommunicable diseases (NCDs), are a result of close and complex interactions among ecosystems, people and socioeconomic processes (WHO and The CBD 2015).

The World Health Organization (WHO) defines health as a "*state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity*". Health, in general, needs to be viewed beyond the human-only context to include ecological systems and the variability of all other species (WHO and the CBD 2015). The inclusion of all other species in health considerations arises from the understanding that an ecosystem is one that provides food, clean air, good quality and quantity of fresh water, medicine, climate regulation, pests, and disease regulation as well as disaster risk reduction (WHO and the CBD 2015). A declining ecosystem in terms of both quality and size compromises not only the health of humans but also the entire Earth system, which regulates the flow of energy and weather changes (WHO and the CBD 2015).

Globally, biodiversity in the biosphere has been declining at an unprecedented rate, and tropical regions bear most of the burden. Forest ecosystems are being destroyed in the name of urbanization, ranching, dam and road building and palm oil production (Shah and Ayiemba 2019; Cardinale et al. 2012), and biodiversity is depleted as habitats are destroyed, leaving biological actors with no place to call home. All this has resulted in various species approaching extinction faster than expected. Annual extinctions are between 10,000 and 100,000 species. To address these negative effects, other strategies involve the introduction of invasive species, which have increased by 40% globally since the 1980s (IPCC 2018).

Methods and Data

The study used the ecological accounting methodology developed by the Global Footprint Network (GFN) and defined how much of the planet's resources humans consume as a footprint (Ewing et al. 2010). Ecological accounting is an estimation that shows the extent to which humanity is living within the ecological limit or consuming natural resources faster than the planet can renew them and absorb the waste that is generated. When the global demand for ecological services exceeds the capacity of the planet to regenerate resources and absorb waste, the final outcome is declining planetary health. Additionally, the cumulative effects of exceeded ecological limits make it difficult to meet various conservation objectives, including sustainable development goals (SDGs).

The chapter builds on the current supply and demand of ecological resources, as this is what defines the level of access or lack of access to much-needed ecological resources that support life on the planet. The current state of planetary health is a result of human activities and can be grouped into three categories: i. the demand to support total production, ii. The supply to total consumption, and iii. waste generation from consumption (GFN 2021). The study analyzed and compared the global production and consumption of resources across all regions and five continents. The capacity of the planet to support current global and regional human consumption was estimated based on the level of ecological resources available. Waste is seen through climate change and water and air pollution.

Secondary data were obtained from the GFN website and existing literature. The data consisted of the global human population, production and consumption of resources measured in biocapacity terms. Biocapacity is the ability of the planet to supply an adequate amount and good-quality ecological resources. The level of ecological resources available was estimated to determine the extent to which people are living within the capacity of the planet to support them.

Findings

Table 9.1 provides some insights into the state of ecological resources and the impact of the rising human use of these resources and pressures on the planet's ability to support all human activities. Based on the current levels of production, consumption and waste generation and the ability of the natural world to absorb this waste, humans need more than one planet to support their current needs. The current global demand has resulted in the need for 1.73 Earths per year, which is a deficit of 0.73 Earths. As seen from the column on the number of Earths, Africa needs 0.84 Earths annually, meaning that the continent has a surplus/reserve of 0.26 Earths. However, if everyone lived the lifestyle enjoyed by people in North America, then the global population would need an equivalent of 4.14 Earths per year. The lifestyle of people in the European Union requires an equivalent of 2.88 Earths per year to meet all human needs. The problem is that we have only one Earth, and the need for more than one Earth shows the extent of the overuse of ecosystems, eroded biological productivity, destabilized climate, and inadequate absorption of waste, which compromise planetary health.

Many studies have taken an easier route and blamed the erosion of ecological systems on the growth of the human population (Editorial 2014; Bogardi et al. 2013). While a growing human population leads to increased competition for the available and dwindling natural resources (Bradshaw et al. 2021), it is not a problem that has historically driven the planet toward ecological collapse; rather, it is people's lifestyles. As shown in Table 9.1, the Asia–Pacific region has more than 4 billion people, almost 10 times more than the population of North America. The Asia–Pacific region's production and consumption levels are 2.24 and 2.39 ecological hectares per

Table 9.1 Ecological global status as of 2017

Region	Population millions	Total ecological footprint		Biocapacity total	Ecological (deficit) or reserve	Number of earths required
		Production	Consumption			
World	7550.26	2.77	2.77	1.60	−1.17	1.73
Africa	1242.787	1.21	1.34	1.14	−0.20	0.84
Asia–Pacific	4087.7	2.24	2.39	0.83	−1.56	1.49
Central America/Caribbean	87.454	1.47	1.85	1.06	−0.79	1.16
EU-28	504.829	3.94	4.61	2.03	−2.58	2.88
Middle East/Central Asia	454.012	2.86	3.11	0.84	−2.27	1.95
North America	490.307	6.58	6.61	3.70	−2.91	4.14
Other Europe	237.642	5.35	4.58	5.20	0.62	2.87
South America	420.935	3.36	2.70	6.95	4.25	1.69

Source Estimates by authors from the global footprint website 2021 capita annually, respectively, and it has a cumulative ecological deficit of −1.56 and needs 1.49 Earths per year to meet its population needs. Conversely, North America has just 490 million people, has production and consumption levels of 6.58 and 6.61 ecological hectares per capita, respectively, and has a cumulative ecological deficit of −2.91, needing 4.14 Earths to meet its population needs.

The magnitude of the global health crisis related to ecological destruction has been growing, but the politics and policies in regions that have had the greatest negative impact are doing very little to reverse these conditions. The United States, for example, has overshot ecological boundaries by the greatest margin but is politically polarized, where the political right does not see environmental protection, such as self-preservation and planetary protection for all humans, in a positive way (Bradshaw et al. 2021). When production and consumption from the greatest contributors to ecological erosion cannot be slowed or curbed "so it fits within the boundaries of what Earth's ecosystems can support and renew", the slow use of the same resources by the least contributing regions will not reverse the declining planetary health.

Other insights from Table 9.1 show that different regions of the world are not using ecosystems at the same rate and that consumption does not depend on the size of the population. The European Union and North America, for example, with a total population of 995.1 million, have a combined production of 10.53 and consumption amounting to 11.22 hectares per capita compared to Africa, which has a much larger population (1242.79 million) but has a production value of 1.21 and a consumption value of 1.34 hectares per capita. Inequality in terms of the distribution of the use and benefits of ecological resources can be seen across all regions of the world (see Table 9.1). The levels of inequality are even larger when individual countries are considered. For this reason, Al-Delaimy et al. (2020) found that "more than 50% of climate pollution is emitted by the wealthiest one billion people, while the poorest three billion, who suffer the worst consequences of climate change, contribute less than 5%" of pollution.

The glaring regional cumulative ecological deficits for the Asia–Pacific at −1.56, Central America and the Caribbean at −0.76, the European Union at −2.58, the Middle East at −2.27 and North America at −2.91 global hectares per capita have not scared these regions into putting an end to their overtasking of the planet. The "mother of all resources, the biological asset, is the planet's biocapacity" (ecological supply) (Wackernagel and Beyers 2019), which, when eroded by human activities, fails to renew itself. An ecosystem is the total sum of the biological diversity (the variety and variability of species in a place), which when taken together provides more resilience (ability to absorb shocks) to ecological systems and can return back to their original structure and functioning in the shortest time possible. An eroded ecosystem is robbed of the capacity to absorb shocks and the ability to return to natural functioning and is thus unable to support human needs. Putting an end to ecosystem decline and unsustainable practices is the only way to prevent declining planetary health, and this must start with those countries with ecological deficits recognizing these dangers and being willing to take responsibility and find ways limit growth and stop adding to ecological deficits.

Current Approaches to Managing Ecological Losses

Raven and Wackernagel (2020) proposed three strategies for stopping ecological losses: curbing human demand within the bounds of what Earth's ecosystems can support, protecting areas with the highest biodiversity concentration and documenting the distribution of biodiversity globally. However, curbing human demand at any level and protecting areas currently rich in biodiversity would mean abandoning global priorities related to employment, economic growth, and lifestyle. This might not be politically feasible because, although not equitably distributed and remaining contested, it is argued that economic growth has been the main contributor to good public health (Lang and Rayner 2015). However, much that has gone into current development and health improvement involves mortgaging the resources of future generations to realize present health and development outcomes (Myers 2017).

Prescott and Bland (2020) introduced the concept of restoration, an approach where attempts are made to restore missing microbes or introduce other species, also known as "rewilding". The success of a restoration approach has its own challenges, including the difficulties involved in changing how and what ecosystems are used for and the perception of ecosystems as free resources that are simply there to meet human needs.

Other researchers have proposed biodiversity-offsetting interventions designed to balance economic development and specific conservation activities. Offsetting is a very popular approach, in part because it can meet biodiversity conservation goals and economic growth goals simultaneously (Bull et al. 2013). This approach allows for ecological losses from economic development activities in one area in exchange for compensation with equivalent gains through conservation offsets that lead to "no net loss" (NNL) in other areas (Bezombes et al. 2019). The intervention follows in order of priority from avoidance, then minimization and finally offsets. Offsets are applied after avoidance and minimization fail to gain traction in reducing the impacts of development projects (Goncalves et al. 2015). There is no evidence showing that offsetting interventions have led to an NNL outcome (Bezombes et al. 2019), raising questions as to their viability as a strategy. Many of the existing approaches to managing or stopping ecological losses are either weak or inadequate.

Stopping Ecological Losses

Table 9.2 shows the application of the current approaches to the state of the ecological footprint in all regions of the world. The total deficit/surplus column shows whether a region has a cumulative ecological deficit or surplus/reserve. From a global perspective, the world has an ecological footprint deficit of −8859.25 million hectares. Regionally, Africa has a deficit of −250.42 million hectares, and South America has 1788.64 million hectares in surplus/reserves. Regarding the strategy to curb

Table 9.2 The reality of ecological depletion and strategies to stop ecological losses

Region	Population (millions)	Ecological deficits/reserves	Total deficits/reserves (million hectares)	Ideal strategies
World	7550.26	−1.17	−8859.25	Reverse development, give back to nature, rewild, curb demand, restoration, avoidance and minimization
Africa	1242.787	−0.20	−250.42	Reverse development, give back to nature, rewild, curb demand, restoration, avoidance and minimization
Asia–Pacific	4087.7	−1.56	−6372.42	Reverse development, give back to nature, rewild, curb demand, restoration, avoidance and minimization
Central America/Caribbean	87.454	−0.79	−68.98	Reverse development, give back to nature, rewild, curb demand, restoration, avoidance and minimization
EU-28	504.829	−2.58	−1304.15	Reverse development, give back to nature, rewild, curb demand, restoration, avoidance and minimization

(continued)

Table 9.2 (continued)

Region	Population (millions)	Ecological deficits/reserves	Total deficits/reserves (million hectares)	Ideal strategies
Middle East/Central Asia	454.012	−2.27	−1029.08	Reverse development, give back to nature, rewild, curb demand, restoration, avoidance and minimization
North America	490.307	−2.91	−1428.54	Reverse development, give back to nature, rewild, curb demand, restoration, avoidance and minimization
Other Europe	237.642	0.62	146.60	Avoidance, minimization and offsets
South America	420.935	4.25	1788.64	Avoidance, minimization and offsets

Source Estimates by authors from the global footprint website 2021

human demand within the bounds of what Earth's ecosystems can support, restoration, avoidance and minimization seem to be ideal approaches globally and for all regions with ecological deficits. Those regions with ecological surpluses need to avoid and minimize their use of ecological resources to maintain or increase their surplus.

The implementation of strategies that can stop ecological losses in countries that have ecological deficits is where the difficulties start. When deficits reach millions of ecological footprint hectares, this signifies that countries are already consuming beyond the ecological boundaries of the planet, and curbing, avoidance and minimization will not be able to help these regions increase their ecological reserves. Returning to a level of ecological reserve or surplus can happen only when regions with ecological deficits start to give millions of ecological hectares that they have acquired, equivalent to estimated deficits, back to nature, including the implementation of serious restoration efforts. This would mean not just putting a stop to all development activities but also reversing all human activities (urbanization, roads, and rewilding forests), an approach that many countries would oppose. This is possible only if countries are willing to rediscover the reality of ecological depletion, the extent of how ecological resources are shared and used globally and the guidance of science for evidence for environment-related health challenges. These countries also need to invest in offset interventions by working with regions that still have ecological reserves. Countries or regions with ecological reserves should avoid and minimize their use of ecological resources to stay within ecological boundaries.

Nexus Between Human Health and Ecosystem Decline

With these high levels of deficits, the proper function of ecological systems that have sustained human survival on the planet has now been eroded and is starting to crumble under the weight of human activities. Additionally, the global efforts being put forward to maintain or improve the functioning of ecological systems keep falling short in realizing substantive outcomes. Such efforts include the goals of the Convention on Biological Diversity, such as the 2010 targets, halting species extinctions and the United Nations SDGs (Bradshaw et al. 2021; Prescott and Bland 2020).

With the poor functioning of ecosystems and declining biodiversity, humans are now facing a physical environment consisting of the atmosphere, hydrosphere and lithosphere that cannot support life on Earth. The atmosphere provides clean water and oxygen to breathe and regulates the water cycle; the hydrosphere provides fresh water for the survival of humankind and is the life blood of aquatic ecosystems; and the lithosphere caters to terrestrial ecosystems (Millennium Ecosystem Assessment [MA] 2005).

Expected Poor Planetary Health

The confluence of the natural world provides a space for interactions among "humans, animals, plants, and other life forms" on the planet (Aisher and Damodaran 2016). Such interactions are supposed to be beneficial to humans and all other species, but the interaction between humans themselves, driven by greed and obsession with material wealth, has numbed the feelings of the privileged few, leading to desperation and hopelessness in finding meaning in life for the less privileged majority (Caro 2021). At one extreme, billions of people are using very little ecological resources and struggling daily to meet their basic life needs and maintain dignity that brings some meaning into their lives. At the other extreme, millions of other people are using so many ecological resources and living in abundant wealth and are oblivious to the struggling majority (Caro 2021). This by itself is not a healthy relationship.

Table 9.3 shows the ecological variables that cause poor planetary health when eroded. These variables function well in a rich biodiverse environment, a less-polluted environment and on land that provides space with a range of habitats. Decreasing biodiversity, polluted environments or fragmented landscapes are an indication of broken relationships that support the functioning of ecosystems. Taken together, the

Table 9.3 Why it is important to live within planetary limits

Ecological variable	Planetary health	Effects of living beyond planetary boundaries
Genetic diversity	Biodiversity	Beyond the loss of biodiversity in terms of the variability, number, amount and condition of ecosystems reducing nutrient cycling, water regulation, pollination, food and medicinal products that benefit humans directly, all other species have a moral right to find favorable conditions to exist (Balmford et al. 2008)
Species diversity		
Ecosystem diversity		
Air	Pollution	"Pollution is the largest environmental cause of disease and premature death in the world today, but the effects are often underestimated in the calculations of the global burden of diseases" (The Lancet Commission 2017). The polluting of seas and oceans kills aquatic species, and the reproductivity of those that survive is affected, and in many instances, their metabolism is suppressed, and such deaths disrupt the food chain (FAO et al. 1996)
Water		
Seas and oceans		
Soil		
Energy–oil and gas		
Chemicals		
Forests	Land	It is on Earth's land surface that humans carry out their activities with little regard for how these activities affect other species. Deforestation affects medicinal supplies, as almost all medicines are derived from natural compounds from plants, animals and microbes. Environmental changes and climate change on landscapes and in fresh waters and oceans are responsible for the rapid circulation of pathogens between wild species and infections in humans, as well as species extinctions (Estrada-Pena et al. 2014; Chivian and Bernstein 2010). Urbanization has attracted more people to cities, and cities have become centers of very high consumption and greenhouse gas emissions, which cause climate change
Agriculture		
Settlements		
Urbanization		
Climate change		

Source Author generated based on reviewed literature

cumulative effects of declining biodiversity, increased pollution and land fragmentation reduce the ability of the natural environment to supply health ecological services to all forms of life.

As human demands have gone beyond the planet's natural capacity to supply ecological resources, it is difficult for plants and all other forms of life to healthily coexist in the face of declining habitats, pollution, and climate change. This imbalance leads to a weakened ecosystem that cannot support healthy planetary conditions. Such weakened ecosystems cannot mitigate natural events, including diseases, climatic disruptions and natural disasters.

The estimation of ecological costs equivalent to planetary health can be seen from the amount of ecological deficits or reserves within various countries and regions. It is safe to assume that in regions or countries that have deficits in their ecological resources, the extent of the health damage inflicted on the planet is equivalent to the existing deficits or shortages of ecological services as a result of the deficits. Countries or regions that still have some reserves in terms of ecological footprint still have health resources to supply to humans as needed. Overall, as seen in Table 9.1, the total deficits are much higher than the total reserves, and therefore, it can safely be concluded that the entire planet is exposed to severe health consequences.

Discussion

An understanding of ecological functions and how ecological deficits affect planetary health is critical to framing the right policies and decision-making strategies to protect the planet and make it hospitable to humans. The level of ecological surpluses can be used as a measure of good health, and the cumulative deficits can represent planetary health deficits. How to keep the ecological surpluses and reduce deficits is not clear, as many of the strategies clearly do not go far enough and are not very precise. For example, offset interventions, when examined from the concept of "Pareto improvement", where the lives of some people are improved without making any individuals worse off, are extremely difficult to implement in the real world (Bazerman et al. 2001, p. XV). The near "Pareto improvement" that is argued can provide many benefits for some people and minimal losses for others, and the call for tradeoffs between economic losses and ecological growth has proven difficult for ecologically deficit regions to accept (Bazerman et al. 2001, p. XV).

Although there is evidence of existing global inequality in consumption, rich countries that also happen to have the largest ecological deficits have exhibited extreme opposition to realistically accepting some tradeoffs in their pursuit of economic growth with environmental protection. Anyone working to reduce ecological deficits should know that ecosystem functioning is so complex and at a scale so vast that it is beyond human ability in terms of knowledge, finance and technology to support this function or substitute it (Chivian and Bernstein 2010). No region or country should be indifferent to the risks associated with the cumulative global ecological deficits. All countries therefore should develop standards that regulate human activities and accept tradeoffs to give space for ecosystems to function naturally. Sustainable use approaches and environmental protection legislation need to account for a healthy state of ecological resources and function at the point of their implementation.

Biodiversity

Changes to landscapes such as habitat changes through clearing forests, fragmentation and land-use forms affect human conditions and behavior through interaction and encounter rates with different environmental conditions, thus increasing the probability of exposure to vectors and hosts (UNEP 2016; Estrada-Pena et al. 2014). From 1990 to 2020, the world lost 178 million hectares of forests. The rate of decline from 1990 to 2000 was 7.8 million hectares per year, while from 2000 to 2010, it was 5.2 million hectares per year, and from 2010 to 2020, it was 4.7 million hectares per year (FAO 2020). As forests dwindle, habitats change, biodiversity is lost, and land becomes more fragmented, bringing humans closer to other wild organisms that have the potential to spread diseases. The loss in biodiversity translates to degraded ecosystems because of habitat loss and degradation, overexploitation, species invasion, and climate change (Balmford et al. 2008). It is also understood that ecosystem functions and the services they provide are in turn determined by biodiversity and are linked to human and planetary health (Naeem et al. 2016).

Conclusions

As economies develop, the gap between supply and demand for ecological resources has been widening and trending toward worsening deficits. All countries in the European Union and North America and many countries in Africa and Asia are in an ecological deficit, meaning that they have surpassed the planetary boundaries that can safely support human health. Humans are now facing a planetary system that is less able to regulate itself to create a natural environment that sustains itself and that supports all forms of life. People, regardless of their region on Earth, have an "*immutable right to live and to a quality of decency and dignity as well as duties and responsibilities to promulgate development and health for all*" (Caro 2021). This is not the case when some countries are consuming an equivalent of four Earths per year while others cannot utilize all that the planet has to offer in one year. Thus, the Lancet Commission's (2017) report found that pollution kills mostly the poor and the most vulnerable people in low- and middle-income countries that have not contributed to or made a significant contribution to atmospheric pollution. If the global community does not work to reverse trends toward ecological deficits in both deficit and surplus regions, it is correct to conclude that planet health is in serious trouble. In addition, the idea that economic growth supports planetary health is a false argument, as resources that go to such growth are taken from future generations.

Over the years, several proposals to curb the use of ecological resources have been made and implemented in many parts of the world but have not brought about significant changes. Some of these proposals include curbing human demand within the bounds of what the Earth can support, initiatives to protect areas with high biodiversity concentration and biodiversity offsetting interventions (Prescott and Bland 2020; Bezombes et al. 2019; Bull et al. 2013). Improvement of the planet's health would require radical policies that would include cutting back human activities to reduce greenhouse gas emissions, reverse urbanization trends, and "rewild" former wild regions. These policies require setting limits to economic growth. The limits to growth are not policy decisions that countries with ecological deficits and those that will soon face deficits would be willing to undertake. This is because the current limits to growth are based on how and when humans are satisfied, but again, humans are never satisfied.

The study concludes that improvement of Earth's health is not yet in the front and center in many economic development policies because for that to happen, there has to be global, regional and national definitions of the limits to production and consumption based on the capacity of the planet to supply resources and not on human satisfaction. The trends in biodiversity losses, ongoing species extinctions, deforestation, pollution and climate change are indications that scientific efforts to reverse ecological decline are behind the curve in terms of solving planetary health challenges. None of the current approaches that include sustainable development want to go further and curb growth regarding the use of ecological resources because doing so is not politically acceptable.

Recommendations

At one level, countries and regions with the worst ecological deficits should work together more closely and in collaboration with the private sector to create an understanding of how their production activities, consumption and waste impact global ecological health. At another level, countries with the worst ecological deficits should also work with countries or regions with surpluses or those that have near surpluses of ecological resources to ensure that these countries continue to trend more toward greater reserves and less toward deficits. This approach would mean identifying barriers to creating such an understanding and space to work with other regions to grow ecological reserves. Preservation strategies identified in the literature, such as offset schemes or restoration, can work if accompanied by cutting back on subsidies that support unsustainable and high-level production in ecologically deficit regions and instead investing those subsidies in the preservation of existing ecological resources in surplus regions. Policies to expand protected areas to support a cumulative increase in the size of biodiversity-rich habitats should be developed and adopted by all countries.

Three key barriers to the successful preservation of ecological resources include i. the absolute pursuance of economic development without paying attention to spillover costs that come with development activities, ii. the perception that balancing economic development and environmental protection is costly and inhibits economic growth (Bazerman et al. 2001, p. 46), and iii. the inability to see shared ecological resources beyond one's political and economic boundaries. Negotiations related to maintaining planetary health should be based on win–win approaches because a healthy environment benefits everyone. This means also working to develop alternative ways of growing economies that do not increase ecological deficits beyond one's economic and political boundaries. The best way forward is to develop a tradeoff framework that includes offset schemes between economic development within and across countries that would first stop ecological degradation and negotiation strategies that work from that point. The global community should create relationships and a culture that recognize global common resources and work together to create standards that allow sacrifices globally and provide health conditions that do not hurt people anywhere on the planet.

Effective ecological protection measures would require a balanced understanding of consumption and production levels between regions, waste generation and how activities in each country or region impact environmental health. Rich countries understand this but are not often willing to trade short-term economic growth with long-term environmental protection, especially when the negative impacts are not visible at the moment. Similar to the "the tragedy of the commons" dilemma advanced by Garret Hardin, the current global ecological deficit means that all countries, whether in regions of ecological deficits or surpluses, will be hurt by poor planetary health. What is required is a global consensus to cut back and change the culture of consumption.

Limitations of the Study

First, this research took a global analysis and examined the state of ecological resources from a global perspective. This does not show how and the extent of ecological degradation at the local and sectoral levels and within individual countries. Second, the research did not examine individual sectors and communities to understand how their specific activities contribute to ecological degradation and poor planetary health. Finally, the research did not provide ecological trends and corresponding changes in planetary health. Taking this work forward, there is a need to look at individual countries, individual sectors, industries and specific community activities to identify targeted policies and initiatives that can be used at micro levels to reduce ecological decline and improve planetary health. Data on ecological trends over a reasonable time period with the corresponding changes in planetary health can create some sense of urgency on the need to cut back and change how natural resources are used.

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Chapter 10
Planetary Health in Brazil

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Abstract We are witnessing an unprecedented social, political and environmental crisis, with intense deforestation, extensive fires and biomass burning, altering the biomes of the planet. To this end, this chapter presents a structured literature review and an analysis of this bibliometric network to identify thematic clusters that point out the relationships between health education and planetary health. The results presented here show that achieving good planetary health is a transdisciplinary issue and it depends on human behavior and, consequently, education for sustainability. A limitation of this study is believed to be a lack of quantitative studies available to help us to understand the dimension of the impacts of the environment on the health and well-being of people and human activities on the health of the planet.

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_10

Introduction

When looking at the development of humanity in the civilized world, we are perhaps experiencing one of its best moments, especially when we consider the technological, humanitarian, and social features such as policies of inclusion and well-being of the population, as well as the gradual consolidation of human rights. However, when it comes to environmental issues, life on earth has never been at greater risk. Studies of the human footprint on the earth bring to the fore an alarming perspective that threatens not only the future for mankind but of life on earth as a whole (Myers and Frumkin 2020). Ebi et al. (2020) expand on this topic with the conclusion that the health and well-being of people and the health of the biosphere are strongly linked. The state of Earth's life support systems, including freshwater, oceans, land, biodiversity, atmosphere and climate, affect human health, and, at the same time, human activities, namely, industries and agriculture, are adversely affecting the Earth's natural systems.

From this scenario, Planetary Health emerges as a topic requiring our urgent attention and has been defined by the Rockefeller Foundation-Lancet Commission on Planetary Health as the achievement of the highest attainable standard of health, wellbeing, and equity worldwide. These aims are to be achieved through judicious attention to the human systems that shape the future of humanity and the Earth's natural systems that define the safe environmental limits within which humanity can flourish (Horton and Lo 2015). However, according to Whitmee et al. (2015), natural systems are being degraded to an extent that is unprecedented in human history, exposing populations to highly potent dangers that require urgent and transformative actions to protect the present and future generations. Thus, Planetary Health seeks a balance between the development of human civilization and the natural resources provided by the planet. Historically, the growth of human societies on earth has impacted directly the availability and consumption of resources which, by tradition, have been seen as unlimited, is now destroying the biosphere on several levels. Nevertheless, the interdependence of human health with the Earth's natural ecosystems has become apparent through the intensification of environmental changes that are influencing global economic development, i.e., abundant floods and droughts resulting from climate change (Myers 2017).

More recently, other researchers have come together to improve the planetary health agenda, contributing to different conclusions. Hinsley (2022) highlighted the changes in the Earth's forest cover and its effects on local biodiversity which bring ecosystem disturbances that impact human health, particularly through zoonoses and vector-borne diseases. Myers et al. (2021) draw attention to the crossroads that humanity and life on Earth are at right now, noting that, in recent decades, the level of human impacts on Earth's natural systems has increased exponentially, exceeding the planet's capacity to absorb the waste generated or to provide the resources necessary for our sustenance.

In Brazil, concerns about planetary health are equally pressing with some issues being highlighted as requiring urgent attention. For example, Stenvinke et al. (2020)

point out that global warming is a concern for the health of the population when considering the impact of temperature on the proper functioning of our kidneys and the fundamental role they play in protecting the body against temperature fluctuations. Silva et al. (2021) bring to the debate concerns about food consumption and the detrimental impact on the environment linked to the changes in the Brazilian diet which has seen a sharp increase in the last three decades, thus demanding more healthy and sustainable approaches to food production. Recently, the Annual Meeting and Festival of Planetary Health of 2021 (held in the State of São Paulo, Brazil) highlighted the urgency of effective actions to safeguard the health of the planet for future generations (Myers et al. (2021). Supported by the United Nations Development Program, the meeting was attended by almost 350 participants representing more than 70 countries.

Considering the growing and more widely accepted concerns about our environment today, this chapter seeks to conceptualize the subject of Planetary Health, presenting its relationship with education, especially health education, not only as a discipline, but as a space for professional training of citizens wishing to enjoy and contribute to a positive impact on our biosphere. To this end, this chapter presents a structured literature review and an analysis of this bibliometric network using the freely available VOSviewer software tool to identify thematic clusters that point out the relationships between health education and planetary health. Hence, the results presented here show that achieving good planetary health is a transdisciplinary issue and it depends on human behavior and, consequently, education for sustainability.

Theoretical Grounds

Redvers et al. (2020) argue that the principles of Planetary Health are rooted in the planet's beings, based on the existence of complex process interconnectivity that within it carries the traditional indigenous knowledge as defended by the various populations. Therefore, the role played by Planetary Health refers to the application of knowledge in the world, on the species and on the environments that compose it (Bennett et al. 2014). Özdemir (2019) observes further the fact that planetary health has also recently benefited from technological systems, such as artificial intelligence and digital health.

Pettan-Brewer et al. (2021) state that it is necessary to encourage collaborative partnerships among different players, mainly from communities, to promote the health not only of people, but also of animals, plants, the environment and the entire planet with, consequently, significant results for planetary health. Thus, developing a healthier world with inclusion, equity and equality, constitutes motivating elements for planetary health. Camargo and Barros (2019) studied one of the most important female social movements in Latin America, rooted in Brazil, which aimed at curbing violence and supporting the autonomy of rural, forest and riverside women, who are intrinsically related to the socio-environmental sustainability agenda of their communities and the notion of planetary health. For example, people from rural areas are more subject to temperature variability than those who work in climate-controlled environments. Beltran-Sanchez and Andrade (2016) and Tian et al. (2019) point out that people in Brazil with less education are more affected by chronic diseases such as diabetes and asthma.

Moysés and Soares (2019) contribute to the discussion by highlighting those anthropogenic activities causing a growing impact on the environment and the relationship between human beings and the earth system, exerting direct and indirect influences on natural and social processes. In the same vein, Magistretti et al. (2021) develop the discussion further by stating that climate change of an anthropogenic nature threatens health due to the degradation of ecosystems, the increase in temperatures, the extinction of species, malnutrition and the emergence of new diseases; all this could be avoided with a healthier and more sustainable environment.

As early as 2017, Myers (2017) highlighted that the impacts of human activities on natural systems had increased rapidly in recent decades, causing the interruption and transformation of most natural systems. Horton et al. (2014) and Whitmee et al. (2015) contributed to this by stating that it is healthier for the planet's harmony to adopt differentiated organizational behaviors, which result in more durable products being produced by manufacturing methods based on less energy usage and less expenditure of materials. Also, the practice of recycling, reuse and repair, and the guarantee of safety by switching to less hazardous materials and minimizing waste. Based on his research carried out in 2017, Pérez-Escamilla et al. (2017), warned of food insecurity in the world, which negatively affects people's physical, social, emotional and cognitive development which are key elements of the United Nations' SDGs. The author recommends developing actions to improve food security governance based on solid, equitable and sustainable food systems that benefit from modern information and sustainable and equitable agricultural technologies; initiatives essential for countries to meet the SDGs.

Ethics in planetary health question the extent to which food security can be ensured, coexisting with the assurance of access to a healthy life and human well-being. However, the correct functioning of ecosystems relies not only on improving and maintaining their processes, but on the need to reduce climate change (Singh and Chudasama 2021). The growing sign of inequality, evidenced in certain parts of the world, suggests a social paradox of improvements in indicators of life expectancy, infant mortality, and deaths resulting from infectious diseases and malnutrition, is being masked by these global trends (Galea and Vlahov 2005; World Health Organization—WHO 2016).

The current paradox of planetary health concerns its guarantee of protection against the new format of food systems, which seek to enable large-scale access to healthy diets, characterized as a challenging scenario for humanity (Herrero et al. 2020). In this contexed, it is a positive feature that the reduction of environmental impacts and the care for the environment directly impact other aspects such as the improvement and maintenance of human health. In other words, the process of the integration of conditions relating to human health, as well as the ecological systems that make up nature, form the concept of Planetary Health (Horton et al. 2014; Whitmee et al. 2015; Myers 2017).

Researchers Conijn et al. (2018), Springmann et al. (2016), Willett et al. (2019) and Rockstrom et al. (2020), in the framework of food production, mention that a healthy standard of diet that meets the aim of planetary health should be represented according to planetary biophysical limits without exceeding the criteria of nutritional needs that are used in sustainability assessments. Thus, the relationship between the attitude adopted by human beings towards natural systems and their consequences on public health constitute some of the concerns inherent to planetary health (Mool et al. 2001). The so-called "planetary healthy diet" has increasingly been replaced in recent years by ultra-processed sugar-based foods, with greater consumption of animal proteins (Baker and Friel 2016; Hansen 2018; Marinova and Bogueva 2019). In this connection, Henchion et al. (2021) warns that both human health and planetary health drive the sustainability of food of animal origin and generate concerns resulting in these changes in a basic and traditional diet that was characterized by local plant food (Willett et al. 2019).

Concerning the Brazilian framework of Laporta (2019), Amazonian biodiversity is threatened because of the widespread depletion of habitats for native species. Ellwanger et al. (2020) emphasize that the loss of forests contributes to the increase in regional and global temperatures and the intensification of extreme weather events, whereas Krystosik et al. (2020) point to the growing emergence of disease. Nembaware et al. (2020) exemplifies the situation with sickle cell disease (a change in red blood cells causing anemia) while Lee et al. (2020) reported an increased risk of mortality due to increased daytime temperatures while Lowe (2014) discuss the risk of dengue linked to extreme rain conditions. Moreover, Gao et al. (2021) emphasize that temperatures, globally, regionally or locally, are associated with premature deaths when humans are exposed to extremes, either very hot or very cold. These same authors express the hope that their findings will benefit international, national and local communities in developing preparedness and prevention strategies to reduce the impacts associated with climate change. It should also be noted that Beltran-Sanchez and Andrade (2016) and Tian et al. (2019) point out that Brazilian people with less education are more affected by chronic diseases such as diabetes and asthma.

The organizational principles of Regionalization, Hierarchization, Decentralization and Peoples' Participation seek to guarantee the structuring principles in Brazil. Regionalization and Hierarchization establish that services should be organized at increasing levels of complexity in a defined geographic area and should be planned according to epidemiological criteria, based on the knowledge of the population to be served (Brasil 2021). Decentralization refers to the redistribution of power and responsibility between the municipal, state and federal levels of government. Each government sphere is autonomous and sovereign in its decisions and activities, respecting the general principles and participation of society. People's Participation, on the other hand, provides for the participation of society through Health Councils and Conferences, which aim to formulate strategies and control and evaluate the implementation of health policies (Brasil 2021).

In this scenario, the interaction of social, economic and environmental determinants and, subsequently, social empowerment through critical thinking and intellectual autonomy is fundamental to the formation of health professionals. Moreover, education represents a political-pedagogical process for the development of critical and reflective thinking to understand the reality that determines the health-disease process and to propose transformation actions that lead individuals to autonomy and emancipation as historical and social subjects, capable of proposing and giving opinions in health decisions and to take care of themselves, their families and their collectivity. In addition, the social perception of the subject is essential to comprehend how factors such as economic disparity and inequalities affect the development of diseases (Machado et al. 2007).

Methodology

In the context of Planetary Health in Brazil, the qualitative research approach presented here allows the identification of the particularities of reality by describing the complexity of a specific problem (Flick 2009). Considering the literature appearing in databases over the past five years a bibliographic research strategy is used to identify and expand the knowledge on this subject. To capture the situation of the subject as widely as possible, this focused bibliographic search was carried out in the Scopus, Web of Science, Science Direct and PubMed databases including a review of the reports held by the national and international institutions World Health Organization, Pan American Health Organization, Osvaldo Cruz Foundation/Brazil, Brazilian legislation and its national health services, Single Health Service (SUS).

For the searches in the databases, the following strategies were used: (((“educati*” OR “teaching” OR “learning” OR “curricula” OR “curriculum” OR “universit*” OR “higher education institut*”) NEAR/10 (“one health” OR “planetary health” OR “health system” OR “well being” OR “wellbeing” OR “well-being” OR “air pollution” OR “biodiversity loss” OR “ocean acidification” OR “land conversion” OR “biogeochemical changes” OR “biochemical flows” OR “environmental preservation” OR “preservation of the environment” OR “environmental degradation” OR “environmental protection” OR “ecosystem services” OR “climate change” OR “climatic change*” OR “equity” OR “justice” OR “peace” OR “equality” OR “distribution of income” OR “distribution of services” OR “access to services” OR “quality of life” OR “working conditions” OR “leisure conditions” OR “housing conditions” OR “housing quality” OR “food” OR “sanitation”)) AND (“bra*il*”)), and 1087 articles were identified.

Using VOSviewer, it was possible to identify 4 important clusters, as shown in Fig. 10.1.

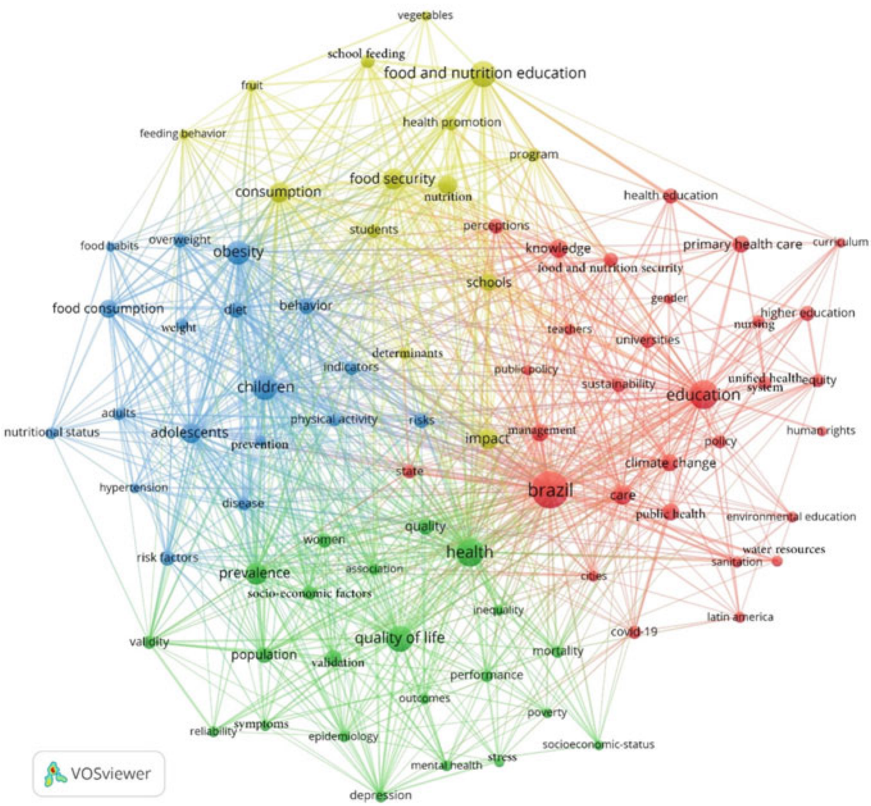

Fig. 10.1 Four major thematic clusters on planetary health and health education in Brazil issues

Results and Discussion

The results obtained from this literature search show that existing research on planetary health and health education in Brazil is focused on four major thematic clusters that are shown in different colors in Fig. 10.1. Where:

- the red cluster represents the focus on issues related to planetary health, climate change, sustainability and environmental education
- the green cluster represents the focus on public health, quality of life and socioeconomic factors such as poverty
- the blue cluster represents the focus on dietary pattern, physical activity, and obesity, particularly among children and adolescent
- the yellow cluster represents the focus on food insecurity and malnutrition.

In the context of Brazilian education curricula, we can observe that basic and higher education schools seek to include content related to sustainability, based on environmental education in classrooms or extension activities. According to the

Brazilian Ministry of Education and Culture (Resolution No. 7, dated 12/18/2018), Government establishes that at least 10% of the total workload of undergraduate courses should be performed through Extra-Mural activities. The legislation guides the promotion of initiatives that express the social commitment of higher education institutions in all the areas of communication. These are culture, human rights and justice, education, environment, health, technology and production that work, in line with policies linked to the guidelines for environmental education, ethnic-racial education, human rights, and indigenous education. Some examples of Brazilian initiatives that highlight these concerns in their curricula are from Marchezini and Londe (2020) who developed a study in elementary schools in the Municipality of São Paulo/Brazil to identify in teachers their knowledge and perceptions on the subject of "climate change", to support them with better planning for future activities in their schools and training. It is these teachers who will be among those responsible for preparing younger generations of citizens for future challenges, including climate change that impacts planetary health. Teacher training to deal with climate change issues was also reinforced by Rocha, Brandli, and Kalil (2020).

Addressing the issue of "climate change" in schools is necessary and emerging, especially in developing countries that are, for the most part, at greater risk of climate change. In 2012, based on a study carried out in neighborhoods of El Salvador and Brazil, Wamsler et al. (2012) warned of locations where climate-related disasters are recurrent. In these locations, it was found that the average levels of schooling were lower for households living at high risk, as opposed to residents of lower-risk areas. This fact impacts the ability to preserve the environment and understand the risks, that is, people's level of education, which in turn reduces adaptive capacity, resulting in a vicious circle of increasing risk. In this sense, it is urgent to talk about climate change in schools as a way of involving students and teachers in the debate on this on this issue, especially in schools in developing countries, since the impacts on people's quality of life (education, health, income generation, and employment) are much more pronounced and difficult to deal with financially.

When dealing with education, Rangel et al. (2014) highlighted, from a study in a small school, the existence of a relationship between eating habits and chronic diseases in adolescents, due to cases of obesity. This fact demonstrated the need for differentiated movements in schools, guided from the perspective of healthy diets and reduction of obesity, a scenario reinforced by the condition of 35% of overweight students, as verified by the nutrition division of the municipal health council (Rangel et al. 2014). More recently, Verthein and Amparo-Santos (2021) reinforce the discussion by pointing out that school meals and culture should encourage the promotion of educational projects in schools, in an attempt to promote awareness of bad eating habits and behaviors, which are typically masked socially. These social conditions are responsible for various issues such as food security, access to quality food, social inequality, management of food production, distribution and consumption, obesity, in addition to sustainability and agroecology (Verthein and Amparo-Santos 2021).

When it comes to aspects such as food culture, social life, and the environment, there is a clear negative relationship between health problems represented by heart disease, obesity and chronic diseases, and the rampant consumption of processed foods (Geraldi et al. 2017). In addition, Alvarenga et al. (2013) pointed to physiological elements such as dissatisfaction with the body, problems with self-esteem, diets, binge eating, media influence, excess, and preoccupation with weight, as common agents that cause eating disorders. Henriques et al. (2018) emphasize that the formulation of policies can contribute to the access and adoption of standards that result in the availability of healthy eating practices, based on actions to combat childhood obesity, overcoming the use of information, in the condition of encouraging healthy eating. Within the scope of the quality-of-life requirement of university students, it is noted that the improvement of this parameter is associated with a higher level of student perception regarding their competencies to manage their health. Thus, in this quality-of-life assessment process, among the criteria with the greatest impact, one should consider body image, eating behavior, and academic conditions (Silva et al. 2018).

Considering the dimension and the social scope related to the lack of control of body weight, different strategies have been adopted in Brazil to face the rates of obesity and overweight, which represent an improvement in the quality of life, and a decrease in the rate of diseases (Jaime et al. 2013). On the other hand, Tempski et al. (2015) also report that in the academic environment, the perception of students and their quality of life involves factors ranging from the quality of teachers, curricula, sleep, physical activities and eating habits. According to Silva et al. (2010) lack of physical activities and poor diets, correspond to postures adopted by individuals characterized as obese.

Further to the dietary profile of university students, it is important that encouraging the practice of healthy habits and group meals be an integral part of the philosophy and values of health promotion on the part of foodservice providers on university campuses, whether public or private (Alves and Boog 2007). Therefore, it is necessary to reinforce the urgency of implementing institutional behaviors that are translated into initiatives that promote the transition of children's eating habits, by health units and schools, through public policies and food education programs (Gomes et al. 2017; Carvalho et al. 2018; Hartmann et al. 2018). It is, according to Amorim et al. (2012), a process of improving the health of students and the school community as a whole based on the assumption that access to healthy food should be treated as synonymous with guaranteeing a human right.

The paradox defined by the high consumption of fatty foods, and the reduced practice of physical activities, has resulted in the creation of nutritional education programs, as is the case of the Brazilian National School Feeding Program (PNAE), proving the existence of a marked population profile characterized by overweight and obesity in children and young people (Fernandes et al. 2014). However, Azzi et al. (2021) identified that individuals with a greater commitment to physical activities tend to fit into a group of students characterized by high purchasing power and, therefore, a better quality of life, representing a smaller number of people who dedicate themselves to both academic studies and work activities. Given this, Menezes et al. (2011) draw attention to the fact that preschoolers from the Brazilian state of Pernambuco, who enjoy quality consumer goods, with obese mothers and with a better level of education, and who belong to families with higher incomes, are classified as obese and overweight children. Therefore, in seeking the best conditions so that these children do not become obese in the future, it is essential to monitor the progress of obesity and excess weight gain (Menezes et al. 2011).

The role of Brazilian university restaurants generates impacts on the social sphere, as, in most cases, it allows access to healthy food that meets nutritional requirements, surpassing the quality of meals outside the academic environment, especially in dealing with low-income students. In addition, it is observed that the greater consumption of fruits and vegetables in these restaurants occurs due to the frequency with which they are offered. These movements are consolidated through the existence of student assistance programs and the food and nutrition policy, which materialize in university restaurants as educational actions, exerting an influence on students' food decisions (Hartmann et al. 2018).

In the context of elementary school education, dos Santos et al. (2015) and Carvalho et al. (2018) highlight that progress in raising awareness among elementary school students about approaching healthy eating practices also relies on the educational intervention of food education programs. Given this, it becomes noticeable that the consumption of industrialized products, such as sausages, soft drinks, and snacks, are replaced by foods that guarantee a quality diet (Dos Santos et al. 2015; Carvalho et al. 2018). In the case of adolescents from underprivileged areas, the Brazilian Ministry of Health's Food Guide for the Brazilian Population, whose inspiration has promoted changes in indices of cholesterol and cardiovascular risk factors by encouraging healthy eating habits such as the greater consumption of vegetables (da Silva et al. 2015). In addition, it is not only about offering healthy foods and food education, but also about conveying to this group of schoolchildren the issues of health and well-being in terms of eating sufficient amounts of food (Vicenzi et al. 2015). Food insecurity is most often linked to students with high restrictions to diets and with high nutritional value and, considering that temporality characterizes the causal relationship defined between food insecurity and overweight, it is important to invest in the advancement of studies in this area (Vicenzi et al. 2015). Dumith et al. (2021) also point to concerns about food insecurity as an unfavorable condition for quality of life as well as its relation to violence in terms of conflict.

Ruderman et al. (2019) reveal that the better the male economic situation, the greater the overweight tends to be, in the same way, that, in the female universe, low levels of obesity and a high level of education can represent a strong negative correlation. Thus, the fight against the advance of obesity has as a strong ally the fight against a sedentary lifestyle through successful programs that motivate people to opt for more active lifestyles (Ruderman et al. 2019). In the context of the health and well-being of children and adolescents, so that complications such as obesity and overweight are avoided, they must be introduced as early as possible into a routine, of physical activities and eating habits in adequate quantity and quality (Rosaneli et al. 2012). Therefore, for this process to be successful, parents must be engaged in the process as conscious and well-informed agents, working in the prevention of childhood obesity (Rosaneli et al. 2012).

Fig. 10.2 Four major thematic clusters

To end the "Results and Discussion" section, Fig. 10.2 is presented that represents the main topics discussed, based on the four major thematic clusters.

Summary Considerations

The work presented in this chapter sought to identify the principal thematic clusters that point out the relationships between health education and Planetary Health in Brazil focusing on the Brazilian environment. The results of a structured literature search revealed the four thematic clusters of sustainability, environmental education; public health, quality of life and socioeconomic factors that include food and body care; food insecurity and malnutrition. These four cluster groups also have a global context as well as that of Brazil and showed alignment with the wider planetary health agenda, envisioning the health and well-being of human civilizations and the conditions of the natural and biological systems on which life depends.

The Intergovernmental Panel on Climate Change, in 2018, announced that to contain the increase in global temperature by 1.5 °C, greenhouse gas emissions must decrease by 45% by 2030 compared to 2010. MacNeill et al. (2021) point out that actions towards zero emissions have become a challenge and a necessity, since the health and well-being of people, as recommended by Sustainable Development Goal 3, is dependent on the environmental, social and economic health of the planet. Therefore, sustainability indicators can become strategic variables in this decision-making universe when considering sustainable performance management as formed by a set of Planetary Health indicators (Plag and Jules-Plag 2019). On the other hand, human activities also impact natural systems and, for Myers et al. 2021), natural systems are unable to deal with excessive waste or demand for resources, thus reducing planetary health. Santos Rotta and Zuquette (2021) point out that in Brazil, planetary health is threatened constantly by human activity through activities such as the constant deforestation that occurs to create spaces for cattle ranching (Skidmore et al. 2021). This results in increased emissions of carbon and other greenhouse gases and decreased air filtration in the area, reducing further the quality of life (Assis et al. 2020). In addition, deforestation contributes to the loss of habitat and destruction of biodiversity as was seen when turtles in Brazil were threatened by deforestation in unprotected areas (Fagundes et al. 2018). The restoration of natural vegetation has been described as a powerful tool to increase Brazilian rural development (Bustamante et al. 2019).

Regarding people's health and well-being, the study by Lima-Camara (2016), already warned of the emergence and spread of human infectious diseases in Brazil, transmitted by vectors due to changes in the environment by human actions. This author addressed the recent entry of three arboviruses in Brazil, Chikungunya (CHIKV), West Nile (WNV) and Zika (ZIKV), focusing on the challenges for Public Health in the country. The Brazilian population is exposed to infection by these three arboviruses, requiring constant actions in the control and prevention of these arboviruses in the country.

Socioeconomic inequalities among Brazilians have increased and impacted their health and well-being. Leal et al. (2020) state that regional inequalities in Brazil, about access and quality of prenatal care and childbirth, need improvements to reduce prematurity rates and, consequently, reduce morbidity and mortality rates of children in the country. Anadrade and Andrade (2021) argue that socioeconomic inequalities make access to dental treatment difficult with individuals with lower family income having a higher prevalence of need. Concerning the relationship between food and body care, Silva et al. (2021) claim that dietary patterns in Brazil have harmed human and planetary health, where the emphasis is on the relationship between ultra-processed foods and the occurrence of obesity and other non-communicable diseases. Thus, improvements in food systems to make them healthier in a more sustainable way are required. Brazilians, according to the research by Marchioni et al. (2022), showed low adherence to a healthy and sustainable dietary pattern, despite knowing that diets are simultaneously linked to the health of the population and the environment. More recently, in Brazil, the São Paulo Planetary Health Declaration was signed to create a concerted effort to increase planetary health. The declaration was created to bring countries together to build resilience while promoting a global pandemic equitable stance and has been signed by 70 countries (Myers et al. 2021).

Finally, we are witnessing an unprecedented social, political and environmental crisis, with intense deforestation, extensive fires and biomass burning, altering the biomes of the planet. We can conclude that from this investigation that the topic of Planetary Health is based on transdisciplinary actions. For this, the training of the actors involved in finding solutions is essential for Brazil to be able to change its current situation, Flos et al. (2021) corroborate this view stating that education in planetary health, addressing the essential issues of how humanity inhabits the Earth and how humans affect and are affected by these natural systems. The work presented in this chapter sought to expand and systematize knowledge about Planetary Health in the Brazilian context. It should be noted that, according to the Scopus Database, Brazil is the 6th country in scientific publications on the subject, from 2017 to 2022. As for the limitations of this chapter, it is believed that there is a lack of quantitative studies available to help us to understand the dimension of the impacts of the environment on the health and well-being of people and human activities on the health of the planet.

Acknowledgements This study was conducted by the Centre for Sustainable Development (Greens), from the University of Southern Santa Catarina (Unisul) and Ânima Institute (AI), in the context of the project BRIDGE - Building Resilience in a Dynamic Global Economy: Complexity across scales in the Brazilian Food-Water-Energy Nexus; funded by the Newton Fund, Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina (FAPESC), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), National Council for Scientific and Technological Development (CNPq) and the Research Councils United Kingdom (RCUK).

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Part II
Practical Experiences and Case Studies

Chapter 11
Coastlines Caught in the Middle: How Development Policy and Sea Level Rise Are Eroding Coastal Ecosystems in the United States

Chad J. McGuire

Abstract Coastal ecosystems provide a tremendous amount of value to human well-being. Not only do they yield a wealth of services that benefit humans, such as acting as hatcheries and nurseries for commercially valuable fish species, but they also provide more indirect benefits like protecting nearshore development from coastal storm surges. Climate induced sea level rise presents a unique challenge to coastal ecosystems as the natural attributes between the sea and land are impacted through rising waters. Under ideal conditions, coastal attributes would be able to migrate landward as sea levels rise. But in many areas of the United States, coastal ecosystem migration is prevented by both existing and planned coastal development. In essence, there is no place for the coastline to migrate. In the United States of America, current national and state policies that favor both the creation and protection of coastal development at the expense of protecting coastal ecosystems is playing a significant role in exacerbating this problem. The purpose of this paper is to overview the importance and value of coastal ecosystems, show the impact of sea level rise on coastal ecosystems, and examine the role of current coastal development policy in the United States in exacerbating coastal ecosystem decline in an era of climate change. The goal is to show how existing policies, some aligned to mitigate the impacts of climate change, can have the effect of disturbing—and even eradicating—important coastal ecosystems.

Introduction

Human health and wellbeing are intricately linked to ecosystem health and functioning. As Li (2017) notes, intact ecosystems provide the foundation for the services that provide humans worldwide with basic necessities for survival: food, clean air, clean water, productive soils. And this is certainly true of coastal ecosystems worldwide. The literature over the past fifty years shows that coastal ecosystems provide

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_11

important services to humans. When coastal ecosystems are harmed, the literature also shows the harm accrues to both human and planetary health.

In 1997, two seminal works came out that attempted to identify and quantify all of the values of nature. An edited book by Gretchen Daily attempted to introduce the concept of ecosystem services and natural capital (Daily 1997). And in conjunction with this work, Robert Costanza and colleagues published an article in *Nature* on the value of the world's ecosystem services and natural capital (Costanza et al. 1997). Covering 17 ecosystem services for 16 biomes, the analysis suggested the natural assets of the Earth provided humans somewhere between 2 and 3 times the global gross national product in direct and indirect services. The book and article expanded on earlier research that attempted to combine the disciplines of ecology and economics (see Ehrlich and Ehrlich 1981; Ehrlich and Mooney 1983; Westman 1977). This collective work was an earnest attempt to understand the value of what nature offers humans; not only what we take from nature, for example commercial fishing, but also important regulating services such as clean air, clean water, and natural storm protection.

From 1997 to the present, there have been continuing efforts to better understand the scope of nature's capital, quantify it, and then link it to human behaviors and decision-making processes. In the early 2000's the Millennium Ecosystem Assessment attempted to identify and quantify the earth's ecosystem services, and then place them into a conceptual and decision-making framework for policymakers (MEA 2005). This effort coincided with the work of the Intergovernmental Panel on Climate Change to understand the causes and impacts of a changing climate, including impacts on the Earth's natural capital (IPCC 2014). Applications of this work have included, among others, attempts to place a price on the cost of carbon emissions relative to their impacts on natural capital (Nordhaus 2017). And recently, Costanza et al. (2017) have provided a 20-year update on the state of ecosystem services since their original published work, including a summary of research that has been undertaken on this topic since 1997.

An important part of this effort to quantify the value of nature includes work that has been done on the value of coastal ecosystems. While the ecology and defining characteristics of coastal ecosystem components (coral reefs, seagrass meadows, salt marshes, mangroves, sand beaches and dunes) is well understood, less understood are how these habitats, individually and collectively, lead to human benefits as defined in an economic sense. The traditional economic definition of benefits for environmental goods and services is the sum of what all members of society would be willing to pay for those goods and services (Mendelsohn and Olmstead 2009, p. 326). There is some disagreement on how to calculate these services (for example, see Boyd and Banzhaf 2007; Polasky and Segerson 2009). Even with disagreement on calculation methods, there is general consensus that the underlying functions of these coastal ecosystems provide a wide array of values to human wellbeing (Braat and De Groot 2012; Gomez-Baggethun et al. 2010).

Estimates of the value of coastal ecosystems vary. Costanza et al. (1997) provided an early estimate of marine contributions to human welfare at equal to global GNP in the late 1990s, with 60% of that total estimated to come from coastal and shelf systems, with the remaining 40% attributed to open ocean resources. This estimate was updated significantly in the past ten years. de Groot et al. (2012) and Costanza et al. (2014) calculated coastal ecosystems account for a multiple of global GNP: somewhere between 2 and 3 times. The change between 1997, 1999, and 2014 can be attributed, in large part based on climate change impacts and projects, to revising the value of these coastal resources for storm surge protection, biodiversity, and early life nurseries for commercially important marine species.

By all measures, coastal ecosystems are seen as important to humans not only for direct human use, but also in how they support human wellbeing. And while climate change is heightening the value of coastal ecosystems in terms of what they provide to humans, it is also threatening their continued existence. Climate change is causing seas to rise, while also increasing the frequency and intensity of coastal storms worldwide (IPCC 2014). It is increasing acidity of surface water temperature and acidity, placing critical habitats like mangroves, seagrasses, and coral reefs at-risk (He and Silliman 2019; Hewitt et al. 2016) All of this, and more, demands a public policy response. But are our public institutions responding? If they are, what does that response look like? And if not, what factors are influencing a lack of response?

The United States of America (US) is doing a poor job overall of protecting its coastal ecosystems, mainly due to preexisting policy initiatives that prioritize and incentivize coastal development. A history of coastal development, policy incentives for continued coastal development and redevelopment after disaster, and a path-dependence that favors protecting built resources at the expense of coastal ecosystems collectively creates a policy environment that neither properly accounts for nor protects coastal ecosystems. Solutions to this current policy conundrum include removal of subsidies that obfuscate the risk of coastal living to provide a proper context for development and hard armoring choices and, as a consequence, reprioritizing proactive retreat and non-development options as ways of balancing coastal asset resource protection against incentivizing and protecting coastal development.

This paper provides a case study of how existing US policies influence coastal ecosystem protection in an era of climate change. It begins by defining and interpreting the value of coastal ecosystems. It then provides an overview of the influence of sea level rise and climate change on coastal ecosystem integrity. A discussion and interpretation of current US policies that frustrate coastal ecosystem protection follows. The examination, while limited to US policies, helps provide a framework for examining coastal nation policies as a way of determining their ability to proactively protect coastal ecosystems in an era of climate change.

The Importance and Value of Coastal Ecosystems

Coastal ecosystems provide an abundance of benefits to humans (Barbier et al. 2011). The benefits provided vary, in economic terminology, based on how humans derive the value out of what coastal ecosystems provide. Generally speaking, there are direct benefits (the goods provided by coastal ecosystems directly sought by humans), indirect benefits (the services ecosystems provide that lead to human benefits), and non-use benefits (the spiritual, religious, and heritage values of coastal ecosystems). All of these kinds of benefits are generally classified as ecosystem services (Barbier 2007).

Coastal ecosystems can generally be categorized into five distinct regions. Beginning at the nearshore and moving towards the ocean, the five regions are as follows: sandy beach and dunes, mangroves, salt marshes, seagrass meadows, and finally coral reefs (Alongi 2020). Each of these regions have distinct and defining characteristics, but also share characteristics and functions with other regions. A summary of the kinds of ecosystem services (benefits to humans) provided by each coastal ecosystem is provided in Table 11.1.

From a policy standpoint, it is generally the raw material, tourism, and, to some extent, wildlife services that are most regularly associated with coastal ecosystems. When one thinks of coastal regions, the use of these areas for tourism and recreation pursuits generally comes to mind. Beaches and nearshore waters are popular destinations for many coastal areas of the United States of America (US), bringing in important revenue for local and coastal state economies. In addition, commercial and recreational fishing and other extractive practices of coastal resources provide direct economic benefits.

What is often less well understood are the more indirect and non-use benefits provided by coastal ecosystems. In particular, the role of these regions in purifying and retaining fresh water as part of water resource management in coastal areas is not well understood (Carter 1990; MEA 2005). Nutrient cycling and biodiversity protection are other services that help to ensure productive and healthy oceans. These services are also marginally understood. And the critical roles of carbon sequestration, erosion control, and coastal protection that most of these coastal ecosystems provide are becoming ever more valuable in an era of climate change. This is particularly so in low-lying coastal areas of the US where large financial investments in development have occurred. These investments are increasingly under threat due to effects and impacts of climate change (USGCRP 2018). As these threats increase,

Table 11.1 Ecosystem services provided by different coastal ecosystem regions (Barbier et al. 2011)

Service provided	Sandy beach and dunes	Mangroves	Salt marshes	Seagrass meadows	Coral reefs
Raw material	X	X	X	X	X
Coastal protection	X	X	X	X	
Erosion control	X	X	X	X	
Fresh water protection	X	X	X	X	
Nutrient cycling					X
Wildlife	X	X	X	X	X
Carbon sequester	X	X	X	X	
Tourism, etc.	X	X	X	X	X

the US is spending more to remediate their impacts through redevelopment efforts and measures to replicate these mitigation functions.

There are ongoing efforts to quantify the value of coastal ecosystems as a whole and within specific regions. The goods, as compared to the services, provided by coastal ecosystems are generally easier to quantify. Many of the goods derived from our coastlines, say commercial fisheries for instance, are already imbued into our economic system. This is also true for tourism and recreation dollars spent on traveling to and using coastal ecosystems. However, this measure is a bit more difficult because many of the coastal resources act as support systems for the more direct activities. If one wishes to sunbathe on a beach, then sand dunes are incredibly important in maintaining the sandy beach characteristics in many coastal areas. Equally important for maintaining sandy beach characteristics are the coastal storm protection characteristics of mangroves, salt marshes, seagrass meadows, and coral reefs. But these kinds of services are indirect. Mangroves, saltmarshes, and the like are not directly sought by sunbathers who wish to bathe on a sandy beach. However, they are critical to ensuring the sandy beach's continued existence. In this way, these services are much like human infrastructure projects. No one really wants a highway or a sewer system for its own sake. They are necessary to provide what humans really want: efficient and fast transportation and removal of waste products.

Calculations based on assumptions suggest the panoply of services provided by coastal ecosystems is a multiple of total global economic output (Costanza et al. 2014; de Groot et al. 2012). These calculations are reasonable when seen as logical extensions of known market values and methods for determining indirect service provisions. It is difficult to have consistent and reliable estimations because so much of what coastal ecosystems provide are dynamically linked to supporting other human activities and benefits. Without fully understanding the dynamics of an ecosystem, including all of the inputs and interactions that can affect the ecosystem stability, it is hard to accurately connect how the ecosystem operates with the values that flow to humans from that operation (Polasky and Segerson 2009).

One example might be a watershed that naturally purifies drinking water for a local municipality. A relative value for that watershed may be calculated by substituting the cost of building and operating a water purification system providing the same purity and quantity of drinking water as the watershed. But understanding the biological, chemical, and physical nuances of the watershed that ensure it can act as a reliable water filter is more dynamic and difficult to assess. However, these ecological components that help the watershed to function for this purpose are critical to quantifying its value. And even if this can be accurately calculated, the value derived only speaks to the watershed as a filter for water. It does not speak to other services it may provide, known and unknown, that benefit humans.

Aside from the nuances and difficulties in understanding total valuations, coastal ecosystems are valuable to humans. And that value is such that it likely exceeds the current economic activity being accounted for in our global coastal regions. But coastal ecosystems are under threat from climate change and, in particular, the impacts of climate-induced sea level rise.

The Impact of Sea Level Rise on Coastal Ecosystems

Direct human activities have been negatively impacting coastal ecosystems for well over the past century. As Barbier et al. notes (2011), 50% of salt marshes, 35% of mangroves, 30% of coral reefs, and 29% of seagrasses are either lost or degraded worldwide (citing FAO 2007; MEA 2005; Orth et al. 2006; UNEP 2006; Valiela et al. 2001; Waycott et al. 2009) The United States of America (US) is no exception in this regard. Historical actions like reclamation projects, coastal agricultural operations, and flood control have aided in removing between 30 and 50% of the historical coastal wetlands in the US (Zedler 2004).

Sea level rise is responsible for the majority of coastal wetland degradation today. For example, between 2004 and 2009, it has been estimated that US coastal wetland environments—mainly saltmarsh ecosystems—have been lost at an average rate of approximately 80,160 acres per year. This loss is due almost entirely to observed sea level rise, with over 70% of that loss occurring in the Gulf of Mexico. And based on future predictions, it is probable that the US will lose an additional 16% of its remaining coastal wetlands by 2100 (USGCRP 2018).

Climate change impacts coastal ecosystems in multiple ways. Sea level rise can occur at a rate that is too fast for mangrove, saltmarsh, and beach/dune ecosystems to migrate landward (Sandi et al. 2018). Alternatively, humans can respond to observed sea level rise by constructing hard barriers to protect built assets along the coastline. In these instances, even if the rate of sea level rise is slow enough to allow coastal ecosystem attributes to migrate, the building of seawalls and other hard structures prevent migration (McGuire 2017). Seagrasses and corals, although submerged, are subjected to increased ocean acidity and higher temperatures that impact their ability to function (Wilkinson and Salvat 2012). Combined, climate change creates a set of cascading effects that place coastal ecosystems at-risk and, as a consequence, diminish the services they provide in support of human wellbeing.

Sea level rise will have differential impacts on the five categorical coastal ecosystem regions described earlier. Coastal sand/dune ecosystems, as the interface between land and sea in many coastal regions, provide the conditions for ocean-related recreational activities. Whether using the beach directly, or as a staging ground for water-based recreation, the sand/dune ecosystem is the “infrastructure” through which those activities occur. Thus, the relative value of its existence as a medium for ocean-related recreation can be determined. For example, the vast majority of the US population and international travelers visits a beach during a planned vacation representing US$285 billion in direct spending in 2017 (Houston 2018).

The coastal sand/dune ecosystem has a multitude of benefits beyond recreation that it provides to human wellbeing. For millennium, it has been a source of raw materials for humans. Sand is regularly harvested for its silica and feldspar components. It is used as fill and as a basic ingredient in cement and other construction materials. And more recently, sand from beach areas with large dune systems (which provide natural renourishment) has been transported to other coastal areas suffering from erosion as a form of nourishment to reinforce the recreational values of other coastal areas.

There are numerous values humans get out of coastal resources (see Table 11.1), but one of the more important values for sand/dune regions is acting as a buffering nearshore and inland development from coastal storm activity. For many areas around the world, and certainly for US coastlines, climate change and sea level rise are increasing the intensity and frequency of coastal storms (IPCC 2014; USGCRP 2018). Beaches associated with sand dunes generally provide substantial protection because they attenuate the storm surge and wave activity due to their unique morphology (Ruggerio et al. 2010). Dunes tend to congregate landward of sandy beach areas and are often connected to vegetation that is endemic to the sand dune environment. The dunes not only replenish sand along the beach area through normal wind action, but they also provide natural breaks from the storm surge and are supported by the vegetative communities that thrive in the dune ecosystem (Hacker et al. 2011; Hesp 1989).

In areas of significant coastal development, coastal sand/dune ecosystems are integral in protecting human assets from existing and emerging risks of coastal storm damage. And they provide a natural defense (through dune renourishment) to the effects of erosion brought on by climate change and sea level rise. Without this ecosystem, humans would have to provide renourishment if they wanted to maintain the sandy beach attributes of the coastline, and armoring or breaks if they wanted to achieve the storm surge dissipation attributes of the sand/dune ecosystem. Mangroves serve a similar function for storm surge dissipation and erosion prevention landward of the mangrove ecosystem (Valiela et al. 2001; Wilkinson and Salvat 2012). The same can be said for saltmarshes (Sandi et al. 2018). As the impacts of climate change progress and aggregate, it is reasonable to assume the value of coastal protection these ecosystems provide will increase.

It is apparent that coastal ecosystems are valuable, by most reasonable estimates a multiple of total global economic output. Attaching that value to human wellbeing is, in some cases, relatively easy. Many people directly interact with coastal beaches for, at least, recreational purposes. In this way, they can attach their recreational preferences to their spending. In other cases, it is harder to show the value of coastal ecosystems, particularly their more indirect provisioning services like coastal storm protection, nursery habitat for commercially and recreationally valuable fish species, nutrient cycling and filtration, and more recently carbon sequestration. And because it is hard to attach these important provisioning values to human spending, it is hard to see how private actions can be relied upon to protect these resources.

Because many of the coastal ecosystem services provide benefits that are not priced in a private market, and because those benefits are distributed and available to humankind generally, they may be categorized as public goods and thus require government action for protection (Loomis and Paterson 2014). One way of looking at what government is doing to protect coastal ecosystems is to identify and analyze policies enacted specifically for this purpose. Another way, and the one explored in the following section, is to examine existing government policies that impede the ability to protect these coastal ecosystems. What follows is an exploration of key national policies in the US that support and protect coastal development and redevelopment in ways that contribute to the decline of these coastal ecosystems.

United States Coastal Development Policy and Coastal Ecosystem Decline

The current effects of climate change already pose a significant threat to coastal ecosystems (He and Silliman 2019; IPCC 2014; USGCRP 2018). This threat presents itself equally to developed and undeveloped coastlines sharing similar geospatial and geomorphological attributes. However, developed coastlines have considerations beyond the background risks associated with climate change. The effects of existing and planned coastal investments, as well as the tendency to protect those investments, create additional risks.

The United States of America (US) has a long history of subsidizing coastal development. Today, over 50% of the population lives in a coastal county, encompassing an area that is less than 20% of the contiguous US land mass and having a population density over four times that of the continental average (NOAA 2020). And coastal population is increasing. Overall, the greatest increases are being seen in the Gulf Coast region, an area that is disproportionately at risk to both sea level rise and climate-related storm activity, particularly hurricanes (KC et al. 2020). These trends create pressure for new coastal development, redevelopment after damage, and protecting existing development in some of the most at-risk regions.

Policies Favoring Development and Redevelopment

The US has supports, through various subsidies, the development of coastal areas (Onda et al. 2020). There are historical reasons for developing along coastlines. Early settlement by Europeans from sailing vessels and marine shipping as a main source of commerce between regions (see McGuire 2020). The effect of incentivizing coastal development, mainly through infrastructure, created a kind of path-dependence for coastal living that has led to the majority of its population living in and around coastal regions.

In more recent times, support for coastal development and redevelopment in the US has taken the form of disaster economics: a complex set of federal policies aimed at mitigating the impacts of increasing risk associated with coastal living. As Knowles and Kunreuther (2014) summarize, the US has been providing disaster assistance since its founding as a nation in 1776. The concept of disaster assistance is to provide federal assistance—mainly financial—to those who have suffered from harm caused by a “natural” phenomenon. Sometimes the definition of a natural phenomenon is clear, like an earthquake, flood, or hurricane; it is an event caused by natural forces. Sometimes the concept of natural is less clear, for example a wildfire initially caused by human negligence. What is common among federal disaster assistance declarations is the notion of no-fault; the event causing harm is not seen to be the fault of those who have suffered the harm.

One issue with federal disaster assistance is that it provides a financial backstop for coastal risks. Those developing and living in coastal areas can effectively discount the risks of loss as federal disaster assistance is made readily available when a coastal storm occurs and causes damage. This assistance helps to make both the coastal municipality and private homeowner whole. In effect, federal assistance diminishes the need to consider the risk of loss when making local decisions about coastal development. All of the benefits of allowing development accrue to the local community, while the risk of loss can be mitigated by federal assistance (McGuire 2015).

The effects of federal disaster assistance can be seen in relation to increased population densities in coastal regions of the US, particularly risky regions along the Gulf of Mexico, and the increasing influence of climate change and sea level rise. According to the Congressional Research Service (CRS 2020), between 1964 (when records began) and 2020, the federal government has spent a total (adjusted to 2020 dollars) of US$435 billion on disaster assistance. US$200 billion, approximately 46% of the total, has been spent in the last decade. When observed in terms of numbers of disasters declared and amounts spent for disasters the picture becomes clear; more money is being spent today on disasters, and each disaster is becoming more expensive by an inflation adjusted comparison.

Elliott and Clement (2017) have provided some context on the dynamics of disaster relief and its impacts on local development. The have found that federal disaster relief not only provides an economic impetus for redevelopment, but it also incentivizes new development in the very same coastal areas. A mix of direct government relief funding, subsidized development loans, and government-backed guarantees on private mortgages—along with a ready-made building workforce brought in for redevelopment—helps to create the conditions for both redevelopment and new development. Ouzad and Kahn (2019) have added to this research by looking at financing activity in coastal areas immediately after a disaster. They note loan originations for coastal development *increases* after a disaster. The rate of private mortgage origination is higher post-disaster than its equilibrium rate in the years preceding the disaster event.

The mix of direct payments, loan guarantees, and other aid reinforces the concept of coastal areas as desirable places to live regardless of the risk. The public spending creates a safety net for coastal development, and the government guarantees help to spur new and expanded private investment in low-lying coastal areas highly sensitive to the influences and impacts of climate change. In such a situation, it is hard to see how coastal ecosystems, and their services, can complete from a policy prioritization standpoint. The more that is invested in coastal areas for development purposes, the easier it is to prioritize protecting those investments over coastal ecosystems and the services they provide.

Climate Mitigation Policies and Coastal Ecosystem Decline

Federal subsidies collectively act to tip the scales of a benefit–cost analysis towards coastal development by externalizing the risks of coastal living. And in doing so, they make it more difficult to prioritize protection of coastal ecosystem resources as they come into conflict with coastal development priorities. This balance in favor of prioritizing development while deprioritizing risk yields additional perverse outcomes when public policies, under the guise of climate adaptation, are enacted to mitigate the impacts of climate change to the built coastal environment.

As already discussed, current policies in the US favor coastal development and redevelopment. These policies, taken as a whole, move significant capital towards coastal development. And as emerging research shows, this movement positively influences demand for coastal real estate by making capital readily available at discounted rates with reduced underwriting requirements due to government guarantees (see Bakkensen and Barrage 2017; Ortega and Taspinar 2018; Zhang and Leonard 2019). This can lead to coastal climate adaptation and mitigation policy being operationally prioritized as human-built asset protection above other competing interests. As summarized below, where sandy beaches are identified as a significant economic driver for a particular coastal area, nourishment tends to be identified as a policy solution. Otherwise, for built areas, armoring is often the preferred policy solution. It is only for undeveloped coastal areas that non-invasive adaptation responses (allowing landward migration for example) are often identified.

Coastal armoring is the process of placing physical structures (seawalls, bulkheads, revetments, jetties, groins, breakwaters, etc.) at the shoreline to limit the influence and impact of the ocean on dry land. There are generally two categories of armoring: hard and soft. Hard armoring provides a solid structure, like a seawall, to provide a substantial barrier between the sea and land. Soft armoring is made of less resilient, often organic materials that attempt to mimic the shoreline's natural contours. Soft armoring is generally favored in lower energy areas like bays and inlets. Hard armoring tends to be used in high energy areas, particularly coastlines directly facing the open ocean (McGuire 2013).

Hard armoring leads to both active and passive erosion. Under conditions of sea level rise, the area in front of a seawall experiences active erosion as the ocean approaches and contacts the wall (CRS 2016). Passive erosion occurs by preventing migration of coastal features landward (Dugan et al. 2008). The cumulative effects of hard armoring diminish and degrade sandy beach, saltmarsh and mangrove ecosystems. They can also impact seagrass meadows and coral reefs through nutrient flow interruption.

Coastal armoring, particularly hard armoring, is favored as an adaptation strategy for most of the built areas along the coastline of the US. As shown by Peterson et al. (2019), armoring is highly correlated with coastal development and climate change adaptation strategies in a positive feedback. The more demand for coastal development, the more likely it is that hard armoring will be chosen as a method to protect those assets from the effects of climate change. McGuire (2017) analyzed hard armoring in the coastal state of Massachusetts in the US. Over 27% of the ocean-facing coastline was found to have some form of public or private hard armoring protection. Preferences for hard armoring was even shown in low energy bays and estuarine rivers. Many of these projects were private and done in conjunction with single-family developments. Most were limited in scale and thus not subject to stricter environmental review requirements under US federal law. But when linked together, they created a substantial "wall" stretching hundreds of miles of inner coastline across the State.

Beach nourishment is another method actively employed in coastlines where shoreline attributes, particularly sandy beaches, are desired (Armstrong et al. 2016). The US has employed beach nourishment as a main strategy to combat coastline erosion and protect coastal assets since the 1970s (NRC 2014). It has regularly been used to protect and reinforce coastal development. Nourishment can have the same impacts as hard armoring, even in undeveloped areas. If the nourishment takes the place of natural seascape migration landward, then the normal coastal features, including mangroves and saltmarshes, are inhibited from migration through the depositing of new sand. Otherwise, for developed coastlines, nourishment buffers the rising tides and their effects—at least for a time—from development.

Besides inhibiting the natural movement of nearshore coastal features, nourishment has a similar effect as armoring on public perceptions of risk as measured through development. Numerous studies have shown that nourishment protection for coastal properties spurs additional coastal development (see Gopalakrishnan et al. 2011; McNamara et al. 2015; Nordstrom 2000). So, while less directly intrusive as hardscapes such as seawalls, nourishment as a mitigation measure for climate adaptation can lead to increases in coastal development in the very areas that are most at-risk in experiencing the impacts and effects of climate change.

Conclusions

Coastal ecosystems provide a tremendous amount of value to humans. Conservative estimates place that value, in monetary terms, as a multiple of global economic output on an annual basis. Some of that value is captured in our economic accounting in the form of direct and, to some degree, indirect human uses. We value sandy beaches not only for the sand and other resources that we find, but also for the many commercial and recreational activities we enjoy that beaches help supply.

There are many other supporting services coastal ecosystems provide that are less well understood. The sands of beaches help purify and store fresh water for human consumption. Salt marshes, mangroves, seagrass meadows, and coral reefs all provide critical nursery habitat for many of the marine species we value commercially and recreationally. All serve as important nutrient uptake and distributions systems that are critical to biodiversity. And all play an increasingly important role in mitigating the effects of climate change. These lesser understood functions, by most estimates, provide the greatest amount of value in service of human wellbeing.

Coastal ecosystems around the globe, and certainly in the United States of America (US), are under threat from climate change. Storms are getting more frequent and intense while seas are rising. Moving carbon from stored locations within the Earth is warming our surface waters and increasing their acidity. These climate-induced changes pose risks to global coastal ecosystems. The US, like many other coastal nations, is aware of the causes, effects and impacts of climate change. Like others, it is developing and implementing mitigation and adaptation strategies. But do these plans take full account of coastal ecosystem values and, as such, prioritize their wellbeing in existing policy instruments. At present that answer is no.

Current US policies, particularly those supporting coastal development and disaster assistance, are prioritizing development over coastal ecosystem protection. The current paradigm incentivizes the discounting of existing and emerging coastal risks. When coastal disasters occur, federal assistance subsidizes relief efforts with direct payments, redevelopment loan guarantees, and other financing for projects including hard armoring, soft-armoring, and beach nourishment. As has been shown in the literature and explained in this paper, these mechanisms not only lower the perception of risk, but they also induce additional demand and new development in risky coastal areas. More development and financing yield a greater overall investment in these coastal regions. This supports higher property valuations, prioritizing adaptation and mitigation policies towards protection of these assets through seawalls and nourishment projects that collectively lead to coastal ecosystem degradation. In many ways, the US is caught in a cycle of investment and reinvestment that blinds itself to meaningful coastal ecosystem protection.

It is clear that if the US is to break this cycle of coastal investment and reinvestment, it must fundamentally alter its current policies that, collectively, discount the evolving risks at its coastlines. It may be difficult to fully internalize the multitude of values of coastal ecosystems into policy development. It will certainly be difficult to gain support from an ill-informed public. But much can be achieved by removing the externalization of risk in current policy through the multitude of subsidies overviewed in this paper. By doing so, market forces free from distortions can better aid policymakers in balancing risk-adjusted demand for coastal living with the valuable services provided by coastal ecosystems.

The examination of US coastal policy provided here creates a template for examining coastal policies in other nations that exhibit similar characteristics of prioritizing development over coastal ecosystem protection. Similar among the US experience for most nations is the inability to fully internalize the values—particularly provisioning services—provided by coastal ecosystems. Different from the US experience will be the history of coastal development, the cultural dimensions, and the expectations of those who live along the coasts. In some cases, it may be easier to implement more proactive protection strategies in other coastal nations than is experienced in the US. And in some cases, it may be more difficult. While differences in analysis will likely occur, the framework of looking at existing policies as either barriers or pathways for coastal ecosystem protection is an important means of protecting planetary and human health under conditions of climate change.

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Chapter 12
Vulnerabilities of Waste Scavengers to COVID-19 Impacts: Outcomes of an Exploratory Study in Ghana

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Abstract The impact of the COVID-19 pandemic has affected multiple dimensions of daily activities, including the waste scavengers' activities. This paper focuses on the effect of COVID-19 on waste scavengers' business, income, quality of life and family quality of life in three Metropolitan, Municipal Assemblies in the eastern part of Greater Accra, Ghana. A questionnaire was distributed to 46 waste scavengers using a non-probability sampling approach for a voluntary response, from March to April 2021. The sample is mainly composed of 84.8% male scavengers, most aged 18 to 47 years old and married (58.2%). The results indicate that the majority of respondents believe that COVID-19 is real and poses a health threat, but more than 21% reported not wearing Personal Protective Equipment. The study showed that 60% of waste scavengers were prohibited from entering households, thus affecting the family life income. The less sale of waste material due to COVID-19 contributed to a lower income by the waste scavengers, causing different difficulties and financial insecurity. This study showed that waste scavengers in Ghana, an essential activity, are in the front line regarding the COVID-19 pandemic and public policies intended to cover their social, economic and health vulnerability to the virus, need to be addressed.

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Introduction

Human and planetary health explores the complex interactions between global environmental changes and human health and wellbeing (Demaio and Rockström 2015). The disturbance of one part weakens the rest, resulting in an imbalance, threatening the health of all species, human and non-human. The COVID-19 pandemic can be seen as an "wake-up call" to safeguard planetary health (Pachauri et al. 2021). The designed responses to deal with this pandemic must consider both human and planet ecosystems. The global crisis related to waste production, namely due to the increase of the use of plastic and non-biodegradable materials in the context of the COVID-19 pandemic (Prata et al. 2020; Patrício Silva et al. 2021) needs to gain more visibility, not only from the side of academia, but also from the stakeholders and governments perspective (Filho et al. 2021). Alongside, inequalities and vulnerabilities related to this phenomenon are somewhat neglected, speciality the long-term exposure of waste scavengers to waste hazards and, more recently, the COVID-19 pandemic impacts on their scavenging activities. In a context of intense urban growth and insufficient solid waste management activities in developing countries (Oliveira et al. 2020; Debrah et al. 2021a) a significantly growth of waste scavenger activities has been observed. In most developing countries, waste scavengers collect valuable material from landfills, container sites and households for a living (Gutberlet 2013), with many persons depending on this activity for survival. According to Medina (2007), the activities of waste scavengers provide billions of United States dollars (USD) income to over 15 million people in Asia, Africa, and Latin America.

In developing countries, 2% of the urban population depends on waste scavenging (Muhammad and Manu 2013). This activity leads to ecological and public health issues for both individuals involved and society (Debrah et al. 2021b). Some of the environmental and public health problems include the occurrence of injuries by sharp materials, hepatitis, and other infectious diseases from contact with infected waste (Aboagye-Larbi et al. 2014; Dinis 2016; Cruvinel et al. 2019), affecting the health and wellbeing (SDG3) of all involved, in particular of those that are more vulnerable and exposed to these issues. Waste scavengers are exposed to multivulnerabilities, i.e., due to their occupation they are more likely to be infected by the virus causing COVID-19 and, also, they have less ability to recover due to their poor socioeconomic condition. The health issues related to their occupation have worsened during the COVID-19 pandemic, thus negatively affecting their health and wellbeing. Waste scavengers are a paradigmatic example of how COVID-19 pandemic has severely affected developing countries (more than other countries in different situations) and underserved communities. Also, research pointed out skin, eye, and other respiratory infections due to polluted dust and smoke and chemical burn from hazardous waste (Mochungong 2011). The waste scavenging activities in most developing countries result from poverty due to unemployment (Simatele and Etambakonga 2015). Nyathi et al. (2018) estimated that an average of USD $91 income is generated per individual from waste scavenging in a month, in developing countries such as South Africa. In Ghana, about USD $7 to $17 are earned by a waste scavenger per day (Rockson et al. 2013), and most families depend on waste scavenging activities for daily or monthly income.

The activities of the waste scavengers in developing countries, including Ghana, have been reduced in recent times, mainly due to the global COVID-19 pandemic outbreak. The pandemic poses environmental and health threats and exposes waste scavengers to the risk of COVID-19 infection, particularly in developing countries, where waste scavengers are mostly stigmatized (Kampf et al. 2020) because of the nature of their work. The waste generated might contain the virus, which can then be transmitted to the waste scavenger. It is known that SARS-CoV-2 can survive for some days, depending on the surface, temperature or the medium where the virus finds itself (Adams and Walls 2020).

The spread of COVID-19 has not only threatened public health (Bai et al. 2020; Pérez-Campos Mayoral et al. 2020), but it has also hindered global economic growth (Lai et al. 2020; Magano et al. 2021), with developing countries being highly affected (Gita Gopinath 2021). This pandemic has disrupted the purpose and plans made by most of the low and middle-income countries in achieving the Sustainable Development Goals (SDGs), i.e., on poverty (SDG1), healthy conditions (SDG3), equal and quality education (SDG4), work opportunities (SDG8), among several others (United Nations 2015). COVID-19 has affected formal and informal sectorial jobs, with specific emphasis in developing countries. The significant negative impact on human health caused by the virus outbreak (Qiu et al. 2018) was expected to drive the death of 300,000 people from 122 million infections, with 2.3 million hospitalized in Africa (U.N. Economic Commission for Africa (UNECA) 2020). So, most African leaders established measures to prevent the COVID-19 pandemic's spontaneous spread by encouraging social distancing, imposing border and travel restrictions, school closure, and the prohibition on large meetings and both partial and complete lockdowns. Though these measures hindered the spontaneous spread of COVID-19, they have negatively affected the growth of the African economy between −2.1 and −5.1% in 2020 (OECD 2020), consequently expected to increase poverty in Sub-Saharan Africa.

As far as the authors are aware, there is only one other study conducted by Adekiya (2021) regarding the occupational risk of waste scavengers to COVID-19 in developing countries, revealing the need to further explore this specific group and their vulnerability to the COVID-19 pandemic.

To assess the impact of the COVID-19 pandemic in one of the important informal sector jobs in Ghana, an investigation was conducted on waste scavengers in some of the Metropolitan Municipal Assemblies (MMAs) within the Greater Accra region of Ghana. The research focused on the effect of COVID-19 on waste scavengers' business, income, quality of life, and family quality of life.

Methodology

Study area

The study was conducted in three of the MMAs in Greater Accra, Ghana. These MMAs are Tema Metropolitan, Ashaiman Municipal, and Kpone Katamanso Municipal Assemblies, located about 25 km to the east of the Greater Accra. The selected MMAs were chosen since the region's biggest engineered landfill site is situated within this area, thus attracting waste scavenging. Most places in this county have well-designed layout settlements with good roads, making door-to-door movement by waste scavengers easy, convenient, and accessible. This area was also selected because it has many industries purchasing recovered waste material. The biggest seaport in Ghana is located within the area, and therefore, it makes exporting and importing scavenging waste materials easier. Figure 12.1 represents the map of the studied MMAs in Greater Accra, including Tema, Ashaiman, and Kpone Katamanso county shaded.

Materials

The questionnaire development followed the steps proposed by past studies (Agarwal et al. 2021; Kumari et al. 2021). It was divided into two sections comprising different kinds of questions: 22% of open answered questions and 78% of closed answered questions. Due to the nature of interviewed waste scavengers participating, the survey necessarily comprised extremely simple questions; otherwise the expected response rate would be very low. Waste scavengers in Ghana are harsh to allow establishing direct contact and their availability to answer some questions is quite low. The survey was expected to be completed in 7 min. The first section collected information on socio-demographic data related to age, sex, marital status, education, and nationality. The second section collected information on waste scavengers COVID-19 awareness, operational activities, income, quality of life, and family quality of life. Because the waste scavengers were always moving from one scavenging place to another, making them non-static for a voluntary response, a non-probability sampling approach was used to administer the questionnaire (Parker et al. 2019; Saunders et al. 2020). In facing an emerging topic, such as the COVID-19 and waste scavengers, this sampling method allows to reach the results faster, providing up-to-date evidence (Bornstein et al. 2013).

The data collected was analysed using an exploratory-descriptive and a quantitative approach. The criteria for the selected voluntary response questionnaire were waste scavengers working at landfills, sanitary container sites, and those moving from door to door with wheelbarrows.

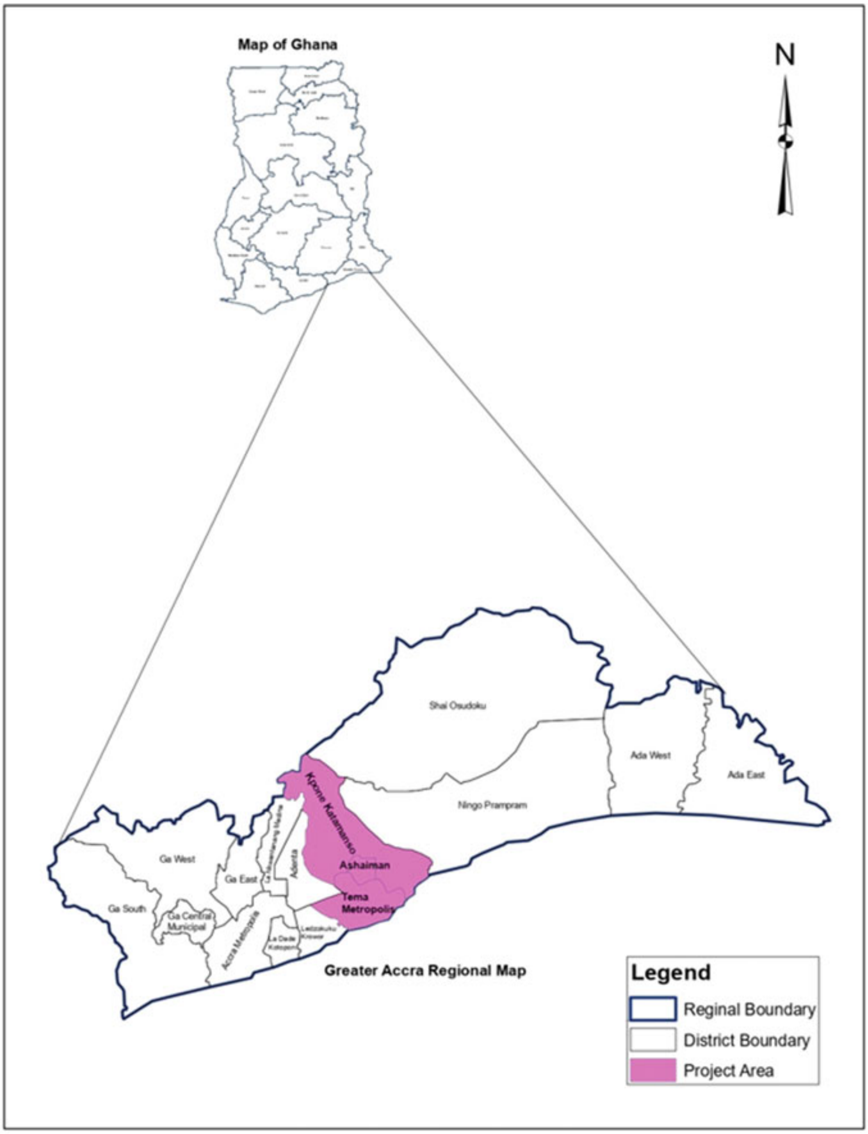

Fig. 12.1 Tema, Ashaiman, and Kpone Katamanso MMAs shaded on the map

Procedures

Due to the study nature of exploratory type, a self-administered questionnaire was administered to 46 waste scavengers from March to April 2021 through a convenience sample. Exploratory and preliminary studies are important to understand how to move forward in future procedures, which dimensions need further study and which deviations exist in relation to the respondents. According to Hallingberg et al. (2018), exploratory studies are also important to identify possible gaps in the design of the project and to provide vital information to support stricter analyses, reduce costs and minimize potential damage, where it is not expected to present a representative sample, as it is still in the process of completion and stabilization. Additionally, Daniel (2012) states that exploratory and preliminary studies involve small samples (which is sufficient) since the researcher does not intend to draw conclusive analyses, but rather analysis clues.

Waste scavenging is an unofficial and unregistered occupation, so there is not an official number of active scavengers. However, and according to the Secretary of the waste scavengers at those landfills, there are about 125 active scavengers in the study area.

All procedures were in accordance with the ethical standards of the Ghana Health Service Ethics Review Committee, no specific reference assigned, date acting as reference identification (2 November 2020), approved, and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was made available and obtained from all individual participants included in the study. Data anonymity and confidentiality were assured to all the participants.

Results

The data collected from the 46 waste scavengers' respondents were divided into two categories. It consisted of the demographic profile of the scavengers and COVID–19 effects on business affecting income, quality of life and family quality of life.

Table 12.1 presents the socio-demographic profile of the interviewed waste scavengers, regarding age, marital status, education, gender, and nationality.

The results in Table 12.1 show the sociodemographic characteristics of the waste scavengers in the three selected Tema, Ashaiman, and Kpone Katamanso MMAs in Ghana. Most of the waste scavengers are in the range of 28–37 years old, representing 41.3%, and only 2.2% are more than 48 years old, emphasizing that this is an activity mainly performed by the Youngers. Also, 58.7% of the waste scavengers are married, 39.1% are single, and 2.2% are widows/ers. The responses also reveal the waste scavenger's educational level: 78.3% have had some level of formal education, and the remaining have no formal education. Out of the 78.3% with some formal educational background, 41.3% had their education up to the basic level, 32.6% managed to continue to secondary school and only 4.3% entered tertiary education. These results highlight that this activity is mainly carried out by poorly educated individuals, as expected.

The results further showed that 84.8% of the waste scavengers are male, being essentially a men's activity. The study's data indicated that 82.6% of these waste scavengers are Ghanaian, with the remaining from abroad.

Table 12.1 Socio-demographic characteristics of inquired waste scavengers in Ghana

Variables	*N*	%
Age group		
18–27	15	32.6
28–37	19	41.3
38–47	10	21.7
≥48	2	4.3
Marital status		
Single	18	39.1
Married	27	58.7
Widow/er	1	2.2
Education level		
No education	10	21.7
Basic school	19	41.3
Secondary school	15	32.6
Tertiary	2	4.3
Gender		
Male	39	84.8
Female	7	15.2
Nationality		
Ghanaian	38	82.6
Foreigner	8	17.4
Total	46	100

Table 12.2 also presents the impact of COVID-19 on the waste scavengers' business and quality of life.

Table 12.2 demonstrates that most of the inquired Ghanaian waste scavengers already practiced the activity before the COVID-19 pandemic. 39.1% have been scavenging waste for a period between 3 to 5 years, and 26.1% have been scavenging for 6 to 8 years. The study also found that 15.2% of the waste scavengers have been scavenging waste for more than 12 years. 19.6% of the waste scavengers started working within 0–2 years before the inquiry. Waste scavengers operate either at landfills, container sites or moving from house to house. The study showed that 82.6% of the waste scavengers collect their waste at the landfills, 10.9% move from house to house and 6.5% collect at container sites. Though the waste scavengers are moving from door to door, 60% are banned from entering the places during the COVID-19 pandemic.

Though 80% of the waste scavengers reported believing that the COVID-19 pandemic exists, 15.2% of the participants do not believe it is real, and 4.3% of

Table 12.2 Work and COVID-19 waste scavenging related issues

Variables	*N*	%
Years of work		
0–2	9	19.6
3–5	18	39.1
6–8	12	26.1
9–11	0	0.0
≥12	7	15.2
Scavenging area		
House to house	5	10.9
Container sites	3	6.5
Landfills	38	82.6
Do you use protective wear?		
Yes	34	73.9
No	12	26.1
Does COVID-19 exist?		
Yes	37	80.4
No	7	15.2
I don't know	2	4.3
Has COVID-19 affected waste scavenger business?		
Yes	37	80.4
No	9	19.6
Are waste scavengers prevented from entering households?[a]		
Yes	12	60.0
No	8	40.0
Is the activity of waste scavenger in high risk of COVID-19?		
Yes	36	78.3
No	7	15.2
I don't know	3	2.2
Has there been an increase in sales of waste scavenging material during COVID-19?[b]		
Yes	7	15.2
No	29	84.8
Do waste scavengers have enough waste in COVID-19 pandemic?		
Yes	8	17.4
No	36	78.3
I don't know	2	4.3
Has scavenging sales decreased the income level during the COVID-19 pandemic?		
Yes	37	70.4

(continued)

Table 12.2 (continued)

Variables	*N*	%
No	8	17.4
I don't know	1	2.2
Has COVID-19 affected the family quality of life?		
Yes	39	84.7
No	6	13.0
I don't know	1	2.3
Total	46	100

Notes [a] Missing $n = 26$; [b] Missing $n = 10$

the waste scavengers do not know what to think. However, 80.4% of waste scavengers believe that the COVID-19 pandemic has seriously affected their business putting a lot of stress on both family and their own quality of life.

The research showed that 78.3% of the respondents believe that their activity is vulnerable to COVID-19, but 15.2% do not believe so. 73.9% of the waste scavengers wear Personal Protective Equipment (PPE) such as hand gloves, nose covers or safety shoes. It is also clear that 78.3% of the respondents believed that there had been a decrease of collected material by waste scavenging, with 17.4% stating that there has been an increase in collected material. 84.8% of the surveyed waste scavengers have seen their waste scavenging activity decreased by more than half during the COVID-19 pandemic.

According to the waste scavengers' reports to the survey, 70.4% of the respondents revealed that the sales of waste scavenging activities have reduced during the COVID-19 pandemic. This has caused a reduction of their income due to the lack of sales attributed to the drastic decrease of waste scavenging materials in the COVID–19 pandemic. It is significant that 84.7% of the respondents mentioned that the COVID-19 pandemic had affected their family's quality of life.

Discussion

This paper aimed to explore how the COVID-19 crisis impacted waste scavengers' operational activities in three MMAs in the eastern part of Greater Accra, Ghana.

The study showed that more men are waste scavengers in Ghana, contrary to the study conducted in South Africa by Nyathi (2018), which indicated that both men and women are equally involved in waste scavenging. However, this study confirmed Magaji and Dakyes's (2011) findings that waste scavenging activity was primarily made by males in Abuja, Nigeria, another developing country.

The study revealed that most waste scavengers in the studied MMAs in Accra, Ghana, were between 18 and 47 years old. Most of them were scavenging waste due to the absence of formal jobs requiring their services. No respondents or waste scavengers under 18 years in the researched area were identified, which contradicts the Owusu-Sekyere (Owusu-Sekyere 2014) study in Kumasi, Ghana with 30 respondents reporting that some of the waste scavengers were below 18 years old. The absence of waste scavengers under 18 years might be attributed to the Ghana government's new direction of free mandatory primary education and free senior high secondary level policy (Ministry of Education 2019). This has led to an increase in school enrolment because no child is allowed to pay anything, i.e., education is now free. Under the current free secondary education at Ghana public schools, all children's fees are paid by the Ghanaian government, including free uniforms and food. As a result, free education has promoted lifelong learning and educational opportunities for all (SDG4). which is expected to reduce inequality (SDG10) in all aspects of life by 2030, where free education is expected to be achieved. However, this research reported that only 4.3% of the interviewed waste scavengers managed to complete tertiary education. 21.7% of the waste scavengers had no education level, with most dropping out at the primary level, with only 32.6% advancing to secondary school. It is important to highlight that some of these waste scavengers could not complete secondary education due to financial constraints imposed by a lack of available job opportunities and corresponding monetary support.

The collected data reveals that 58.7% of the waste scavengers are married and 39.1% are single. 15.2% of the waste scavengers who were from abroad are all married and their families remain in their respective countries.

The analysis of the results indicates that about 82% of the waste scavengers in these MMAs operated at the landfills, with the remaining 22.6% working at container sites and moving from house to house. 65.2% of the waste scavengers have worked between 3–8 years since they started scavenging waste. About 15% of waste scavengers had worked for more than 12 years, thus showing the importance of this activity in Ghana, considered as a family business, transferred from one generation to the other. In Ghana, the waste scavenging activities help in reducing the impact of climate change (SDG13) by collecting up some of the littered materials from the environment for being recycled and reused (SDG11 and SDG12), supporting the environmental sustainability and contributing to keep drains clean from flooding.

Though more than 80% of the waste scavengers believed COVID-19 exists, its acknowledgment has contributed to enhance the awareness of the hazardous materials collected by waste scavengers at the landfill or containers. However, 15.2% do not recognize the existence of the present COVID-19 pandemic. These waste scavengers can be infected from COVID-19 contaminated waste, transmitted from one person to the other if the waste scavengers do not wear the necessary PPE, and observe the required social distance. The data collected also showed that 21.6% of the waste scavengers do not wear any PPE when scavenging waste at the various waste collection points, thus contributing to the eventual surge of future health issues. Some of the health issues deriving from the lack of PPEs could include headache, diarrhea and shortness of breath (Nyathi et al. 2018). Though a high percentage, of the waste scavengers report using the PPE, 73.9%, it was observed that some do not respect the necessary social distance and could not wear the protective gear long due to the heat, dust and rigorous nature of their work, which makes them sweat profusely, also originating other health issues and headaches.

The research further indicates that 80.4% of the respondents' waste scavenging business was affected by the COVID-19 pandemic. Some of the effects include 60% of waste scavengers prevented from entering households due to the fear of infection, resulting in less waste being collected, with consequences in the income of those involved in the activity. However, the data showed that about 70% of the waste scavenger respondents did not get enough waste recycled material collected during the COVID-19 pandemic, which has affected 80.4% of the waste scavengers' sales, resulting in a massive negative impact in the income. The dropped in sales of the recycled waste collected from the partial lockdowns and restrictions to social activities such as parties, funerals, attending to beaches, night clubs, and others, where significant waste is generated, greatly affected the income resulting from this activity. The corresponding drop in sales has affected the waste scavengers' quality of life and that of their family's too, resulting in a poorer standard of living and financial insecurity due to the COVID–19 pandemic, threatening SDG8 related with economic growth and work opportunities and SDG1, no poverty, from achieving by 2030. 84.7% of the waste scavengers attributed the family quality of life to financial issues because they are unable to provide economic family needs due to the COVID-19 pandemic. Waste scavengers' life satisfaction, including leisure and social interactions with friends and relatives, education for the children (SDG4), and promotion of a healthy lifestyle (SDG3), were negatively affected due to financial constraints resulting from the impact of the COVID–19 pandemic continuous lockdowns and restrictions.

The study further revealed that due to the partial lockdown and cancellation of social meetings by the Ghanaian Government, as it happened worldwide, families could not visit relatives and loved ones, which has affected family relationships, especially those involving children. The study by Banati et al. (2020), conducted in the low and middle-income countries, reports that the COVID-19 pandemic had reshaped relationships, education and wellbeing of young people. The respondents of this study also realized that the COVID-19 had widened the existing inequalities among the waste scavengers, considered inferior people. Armitage and Nellums (2020) found that most children are disadvantaged in this COVID-19 pandemic, since they pay the most significant price due to falling further behind in academics due to the fewest resources available to catch up with the rich ones when the present pandemic threat is over. So, while the rich people managed to organize online or access internet classes for their children, the waste scavengers could not afford doing it for their children. This has caused a lot of stress on the families, and the children have seen their academic efficiency in school reduced, affecting the family quality of life.

Conclusions

Developing countries and African countries, in particular, were severely affected by the COVID-19 pandemic. Even though the impacts are far from being fully known, waste scavengers were deeply affected by the collateral impacts of the present COVID-19 pandemic. To further explore pertinent issues related to the waste scavenger's income, quality of life, and of their families, a self-administered questionnaire was applied to 46 out of 125 waste scavengers in three MMAs in the eastern part of Greater Accra, Ghana. It was found that waste scavenging is an activity mainly performed by men and less educated individuals. The findings of this exploratory study show that the COVID-19 pandemic has negatively impacted waste scavengers' lives and activities. Most of the waste scavengers were left out of business due to the lack of waste collection they depend on for sale and consequent income, on a daily basis. This COVID-19 pandemic has also affected the quality of waste scavengers' family life. The restrictions imposed on social meetings and other activities due to the COVID-19 pandemic have resulted in strong economic implications on the waste scavengers' activity, increasing the risk of poverty and vulnerability to health risks, so important in the context of developing countries, threatening SDG1 and SDG3. Lastly, the COVID-19 pandemic has widened the academic knowledge gap between the poorer and the richest, resulting in additional inequalities among children, thus affecting SDG4 and SDG10. To avoid worsening inequalities that will undermine sustainability efforts, public policies in Ghana should address the waste scavengers' activity significantly contributing to the income of the poorest people, aiming to promote employment and health and enforce the policies involving education.

Some limitations need to be pointed out. Being an exploratory study in the context of a developing country like Ghana, limited the data analysis to be carried out. Considering the simple nature of the questions integrating the survey, statistical analyses were merely descriptive. More robust statistical analyses should be attempted in future studies. Regarding the questionnaire used, it will be important to perform some improvements in future studies, such as integrating specific questions related to the health impacts of COVID-19 on waste scavengers. This subject needs to be developed in future studies aiming to further study the waste scavenger's reality in Ghana, a goal to be pursued through simple questions, considering the low level of education of the respondents. Also, it would be important to achieve a larger number of respondents in the near future, although waste scavengers in Ghana do not easily allow to establish direct contact and their availability to answer questions is low.

Although limited in scope, this study is considered important and is valued in the context of developing countries, such as Ghana, aiming to contribute to global sustainable development at this level. A need for a long-term vision and recommendations considering both human and planetary health is urgent to properly address these multi-scale issues.

Acknowledgements The authors would like to thank to Adu Stephen by the figure construction. Also, the authors would like to express their gratitude to all the study participants.

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Chapter 13
Impact of Tourism Activities on Human Health and the Environment of a Riparian Ecosystem in Mexico

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Abstract Historically, humans use natural resources for recreational purposes such as tourism. Studying the state of conservation and evaluating the impact of tourism on riparian ecosystems, is basic information to propose mitigation measures and environmental control. The objective of this study was evaluated the impact of tourism on the environmental characteristics of the riparian ecosystems of basin Jamapa, Veracruz, Mexico. (a) water quality (analyzed physicochemical and microbiological characteristics of water); (b) intensity of landscape use (161 questionnaires were applied to tourists and managers of riparian ecosystems; it was asked about the environmental damage and to human health, and this was classified with a problem tree), and (c) landscape quality (tourist´s assessment of the aesthetic appearance of the landscape and the presence of pollution indicator plants), were three environmental indicators evaluated. Indicators classify this riparian ecosystem with high degree of environmental deterioration: water presented fecal microorganisms that affect human health such as gastric and skin problems; the waste generated by tourists pollutes

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_13

the riparian ecosystem, causing a decrease in its quality and environmental value; on the riverbank, plants have indicatory of contaminated soils. Influence in the area with public policies of conservation and sustainability, would allow a sustainable ecotourist to use and improve human health.

Introduction

Water is a natural element, a renewable resource that is essential to the survival of species (Chávez 2018), is one of the most important natural resources on our planet and is the connection between society and the environment (ONU 2018). Globally, it has been estimated that there is an average of 1,386 million km3 of water available per year. Of this total, however, only 35 million km^3 (2.5%) comprise fresh water. Of this, 70% is unavailable due to being found frozen in glaciers, snow, and ice, and only 135 thousand km^3 exist as lakes, rivers, soil moisture, air humidity and in wetlands, plants and animals and that is utilize for consumption (Ali et al. 2016).

As the world's population grows, demand increases, intensifying the competition with commercial requirements for hydric resources, so that communities can have sufficient water to satisfy their own needs (ONU 2018). Given the decreasing availability of potable water worldwide, approximately one fifth of the world´s population suffer from a scarcity of water according to reports published during the last ten years (Jackson et al. 2001; Tapia-Silva 2014). This is due to a range of problems, ranging from overexploitation of the aquifers, the natural distribution and disposition of the water, contamination and a lack of control over concessions (Tapia-Silva 2014).

All human activities, since agriculture and livestock production, industry, health or services, have direct and indirect impacts on the environment, especially when developed in an unsustainable manner (Aronson and Clewell 2013). To minimize damage and to assume an ecologically appropriate management, different measures are often taken based on the results of environmental diagnostics. This can help the restoration of ecosystems, as well as conservation of the natural capital, such that it can be freely enjoy and utilized by society (Aronson and Clewell 2013).

For example, for the planning of basic resources such as water, the diagnostic should be based on the protection, rational use and sustainable management of the resource. In recent years, the need to establish methods to benefit natural resources has led a constant increase in the creation and application of these diagnostics (Troyo 2011). In the environment, as other fields, indicators were developed to understand, describe and analyze different socio-ecological phenomena (Semarnat 2011). A diagnostic of the socio-environmental characteristics of the Tequecholapa River it was applied, in order to determine the state of conservation or degradation of this water recourse in Veracruz State, México.

Method

Study Area. The municipality of Naranjal is located in Veracruz, Mexico (Fig. 13.1) and comprises nine localities and 4,742 inhabitants, regarded as a rural municipality with a high degree of marginalization, but one in which exist different sites with Eco-touristic potential that could contribute to an increase in the quality of life of the inhabitants of the municipality. Its climate is temperate-humid, with a mean annual temperature of 21.4 °C, abundant rains in summer and the beginning of autumn, and an annual mean rainfall of 2,106 mm. Presents land uses of agricultural land (89%), urban zones (7%) and tropical forest vegetation (4%). Minerals such as alluvium and limestone represent its richness. Presence of species of sweetgum, oak, ash, cottonwood and willow, hosting a fauna composed mainly of rodents and birds, such as wild doves, hummingbirds, woodpeckers, sparrowhawks and owls (Instituto Nacional para el Federalismo y el Desarrollo Municipal 2016); Secretaria de Finanzas y Planeación 2020).

A diagnostic was conducted following three indicators, in order to understand the problems that exist in the site, factors that influence these situations, potentialities of the site, public opinion and the possible solutions that could be applied.

Indicator One: Water Quality. With the aim of comparing the parameters obtained and determining the factors related to the alteration of the water resource, was conducted in monitoring of water of three phases of analysis. The first analysis was conducted in the month of February, the second in March (a period defined by the spring vacation) and the third analysis was conducted in April. To determine if the quality is adequate, water analysis was conducted using for referencing the Mexican Official Norm NOM-127-SSA1-1994, “environmental health, water for human use and consumption-permissible limits of quality and treatments to which water must

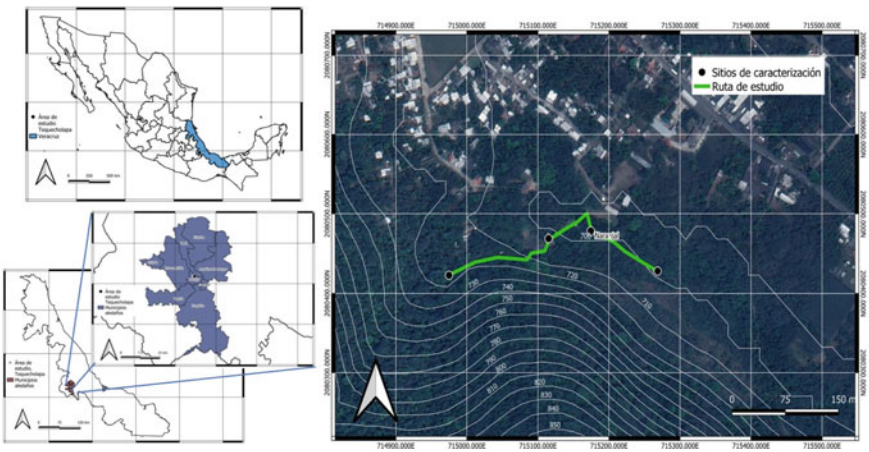

Fig. 13.1 Localization of the study area and sampling sites evaluated in this study

be subjected for potabilization". The physico-chemical study determined the level of metals, alkalinity, dissolved solids (Sánchez and Perevochtchikova 2012). This procedure was replicated five times for each site.

In each analysis, were made following the indications of NOM-014-SSA1-1994. The analysis was microbiological and physico-chemical, for which season, once the samples were taken, they were analyzed in the Laboratorio de Microscopia of the Faculty of Biological Sciences and Agriculture of Veracruz University (FCBA). With the applied microbiological analysis, to determine the microorganisms present in the water samples (Camacho et al. 2011), the pathogenic microorganisms present in the water were isolated and identified (Obon 2017).

The data from the microbiological and physic-chemical analyses were evaluated using a multivariate analysis. This utilized the partial least square (PLS) technique, which serves to analyze relationships among the variables, helping to explain the observed data, analyzing the approach in the distribution of the data (Ávila 2018). This analysis was conducted in order to describe more clearly the situation regarding the water quality in the river. For this, the program Infostat was used (Di Rienzo et al. 2012).

Indicator Two: Intensity of Use. A survey with 31 multiple-choice questions and one open response question was applied, to determine the activities of the local inhabitants in the Tequecholapa Rive. Validation of the survey was conducted by applying a cognitive pretest or pilot test to a set of 30 people. To obtain the sample size (number of subjects to survey), the following formula was used, as recommended by Vallejo (2012): $n : \frac{N}{+1\frac{e^{2(N-1)}}{Z^2pq}}$ where: n: total number of subjects to interview, N: known population size; e: acceptable error margin; Z: acceptable confidence level; pq: variance of the population.

According to this formula, with a population of 4,742 people, a confidence level of 90% and an error margin of 5%, the number produced by the calculation for the adequate application of surveys was 161. The surveys were applied in the study area, in the different sampling sites, during three days of the spring vacation.

With the results of the survey, a problem tree was built to identify the problem and organize the information compiled, generating a model of causal relationships (Hernández-Hernández and Garnica-González 2015).

Indicator Three: Landscape. In the study area, the forestry coverage was estimated (Conafor 2018) for landscape assessment. In each site (Fig. 13.1), to estimate the herbaceous stratum, a quadrant of 1 × 1 m was established and all of the herbaceous plants present within identified. For the shrub stratum, a quadrant of 5 × 5 m was established, and all shrubs present within were identified. For the arboreal stratum, a circular plot of radius 18 m was established, and all trees present within were identified (Conafor 2018).

Fieldwork was conducted, by trips along the bank of the river. In the sites, we found and subsequently identified species that indicated the cleanliness of the ecosystem, and others that indicated its alteration. Each species was subsequently corroborated using the website www.tropicos.org.

Results and Discussion

Indicator One Water Quality. The results reveal the existence of factors that are the causes of the changes that occurred during the period of these three samplings (Table 13.1). We observed that the levels of the biological elements and organisms were lower than in the subsequent analysis, more specifically, site 1 was indicated to be the least disturbed site. The opposite was observed in site 3, which presented the highest levels. Indeed, all four sites increased in levels of biological elements and groups, but site 3 presented the most significant changes. The third analysis provided important values, since it showed how the values decline. Comparing our results with the permissible limits it was found that the first analysis showed within the limits set out in NOM-127-SSA1-1994, with values very much lower than the term. For the values that are not mentioned, water analysis literature has been cited and it was found that they are also below the limit, thus taking into account the veracity of NOM-127-SSA1-1994. Besides the Official Diary of the Federation on 22nd of November 2000 indicated that the Tequecholapa River is not considered to be in a serious state and is thus suitable for consumption.

In the first water analysis, site 1 presented elevated levels of K, which did not seem to affect the presence of the protozoans, apart from the *Spirogyra*, which is slightly projected in relation to site 1. Site 2 presented the lowest levels of chemical parameters. Site 3 and 4 presented the highest levels of NO_3 and relatively high Na, with the latter indicating a positive projection for the presence of spirogyra (Fig. 13.2).

In the second water analysis, site 1 seems to be in the best condition compared to the other sites, presenting low parameter levels and apparently no correlation. In site 2, relatively low levels of K were recorded but high level of NO_3. Site 3 and 4 presented an elevated level of Na and NO_3 (Table 13.1), these is correlated with the four protozoan organisms in those environments, positively influencing the *Spirogyra* (Fig. 13.3).

The third water analysis (Fig. 13.4) indicated that, in sites 1 and 2 are correlated with the highest level of NO^3. In site 3 and 4, presented similar amount of the five types of protozoans, but particularly the *Fragilaria* and *Spirogyra.*

In the first analysis, site 2 presented the lowest levels of mineral and protist, then best environmental condition compared to other sites. Noting that this is the site into which is discharged water of continuous use from a swimming pool that is open to the public. It could be due to the adequate cleansing of the site that the levels of elements and organisms present are better even than those of site 1. In contrast, site 4 presented the worst conditions (noting that this is the touristic end of the river), since it presents a higher pH than all of the other sites and a slight increase in *Fragilaria* compared to the other sites. Nevertheless, all of these parameters were still within the permissible limits for human consumption and were not considered prejudicial to health. For the second water analysis conducted in the month of March, vacation season, the best environmental condition was presented in site 1 (where the water

Table 13.1 Results of the measurements of water parameters and organisms present during analysis; and comparison between the obtained parameters and the permissible limits as stated in NOM-127-SSA1-1994. Asterisk indicates exceeded values

Physicochemical characteristics						Biological characteristics				
Reference	NOM- 127	6.5–8.5	Not stated	10	200					
Fase analysis	Sites	pH	K	NO_3	Na	*Lepadella*	*Spirogyra*	*Flagelaria*	*Paramecium*	*Vorticella*
First analysis (February)	1	7.71	166.4	2.8	17	0	5	0		
	2	7.8	42.6	1.2	13.8	2	2	1		
	3	7.75	89.4	3.6	14.6	3	7	3		
	4	7.93	79.6	4	17.6	4	6	4		
Second analysis (March)	1	7.94	57.5	22*	175.2	2	0	0	3	
	2	7.6	27.5	28.7*	81.8	5	9	4	3	
	3	8.05	54.7	11*	804.2*	8	13	8	6	
	4	8.17	61.2	20.5*	972*	7	17	7	4	
Third analysis (April)	1	7.72	10.2	35.8*	8.2	2	3	8	0	0
	2	7.8	28	53.4*	9.5	2	7	11	0	0
	3	7.93	83.6	18.6*	10	8	13	23	8	3
	4	7.63	29.4	12*	9.2	8	10	19	7	2

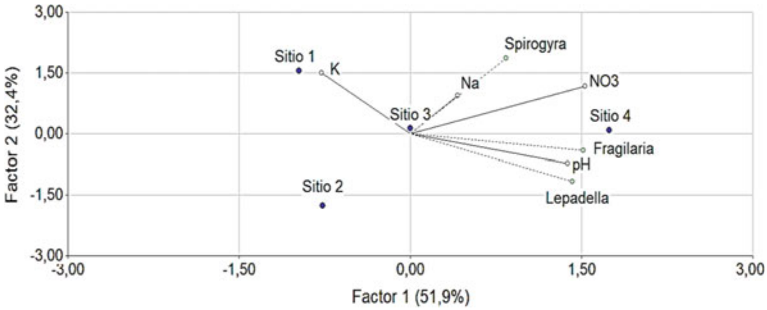

Fig. 13.2 Result of Partial Least Square (PLS) technique, which serves to analyze relationships among the variables of 4 chemical parameters and 4 sites against a matrix of 3 protozoan's species

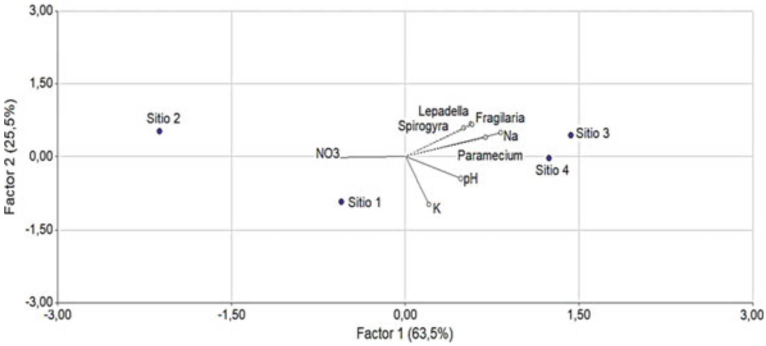

Fig. 13.3 Result of Partial Least Square (PLS) technique, which serves to analyze relationships among the variables of 4 chemical parameters and 4 sites against a matrix of 4 protozoan's species

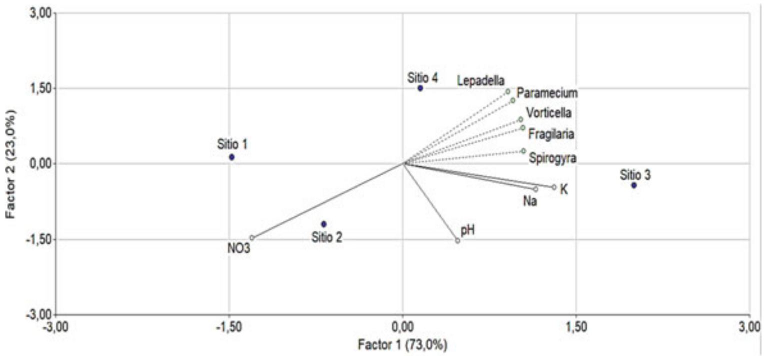

Fig. 13.4 Result of multivariate analysis, Partial Least Square (PLS) technique, which serves to analyze relationships among the variables of 4 chemical parameters and 4 sites against a matrix of 5 protozoan's species

springs naturally from the mountains), in which all of the elements and organisms presented their lowest values of all four sites.

The worst environmental condition was presented in site 3 (where grey water directly enters the river), in which the main element present was Na. Sodium is found naturally in the water, since it comes from the rocks and soil (Can et al. 2008). However, the levels present exceed the permissible limits, which could be due to the large number of people in the river at this time of the year since we know that the human body releases substances, mainly potassium and sodium, in sweat, explaining the relatively high levels of these two elements compared to the first water analysis, when they were within the permissible limits. Sodium at levels higher than 157 mg/L in the water presents serious problems for fish, causing illness or even death and the subsequent loss of these organisms from the water body. For humans, ingesting too much sodium is prejudicial to health, causing problems that range from edemas to hyperosmolarity (Can et al. 2008).

In the second and third analysis, site 3 showed the highest levels of elements. Nitrates are also naturally present in the water in low quantities, but products such as fertilizers contribute to the increase in this element (De Jong et al. 2007). The most abundant organisms were the Spirogyra and *Fragilaria.* The former are algae that are commonly found in bodies of fresh water, while the *Fragilaria* are different types of diatoms that act as good indicators, since they constitute a large part of the primary productivity (more specifically, to the rate of photosynthesis). In sites 3 and 4, where they are most present, they are associated with the soil sediment and algal walls (Segura-García et al. 2012).

Of the whole area covered by the river, the cleanest site is that where the water springs naturally and gives rise to the river itself. Here, the pH is in its acceptable state, even at the times when the other elements act to alter it. A balanced pH indicates good water quality, since it is neutral. If it were low, it would damage the fish or even cause their death (Gangwar et al. 2012). Sodium was also found within the limits in the three sampling periods, while the nitrates exceeded the limits only in the presence of many people during the vacation season. Under normal conditions, the presence of nitrates is considered acceptable.

From the data obtained in the surveys, 68% of the use is for consumption, while the main activities conducted are swimming (68%), washing (12%), bathing (9%) and others (11%) (Including walks, taking exercise, selling of products and spending time with the family).

The perception obtained in terms of the environmental aspects indicated that more than half of the population is aware that there is a problem in their river (Fig. 13.5). The degradation and loss of forest cover is since more areas free of vegetation are required at this site to allow the movement and relaxation of the tourists visiting the river. To this can be added the practices of sowing and grazing, which are factors that contribute to the loss of the original deciduous forest. Degradation is an important process that must be evaluated, especially in relation to changes in biomass and biodiversity (Keenan et al. 2015). It is necessary to find a balance between the ecosystem and the tourism, in order to satisfy the needs of tourism in a sustainable manner.

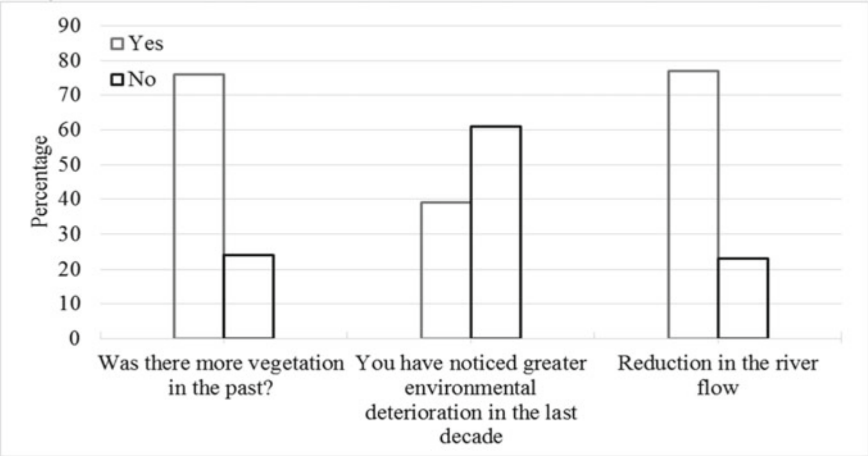

Fig. 13.5 Public perception for decline in vegetation, environmental deterioration and reduction in the river flow Tequecholapa River

Garbage not only prejudices the appearance of the landscape, but the materials of which it is composed can also act to modify the chemical and physical conditions of the location where they are disposed, and to modify its original composition. In this case, as well as the superficial contamination of the river, in the places where the garbage is found, liquids filter that contaminate the water and damage the aquatic species. The disposal of garbage in streams causes reduction and obstructions in the flow of water, which in the case of strong rains can cause flooding that affects the population, to give some of many examples. More than 70% of the respondents reported the real problem of diminution of the water flow. This is a problem that is given notably more prominence than the others are, since it is something that has even been reported to local media as a crime, alleging that the problem is due to deals made by the municipal government for their own benefit, selling the river water to other municipalities. The Comisión Nacional del Agua in México is the body that establishes that the hydric resource is for everyone and that no-one can be denied it (Conagua 2016). While the fieldwork was ongoing, during the observation period, a considerable change was noted in the volume of water in the river.

The reduction in river flow is a real problem; however, there still are resources for the capture and retention of water. The river receives the support of the population to maintain a favorable state for society and its habitat, an example of one human activity acting to ameliorate another (Fig. 13.6). This is just one of the multiple methods used in ecological rehabilitation, the objective of which is to improve and accelerate natural processes of regeneration (Vargas 2007).

In terms of the season of greatest demand in our water body, we can refer to two situations. The first is its use in terms of the exploitation of national waters for consumption by society, and the second, is that of the activities that take place centered on the water body itself. According to Fig. 13.7, 109 people, representing

Fig. 13.6 The Tequecholapa River landscape and examples of microorganisms in water samples

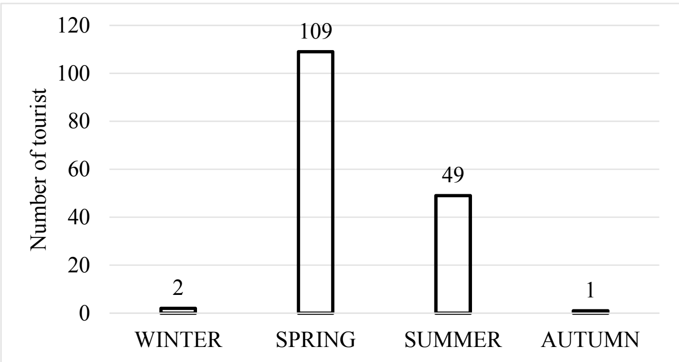

Fig. 13.7 Number of tourists visiting the site according to season of the year

68% of the population that visits the Tequecholapa River in the season of spring, many people coincide in their justification of this because it is a short vacation period for which reason; they do not have the time to plan a longer trip. The river at their disposal is therefore the perfect place to go to enjoy oneself during this vacation.

Another 30% prefer to visit the site during summer since they say the climate is warmer and the water is perfect at that time of the year. The remainder is divided

Fig. 13.8 Example of the regulatory posters in the study area

between the two remaining seasons of winter and autumn when, although the climate is not suitable, the people prefer the tranquility than the water temperature. Taking this into account, it is very clear that the people visit the area more between the months of March and June. For this reason, the activities in the environmental aspects intensify in this period, which leads us to conclude that this is the time when good management or administration should be carried out as correctly as possible. However, from the fieldwork, it became clear that there were no patrols or committees of cleansing and security in the area, the rules and prohibitions only appear on paper posters (Fig. 13.8). Such that when these decompose, they form yet another piece of garbage to add to the rest, and of course the fines and sanctions are never applied.

A tree of problems (Fig. 13.9) and solutions (Table 13.2) was produced, in which the objective was to explore the three main problems identified by the population itself: (a) contamination, (b) maintenance, and (c) diminution of river flow.

Species were sought that could indicate contamination or cleanliness, utilizing the work of measurement of the forest cover, in addition to the visual evaluation of the people regarding the site. Below, a description is given of the situations in which the sampling sites of the Tequecholapa River were found.

Site 1: This is the site least visited by people. On arrival at the site where the water springs, we found liverwort plants at a distance of no more than 2 m. These bryophytes are indicators of good environmental quality, and are sensitive to contaminated air (Díaz 2005). We found these plants in great abundance, indicating that a constant humidity exists at the site. They were also of large size and of a darker green color, which is an indicator of the water purity. Another good signal in the site is that we found *Phytolacca dioica* a tree that is not present in disturbed sites. Out of the water, we found specimens such as *Xanthosoma robustum* on the riverbank and *Hedychium gardnerianum*. The former is an indicator of contamination of the soil since it grows in more acidic substrate. It should be noted that two main aspects interact in the

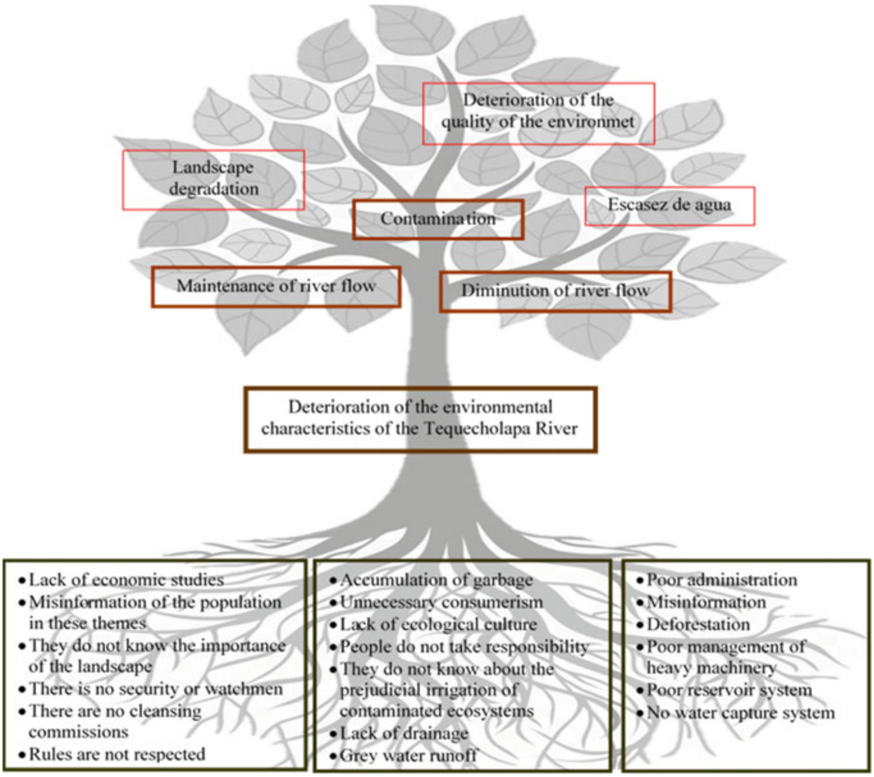

Fig. 13.9 Tree of problems-solutions detected in the Tequecholapa River, Veracruz, Mexico

Table 13.2 Solutions proposed for each effect in the problem tree

Contamination	Maintenance	Diminution of river flow
Environmental education, mainly for the children and young adults	Informative posters	Create a reservoir system with the help of experts in this field
Wetlands for filtering water	Rules cited by the corresponding laws	Reforestation of the original vegetation of deciduous forest
Create a cleansing commission	Application of fines by the municipal authority	Water capture systems
More garbage bins, as dictated by Semarnat (1996)	Maintenance, cleansing, committees for patrolling	–

site; the first is the basic vegetation of the deciduous forest and the second is the opportunistic vegetation from the coffee plantation that is found neighboring the river source.

The botanic species of the shade coffee plantation are gaining space at the river source and replacing the original vegetation, since they are of rapid growth. There are other opportunistic plants, but these are present because the people have sown them. They include lemon (*Citrus lemon*), orange (*Citrus sinensis*) among others. However, there are also endemic plants such as *Brosimum alicastrum*, and others belonging to the genus *Peperomia.*

Site 2: We found *Cuphea hyssopifolia*, this is an indicator of water purity, it was found in small quantities. We found different types of grasses, the most common being star grass. Other species present were *Piper amalago*, *Hypoestes phyllostachya* which is a species introduced originally from southern Africa, *Pteridium aquilinum*, which is a pest and given time will cover the other vegetation. This describes practically everything from the site, since the people who visit the river, more heavily transit it, and evidently, the passage of people prevents more plant species from growing. The trees are scarce and most are introduced species.

There was an absence of deciduous forest. It could be seen at short distance that there was a greater quantity of the vegetation of the shade coffee plantation, but we also found *Dioscorea composita* which is an important medicinal plant, and closer to the river were species that have been introduced, such as the *Bursera simaruba*, *Ficus benjamina*, *Washingtonia robusta*, *Erythrina americana* and *Acrocomia aculeata.*

Site 3: The shrub stratum was practically absent. As in site two, the star grass is very abundant where the people do not tread, which are the edges of the river. We could find weeds and other plants such as *Bidens pilosa*, *Mimosa sensitive*, *Taraxacum officinale* and some species of verbena. The herbaceous plant stratum was very similar to that of site 2, since the same introduced species were present, along with some still conserved species such as *Prunus dulcis*, which is characteristic of the deciduous forest.

Site 4: There are trails or small paths along which the people transit. At the extremes, *Thunbergia alata* was present, and some species of *Penstemon* among those most abundant. At the other side of the river, we could observe *Costus arabicus*, which generally grows in swampy zones with high humidity (Monsalve et al. 2018) but its appearance was also due to the presence of soap in the water. The herbaceous plant stratum is completely absent, except at a distance could be seen vegetation of the shade coffee plantation, such as *Bouvardia ternifolia.*

In summary, the landscape was generally found to be disturbed, with a high degree of impact. There were opportunist species that had been introduced directly by people, and the species present allowed us to speculate that, the local inhabitants first arrived at the site and cut all the species of plants that were present, before sowing others according to their particular needs (in sites 2 and 3). Other opportunist examples were those that have been gaining ground from the shade coffee plantation located very close to the site. This has, in turn, increased the displacement of the original vegetation of the deciduous forest. There were sites where there is an almost complete absence of the two strata and this is due to the people who constantly walk along these paths, as well as cleaning and cutting the plants to open clear passage, although there were notable differences between where this occurs and where it does not. For example, in site 1 there were more shrub and herbaceous plant strata, while this was not the case for the other sites since these are the places where tourism is more highly concentrated. No more than three species were found that were indicators of contamination, but neither were many indicators of cleanliness or water purity found. However, the landscape still hosts species endemic to the forest, indicating that there is still time to work on it, i.e., there is still a point of return for the forest to be restored and, in turn, to improve the quality of the water.

Only 27% of the respondents gave the highest qualification to the landscape. It did not exceed 50%, which is half of the population, however, they agreed with the previous data regarding the deterioration of the environment. Despite this, however, more people defined the landscape as agreeable or attractive than as low and tarnished. Although the perspective did not officially prove the point of degradation or stability of the area, it is a good indicator of the appreciation and approval the people have for it and this is a factor that influences their decision regarding whether or not to visit the river (Fig. 13.10).

Vegetation of strata were found in a condition of decline in sites 2, 3 and 4 (Table 13.3). The arboreal stratum is 80% conserved in site 1, which is the least disturbed of all the sites. In the other sites, there is a great difference in which this stratum exists at lower presence. In terms of the lack of herbaceous stratum, we observed that sites 1 and 4 had the greatest abundance, but it remains insufficient, since it did not even reach 50%. For the other sites, the situation was even worse, reaching near total absence in site 2. Finally, for the shrub stratum, site 1 again had the best position

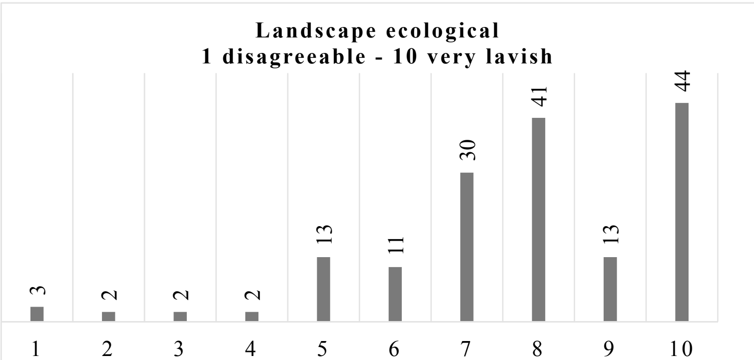

Fig. 13.10 Perception of the people regarding the appearance of the landscape

Table 13.3 Percentage of forest cover in the different sites of the study area

Sites	Arboreal stratum (%)	Herbaceous stratum (%)	Shrub stratum (%)
1	80	25	50
2	20	10	10
3	10	20	10
4	25	25	25

with a presence of 50%. In the other sites, there was no great difference, since they did not reach 25%, which is considered a very low value.

The main causes of the loss of the original forest cover are the anthropogenic activities, which are requirements that bring and will continue to bring serious consequences that affect one or many forms of the forest and the environmental services it provides (Brockerhoff et al. 2017).

Plant species that are indicators of contamination: *Hedychium gardnerianum* (grows in soils contaminated by detergent), *Xanthosoma robustum* (grows in acidic soils or those that have been altered by agrochemicals) and *Costus arabicus* (grows close to the outflows of drains contaminated mainly by detergent), and plant species that are indicators of cleanliness: *P. dioica* and *C. hyssopifolia*, does not grow in contaminated areas, a large group belonging to the class of liverworts what indicate an ecosystem free of contaminants. The indicator species have characteristics, such as sensitivity to contaminants, distribution, abundance or reproductive success. Consequently, they are classified and used to estimate attributes of other species or environmental conditions (Manteiga 2000).

The list of species was not greater than was thought at the beginning of the diagnostic, which helped to justify its application. However, despite the low number of plant species, it is reassuring to see that these are equilibrated in terms of what their presence indicates. Adding this to the other fields of this environmental indicator, we can conclude that the landscape is indeed disturbed. However, the same vegetation indicates to us that it can sustain, and with the help of human activities, rehabilitate and even restore this ecosystem.

Conclusions

Three microbiological and physicochemical water analyses were conducted in three periods, providing results that indicated the existence of a relationship in the increase of physicochemical elements and the biological groups found, which increase in levels during the use of the water because of the quantity of people present in the river.

In addition to these relationships, the general analyses of this biological indicator allowed us to determine the conditions of the water quality and conclude that, based on the norms established officially by the law, the environmental characteristics of the river are within the permissible limits, which is equivalent to that of a water body destined for human consumption.

A total of 161 surveys were applied to the public of the municipality of Naranjal. This provided different data that helped us to see the perspective of the people. Thus, the environmental and social importance of the water body to the community was determined.

This study diagnosed that the main problems in the area are the contamination, maintenance and flow diminution of the river, and action must therefore be taken regarding these factors in order to eliminate the risk of contamination and loss of the Tequecholapa River.

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Chapter 14
Planetary Health Begins on Campus: Enhancing Students' Well-Being and Health Through Prairie Habitat Restoration

Bruno Borsari and Malcolm F. Vidrine

Abstract Terrestrial ecosystems have been mostly converted into crops and pasture lands by modern agriculture in fulfillment of food needs for a growing human population. The purpose of this work consisted in engaging a population of undergraduate students (N = 830) in prairie restoration and management projects on a university campus in southeastern Minnesota, between 2006 and 2014, with the objective of evaluating the effects of these experiences on the health and overall well-being of students who were enrolled in 2 different science courses: freshmen biology and junior ecology. Quantitative data derived from 8 critical questions that had been purposefully designed for this study and were part of the course evaluation survey. Qualitative data were collected from focus groups with every class after each outdoor experience and through an analysis of the literature that was relevant to the topic under study. Connecting with the land while restoring prairie habitats was meaningful for most students as indicated by the correlation coefficient (Pearson's) from the mean frequency scores that derived from the answers to the 8 critical questions of the survey ($r = 0.94$). Also, this relationship among scores from students in the 2 science courses was statistically significant ($p = 0.0137$). Qualitative data substantiated the findings from the survey data. Expanding this pedagogy is recommended to shift present anthropocentric worldviews into eco-centric awareness necessary for humanity to legitimize living within planetary boundaries and health.

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_14

Introduction

The fast conversion of grasslands and other terrestrial biomes to farmland is a process of landscape homogenization that was initiated in the Midwest of the U.S. with the arrival and settlement of European immigrants (Jackson 1980; Borsari et al. 2014a). The vocation of prairie soils for crop production established the most viable agriculture in the heartland of North America, yet its massive expansions changed the attributes of the landscape, while posing significant threats to human and planetary health (Borsari and Kunnas 2019). A simplistic rationale that justified the industrialization of agriculture has been predicated as the only way of ensuring adequate food for a growing human population. This linear rhetoric is maintained to present times worldwide, despite the on-going sacrifice of land, biodiversity, and ecological services from which agriculture has been benefitting for the last 10,000 years (Jackson 2010).

Additional losses have been affecting education, rarefying, or even eliminating learning opportunities for students to experience more directly how nature and landscapes (Louv 2011) shaped cultures that brought to the rise and demise of civilizations (Diamond 2011). Colleges and universities remain valued, learning hubs and within these environments, there is potential to transform instruction, through placed-based education approaches, where students may develop an appreciation for the natural attributes of their regions and an understanding of basic ecological principles. Orr (1994) conceded that basic concepts of natural history and ecology are pivotal in the education of youth to foster stewardship, community, and an overall sense of belonging. When instruction abounds with outdoor activities, or simply time devoted toward observing nature, even within the borders of a college campus, then education may become transformative, rewarding, and contributive to health and well-being. Therefore, campus open spaces acquire high relevance and enhance ecological education with implications for also learning how to live more sustainably (Borsari et al. 2014a). For example, converting lawns into prairie gardens or any other type of wildlife habitat (Nabhan 1998) portrays the bioregional attributes where the school is sited and may augment the efficacy of curricula and students' learning. A more biologically diverse campus landscape has potential to become a distinctive laboratory and/or classroom open for a variety of courses and an effective tool for the recruitment of new students. To spur education in environmental studies in southeastern Minnesota, USA, Winona State University (WSU) has embraced the idea of restoring many open spaces surrounding its campus with woody plants and native prairie gardens (Borsari et al. 2018). These are framed within the ecosystem characteristics of this unique bioregion that stretches along the banks of the Mississippi river (Borsari et al. 2014b).

This work aimed at engaging a population of undergraduate students (N = 830) at WSU in various prairie restoration activities (e.g., transplanting native seedlings, prescribed burns, seed collection, weeding). These took place on modest open spaces at the university and were carried out between 2006 and 2014, with the objective of assessing the effects of these experiences on the health and overall well-being of students. Students were enrolled in 2 different science courses: freshmen biology and juniors' ecology. The framework of this study was inspired by Orr's concept of placed-based learning, which he proposed as a powerful model to restore ecological literacy in modern western society (1992) and the one-health concept (Coker et al. 2011; Xie et al. 2017). Also, some of the goals for sustainable development as established by the United Nations (SDG#4-quality education; SDG#11-sustainable cities & communities; SDG#13-climate action; SDG#15-life on land) constituted another important inspiration source for this study.

Methodology

This work employed quantitative and qualitative research methods to assess students' appreciation, health, and well-being, when they were engaged in prairie restoration activities, in a freshmen biology and an ecology course. Quantitative data derived from an 'ad hoc', 8 questions that were part of the final, course evaluation survey. Responses to these 8 questions were collected on the same day of the outdoors, prairie experience. Qualitative data derived from focus groups that were conducted during the class period after the prairie restoration work. More qualitative data were obtained from a document analysis review of the literature about restoration/reconstruction of natural habitats and benefits to human health. In this manner, a triangulation of the data ensured the trustworthiness of the study (Popham 1993).

The Students

These were freshmen (n = 515), men and women, who were enrolled in an introductory biology course for non-majors, whereas junior students majoring in biology (n = 315) were enrolled in ecology (Table 14.1).

Table 14.1 Students' enrollment in non-major biology (a) and ecology courses (b)

a	Male	Female	b	Male	Female
Fall 06	66	98	Fall 07	29	37
Spring 07	78	112	Fall 08	15	33
Fall 07	62	99	Fall 09	19	36
			Fall 10	13	28
			Fall 12	20	24
			Spring 14	14	47
Total	206	309	Total	110	205

Prairie Restoration Sites

Four sites were the open spaces where the prairie restorations took place through the years. Science Laboratory Center (SLC) and Integrated Wellness Complex (IWC) are located on the main campus, whereas Conference Center (TAU) is at the western campus of WSU. The fourth site is off campus (about 2.5 km) south of Winona, at Garvin Heights Park (GHP).

Prairie Gardens at Winona State University Main Campus

The SLC prairie garden was established in 2006 on a small space of about 280 m^2 adjacent to the SLC, which had been left unused after the new building construction in was completed in 2004. Initially, this project engaged 164 undergraduate students enrolled in the introductory environmental science course for non-majors. Propagules of prairie grasses and wildflowers were purchased locally and transplanted by students who worked for five days in groups of 20–24 students (Fig. 14.1a, b).

Fifty-eight species (mainly wildflowers) were transplanted in the fall of 2006 with switchgrass (*Panicum virgatum*), little bluestem (*Schizachyrium scoparium*) and Canada wild rye (*Elymus canadensis*) as iconic grass species. Since then, the prairie garden has been used for instruction in biology, ecology, geoscience and for senior capstone research projects.

Creating the IWC garden (750 m^2) emerged from the need of retaining the IWC—LEED Gold Certification. This project demonstrated a native landscape adjacent to this building that does not need to be irrigated nor mowed as the pre-existing lawn, thus conserving water and soil. The turf on this plot had been damaged by an extremely hot and dry spell in 2012. This project began the same year with the goal of designing and establishing a prairie garden in 2013 as a living display of sustainable landscape on the south side of the IWC. This work also aimed at proving

a) b)

Fig. 14.1 **a** SLC prairie garden view and **b** Students transplanting native, prairie plants (2006)

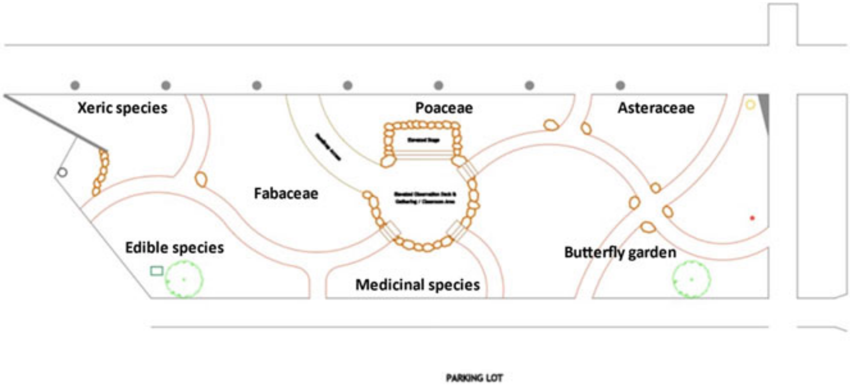

Fig. 14.2 Garden design (IWC) with thematic areas for the diverse plant communities

the effectiveness and value of a senior student-faculty team projects capable of initiating successful collaborations between Facilities Services staff and the WSU Land Stewardship and Arboretum Committee, while engaging more students in the prairie garden restoration/maintenance efforts in the years that followed. This reconstruction design included seven thematic areas separated by a network of paved trails and signage to increase visitor's/passer byes' appreciation (Fig. 14.2).

Seedlings of 40 perennial forbs and 6 grasses were transplanted in the theme areas; these included species of major perennial families (Fabaceae, Poaceae, Asteraceae, Asclepiadaceae (now Apocynaceae) & Labiatae), that are attractive to birds and/or butterflies, edible and/or possess medicinal properties. An iconic plant among the xeric species is prickly pear (*Opuntia humifusa*, family Cactaceae), which was planted in the driest and most elevated corner of the garden highlighting the diversity of local prairies that persist within the driftless region of southeastern Minnesota. Distinctive species at the garden include White wild indigo (*Baptisia lutea*), Big bluestem (*Andropogon gerardii*) and Blazing stars/Gayfeathers (*Liatris spp.*), with several asters (*Aster* spp.). Many more species were planted in specific garden sections to represent native edible and/or medicinal taxa, including forbs that attract pollinators (butterflies) and birds (Table 14.2).

TAU Prairie Garden

The TAU site is about 400 m^2 behind the Conference Center on the west campus of WSU. The prairie garden is adjacent to the athletic fields of Cotter High School and split in two sections by Gilmore creek, which is flowing through this landscape. In the Fall semester of 2007, 161 students enrolled in the biology course were

Table 14.2 Selected plant species for the edible, medicinal and wildlife themes at the IWC prairie garden (Modified after: Borsari et al. 2014b)

Theme	Tot. Spp. #	Selected species	Common name
Edible spp.	9	*Sambucus canadensis; Ceanothus americanus; Vaccinium angustifolium; Pycnanthemum pilosum; Phyllanthus acidus; Fragaria virginiana*	Elderberry; New Jersey tea; Low bush blueberry; Hairy Mountainmint; Gooseberry; Wild strawberry
Medicinal spp.	5	*Veronicastrum virginicum; Echinacea purpurea; Eryngium yuccifolium*	Culver's root; Purple coneflower; Rattlesnake master
Pollinators' spp.	8	*Asclepias tuberosa; Coreopsis lanceolata; Dalea purpurea; Tradescantia ohioensis; Liatris aspera; Phlox pilosa*	Butterflyweed; Tickseed; Purple prairie clover; Spiderwort; Button blazingstar; Phlox
Birds' spp.	7	*Geranium maculatum; Monarda fistulosa; Aquilegia canadensis Penstemon grandiflorus; Echinacea purpurea; Baptisia australis; Koeleria cristata*	Wild geranium; Bergamot; Columbine; Beardtongue; Purple coneflower; Blue wild indigo; June grass

engaged in this restoration project; efforts included transplanting 340 seedlings from 24 different species of native grasses and forbs. Through the years, this space has served for instruction through narrated tours and various hands-on activities (Figs. 14.3 and 14.4).

Fig. 14.3 Prairie Garden restoration at the west campus in 2007. Thinning woody vegetation on the banks of Gilmore creek (**a**). Native plants are being transplanted on lawn patches that had been solarized (**b**)

Fig. 14.4 Students are preparing to conduct a prescribed burn under the guidance of a MNDNR expert (**a**) Students in action while controlling the fire (**b**)

GHP Prairie Savanna

GHP in Winona, MN is a distinctive 12 ha property, which includes bluff prairie, dry hill oak savanna, and southern dry-mesic oak-hickory woodland, overlooking the Mississippi river. After decades without management, the Garvin Heights savanna that was once dominated by the iconic bur oak (*Quercus macrocarpa*), became overgrown with buckthorn (*Rhamnus cathartica*), thus demanding restoration (beginning in 2004), through a collaboration between the City of Winona, Winona State University, and the Minnesota Department of Natural Resources (Borsari et al. 2014a). After buckthorn removal, native shrubs and seeds of savanna forbs and grasses were sown, these efforts often engaging students and volunteers. Seasonal prescribed burns continue to be carried out with the assistance of Minnesota DNR to inhibit the propagation of buckthorn and other invasive plant species.

Research Instruments: The Survey

The survey instrument was the course evaluation survey that consisted of 20 multiple-choice questions on a 5-point-Likert scale (Fig. 14.5). This survey was structured in 5 domain categories (A-E) and served the purpose of collecting the quantitative data.

Eight critical questions referred more specifically to the purpose and needs of this study; these were placed in the corresponding domain as follows: domain B (Qs.: 5 and 8), domain C (Qs.: 11, 13, 14), domain D (Qs. 17), and domain E (Qs.: 18, 19). A reliability coefficient (Cronbach's alpha) was calculated to substantiate the internal consistency of every survey question, as suggested by Kline (2015). This research instrument was drafted in 2005 and reviewed by a panel of 5 professors from Winona State University to yield a valid assessment tool. Two of these experts were from the Department of Biology, one from Health Sciences, one from Psychology and one from Recreation, Tourism & Therapeutic Recreation. Various adjustments were made to the document during the four-month review process between the investigators and

Biology Dept. Course #: BIO. 104 and/or 312 Section #: _____ Date: ___

This survey is part of an effort to improve curriculum and teaching, and some of the best data that I can gather about these come from you. The information that you provide on this survey can help me modify the course to make it more effective. Please answer each question carefully and thoughtfully. Please indicate how much you agree or disagree with each statement by marking one choice (a,b,c,d,e) on your Scantron.

	Strongly Agree	Agree	Disagree	Strongly Disagree	Neutral
A) Course Goals and Outcomes:	**a**	**b**	**c**	**d**	**e**
1. Course objectives/ goals were clear throughout the semester.					
2. Coursework (papers, exams, and other assignments) addressed course objectives/goals.					
3. I received clear instructions for completing assignments.					
B) Assessment & Independent Thinking:					
4. I always received feedback in a reasonable time, which helped me succeed in this course.					
5**. My learning was evaluated in a variety of ways (e.g:. tests, presentations, demonstrations, peer response, hands-on activities, outdoors work and excursions).**					
6. The criteria on which my work was evaluated were clear to me.					
7. The course provided opportunities for me to become a better thinker.					
8. **The course provided opportunities for me to learn more about restoration ecology.**					
C) Learning Environment:					
9. Class/Lab. sessions had always a clear purpose.					
10. The instructor created an atmosphere that encouraged students' expression of ideas.					
11**. I appreciated the instructor holding class, or Lab. outdoors.**					
12. I felt comfortable asking the instructor for help if I needed it.					
13. **The prairie restoration activity was relevant to my learning and for understanding the need of reconstructing/conserving habitat and biodiversity.**					
14. **The prairie restoration was a keystone activity of this course.**					
D) My commitment & contributions to this course:					
15. I have attended class and taken notes on a regular basis.					
16. I was always prepared for this class and contributed to discussions and/or group work.					
17. **Learning outside of the classroom motivated me to succeed in this course.**					
E) My wellbeing & Overall Evaluation:					
18. **I have always been happier learning outside more than in class, or Lab.**					
19. **Outdoor learning makes me more fit and healthier.**					
20. I would encourage my friends enrolling in this course.					

THANK YOU FOR COMPLETING THIS COURSE EVALUATION!

Fig. 14.5 Evaluation instrument with the eight critical questions (in bold)

each panelist. Rewordings of some statements were suggested, and corrections were made until a consensus among the panelists was reached at the end of 2005. Students' protections for the administration of the survey were ensured through approval of the Institutional Review Board (IRB) of Winona State University.

Focus Group Questions

A list of 4 questions was intended as a mean to collect qualitative data for this study. The focus group approach can become an effective research method when researchers work with human subjects (Glesne and Peshkin 1992). However, Rossman and Ralls (1998) warned researchers that attention to potential biases should be considered to avoid threats to the validity of their studies. To eliminate any possible bias, the senior author who served also as instructor for both courses for the entire duration of this study, underwent this task without attempting to prove anything, nor advocating a personal agenda. To collect data successfully through a focus group, there is a relationship that must be established between the researcher and the respondents (Glesne 1999), making certain aspects such as personal appearance and behavior important during the data collection phase.

Four areas of concern were identified for the focus group portion of this study. These concerns, stated in question format with additional probes for clarification of the focus group participants' thoughts, were articulated as follows:

1. What was most memorable about the prairie restoration experience? What could be done to improve this component of this biology/ecology course a step further?
2. How did the prairie restoration experience contribute (if it did) to your learning about the subject matter?
3. How did you feel about being directly engaged to contribute to improving the health of your campus landscape through this experience? What else could be done?
4. What personal health benefits do you think you gained by participating in this prairie restoration activity? Did this activity help you achieve an overall well-being during this semester of study?

Results: Quantitative Data

The quantitative data were collected the same day of the outdoor experience on a reduced version of the course evaluation survey, which had only the 8 questions (**in bold**), from the original survey document. Also, for the courses held in the spring semester this hands-on activity was postponed to the end of the term (April–May), whereas outdoor learning had to be accomplished in the early fall (August–September), to be able to work outside in pleasant weather conditions before winter ensued. Data were collected from 2 student samples in a freshmen biology ($n = 515$) and ecology ($n = 315$) courses. The mean frequency scores for the 8 critical questions in the freshmen biology course were considered in this study (Table 14.3).

Most responses were in the strongly agree (31.6%) and agree (49.6%) categories whereas some disagreed (7.7%), strongly disagreed (1.6%), or simply chose to maintain a neutral stance (3.7%). A goodness of fit test on the students' survey responses from the mean scores for each one of the five-point categories on the Likert scale

Table 14.3 Mean frequency scores in the freshmen biology course

	Strongly agree	Agree	Disagree	Strongly disagree	Neutral
(B) Assessment & independent thinking:	**a**	**b**	**c**	**d**	**e**
5. **My learning was evaluated in a variety of ways (e.g.:. tests, presentations, demonstrations, peer response, hands-on activities, outdoors work and excursions)**	0.307	0.506	0.073	0.017	0.013
8. **The course provided opportunities for me to learn more about restoration ecology**	0.202	0.516	0.151	0.009	0.122
(C) Learning environment					
11**. I appreciated the instructor holding class, or Lab. outdoors**	0.251	0.593	0.044	0,011	0.058
13. **The prairie restoration activity was relevant to my learning and for understanding the need of reconstructing/conserving habitat and biodiversity**	0.354	0.486	0.032	0.028	0.047
14. **The prairie restoration was a keystone activity of this course**	0.213	0.596	0.092	0.027	0.007
(D) My commitment & contributions to this course:					
17. **Learning outside of the classroom motivated me to succeed in this course**	0.403	0.472	0.025	0.012	0.014
(E) My wellbeing & overall evaluation:					
18. **I have always been happier learning outside more than in class, or Lab**	0.516	0.328	0.017	0.008	0.024
19. **Outdoor learning makes me more fit and healthier**	0.289	0.475	0.184	0.023	0.018
Mean	0.316	0.496	0.077	0.016	0.037

from the eight critical questions was performed as recommended by Sullivan and Artino (2013), when conducting studies employing this methodology. From this statistical analysis, we concluded that the prairie restoration experience was effective to foster learning in the freshmen biology course, while enhancing students' health and well-being, χ^2 (4, n = 515) = 512. The probability was highly significant ($p < 0.005$).

Also, in the ecology course most responses selected by students were in the strongly agree (42.6%) and agree (41.8%) categories. Some were in the disagree (8.2%) and strongly disagree categories (2%), whereas 4.2% of ecology students remain neutral when answering the 8 critical questions presented by the survey. The mean percentage scores for the 8 critical questions in the ecology course are reported (Table 14.4). A goodness of fit test on the students' survey responses to the 8 critical questions was performed substantiating that also for the ecology students the prairie restoration experience enhanced learning in the subject, while promoting the health and overall well-being for most students, χ^2 (4, n = 315) = 313. The probability was highly significant ($p < 0.005$).

The Pearson's correlation coefficient ($r = 0.94$) was calculated from the mean frequency scores that derived from the answers to the 8 critical questions of the survey and this showed a strong relationship between the two student samples which was statistically significant ($p = 0.0137$), when $\alpha = 0.05$.

Results of Qualitative Data (Focus Groups)

The class following the outdoor activity was dedicated to the collection of qualitative data through a focus group session with students in both courses. Students worked in groups of 4 to 6 students (n = 82) in the biology course and (n = 53) in the ecology course. Every question was discussed by the groups in the order presented by the instructor for 5 min. A spokesperson selected by each group answered the questions. Each question was discussed for about 12–13 min with the instructor's assistance. Because there was a very large amount of narrative data, only selected excerpts of students' answers that derived from focus group discussions were used to highlight key findings. Three most significant sets of data were reported from respondent groups in the freshmen biology (Table 14.5) and 2 sets from the ecology groups (Table 14.6).

Every focus group session lasted 50 min and was recorded on the senior investigator's laptop computer. The instructor attempted to maintain a neutral stance, while asking the questions and moderating the discussion to optimize students' participations. Also, he annotated what was being discussed without showing any non-verbal cues that might have indicated his agreement or disagreement.

Results of Qualitative Data: Document Analysis

A robust body of literature has substantiated the benefits of an experiential education in outdoor settings (Apfelbaum 2009; Borsari et al. 2014a; Vidrine et al. 2001; Urbanska et al. 1999), as well as how important it would be to initiate this practice at

Table 14.4 Mean frequency scores in the ecology course

	Strongly agree	Agree	Disagree	Strongly disagree	Neutral
(B) Assessment & independent thinking:	**a**	**b**	**c**	**d**	**e**
5. **My learning was evaluated in a variety of ways (e.g.:. tests, presentations, demonstrations, peer response, hands-on activities, outdoors work and excursions)**	0.302	0.49	0.091	0.075	0.003
8. **The course provided opportunities for me to learn more about restoration ecology**	0.356	0.542	0.074	0.006	0.015
(C) Learning environment:					
11**. I appreciated the instructor holding class, or Lab. outdoors**	0.476	0.498	0.158	0.066	0.069
13. **The prairie restoration activity was relevant to my learning and for understanding the need of reconstructing/conserving habitat and biodiversity**	0.621	0.320	0.002	0.000	0.004
14. **The prairie restoration was a keystone activity of this course**	0.576	0.373	0.005	0.000	0.009
(D) My commitment & contributions to this course:					
17. **Learning outside of the classroom motivated me to succeed in this course**	0.295	0.368	0.121	0.006	0.103
(E) My wellbeing & overall evaluation:					
18. **I have always been happier learning outside more than in class, or Lab**	0.498	0.248	0.101	0.008	0.019
19. **Outdoor learning makes me more fit and healthier**	0.286	0.511	0.105	0.001	0.116
Mean	0.426	0.418	0.082	0.02	0.042

a very early age (Louv 2011). According to Bauerle and Park (2012), outdoor learning was effective in fostering academic achievement in the plant sciences, whereas Hynes and Howe (2004) pointed out the psycho-physical benefits of community gardening in urban environments across the age spectrum of gardeners. Undoubtedly, the open space surrounding a college campus can be attractive to students and influence their

Table 14.5 Excerpts from the focus group questions by respondents in the freshmen biology course

Semester	Q.1	Q.2	Q.3	Q.4
Fall 06	"Working with my hands and doing this together with my classmates outside of the classroom, under the sun"	"It is difficult to say yet, it felt good being outside"	"It felt empowering knowing that we did something to heal the environment"	"Working outside was fun but I do not think that my health benefitted from this experience"
Spring 07	"Being involved in a prescribed prairie burn was (and will ever be) an unforgettable experience. The learning from the leaders was unique. Offer similar experiences to future students"	"The big learning during the outdoor experience consisted in understanding the power of fire as a tool in restoring the environment"	"We need more protected areas for a variety of reasons, including leisure and recreation"	"Probably not! However, learning outside made us feel good and kept us focused on what we were taught"
Fall 07	"Being outside to do something to improve environmental quality was very special and most personal. More opportunities like this one should be offered"	"Respecting nature and learning how to conserve or bring back habitat complemented well what we have been learning in this course"	"Restoring habitat is feasible and much needed. This activity taught us that we could lead a similar activity in our own community"	"We were happy to be outside therefore, outdoor learning should happen more often if the weather allows it"
Fall 06	"Learning how to transplant prairie species in the soil is something we never experienced before. Thank you for this great opportunity"	"Plant roots of all species were more developed than the above-ground parts of the seedlings. This is amazing!"	"It was hard work if you wanted to get involved. The reward being doing something good for our planet"	"More than health benefits the experience outside was enjoyable and hopefully there will be more of this kind also in other courses at WSU"
Spring 07	"Although we did not have tools to assist with the burn it was incredible to witness how fire can be used to improve the land"	"We never thought that uncultivated grasses have value to support wildlife and mitigate climate from changing"	"All that smoke was intimidating at first yet, it was amazing to witness the power of fire"	"It felt good to be outside. The smoke was not pleasant though"

(continued)

Table 14.5 (continued)

Semester	Q.1	Q.2	Q.3	Q.4
Fall 07	"Digging in the soil to plant prairie species that are native to this region was useful work"	"In our group half of us thought this experience was not effective to improve our learning in the subject"	"An activity of this kind is not my cup of tea but yet, it was nice to be outside"	"It was cold outside. Perhaps this activity should be held in the late spring semester"
Fall 06	"It was fun restoring a prairie patch on campus and learning from the professor but also from one another"	"This experience showed that it is doable bringing back prairies to the upper Midwest"	"Empowerment and enthusiasm to want to do something like this again"	"This question is more of an invitation to develop a healthy lifestyle in the outdoors and as this experience pointed out"
Spring 07	"Playing with matches can serve the environment sometimes and this lesson will never be forgotten"	"This is a very hard question to answer. The course covered so many other topics"	"Felt good about assisting with the burn although mainly from the distance. Hope to get involved more directly, next time"	"After a long, cold winter it was wonderful to be outside for learning as the snow is gone and nature is beginning to wake up again"
Fall 07	"Doing something hands-on and with my friends was meaningful to my learning and valuable to my education"	"Environmental sustainability is a priority task if we want to conserve also healthy, human life"	"This activity was inspiring but my studies will not offer anything similar to this"	"Being outside, learning in nature was peaceful and relaxing. We cannot live without wild things….perhaps!"

Legend The column numbers refer to the focus group questions

choice selection of the university. Also, students appreciate the outdoor attributes of their campus, as indicated by Harmening and Jacob (2015), who discovered that 50% of freshmen who were surveyed at a university in the Midwest (U.S.) valued the outdoor space on campus, accrediting to these traits the main reason for their well-being.

On a larger scale, Borsari and Kunnas (2021) suggested that outdoor learning and similar approaches to education are needed more than ever to reconnect humankind with nature, while veering the future on a trajectory that aims at achieving planetary health. Thus, humanity should conserve biodiversity through restoration and policy making because its preservation has enormous implications for human health and well-being (Sandifer et al. 2015).

Table 14.6 Excerpts from the focus group questions by respondents in the ecology course

Semester	Q.1	Q.2	Q.3	Q.4
Fall 07	"Having the opportunity to learn by doing about restoring a habitat and conserve biodiversity"	"The learning with this experience was very good and reinforced my wish to pursue a career in ecology"	"This experience was invigorating and fulfilled our expectations"	"The wellbeing effect of immersing in nature is conducive to a healthy life"
Fall 08	"Understanding finally what ecology can be when applied to landscape. We need to shift lawns into prairies"	"Being assigned to read Leopold's Land Ethic was essential to understand what we did outside, the other day"	"Extremely beneficial to learning ecology as a complex science"	"It is known to us that exposure to nature has many benefits, including getting better grades"
Fall 09	"Collecting seed and observing the diversity of these little things was amazing. Can't wait to plant it and watch the seedling grow!"	"The experience outside helped us understand the interconnectedness among living beings and their environment"	"It was not only about collecting seed for future planting but also understanding more directly the ecological functioning of prairies"	"Working outside was fun and a meaningful learning experience yet, it is hard to believe that one hour seed collection may have improved our health"
Fall 10	"Noticing that this is the only space on campus where crickets are chirping and some little birds are flying around this place. Amazing!"	"This action-learning activity was valuable to us all and reinforced our interests in wanting to continue studying ecology"	"Working for an amplification of the environmental services provided by the campus prairie was empowering"	"No, it didn't. However, the activity was pleasant just for being outside on a nice fall morning"
Fall 12	"Even though goldenrod and aster are blooming this garden is attractive to us and other animal species. We should have another activity like this one again"	"This hands-on learning was very meaningful to understand how interlaced and complex are ecosystems"	"Learning and exchanging ideas while working outside was a magnificent experience"	"Everyone seemed happy to be outside of for class, doing something. Therefore, this activity may be conducive to an overall wellbeing of us students"
Spring 14	"Preparing the campus garden for the burn was hard work yet we learned a lot about prairie management"	"The big lesson here was the interaction between plants and grazers like antelopes, or buffaloes. Fascinating topic"	"This experience led beautifully toward learning from one another"	"At the end of a long winter it was good to be outside observing the greening of the land"

(continued)

Table 14.6 (continued)

Semester	Q.1	Q.2	Q.3	Q.4
Fall 07	"We did not know what to expect yet, removing invasive species together was an enjoyable and valuable experience"	"What a challenge is to conserve the integrity of ecosystems from invasion and spreading of alien species!"	"Hopefully, there will be more experiences of this kind in senior-level ecology courses"	"Perhaps students' health could improve if almost every class was organized in this way"
Fall 08	"Measuring the height of grasses and wildflowers was interesting and look forward discovering whether there will be differences"	"The outdoor experience contributed to our learning and to understand the meaning of microclimate"	"Inspiring experience. We all worked together and learned a lot about abiotic factors that affect plants' growth"	"Most likely it did not! Yet, if this would boost GPAs many of us would be willing to do this more often"
Fall 09	"Working outdoors while understanding that what we were doing contributed to restore Earth was memorable indeed"	"Great learning happened outside reiterating the fact that as many activities as possible should be done outside in this course"	"The experience was well guided by the professor who enthused us to want to learn more about prairie ecology"	""The experience outside was enjoyable and we look forward to more chances like this in other ecology courses that include Lab time"
Fall 10	"Breathing fresh air and doing meaningful work (sowing seed) was a terrific learning experience"	"We improved the biodiversity of our campus and this activity proved how needed is moving in this direction"	"This restoration effort should make the use of herbicides on campus become obsolete. We want more space"	"One experience only will not suffice but these kinds of activities could be conducive to wellbeing and health"
Fall 12	"Discovering a duck's nest with eggs within the tall grasses"	"Even a small space can become habitat for many species"	"Some students' initial engagement drove the will of everyone to get involved in the task"	"No! The activity did not benefit our health, nor academic performances"
Spring 14	"Trampling on the dead vegetation like a bison within his herd"	"Ecosystems are complex, yet it is exciting studying these and the interactions among their populations"	"Initially, it appeared silly but eventually we understood the meaning of the hands-on activity"	"All students seemed content. Everybody was happy and looked healthy too"

Legend The column numbers refer to the focus group questions

Discussion

The data here presented demonstrated the benefits of ecological restoration activities in biology/ecology courses for different levels of instruction in outdoor settings, even when these were limited to a single event. The data collected from non-major, freshmen students revealed a remarkable level of enthusiasm that was comparable to that of students in ecology. Also, 12 freshmen (2.3%), who had enrolled as "undecided" during their first academic year between Fall 2006 and Fall 2007, declared biology as their major in their second year of studies at the university.

Through decades of restoration activities, efforts to preserve the coastal prairie of southwestern Louisiana in Eunice have demonstrated the power of leadership and community engagement at various levels, when the goal is reconnecting with nature to bring back a distinctive ecosystem [Vidrine 2018]. Borsari and Mora (2020) proposed the *edusphere* (world of learning) concept as the outcome of an education reform that should shift from anthropocentrism to ecocentrism and sustainability. In sum, we think that prairie restorations can serve six major purposes for planetary and human health and well-being. These are:

1. Conservation of native plants and animals in concert with soil rehabilitation with a beautiful floristic display appropriate for tourism,
2. Carbon sequestration, with potential income for carbon credits,
3. Wetland mitigation banking, as some coastal prairies are wetlands, as recognized by the Army Corps of Engineers, with hundreds of hectares already being restored for banking, a real source of income in perpetuity,
4. Pollinator gardening, important as insect pollination provides at least one out of every 3 bites of food for Americans,
5. Grazing for cattle herds managed in rotational grazing systems,
6. A seed source, as native seeds have rarefied, with many species are simply not available except for hand collecting.

With an eco-centric education, planetary health is achievable and should start on campus through learning experiences that have the power of inspiring and transforming human lives and culture toward sustainability. In this manner, the drastic effects caused by the Anthropocene can be harnessed, leading human future along a trajectory that offers tangible opportunities of fixing planetary problems, while achieving health to a level that will continue to ensure Earth's recovery from perturbations caused by human activities (Rockström and Gaffney 2021).

Conclusion

The assessment nature of this study constituted a tangible limitation, meaning that data in evaluation studies may measure the "worth" of a program; yet, the findings lack generalizability, and they could not be applicable elsewhere, without specific adaptations (Popham 1993). Also, the one-single outdoor event per each class represented another constraint. An additional limitation could have considered the variance among space sizes for outdoors course activities. These spaces conceivable as outdoor labs can be as small as ‘postage-stamp (pocket prairie garden),’ a creek’s edge or a pond. It is a matter of scale only in part, since ecological resources are apparent even in a single flower being serviced by a pollinator companioned with the succeeding production of an edible fruit for man or beast (Vidrine 2018). Thus, there is only one limitation in this context: absence of imagination on the instructor’s part or, worse yet, absence of knowledge of ecosystem function! The latter notion (sheer ecological ignorance) is common in a society with its entire focus on commodity development, marketing, and consumption, all the while lacking any knowledge of the role that ecosystems and their resources provide (Louv 2005).

We wish to emphasize that prioritizing the study of ecosystems and their restoration/reconstruction in education is not an eccentric new approach to learning, nor a volatile education trend (Borsari and Kunnas 2021). Eco-centric education is rather a well-articulated plan of instruction and actions that are molded by interdisciplinary learning and a holistic comprehension of life whose knowledge connects and inspires everyone, while enmeshing solidly in every societal context. Present societal affluence and consumptive lifestyles continue to erode biodiversity and the services it provides, including human health (Sandifer et al. 2015), making indigenous knowledge and worldviews prized resources to expedite students’ connections with nature. This connectivity becomes a vehicle for a transformation of education that will transition from a reductionist to a more holistic one. These are the pedagogical principles and auspices we advocate with urgency to reestablish and preserve planetary health.

Acknowledgements The authors are grateful to Winona State University Foundation for the financial support that was given to these restoration projects, through the years. We dedicate this work to our friend and colleague, Dr. Charles M. Allen for introducing us to the study of remnant, coastal prairies.

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Chapter 15
"Health as a Social-technical Enterprise Anchored in Social-ecological Justice and Stakeholder Collaboration: Insights from Mexico-Lerma-Cutzamala Hydrological Region"

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Abstract Human health and wellbeing depend on the health and integrity of ecosystems we co-inhabit with other species and the ways we use natural capital in our economy. They depend on the ways people are able (or not) to satisfy basic needs: breathing clean air, drinking clean water, eating healthy food, and having access to healthy housing, a safe and secure neighborhood, a stable livelihood, and healthcare. Science grapples with deciphering how environmental, biological, and lifestyle/behavioral factors interact to co-determine health. Meanwhile, major

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_15

promoting and degrading factors are *highly unevenly distributed* across populations and landscapes; significant social-ecological health injustice prevails. We present four innovations to address recognized limitations of existing health research and practice: (1) an *integrative framework* to tackle innate conundrums and conceptualize important domains; (2) an *integrative operational process* for designing health-water-ecology-climate projects that enable multi-component research and its translation; (3) coupled *mixed methods systems modeling-GIS/geospatial analysis*, plus *exposure vs. response/risk curves* for groups with differential vulnerability to stressors—to reveal promoters and degraders of health, and structural injustices; and (4) a *social-technical capacity building enterprise* model to frame health-sustainability projects based on prior successful multi-stakeholder experience in Mexico. Our ongoing project—"*Climate Change Impacts & Resilience in the Mexico-Lerma-Cutzamala Hydrological Region*"—illustrates their application. We argue health, sustainability and climate resilience challenges be reframed as opportunities to co-create *social-technical enterprises* at different spatial, temporal and human scales, firmly anchored in the moral pursuit of social-ecological justice, and enabled by stakeholder partnerships.

Introduction

Integrative Health Paradigms

The last 25 years have seen a series of high-level efforts to better understand how human health and wellbeing are inextricably linked with the integrity of the local and regional ecosystems we inhabit, and the planetary biosphere as a whole. The CDC's *One Health* is "a collaborative, multisectoral, and transdisciplinary approach—working at the local, regional, national, and global levels—with the goal of achieving optimal health outcomes recognizing the interconnection between people, animals, plants, and their shared environment" (CDC 2021a). In recent literature of global reach, scholars and agencies argue for the kind of intersectoral, integrative and collaborative approach to human and planetary health we illustrate. Schütte et al. (2018) argue that planetary health, climate change and forced migration need to be considered as interdependent, with shared research agendas that inform consistent policies. The inextricable links between climate change and human and planetary health are recognized by *the United Nations* (UNFCCC 2021). The *Rockefeller Foundation*, in partnership with *The Lancet*, signaled planetary health as "public health 2.0", a new discipline that expands the global health paradigm to encompass both human and natural systems upon which we depend (Rodin 2015). Horton and Lo (2015) argue for new collaborations across diverse disciplines to fill knowledge gaps and bridge methodological failures.

Myers and Patz (2009) provide a comprehensive review of the literature on the human health impacts of ecological degradation, while Myers et al. (2013) identify key gaps and limitations in our traditional approaches to research. They include: (1) too much work looks at only one adverse health outcome instead of how changes to the natural environment impact health in multiple simultaneous ways; (2) not looking at the health impacts of multiple ecosystem changes that are themselves interrelated (and the lack of methods to do so); (3) ecosystem change, while causing some negative impacts, may also cause positive ones (e.g. expanding agriculture may remove forest that recharges aquifers, increasing water scarcity, yet improve food security and livelihoods)—arguing for a closer look at the net impact on health; (4) a lack of attention to how humans adapt to environmental change and mitigate adverse health impacts; and (5) too rarely do we question whose health is most at risk, who bears heavy negative impacts of anthropogenic ecological change while receiving few, if any, positive ones, often with weak ability to adapt and cope—i.e. Who is most vulnerable[1] and why? Myers et al. (2013) rightfully emphasize the last one: *health equity and social-ecological justice* must anchor a sustainable future.

To these we add shortcomings in research project design and practice from our own experience as reviewers[2]: (i) biomedical scientists tend to drive projects, with social science and environmental science components only weakly integrated; (ii) multi-component projects are rarely more than the sum of their parts because they do not actively exchange data and information; (iii) bi-directional communication between researchers and target communities remains elusive, resulting in the former driving the agenda and the latter unable to meaningfully influence the research; (iv) biomedical research project design and deployment rarely include translation of academic findings into policies and practices to improve health, with monitoring of the same to inform follow-on work.

Consideration of the *social determinants of health* (SDH) has become prominent as a way to temper and inform the biomedical paradigm of diagnosing and treating illness without considering the complex interplay among social, economic, cultural, political and ecological risk factors, 'health determinants', and root causes of morbidity and mortality (Solar and Irwin 2010). In the U.S., *Healthy People 2030* is the fifth in a series of aspirational governmental initiatives to apply the SDH framework, and considers five domains: economic stability; education; social and community context; health and health care; and neighborhood and built environment (CDC 2021b). Intervening to modify the SDH require the increased effectiveness of public health systems interacting with other sectors (Lipshutz et al. 2021).

Planetary Health is the latest paradigm that seeks to more fully capture the dynamic, hyper-complex interdependencies between human wellbeing and social-ecological systems. According to the Planetary Health Alliance (PHA), it is "a

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[1] Vulnerability is a function of three dimensions: (i) *exposure* to hazards, risk agents, stressors or negative climate impacts, e.g. water scarcity; (ii) sensitivity or *susceptibility* to express adverse health outcomes as a result of exposure, and the severity of them; and (iii) capacity to *adapt* or cope with adverse health outcomes, mitigate them and/or recover (Downs et al. 2010).

[2] Includes expert reviews of proposals for large multi-component research programs funded by U.S. National Institutes of Health, including: Environmental Health Centers (P30); Children's Health Research Centers (P50); Superfund Research Program (P42); Centers for Oceans & Human Health Program (P01).

field focused on characterizing the human health impacts of human-caused disruptions of Earth's natural systems" (PHA 2021). The purpose of this chapter is to make integrative approaches not merely aspirational but operational, using practical frameworks and innovative methods, then illustrating their use in Mexico.

Health as 'System', Response as 'Enterprise': Our Theory of Change

There is a compelling argument for us to embrace human health and wellbeing as integral to the healthy, sustainable state of all social-ecological systems, local and global, an existential and moral imperative—with *social-ecological justice* as its guiding principle. Thus, we must model the geographical/socio-demographic distribution of positive and negative impacts of social-ecological change, as well as the promoting and inhibiting factors for health and wellbeing. To do this is far from trivial; it confounds most conventional methods and approaches. Exhibit A: The way that "health as a system" (as usually conceived) centers on the *healthcare* system, one based on highly limiting biomedical diagnosis and treatment models. Rarely does this model consider why people are getting sick in the first place, the upstream drivers of illness and death, let alone the array of social-ecological vulnerability factors. We have previously argued that the governmental *public health research system* (e.g. Mexico's National Institute of Public Health; the U.S. National Institutes of Health)—in concert with universities—be the engine of stakeholder collaborations, working beyond the *healthcare system* boundaries (Santos-Burgoa et al. 2018). The former contributes evidence-based health protections (including regulatory ones), surveillance, health promotion and disease prevention; the latter effects clinical prevention, medical treatment, rehabilitation, and palliative care (ibid).

How *can* we address aforementioned limitations of existing health research and practice? We present four innovations: (1) an *integrative framework* to tackle innate conundrums and conceptualize important domains; (2) an *integrative operational process* for designing health-water-ecology-climate projects that enable multi-component research and its translation; (3) coupled *mixed methods modeling-GIS/geospatial analysis*, plus *exposure versus response/risk curves* for groups with differential vulnerability to stressors - to reveal promoters and degraders of health, and structural injustices; and (4) a *social-technical capacity building enterprise* model to frame health-sustainability projects based on successful multi-stakeholder experience (Downs 2001, 2007; Downs and Larsen 2007). Collectively, they represent our *theory of change*. We describe them in more detail in Sect. "Integrative Frameworks and Approach", then in Sect. "Case Study Application" illustrate their application.

Knowledge Co-production

To bolster our theory of change, we draw heavily on the theory and practice of *knowledge co-production.* Meadow et al. (2015) consider five modes of knowledge co-production for climate-change work: (1) *action research*—often with a social and environmental justice focus, in which researchers support and facilitate research co-defined with stakeholders (often marginalized communities); (2) *transdisciplinarity*—similar to action research, often tackling a hyper-complex problem requiring disciplines from social science, natural science, engineering and others; (3) *rapid assessment*—typically social scientists consult and collaborate with stakeholders who are tackling a problem (often using ethnographic methods); and (4) *participatory integrated assessment*—a synthesis of the above, consultative, collegial and collaborative in its engagement, involving scenario modeling and planning, with researchers as facilitators and providers of technical support. There is a growing literature on the pivotal role of knowledge co-production to tackle complex social-ecological issues (see Jasanoff and Wynne 1998; Lemos and Morehouse 2005; Dilling and Lemos 2011; Robinson and Tansey 2006; Lemos et al. 2014 among many). However, few scholars actually practice it, because of its higher demands on time and relationship building and a lack of incentives in traditional academic advancement (Cvitanovic et al. 2015), but also a lack of education and training in *how* to do it.

Integrative Frameworks and Approach

Conundrums and Integrative Domains

As our first innovation, from earlier work, we contemplate *three conundrums* for sustainable development relevant for re-thinking our approach to planetary health science and policy (Downs et al. 2017a):

I. The *social-ecological complexity* conundrum—How do we gain sufficient understanding of systems that are inherently very hard to decipher, are unpredictable, nonlinear and in too many ways are becoming increasingly unstable? This is the classic modeling conundrum: the model must be simple enough to be practicable, but not too simple that it fails to explain observed behaviors.

II. The *varying spatial and temporal scales* conundrum—How do we simultaneously consider the local, regional, national and global scales of health impacts and responses? How do we concurrently consider the very short (days to months), short (few years), medium (major life stages), long (lifespan), very long (multi-generational) time frames in impact science and policy?

III. The *social diversity* conundrum—How do we recognize the rich cultural diversity that exists in populations and places, mobilize it and celebrate our common humanity? How do we do this in the face of structural, deeply rooted social injustices? *Tackling this conundrum governs success* of any social enterprise.

We further apply a framework of *six integrative domains* to guide ways to understand and respond to health, sustainability, poverty, and climate change problems (ibid). Domains inform the conceptualization, design, implementation and management of projects and programs; they also serve to inform educational programs (Downs et al. 2017b; Downs and Golovko 2017). They are:

1. *Ethos and concept*—At the earliest stage of a project or program, we need to embrace the philosophy and reality of interconnectedness among humans themselves, and among humans, other species and the ecological systems we share (as a social-ecological system); our fates, our health are inexorably bound together. This "inter-being" ethos (Eisenstein 2018, p. 9) then guides our thinking, feeling and doing in the form of health projects, practices and policies.
2. *Sectors, issues and topics*—Health depends on so many other things: safe water and adequate sanitation; secure access to enough healthy food; safe, uncontaminated and secure places to live, work and study; reliable clean energy to power homes, settlements and economies; an economy that is inclusive and equitable—a socio-political system that dismantles racism, sexism, classism and all forms of structural injustice and inequity. Our approach to health must recognize this system of interdependence.
3. *Social groups and stakeholders*—People inhabit diverse groups who have stakes in the present and future state of the planet. We seek to strengthen and mobilize the integration of human, social, financial and manufactured capitals[3] to secure a healthier future, the first two as governing.
4. *Knowledge types*—Hyper-complex problems and issues defy simple explanation, requiring the bringing together of diverse types and knowledge and ways of knowing. These include: academic disciplinary knowledge; professional knowledge; experiential knowledge; generational indigenous knowledge. Scientific and technical fields typically have much more influence over health assessment and planning than social science, with social context and social justice concerns marginalized. Similarly, in the international development arena, market-based economics, law, IT and engineering enjoy dominance (Downs et al. 2017a). Among types, indigenous knowledge has the least influence, also an artifact of socio-political and cultural histories and power dynamics that benefit an elite few and marginalize the vast majority. Recognizing structural barriers to knowledge integration, we need to dismantle them and harness the potential of knowledge partnerships (Sect. "Knowledge Co-production").
5. *Spatial and temporal scales*—Spatially, it is important to consider the local scale (e.g. neighborhood) as well as the municipal, regional, national and global scales in conjunction since they influence each other. Similarly, social-ecological changes and associated health impacts happen at varying temporal scales, from

[3] This draws from the five-capitals sustainability frame—natural, human, social, financial, manufactured. At: https://www.forumforthefuture.org/the-five-capitals.

very short (e.g. impacts from catastrophic storm events, or accidents), through life stages lasting from months to several years,[4] to generational time frames of 25, 50, 75, 100 years and beyond.

6. *Social and technical capacities*—Little attention is paid to what kinds of social and technical capacities we need to be co-creating in order to adequately understand hyper-complex problems and be able to respond in positive ways for a more sustainable, socially just, healthy and climate-resilient future. Co-creation of them lies at the heart of the enterprise paradigm (Sect. "Social-technical Capacity Building Enterprise").

Our second innovation is both conceptual and methodological: We harness the potential of collaborative mixed-methods system dynamics modeling (CM3)[5] in conjunction with Geographic Information Science/Remote Sensing (GIS/RS) to lend invaluable geographical and socio-demographic patterns and mapping that reveal inequities and injustices; the two are very rarely integrated so this represents an important methodological innovation. GIS is becoming well established to reveal and interrogate health inequities (including Covid-19) and spatial associations among factors (Kamel Boulos and Geraghty 2020; Franch-Pado et al. 2020; Ozdenerol 2017; de Snyder et al. 2011). The RS aspect reveals important land use/land cover variability that is indirectly related to health, e.g. in terms of its influence on hydrology, the impact on the urban heat island effect. CM3 is practiced as a collaboration with stakeholders, consistent with Sect. "Conundrums and Integrative Domains"; helpfully, there is a growing interest in the modeling community to co-create models with stakeholders (Voinov and Bousquet 2010; Hovmand 2014; Kotir et al. 2016; Bou Nassar et al. 2021). Consistent with the lexicon of system dynamics modeling, Fig. 15.1 shows health as a 'stock'. Whether it is increasing, decreasing or steady over time depends on competition between promoting factors that add to health over time (adding 'flows') and degrading ones (subtracting 'flows') that take away. Factors that determine those flows are socio-economic, social-ecological and lifestyle/behavioral. Health is also mediated by biological processes—physiological, genetic, phenotypical—unique to the individual; phenotype is a function of gene-environment interaction. Importantly, many factors are interdependent with one another and with health status, and most are a function of just *vs.* unjust social-ecological systems. Note: logically, promoters and degraders that are their opposites cannot co-occur at the individual scale; one or the other operates on a person's health. At a population scale, though, some members may enjoy promoters while others suffer degraders that are their opposite. The working hypothesis is that for a given setting, population health is a non-random biological signal: spatial/socio-demographic patterns and

[4] The earliest life stage—also the riskiest one for environmental hazards—is in-utero for babies (9 months on average), also a vulnerable transient stage for mothers. Later life stages are cumulatively riskier for chronic degenerative illnesses, depending on a complex interplay of genetic, environmental and lifestyle risk factors.

[5] CM3 emphasizes that the modeling is both quantitative and qualitative, including geospatial and narrative forms of data, information and ways of knowing. Conventional systems modeling is perceived to be the domain of natural scientists and engineers, with quantitative descriptors dominant.

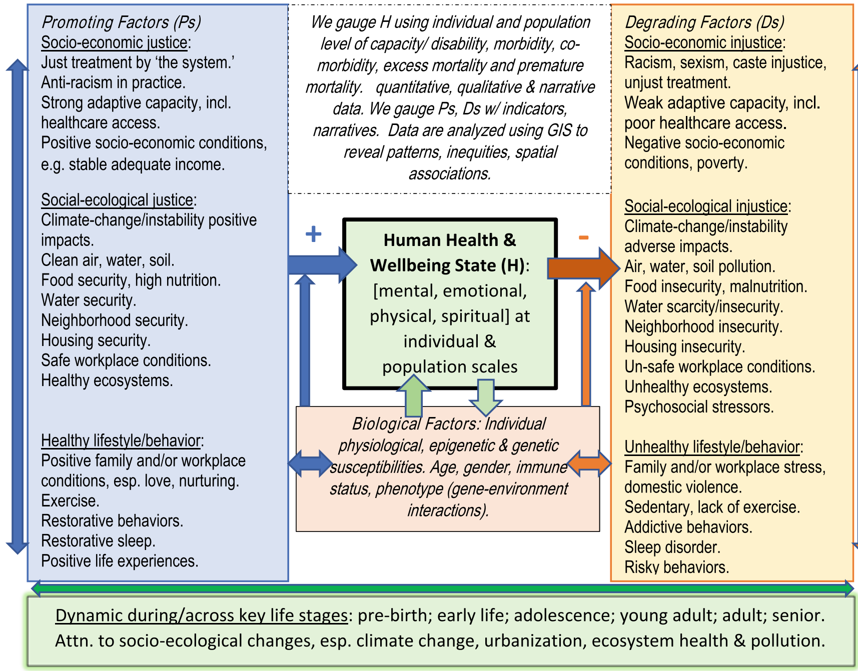

Fig. 15.1 Human health and wellbeing at individual/population scales as a dynamic system. Shows health as a 'stock', with competition between 'flows' of promoters and degraders over time explaining 'net health' at any given time: whether it is increasing, decreasing or steady. Social justice/injustice and anti-racism/racism need to be made explicit in understanding structural drivers of health/disease. Notice that the majority of the factors vary spatially, i.e. are spatially explicit, signaling that CM3-GIS/RS is necessary

disparities in population health are significantly associated with patterns in specific promoters and degraders; spatial statistics are applied.

Integrative Health Models and Methods

Individual and populations exist in a dynamic, transient state of health vs. disease, including acute and chronic, communicable and noncommunicable diseases that may influence their capacities, disability and premature morbidity and mortality. Furthermore, individuals have potential to act in confronting their biological and ecologic context, being agents who may protect themselves and their groups, promote better health conditions for themselves in their given settings. Collaborations between the population, public health institutions, health care institutions, and health researchers can enhance this capacity if they are authentic and multi-directional (Sect. "Integrative Health Paradigms"). Together, they can enhance health protection and promotion

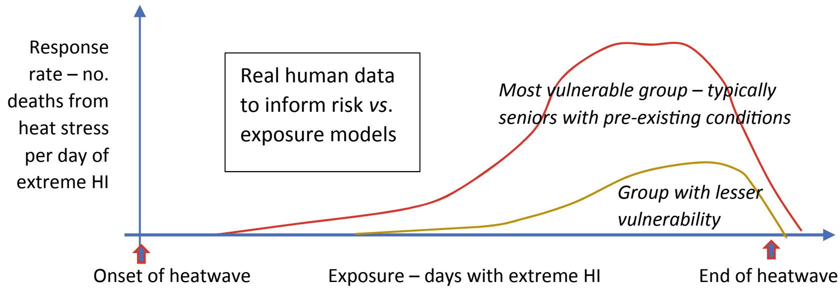

Fig. 15.2 Hypothetical exposure–response curves for subpopulations with differential vulnerability. Uses death from exposure to extreme heat index (HI) as the climate-based example. Area under a curve = total deaths

health (public health), increase effective coverage, i.e. accessibility and effectiveness (health care), reducing disease burden and avoiding preventable disability and death.

Drawing on environmental health science, exposure–response curves derived from human studies are real data of the number of people with adverse outcomes vs. the exposure (or contact over time with the stressor). The loss of 70,000 lives to heat stress in France in summer 2003 is one such case (Vandentorren and Empereur-Bissonnet 2005). Such data can be analyzed by sub-populations with varying vulnerability factors, with curves for each group (Fig. 15.2). These can be converted to risk curves by simply dividing the number of outcomes by the number of people exposed. The gradient of such curves has meaning: the change in risk per unit change in exposure. These curves could then be used in systems modeling of health outcomes under different exposure scenarios, e.g. different heat index[6] scenarios for a city/region based on IPCC climate change scenarios. In Mexico, among the workers of farming communities, climate determinants and others may be conspiring to explain considerable excess premature mortality; this is one of the hypotheses we plan to test in the case study project (Sect. "Case Study Application"). In theory, new sub-fields of spatial epidemiology and risk/impact science that consider socio-ecological justice are poised to make important contributions. However, it is important to note that the data to model interactions and scenarios are limited, especially in the 'Global South' (so-called 'developing countries'), but also in the Global North'. For this reason, the co-creation of shared information resources—Level 3 of our capacity building enterprise (Sect. "Social-technical Capacity Building Enterprise")—is fundamental.

[6] Heat Index combines air temperature with relative humidity to yield human-felt equivalent temperature.

Integrative Operational Frame

The third innovation is operational: We conceptualize collaborative projects—whether research projects or development projects, or a combination of both, as comprising several operational stages, including: ethos and concept; integrated assessment; integrated planning; project design resulting from the prior stages; project implementation and management; monitoring and evaluation (Fig. 15.3). The process is adaptive such that findings and insights from any stage have ways to loop back and inform upstream stages and ongoing work to encourage social learning. Such adaptability is also vital to allow projects, policies, technologies and programs to adapt to changing social-ecological conditions such as climate change and climate instability, or social change, or economic change—subject to which priorities for action and response may shift quickly. Operational thinking is helpful in intentionally coupling health research, policy and practice, reinforcing that each part depends on the others. Worthy of note here is that with such an integrated collaborative approach, stakeholders share ownership of models and indicators by helping to co-create them; indicators become meaningful and not merely those imposed by a donor, for example, to satisfy a performance review. Once again, however, it is important to recognize that such co-creation must recognize the constraints, priorities, and existing capacities of 'Global South' countries. For this reason, Global North-Global South capacity building enterprises will be drivers of success—indeed in our climate-changing world, nothing short of a new framing of international development is needed, one that is less aid-based, more shared-interest/co-capacity based. *No one country has adequate capacity to understand and respond to climate-change impacts, or to the host of other health determinants.*

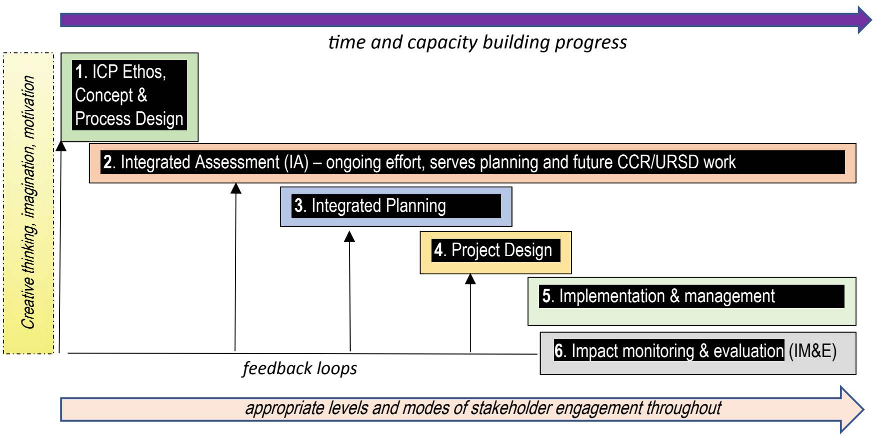

Fig. 15.3 Integrative Operational Frame. Comprises recognizable stages from ethos and conceptual design of the process, through integrated assessment (IA), planning, project design, implementation and management, monitoring and evaluation—as an adaptive loop

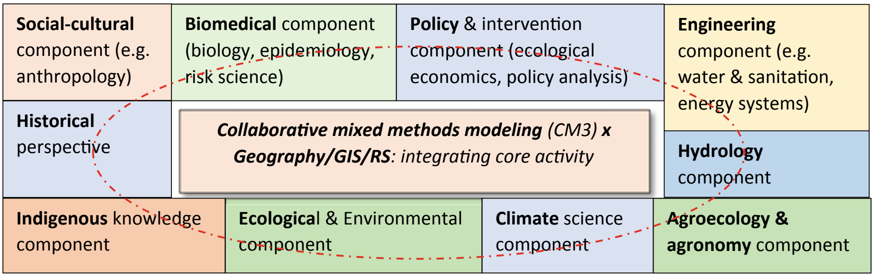

Fig. 15.4 Multi-component research-to-action. Project components actively exchange data and information, maximizing synergy and integrative power to understand complex problems and adaptively respond. Actual components are case/context-specific, and depend on recognizing and strategically mitigating local resource/capacity constraints by collaboration

This model also encourages those primarily responsible for assessment (e.g. researchers) to see assessment as an integral part of the continuum: the work is conceived and designed to foster synergy and translation of findings into action. Integrative health research projects need to be designed and deployed in ways that exploit synergies and actively exchange data and information (Fig. 15.4).[7]

Social-technical Capacity Building Enterprise

The fourth innovation is philosophical and conceptual: We frame health and environment work as a *social-technical capacity building enterprise*, with roles and responsibilities for different stakeholder groups working in collaboration to co-create an adequate understanding of hyper-complex problems and a transparent choice among alternative responses: local communities, NGOs, local and regional governments, businesses, donors, the media, and academics. The premise is that existing capacity—social and technical—is fragmented and insufficient, and that the key to success lies with unlocking the potential of social capital (Downs and Larson 2007). In foundational work that directly informs our Mexico case herein, Downs (2001, 2007) facilitated a multi-stakeholder process of *participatory integrated capacity building* to co-assess conditions and stakeholder assets, co-identify and mobilize social and technical capacities in pursuit of sustainable water supply and sanitation (WATSAN) systems in three pilot cities.

Six components of capacity were identified from workshops, literature review, experiential knowledge and an analysis of the predictors of success in a sample

[7] This avoids the chronic issue of health scientists, for example, doing science without considering translation into policy or action—bridges among science, policy, monitoring and evaluation are ‘baked-in’ to the enterprise design. It also avoids the related issue of project components being disconnected—the design makes exchanges of data and information explicit so the whole is more that the sum o its parts.

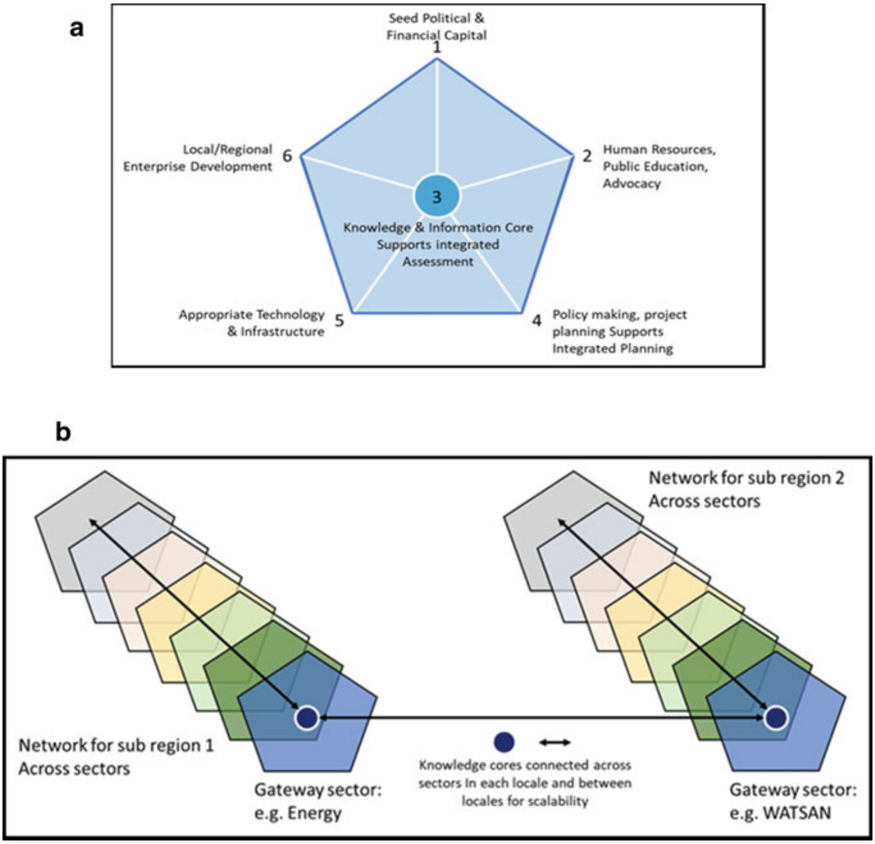

Fig. 15.5 **a** Six components of social-technical capacity. The components are interrelated and comprise a system, connected by flows of information and the information core. **b** Capacity-building enterprise as a scalable social-technical network. The six components of capacity connected across sectors, e.g. #2: education and training across energy, water, food, health etc.), with #3: *information resource* as core. Networks can be scaled-up or down across neighborhood, municipal, regional, national and international scales. There will be unevenness in components across sectors; the image merely depicts intent to integrate across them such that the whole is greater than the sum of its parts via synergy

of international development projects. They are: (1) political and financial seed capital; (2) education, training and awareness raising; (3) information resources; (4) policy making; (5) appropriate technology; and (6) economic enterprise development (Fig. 15.5a). Importantly, the enterprise is scalable across sectors and locations (Fig. 15.5b).

The role for universities is of special note in this enterprise, given their place in society as relatively independent entities with missions to educate students and carry out research that furthers knowledge for the collective good. Among stakeholder groups—civil society, business, government, NGOs, donors and universities/colleges—in theory, universities have the least loyalty to the business-as-usual development paradigm,[8] the healthiest bias, and thus the potential to play the role of knowledge integrator, catalyst for change, and facilitator of the social-technical enterprise process (Downs and Golovko 2017).

Case Study Application

Ethos, Framing and Questions

To illustrate our integrative approach and the application of frameworks and methods, since 2019, we have been exploring how to co-create shared understandings of social-ecological complexity by assessing and modeling the nexus of climate change, water, health/wellbeing, livelihoods, and agroecology. The project—"*Climate Change Impacts & Resilience in the Mexico-Lerma-Cutzamala Hydrological Region*"—is a multi-stage, multi-component project framed as a long-term social-technical capacity building enterprise among diverse stakeholders, to assemble knowledge and apply it to co-design ways to respond. Social justice is a central theme: we are assessing gradients of vulnerability to water scarcity and health risks across a region that includes 193 municipalities and five states. Our study region is the *Mexico-Lerma-Cutzamala Hydrological Region* (MLCHR) chosen for its profound representation of the three conundrums (Sect. "Conundrums and Integrative Domains"), and because long-standing relationships of trust, mutual respect and shared ethos exist among the academic partners. Our foundational first-stage research questions contemplate three health aspects that inform each other:

Q1. *Impact science aspect*: What are the existing and projected impacts of climate change/climate instability on hydrology, water resources, water supply and wastewater/stormwater sanitation (WATSAN) systems at regional and municipal scales? What is the influence of land use/land cover (LU/LC) change, population growth, and urbanization in this regard?

Q2. *Impact equity aspect*: How do these impacts in-turn impact human health and wellbeing, livelihoods, and agroecological systems? Who is most impacted, and why?

Q3. *Impact response aspect*: How can we co-create adaptive social-technical capacities with diverse stakeholders to mitigate impacts, and to significantly improve health, social justice, climate resilience and sustainability?

[8] Universities may actually reinforce *status quo* innovative approaches—perhaps unwittingly—by teaching them to students, by doing research that serves status quo interests and is funded by them.

Mexico-Lerma-Cutzamala Hydrological Region (MLCHR)

The Mexico City Metropolitan Area (MCMA, urban and peri-urban) comprises 76 municipalities, with population 21.9 M in 2021 (world's 5th largest urban area), while *Toluca de Lerdo* has 2.5 M (See: https://populationstat.com/mexico/mexico-city). Average elevation of the Central Mexican Neovolcanic Highlands is about 2,000 m—characterized by alluvial plains and lakes surrounded by volcanic slopes with oak, pine, fir, cedar, and cypress forest. The *subtropical highland climate* has cool, dry winters (some freezing temperatures), and mild, wet, humid summers. There is an extended dry season (November to April), and rainy season (May to October); rainfall in the range between 480–1700 mm/year—well suited for agriculture. In Tlaxcala (northeast corner of the region), for example, there is an energetic small-scale organic farming movement growing high-value crops: fruits, vegetables, cereal grains, honey and its derivate products (Marquez-Berber et al. 2015).

Social-ecological Complexity: Defining the Study Region

To tackle the *social-ecological complexity conundrum*, we chose water as our *gateway issue/sector*—the way-in to the climate-health-sustainability story. A gateway resonates with all stakeholders, is pressing, and serves as a catalyst for exploring the interrelationships that characterize social-ecological systems given its governing role for human health and wellbeing, the economy, and the ecosystem at multiple scales. Eisenstein (2017) refers to "the water paradigm" in his re-imagining of climate-change challenges, and we have previously used water, sanitation and vulnerability as a practical gateway for thinking about the sustainable development of Mexico City (Downs et al. 2000; Mazari-Hiriart et al. 2006). Hence, we defined our study region using surface water and groundwater hydrology (watersheds and aquifers), and the WATSAN network that serves the MCMA (Fig. 15.6a, b). The latter results in an anthropogenic coupling of 29 watersheds; water taken from the west and pumped to the MCMA impacts the former negatively and the latter positively. Climate change/instability—primarily in the form of changes/instabilities in precipitation and temperature have actual and projected impacts on water resources; both surface and groundwater. Urbanization, driven by population and conventional economic development—especially in the MCMA, Toluca, and Pachuca (Fig. 15.6c)—also impact water resources by increasing the impermeability of land cover (land use/land cover change from soil, pasture or forest to pavement). More pavement means less infiltration to recharge overexploited aquifers, more rapid runoff contaminated by oils and greases from traffic, and increased urban heat island effect with more rapid evaporation. Disruption of the water cycle may increase water scarcity, already a chronic issue for centuries, exacerbated on recent decades (Eakin et al. 2017; Tellman et al. 2018), with effects also on the quality of the water resources (Mazari-Hiriart et al. 2019),

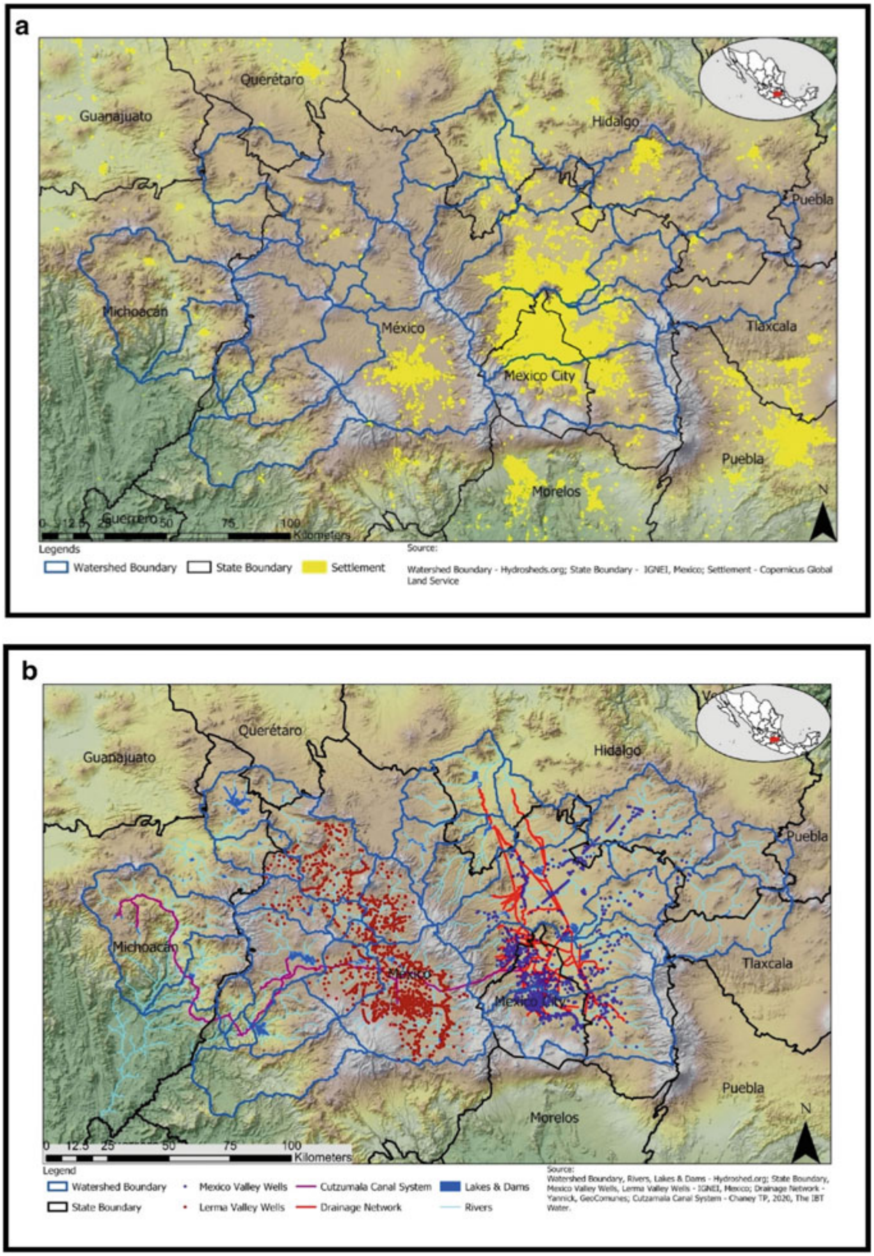

Fig. 15.6 **a** MLCHR including watersheds and states. **b** Main water supply and wastewater/stormwater sanitation infrastructure. **c** The 193 municipalities of the MLCHR

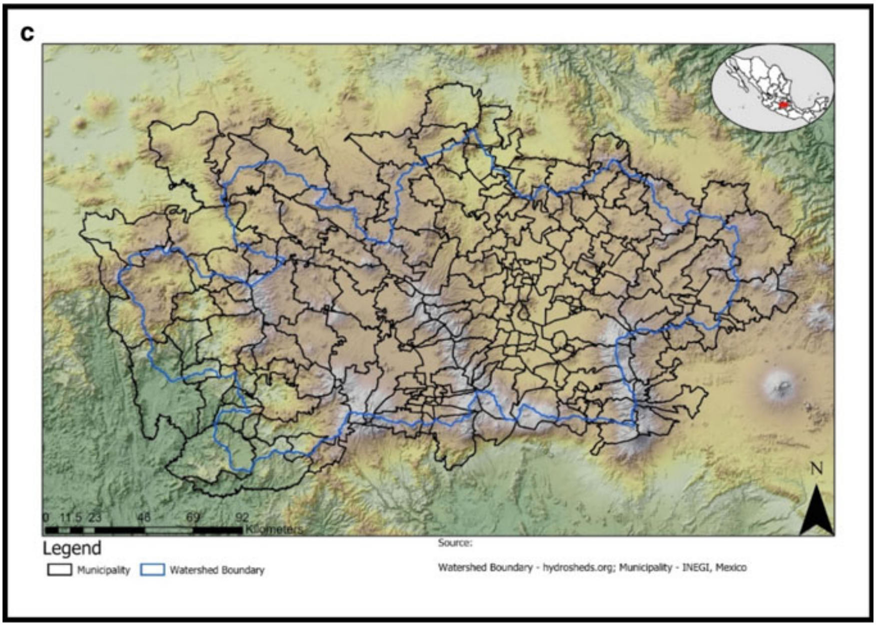

Fig. 15.6 (continued)

affecting the health, wellbeing and livelihoods of urban and rural populations—especially a growing majority who are already marginalized with high vulnerability (Sect. "Stakeholder Enterpris").

Spatial and Temporal Scales

Considering the *varying spatial and temporal scales conundrum*, human spatial scales range from sub-municipal, to municipal, megacity, sub-regional to regional, and the hydrological ones range from reservoir, sub-watershed and aquifer to major hydrological region. Our temporal scales range from the present to short, medium and long-term horizons using IPCC climate scenarios to 2050.

Stakeholder Enterprise

The *stakeholder diversity conundrum* is framed as an opportunity to create social-technical capacity at scale (Sects. "Conundrums and Integrative Domains and Social-technical Capacity Building Enterprise). We have an academic core partnership comprising Clark, GWU, UNAM and IPN, and are in the process of developing

Table 15.1 Capacity building components in the mexico project context

#	Project context
1. Seed political & financial capital	Seed political capital in the form of the academic research partnership that builds a network of diverse stakeholders with shared interest in health, water and climate. Seed $ provided in the form of a small grant from Leir Foundation for exploratory field visit 2019. Ongoing grant-writing activity with equitable investments of in-kind effort and rewards
2. Education & awareness-raising	The core academic partnership is developing new courses to serve shared interests and students at each institution, framed by a shared integrative vision for health, water, climate and sustainability education. Efforts planned to extend education to K-12 schools, professional training, and to community-based outreach and awareness-raising programs
3. Information resources	Foundational work is addressing relevant questions (Sect. "Ethos, Framing and Questions") and developing integrative methods of modeling and analysis (Sect. "Conundrums and Integrative Domains" #4). Datasets include IPCC scenario models, hydrological and WATSAN data, heath data and relevant vulnerability factors.[9] Among the health methods are environmental and social epidemiology, health anthropology and ethnography, health GIS and spatial analysis, and systems dynamic modeling
4. Policy making	We are assessing existing policies and practices at the health-water-climate nexus, incl. municipal and regional climate action plans, international cases of "best practice", health impact assessment and policy analysis
5. Appropriate technology (AT)	We are assessing existing WATSAN technologies with the goal of developing more climate-resilient systems that mitigate inequities of health impact. The spatial and temporal scales of AT, levels of efficiency, sustainability and redundancy, and 'smart' control are key
6. Economic enterprise development	We emphasize the co-stimulation and co-development of local and regional providers of products, services, information and investment - thereby reducing dependence on external sources. The goal is to replace seed $ capital from Level #1 for economic sustainability. Examples: provision of WATSAN hardware, climate monitoring, and health monitoring

meaningful, mutually beneficial relationships with *Isla Urbana* (social-technical entrepreneurial NGO), and the farming cooperative *De la Chinampa a tu Mesa* (from the chinampa to your table), based on indigenous 'floating gardens' (chinampas) agroecological practices in the municipality of *Xochimilco*, Mexico City. We are also planning to establish relationships with a representative sample of municipal governments and civil society groups in the region, including urban/peri-urban Mexico City, Toluca, and Pachuca, as well as semi-rural/rural municipalities. Table 15.1 shows the six components of social-technical capacity being considered in the Mexico context, with #3—Information Resources at the core; the research collaboration builds the capacity to create these resources with each stakeholder partner contributing to them, and benefitting in tangible ways. It is this dynamic that sustains buy-in and builds

[9] These data will be compiled and store with "open-science tools" and customs where appropriate and non-identifiable—open, accessible, reusable, reproducible (Hall et al. 2021).

trust over time. This framework also serves to assess existing capacities and priority gaps, as well as other stakeholders with capacity to lend.

Preliminary Systems Model

Since health is a focus, we are in the early stages of creating a systems model of health that captures both the *promoting factors* and *degrading factors* at population scale (Fig. 15.1). This informs the creation of a influence diagram; Fig. 15.7 shows a preliminary influence diagram relating climate change, water, health, population, farming livelihoods, energy systems (and GHG emissions), and the economy. We will be engaging in collaborative mixed methods modeling (Sect. "Integrative Health Models and Methods") as an integral part of the capacity building enterprise approach (Sect. "Social-technical Capacity Building Enterprise") to revise and improve this model and it will be co-created with shared ownership.

Impact Science and Policy

The study region enjoys high social and ecological diversity (Fig. 15.6a, c). We hypothesize that vulnerability to climate impacts will vary significantly from municipality to municipality, and also within municipalities with large socio-economic gradients. Again, using the gateway of water, we are gauging the relative vulnerability of municipalities to water scarcity associated with climate change/instability, land change and urbanization. For example, we are using GIS/RS to map aquifer recharge zones that are themselves vulnerable to loss, and may suffer more loss under projected urbanization. We are also looking at the vulnerability of surface water, especially the reservoirs of the *Río Cutzamala* watersheds that supply MCMA (Fig. 15.6b); the levels fluctuate based on inflows and outflows, the former impacted by precipitation and runoff (and thus climate), the latter impacted by water demand. Another way that the CM3 and GIS/RS are used in concert is the mapping of the WATSAN network at both regional (Fig. 15.6b) and municipal scales, to consider which populations receive piped water, which do not, and the source(s) of their water (local aquifer, surrounding aquifers import, or surface water import). These data and maps, coupled with the modeling (Fig. 15.7) that relates climate change to changes in water resources (quantity and quality) will allow us to estimate which municipalities and populations are most vulnerable to water-related climate impacts—both under existing conditions and under the latest projected IPCC scenarios. To improve our understanding of the *water-health-livelihoods-climate nexus* in a comprehensive way—and our corresponding models—calls on us to invest the time and energy needed to meaningfully engage with our stakeholder partners (Sect. "Social-ecological Complexity: Defining the Study Region") in the places where they live and work.

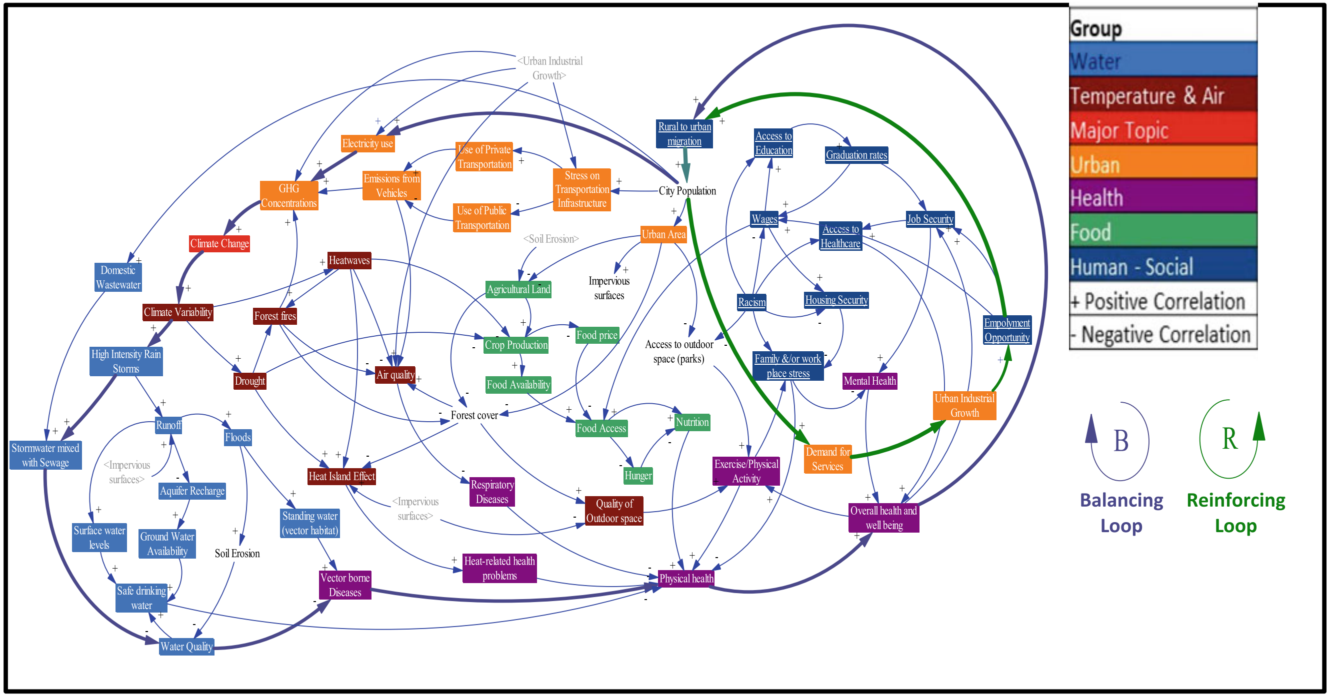

Fig. 15.7 Preliminary influence diagram for conceptualized health-water-climate system showing groupings and hypothesized relationships. This emerged from dialogue among the co-authors, with further co-creation by stakeholders planned as CM3 approach. The signs or 'polarities' of relationships are positive (+) if change in X causes the same change in Y, are negative (−) if change in X causes the opposite change in Y. Balancing loops represent negative feedbacks (net product of polarities is negative), reinforcing ones positive feedbacks (net product of polarities is positive). Notice that the majority of variables are spatially explicit, i.e. can be represented and analyzed using GIS. Some are in turn influenced by land use/land cover, amenable to GIS/RS tools

This is where ethnographic methods, qualitative and narrative data - in concert with GIS/RS and CM3—promise to deliver the analytical power we need.

On the impact response and adaptive capacity side of the project (Sect. "Ethos, Framing and Questions" **Q3** and **planning stage** of Fig. 15.3), the same place-based data will be used to inform ways to mitigate existing and projected impacts. As a starting point, we are learning about impact-relevant social and ecological conditions, and existing climate action plans in a sample of 12 municipalities: three transects of contiguous urban, peri-urban, semi-rural and rural municipalities, one in each of the three major hydrological subregions of *Cutzamala*, *Lerma* and *MCMA* (Fig. 15.6a). Here, we use international case studies from comparable settings and high-level sources (e.g. UNEP 2021; USAID 2021; World Bank 2019) to inform place-based 'best climate-health resilience practice' for the region. Alternatives will be considered and compared using the same impact criteria used in the impact modeling to identify the most sustainable option; the same SDM is applied to policy analysis. Once a project, policy or intervention is chosen, it undergoes detailed design, is implemented and managed, and its performance is monitored and evaluated (Fig. 15.3) as an adaptive loop. It is important that monitoring and evaluation also use the same set of impact criteria, and that data are fed back to adapt the project over time.

Limitations

The limitations of the work lie in the early-stage design and development of the case study project; the influence diagram Fig. 15.7 is described as preliminary, for example. This means that while all four innovations rest on both experiential and theoretical foundations, their efficacy in the context of the case study have yet to be shown.

Conclusion

Hyper-complex challenges at the nexus of climate-water-food-health/wellbeing-sustainability call on us to develop and test new integrative concepts and methods for research, practice and education. Such perspectives emphasize and exploit innate interdependencies among the dimensions of dynamic social-ecological systems. Four innovations working together hold the promise to address major structural weaknesses in existing concepts, framings and approaches: (1) an *integrative framework* tackles innate conundrums and conceptualizes important domains; (2) an *integrative operational process* informs the design of health-water-ecology-climate projects, enabling multi-component research and its translation; (3) coupled *mixed methods systems modeling-GIS/geospatial analysis*, plus *exposure versus response/risk curves* for groups with differential vulnerability to stressors, reveal both promoters and degraders of health, and structural injustices; and (4) a *social-technical capacity* *building enterprise* model frames health-climate-sustainability projects based on prior successful multi-stakeholder experience in Mexico. Our ongoing project illustrates their application and will inform future prospects and avenues as we garner experiential knowledge and learn lessons along the way.

We conclude health, sustainability and climate resilience challenges be reframed as opportunities to co-create *social-technical enterprises* at different spatial, temporal and human scales, firmly anchored in the moral pursuit of social-ecological justice, and enabled by stakeholder partnerships. Global North-Global South capacity building enterprises will be drivers of success—indeed, in our climate-changing world, nothing short of a new framing of international development is needed, one that is less aid-based, more shared-interest/co-capacity based. While no one country has adequate capacity to understand and respond to climate-change impacts, or to the host of other health determinants, in collaboration, the odds tilt favorably. Making more probable a healthier, more socially just, climate-resilient future hinges on the energy and creativity of diverse social groups to co-create reinforcing social-technical capacities. Such work is needed to reveal and address both promoting health factors and degrading ones, and to make explicit the structural health and impact injustices that conspire to forestall it.

Acknowledgements We received a travel grant to undertake exploratory partnership building for the MLCHR project in 2019, part of an award from the *Leir Foundation* to support innovative health science work at Clark University. Thanks to Alex Stever and Ryan Mitchell for helping with the influence diagram.

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Chapter 16
Greek Students' Planetary Health Profile: A Master's Program in Environmental Communication and Health Promotion

Chrysoula N. Sardi, Michalis Karamperis, Alexandros Lingos, Nikolaos Klioumis, and Constantina Skanavis

Abstract The emergence of Covid-19 demonstrates a breakdown in humanity's relationship with the natural world (Frumkin and Myers, Planetary health: protecting nature to protect ourselves, pp 487–496, 2020). Escaping the "Pandemic Era" will need transformational adjustments and a profound rethinking of our connection with nature (The Lancet Planetary Health, Lancet Planet Health 5(1):E1, 2021; Harris, Participatory media in environmental communication, 2019). Considering how demanding—and at the same time unique this time is- early Anthropocene 2.0 consciousness is a concept worth exploring. Anthropocene 2.0 requires the development of communication skills on issues of environmental and public health concern. Our global health research and training communities and institutions must examine, reflect on, and reform the methods through which we promote and maintain planetary health (Haldane and Berry, The Lancet Planetary Health 5:E10, 2021). Professionals must successfully translate science, convey costs and benefits, and involve stakeholders in pressing environmental issues. Lessons from the pandemic emphasize the significance of systems thinking, the need for collaborative action, and the potential of rapidly changing global behavior. The present Covid-19 "silent period" offered a unique chance to launch a new graduate program in Environmental Communication and Health Promotion at the University of West Attica in Greece. It is critical to know the profile characteristics of those who were selected to attend this graduate program. The pertinent information will give a clear understanding of why people choose the specific field of study. This paper evaluates trainees' health consciousness, environmental awareness, pro-environmental behavior, environmental activism, and personal values.

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_16

Introduction

The year 2020 has been a wake-up call to those who believed that environmental deterioration didn't affect them (The Lancet Planetary Health 2021). This pandemic serves as a chance for us to recognize that we require a healthy world to safeguard the health of all people (Plowright et al. 2021). Covid-19's appearance reveals a rift in society's interaction with nature (Frumkin and Myers 2020). The Covid-19 pandemic and the recent Ebola outbreak in Guinea make us think just how delicate the balance is between human health and the health of planet Earth. This world suffers from anthropogenic climate change (Fabbiano et al. 2021). Climate change may potentially act as a brake on the next human leap ahead, but chances for that are dim (Inogwabini 2019, p.223). Therefore, to be tackled successfully in the future, climate change needs to be better communicated (Skanavis and Kounani 2018).

Coronavirus may spark a reconsideration and assist in the far-reaching shift that global health requires (Frumkin and Myers 2020). Escaping the "Pandemic Era" will need transformational adjustments and a profound rethinking of our connection with nature (The Lancet Planetary Health 2021).

According to The Lancet Planetary Health (2021), Covid-19 was not a unique incident but rather an indication of ecological instability. What the Covid-19 pandemic demonstrates, in the broadest strokes conceivable, is the sheer degree to which life on this planet is intertwined (Bai 2020). Covid-19's origin was related to human interactions with the environment and animals, our food system, and changes in demography and technology (Myers and Frumkin 2020). According to Myers and Frumkin (2020), recognizing the significance of keeping our world healthy would enable humanity and the natural systems we rely on to thrive today and in the future. According to Guzmán et al. (2021), there is no successful human future without a healthy ecosystem. The interrelated environmental, socioeconomic, and health issues generate difficulties that we must address.

Health is one of the fundamental human rights. We depend on healthy ecosystems to support healthy people and healthy societies (Halonen et al. 2021). The 2030 Agenda for Sustainable Goals can be advanced by identifying and strengthening the interactions between human health and environmental changes. Crucial role plays the adoption of a holistic frame that covers the solution of overlapping problems. Additionally, the concept of planetary health can map the respective detection of expected benefits across goals, intentional actions, and partnerships and achieve policy coherence (Pereira and Marques 2022). In turn, the Sustainable Development Goals (SDGs) agenda offers chances and room to advance planetary health. (Wang et al. 2020).

According to the Lancet Commission on Planetary Health (Whitmee et al., 2015), planetary health can be defined as "*the achievement of the highest attainable standard of health, wellbeing, and equity worldwide through judicious attention to the human systems—political, economic, and social—that shape the future of humanity* and *the Earth's natural systems that define the safe environmental limits within which humanity can flourish. Put simply, planetary health is the health of human civilization* *and the state of the natural systems on which it depends*". Therefore, the meaning of the term "planetary health" is rooted in the understanding that the condition of the natural systems of the planet determines the quality of human health. The interdisciplinary influence that stems from this realization can have significant implications. For instance, the practical application of planetary health conceptualization on healthcare systems may help clinicians search for connections between ecosystems and the health of their patients. Medical students could learn that medicine production makes up 25% of the National Health System carbon footprint (NHS Net Zero Expert Panel 2020) or that people with diabetes are vulnerable to high temperatures and climate change threats (Zilbermint 2020). Their instructions and decisions could change drastically. They may even write a patient's history report that incorporates their environmental and community conditions look for the possible relationship between health and the environment (Moore 2021).

Planetary health is a field that incorporates many and different disciplines, and each of them often proceeds in the absence of a unifying culture of interdisciplinary research. The direction should be to build bridges among all the relevant disciplines to comprehend complex systems and achieve potential policy solutions (Whitmee et al. 2015). This is a challenging but necessary task. The 2015 launch of the Rockefeller Foundation Lancet Commission on planetary health (Whitmee et al. 2015) was the spark that started a great deal of interest regarding planetary health education among many fields of study. Along with urgency for planetary health education arises the need for efficient environmental communication skills that help promote planetary health and have another role. The role to be embedded in different disciplinary fields so that inter-disciplinary research on planetary health and promotion can be conducted efficiently. However, various scientific areas and settings (i.e., non-governmental organizations) tend to employ different communicator strategies and use different contexts of understanding environmental communication and other terminology (Schwartz et al. 2017; Martin 2020; Akerlof et al. 2021). Akerlof et al. (2021) examined how researchers and communicators from different backgrounds who endeavor on environmental issues may have different perspectives and priorities on the components that constitute environmental communication. The need for all key stakeholders to devote their attention to planetary health is imperative. Due to its unifying frame, planetary health can incorporate and promote SDG actions for national governments, the UN alliance, and many more stakeholders (Pongsiri et al. 2019). It is abundantly evident that the world needs a fundamental transition based on Sustainable Development Goals. Like planetary health, the SDGs need global leadership and intersectoral collaboration for all national or local actions. Moreover, they require direct integration of several benefits and trade-offs for the environment, health, and sustainable development objectives (Pongsiri et al. 2019).

In any socio-ecological system, the focus must change from individual-independent "universal health" to an interdependent "ecohealth" lifestyle (Moji 2019, p. 82). What is known is that larger social identities, solidarity, and shared values are required to provide a foundation for long-term planetary health to become a key value for individual and collective human activity. According to Helliwell and Hall (2020, p. 277), life satisfaction results from shared social identities and values that bring people together.

Ecological Consciousness

According to Bai (2020), the modern world is characterized by a lack of soul or spirit nourishment. In the same way that when we are hungry and feeling faint, we cannot hear (or see) very well, a malnourished consciousness struggles to hear the world around us. The prevalent consciousness is still that the environment is 'out there,' it is also perceived as distant from us and our daily lives (Craig 2019, p. 208). Anthropocene 2.0 consciousness is the change in purpose from maximizing human benefits to improving whole-system functioning, according to Motloch (2019a, b, p. 2087). Emerging Anthropocene 2.0 consciousness is based on a better knowledge of systems, complexity, and complexity science (Motloch 2019a, b). According to Motloch (2019a, b, p. 2087), as evidence that this transition is in progress is the increasing awareness of the need to maintain, regenerate, and co-manage the energy-water-food nexus as an interdependent set of critical life-supporting systems. Towards a sustainable future, Anthropocene 2.0 consciousness is already building and adopting the analogically robust knowledge system required to understand the complexity and embrace complexity-centric co-design. Anthropocene 2.0 consciousness has the potential to optimize functioning in today's unsustainable environment while also reprovisioning the planet to become more sustainable (Motloch 2019a, b, p. 260). Awareness of sustainability issues is to comprehend the fragility of the environment and the necessity of its preservation, thinking in terms of ecological consciousness. It involves developing awareness, understanding, and consciousness of the biophysical environment and its problems, including human interactions and effects (Raymundo et al. 2019, p. 76). Early efforts to explain and influence pro-environmental behavior depended on a very linear model of human behavior. Awareness of an environmental issue is regarded as the main predictor of action on it. Bendor (2018, p. 29) claims that for a person to become knowledgeable about an issue, they must first become aware of it and then develop a concern about it because providing compelling information about an issue expect to create attitudes that would, in turn, spur appropriate behavior.

It is essential to note that four key components are necessary for the much-needed change to take place. We need compelling shared visions that inspire hope and optimism; we need to alter how we produce and share information; we need to strengthen our human connection to the natural world, and we need to develop social action movements to bring about the change we need (Myers and Frumkin 2020, p. 480).

How Can We Create a Shift in Consciousness?

"What can we do about individuals who continue to do activities that are harmful to their health, and perhaps for others, even though they are aware of the consequences? Lawrence (2015) raises this question. Among the personality characteristics, responsibility consciousness has substantial impacts on environmental consciousness and health consciousness (Kaynak and Eksi 2014). Flor (2004, p. 18) emphasizes the need to understand that environmental consciousness results from a society's collective worldview and values, making it impossible to alter with a press release, a billboard, or a thirty-second television commercial. He then says that the most effective method to increase environmental consciousness is a social transformation or cultural change. Health consciousness refers to how individuals pay to or focus on their health, an inner state of self-awareness to self-relevant signals expressed in cognition and physical sensation (Gould 1990).

Living differently requires changing our view on the world and ourselves in the sense of profoundly modifying our way of existence (Bai 2020). Transformative pedagogies contain the potential for a significant shift in thinking and behavior. Epistemic learning does not need learners to accomplish things better or even better, and it challenges people to look at the world in new ways. It can permanently remodel students' consciousness and alter their way of being in the world (Salonen and Siirila 2019, p. 1970).

Ohu and Ogunyemi (2020, p. 505) argue that enhanced consciousness and mindfulness training are essential for sustainable consumption. They also suggest that the term "sustainable" be equivalent to "ethical" in this context since it involves doing what is suitable for people, the Earth, and the economy. Achieving planetary health may also include addressing this spiritual component, and it may need to reaffirm what so many people feel: a spiritual connection to the natural world (Myers and Frumkin 2020, p. 482). As a result, mindfulness may offer the psychological resource required for this change. People who voluntarily choose to consume ethically do so because they are persuaded of its benefits, as Ohu and Ogunyemi (2020, p. 505) point out.

According to Kevany (2019a, b, p. 445), ecopsychology cultivates a consciousness that promotes the development of worldviews and behaviors that allow the growth of the human experience by being sensitive and respectful of the environment, particularly from forms of human devastation. Concerning the connection between human health and their surrounding environment, ecohealth is likewise a relatively new subject (Watanabe and Watanabe 2019, p. 2).

According to Gaffney and O'Neil (2019), as quoted in Sterling (2017, p.41), a shift in educational paradigm, one that is inclusive and participatory, is required to generate a shift in consciousness, which in turn will bring about a change in educational thinking, policy, and practice. This shift will need systemic change, and it should be capable of assisting educators in developing suitable learning outcomes and modifying existing curricula to include concepts that encourage sustainability. (Gaffney and O'Neil 2019; Sipos et al. 2008). A fundamental idea for promoting this paradigm change is to engage in three distinct brain domains: cognitive, psychomotor, and emotional domains, or head, hands, and heart (Gaffney and O'Neil 2019, p. 660).

Environmental education, which is desperately required, offers a fertile ground for human development innovations based on a new educational approach to consciousness and health promotion (De Almeida and Da Silva Carvalho 2018). Environmental education must be integrated into society to the point that it becomes a synonym for citizenship, defining a new consciousness for all planet inhabitants (Morgado et al. 2020, p. 636).

Referring to the work of Bai (2020), a question arises regarding environmental education. As Bai (2020) argues, today's environmental education retains the outdated and problematic habit of thought that views the external world needing assistance and repair. Bai (2020) asks if it is logical to continue doing environmental education in the same manner after the present pandemic, and if not, how might it be done differently?

Environmental Communication

Communication intrinsically connects to our understanding of the world and our duties within it. Environmental communication conveys both the dangers and the marvels of the environment (Pezzullo and Cox 2018). Even while researchers worry a lot about sharing complexity and ambiguity, Clement (2021, p. 249) believes that researchers' knowledge communication must be simple to alter practice effectively. Harris (2019, p. 9), as cited in Lie and Servaes (2015, p. 251), interprets environmental communication as a relatively new sub-discipline within communication science that overlaps with environmental education and health communication on public engagement and public opinion. Because environmental communication is multidisciplinary, it is discussed in environmental science, environmental planning, development studies, and disaster risk management. According to Harris (2019, p. 9), climate change communication is one of the sub-themes that dominate environmental communication. Without an environment, there is no communication, and life on Earth may be preserved or destroyed through communication (Pezzullo and Cox 2018).

Education

It is essential for our global health research communities and training institutions to examine, reflect on and rethink how we promote and maintain planetary health (Haldane and Berry 2021). Concina (2019, p. 352) states that higher education fosters cultural sustainability, essential in a diverse society. To achieve the 2030 Sustainable Development Goals agenda, we must engage in learning movements that encourage the re-education of values and paradigms via training from social actors, such as environmental educators and health promoters as De Almeida and Da Silva Carvalho (2018) present in their work. In collaboration with other areas of study, environmental educators have increased awareness of the nature of the self, the environment, and the interconnectedness of all creatures and systems (Kevany 2019a, b, p. 282). Individuals who provide interpretive programs are referred to by the terms "interpreters," "educators," "naturalists," "nature guides," "docents," "tour guides," "heritage interpreters," and "heritage interpreters" (Skanavis and Giannoulis 2009). Interpreters aim to instill a feeling of responsibility in visitors toward the resource and a sense of belonging. Environmental interpretation plays a significant part in informal free-choice learning settings, as it attempts to educate visitors on complicated natural resource concerns related to national and local protected areas, as well as sensitive ecotourism settings. People may help to promote sustainability by taking on the role of environmental steward. To fulfill the position of environmental steward, one must act responsibly toward or within the ecosystem. Aside from being active in academic research, environmental education, and expressing their environmental expertise to others, the environmental steward may take their responsibility even further by participating in various additional activities. Another step forward is Biosphere stewardship, a multi-actor approach to sustainability that emphasizes collaborative action and governance rather than individual activity. In this setting, young stakeholders have the potential to play a critical role in the resolution of social-ecological concerns. As a result, planetary health communicators can organize many activities, actions, and initiatives to bring together as many people as possible from diverse backgrounds to actualize solutions.

According to Flor (2004, p. 29), environmental communication initiatives should be bottom-up and top-down to convey these concepts effectively. Flor (2004, p. 29) argues that the overall purpose of environmental communication is to achieve mutual understanding, which can be equal to societal, environmental consciousness.

Master in Environmental Communication and Health Promotion

It is becoming more evident that understanding the human aspects of environmental change is necessary to comprehend how we create our environment and how we are impacted by its deterioration (Harper, 2010). Therefore, environmental communication and health promotion may become the dominant method to alter our mindset and behaviors. According to Benatar et al. (2009), a thorough reflection about our present value system is necessary to accomplish a paradigm shift that may reverse current trends and lead to global health gains as well as reduced human insecurity. Myers and Frumkin (2020) suggest that some of the lessons we are learning about managing the pandemic highlight the significance of systems thinking, the necessity for collaborative action, and the possibility of fast global behavioral change. Therefore, making this worldwide pause a unique chance to start new postgraduate studies in Environmental Communication and Health Promotion at the University of West Attica.

The program commenced in October of 2020 with 49 trainees. The purpose of this Master's program is to provide a high level of postgraduate education in the scientific field of Environmental Communication and Health Promotion. It is designed to provide specific information and critical assessment skills on environmental issues that undoubtedly have various effects on public health. The combination of education on health promotion and environmental communication ensures that the trainees will be able to participate in—and lead—processes of decision-making. Thus, they will be capable of understanding deeply respected issues and help evaluate and form strategies that affect the quality of life and the quality of the environment. Furthermore, the creative and strategic communication skills which this Master teaches will give the competence to the trainees to communicate with efficacy environmental issues to different groups of people from different educational and cultural backgrounds. The trainees will support environmental awareness in interpersonal, community, organizational, and public settings.

The program aims to:

- Provide academic knowledge in Environmental Communication and further expansion of the knowledge capital in Ecotherapy and Health Promotion.
- Conduct research studies in the relative discipline field and introduce innovative epidemiological research programs.
- Promote and highlight the applications of Environmental Communication in the fields of Ecotherapy and Health Promotion.
- Develop research in the section of new technologies related to Ecotherapy and Health Promotion.
- Evaluate advanced and complex concepts, approaches, and methods from the science of communication, regarding the intra- and interdisciplinary problems and practices found in the scientific literature.
- Implement appropriate design for quantitative and qualitative empirical research, select appropriate research methods for data collection and analysis, and demonstrate the ability to identify needs for new theoretical, methodological, and practical approaches.
- Promote the collaboration of the trainees about the professionals, the scientists, the policymakers, and the general public and the implementation of oral and written work based on cooperation in an interdisciplinary team.
- Promote the initiation of constructive intersectoral and interdisciplinary discussions and collaborations within and between various social and scientific organizations and professions.
- Critically analyze how different knowledge, communications, and practices of health, wellness, and healthcare are used to shape and organize the lives of individuals, groups, and populations.
- Evaluate the tools used in scientific and social approaches to understanding, mediating, advocating for health and well-being, and designing innovative ways to bridge these approaches.

- Create scientists with the necessary skills for successful careers in the private, public, and academic sectors in the prevention and promotion of Public Health.
- Contribute to upgrading the health system and the cooperation of the private sector with the public sector.
- Prepare the trainees for postgraduate studies at the doctoral level.

The Master's program and has a duration of three semesters (1,5 years). A program planned with planetary health in mind features a comprehensive curriculum that inspires environmental and health consciousness cultivation. The core curriculum of the Master's program covers topics such as Foundations of Environmental Communication—Defending Health, Introduction to Epidemiology and Public Health for Communication Professionals, Health Education and Promotion from school to the community, Communication Policy in Crisis Management, Project Management Communication Plan & Funding Insurance, Communication Strategies on Health and Environmental Issues, Communication for Behavior Change: Individuals and Communities, Health Communication and Mass Media, Ecotherapy: From Theory to Practice, Intercultural Communication in the field of Environmental Health, Technology and Digital Design in Health Communication. The Master's program has an ECTS value of 90 credits.

Methodology

Study Design

The study involves the first phase of a longitudinal prospective quantitative study. This initial section collects data from a specific set of people (Master's program trainees) to examine their planetary health profiles. We specifically studied key indicators (provided in sections below) among trainees on this Master's program titled "Environmental Communication and Health Promotion" utilizing anonymous questioners. The first graduate program in Greece, from which the research participants were chosen, attempted to evaluate their initial environmental concern expectations. An online survey was used to collect data. The poll was anonymous, and participation was entirely optional using the aforementioned online form. Forty-eight (48) of the program's 49 students filled in the questionnaire. Participants were advised that if they felt uncomfortable, they may leave the survey at any moment with no questions asked.

The research was conducted by the Research Unit of Environmental Education and Communication of the Department of Public and Community Health, School of Public Health, University of West Attica (www.uniwa.gr).

Means of Sampling

The questionnaire was developed based on thorough literature research. It consisted of 68 questions of open- and close-ended types separated into two sections.

In the first section of the questionnaire, specific demographic data were collected from the participants to outline better their basic profile and some data about the connection of Covid-19 awareness towards their environmental concerns. In the second section of the questionnaire, we evaluated the levels of Covid-19 awareness and their environmental concern, health consciousness, environmental awareness, pro-environmental behavior, values, environmental activism.

Section 1—Covid-19 Awareness and the Environment

Section 1 includes five questions investigating whether pandemic affects this postgraduate program's selection and environmental health awareness due to the Covid-19 pandemic.

Section 2—Health Consciousness

The Health Consciousness scale created by Gam et al. (2020) and Shimoda et al. (2020) was utilized for this research. This scale consisted of five questions, and the trainees were asked to respond to a five-point scale ranging from 1 (low consciousness) to 5 (high consciousness).

Section 3—Environmental Awareness

The Environmental Awareness measure developed by Blok et al. (2015) was utilized for this research. This scale consisted of seven questions, and the trainees were mainly asked to respond on a five-point scale ranging from 1 (low awareness) to 5 (high awareness).

Section 4—Pro-Environmental Behavior

The Pro-Environmental Behavior scale developed by Blok et al. (2015) was used for this study. This scale consisted of five questions, and the trainees were asked to respond on a five-point scale ranging from 1 (low Pro-Environmental Behavior) to 5 (high Pro-Environmental Behavior).

Section 5—Pro-Environmental Behavior (Consumption)

The Pro-Environmental Behavior (Consumption) scale developed by Alsmadi (2007) cited in Shimoda et al. (2020) was used for this study. This scale consisted of eight questions. The trainees were mainly asked to respond on a five-point scale ranging from 1 (low Pro-Environmental Behavior) to 5 (high Pro-Environmental Behavior).

Section 6—Values

The Values scale developed by Blok et al. (2015) was used for this study. This scale consisted of one question, and the students were asked to respond on a three-point scale ranging from "Not Important" to "Extremely Important" for each of the thirteen given values.

Section 7—Environmental Activism

The Environmental Activism scale developed by Abun and Aguot (2018) was used for this study. This scale consisted of eight questions. The trainees primarily responded on a five-point scale ranging from 1 (low activism) to 5 (high Activism).

Section 8—Information Sources

The Information Sources scale developed by World Health Organization (2020) was used for this study. This scale consisted of two questions. The trainees were asked to respond on a five-point scale ranging from Never (low Frequency) to Always (high Frequency) for the first question and on a five-point scale ranging from None (amount of agreement-disagreement) to Absolutely (amount of agreement-disagreement).

Results and Discussion

Demographics

In the first section of the questionnaire, some demographic data were taken from the participants to outline their basic profile better. The results are shown in Table 16.1.

Regarding their demographic profile, most of them are female, between the ages of 22–39, have a Bachelor degree in Health and Humanities sciences, reside in urban areas, with an income of up to 20,000 euros/year, and they chose this particular Master's program due to their interest on the field of study.

- **Section 1—COVID-19 Awareness and the Environment**

Most of the participants (83%) answered that they participated in this postgraduate program for their professional development. The remaining 17% stated that they wanted to become better qualified for an income increase (Fig. 16.1).

The majority of the participants strongly believe that a postgraduate program should cover and respond to their concerns about environmental health (Fig. 16.2).

When asked about the extent to which the Covid-19 pandemic contributed to their decision to study this postgraduate program, participants stated that the pandemic was a factor for them to consider starting this Master's program (Fig. 16.3).

Table 16.1 Basic profile

Demographic characteristics of the study sample (n = 48)			
Variables			Values (n, %)
Sex			
Male			8 (16.7)
Female			40 (83.3)
Missing			0 (0)
Age group (years)			
22–29			19 (39.6)
30–39			16 (33.3)
40–49			9 (18.8)
50+			4 (8.3)
Education			
B.Sc			32 (66.7)
M.Sc			16 (33.3)
Ph.D			0 (0)
Scientific field of B.Sc			
Environmental Sciences			8 (16.6)
Health Sciences			20 (41.7)
Humanities			17 (35.4)
Computer and Communications Sciences			3 (6.3)
Region			
Urban (>100.000 Population)			28 (58.3)
Urban (25.000–100.000 Population)			8 (16.7)
Urban (2.500–24.999 Population)			11 (22.9)
Rural (<2.500 Population)			1 (2.1)
Family Status			
Unmarried			29 (60.4)
Married			18 (37.5)
Divorced			1 (2.1)
Children			
Yes			16 (33.3)
No			32 (66.7)
Income (EUR/year)			
Median income (Median, IQR)			
0–10.000€			25 (54.3)
10.000–20.000€			14 (30.4)
20.001–40.000€			7 (15.2)

(continued)

Table 16.1 (continued)

Demographic characteristics of the study sample (n = 48)			
40.001–60.000€			0 (0)
60.001–80.000€			0 (0)
80.001–100.000€			0 (0)
100.001–120.000€			0 (0)
120.001–150.000€			0 (0)
>150.000 €			0 (0)
Selection of MSc degree			
Scientific field			30 (62.5)
Academic staff			2 (4.2)
Online courses			3 (6.2)
Professional rehabilitation			12 (25)
Promotion actions			1 (2.1)

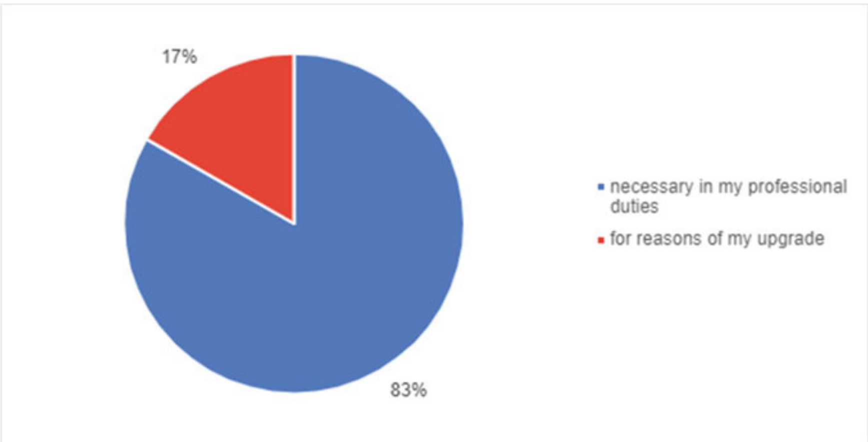

Fig. 16.1 Reasons for participating in this postgraduate program

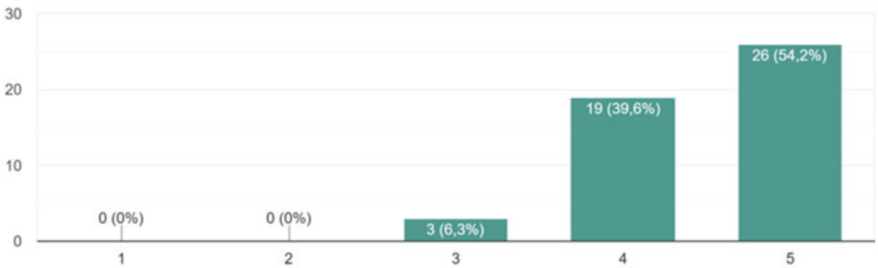

Fig. 16.2 Importance of a master's degree to address personal concerns

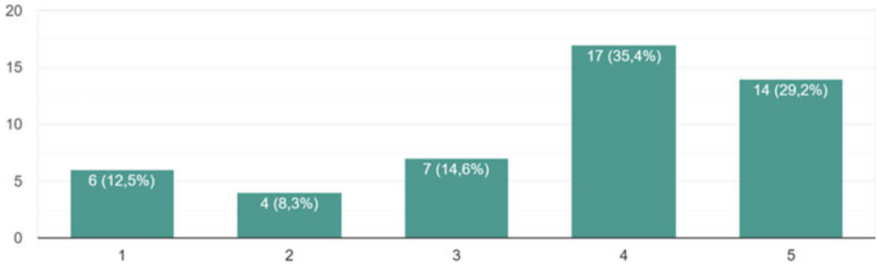

Fig. 16.3 Contribution of the Covid-19 pandemic to the selection of this postgraduate program

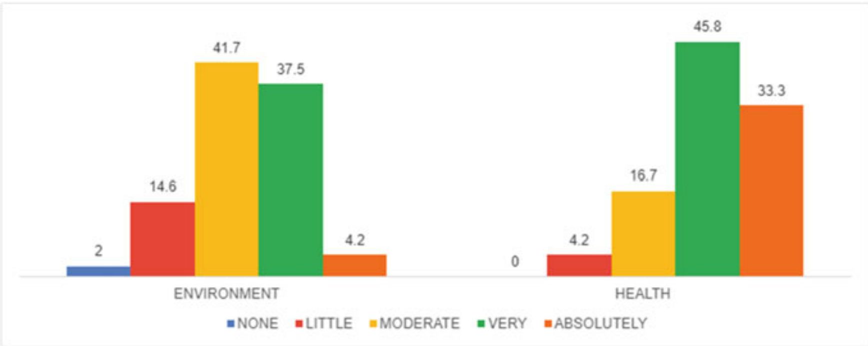

Fig. 16.4 Raising awareness of the environment and health due to the Covid-19

The participants were asked if they think the Covid-19 pandemic will affect people's awareness of the environment and health. More specifically, concerning the environment, 20 believed that there wouldn't be a significant change and seven that there would be a minor increase in people's awareness. However, 22 stated that people would become more aware of health issues (Fig. 16.4).

The majority of the participants (75%) believe that programs in Environmental Communication and Health Promotion are playing an essential role in public awareness (Fig. 16.5).

- **Section 2—Health Consciousness**

The majority of the respondents consider their health protection one of their key issues (Fig. 16.6).

Participants were asked if they feel insecure about the state of their health. An 18.8% of them feel insecure about their health. However, most participants didn't feel seriously concerned about their health state (Fig. 16.7).

Almost every participant is aware and responds to related messages about the state of their health, with 17 of them supporting it at all times (Fig. 16.8).

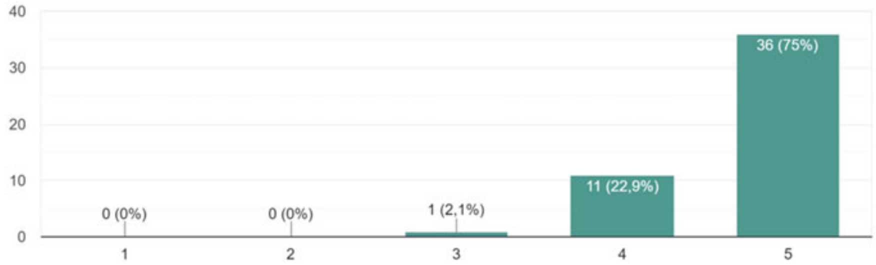

Fig. 16.5 Environmental Communication and Health Promotion Programs with regards to public awareness

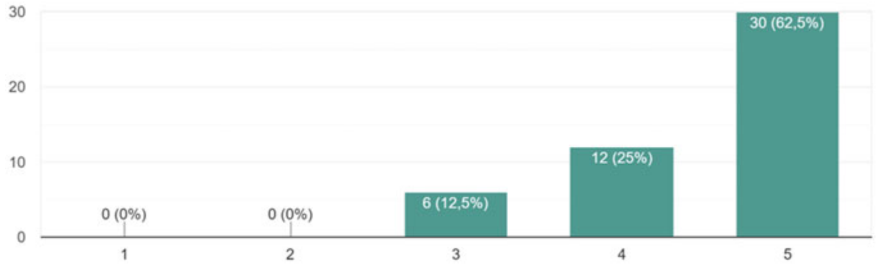

Fig. 16.6 Health as a significant concern

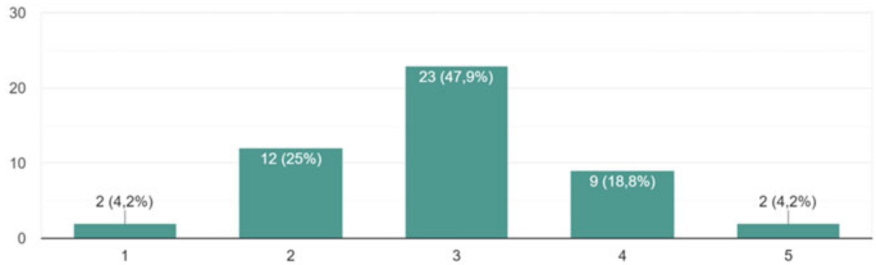

Fig. 16.7 Insecurity about health

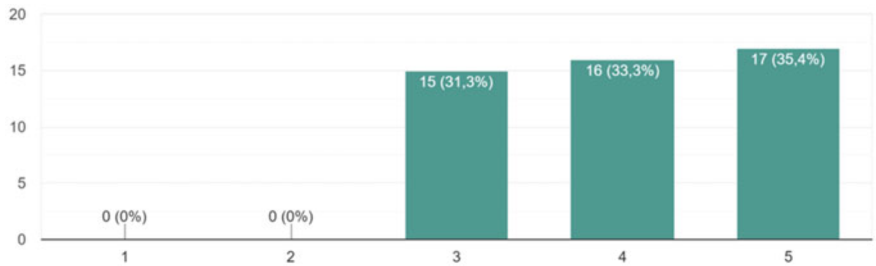

Fig. 16.8 Monitoring internal health messages

When asked if they have frequent preventive medical examinations, most participants (83%) stated that they do. The remaining (17%) don't have frequent medical check-ups (Fig. 16.9).

Most of the participants rarely monitor their health during the day, and only 14.6% of them closely observe the state of their health throughout their day (Fig. 16.10).

- **Environmental Awareness**

Ninety-eight percent of the participants fear that there is a continuous degradation of the environment. An 85.41% stated that initiatives concerning the rescue of endangered species are not unnecessary actions and should exist. Concerning the statement that individual responsibility plays a vital role in achieving better environmental conditions, most participants (81.2%) believed that personal responsibility is of great

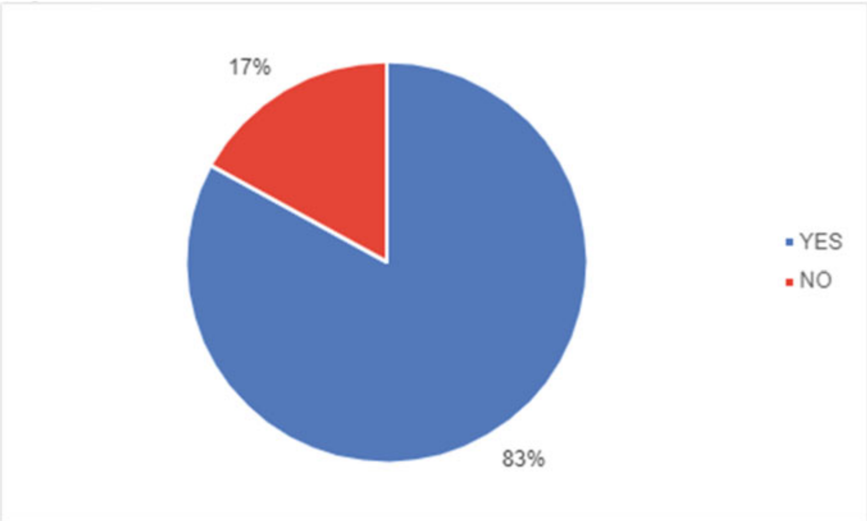

Fig. 16.9 Systematic preventive medical examinations

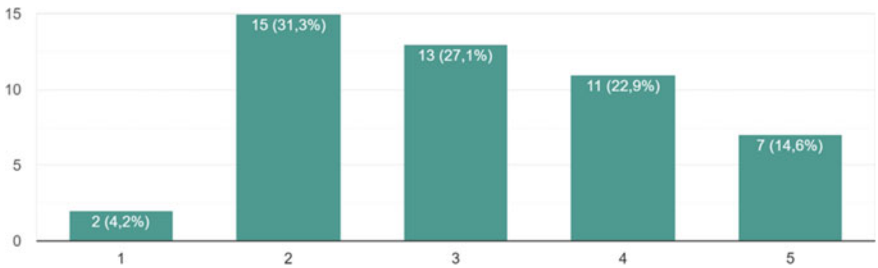

Fig. 16.10 Monitoring the state of health during the day

importance. A small percentage was indifferent or disagreed with this statement—almost all participants exhibited an environmental awareness about the related issues (Fig. 16.11).

Participants were asked if they believe that environmental issues will become more intense and threatening for the next generations; 81.3% answered that they agree with this statement, and only 2.1% were indifferent about it (Fig. 16.12).

In the question of whether they believe that environmental issues are exceedingly presented in public, the majority of the participants disagreed and stated that environmental issues are not a well-communicated topic (Fig. 16.13).

When asked if indifference to the environment is a sign that indicates a lack of responsibility, 25% of participants answered that they agreed, and 33.3% neither agreed nor disagreed with this statement (Fig. 16.14).

- **Pro-Environmental Behavior**

Participants were presented with a list of recycling materials (glass, plastic packaging, batteries, and paper) and were asked how often they recycle them. The majority of the participants almost always recycle all the presented materials, with the most recycled plastic packaging and paper, followed by batteries and glass.

Participants were asked if they switch off the heating devices when they are not in their house. A significant amount of them (87.5%) turn off their heating devices when away (Fig. 16.15).

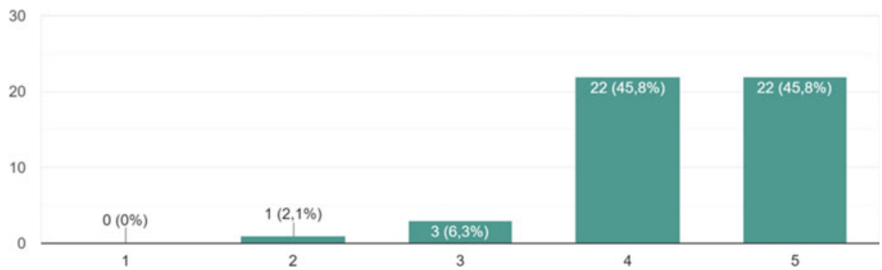

Fig. 16.11 Interest in environmental issues

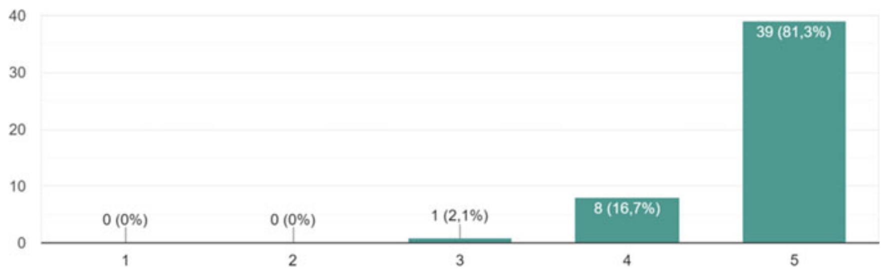

Fig. 16.12 Environmental problems and future generations

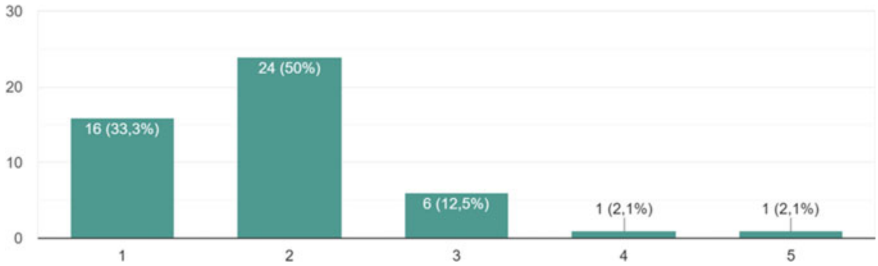

Fig. 16.13 Environmental problems are overemphasized

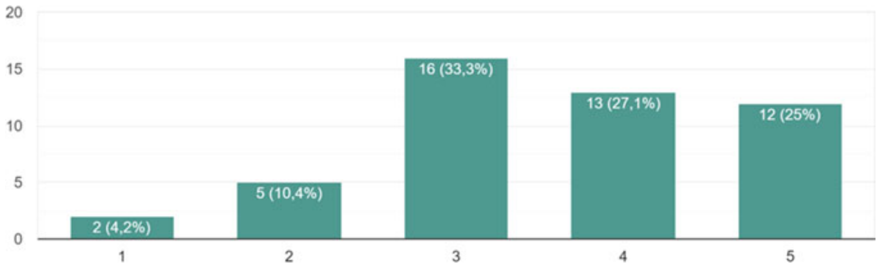

Fig. 16.14 Indifference to the environment and responsibility

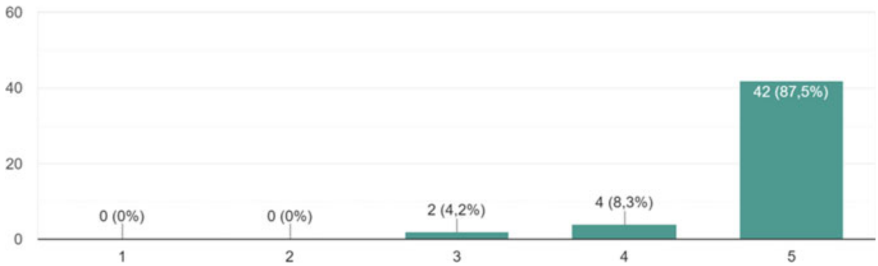

Fig. 16.15 Switching off the heating when away

Regarding whether participants use reusable cups for their beverages, their answers were spread in all the five options, with 29.2% using reusable cups frequently and only 8.3% using single-use plastics or other containers (Fig. 16.16).

More than thirty-five percent of the participants use a new plastic cup every time they buy something to drink, and only 16.7% of them use their cup for their beverage (Fig. 16.17).

When asked if they turn off their computer when they do not use it for a significant period, seventy-five percent answered that they always have their computer turned off when not using it (Fig. 16.18).

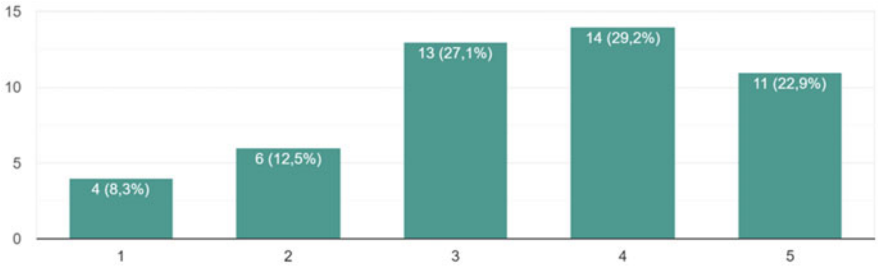

Fig. 16.16 Consuming behavior and reusable cups

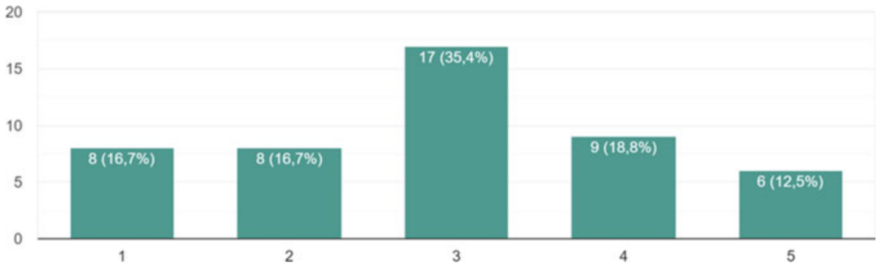

Fig. 16.17 I use a new plastic/packaging every time I buy a new drink

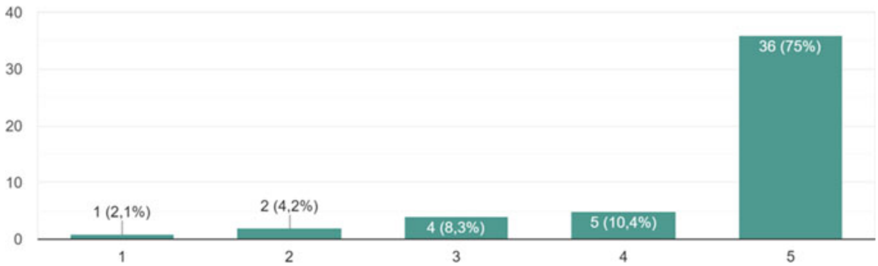

Fig. 16.18 Switching off electronic devices when not using them

- **Pro-Environmental Behavior (Consumption)**

A 19% of the participants are unwilling to spend time trying to buy environmentally friendly products, whereas 81% spend time and effort buying environmentally friendly products.

A 33.3% percent of the participants always avoid products that have been tested on animals (Fig. 16.19).

When asked about their food preferences, 43.8% of the participants frequently prefer to buy organic food, and only 8.3% do not give great importance to whether their food is organic or not (Fig. 16.20).

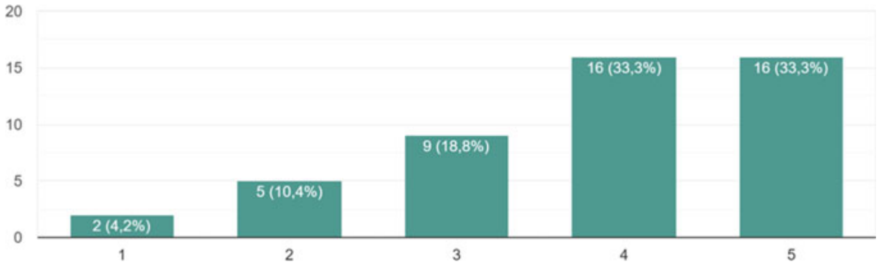

Fig. 16.19 Preference for products not tested on animals

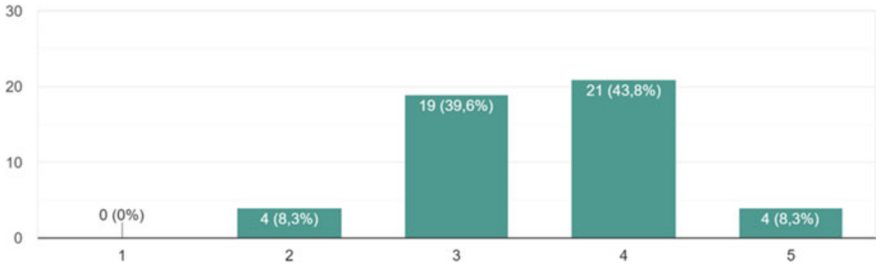

Fig. 16.20 I choose organic food

A 56.3% of the participants prefer to buy materials that can be recycled, whereas only 6.3% of them do not have as a priority to purchase staff that could be recycled (Fig. 16.21).

More than half of the participants tend to choose energy-saving products, with 45.8% of them selecting only products that are saving energy (Fig. 16.22).

Regarding whether participants try to encourage others to buy environmentally friendly products, most of them (45.8%) do it quite often (Fig. 16.23).

A 45.8% of the participants choose products with reusable packaging, and 20.8% of them always buy products that all of their contents can be recycled (Fig. 16.24).

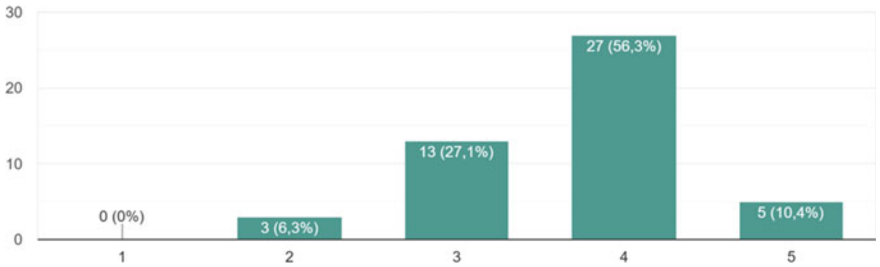

Fig. 16.21 I choose recyclable products

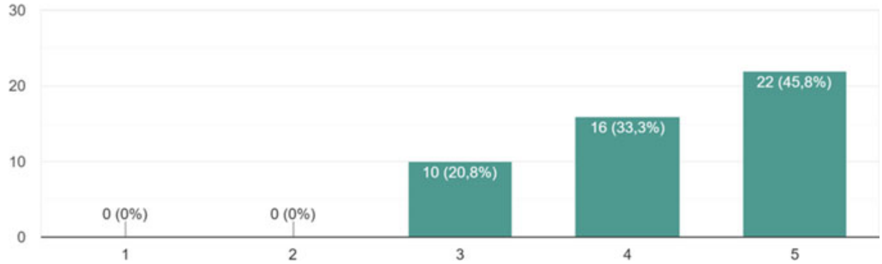

Fig. 16.22 I choose energy-saving products

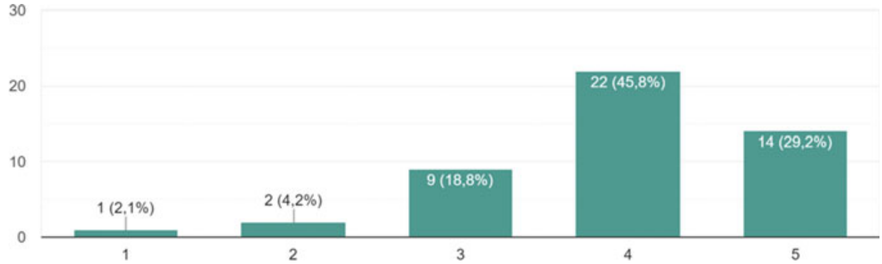

Fig. 16.23 I encourage others to buy environmentally friendly products

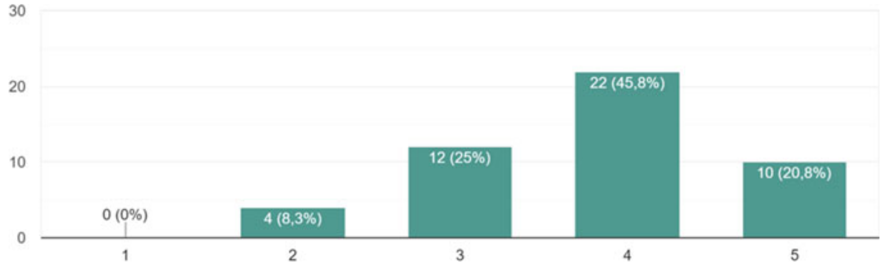

Fig. 16.24 I choose products with reusable packaging

In the statement of when they buy a product, they think about its impact on the environment, a significant number of the participants (41,7%) stated that they consider that (Fig. 16.25).

- **Values**

Participants were asked to evaluate the degree to which the presented values are guiding principles in their life. Peace, family security, and respect for parents and the elderly are the values that played an essential role in the life of most participants. However, wealth, axioms, and social power are considered the ones with minor importance for most of them (Fig. 16.26).

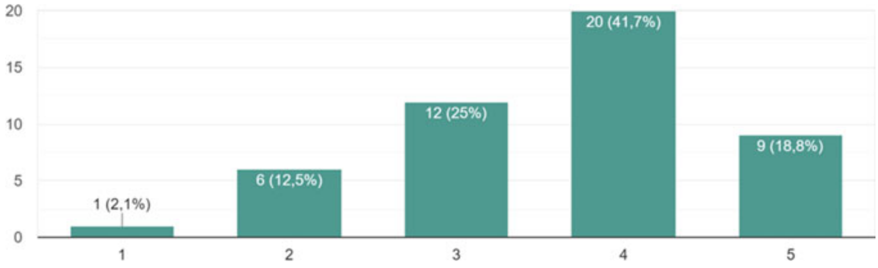

Fig. 16.25 When I buy a product, I think about its impact on the environment

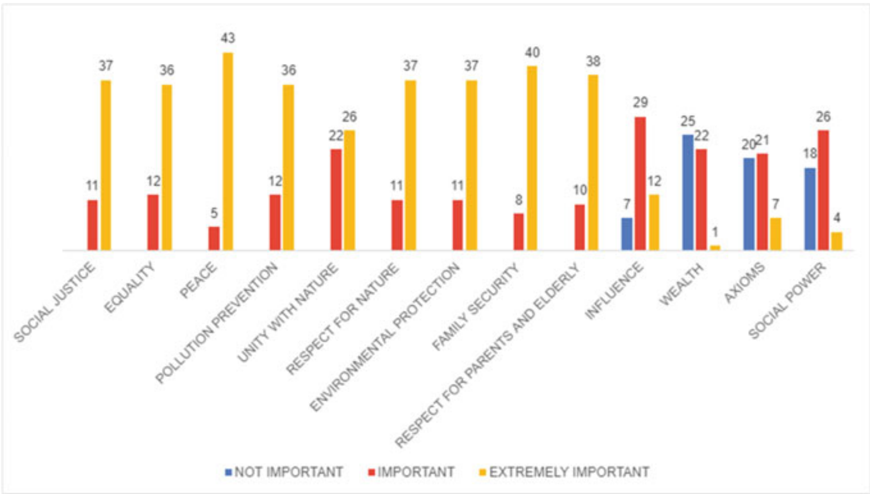

Fig. 16.26 Values as principles of life

- **Environmental Activism**

When asked whether they would like to join an environmental action group, most (90%) reacted positively and were motivated to do so. A 77% of the participants are not funding environmental protection actions, whereas 23% donate to efforts that aim to protect the environment.

The majority of the participants (47.9%) are informed about the environment through various means (Fig. 16.27).

Participants who will convince others on how important it is to protect the environment all agreed with this statement (Fig. 16.28).

A 79% of the participants support in every way they can recycling campaigns (Fig. 16.29).

When asked if they prompt other people to use public transport instead of their vehicle, 20 participants answered that they do it often. Only six said they try to change other people's opinions on transportation on an ongoing basis (Fig. 16.30).

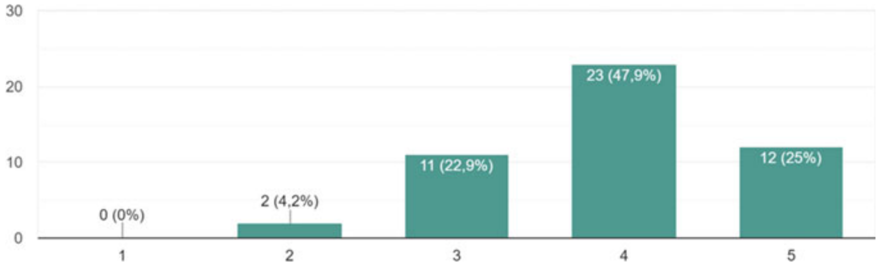

Fig. 16.27 I am informed about the environment (through programs, publications, etc.)

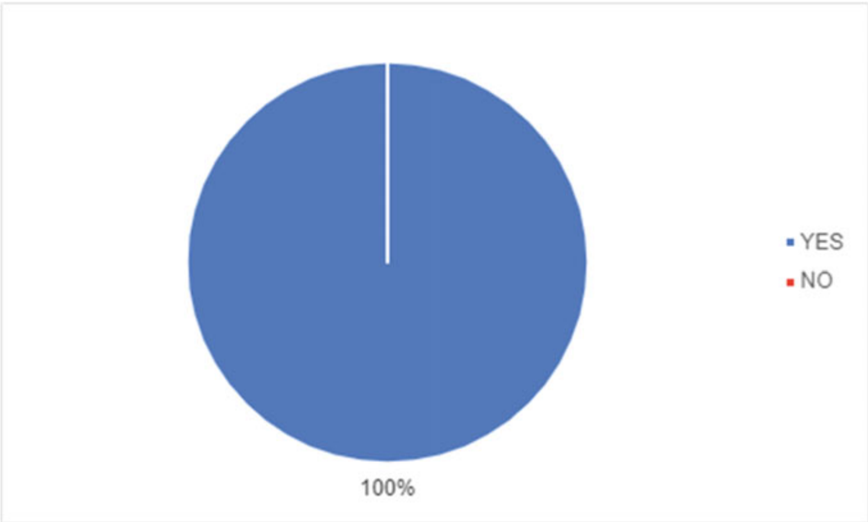

Fig. 16.28 I want to convince others of the importance of protecting the environment

When asked if they vote based on political beliefs that support the protection of the environment, a good percent of the participants agreed (39.6%). Only 10.4% are not voting according to the political party's actions regarding environmental protection (Fig. 16.31).

More than half of the questioned participants would report authorities' actions that damage the environment or pertinent activities involving animal abuse (Fig. 16.32).

- **Information Sources**

The majority of the participants depend on environmental information on environmental health scientists, colleagues, news websites or web pages, social media, and public TV stations. The participants expressed that they use private radio stations and TV stations the least (Fig. 16.33).

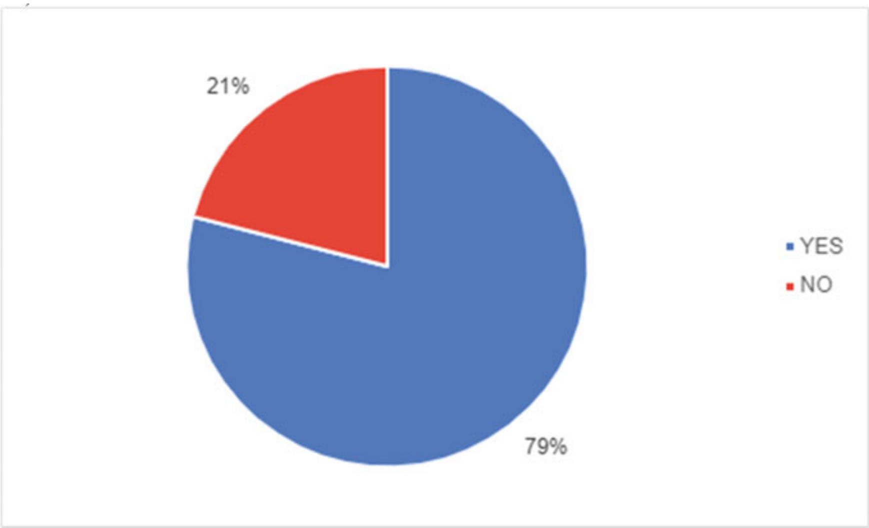

Fig. 16.29 I help with recycling campaigns in my way

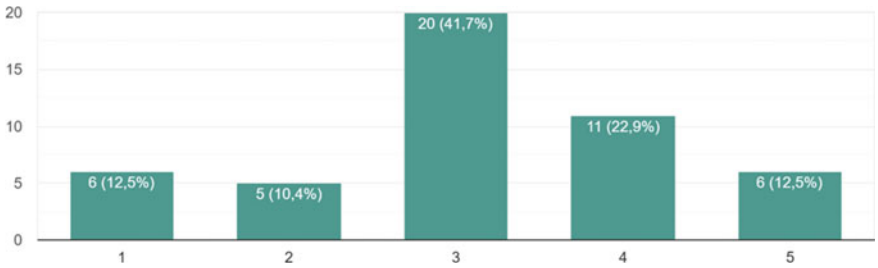

Fig. 16.30 I encourage others to use public transport instead of their private car

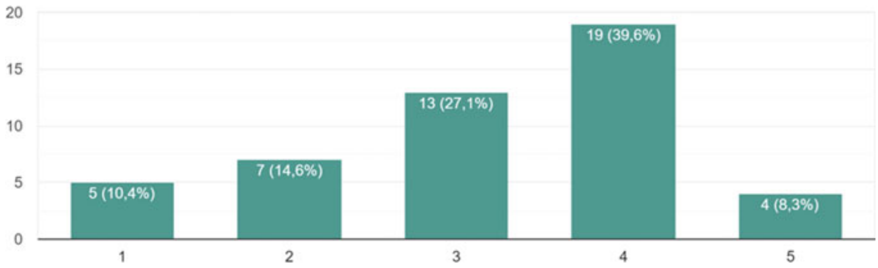

Fig. 16.31 I am voting by political beliefs that contribute to protecting the environment

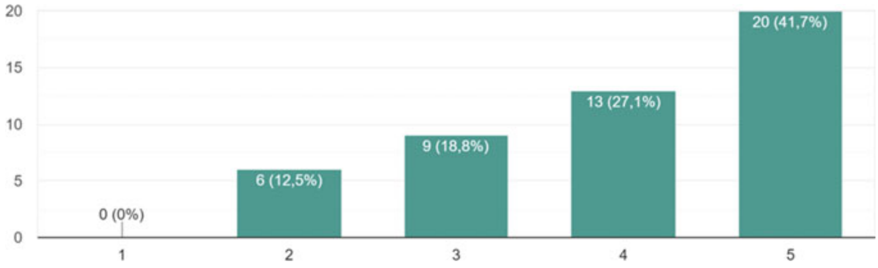

Fig. 16.32 I denounce illegal acts that alter the environment or abuse animals

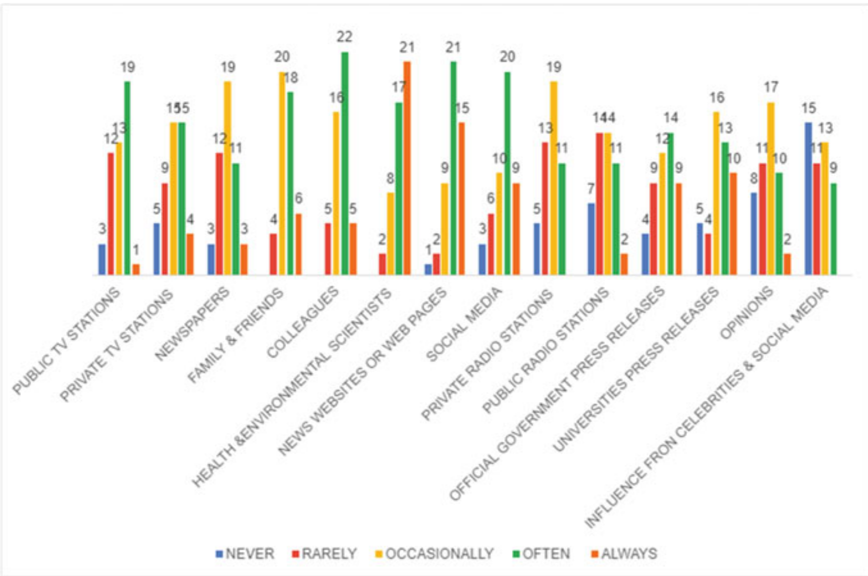

Fig. 16.33 Sources of information regarding the environment and health

Regarding which of the following sources of information participants trust the most; Health and Environmental scientists and Press releases are chosen by most of them. Furthermore, public TV stations are used as a valuable information source by many of them. On the contrary, celebrities and social media do not inspire any confidence in the information they convey (Fig. 16.34).

This study aimed to decode the profile of the trainees of the Master's program "Environmental Communication and Health Promotion" right before the beginning of the first semester. The profile consisted of the following concepts: Covid-19 awareness and the environment, health consciousness, environmental awareness, pro-environmental behavior, values, environmental activism, and information sources.

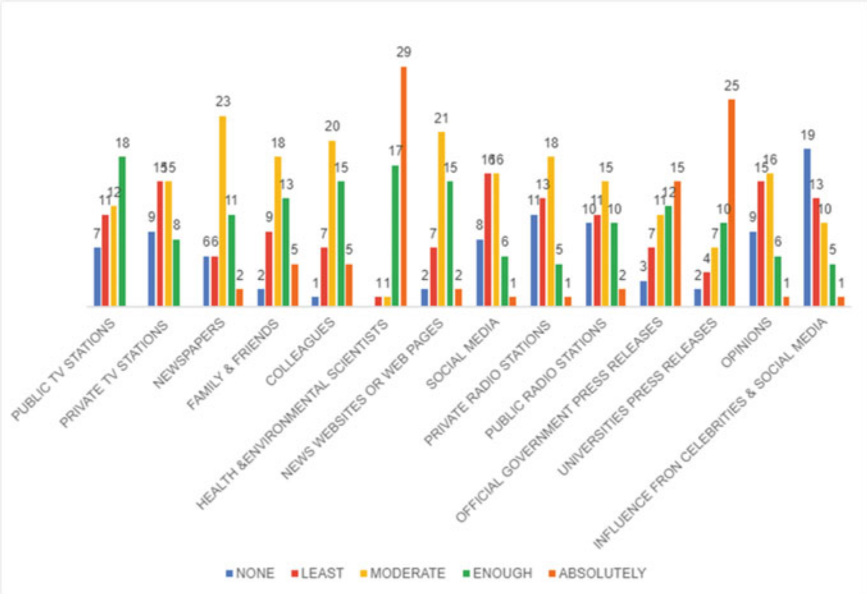

Fig. 16.34 Trustworthy sources of information

The participants who chose to study this Master's program are already—to a fair extent—motivated by their pre-existing environmental awareness and pro-environmental behavior.

Bendor (2018, p. 29) supports that knowledge and concern about an issue precede action. The participants showed that they possess health consciousness and environmental awareness, and thus their choice to enroll in this specific Master's program could be interpreted as appropriate behavior. Their evaluation of wealth, axioms, and social power show that they are the least significant values, while peace, family security, respect for the parents and the elderly are the most important, which could indicate the life priorities of the participants. They care more about the world and their family than personal economic gain and social power. So, it might be stated that it is more feasible to participate in educational activities that include the aspect of working towards the well-being of people and the world and at the same time feel pleasure doing something based on their value system. From the academic point of view, their interest in Environmental Health reveals a form of responsibility and consciousness, which positively affects both environmental and health interests (Kaynak and Eksi 2014).

Good levels of pro-environmental activity hint towards the presence of an early Anthropocene 2.0 consciousness. The participants engage in sustainable environment behaviors and seem to optimize resources responsibly, approaching the energy-waste-food nexus (Motloch 2019a, b, p. 2087). This situation shows that the participants are not ignorant of sustainability issues and understand the consequences of their actions on the environment. This way of acting and thinking is a significant part of ecological consciousness (Raymundo et al. 2019, p. 76).

The majority of the participants believe that programs in Environmental Communication and Health Promotion are playing an essential role in public awareness. According to De Almeida and Da Silva Carvalho (2018), environmental education provides a promising field for innovations in human development based on a new approach to the education of consciousness and health promotion.

This pandemic played an important factor in participants' decision to start this postgraduate program. This finding endorses the point made by Toquero (2020) that higher institutions should integrate environmental and health courses in the curriculum, highlighting that it is of great importance to make the curriculum responsive to the needs of the world at the present times. Another interesting result is that most participants believe that the Covid-19 pandemic will increase awareness of health and the environment. This finding is confirmed by the Severo et al. (2021) research. They present that people with high levels of environmental awareness, sustainable consumption, and social responsibility feel that the situation the world experiences with Covid-19 will create further environmental health pressures.

Conclusions

In this study, we examined the planetary health profile of the trainees of the "Environmental Communication and Health Promotion" Master's program at the University of West Attica. After reviewing the online survey results that the participant trainees filled out, our analysis concluded that the bulk of the students showed good levels of environmental awareness and pro-environmental behavior. Well-designed and well-delivered epistemic learning as a transformative pedagogy can give birth to an environmental consciousness shift. Furthermore, it would be a valuable tool to evaluate the impact of the Master's program on the participant's environmental values and health promotion consciousness. But this shift alone will be of little use if it cannot be communicated from one person to the other if it cannot be disseminated. The role of environmental communication is equally important. It is a science that embraces environmental education and health communication (Harris 2019, p. 9; Lie and Servaes 2015, p. 251). The combination of environmental communication with health promotion can bring positive changes in culture and public involvement. Thus, after this longitudinal study, the results will also focus on the potential shift of appreciation of the effectiveness of efficient environmental communication.

The environmental challenges that the world is facing are significant and complex; efficient well-designed communication may be the missing link that may organize all the different actions and approaches to environmental issues under a comprehensive umbrella. Without an overarching understanding of the diversity of communication strategies and approaches, academics and practitioners may be left unaware of the work and advances done in neighboring spaces. This Master's program attempts—among other aims-to meet this challenge by offering a pluralistic curriculum yet maintaining its focus on the importance of environmental communication among phenomenologically different scientific fields since planetary health is the reason behind every environmental action.

The prospects of this research are to comprehend whether the graduate program could cultivate environmental awareness and consciousness. The complete study results will help educational institutes form and organize programs with similar purposes that persuade and motivate the trainees to understand and care about planetary health (Haldane and Berry 2021; Concina 2019, p. 352).

Limitations

This study is not without limitations. Our sample size was not sufficient to conduct statistical analysis for possible correlations of the involved variables. This limitation could not be overcome because the participants were our whole population since the maximum number of attendees in the graduate program is set to 49 per academic year.

Recommendation For Future Research

Future studies are recommended to investigate whether the educational programs of "Environmental Communication and Health Promotion" can shift the trainees' consciousness toward transformation mindfulness, thus helping the transition to the much-needed Anthropocene 2.0 consciousness.

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Chapter 17
The Untapped Potential of Early Childhood Education for Planetary Health: A Narrative Review

Jane Spiteri

Abstract The United Nations Children's Fund (UNICEF 2021) declared climate change as a major threat to children's rights and their health. Young children need to be equipped with the competencies to live a sustainable lifestyle that promotes planetary health. Education, and early childhood education (ECEC) in particular, plays a vital role in achieving this. The narrative review in this chapter draws on the literature related to ECEC and planetary health to suggest the introduction of early childhood education for planetary health, an emerging field of research currently characterised by paucity of literature. To reduce the considerable lack of research, a broader range of research needs to be conducted to support the field and provide preliminary guidance to move the field forward. Therefore, narrative reviews such as this one can provide some preliminary guidance. As a result of this review process, suggestions are identified for future research, policy and practice.

Introduction

This chapter explores the relationship between early childhood education and care (ECEC) and planetary health. In general, the term 'health' implies the level of physical health of individuals, and it does not take into account the cost incurred in achieving those health gains (Whitmee et al. 2015). While it is essential to understand the importantce of the progress made so far in human health and wellbeing, the ecological impact of such progress needs to be factored in as well. Human health and the health of the natural environment are interconnected, hence the term 'planetary health'.

Planetary health addresses the various environmental changes that take place over time and their impact on human health and the health of the planet. "Planetary health is an emerging concept that describes the critical interdependence between human

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_17

health and the earth's environment" (Chesney and Duberstadt 2022, p. 1). Specifically, planetary health refers to "a solutions-oriented, transdisciplinary field and social movement focused on analyzing and addressing the impacts of human disruptions to Earth's natural systems on human health and all life on Earth" (The Planetary Health Alliance, n.d.). Put simply, planetary health explores both the dependence of the human race upon a healthy and sustainable ecosystem, and humanity's responsibility towards maintaining a healthy ecosystem. In addition, planetary health"addresses the challenges of how best to protect and promote human health in the Anthropocene epoch" (Whitmee et al. 2015, p. 1978). To ensure a liveable future for current and future generations of human and more-than-human species on Earth, the health of the planet and all life systems therein, should be founded on the knowledge and understanding of the interdisciplinary relationship between humans and all living species on the planet. Such endeavour requires long-lasting behavioural change in lifestyle.

The focus on planetary health provides a positive vision for the future of all life systems on the planet, where the political and economic forces that destroyed the health of all living species and the planet itself are critically analysed, and an attempt is made to either fix or reshape them (Guinto 2020). As such, planetary health is founded of an exchange of intergenerational knowledge (von Borries et al. 2020), and the advocacy of global economic reforms that protect the health of humanity and the planet, now and in the future (Whitmee et al. 2015). As an emerging field of research, planetary health urges humanity to understand its interconnection and interdependence with nature, and work towards identifying suitable solution to the current complex changes (Guzman et al. 2021). This can be achieved through the reorientation of education systems that change society's views around planetary health, and through meaningful participation of young children in policies and decision-making related to planetary health (von Borries et al. 2020).

To date, there is plethora of research related to young children and various environmental issues (e.g., Ardoin and Bowers 2020; Arlemalm-Hagser and Elliott 2020; Davis and Elliott 2014) but research about planetary health in ECEC is scant. In fact, reports on research that formally examines the two fields together (ECEC and planetary health) does not exist. This chapter is aimed at reviewing related research on environmental education in ECEC and then, discuss the potential efficacy of the introduction of early childhood education for planetary health. For the scope of this chapter, early childhood education for planetary health is a form of learning in the early years in which knowledge, skills and values about the impact of environmental issues on planetary health are taught. Just like the literature in the field, this is an emerging definition that captures the most salient features of the intersection of ECEC and planetary health.

This chapter is structured as follows: in the next section, the methodology of this chapter is explained. The third section, offers an overview of human health and the environment, and the interconnection between the two. Next, the relevance of planetary health education in the early years is discussed. In the fifth section, the relevance of climate change education in ECEC, and how it is related to planetary health is explored. Here, the chapter presents an argument for the introduction of early childhood for planetary health. The sixth section presents the strengths and limitations of this chapter, followed by suggestions for further research. The final section, ends with a summary of the core argument of this chapter.

Methodology

Given the lack of research in the field specifically in relation to young children and planetary health, a narrative review methodology was selected. Narrative reviews are well-suited to explore new areas of research, particularly when developing innovative areas of practice (Grant and Booth 2009). As such, this narrative review will locate articles (peer-reviewed and grey literature) related to ECEC and environmental issues in the sector. This chapter will then move on to briefly highlight key concepts in the fields of planetary health and ECEC practices, and discuss the two in light of the limited body of research currently available. By discussing the intersection of these two fields, this chapter aims to provide a rationale for the inclusion of the field planetary health in ECEC. As such, it pulls together the currently fragmented information about young children, ECEC and planetary health that can be found in the literature in an attempt to point out the relevance of planetary health education in the early years. A search on PubMed database using the following keywords: 'young children', 'children', 'early childhood education', 'early childhood', and 'planetary health' was conducted. Relevant articles related these fields are included in this narrative review.

Health in the Anthropocene Epoch

During the ecological epoch of the Anthropocene (Steffen et al. 2007), human activity has changed the balance of the ecosystem globally, leading to the current crises—climate change, rising sea levels, loss of biodiversity, desertification and air pollution, to mention just a few (Steffen et al. 2018). The concept of the Anthropocene has been criticised for its ideology around issues such as climate change and humanity's dominance over nature, and its disregard to the conditions that brought us here (Malm and Hornborg 2014). One such criticism comes from Ribot (2014), who argues that the Anthropocene fails to take into consideration the deep structural systems that give rise to the vulnerability of many. Indeed, human-driven ecosystem degradation has altered the planet's health and has led to the current environmental and health crises, with some populations experiencing more devastation than others, through no fault of their own. This situation has also led to increased poverty, and a sharp rise in human migration around the world (Arlemalm-Hagser and Elliott 2020).

In the past 70 years, humanity has made tremendous improvement in terms of health gains (Myers and Frumkin 2020) that resulted in an increase in global population and life expectancy, and a reduction in extreme poverty and child mortality

(Whitmee et al. 2015). But this has come at a cost. To achieve the current standard of living in the Western world, humanity had to exploit the Earth's resources to the extreme (Brouselle and McDavid 2021; Myers and Frumkin 2020). Not only that, but within the mainstream neoliberal-oriented economic and socio-political systems, the focus on economic growth as a sign of progress, measured by consumerism and humanity's dominance over nature, resulted in the exploitation of natural resources and environmental degradation (Deem et al. 2019; Whitmee et al. 2015).

It is true that human health and life expectancy have increased exponentially, but human activity has created changes and challenges to the rest of the biosphere, the impact of which has been immense and will be felt for a long time by current and future generation of people and living species on Earth (Deem et al. 2019; Myers and Frumkin 2020). It is therefore clear that the current and unprecedented environmental crisis is hazardous for human health, requiring increased awareness and action on planetary health (Frumkin 2020; Whitmee et al. 2015). Collectively, human overconsumption has created a shift in biodiversity, emergence of infectious diseases and invasive species, loss of resources, global pollution, climate change, depletion of natural resources and an increase in environmental contaminants (Brouselle and McDavid 2021; Deem et al. 2019; Myers and Frumkin 2020). In short, our health and that of future generations, and the health of the planet have been compromised for economic and development gains in the present (Whitmee et al. 2015). While the health gains made so far are irreversible, they can be lost if we fail to learn the lessons from the current crises (Horton et al. 2014). In sum, the current environmental and health crises are rooted in the human–environment relationship, illustrating the urgent need to care for planetary health (Guinto 2020; von Borries et al. 2020).

In the past, researchers have warned that should current trends in development continue to exploit the ecosystems and the Earth's resources, the risk of the emergence of new infectious diseases is likely to increase (Deem et al. 2019; Lewis 2021). Much to everyone's surprise, in 2020, life's smallest entity, SARS-VoV-2, also known as the COVID-19 virus, brought the world to its knees, causing loss of lives all over the world. The COVID-19 pandemic is not an unusual event that just happened on its own. Rather, it is the direct consequence of the global climate crisis that influences the transmission of diseases, this is because the rise in global temperatures caused by climate change increases the spread of infectious disease even in colder northern countries (Leal Filho et al. 2022). In this sense, the COVID-19 pandemic should serve as "a wake-up call toward more sustainable living" (Lewis 2021, p. 4). In one of his speeches, the Executive Director of the WHO, Dr Michael Ryan, described COVID-19 as a pandemic of our own making, highlighting how the pandemic is a symptom of our irresponsibility towards planetary systems (Trocaire 2021). Dr Ryan explains that the coronavirus that causes COVID-19 emerged because of the current unsustainable lifestyles in the name of globalisation and economic growth, all of which have put a huge strain on the planet's resources and life systems to the point where the balance of ecosystems worldwide has been disrupted (Trocaire 2021). Consequently, Dr Ryan calls on governments to move away from the current patterns of unsustainable economic growth with a focus on profit that are depleting the planet's resources, towards an economic growth that is sustainable and that takes into account the wellbeing of all planetary systems and that of children and future generations, who will pay the highest price in times of crises (Trocaire 2021).

During the COVID-19 pandemic, governments all over the world went to great lengths to save the economy from a catastrophic collapse. At one point, in early 2020, it seemed that as a prototypical planetary health story, COVID-19 was an extraordinary moment that could have provided humanity with the opportunity to chart new and sustainable lifestyles (Myers and Frumkin 2020). To reduce the risk of infection from the COVID-19 virus, people had to protect themselves and change their lifestyle. In this regard, the pandemic certainly influenced human activity, society and the environment. During the pandemic governments worldwide issued public health measures, such as partial or total lockdowns. These strategies limited global mobility and industrial activity, which in turn helped decrease greenhouse gas emissions by 5.4%, in 2020, and by 4.8%, in April 2021 (United Nations Environment Programme [UNEP], 2021). These strategies also helped reduce the production of waste to a certain extent. In fact, during lockdowns, travel restrictions significantly reduced air pollution (Sharifi and Khavarian-Garmsir 2020), consequently, less energy and fossil fuels were consumed leading to a reduction in greenhouse gas emissions, that provided temporary relief for biodiversity to thrive (Verma and Prakash 2020). However, the world soon realised that in order for leaders to save the global economy, life had to return to some new form of "normality". While lockdowns contributed towards a reduction in air-pollutants that corresponded with an improvement in air quality, ironically, private car use, as a safe alternative to public transport, increased, leading to an increase in greenhouse gas emissions nonetheless (Sharifi and Khavarian-Garmsir 2020). Another precautionary health measure suggested by health authorities worldwide during the pandemic was the use of face masks. This move increased the demand for disposable face masks, that in turn, increased in the production of disposable facemasks that contain microplastics. This increase in production of face masks containing microplastic, coupled with lack of policy to control the proliferation of plastic waste during the pandemic, increased waste in landfills (Aragaw 2020; Fadare and Okoffo 2020). Even worse, the inappropriate disposal of face masks increased microplastic pollution in the oceans and seas worldwide (Aragaw 2020; Fadare and Okoffo 2020).

The rapid response to the COVID-19 pandemic produced some positive results in curbing the spread of infection over time and has contributed to the temporary reduction in air pollution. It is time that the international community takes this lesson from the pandemic. Similar responses are required to save the health of the planet, and the health and wellbeing of current and future generations of all the living species on the Earth. Nevertheless, countries are failing to prioritise planetary health, and in doing so, they are missing out on the opportunity presented to them by the pandemic to create low-carbon and climate-resilient economies that would ensure long-term sustainability (UNEP 2021).

It is clear that the current environmental and health crises call for urgent action towards restoring a balance in the ecosystem at all levels of society (Brouselle and McDavid 2021; Deem et al. 2019; Myers and Frumkin 2020; Whitmee et al.

2015). Failing to account for these challenges has increased the anthropogenic environmental changes that are destructive to all life forms on Earth. Therefore, it is our responsibility and moral duty to take action before it is too late! Education plays a powerful role in providing solutions to some of these challenges (United Nations 2015; United Nations Educational, Scientific and Cultural Organization [UNESCO] 2017, 2020). For example, such solutions could be achieved through education programmes aimed at teaching young children about the importance of maintaining planetary health.

Early Childhood Education for Planetary Health

The first few years of human life have long been acknowledged as the most significant in human development and in the development of lifelong environmental literacy (Davis 2009, 2018; Engdahl 2015; Pramling Samuelsson and Kaga 2008; Spiteri 2020a; United Nations 2015; UNESCO 2017). Neuroscience and behavioural research confirm that during the first five years, the human brain undergoes rapid architectural changes (Centre on the Developing Child Harvard University, n.d.), providing a foundation for both human flourishing and the development of a sustainable society (von Borries et al. 2020). Such development is also influenced by early childhood experiences, that could have both positive and negative impacts on brain development (Centre on the Developing Child Harvard University, n.d.), making the early years ideal for helping children develop the values and skills to deal with the socio-cultural, economic, environmental and political issues of sustainability (Arlemalm-Hagser and Elliott 2020). Also, since habits and behaviour are formed early in life, the first few years of human life provide strong foundation to raise awareness and encourage action for planetary health across generations. In fact, it has been shown that educating young children how to connect with nature, encourages them to become citizens of the Earth who are conscious about the environment (UNESCO 2021). Such actions are more likely to foster environmental stewardship into adulthood.

Internationally, education, across all sectors, has been recognised for its potential to teach individuals the knowledge, values and skills needed to adapt to the challenges of climate change and other environmental issues (United Nations 2015; UNESCO 2017; 2020). Other than a fundamental human right, education is believed to be key to advancing human achievement (UNESCO 2020a). Good quality education in the early years is important for "personal development, social integration, successful lifelong learning and later employability of all children" (European Commission 2021, p. 7). Therefore, given these benefits, education systems worldwide should reform and reorient early childhood care and education (ECEC)[1] so as to change society's behaviour towards maintaining the health of the planet by empowering

[1] Early childhood and education (ECEC) refers to the education for children from birth to eight years old has been defined by UNESCO (2021).

young children to become capable, resilient, responsible, independent, and creative agents of change for the health of humanity and the planet.

Attempts to safeguard the environment by educating the public started decades ago. Environmental education started gaining international recognition in 1970s, but it was following the Tbilisi Conference that the environment was considered holistically (Gough 2017; Hume and Barry 2015; UNESCO 1978). Of interest to this chapter is the fact that the importance of ECEC for the achievement of a sustainable future was not recognised until 2007 (Pramling Samuelsson and Kaga 2008; UNESCO 2008). Now, it is widely acknowledged that ECEC can help shape the future of humanity (UNESCO 2021). More importantly, ECEC has been recognised as providing the foundation for environmental learning, that can have lifelong impacts on individual and collective pro-environmental behaviour (Davis 2018; Davis and Elliott 2014; Pramling Samuelsson 2011; Pramling Samuelsson and Kaga 2008; UN 2015; UNESCO 2016). In fact, recently, UNESCO (2020) reaffirmed the importance of ECEC in achieving a sustainable future through the Sustainable Development Goals [SDGs] (United Nations 2015). The UN explains:

> At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries—developed and developing—in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth—all while tackling climate change and working to preserve our oceans and forests. (United Nations 2020)

As a framework, the SDGs present the United Nation's international agenda on the social and environmental determinants of health and the wellbeing for all living species on the planet. The SDGs (UNESCO 2017) call for "inclusive and equitable quality education" (SDG 4), providing children with the knowledge and skills to "take urgent action to combat climate change and its impacts" (SDG 13), and "conserve and sustainably use the oceans, seas and marine resources for sustainable development" (SDG 14). Specifically, this framework "shows how the proposed SDGs representing human wellbeing (…) are dependent on those that provide the enabling infrastructure for development (…) and the supporting natural systems (…)" (Whitmee et al. 2015, p. 2015).

Indeed, ECEC offers several unique opportunities for teaching young children to become agents of change for a sustainable future (Leffers 2022). Historically, pedagogy in the early years has been designed around nature-based and play-based learning, mostly in natural settings (Ardoin and Bowers 2020; Bascopé et al. 2019; Spiteri 2020b). The environment has been given prominence by the great theorists in the field, such as Froebel, Pestalozzi, Malaguzzi and Montessori, amongst others. From an ecological perspective, one's environment, be it the natural environment or the home environment, plays a crucial role in human health and wellbeing (Bradley 2020). In childhood, the environment can either facilitate or disrupt one's development (Bronfenbrenner and Morris 2006). Increasingly, researchers are also recognising the importance of outdoor play for child development, wellbeing and lifelong appreciation of nature (von Borries et al. 2020). The natural environment enhances children's curiosity and sense of exploration of new knowledge (Guzman et al. 2021). The positive relationship between time spent in nature and children's wellbeing and holistic development is well-established, making outdoor play a public health priority. This can be achieved by providing children with authentic experiences in, for, with and about nature, and its elements (Bonnett 2021), making outdoor play, in nature, an ideal starting point for the exploration of issues about planetary health, climate change and wellbeing. However, simply being physically in nature is not sufficient to help individuals develop respect for the intrinsic value of nature (Bonnett 2021). Rather, young children need to be invited to enhance their creativity by exploring their natural surroundings in meaningful ways so that through play, they actively connect with nature.

Ultimately, the primary aim of teaching children about the environment and planetary health in ECEC is to equip them with the knowledge, values and skills that enable them to protect the planet and achieve the SDGs (United Nations 2015). The field of environmental research with young children is flourishing. This achievable goal of education has been supported by prior studies that demonstrate young children's understanding of environmental issues in different countries (e.g., Engdahl 2015). Recent research exploring the benefits of environmental learning in the early years too confirmed that young children are capable of understanding certain environmental concepts (Arlemalm-Hagser and Elliott 2020), therefore supporting the introduction of education about planetary health in ECEC.

Climate Change and Children

Environmental research strongly suggests that children are capable of understanding environmental issues and they can talk about them in ways that make sense to them (e.g., Engdahl 2015; Monus 2021; Sageidet et al. 2019; Simsar 2021; Spiteri 2021a, 2021b). Moreover, such research supports the possibility of introducing education around concepts of planetary health, such as climate change, in the early years.

The World Health Organization (WHO 2021) has declared climate change as the biggest threat to human health, undermining the social determinants of health in many parts of the world. Climate change poses a severe and growing burden on life on the planet and also on human health (Intergovernmental Panel on Climate Change [IPCC] 2021). Indeed, climate change is the greatest health threat facing young children, who are more vulnerable to it effects (Leffers 2022; United Nations Children's Fund [UNICEF] 2021). Research shows that a 2 °C increase in the global temperature is dangerous to all life forms on the planet (Bascopé et al. 2019). It is estimated that carbon dioxide emissions in the atmosphere are to be cut by 45% by 2030 to prevent the global temperature from rising above 1.5 °C by 2030 (UNICEF 2019). The increased health risks of a rise in temperature above 1.5 °C are now well-established as being unsafe to life on the planet (IPCC 2021). However, recently, the UNEP (2021) warned that the aspirations of the Paris Agreement of keeping global warming below 1.5 °C this century is hard to achieve unless the annual greenhouse gas emissions are reduced by half in the next eight years.

Climate change is both an environmental issue and a children's right issues since it undermines their rights, health and future prospects (Chesney and Duberstadt 2022; UNICEF 2021). "The climate crisis is a child rights crisis" (UNICEF 2019, p. 3) because it deprives children of their right to realise the rights granted to them by the *United Nations Convention on the Rights of the Child* [UNCRC] (UNICEF 1989, 2021). Specifically, UNICEF (2019, p. 3) explains that since climate change cuts across the UNCRC, it denies children their rights for survival and development (Article 6); health (Article 24); education (Article 28); indigenous culture (Article 30); recreation and play (Article 31); and, it makes children more vulnerable to violence and exploitation (Articles 19, 32, 34–36).

From a medical perspective, children are more vulnerable to the physiological, developmental, behavioural, and social impacts of climate change than adults, yet children are often excluded from discussions around climate change (Leffers 2022). Recent research has confirmed the negative impact of climate change on children's health, morbidity, mortality rate, education, nutrition and wellbeing, now and in the future; suggesting that climate change could possibly even reverse the improvements in health and wellbeing that have been achieved in recent decades (Cheney and Duderstadt 2022; Hellden et al. 2021). The changing climate affects children's health prospects, directly and indirectly. Higher temperatures, extreme weather events, such as floods and droughts, acidification of the oceans and the rise in sea level, air pollution and aeroallergens cause direct harm to children by increasing their risk of disease and poverty, all of which could have lifelong impacts (Cheney and Duderstadt 2022; Hellden et al. 2021; UNICEF 2019, 2021).

The indirect impacts of climate change relate to poor mental health, such as depression, post-traumatic stress disorder and anxiety, even if, to date, the research in this area is stilll in its infancy (Cheney and Duderstadt 2022; Hellden et al. 2021). Poor families are more likely to struggle with climate change. Environmental issues, such as air pollution, are a major threat to human health and capital, and economic development all over the world, but it is even worse in developing countries (Fisher et al. 2021). For instance, research confirms that as air pollution increased in Africa, pollution-related diseases, morbidity and mortality increased too (Fisher et al. 2021), making some populations more prone to the impacts of climate change. Under such circumstances, vulnerable children, under five years of age, are more likely to be disproportionately affected by the direct and indirect health challenges posed by climate change, thus increasing their incidence of poverty, lack of education, risk of disease (Malaria and dengue fever), and mortality (UNICEF 2019). Therefore, the climate crisis requires humanity to adopted different ways for living that safeguard the health of all living species on the planet as well as planetary health (Berrang-Ford et al. 2021; Deem et al. 2019).

Research around the issue of climate change in ECEC is still in its infancy (Rousell and Cutter-Mackenzie-Knowles 2020). The few published research thus far has explored the importance of introducing concepts about climate change to young children (Ardoin and Bowers 2020; Bascopé et al. 2019; Davies et al. 2016; Rousell and Cutter-Mackenzie-Knowles 2020). Such research is important and this chapter calls for more research related to climate change and planetary education in ECEC. While children are the least responsible for the current climate crisis, the impacts of climate change on them are clear—they will bear the greatest threat to their growth and survival (UNICEF 2019). Therefore, it is important that from an early age, children are taught about the causes, consequences and mitigation measures of climate change (Jorgenson et al. 2019; Rousell and Cutter-Mackenzie-Knowles 2020). Doing so, would be the first step toward introducing concepts related to planetary health in ECEC.

Embedding planetary health education in curricula, across all levels and disciplines, is important in achieving the much-needed transformative change towards sustainability. To date, education on planetary health has been introduced at college or university level (Guzman et al. 2021; Wabnitz et al. 2020). However, in reviewing the literature, no data were found on the question of planetary health education in ECEC. Amid the current environmental and health crises, there is still lack of guidance for embedding planetary health across the early years' curriculum. Ironically, despite the importance of ECEC for human development and its educational value, issues about planetary health are rarely addressed in ECEC, or if they are, these have not been documented. In an era marked by uncertainty and unprecedented change, young children's lives will be the most at stake (Arlemalm-Hagser and Elliott 2020; UNESCO 2017; UNICEF 2019; WHO 2017).

More importantly, to date, it is clear that while the COVID-19 pandemic has indeed highlighted the importance of the early years' sector in supporting families and society at large, when compared to other sectors of education, the ECEC sector has not been appropriately supported during the COVID-19 pandemic (European Commission 2021), thus denying children their right to education (UNICEF 1989). Hence, now, more than ever before, the need to invest in ECEC is more pronounced (European Commission 2021). Not including planetary education in ECEC, denies young children the right to learn about the issue (von Borries et al. 2020). Depriving young children of the right to learn about planetary health will have an individual impact on their lifestyles, and a collective impact on society, moving it further away from achieving a sustainable future. Consequently, this chapter calls for the introduction of early childhood education for planetary health in ECEC sooner, rather than later.

Strengths, Limitations and Future Directions

The intersection of ECEC and planetary health is an emerging field of research. It is hoped that this chapter helps lay the groundwork for future research into the emerging field of early childhood education for planetary health. A key strength of this chapter is that, as a first, it represents a comprehensive examination of the field of early childhood education for planetary health, an emerging field of early childhood research.

Still, several questions remain to be answered and a number of limitations need to be noted. The discussion here suggests that the limitations of this chapter provide insight into gaps within the literature. First, the current narrative review is limited by the paucity of literature about planetary health and ECEC. Given the insufficient published research to allow the importance of the two fields (ECEC and planetary health) to be addressed, the relevance of the two fields has been proven to some degree but requires further investigation. Therefore, the lack of research in the field adds further caution regarding the generalisability of the arguments presented above.

Second, while the discussion in this chapter may be applicable to ECEC, it may not be relevant in certain geographical locations and cultures, for example, where access to ECEC is not available. Consequently, this calls for further research to be undertaken in different geographical and cultural contexts to consolidate the field.

Third, the ideas outlined above may be deemed as being human-centric as they described primarily the impact of the environmental and health crises on humanity and the planet, with a specific focus on young children. As such, these environmental issues have attributes that seemingly affect both the health of the environment and the health of the human community. The idea though is that a healthy environment is needed to support the health of communities of human and more-than-human species. Perhaps, future research that adopts a more eco-centric lens, to include factors such as safeguarding the forests, indigenous land rights and the impact of colonialism on these can create new knowledge and new understandings within the field of early childhood education for planetary health.

Cetainaly, if the debate is to be moved forward, a better understanding of early cihldhood education for planetary health needs to be developed. To date, no clear evidence exists of programmes that include early childhood education for planetary health. In turn, this entails the introduction of programmes about planetary health in ECEC, and further research is required to evaluate such programmes. For instance, a further study could assess both the short-term and long-term outcomes of such programmes. Future research can also employ different methodologies and theoretical perspectives to explore different ways of implementing early childhood education for planetary health.

Conclusion

This chapter addressed the lacuna in the literature related to ECEC and planetary health, and provided some preliminary guidance. It argued that perhaps the greatest threat to planetary health is the continued failure of humanity to take action to save itself, its habitat, planetary systems and the planet it inhabits. Unless we understand that human health depends on the health of the planet, current and future generations of children, particularly the most disadvantaged, through no fault of their own, will continue to bear the high price of the environmental crisis. Therefore, urgent social change is needed. Undoubtedly, one way of addressing the issue of planetary health is by teaching children about sustainable lifestyles, starting in the early years.

Next, this chapter has presented an overview of the two fields (ECEC and planetary health) and has examined whether the intersection of the two is both beneficial and possible, proving that it is, even though research is the field is scant. Consequently, this chapter supports the idea for the inclusion of early education for planetary health as an appropriate means of providing solutions to the current environmental challenges and to ensure the health and sustainability of all life systems on Earth. Overall, this chapter has reaffirmed the key role of ECEC in promoting planetary health.

More broadly, this chapter has laid the groundwork for future research on young children and planetary health. Young children are important agents of change. Given the importance of ECEC and the connection to nature for human health and wellbeing, continued efforts are needed to make education about planetary health a priority. It is possible therefore that through age-appropriate themes, education systems worldwide take advantage of this growing awareness and prepare young children for a healthy future and a healthy planet. This will ensure that young children become agents of change for the health of all life systems on the planet, who will be prepared for the challenges ahead. It is hoped that in the future, young children will be able to advocate for a healthier and more sustainable planet, and for a healthier way of life.

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Chapter 18
Enviro-Health Consequences of Unpaved Road Deterioration in Liberia: Implications for Development

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Abstract Unpaved roads are the major road network connecting Liberia. Though it appears to be in a very poor condition and sometimes impassable particularly during the rainy season. This situation has persistently led to environmental and health consequences, disrupting economic activities. However, there exists a gap in knowledge on these consequences associated the unpaved road deterioration. We used the unpaved Ganta-Zwedru road as a case study. We surveyed 200 road users to get their perceptions on the environmental and health consequences of plying the road. We found that 80% of the road users adjudged the general condition of the road to be of a serious public health concern. The specific conditions characterizing the road were dustiness and potholes during the dry season, and deep potholes which contributes to high waterlogging and slipperiness during the rainy season. The average travelling time was approximately 6 days, instead of 4–5 h if the road was good. Factors that cause travelers' delay were found to be the muddy nature of the road, drivers travelling with insufficient gasoline/diesel, vehicles travelling without off grip/road tires and four-wheel drive especially during rainy seasons. Land degradation, water/air pollution, deforestation and soil infertility were some of the environmental consequences associated with the road while exposure to dust

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_18

particles, water borne diseases, insect/snake bite were some of the health consequences emanating from the environmental conditions of the road. Among others, we recommend for a long-term solution/improvement on the condition of the road network to be implemented by the government and development partners to not only stimulate economic activities but also have far reaching health and environmental benefits.

Introduction

Liberia is Africa's oldest republic having got her independence in the year 26 July 1847 (Hoh 2016). It is situated in the coastal western part of the continent. It has approximately 4.9 million people (4,894,920) (Worldometers 2018), with 49.2% living in the rural areas (LISGIS 2017). The country's road network generally is classified into primary (paved), secondary (unpaved) and tracks. However, the roads have been in a bad condition since her independence with only a few paved and majority unpaved. Due to the civil crises and poor financial capability, it has not received the needed attention especially for its maintenance or asphalting (Iimi and Rao 2018). The deterioration level of most of these road networks across the nation makes it one of the least developed road network in West Africa with about 60% of the unpaved roads unfit or in very poor condition to travel thereon (Harley 1939; Iimi and Rao 2018). Many parts of the unpaved roads and highways remain death traps due to its poor condition, particularly those in rural areas (GIF 2018; Harley 1939; Saha and Ksaibati 2017). This condition is predominantly worse in the southeastern region, the farthest distance from Monrovia the state capital. At present, about three million Liberians lack all-weather road access (GIF 2018; Iimi and Rao 2018; UN-Habitat 2013). This has, negative effect on the environment, health and the economy with multiplier effects on all sectors, including trade, agriculture, healthcare, education etc. (GIF 2018; Harley 1939; Stanley 1971). While the dominant transportation mode in the country is by road, limited road transport connectivity has been one of her main challenges.

The country have continued to engage in major infrastructural reconstruction ensuing her fourteen years brutal civil war, which resulted in about 200,000 deaths and leaving the state bereft of her many basic infrastructures especially roads (Cain 1999). Liberia has an overall length of 9,916 km road system with 9,182 km unpaved (Iimi and Rao 2018; MoT 2012; Styles and Camilla 2018). The road system is classified as primary, secondary and feeder/track roads (Table 18.1). However, the unpaved roads are mainly characterized by deterioration due to overloaded trucks, lack of maintenance, heavy rains and lengthier rainy season lasting up to 8 months, during which the roads are mainly inaccessible, most especially in the Southeastern Region (Grand Gedeh, Lofa, Sinoe, Gbaporlu, Nimba, River Gee, River Cess and Maryland counties) (Iimi and Rao 2018; Styles and Camilla 2018). Less than a

Table 18.1 Liberia's road network and type (km)

Type	Paved	Unpaved	Total
Primary	734	1,130	**1,864**
Secondary	0	2,350	**2,350**
Tracks/Feeder	0	5,702	**5,702**
Total	**734**	**9,182**	**9,916**

Source (MoT 2012; Styles and Camilla 2018)

quarter of the Liberian road is classified as year-round road. The Monrovia-Ganta Road paved in 2015 is in good condition, however, have started recording cracks along its coast, also the Monrovia—Buchanan Port and Monrovia—Bo are equally paved and accessible. But from Ganta to Maryland is unpaved and in very bad condition, therefore, making road travel difficult and hazardous for health (Harley 1939; Iimi and Rao 2018; MoT 2012; Styles and Camilla 2018).

The Context of the Roads

Liberia has a very poor/inadequate road network which has been a major constraint on mobility over the years. According to the Rural Access Index (RAI), more than half of the population is deprived good road access (World-Bank 2016). Most of the counties are mostly or completely inaccessible during summer, typically from May to October (Iimi and Rao 2018). This disrupts economic activities thereby, exacerbating poverty, adversely affecting health, food security, and slowing down development and educational opportunities. This makes it difficult to ensure core human rights, such as the right to adequate standard of living, education and health.

Travelling along this terrain is extremely challenging owing to the potholes, mud and rough surfaces. Worse still, majority of the vehicles, trucks, and taxis plying this road are often overloaded with people and goods (Styles and Camilla 2018). Normally, travelling time from Ganta to Zwedru should be between 4–5 h but during the rainy season, travelers risk spending between 3–7 days on this road due to the poor/bad conditions of the road. It is mainly impossible for vehicles and trucks without four-wheel drive (4WD) or off grid tires between July to late November of every year.

The Ganta—Zwedru road is the main road linking Ganta and Zwedru cities, the commercial hub of Nimba and Grand Gedeh counties respectively. It is the case point of this study and is shown in Fig. 18.1. It witnesses recurrent closures, mostly between July to October. Besides the health complications created by the poor state of this road, it also creates environmental, economic and social problems for traveler's and inhabitants by exposing them to toxic pollutants detrimental to health, environmental degradations; erosion, flooding, soil infertilities, loss of aqua life etc., disrupting businesses, separating families, and creating shortages of foods and other basic goods. Travelling along this road can take up to three weeks during those months. With an

Fig. 18.1 The unpaved Ganta—Zwedru road. *Source* (LISGIS 2019; MoT 2012)

increasing possibility of users being exposed to various health hazards which includes respiratory diseases, diarrhea, malaria, body pains, snake/insect bites, cough, fever etc. can be as a result of their exposure to dust or unhealthy habits practiced in the communities or while travelling such as drinking of unclean water, exposure to insects/extreme weather, open defecation and starving or eating unhealthy foods.

Infrastructural development such as road asphalting is expected to reduce this existing health and, environmental challenges, economic discrepancies and food insecurity among those in this region. The two corridors with the highest transportation cost are southeast and northeast corridors. This is as a result of the bad conditions of the roads. For instance, a ton conveyance cost of goods along the Ganta-Zwedru road is found to be relatively higher when compared with the paved Monrovia—Ganta road. In December 2016 the parliament passed into law the National Road Fund Act which is enacted to finance road maintenance works and directly associated with planning and management of road related activities (MCA 2019) but is yet to be made operational thereby stagnating the road sector reform activities. In 2018, with support from the World Bank, the Liberia secured \$500 million loan assistance to support the construction of roads across the country. This initiative is being managed by the Ministry of Public Works; however, work is albeit slow.

So far, in the area of empirical analysis and to best of the researcher's knowledge, there has not been any scientific study examining the health and environmental effects of the unpaved roads in Liberia. Unfortunately, there is limited research in the areas of health and environmental sustainability. This may be due to the ongoing reconstruction ensuing the war. Available studies on road in Liberia have been on roads and travails (Harley 1939; Iimi and Rao 2018; World-Bank 2016), construction priorities of farm to market roads (Stanley 1971), and transport expansion priorities. The present study therefore, tries to bridge this literature gap by not only contributing to renewed interest and relevance of environmental research but also to provide data as the basis for impending empirical studies and policy making in that regard. Thus, this study aims to ascertain user's perception of the health and environmental effects of the unpaved Ganta-Zwedru road by determining the period of travelling, and perceived health and environmental issues associated with it.

Methodology

Data Generation

Liberia lacks knowledge on the health and environmental challenges associated with traveling along her unpaved roads. Yet this is vital for policy makers especially government and development partners working on restoring sustainable peace and development in the country. Data were generated along the Ganta and Zwedru road located between Nimba 6.8428° N, 8.6601° W (Google Coordinates, n.d.-b) and Grand Gedeh 5.9222° N, 8.2213° W counties (Google Coordinates, n.d.-a) with a distance of 209 km (MoT 2012).

Using a multistage purposive random sampling technique, a total of 200 travelers were studied. The four towns; Ganta, Tapitta, Toe town and Zwedru were purposively selected due to their strategic locations along the road. From these selected towns, fifty (50) users comprising 30 travelers and 20 residents were selected. The meagre number of respondents surveyed was due to limited funding. Data were gathered from June 2019 to January 2020 using pre-validated questionnaire by the Environmental Protection Agency (EPA) focal points in both Nimba and Grand Gedeh counties administered in two periods rainy season and dry season, with a response rate of 91.50%. Consent of respondents were sort after prior to answering the survey questions.

Data Analysis

The Statistical Package for the Social Sciences (SPSS) software was used to code and analyze data. Descriptive statistics and a five point mean rating with 3 as the mean decision cutoff point. To get the mean score, the responses were graded in the following order: 5 points for each strongly agreed, 4 for agreed, 3 for undecided, 2 for disagreed, and 1 for strongly disagreed. The mean decision cutoff point was gotten by dividing the total ratings (15) by 5 to get 3, the mean decision cutoff point (Apeh 2018). Therefore, mean responses above or equal to 3 were categorized as 'serious', while those below were categorized as 'not serious.' Respondents were asked about their general perceptions on the road condition, and their perceived health and environmental issues associated with the road.

Results

In this section, we present the results of the survey which we analyzed and interpreted in accordance with the data collected through the survey on the specific objectives of the study. And the results are presented in Sects. "Methodology", "Results", "Discussion" and "Policy Consequences" below.

Section One; Demographic Features of Users

This section discusses the demographic features of users as presented in Table 18.2.

The result in Table 18.2 shows that majority of the Ganta-Zwedru road users are male (53%) with approximately an average age 29 years.

Section Two: Users General Perceptions on the Condition of the Road

This section discusses the user's general perceptions on the condition of the road as presented in Table 18.3.

The outcome of the result in Table 18.2 show that most of the travelers (80.3%) adjudged the general condition of the road to be bad. The study found that the peculiar conditions on the road are dust ($\tilde{x} = 3.14$), potholes ($\tilde{x} = 3.64$), slippery ($\tilde{x} = 3.04$) and waterlogs ($\tilde{x} = 3.23$) and that the communities living along the road live in

Table 18.2 The demographic features of users

Age	Frequency	Percentage (%)	Mean ($\bar{x}$)
Under 18	24	13.11	28.5 months
18–24	60	32.79	
25–34	50	27.32	
35–44	34	18.58	
45–54	9	04.92	
55 and above	6	03.28	
Gender	97	53.00	
Male	86	47.00	
Female			

Field Survey, (2019)

Table 18.3 Users general perceptions on the condition of the road

General conditions of the road	Freq	Percent (%)
Good	36	19.70
Bad	147	80.30
Perceived conditions of the road	Mean score ($\overline{x}$)	Standard deviation
Dust	3.14[a]	1.41
Potholes	3.64*	1.01
Mud	2.96	1.41
Slippery	3.04[a]	1.50
Rocks	2.65	1.33
Waterlogged	3.23[a]	1.40
Living conditions of communities living along the road compared to Monrovia	Freq	Percent (%)
Better	4	02.20
Good	40	21.90
Same	31	16.90
Difficult	52	28.40
Extremely difficult	56	30.60
Change in the condition of the road since 2003 after the war	Freq	Percent (%)
Improved	55	30.10
Worsened	61	33.30
Remained the same	67	36.60

Source Field Survey, 2019; [a] Represents Significance, Cut off point = 3.00

extreme difficulty (30.6%) compared to the living conditions in Monrovia the state capital.

Also, the study found that insecurity/crime ($\tilde{x} = 3.08$), inadequate drinking Water supply ($\tilde{x} = 3.18$), poor electricity supply ($\tilde{x} = 3.13$), poor access to health care ($\tilde{x} = 3.07$), poor access to education ($\tilde{x} = 3.00$), bad transport system ($\tilde{x} = 3.46$) and unemployment ($\tilde{x} = 3.08$) were the major problems affecting the communities living along the road. And that the conditions of the road have remained the same (36.6%) since 2003 after the civil war.

Section Three: Factors Affecting Travel Along the 209 Km Ganta-Zwedru Road

In this section, the travelling time along the Ganta-Zwedru road is presented in Table 18.4; the time spent on the road and perceived factors affecting travel.

The study found that majority approximately (55%) of the travelers spend 1–5 days traveling along the unpaved 209 km Ganta to Zwedru. The average time is estimated for approximately 6 days. The factors affecting travels were the general

Table 18.4 Travelers perceived experience travelling along the road

Number of days spent on the road	Freq	Percent (%)	Mean ($\bar{x}$)
1–5	101	55.19	5.61 days (134.64 h)
6–10	74	40.44	
11 = 15	7	3.83	
16 and above	1	0.55	
Factors affecting travelling	Mean score ($\tilde{x}$)	Standard deviation	
Condition of the road (dusty, mud, potholes, slippery nature of the terrain, waterlogged, etc.)	3.01[a]	1.46	
Vehicle breakdown	2.99	1.43	
Insufficient amount of gasoline/diesel	3.00[a]	1.36	
Lack of off grip/road tires	3.04[a]	1.43	
Lack of four-wheel drive (4WD)	3.11[a]	1.44	

Source Field Survey 2019; [a] Represents Significance, Cut off point = 3.00

bad condition of the road ($\tilde{x}$ = 3.01), insufficient amount of gasoline/diesel ($\tilde{x}$ = 3.00), lack of off grip/road tires ($\tilde{x}$ = 3.04) and lack of 4WD ($\tilde{x}$ = 3.11).

Section Four: The Environmental and Health Consequences Associated with Travelling Along the Road

This section discusses the environmental and health consequences associated with travelling along the unpaved Ganta-Zwedru Road as presented in Table 18.5.

Table 18.5 Users' Perception on environmental and health consequences associated with the road

Environmental consequences	Mean ($\tilde{x}$)	Standard deviation
Land degradation	4.0[a]	1.00
Water pollution (sediment loads in water courses)	3.80[a]	0.980
Dust generation	3.05[a]	1.51
Deforestation	3.06[a]	1.43
Soil infertility	3.21[a]	1.38
Health consequences		
Dust exposure	3.05[a]	1.40
Exposure to water borne diseases	3.08[a]	1.40
Exposure to snake/insect bites	3.07[a]	1.30

Source Field Survey 2019; [a] Represents Significance, Cut off point = 3.00

The study revealed that land degradation ($\tilde{x} = 4.01$), water pollution ($\tilde{x} = 3.80$), air pollution ($\tilde{x} = 3.05$), deforestation ($\tilde{x} = 3.06$), and soil infertility ($\tilde{x} = 3.21$) were the environmental consequences associated with the road. While dust exposure ($\tilde{x} = 3.05$), water borne diseases ($\tilde{x} = 3.08$), and snake/insect bites ($\tilde{x} = 3.07$) were some of the health consequences suffered by the road users.

Discussion

Demographic Characteristics of Users

Finding from the study shows that preponderance of the road users are young persons, which is in line with demographic distribution reported by the Liberia Household Income and Expenditure Survey (HIES) (2016) which indicated that Liberia has a young population of 44.5% below 15 years of age and only 2.9% above 65 years (LISGIS 2017). This could also suggest that the older people find it difficult travelling on the poor and hazardous conditions of the road, or that greater energy is needed to ply this road as vehicles are frequently stocked in the mud needing travelers to push/dig it back on track, thus, this cannot be done by under aged (below 18 years) or older people (above 34 years). Between August—October when data were mostly collected, the road was virtually impassible due to its ugly condition and within this period, economic activities in most of the towns/villages along this road were almost shut down with limited or zero movement from either side. The only available means of travel at that point was either through flight/inter-state travel from Cote D'Ivorie to Monrovia.

The result equally demonstrated that majority (53%) of those that ply the road are males. This is also indicative of the difficult nature of this road which does not favor women travelling along it especially during the rainy season. Ordinarily, in Liberia women are more involved in business activities and transactions, and are more mobile from one area to the other due to the nature of their businesses therefore should have been more frequent on the road. The few males who do businesses in Liberia are foreigners who are mostly involved in gold/diamond mining, logging and other businesses such as the running of super markets etc. Thus, the nature of the road does not ordinarily favour women to travel because the journey use to be very time and energy sapping, intimidating and breath taking with many collusions resulting to injuries and deaths. It is very unsafe for female travelers especially pregnant and nursing mothers.

Users' General Perceptions on the Condition of the Road

The result of the user perception on the general condition of the road in Table 18.2 shows that 80% of users interviewed agreed to the fact that the general condition of the road is bad. And that conditions peculiar to it are dustiness ($\overline{x} = 3.14$), potholes ($\overline{x} = 3.64$), slippery due to mud ($\overline{x} = 3.04$) and waterlog due to potholes ($\overline{x} = 3.23$) having reached the mean score cut off point of 3 and above. The conditions are seasonal; the road use to be dusty with potholes during dry season and in addition, slippery and water logs during the rainy season. Though pothole being the most predominant condition with the highest mean score (MS = 3.64) likened to other accepted conditions is an all-year condition; experienced in both the rainy and dry seasons. Other conditions such as muddy and rocky conditions are also peculiar to the road but couldn't meet the cut off point for the study thereby were not accepted as serious issues for the study.

The study also shows that approximately 31% of users believe that the living conditions of the communities along the corridor are extremely difficult compared to the living conditions in the state capital; Monrovia. Equally, majority of the travelers (37%) believe that the conditions of the road since 2003 after the civil war have remained the same while 33% believe that the conditions have worsened over the years sequent to the war. The condition of the road is one of the leading causes of mortalities in the communities; in the peak period of the road, patients referred to Tapitha hospital from Zwedru find it almost impossible to travel on the road and are left to live without care while in most cases patients die due to such situation. This condition is so alarming and needs an urgent action to help alleviate the suffering of the people of the communities by unlocking their social, health and economic potentials and most importantly to save lives. This is in line with the position of Stanley (1971) that improving the road conditions of the developing countries helps to unlock their health, social and economic potentials (Stanley 1971) (Fig. 18.2).

Factors Affecting Travelling Along the 209 km Ganta-Zwedru Road

The result of users' experience travelling along the road shows that majority (55%) spent 1–5 days travelling on the road with an average travelling time of approximately 6 days. At this point, it is important to note that mostly, data were collected at the "peak" period of the road; when the road was practically impassable, between July—the middle of November 2019. Equally, the study found that the general condition of the road (dusty, mud, potholes, slippery nature of the terrain, waterlogged, etc.) ($\tilde{x} = 3.01$), insufficient amount of gasoline/diesel ($\tilde{x} = 3.00$), lack of off grip/road tires ($\tilde{x} = 3.04$), and lack of 4WD ($\tilde{x} = 3.11$) were factors affecting travelling time along the road. Most predominant is the lack of 4WD. These delays subject travelers to hunger and impromptu expenses, a times missed appointments/opportunities. In a

Fig. 18.2 Image of the conditions of the road. *Source* Photograph showing vehicles stocked along the unpaved Ganta—Zwedru Road, 2019

discussion with one of the drivers, he affirmed that during the rainy season that it is very difficult to drive a kilometer on the road without 4WD. He further stressed that most of the abandoned vehicles on the road are vehicles without 4WD and it will take the owners till dry season to move them from their various positions. Corroborating this opinion, a truck owner informed us that his truck on transit from Monrovia to Zwedru has been on the road since May 2019 and it would take him till ending of November 2019 to get it to Zwedru because it lacks 4WD. He further stated that at Kpelle town (a major town along the road) inhabitants purposely damage the roads so that travelers will pay to pass through their communities instead of the damaged road.

Environmental Consequences Associated with the Unpaved Roads

One of the main environmental complications associated with the road is loss of soil particles. Users believe that this loss of soil particles can lead to land degradation ($\tilde{x} = 4.07$), water pollution ($\tilde{x} = 3.07$), dust generation ($\tilde{x} = 3.07$), deforestation ($\tilde{x} = 3.07$), and soil infertility ($\tilde{x} = 3.07$). these are caused by human activities on the road and these complications are detrimental to health and environmental sustainability (Gray 2008). The substantial human meddling on the land affects the physical, biological or chemical efficiency or health which may impede production (Johnson and Lewis 1995; Lindskog and Tengberg 1994; Johnson et al. 1997). The vehicular movement on this coast often overloaded with people and goods adversely affects the soil compaction in this area (Styles and Camilla 2018). This can result in severe variabilities in the properties of the land which can reduce soil infiltration capacity, raise soil bulk density, enhance cover crops and soil nutrients losses, and cause soil fertility degradation.

Health Consequences Suffered by the Unpaved Road Users'

The environmental consequences associated with this unpaved road contributes to the health consequences suffered by the road users. For instance, land degradation contributes to dust generation which affects both human and environmental health; the ambient particles can pollute the environment and penetrate the respiratory tract of exposé causing health issues. According to Barnes and Connor (2014) unpaved roads generates dust through the interface between moving vehicles, road surface and weather conditions. In Liberia, the mining and logging activities in most parts of the country especially in the Southern region have continued to exact pressure on the unpaved structure of the road, affecting their structural capacities. The presence of dust, potholes, mud, and water logs are evidence of the loss of the unsealed soil particles on the road and are associated with degradation leading to water pollutions, poor sedimentation and soil infertilities. Dust exposure affects human breathing, damages the lung tissue, causes cancer and premature death (Barnes et al. 2020). On environmental health, dust can amass on the surfaces of crop leaves thereby reducing photosynthesis processes which can meaningfully reduce their yield and accumulated particulate matter (PM) such as PM10 and PM2.5 which may negatively affect the environ by disturbing membranes permeability, premature senescence, and stomatal damage (Aleadelat and Ksaibati 2018; Rai 2016).

Also, some travelers sleep in nearby communities, vehicles and in the open; road side/under the trucks. These practices are unhealthy, very risky and challenging as travelers are being exposed to various dangers such as rape, sexual exploitation, harassment, insect or snake bites, cold, rain, animal attacks (gorillas, elephants etc.) and falling trees. Source of water on transit is also an issue as travelers' access to clean water is not guaranteed, majority drinks from the community well or river/creek. These untreated sources of drinking water are unsafe and detrimental to traveler's health (Barrett et al. 2010). It exposes them to several water borne diseases such as diarrhea, dysentery, trachoma, guinea worm, etc. Water borne disease have been identified by the WHO to have caused 2 million deaths each year around the world, with the majority occurring in children under 5 (WHO 2018). On the same note, bathing in the creek or the like is detrimental to health also as it exposes travelers' skin infections and dangerous especially to the women who are more exposed to rape or sexual harassment which was reported in an interaction with travelers as a regular occurrence. On the other hand, abstaining from bathing have its own problem ranging from body odor, skin diseases, discomfort and other antisocial consequences. Also, of concern is the period of delay which expose the commuters to starvation/hunger, suffering anxiety which may lead to high blood pressure (HBP), stroke, depression and even death. The galloping effect experienced on the road also cause collusions leading to injuries and death of occupants or by-standers. Equally, insect/snake bites can cause malaria or outright death.

WAY FORWARD; Upgrading the Unpaved Ganta—Zwedru Road to Asphalt Standards

Below are the few benefits of upgrading the unpaved Ganta—Zwedru road to asphalt standard:

- **Road Surface Improvement**: With an improved surface of the road, there would be improved coziness, better and reliable means of transportation, unlike the current condition where the use of vehicles, motor bikes, trucks and trekking are difficult and energy sapping.
- **Essential Services Access**: When the road is upgraded, people especially travelers will be able to have access to essential facilities such as medical, food, education and markets in the counties Grand Gedeh and Nimba. Delivery of farm, infrastructural and medical equipment and other produce from one area to another will be done with minimal/zero losses and/delay.
- **Improvement of Local Socio-economy**: Good Road network enhances and boost businesses and the economy not only among the counties but the nation in general. It would equally provide regional connection amid Southeastern region and other parts of the country. The local businesses, markets, supermarkets, and other trading enterprises would expand, enticing investors and entrepreneurs thereby improving returns with improvement in the movement of their goods, since commodities will be frequently transported along the road with ease.
- **Agricultural Development**: Farming is the core economic activity in these two counties. Therefore, upgrading the unpaved road to asphalt standards would enhance agricultural development through:

  - Improved marketing of agricultural produces;
  - The reduction of agricultural wastages especially post-harvest spoilage due to lack of markets and storage facilities;
  - Improved access to enhanced agricultural value chain facilities, and the reduction of its processing/marketing cost;
  - Improved access to agricultural extension officers to enhance farmers education on improved/innovative production practices;
  - Enhanced delivery of agricultural products to the markets especially international markets.

- **Creation of Employment Opportunities**: Good Road creates job opportunities through business opportunities such as petty trading along the road or transport businesses; market creation and opening of trading/business centers and the expansion of existing businesses, i.e., businesses will flourish hence creating more indirect job opportunities.
- **Reduction of Transportation costs and Travel Time**: There would be improved flow of traffic along the road with more vehicles including public passenger vehicles applying the roads more frequent and due to competition, transport fares would decrease. Also, improved road network reduces travel time and creates opportunity for ease of women access to the markets to sell their produce as opposed to using middlemen.
- **Enhanced Security**: Good road would ease the patrol of security agents hence dropping the rates of crime in the area and neighboring counties affected by cases of petty crimes and unlawful organizations.
- **Reduced Vehicle Breakdown**: With an asphalt road, vehicular breakdown would drastically reduce thus saving vehicular maintenance cost.

Importance of Good Road to Agricultural Development

The agricultural sector is one of, if not the most important component of the Liberian Economy. The livelihoods of over 70% of its rural population (larger percentage of poorer section of the society) depends on agriculture. One of the major constraints to development of agriculture in Liberia is weak road network—poor farm to market roads, some communities are not connected by roads and most trunk roads are out of use for the most part during the rainy season. Coastal Counties hold huge agricultural potentials and are reservoirs for Agricultural value chains development. These counties, apart from their own production capacities, are potential conduits for agricultural products from land-locked counties to coastal, regional and international markets. Coastal sea ports and facilities are fabulous attractions for private investors and public–private partnerships to engage in vibrant agro-businesses along the agricultural value chains. Despite the current poor performance of agriculture which is labor intensive and subsistence based, the fact remains that first, Liberia has the right conditions (climate, land area, ample water, etc.) for commercial agriculture to flourish and secondly, farmers are much eager for opportunities to do farming as a business (increase production above their home consumption level and generate substantial incomes). Good all-weather road network in Liberia, would motivate private sector investment which has the potential for the emergence of agro-enterprises to operate at the various stages of the agriculture value chains.

Good road transport system is key to agricultural development due to its role in the movement of agricultural products from the points of production (farms) to the markets and other areas of need such as counties and other countries. It can also help in the reduction of the costs associated with agricultural production, i.e., the costs of inputs and to increase return through increases in output, and finally, to encourage investments in other profitable ventures. Good road infrastructure plays an important role in accelerating production, delivery, and open opportunities for investment in agriculture through the reduction of transport cost. It enables expansion and improvement of market operations, liberalizing and opening up economies for more competition.

Asphalting or paving of the Ganata—Zwedru road will engender connectivity, improve cropping pattern and productivity through the facilitation of inputs availability such as seeds, fertilizer and pesticides, and the realization of better prices to the farmers for agriculture, improve class attendance in schools and above all open new job opportunities in non-farm and service sectors.

This would engender equal gender labour participation rate in agriculture. More market access allows expansion of production of consumable and cost-intensive products. This can lead to a change in demand to a commercial demand thereby highlighting the process of commercializing agriculture and the rural sector. Furtherance, the higher population of the poor in the rural areas compared to the urban areas makes any investment in the rural areas help reduce poverty through increased production, income generation and job creation. Upgrading rural roads enhance agricultural development and the development of other social/health services. It is pertinent to note that good roads tend to greatly impact agricultural production especially in areas where cash crops are grown. This is because food crops, grown by smallholder farmers, has a lower price elasticity of supply than cash crops.

As earlier indicated, upgrading of rural roads impacts agriculture directly by expanding the areas under cultivation. Road development has a two-fold relation with enhanced agricultural production, these has to do with easy movement of farm inputs such as improved seeds, manures, farming equipment and agrochemicals. Improved roads reduce or eliminate geographical barriers in farming. It also prompts a change in agricultural production pattern by commercializing it or moving production from family food crops to commercial crops. Lack of paved roads in rural areas forces farmers to sell at farm gates at cheaper prices. Improved roads would open up the rural areas to markets especially urban markets which would facilitate marketing of rural agricultural products at higher prices. Besides, unpaved roads are responsible for the higher costs of agricultural products due to the high transportation costs which eventually increase the marketing cost. Improved road opens rural areas to not only agricultural development but will help create a general sense of awakening for improved education and health. Industries in the rural areas such as bee-keeping, dairy farming, sericulture, poultry farming etc., can be industrialized as lesser industries to complement their income in their spare time. Improved cottage and small-scale businesses become possible in rural areas when there is a good access to urban markets and the availability of farm inputs at cheaper rates. The important role played by the roads is very much felt during the days of famines. It has been observed regarding some of the Indian famines that the food scarcity in an area was not due to total deficiency. But owing to the isolation from the surplus area. More so, upgrading of rural roads would facilitate the smooth flow of food from areas of surplus (rural areas) to areas of deficit (urban areas) and also align different markets prices to enhance food access and availability. The economic effect of good roads agriculture has been documented in previous literatures as follows;

- Enhanced farming intensity: good roads enhance farming intensity by cultivating the use of machineries and introduction of new innovations such as use of improved high yielding/resistant varieties of seeds in their farming.
- Changes in Cropping Pattern: Improved Road infrastructures help engender change in cropping pattern to commercial cash crops. The change in cropping pattern due to improved transport facility for perishable products such as tomatoes, vegetables, fruits and sugarcane. The expediency in selling milk after upgrading the road induced more land under fodder and farm plots due to the availability of farm machineries in the area and outside.
- Improved crop yield: good road brings about enhanced use of high yielding innovations such as seeds, fertilizers, pesticides, etc. ensuing increase in crop yield.
- Prevents deterioration: good road helps reduce agricultural waste and deterioration by reducing the distance and time in the transportation of agricultural produce especially perishable crops such as vegetables.
- Reduction in transportation cost and job creation: The immediate benefit of a good road infrastructure would be savings in transportation costs and job creation. Farmers would pay less in getting their products to the markets, thereby, encouraging more farming and increase travel frequency by transporters/travelers to the rural areas.
- New business ventures: good roads open more business opportunities for allied agriculture business venture and in other nonfarm business ventures among rural dwellers. It would also open access to job opportunities among rural skilled and nonskilled laborer. Due to the need for enhanced agricultural products value addition, new agribusiness will spring up which may include processing plants, integrated farming, packaging, sale of inputs, passenger and transport vehicles by the villagers, opening of tea/general shops on road side, wage/trade opportunities outside the village and so on.

Whilst the roads asphalting will increase farmers access to markets and attractive incomes, vibrant enterprises (agriculture inputs supply, production, processing, transport, services, etc.) will contribute significantly to the GDP. Additionally, a well-built and connected costal roads creates huge prospects for domestic and regional trade, facilitating free and fast movement of goods from surplus zones to shortage zones throughout the country and across the West African Region and other places on the globe.

Thus, the Ganta–Zwedru road asphalting is very appropriate, relevant and there is no better time than now. It will build a strong agriculture sector, create more jobs particularly for the theming youths and women and will contribute to building a strong economy.

Potential Areas for Agricultural Development

Competitive Value Chains Development: Agro-poles (specialized industrialization centers): setting up of Agro-poles or growth poles have been identified specifically for the counties. Agro-poles are self-sustaining industrialization operations which are linked to comparative advantage that counties possess. Central to the growth pole is a group of dynamic industries connected around a particular resource. The three areas for Agro-poles include: 1. Western Cluster (cassava, oil palm, rubber and aquaculture), 2. Buchanan Cluster (marine fish, horticulture, oil palm and rubber), and 3. South East Cluster (oil palm, cassava, coconut, rubber and aquaculture). It is equally important to note that non-coastal counties also have potentials and interests for which 3 priority areas have been identified for the establishment of agro-poles. Paved Ganta–Zwedru road network could facilitate sustained business links between Agro-poles operating in the areas and those outside the areas. The prospects for this link between the growth poles could result to industrial and economic boom.

Structures that Can Be Created by Good Road Networks

1. **Developed Transport Services**
    - Efficient delivery and distribution of farm inputs
    - Reduced transport cost
    - Opportunities for expanded agricultural trade
    - Market expansion
    - Increased agricultural income and employment.
2. Developed Agro-Industry
    - Creation of Agro-poles or Growth Poles—specialization based on potentials and interest
    - Simultaneous and coordinated investments—support self-sustaining industrialization
    - Combined public and private investments—support PPP
    - Rise of agro-industries connected around a particular resource—stimulate the growth of other industries due to inter-industry linkages

- Enhanced entrepreneurship activities.

3. Improved Trade (Competitiveness of Liberian agricultural)

   - Vital distribution of products
   - Connection of farmers to global markets
   - Promotion and support for economic growth
   - Competitiveness of domestic products in regional and international markets
   - Improved export potentials
   - Trade liberalization: signed Africa Continental Free Trade Agreement (AfCFTA)
   - Opportunities for farmers and agribusinesses to benefit from globalization.

4. Transformation of Liberian Agriculture from Subsistence to Commercialization

   - Adoption and upscale of improved technologies (production, processing, etc.)
   - Farm mechanization
   - Value chains management
   - Market-based agriculture (farming as a business).

   **The move away from inefficient resource use, limited choices, backwardness, low input, low income, etc.

5. Diversified Agriculture

   - Multiple crops, livestock and fisheries production
   - Improved nutrition diversity
   - Sustainable and resilient agriculture—climate smart agriculture
   - Reduced agricultural risks/loss
   - Promote Value addition
   - Improved income (from agricultural activities).

6. Sustained Revenue Generation

   - Increased revenue earnings from export and import markets
   - Improved tax payment from agricultural activities
   - Increased citizens income
   - Job creation
   - Promote the actualization of the Government's Pro-Poor Agenda for Development and Prosperity PADP (economic development).

The implementation of the Ganta—Zwedru road upgrade is in line with the government's road maintenance policy for the upgrade of primary roads. This would help provide access to counties and their neighbors in various regions or outside the country. The Ganta—Zwedru road is also a strategic link to the Lagos—Nouakchott Regional Trans-Coastal Highway identified by ECOWAS with the potential to facilitating regional trade and integration.

The National Transport Policy and Strategy (NTPS)

In 1987, the Executive Law—Title 12 of the Liberian Code of Laws Revised was amended to create the Ministry of Transport. The act mandates the Ministry to establish and implement, (among others) "overall transport policy and develop plans for the movement of goods and people within and outside the Republic of Liberia".

In 2009, the cabinet adopted the National Transport Policy and Strategy document which was developed by the Ministries of Transport and Public Works. The National Transport Policy Document provides the general policy framework for the improvement of the transport sector.

This policy framework sets out medium and long-term goals for the rehabilitation of the road sector which include:

(a) Innovative use of contracting techniques and partnerships with private sector to facilitate long term preservation of road assets.
(b) Establishment of effective maintenance strategy through participation of local enterprises and communities as well as innovative contract methods.

Alternative Mode of Transportation

There are no alternatives to this road that fulfill the functions of providing relatively fast, cheap land transportation. Air, rail, and water transport are unlikely to either complement or to substitute for roads or highways in this region. There is no railroad link in or near the project area. Hence, rail is not considered as an option. There are no water bodies that can be used as a mode of transportation in the project area. Streams or river in and near the project area are neither connected nor navigable. The only possible means is air transport but, this is a rather expensive alternative and cannot be used as an alternative to the road.

Policy Consequences

In Liberia, the ecosystem is fragile and most vulnerable to degradations especially due to unpaved road networks. This could endanger the environment and travelers as well. This could lead to a decline in the ecosystem functioning causing environmental problems, such as loss of productive land, increased erosion (soil, water and wind), dust and poor economic activities.

Paved road has both direct and indirect effects on the environment; it opens up the land, in that way easing vehicular movement, economic activities and natural resource exploitation such as logging and mining. However, with major obstacles faced travelling along the unpaved roads in Liberia, paved roads will help to enhance environmental health, economic activities within counties and access to health care facilities. Therefore, the need for a strategic road maintenance/transportation plans and policies to enhance road network pavement.

Limitations

The study was not a country-wide study due to the funding shortfalls, therefore, the outcomes may not be generalized to all unpaved roads in Liberia. We therefore, recommend a further study to involve more unpaved roads in Liberia.

Conclusion

The present study examined the enviro-health consequences of unpaved road deterioration in Liberia: Implications for Development**.** The findings reveal that the unpaved road connectivity from Ganta to Zwedru; a major road connecting the Southeastern region is in a very poor condition and sometimes impassable especially at the peak of the rainy season. Along this corridor, several factors cause its deterioration such as dustiness due to the detachment of soil particles, potholes, slipperiness and waterlogs. These creates unfavorable travelling conditions and hinder economic activities among communities along this corridor and the surrounding communities/cities. Mainly, travelers spend approximately 6 days on 209 km journey that would ordinarily last for 4–5 h. As a result, travelers face many difficulties while, and/after travelling through the road. Some of the environmental consequences associated with the road are land degradation, water/air pollution, deforestation, poor soil sedimentation and soil infertility. These consequences leads to both human and environmental health challenges such as environmental pollution, respiratory diseases caused by exposure to dust, waterborne diseases, malaria etc. Also, on the social aspect, the social challenges encountered are drinking and bathing with unclean water, sleeping in an unsafe environment, bathing in the open thereby exposing oneself to rape especially for the women and abstaining from bathing. It is therefore recommended that both short and long-term solution to improve the condition of the road network be implemented by the government and development partners to accelerate the growth of economic activities in the region, alleviate poverty, relieve unemployment, improve health and attain/promote food security through industrial/agricultural development and enhance interstate trade with neighboring Cote d' Ivoire and Guinea.

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Chapter 19
The Nexus Between Biomass Burning, Black Carbon Air Pollution and Planetary Health in Africa

Newton R. Matandirotya and Roelof P. Burger

Abstract Black carbon is a prominent climate-altering pollutant that is a by-product of biomass burning, fossil fuels, coal thermal power generation and domestic solid fuel combustion. The purpose of this study was to investigate the association between biomass burning, black carbon air pollution and planetary health in Africa. To estimate the black carbon surface mass the study ran simulations within the GEOS-5 model. Furthermore, the study used MODIS-6 Active Fire to identify biomass burning (active fires) across seasons over the continent. Our study identified seasonal regional hotspots of black carbon for example in central Africa (the Democratic Republic of Congo), West Africa (Nigeria, Central Africa Republic, Ghana), southern Africa (South Africa) and Algeria. Also, the active fire frequency (biomass burning) was seasonal with a marked increase over both Southern Africa and Northern regions during the winter season (JJA) while over the Northern Hemisphere the increase extended into September–October. Our study findings were that in December Ghana, Accra and regions around the Cape Coast recorded an estimated BC surface mass of 5 $\mu g/m^3$ while in Nigeria Lagos recorded an estimated 2 $\mu g/m^3$. Meanwhile in the Southern Africa region South Africa Johannesburg recorded 1.2 $\mu g/m^3$ while the South Western Region of the Democratic Republic of Congo recorded an estimated 2.0 $\mu g/m^3$. During September, October and November (SON) the highest surface mass concentrations were recorded over Angola, Zambia at an estimated 4.5 $\mu g/m^3$ and 4.2 $\mu g/m^3$ respectively. Meanwhile northern part of Zimbabwe also saw a peak which was estimated at 2.6 $\mu g/m^3$. Our study findings highlight the contribution of biomass burning to black carbon load on the continent which presents a threat to planetary health. It is therefore key that authorities on the continent hence craft appropriate policy interventions that result in a reduction in human-initiated biomass burning and reduce the threat to planetary health.

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_19

Introduction

Climate change, greenhouse gas emissions, air pollution and other anthropogenic activities are the biggest contributors to the high burden of disease, premature death as well as destabilisation of natural systems (Cole and Bickersteth 2018; Landrigan et al. 2018). The realisation of links between nature and human health has led to the emergency of the planetary health field that builds on ecological public health, one health and eco-health (Pineo et al. 2021) Planetary health refers to the attainment of the highest standards of health, equality and comfort that is achieved through giving attention to the human systems, economic, political that thrive to achieve a balance between nature and human interaction (Cole and Bickersteth 2018; McKinney 2019; Iyer et al. 2021). Planetary health considers feedback loops for causality that makes associations between how human activities impact natural systems and how natural systems affect human activities including human health (McKinney 2019; Iyer et al. 2021) and at the core of planetary health is that human health is dependent on the natural system that is at determining the availability of clean water, air as well as food production (McKinney 2019; Iyer et al. 2021). One of the goals of planetary health is to establish links between air pollution and diseases (Cole and Bickersteth 2018). Our current study explores the threat posed by black carbon (BC) emissions to planetary health.

BC is a climate-altering pollutant with an estimated radioactive forcing positive potential of $+1.2\ \mathrm{W\,m^2}$ (Bond et al. 2013; Hodnebrog et al. 2016; Jacobson 2016; Das et al. 2017; Kang et al. 2020; Kim et al. 2021) and a negative forcing effect through acting as condensation nuclei (Sahu et al. 2012). BC has a very short atmospheric life expectancy that normally lasts for a few days to a couple of weeks (Doumbia et al. 2012; Chiloane et al. 2017) though in some instances outlives this and gets transported over long distances from region to region (Doumbia et al. 2019) mostly as a result of a reduction in size (Pino-Cortés et al. 2021). The main emission sources of BC include biomass burning (BB), carbonaceous fossil fuels and domestic solid fuel (coal, wood) combustion (Abel et al. 2003; Doumbia et al. 2019; Sahu et al. 2012; Bond et al. 2013; Chiloane et al. 2017; Das et al., 2017; Kim et al. 2021) and is normally a by-product of oxygen starvation that results in incomplete combustion (Middelburg et al. 1999; Pereira et al. 2012; Bond et al. 2013; Miller et al. 2021; Zhao et al. 2021). BC alters the state of the atmosphere through climate forcing (achieved by absorption and scattering of sunlight), cloud effects (altering of cloud properties-distribution) and cryosphere melting (Tummon et al. 2010; Pereira et al. 2012; Bond et al. 2013; Hodnebrog et al. 2016; Chiloane et al. 2017; Holanda et al. 2020; Kang et al. 2020; Oluleye and Folorunsho 2020; Miller et al. 2021; Pino-Cortés et al. 2021) and negative human health impacts (Zhao et al. 2021).

BB activities in Africa and South America (Amazon) significantly contribute to the total global atmospheric BC load (Tummon et al. 2010; Holanda et al. 2020) with Africa contributing an estimated 49% (Miller et al. 2021). On the African continent, an estimated 60–80% of black carbon emissions comes from sources such as domestic solid fuel combustion (Bond et al. 2013) while on a global scale estimates are that

20% of total BC comes from residential solid fuel combustion, 40% from fossil fuels while biomass burning contributes another estimated 40% (Chiloane et al. 2017). BC is the main pollutant emitted from BB and related activities (Bond et al. 2013; Holanda et al. 2020; Morgan et al. 2020) together with some other trace gases and carbonaceous aerosols (Das et al. 2017) through co-emission (Morgan et al. 2020). Some of the distinct physical properties of BC include its ability to absorb visible light at a cross-section of 5 m^2g-wavelength of 550 mm, is refractory in nature and is also insoluble (Bond et al. 2013; Jacobson 2016) and a very strong sunlight scattering capability (Hodnebrog et al. 2016).

Predominantly the African continent has vast tracks of savanna-grass lands (Chiloane et al. 2017; Wu et al. 2020) which are vulnerable to savanna fires. In West Central Africa both solid fuels and vehicular emissions form part of the dominant sources of BC (Liousse et al. 1997; Oluleye and Folorunsho 2020). Furthermore, BC is key in the formation of atmospheric aerosol particulates (Doumbia et al. 2019; Hodnebrog et al. 2016; Chiloane et al. 2017; Morgan et al. 2020) and is a threat to human health (Landrigan et al. 2018). Also, wildfires around the world have also contributed to the loss of human life (Iyer et al. 2021).

Our study aims to investigate the association between BB, air pollution from BC and planetary health on the Africa continent. A better understanding of air pollution coming from black carbon emissions allows appropriate superior policy formulation across the African continent. The study was also motivated by the need to fill the knowledge gap in Africa where there are very few continental studies focusing on air pollution and planetary health. Our article is composed of five sections; Sect. "Materials and Methods" presents the materials and methods, Sect. "Results" presents the results, Sect. "Discussion" presents the discussion and Sect. "Future Opportunities for Air Quality Policymakers on the African Continent" presents the conclusion and policy implications.

Materials and Methods

GEOS-5 Model-MERRA-2 Reanalysis

To estimate the BC surface mass and surface meteorological conditions the study ran various simulations in the Goddard Earth Observing System (GEOS-5 Model). The GEOS-5 has the capability of estimating and forecasting the atmospheric chemical composition (Keller et al. 2021) and is housed at the NASA Global Modelling and Assimilation Office (GMAO)- Goddard Earth Observing System under a composition forecasting modelling system (Keller et al. 2021). Within the model, several components can make near-real-time simulated forecasts and estimates of several pollutants including ozone (O_3), carbon monoxide (CO), dust, black carbon, nitrogen dioxide (NO_2), sulphur dioxide (SO_2), particulate matter ($PM_{2.5}$) including other meteorological parameters (Keller et al. 2021). Besides, the model provides a global hourly analysis on a horizontal resolution of $25 \times 25km^2$ (Keller et al. 2021). Furthermore, in our study it was key to have an understanding of synoptic conditions, seasonal variations and atmospheric air status as these would assist in accounting for the surface changes in BC over different seasons of the year across the continent (Keller et al. 2021) thus our study also made use of a meteorological component of the model. The meteorological component of the model is anchored around pre-computed analysis which exists within the GEOS-5 system (Keller et al. 2021). The detailed GEOS model architecture is well documented in (Long et al. 2015; Hu et al. 2018; Keller et al. 2021). The GEOS-5 model was evaluated using satellite data from 2018–2019 and has shown mean biases of −0.1 to 0.3 (Keller et al. 2021) and also validated in (Hu et al. 2018). The GEOS-5 model has also been applied in similar studies by (Boys et al. 2014; Das et al. 2017; Gelaro et al. 2017; Haslett et al. 2019; Shah et al. 2020; Keller, Evans, et al., 2021; Wang et al. 2021). Meteorological parameters which were simulated included regional surface temperature patterns which were run using the Modern-Era Retrospective Analysis for Research and Applications Version 2 (MERRA-2) reanalysis data that exist within the GEOS-5 model environment.

MODIS 6 Active Fires

Our study used data derived from the MODerate-resolution Imaging Spectroradiometer (MODIS) 6 sensors which are on-board the Aqua and Terra satellites and have the capability of detecting surface thermal anomalies and fire locations within a 1 km resolution (Mendez-Espinosa et al. 2019; Hareef et al. 2020; Miller et al. 2021). Our current study selected active fires which only had confidence levels of 100% to avoid false alarm fires. A similar approach was adopted in a study by (Mari et al. 2008; Mendez-Espinosa et al. 2019). MODIS products have been used extensively in the identification of active fires including in studies by (Edwards et al. 2006; Roy and Kumar 2017; Mendez-Espinosa et al. 2019; Liu et al. 2021; Miller et al. 2021; Nieman et al. 2021). The MODIS detect fires during the satellites bypass (Roy and Kumar 2017) within a spatial resolution of 1 by 1 km at a nadir of 2 by 4.8 km at the scan edge (Roy and Kumar 2017).

Figure 19.1 shows the active fires according to seasons as picked by the MODIS. The study noted that during DJF the frequency of active fires was high within the Southern Hemisphere in countries such as Angola, the Democratic Republic of Congo (DRC), Zambia, South Africa, Malawi while in West, Central and Northern Africa the active fires frequency was observed to be low. Over Southern Africa, this coincides with the summer season which is also characterised by field fires as farmers prepare their land for the cropping season. Besides this season is also characterised by a lot of natural fires as a result of increased lighting incidences. On the other hand, the season MAM is characterised by low active fire frequency except for countries in the West-Central African region for example The Gambia, Guinea Bissau, Guinea and Sierra Lione, Sudan and South Sudan. The same pattern of fire frequency was also observed during the June, July and August (JJA) season in the West-Central region though at

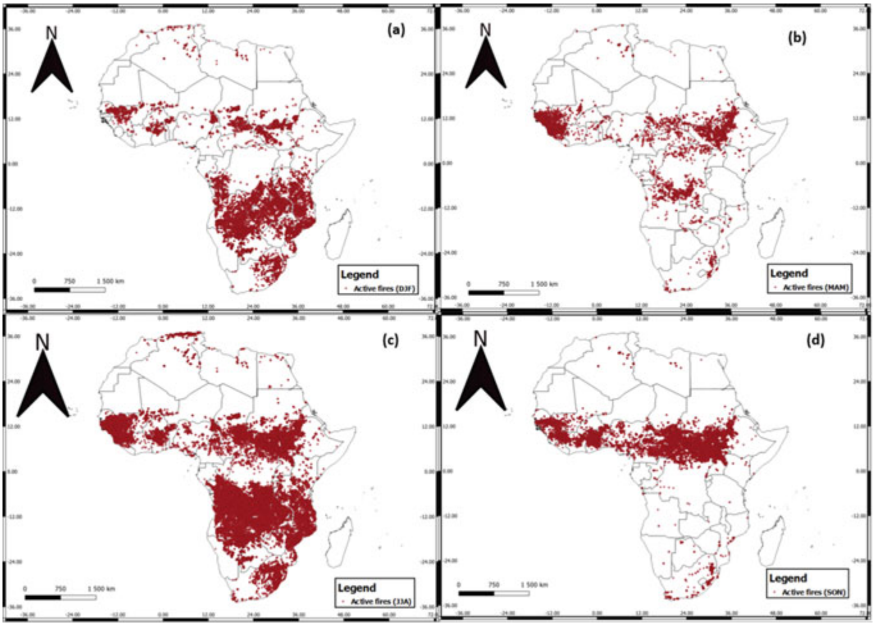

Fig. 19.1 Seasonal spatial distribution of active fires as detected from MODIS **a** December, January and February 2019 (DJF) **b** March, April and May 2020 (MAM) **c** June, July August 2020 (JJA) **d** September, October and November 2020 (SON)

an increased intensity. Also, in the Southern region, the fire intensity increased with the onset of the cold season which demands more space heating. As the transition was made to SON season there is a marked decrease in the frequency of fires for both the Southern and Northern region while active fire frequency increases in the West-Central region.

Results

Our study presents the results the variability of black carbon surface mass over Africa which was conducted within the GEOS-5 model environment supplemented by MODIS 6 Active Fire. The lack of surface air quality monitoring stations on the continent (Pino-Cortés et al. 2021) presented an opportunity for our study to use models and satellite-derived data.

Figure 19.2 highlights the estimated seasonal temperature variations at 2-m levels across the continent. As the seasons alternate during DJF, the southern part of the continent was characterised by high temperatures of between 15 and 30 °C while the Northern hemisphere was characterised by low temperatures of between −5 to 5 C for such countries as Morocco, Algeria, Tunisia and Libya. As the season

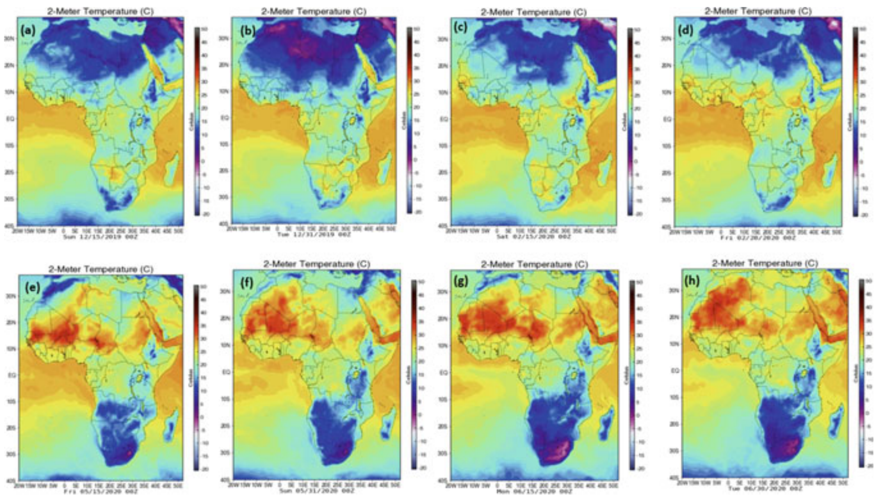

Fig. 19.2 2-m level temperature (**a**–**b**) December 2019 (**c**–**d**) February 2020 (**e**–**f**) May 2020 (**g**–**h**) June 2020

JJA approaches the Southern region is characterised by colder temperatures ranging between −5 to 10 °C with the coldest countries being the interior region of South African Highveld and the Lesotho highlands which calls for supplementary space heating within indoor environments.

Figure 19.3 illustrates a continued illustration of seasonal temperature variations.

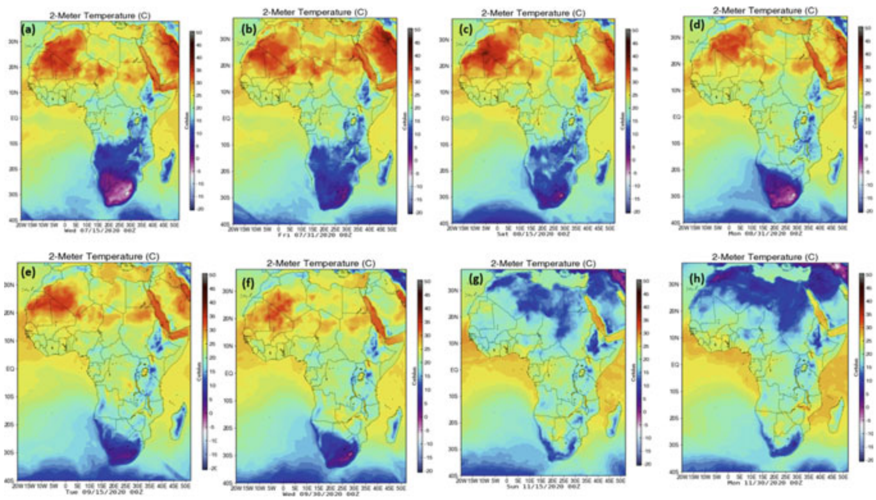

Fig. 19.3 2-m level temperature (**a**–**b**) July 2020 (**c**–**d**) August 2020 (**e**–**f**) September 2020 (**g**–**h**) November 2020

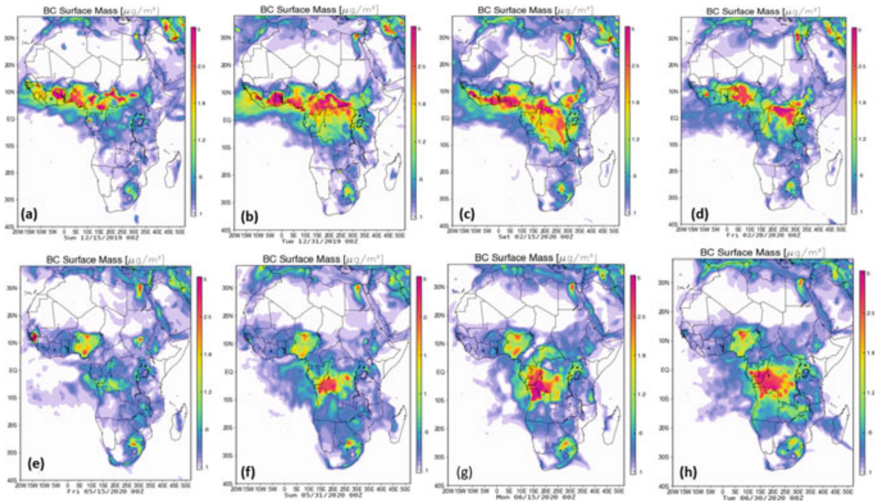

Fig. 19.4 Estimated black carbon surface mass (**a**–**b**) December 2019 (**c**–**d**) February 2020 (**e**–**f**) May 2020 (**g**–**h**) June 2020

Figure 19.3a–d shows that the temperatures in the Southern Hemisphere remained low while in the Northern Hemisphere the temperatures began to rise. On the other hand, as seasons transition the Southern region's temperatures start to increase during the months of SON.

Figure 19.4 highlights the estimated BC surface mass concentrations during different seasons. During DJF high mass concentrations were observed in the West Central region of the continent particularly in Nigeria, Cameroon, the Central African Republic as well as the Democratic Republic of Congo. As the months May -June approach there is a notable increase in the Southern region coinciding with the winter season which also comes with a lot of space burning activities from solid fuels for example wood/coal. Of note, the study established that during December the hot spots were around South Western regions in West Africa. In Ghana, Accra and regions around the Cape Coast recorded an estimated BC surface mass of 5 $\mu g/m^3$ while in Nigeria Lagos recorded an estimated 2 $\mu g/m^3$. Meanwhile in the Southern Africa region South Africa Johannesburg recorded 1.2 $\mu g/m^3$ while the South Western Region of the Democratic Republic of Congo (Kinshasa, Mbanza Ngungu) recorded an estimated 2.0 $\mu g/m^3$. In May, the South West region of Nigeria (Lagos) recorded an estimated 1.5 $\mu g/m^3$ while in Ghana <1 $\mu g/m^3$. On the other hand, in June, the BC surface mass started to increase with the DRC recording an estimated 4 $\mu g/m^3$ $\mu g/m^3$ while South Africa (Johannesburg) recorded an estimated 1.1 $\mu g/m^3$ and Zambia recorded an estimated 1.2 $\mu g/m^3$.

Figure 19.5 illustrates a continuation of Fig. 19.4 with the surface concentrations increasing southwards with a notable peak in the month of August (Fig. 19.5c) Democratic Republic of Congo, Zambia, and Angola and another peak in September (Fig. 19.5e) in counties such as the Democratic Republic of Congo, Angola, Zambia

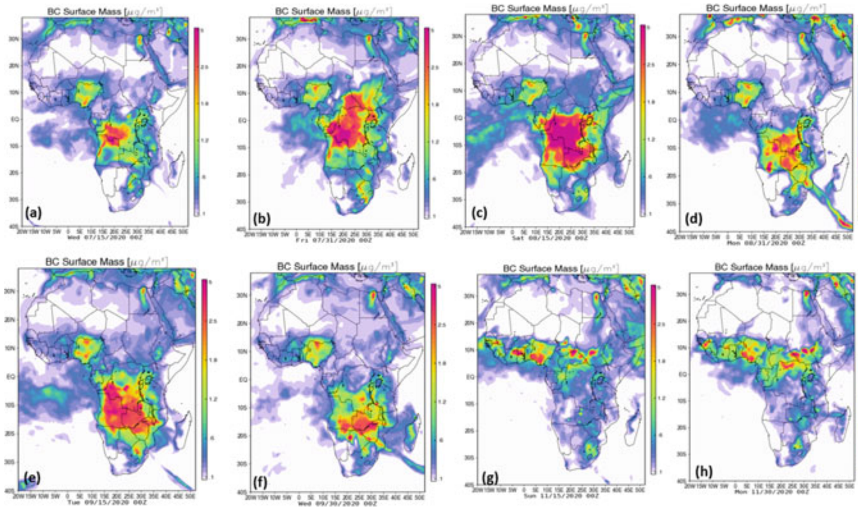

Fig. 19.5 Estimated Black Carbon surface mass (**a**–**b**) July 2020 (**c**–**d**) August 2020 (**e**–**f**) September 2020 (**g**–**h**) November 2020

and Zimbabwe. As seasons transition into SON there is a notable decrease in the Southern region with a slight increase in concentrations towards the West central region (Fig. 19.5g, h) particularly countries Nigeria, Cameroon, Central African Republic as well as South Sudan. In July, Nigeria recorded an estimated 1.2 μg/m^3 while the DRC recorded an estimated 5 μg/m^3 and the same trend continued during August while the surface mass estimates for Zambia increased to 4 μg/m^3. During SON the highest surface mass concentrations were recorded over Angola, Zambia at an estimated 4.5 μg/m^3 and 4.2 μg/m^3 respectively. Meanwhile northern part of Zimbabwe also saw a peak at an estimated 2.6 μg/m^3. In the central-western Africa region, the surface mass concentrations started increasing over the Central African Republic which recorded an estimated 2.0 μg/m^3 while Sudan and Nigeria recorded an estimated 1.8 μg/m^3 respectively.

Discussion

The current study investigated the association between BB, BC emissions and planetary health across the continent of Africa. Simulations were done within the GEOS-5 model, a model with the capability to estimate global atmospheric air pollution at a horizontal resolution of $25 \times 25\text{km}^2$. The GEOS-5 model estimates were augmented with active fire counts which were obtained from MODIS both Aqua and Terra satellites day and night. The active fires are a source of BB over the continent of Africa (Liousse et al. 1997). Our BC simulations indicated seasonality to the spatial surface mass concentrations across the continent. Winter (JJA) for both hemispheres was characterised by BC concentrations particularly hot spot countries which were identified as Ghana, Nigeria, Cote d Ivoire, DRC, Angola, Zambia, South Africa and Zimbabwe. The increase in BC surface mass concentrations also coincided with an increase in the frequency of active fires detected by the MODIS (Fig. 19.1c). The peak estimated surface mass concentrations were estimated at 5 $\mu g/m^3$ in the DRC while Zambia recorded an estimated 4 $\mu g/m^3$ as this constitutes the BB season from June to September (Tummon et al. 2010; Hodnebrog et al. 2016; Wu et al. 2020).

Furthermore, our study findings are similar to findings by (Miller et al. 2021) who also established that during this period there is an increase in BB moreso in central Africa which normally ends in October. For DRC the same trend was observed for the months starting from July, August and September. This DRC trend can be linked to extensive fires which are burnt across the rain forest by farmers clearing land for farming purposes (Tummon et al. 2010) as well as mining activities. In Angola, Zambia and Zimbabwe, the winter season is cold and most communities still rely on solid fuels particularly wood and coal for space heating purposes as well as increased wildfires that increase in frequency during the dry winter season in the Southern Hemisphere (Chiloane et al. 2017). South Africa was also observed to continuously have low to high levels of surface BC, particularly in Johannesburg. This can be attributed to the high number of thermal power stations which are located on the Highveld. On the other hand in Nigeria and Ghana the other two countries recorded high BC surface mass concentrations this can be attributed to the high number of crude oil refineries that are there in the region which emit a lot of BC as a result of incomplete combustion. Besides, Nigeria is also densely populated with a high car population which also contributes to the BC load. Similarly, this was also established in (Doumbia et al. 2019) who observed an increase in BC concentrations during the season from November to April. The same study also attributed the elevated BC levels to long-range north-easterly winds.

During the season DJF the study observed high surface mass concentrations over the Western Africa region particularly Ghana and Nigeria as well as Cote d Ivoire. The regions which were observed to record high BC surface concentrations included the South Western zones of the mentioned countries for example Accra, Lagos and Abidjan for Cote d Ivoire as well as other coastal regions (Oluleye and Folorunsho 2020). This region is awash with several oil fields and oil refineries which are sources of BC (Oluleye and Folorunsho 2020). Our study findings are similar to findings by (Brito et al. 2018; Oluleye and Folorunsho 2020) who established that the whole coastal stretch from Niger Delta, Accra Ghana to Sierra Leone is affected by elevated levels of BC surface mass concentrations particularly the coastal atmospheric region. The high concentrations can also be attributed to the extensive use of solid fuels which exist in the region. Our study however also noted that besides the season the Western-Central Africa region is dominated by high levels of BC as anthropogenic BB takes place across all seasons (Liousse et al. 1997; Rushingabigwi et al. 2020).

The study also observed the influence of temperature on the fire frequency activities for example the study noted that over the Southern African region the colder weather brought an increase in the frequency of active fires identified particularly in the DRC, Angola, Zambia, Zimbabwe and South Africa. The same however was not observed for Northern Africa where the study did not obverse an increase in active fires identified.

Our study had limitations in that the study was based on modelling and satellite-derived only without in-situ surface measurements though this was mitigated by the fact that the GEOS-5 products, MERRA-2 and MODIS have been validated in several studies including but not limited to (Roy and Kumar 2017; Haslett et al. 2019; Shah et al. 2020; Miller et al. 2021; Vetrita et al. 2021). The other limitation was that the continent is so vast that only those regions with which showed elevated BC loads were evaluated. Future studies will therefore do country-focused investigations that can better inform air pollution policy formulation and the probable impact on planetary health.

Future Opportunities for Air Quality Policymakers on the African Continent

The challenge of BC air pollution across African profers air quality policymakers with an opportunity to make forward-looking policy frameworks that embrace clean green energy. A migration from thermal electricity generation is needed as a way to reduce the emission of GHGs that is causing destabilising effects on the climate. Green energy can be achieved through investing in solar-based generating systems as well as household level-based interventions. At the household level, this can imply substituting solid fuels with less BC emitting fuels for example Liquified Petroleum Gas (LPG). Another opportunity lies in shifting agricultural practices to those that reduce the amount of BB that takes place during land preparation and post-harvest activities. This can be also be complemented through community awareness to encourage buy-in from farmers to cut on BB based land preparation.

The same can be done for behaviour change regarding open waste burning which can be changed through community-based awareness campaigns as well as improving waste management practices that can consequently reduce BC emitted from open waste burning. Community awareness can also positively influence against starting unnecessary veld fires. Furthermore, other policies which can also assist in reducing vehicular based emissions include phasing off old vehicles beyond certain ages. This can also be complemented by setting air quality monitoring networks and vehicular testing mechanisms.

Conclusion

The current study investigated the linkages between BB activities, BC emissions and planetary health. Our study established that BB activities are seasonally inclined across the continent with the highest frequency being recorded during winter space heating seasons. For future studies, we will investigate country-specific BB activities and BC load contributions. Our study makes the following conclusions:

- Over the West African belt Nigeria, Ghana, Central Africa Republic, Cote d Ivoire, Cameroon, the Gambia, Guinea were estimated to have high BC loads.
- Over the Central Africa region, the Democratic Republic of Congo was estimated to have a high BC load while in north Africa Algeria was identified as having a high BC load.
- In the Southern Africa region countries with high BC loads were identified as Angola, Zambia, South Africa and to a lesser extent Zimbabwe.
- To improve planetary health there is a need to curb BB activities that will in-turn improve the quality of air as well as reduce the burden of disease and the destabilisation effects on natural systems and a threat to planetary health.

Acknowledgements The authors acknowledge the Centre for Climate Change Adaptation and Resilience, Kgotso Development Trust, Zimbabwe and the North-West University, South Africa for availing facilities and material resources to conduct the study. We also would like to acknowledge the Air Resources Laboratory of the National Oceanic and Atmospheric Administration (NOAA) for the Climatic Data. Furthermore, we would like to acknowledge NASA through the National Aeronautics and Space Administration Goddard Space Flight Centre as well as NOAA-ESRL Physical Sciences Laboratory, Boulder Colorado for the provision of NCEP/NCAR reanalysis data and images used in the study. Furthermore, we acknowledge the NASA Global Modelling and Assimilation Office (GMAO)- Goddard Earth Observing System for GEOS-5 Model and MERRA-2 data.

Authors Contribution Statement Newton. R. Matandirotya-Conceptualisation, Writing original draft, methodology and formal analysis, final draft.

Roelof Burger-Conceptualisation, writing original draft, methodology and final draft.

Funding The study did not receive any funding.

Declaration of Competing Interest The authors declare that they have no known competing interests or personal association or relationships that could have influenced the direction of the study.

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Chapter 20
Climate Change and the Increase of Extreme Events in Azores

Fernanda R. S. Carvalho, Maria G. Meirelles, Diamantino V. Henriques, Patrícia V. Navarro, and Helena C. Vasconcelos

Abstract Our atmosphere is no longer the same: since September 2016, the background concentration of CO_2 in the Azores atmosphere has always been above 400 ppm(v). The results of recent forecasts of various climate models, indicating an increase in air temperature and a decrease in precipitation amount, are also clear in relation to the increase in extreme events in the Azores region. For example, and in the most pessimistic scenario of radiative forcing, it is estimated by the end of 2100 that the length of drought periods will increase by almost 5 days, the events of heavy precipitation by more than 1 day and tropical nights by more than 100 days. These results may be explained by the intensification of the North Atlantic subtropical anticyclone in the Azores region, especially west of the British Isles. This work presents the trends of air temperature and precipitation based on the reanalysis of the ERA5 project, as well as the projections and changes for the end of the century; projections for some climatic extremes were also analyzed and variations for the end of the century were estimated with reference to the most recent period.

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Introduction

Today we know that the Earth's climate has not always been the same and has undergone significant changes over hundreds of thousands of years (Graedel and Crutzen 1993). These changes have had natural causes, some of them due to changes in the chemical composition of the atmosphere (Seinfeld and Pandis 1998). In fact, the Earth's atmosphere is a subsystem of the Climate System, the balance of which is being altered by the increase in the concentration of greenhouse gases of fossil origin. Climate change has a global character, but with different impacts at regional and local scales. Increasing the concentration of CO_2 and other gases capable of absorbing long wavelength radiation emitted from the surface, i.e. with a positive contribution to the atmospheric greenhouse effect, disrupts the initial balance. This disturbance has repercussions on the processes of internal self-regulation and instability with various consequences, such as the hydrological cycle. Thus, we can think of global warming as the main evidence of climate change resulting from the increase of CO_2 in the atmosphere. And the increase in air temperature has in turn direct impacts on the hydrosphere (increase in mean sea level, acidification of the oceans, etc.), the cryosphere (melting of polar ice caps, glaciers, decrease in albedo, etc.), the lithosphere (decrease in permafrost, release of CH_4, increase in surface area without ice, etc.) and the biosphere (extinction of species, etc.).

In the strict sense, Climate is usually referred to as average meteorological weather or more precisely, the statistical description of a set of instantaneous states of the atmosphere, characterized by mean values and variance of relevant quantities (temperature, precipitation, wind, etc.), covering periods from a few months to billions of years (Cubasch et al. 2013). In a broad sense, Climate is the state, including its statistical description, of the Climate System as the meeting of the subsystems Atmosphere, Hydrosphere, Cryosphere, Lithosphere and Biosphere (Peixoto and Oort 1992). Climate is primarily shaped by external factors—astronomical, regional and local—which include solar radiation and the sphericity of the globe, distance to the ocean, relief and the nature of the surface. However, there are still internal factors associated with the intrinsic properties of the atmosphere of which are examples, the composition of the atmosphere, the general circulation and the frontal systems. Here, the concept of Climate Variability emerges, which refers to variations in the mean state and other climate statistics at all spatial and temporal scales in addition to meteorological phenomena. Variability may be due to natural internal processes or natural or anthropogenic external forces.

In accordance with Article 1 of the United *Nations Framework Convention on Climate Change* (UNFCCC), a Climate Change (CA) is one that is directly or indirectly attributed to human activity by altering the chemical composition of the global atmosphere and which overrides the natural variability observed in comparable periods (UNFCC 1992). And the UNFCCC makes a distinction between Climate Change, attributed to human activity that changes the composition of the global atmosphere and Climate Variability attributed to natural causes. According to the *Fifth Assessment Report* (*AR5*) of the *Intergovernmental Panel on Climate Change*

(*IPCC*), the global temperature of the atmosphere will continue to rise throughout the twenty-first century because of continued emissions of greenhouse gases, most of which are of fossil origin (Cubasch et al. 2013). Measurements of background levels of the atmosphere relative to carbon dioxide (CO_2) indicate a steady increase of this gas at least since 1969.

The Azores are located in the subtropical region of the North Atlantic and are therefore greatly influenced by the North Atlantic Subtropical Anticyclone, also known as the Azores High (Ferreira 1955). Being a system of almost stationary high pressures, its position, intensity, development and orientation determine the nature and characteristics of the air masses that reach the region, as well as the frequency and trajectory of the troughs and lows of the North Atlantic Polar Front which is also an important weather modeling system in the Azores. Maximum value of the average atmospheric pressure occurs in July, since the Azores Anticyclone, centered on the proximity of the archipelago is more intense at this time of the year; on the other hand, since the Azores High is less intense and the depressions are more frequent and dug at the beginning of spring, the minimum value of the average atmospheric pressure at the surface occurs in March. Another aspect that characterizes the weather in the Azores is the proximity of the Gulf Stream, which consists of a sea current of hot water that makes the climate mild in these latitudes. In fact, the temperature of the sea water is of great importance in the Climate of the Azores which, according to the Köppen-Geiger *Climate Classification*, is considered predominantly temperate wet, without dry season, with precipitation in all months of the year and with temperate summer.

Our atmosphere is no longer the same: since September 2016, the background concentration of CO_2 in the atmosphere in the Azores has always been above 400 ppm (v).[1] Figure 20.1 shows the series of molar fraction values of atmospheric CO_2 observed in samples taken at the Mauna Loa Observatory (Hawaii) since 1969 and at Serreta (Terceira/Açores) since 1976. If we can observe the consistency of the two series, it will be interesting to note that the value of 400 ppm(v) was exceeded in Hawaii and in Azores respectively on 14 and 17 September 2016.

To understand the immediate implication of this fact, we will have to know how the transfer of energy in the atmosphere takes place, i.e. consider the Earth's Radiative Balance. And it tells us that 25–30% of the solar energy absorbed by the atmosphere contributes to the heating of the highest layers of the atmosphere (stratosphere) while 70–85% of the earth's radiation is absorbed by the atmosphere, contributing to the heating of the lowest layers of the atmosphere (troposphere). When compared to long wavelength (infrared) radiation, short wavelength radiation is of little relevance to the warming of the troposphere. Under these conditions, the air temperature near the surface is mainly a result of the emission of infrared radiation from the surface and of greenhouse gases. Figure 20.2 shows the series of deviations (anomalies) of observed surface air temperature values from the reference period 1961–1990 for the Azores region, it can be immediately recognised that since the 1970s the surface air

[1] The mole fraction (by volume) of CO_2, indicates the number of moles of CO_2 molecules per mole of air molecules and is expressed in parts per million by volume or ppm(v).

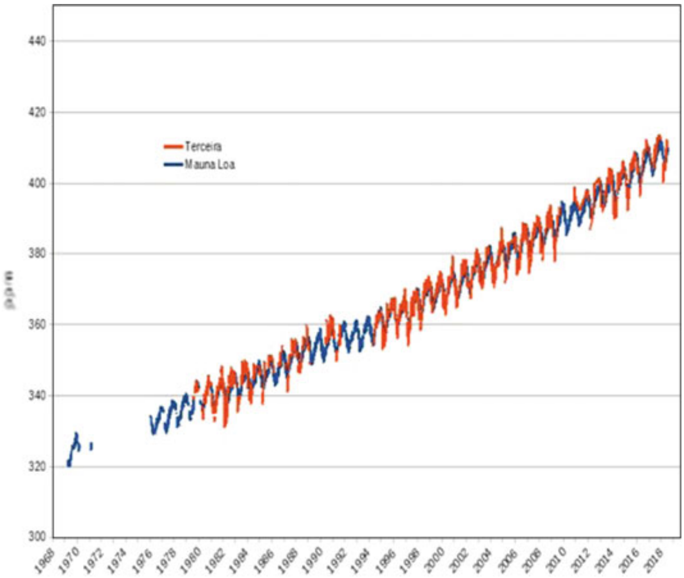

Fig. 20.1 Molar fraction values of atmospheric CO_2 (*source* WDCGG)

Fig. 20.2 Annual average surface air temperature anomalies for the Azores region

temperature has been above the reference value (Meirelles et al. 2019). In the last 30 years, the surface air temperature in the Azores region is about 0.7 ± 0.3 °C higher than 50 years ago and, according to available climate projections, this deviation will be even greater in the coming decades of this century.

The impacts of these changes on Azores should not be as intense as expected for the Portuguese mainland, but nevertheless worrying, given the weaknesses and vulnerabilities of the island regions. And the Azores region has followed the trend on a global scale and, specifically, on a regional scale, in the North Atlantic basin, of rising temperatures: higher temperatures, less rainfall and more intense meteorological phenomena are observed.

The results of the forecasts of several climatic models point to an increase in the average annual temperature in the Azores region between 1 and 3 K until the year 2100. In the case of the most pessimistic scenario, the models show for the Azores a decrease in the average annual precipitation around 9.8 mm / day until the end of the century, compared to the average of the last 30 years.

Small islands like Azores are very fragile ecosystems. Native forests need large amounts of rainwater and humidity to support a high diversity of living organisms (Borges et. al. 2020). For instance, some modelling studies of climate change effects on mosses, vascular plants and native and endemic arthropods show concerning results, with restrictions of survival areas for most of the species (Ferreira et. al. 2016, 2019; Patiño et al. 2016). However, these studies did not include the effects of extreme climate events on small and insulated populations. In addition to the effects on biodiversity, climate extremes also affect the safety and health of populations. Health impacts of climate extremes includes various vector-borne diseases, many enteric illnesses and certain water-related diseases. Worldwide, in 2019, there were 396 disasters that killed 11,755 people, affected 95 million others (Ebi et al. 2021). However, no studies were found so far on the impact of climate extremes in the Azores on human health neither on safety. This work will focus on some climate indicators related to the extreme events more common in the Azores like droughts (number of consecutive days with precipitation less than 1 mm), heavy rain (number of consecutive days with rain greater or equal to 20 mm) and warm periods (annual number of tropical nights).

Methodology

The *General Circulation of the Atmosphere* (*MCGA*) *and Ocean* (*MCGO*) *Models* are based on physical laws that describe the dynamics of the atmosphere and the ocean expressed in the form of mathematical equations. Since these equations are non-linear, they can only be solved numerically using classical mathematical methods and powerful computers. The CMIP coupled general circulation models (Coupled Model Intercomparison Project) constitute a complete representation of the climate system being verified, an evolution towards increasingly complexity (Eyring et al. 2016). Climate models being used for operational purposes in monthly, seasonal, etc. forecasts are also applied as research tools to simulate the climate. But climate models need scenarios that condition their response.

For the projections until the end of the twenty-first century, the results of the CMIP5 project (CMIP phase 5) for the *Representative Concentration Pathways* (RCPs) scenarios were used for the same geographical region —the Azores region between 37–40°N and 32–25°W); the trajectories describe four possible future climate scenarios, which depend on the amount of greenhouse gases that could be emitted in the coming years. The three RCP scenarios used (RCP 2.6, RCP 4.5 and RCP 8.5), correspond to three radiative forcing intervals for the year 2100, relative to the pre-industrial values (+2.6, +4.5 and +8.5 W/m^2, respectively). Most of the climate data and CMIP5 projections used in this work are available free of charge on the portal *Climate Explorer* (https://climexp.knmi.nl/) of the KNMI (*Koninklijk Nederlands Meteorologisch Instituut*).

In this study—for the 1979–2019 observation period and for the Azores region—the *European Center for Medium-Range Weather Forecasts* (ECMWF) reanalysis of the ERA5 project (ECMWF Re-Analyses) were used.

The ERA5 model (Hersbach et al. 2020), through the assimilation of 4D-Var data from the ECMWF Integrated Forecasting System (IFS) with 137 vertical pressure levels, provides atmospheric data at these levels. Surface data are also available, containing 2D parameters such as precipitation, 2 m temperature, radiation at the top of the atmosphere and other quantities vertically integrated into the whole atmosphere. The IFS is coupled with a soil model (surface parameters) and an ocean wave model. The ERA5 data set contains an hourly resolution of 31 km.

CMIP5 projections and ERA5 reanalyses are available for air temperature and precipitation extremes. The annual extreme indices selected for this study were: máximum number of consecutive days with precipitation less than 1 mm, number of days with rain greater or equal than 20 mm and number of tropical nights (daily minimum temperature greater than 20 °C).

Results

The results presented refer to the Azores region between 37–40°N and 32–25°W. For this region, the deviations of air surface temperature, average annual precipitation and also climate extremes were calculated for the maximum number of consecutive days with precipitation <1 mm, ≥20 mm and number of tropical nights of the ERA5 series of reviews in the period 1979–2019 with reference to 1961–1990 (Carvalho 2020). Projections up to 2100 and according to the RCP scenarios 2.6, 4.5 and 8.5 were also estimated for the mentioned indices. Finally, variations were estimated for the end of the century (2071–2100) with reference to the most recent situation of 1991–2020 (Carvalho 2020).

Surface Air Temperature

The anomaly of the average annual surface air temperature in the Azores region and in the period 1979–2019 shows a positive trend of 0.16 K/decade (Fig. 20.3); On the other hand, the averages of the forecasts of various models point to an annual average temperature increase in this region of between 1 and 3 K by the year 2100, with reference to the period 1961–1990 (Fig. 20.3).

In the graph of Fig. 20.4 it is possible to visualize the expected variation of the average surface air temperature for the period 2071–2100 compared to the period 1991–2020 and according to the RCP 4.5 scenario which estimates an average

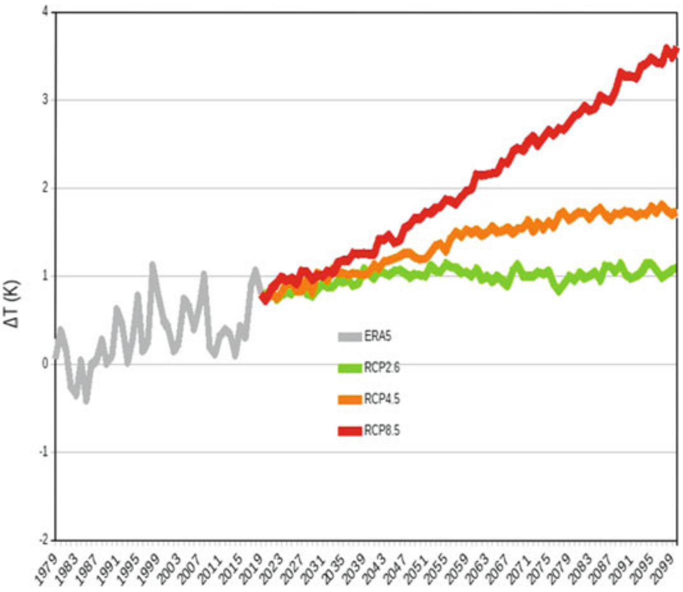

Fig. 20.3 Average annual surface air temperature anomaly for the Azores region

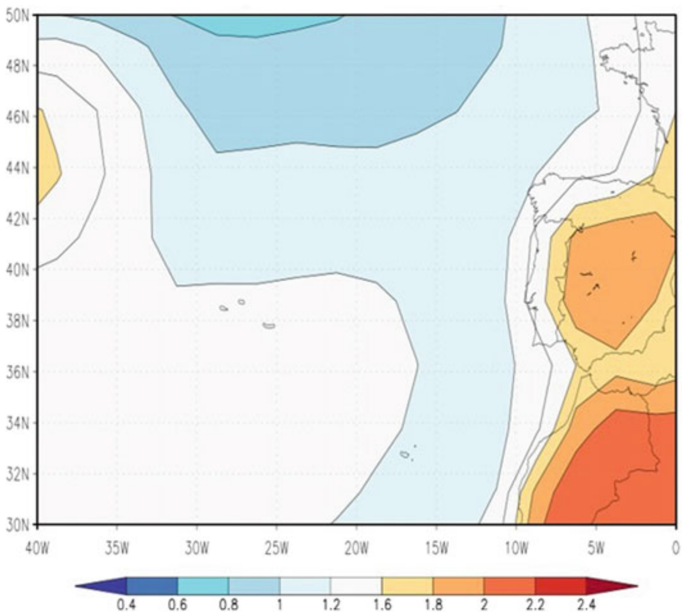

Fig. 20.4 Expected variation of the average surface air temperature (K) to the end of the century XXI

increase of 1.2 K for the Azores region. By comparison, the high figures for the Iberian Peninsula and North Africa can be observed; in both continental regions, this increase is enhanced by the distance to the ocean.

Average Annual Precipitation

The average annual rainfall anomaly for the Azores for the period 1979–2019 was calculated and their projections up to 2100 were estimated according to the RCP scenarios (Fig. 20.5). In this case, although the re-analyses do not show a statistically significant trend, the average variation calculated for the three scenarios for annual rainfall is −7.8 mm; in the case of the most pessimistic scenario (RCP 8.5), the models show for the Azores a decrease in average annual rainfall of about 9.8 mm/day by the end of the century, compared to the average of the last 30 years.

Figure 20.6 shows the expected relative variation in the amount of average annual rainfall for the end of the twenty-first century (2071–2100) compared to 1991–2020, according to the RCP4.5 scenario. There is a decrease from northwest to southwest in the region considered, affecting especially the islands of the central and eastern groups; however, its expression is particularly severe in the south of the Iberian Peninsula, Madeira, the Canaries and North Africa.

The effects of global warming on the evolution and distribution of precipitation are not evident. A warmer atmosphere is capable of retaining more water vapor

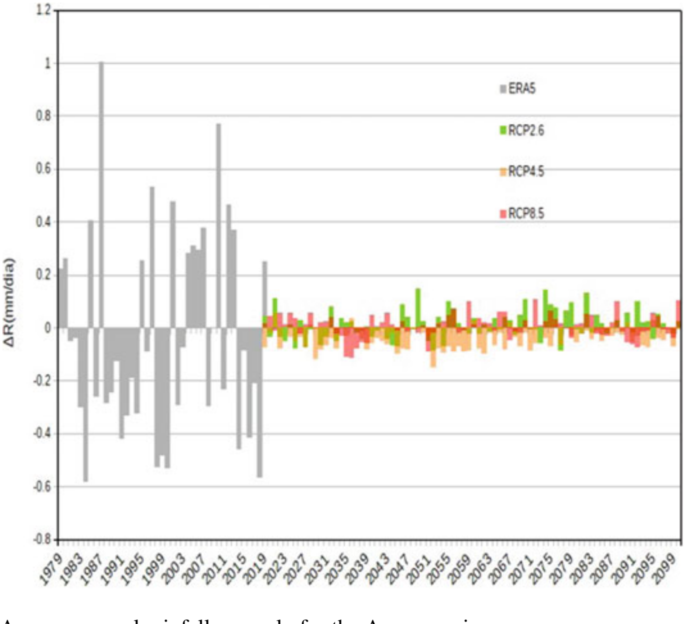

Fig. 20.5 Average annual rainfall anomaly for the Azores region

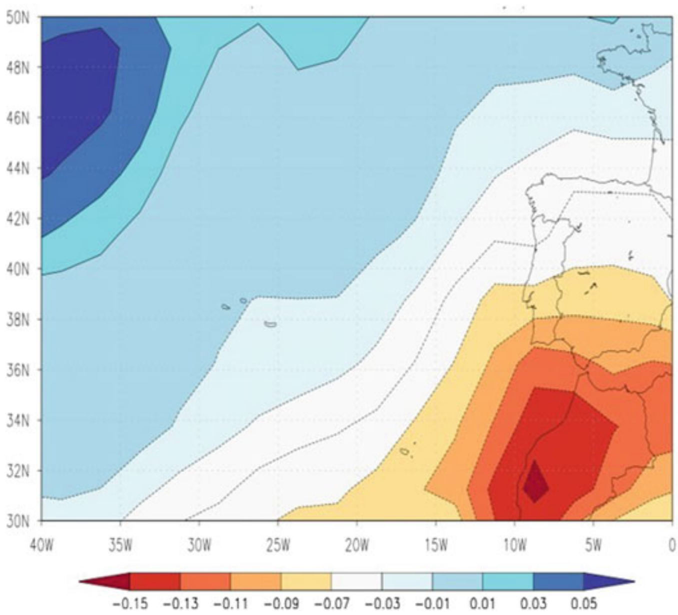

Fig. 20.6 Expected relative variation in average annual rainfall towards the end of the twenty-first century

according to Clausius-Clapeyron's law. Since an increase in evaporation and hence in the amount of water vapor in the atmosphere is expected, it is not clear that this will result in increased precipitation. The evaporation and precipitation processes are very complex and the most advanced models still use parameterizations or rough representations to solve these mechanisms in the atmosphere.

Annual maximum number of Consecutive Days with Precipitation <1 MM

Figure 20.7 shows deviations from the annual maximum number of consecutive days with daily rainfall <1 mm in the 1979–2019 observation period and estimated projections up to 2100 according to the RCP scenarios. The graph shows that both RCP scenarios 4.5 and 8.5 indicate positive deviations; in RCP 2.6 the situation is unclear, indicating an increase in drought periods until around 2040 and a decrease towards the end of this century. The calculation results for the average of the models an increase in the maximum number of consecutive days with low rainfall (<1 mm) from +0.2 to 4.8 days/year until the year 2100.

Figure 20.8 shows the expected relative variation in the annual maximum number of consecutive days with daily rainfall <1 mm for the end of the twenty-first century

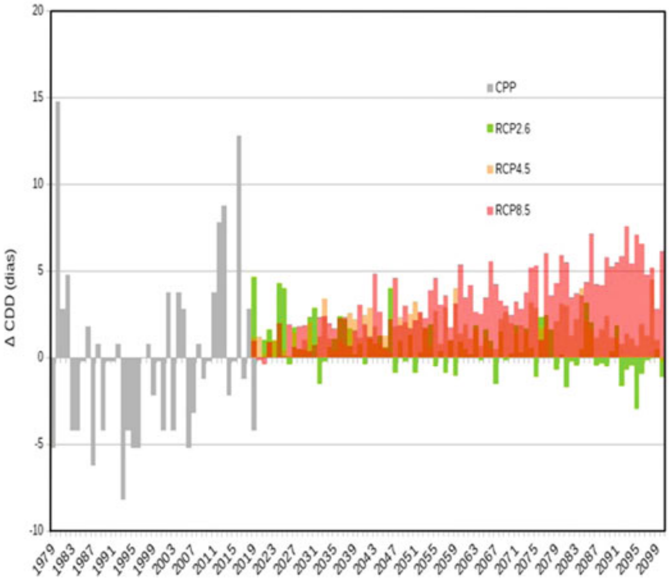

Fig. 20.7 Annual maximum number of consecutive days with rainfall anomaly <1 mm

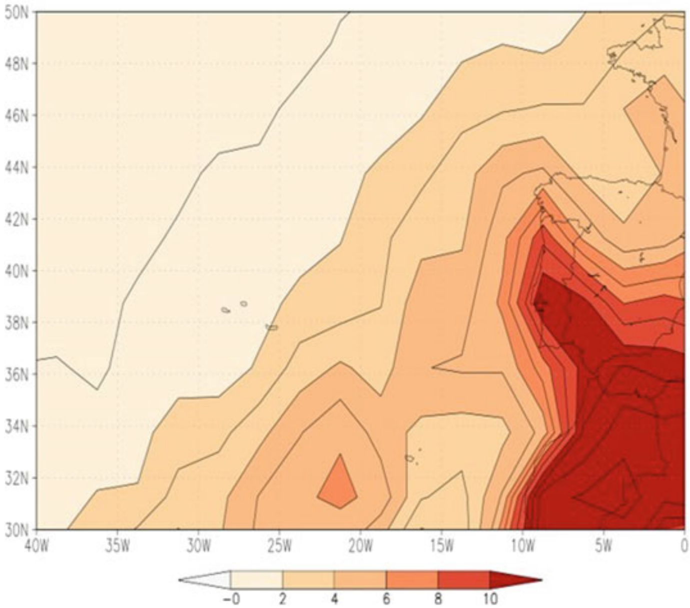

Fig. 20.8 Variation in annual number consecutive of days with daily rainfall <1 mm at the end of the twenty-first century

(2071–2100) compared to the period 1991–2020 and according to the RCP 4.5 scenario, where an average increase of 1.7 days/year is estimated. Again, the forecast of increased drought periods will affect the central and eastern groups the most.

Annual number of Days with Rain ≥20 MM

Figure 20.9 shows deviations from the annual number of days with daily rainfall ≥20 mm in the 1979–2019 observation period and estimates its projections up to 2100 and according to the RCP scenarios. In this case, the projections indicate for the annual number of days with heavy rainfall (≥20 mm) an increase of +0.6 to 1.4 days/year until the year 2100. It can also be observed that the models generally show positive deviations throughout the period.

Figure 20.10 shows the expected relative variation in the annual number of days with daily rainfall ≥20 mm for the end of the twenty-first century (2071–2100) compared to the period 1991–2020 and according to the RCP 4.5 scenario, with an average increase estimated between 1 and 15%.

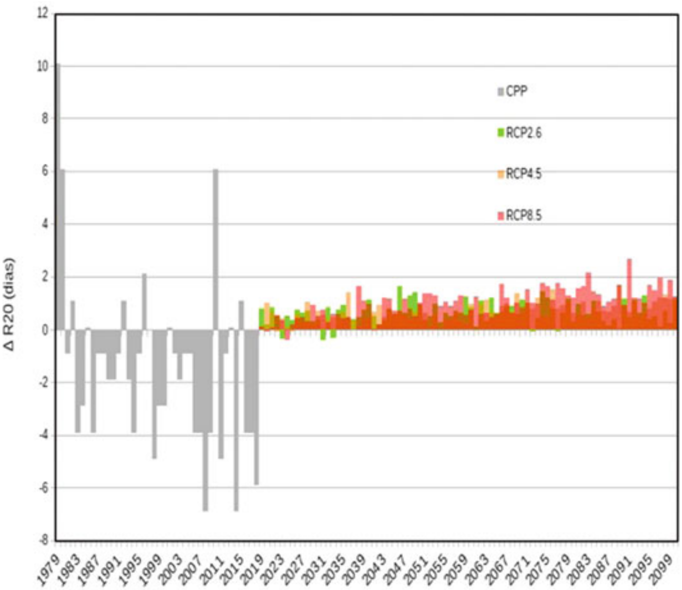

Fig. 20.9 Anomaly of the annual number of days with precipitation ≥20 mm

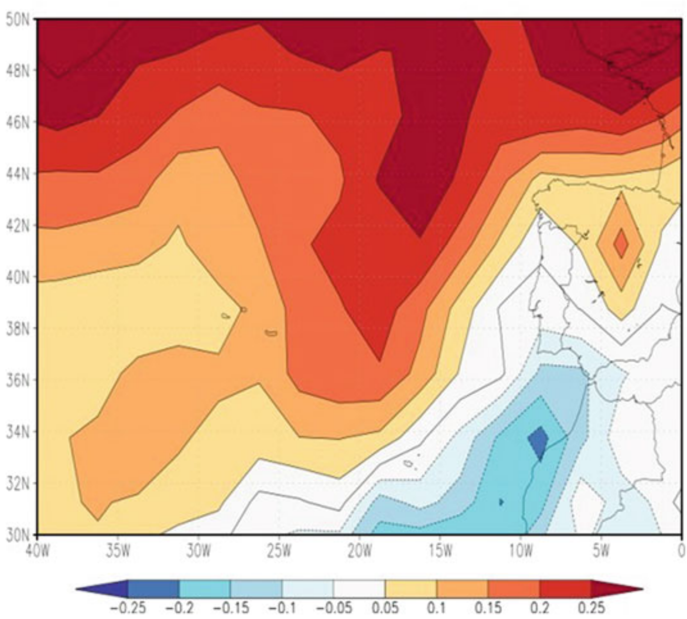

Fig. 20.10 Relative change in annual number of days with rainfall ≥20 at the end of the twenty-first century

Annual Number of Tropical Nights

Figure 20.11 shows the deviations from the number of tropical nights (Minimum >20 °C) in the 1979–2019 observation period and estimates their projections up to 2100 according to the RCP scenarios which indicate an increase of +38 to 101 days/year up to the year 2100.

Figure 20.12 shows the expected variation in the annual number of tropical nights by the end of the twenty-first century (2071–2100) relative to the period 1991–2020, according to the RCP 4.5 scenario, from which an average increase of 45.3 nights/year is estimated.

Intensification of the Azores High

The intensification of the North Atlantic Subtropical Anticyclone (Fig. 20.13) in the Azores region (~1 hPa) and especially to the west of the British Isles (~1.5 hPa) corresponds to a reconfiguration of synoptic scale systems that is consistent with the most significant aspects arising from the current CA. The decrease in wind speed in this region of the Atlantic, as well as the increase in solar radiation at the surface due to the expansion of the subtropical anticyclone to the northernmost latitudes,

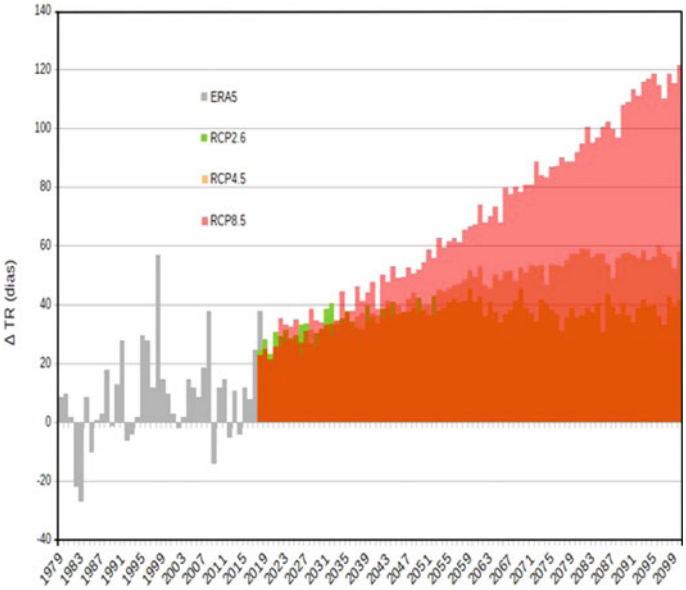

Fig. 20.11 Anomaly of the number of tropical nights

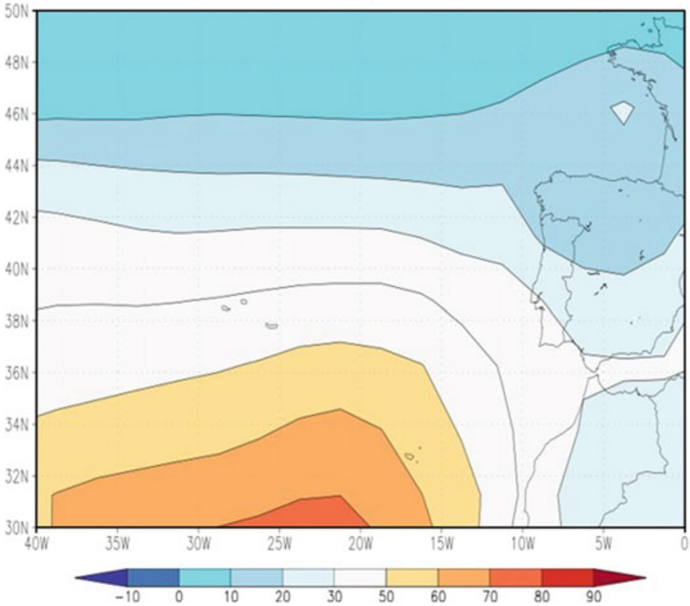

Fig. 20.12 Expected annual number of tropical nights at the end of the twenty-first century

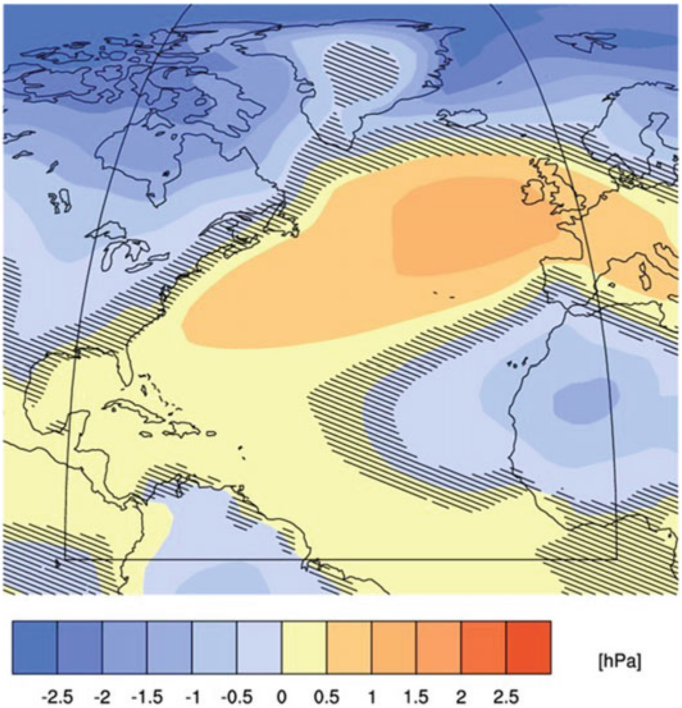

Fig. 20.13 Intensification of the Azores high

pushing the jet stream northward and consequently the polar front, could be a clear signal of a large scale regarding the change in the haze pattern in this region, and is also consistent with the decrease in precipitation projected for the end of the century in the RCP 8.5 scenario.

Discussion

One of the consequences of global warming is the change in weather extremes frequency. To evaluate this impact in the Azores region, CMIP5 projections for three annual extreme indices were retrieved for three RCP scenarios (2.6, 4.5 and 8.5) for the Azores region. The annual indices were chosen in order to analyse extreme meteorological situations like meteorological drought periods (number of consecutive days with precipitation less than 1 mm), heavy rain days (number of days with precipitation greater 20 mm) and warm periods (number of tropical days, i.e. minimum temperature greater than 20 °C).

All CMIP5 projections for the Azores show average surface air temperature increase for scenarios above RCP 2.6 until 2100, specially for scenario RCP 8.5.

Average annual precipitation shows a light reduction, but without a statistically significant trend.

Maximum number of consecutive days with daily rainfall less than 1 mm show positive trends for RCP 4.5 and 8.5, with almost more 5 days (RCP 8.5) by the end of the century. By the other hand, annual number of days with daily rainfall greater or equal than 20 mm shows also positive trends for all scenarios, with almost 15% longer periods. These results suggest that longer drought periods could balance longer heavy rainfall periods. This is consistent with Clausius-Clapeyron's law, i.e. an atmosphere can hold more water vapour in warmer scenario, drying the surfaces but also can cause more heavy rain events.

Orographic rain is a very important way of precipitation in some Azorian islands and therefore heavy rain episodes should enhance in islands with higher mountains. By the other hand, flatter islands (ex. S. Maria and Graciosa) can have longer drought periods. Thus, topographic differences can lead to enhanced differences in precipitation extremes between islands, leading to disruptive effects in vulnerable systems like Azores.

Number of tropical nights (daily minimum air temperature greater than 20 °C) will increase in all the RCP scenarios. However, RCP 2.6 and 4.5 scenarios show a stabilization of about 40 and 45 respectively before the end of 2100 while RCP 8.5 continue to increase to more than 100 days. This result is very relevant when compared with continental territories.

The strengthening of North Atlantic Subtropical Anticyclone, one of the main underlying drivers of Azores climate, will lead to a reconfiguration of synoptic scale systems, with a weakening of winds, reducing cloudiness and an increasing in solar radiation at the surface. The expansion of the subtropical anticyclone to the northernmost latitudes, should push the jet stream northward and consequently the polar front, decreasing large scale precipitation at subtropical belt.

CMIP5 projections reflects changes in large scale features and therefore, these results only show the trends of these changes in the Azores region. Smaller scale changes related to local factors like orography are not considered in this work. On the other hand, CMIP5 results are the average of a set of individual model projections and therefore the amplitudes of year-to-year changes are smoothed. Therefore, while trends are useful for the assessment of the local changes, some caution must be taken with individual years when applying to a specific place or location.

Positive trends on the length of the drought periods can impact native and endemic species while positive trends on heavy rain events can impact the safety of populations. Positive trends of tropical nights can impact cause-specific mortality (Margolis, 2014; Royé et al. 2021).

Conclusions

Extreme weather events increase due to Climate Change around the world and the Azores are no exception. Impacts on human and planetary health are also expected.

The survival areas of some native and endemic species may also be threatened by climate change.

The average results from a set of Coupled General Circulation Models for three selected RCP scenarios were used to assess trends in three selected annual indicators, related to extreme events: maximum number of consecutive days with precipitation less than 1 mm, number of days with precipitation greater than 20 mm and number of tropical nights.

These indices show significant trends in the Azores region, worsening as the radiative forcing of greenhouse gases increases. Although annual precipitation does not show significant trends, the number of dry and rainy days increases, suggesting a change in the distribution of annual precipitation, consistent with the physical dependence of saturated water vapor pressure on temperature.

Perhaps, the most significant result is the increase of tropical nights of +38 to 101 days/year up to the year 2100. This result shows the need to evaluate the relationship of the cause-specific mortality with hot nights.

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Chapter 21
Understanding and Handling Zoonoses

Walter Leal Filho, Marta May, and Julia May

Abstract This paper provides an outline of zoonoses, explaining their characteristics and features. It also explores the relationships between climate change and zoonoses, outlining some of the measures needed to address the problem.

Zoonoses: A Definition

> The significance of zoonoses in the emergence of human infections cannot be overstated.
> Institute of Medicine, Emerging Infections: Microbial Threats to Health in the United States, 1992.

Zoonoses constitute a major public health issue (WHO 2020). According to the definition of the first report of the Joint WHO/FAO Expert Group on zoonoses released in 1951, zoonoses refer to "diseases and infections which are naturally transmitted between vertebrate animals and humans" (Joint WHO/FAO Expert Group on Zoonoses, World Health Organization & Food and Agriculture Organization of the United Nations 1951). In addition, zoonotic pathogens can be classified into the following categories: bacterial, viral, or parasitic (WHO 2020). However, zoonotic diseases can occur due to fungi as well (CDC 2021).

The range of human activities that disturb planetary biophysical systems include:

- Ocean acidification (Absorption of atmospheric CO_2).
- Land use change (Amount of remaining forests)
- Nitrogen and Phosphorus load (Amount of fertilizer use)
- Depletion of the ozone layer in the stratosphere.
- Climate change (increase in greenhouse gases).
- Loss of biodiversity (genetic diversity).
- Toxic chemical pollution (Chemicals in medicine, agriculture)
- Reduction of drinking water (Depletion of non-renewable reservoirs).

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_21

In some areas, such as land-use changes, climate change, and losses of biodiversity, an association with zoonoses is seen.

Zoonoses can be transmitted mainly via direct or indirect contact between the animal source and the (human) host. The first category means to come in contact with body fluids, especially through blood, saliva as well as physical contact with an infected animal. When it comes to indirect contact, previously contaminated surfaces, plants or soil can be considered the main sources of zoonotic infections (CDC 2021). Furthermore, as exemplified by vector-borne, food-borne, or water-borne diseases, contact with insects, contaminated food, or water can result in a zoonotic disease infection (CDC 2021). Thus, humans are particularly at risk since zoonotic pathogens can easily spread to humans due to exposure and contact with animals including domestic and wild ones (WHO 2020).

Previous works have identified the fact that zoonoses comprise around 60% of all emerging infectious diseases (Taylor et al. 2001; Burroughs et al. 2002). Currently, zoonoses encompass a similar and significant portion of newly identified infectious diseases (WHO 2020), of which a variety originates from wildlife. The increase in interactions between humans and animal species is one of the factors that has been contributing to the surge in zoonoses globally (Magouras et al. 2020).

According to Altintas (2008), zoonotic diseases are becoming more frequent while increased awareness is raised about this particular issue. Moreover, the twentieth century was accompanied by environmental changes and ecological disturbances, some of which have been associated with zoonoses. Furthermore, changes in climatic patterns are reflected in declining biodiversity and natural ecosystems (Grace et al. 2016). The population growth of the twentieth century often resulted in humans encroaching into the habitats of wild animals. Consequently, more frequent animal-human interactions amplified the transmission of zoonoses (Grace et al. 2016). As a result, this leads to a surge in a variety of new zoonotic diseases which in turn caused repeated outbreaks in humans as exemplified by the recent Ebola, Zika outbreaks as well as the ongoing coronavirus pandemic (Dhama et al. 2020). As stated by Leal Filho et al. (2022), the increasing spread of the West Nile and Usutu viruses and the establishment of new vector species, such as specific mosquito and tick species, in Europe and other parts of the world are further signs of a growing problem (Leal Filho et al. 2022). The next section deals with the classification of zoonoses.

Types of Zoonoses

As previously mentioned in section one, zoonoses can be classified in accordance with their respective pathogen. Thus, four types of zoonoses can be distinguished: viral, bacterial, parasitic, and mycotic (Chomel 2009). Diseases such as rabies, avian influenza, and the Ebola virus disease (EVD) can be classified as viral zoonoses (Rahman et al. 2020).

When it comes to bacterial zoonoses, Lyme disease, tuberculosis as well as leptospirosis are further examples. In addition to that, plague and salmonellosis fall

Table 21.1 Some zoonoses and their respective vectors

Zoonoses	Vector	References
Hantavirus infection	Rodents	Jiang et al. (2017)
Lyme borreliosis	Ticks	Alekseev et al. (2021)
West nil fever	Mosquitoes	Pauli (2004)
Leptospirosis	Rats	Loan et al. (2015)
Dengue fever	Mosquitoes	Aliaga-Samanez et al. (2021)
Tick-borne encephalitis	Ticks	Betancur et al. (2015)
Leishmaniasis	Sand flies	Chelbi et al. (2021)
Bubonic plague	Rodents (e.g. rats)	Keeling and Gilligan (2000)
Malaria	Mosquitoes	Sato (2021)
Campylobacteriosis	Colonized broiler chicks	Hermans et al. (2012)
Chikungunya	Mosquitoes	Tsetsarkin et al. (2016)

into the category as well (Rahman et al. 2020). Concerning the third type, cryptococcosis, histoplasmosis as well as superficial dermatophytes are considered fungal zoonoses (Seyedmousavi et al. 2018). As far as the parasitic zoonotic diseases are concerned, leishmaniasis and toxoplasmosis belong to that category (Altintas 2008).

A selection of a variety of zoonoses is presented in the following Table 21.1.

Antimicrobial resistance is a complicating factor in the control and prevention of zoonoses. The use of antibiotics in food animals is widespread and increases the potential for drug-resistant strains of zoonotic pathogens to spread rapidly in animal and human populations.

Climate Change and Zoonoses

The relations between climate change and zoonoses constitute a major public health challenge (Greer et al. 2008). Global warming as a whole, and specific climatic factors, in particular, impact the spread of zoonoses due to changes in the interactions between pathogens, hosts, and vectors (Rupasinghe et al. 2021). As a consequence, climate change and altering climatic factors are likely to seriously affect human health (Greer et al. 2008) and the spread of zoonoses. In the following, a wide range of infectious diseases is depicted in the context of progressing climate change.

First of all, future alterations in climatic patterns can result in disruptions of seasonal cycles in natural ecosystems (Butt et al. 2015; Gibb et al. 2020). The 6th

Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2021) has illustrated how changing climate conditions may affect ecosystems. Correspondingly, climate change is linked to changes in ecology impacting the spread of zoonotic diseases (Rupasinghe et al. 2021).

An increase in hantavirus infections- a zoonotic rodent-borne disease- coincides with the cycles of its specific host population which in turn were determined by rainfall and vegetation (Kallio et al. 2009; Gibb et al. 2020). Climatic factors are known to particularly affect populations of rodents as increases in temperature in spring and winter contribute to the growth of rodent populations (Rupasinghe et al. 2021). In this context, intense precipitation enhances crop production which in turn favors the breeding and expansion of rodents (Rupasinghe et al. 2021). Particularly, climate change may influence the distribution of similar infectious diseases, as exemplified by the relationship between pathogens, vectors, reservoirs, and hosts (Greer et al. 2008).

Figure 21.1 outlines some of the influences of climate change on zoonoses.

The transmission of vector-borne zoonoses is also impacted by specific climatic factors, particularly elevated temperature. This particular phenomenon can result in an increase in the reproduction of vectors and the specific pathogens they carry (Martin et al. 2008).

Furthermore, intense precipitation serves as a further climatic factor that coincides with enlarged breeding sites. The latter is often accompanied by aggregated vegetation which in turn provides suitable conditions for the development of vectors (Githeko et al. 2000).

Moreover, mycotic pathogens are highly dependent on the soil in their specific climatic environment. Correspondingly, a surge in fungal infections is anticipated because of altering ecosystems (Greer et al. 2008). Similar to zoonoses transmitted by mosquitoes, the changing climatic conditions also amplify tick-borne zoonoses. This is because the elevated temperature is one of the central contributing climatic

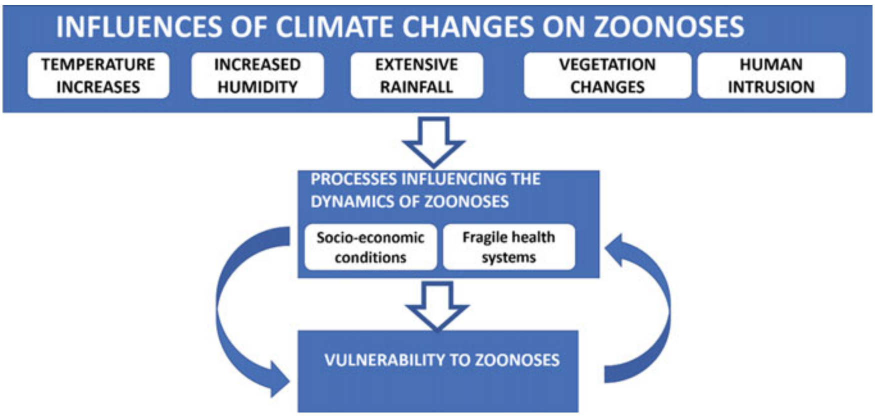

Fig. 21.1 Some of the influences of climate change on zoonoses

factors to the development and spread of ticks as exemplified by a study conducted by Lindgren and Gustafson in (2001). Accordingly, an increase in TBE- a tick-borne transmitted zoonotic disease- was observed in Sweden due to warmer winters (Lindgren and Gustafson 2001). Furthermore, conditions of soil influence the ticks´ development and the survival rates of a variety of other pathogens, due to their dependence on suitable soil conditions (Hugh-Jones and Blackburn 2009).

As previously mentioned, it is important to notice that climate change has a severe impact on the increased distribution of infectious diseases, especially zoonoses by altering the interactions between pathogens, vectors, reservoirs, and hosts as well as their respective transmission cycles (Greer et al. 2008).

As far as mosquito-borne zoonoses are concerned, increased temperatures provide suitable conditions for enhanced mosquito activity and reproduction rates (Martin et al. 2008), and this is associated with the emergence and spread of infectious diseases transmitted by them as vectors (Greer et al. 2008).

As far as water-borne zoonoses are concerned, increases in rainfall and flooding result in water contaminated with pathogens and therefore accelerate the distribution of a variety of water-borne infectious diseases. Furthermore, the increased reproduction of disease pathogens is linked to elevated water temperatures that, in turn, lead to increases in their reproduction rates. This can greatly increase the risks of infections (Rupasinghe et al. 2021). Water-borne diseases are also reinforced by frequent extreme-weather-related events and alterations in rainfall patterns (Greer et al. 2008). The outbreak of the Zika virus in Latin America in the years 2015–2016 (Colón-González et al. 2017) is associated with an unusually wet summer that year. It cannot be excluded that a new outbreak may take place, should the same conditions prevail again.

To conclude, climate change is associated with the spread of zoonotic diseases, due to a combination of:

(a) changing climate conditions,
(b) Increased penetration of humans in the natural environment
(c) closer interactions between humans and animals including wildlife
(d) and a greater variety of animal reservoirs and vectors and extended transmission cycles (Greer et al. 2008).

The risk of zoonosis is also exacerbated by disruptions to ecosystems and their ecology, concerning wildlife populations (Greer et al. 2008).

Moving Towards Prevention

Due to their nature, zoonoses cannot be fully handled in isolation by countries or cities. Rather, a concerted effort is needed, whereby countries combine their efforts in line with the international agreements promoted by the Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change, which seeks through diplomatic cooperation, to reverse the systemic effects of human activities on Planetary Health.

Apart from the global efforts, it should be noted that prevention methods to handle zoonoses differ for each pathogen. However, several practices are recognised as effective in reducing risk at community and personal levels. Safe and appropriate guidelines for the care of animals in the agricultural sector help reduce the potential for outbreaks of foodborne zoonotic diseases, such as meat, eggs, dairy products, or even some vegetables. Standards for drinking water and waste removal, as well as protections for surface water in the natural environment, are also important and effective. Educational campaigns to promote handwashing after contact with animals and other behavioral adjustments can reduce the spread of zoonotic diseases.

It is also important to remind of the fact that pathogens can spread to humans through any point of contact with the domestic, farm, or wild animals. Businesses selling wildlife meat or by-products, which are at high risk because of the large number of new or undocumented pathogens that exist in some wildlife populations, need to be made more aware of the risks.

Also, agricultural workers in areas with high animal antibiotic use should be better informed.

People living adjacent to wilderness areas or in semi-urban areas with higher numbers of wild animals, which are at risk of diseases caused by animals are also a group whose awareness needs to be raised.

And since urbanization and destruction of natural habitats increase the risk of diseases by increasing contact between humans and wild animals, greater care should be exercised, when allocating space for new building projects.

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Chapter 22
Climate Change Health Impacts: The Need for Watershed and Ecohealth Approaches Base for Health Adaptation Strategies and Policies

Marilyn Aparicio-Effen, Oscar Paz-Rada, Ivar Arana-Pardo, James Aparicio, Cinthya Ramallo, Eufemia Briançon, Ximena Huanca, and Gustavo Nagy

Abstract Climate change is modifying regional and local seasonal patterns of rainfall, temperatures, climate variability and extreme events. It is producing reduction in availability and quality of water for the most vulnerable population. Understanding the water problem constitutes a call for collective adoption of measures, through the integrated management of water resources. The health sector isolated action is insufficient to respond to this challenge. In this sense, we developed a comprehensive evaluation of health vulnerability and proposals for adaptation measures. **Objective** Provide evidences on climate change and sanitary impacts, which allows reducing the

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W. Leal Filho (ed.), *Handbook of Human and Planetary Health*, Climate Change Management, https://doi.org/10.1007/978-3-031-09879-6_22

health vulnerability in the Palca watershed, as basis to design adaptation strategies and policies. **Methodology** Mixed research (qualitative-quantitative) descriptive, retrospective and correlational, not experimental; the climate, ecosystem, environmental, water, food and health security components followed specific methodologies to determine the direct and indirect effects of climate change on health. These components were evaluated to respond to prioritized index diseases, in the context of inter and transdisciplinary vulnerability Ecohealth assessment. **Results** The analysis of current and historical climate, presents warmer summers and less cold and drier winters, with significant increases in temperatures, which are warmer than the last 25 years. The rate of warming is increasing between 0.32 and 0.34 °C per decade. Melting local tropical glaciers, environmental mining pollution, head watershed and ecosystems deterioration evidences, was identified. The Sanitary Vulnerability to Climate Change is high for Acute Diarrheal Diseases (VCCADD), in upper, middle and lower part of watershed, related to water quality, which complies with physical–chemical parameters, but presents high levels of total coliforms and *Eschericha coli*. Based on results, an Intervention Proposal has been prepared, as a basis to design adaptation policies and strategies.

Introduction

Planetary health describes the health of humanity globally and the natural planetary systems health on which it depends. Holistic planetary health has been defined as the "achievement of the highest attainable standard of health, wellbeing, and equity worldwide through judicious attention to the human systems …that shape the future of humanity and the Earth's natural systems that define the safe environmental limits within which humanity can flourish" (Whitmee et al. 2015).

The premise of Planetary Health is this: the earth system changes we have wrought are now so far-reaching that they drive a substantial, and increasing, proportion of the global burden of disease. Because we depend on stable earth systems to survive and thrive, environmental destruction amounts to self-destruction. We need to understand these consequences (Myers and Frumkin 2020). In this sense, the present Project tries to understand climate change and other planetary changes impacts on human health of people who lives in mountain ecosystem.

Climate change is modifying regional and local seasonal patterns of rainfall, temperatures, climate variability and extreme events. It is producing reduction in availability and quality of water for the most vulnerable population (CEPAL 2015). Under climate change conditions, the risks for human health in Latin America may increase (IPCC 2001, TAR).

Climate change has adversely affected physical health of people globally and mental health of people in the assessed regions. Climate change impacts on health are mediated through natural and human systems, including economic and social conditions and disruptions. In all regions extreme heat events have resulted in human mortality and morbidity. The occurrence of climate-related food-borne and water-borne diseases has increased. Water and food-borne disease risks have increased regionally from climate-sensitive aquatic pathogens (IPCC 2022; OMS 2022).

Understanding the water problem constitutes a large-scale challenge that must be responded to quickly in the different sectors collective articulation, to avoid a collapse in human and natural systems, searching collective adoption of measures, through the integrated management of water resources. The role of water within households, schools, workplaces and health care facilities is often overlooked or not assigned a value comparable with other uses. Water is a basic human need, required for drinking and to support sanitation and hygiene, sustaining life and health (UNESCO 2021).

Water resources are important for a healthy human condition, without water or with poor quality of it can trigger a series of diseases and in fact the emergence, re-emergence and appearance of new diseases exacerbated by the changing climate and quick ecosystems transformations. These changes probably give rise to new local epidemiological profiles. Under this new scenario, the lonely health sector action is insufficient; to respond to the magnitude of emerging health problems considering a "world with climate change", where it will gradually reduce the "availability and quality of water" for the most vulnerable population (Casadevall 2020; Iniesta Arandia et al. 2009; Jaggernath et al. 2013).

In response to these great challenges, and Projects call issued by Department of Research, Postgraduate and Social Interaction (DIPGIS) of Universidad Mayor de San Andrés (UMSA), Climate Change Environment and Health Unit (UCCLIMAS) of Bolivian Institute of High-Altitude Biology (IBBA) executed Project: "Evaluation of health vulnerability, direct and indirect effects of climate change in Palca Watershed, in La Paz Department, as a basis for design, approach of strategies and policies for adaptation to climate change" financing by IDH public resources.

The selected area was Palca municipality. It is located at climate change sensitive mountain ecosystem with high glacial influence, important level of dissection and strong anthropic pressure.

Study Area Characteristics

The Palca Municipality is located southeast of La Paz city, approximately 68 km, belongs to first Murillo Province section of La Paz Department. It is geographically located at 16° 34′ 00 South Latitude and 67° 57′ 00″ West Longitude between altitudes that vary from 5,880 m above sea level (Murarata) and the 2,398 m.a.s.l. (Tahuapalca) (Bolivia 2012; PDM 2014). It covers a territorial extension of approximately 743.71 km^2 (PDM 2014).

It has three ecological floors that define the economic activity of the region: Andean high floor, inter-Andean valley and valley, these last two are characterized by the predominant agricultural production. In the Andean highlands, the greatest production is of potatoes, broad beans due to low temperatures and climatic characteristics typical of glacial areas.

Overall Objective

Evaluate health vulnerability, to direct effects (extreme weather events) and indirect effects (ecosystems, water and food security) to climate change in Palca watershed, as a basis for design climate change health adaptation strategies and policies.

Methodology

Type of Study

The Project applied a mixed approach (qualitative) with a descriptive, retrospective and correlational, non-experimental design, the climatic, ecosystem, environmental, water, food and health security components followed specific methodologies, to determine health climate change direct and indirect effects. These components were evaluated so that they respond to prioritized Index Diseases, in the vulnerability assessment.

The Project applied a mixed approach (qualitative) with a descriptive, retrospective and correlational, non-experimental design, the climatic, ecosystem, environmental, water, food and health security components followed specific methodologies, to determine health climate change direct and indirect effects. These components for vulnerability assessment were analyzed so that they respond to prioritized Index Diseases, in this case diarrheas.

This study was developed through a comprehensive health research strategy, under two approaches:

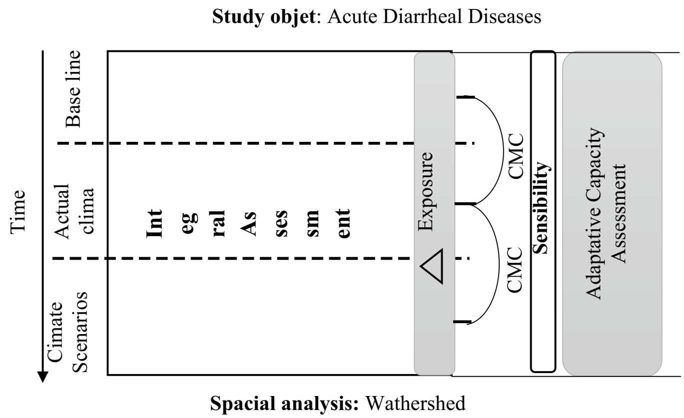
- EcoHealth is an emerging field that examines the complex relationships among humans, animals, and the environment, and how these relationships affect the health of each of these domains. The different types of determinants of health greatly influence human health and well-being. Therefore, EcoHealth's ability to improve human, animal, and environmental health and well-being is, in part, influenced by its ability to acknowledge and integrate the determinants of health (Lisitza and Wolbring 2018).
- Watershed approach as a methodological research strategy: the hydrological cycle has as a unit of movement of water "the watershed", where the water enters through different paths, transforms the environment and modifies itself. In this step, it results in positive or negative human health impacts. Likewise, it gives dynamics to human and natural systems in which internal and external factors influence, configuring complex relationships in direct and indirect influences on human health and the economy of communities (National Academies Press 2012).

Health Vulnerability to Climate Change (VCC) for Acute Diarrheal Diseases

To assess the Sanitary Vulnerability to Climate Change (VCC) for Acute Diarrheal Diseases (ADDs), the water availability degree of reduction and contamination was analyzed as a global warming effect, for which a temporal/spatial evaluation was carried out of climate and water reservoirs that are tributaries of Palca municipality, as well as the determination of type and physical/chemical and bacteriological contamination of water bodies and distribution systems degree (laboratory component).

Vulnerability to climate change is also understood from its dimensions (physical, economic, social, environmental, etc., worked inter and transdisciplinary). Therefore, the representation of climate change health vulnerability evaluation methodology since Ecohealth and watershed approaches include vulnerability factors and dimensions (Aparicio Effen et al. 2016) (Fig. 22.1).

Vulnerability corresponds to a historical and temporal context, since almost "everything real" is a process in motion, so climate system evaluation must be done considering baseline, current climate and future climate. It unfolds in a spatial scope of analysis, which indicates region geographical location, its geographical coordinates, altitude and topographical configuration where human system whose vulnerability is being evaluated is based. In present case, it corresponds to Palca watershed.



V: $f(\mathrm{CMR_{CC}}; \triangle \mathrm{Ex}; \mathrm{Sensb}; \mathrm{C}_{\mathrm{adaptative}})$

V: Vulnerability
CMR: Character
△Ex: variation to which a system is exposed
Sensb: sensibility
$\mathrm{C}_{\mathrm{adaptative}}$: adaptative capacity

Fig. 22.1 Climate change health vulnerability metodology since ecohealth and watershed approaches. Aparicio Effen and Arana (2016)

Vulnerability Concept

The vulnerability concept has its origin in different disciplines of social, biological, and physical sciences, where approaches make difference. Disaster risk management historically integrates a multidisciplinary approach associated with two main models: risk-hazard model and pressure-release model. Under these perspectives, vulnerability is understood as degree to which a system, subsystem or a component of system can be affected by exposure to a threat, disturbance or stressor (IPCC 2012).

$$\text{Where Risk R} = \text{Threat} \times \text{Vulnerability/Response Capacity}$$

A =	Hazard is a function of hazard type (climatic, non-climatic, frequency, and intensity (high, medium, and low)
V =	Sensitivity (negative and positive effects)
Response Capacity =	It is based on Institutionally (formal organization and non-formal organization), economic capacity, Governance (representativeness and relationship)

However, such models generally do not incorporate how systems mitigate or amplify hazard impacts, do not differentiate between subsystems or system elements, which have significant variation in hazard consequences, and are not addressed in assessment. of vulnerability, the interactions within a socio-environmental system (Birkmann 2006; Turner et al. 2003). For its part, the (IPCC 2007) defines vulnerability “as a condition of a natural or human system with a propensity to be adversely affected by vulnerability factors such as: exposure, due to the nature and climatic patterns magnitude change, sensitivity and adaptability”.

On the other hand, it must be considered that all dimensions of human activity are vulnerable. The factors affect dimensions, while responsiveness and adaptability factor will establish a reciprocal cause and effect relationship with dimensions. Therefore, vulnerability will be determined by vulnerability factors and vulnerability dimensions.

- Vulnerability Factors

  Vulnerability (V) can be represented based on the following factors:
  Exp: Exposure, variation to which a system is exposed (Senb) Sensitivity
  (CMC) The character, magnitude and speed of change in weather patterns
  C_(R-Adap)The capacity for response and/or adaptation (IPCC 2001; UN 2001).

Exposure through the spatial analysis of the municipality and based on a physiographic characterization, glacial influence and water sources for human consumption and other uses. *Sensitivity* was assessed from climate-sensitive variables. *Character and magnitude of climate change*: Changes generated in climate behavior, due to natural or anthropic climate variability, which affects or alters system condition under study. Vulnerability to Climate Change (VCC) can be defined = to deltas between current climate and historical climate and future climate and current climate.

= CMC: f(Delta 1). Where: Delta 1: (Current Climate (CA)—Historical Climate (CH))
= CMC: f–Delta 2 Where: Delta 2: (Future Weather (CF)—Current Weather (CA). Future climate under three emissions scenarios A1, A1B, B2.

It constitutes the influence of climate in series representation that are arranged in reference area that includes in its construction thermal amplitude between minimum and maximum average temperatures recorded, and precipitation patterns. Those that respond to altitude ranges in which people live and that influence both temperature and precipitation. This is called Climate Index (CI) and its expression is as follows:

$$IC_i = \frac{IPP(T\max - T\min)}{\Delta h} \tag{22.1}$$

where:

IC: Climate index.
IPP: Precipitation index is ratio between precipitations observed with normal precipitation at analysis periods.
Tmax: Period average maximum temperature
Tmin: Period average minimum temperature
Δh: Range of temperature variation due to altitude change.

This value Δh, is determined by:

$$\Delta h = \frac{n\sum_{i=1}^{n} T_i h_i - \sum_{i=1}^{n} T_i \sum_{i=1}^{n} h_i}{\sqrt{n\left(\sum_{i=1}^{n} r_i^2 - \left[\sum_{i=1}^{n} r\right]^2\right)}\sqrt{n\left(\sum_{i=1}^{n} h_i^2 - \left[\sum_{i=1}^{n} a\right]^2\right)}} \tag{22.2}$$

where:

Δh: Range of temperature variation due to change in altitude.
Ti: i-th observation of mean temperature.
Hi: i-th observation of altitude where temperature was measured.
n: Number of observations series. In this case 10 years of observation.

This index evaluation is applied to each one of diseases that are intended to be analyzed. This indicator allows us to read how climate conditions are modified depending on precipitation index and average thermal amplitude.

Adaptation capacity was based on individual organizational and institutional health capacities. The response capacity based on United Nations Adaptation Policy Framework (UNDP 2007), are the pillars to guarantee process sustainability of generating system resilience. The response and/or adaptation capacities depend on social organization, its relations with the types of development, with the economic, social and human dynamics. They have to do with the intrinsic conditions of the system of organization and relationship with access, coverage of health services and social participation of the community.

Each category of Health Centers capacities were evaluated, in terms of infrastructure, equipment and health personnel. Additionally, the trust that people have in health services was evaluated applying qualitative methods to understand certain relationships between quantitative results analyzed in this study.

- Vulnerability Dimensions

Hydrological and climatic dimension, including the variables of maximum temperature, minimum temperature, temperature delta, annual precipitation and observed decrease determined by Pearson Correlation analysis for comparative analysis between baseline and current climate value denominated Delta 1. Or Delta 2, if it is future climate and flows simulated by assessment communities. For future evaluation, temperature and precipitation deltas were changed according to A1B climate change scenarios for 2020–2030 and some factors whose trend is upward, such as: population increase, increase in solid waste and reduction in water availability, keeping the rest unchanged.

Epidemiological dimension: including acute diarrhea cases historical data by epidemiological weeks and age groups was collected from Palca Health Units. The most frequent types of communities' acute diarrhea cases as a basis for probable etiology identification. Endemic channels were obtained in order to define the expected cases values, geometric mean determination, historical rates and its confidence interval, total population.

Water samples were taken to evaluate the drinking water quality (physical/chemical and bacteriological contamination *Echericha coli*, total coliforms) of each prioritized Communities. The samples were analyzed at UMSA Institute of Sanitary Engineering.

Qualitatively, 376 surveys of population knowledge, attitudes, practices and perceptions were carried out after signing the "Informed Consent" by families' heads, with the purpose of identifying diarrhea risk factors. Communities were organized according to their location in upper, middle and lower parts of watershed.

The correlation between levels and types of contamination and water availability reduction with disorders or pathologies found was sought, and extreme events, food safety, solid waste, sewage and personal hygiene deficits were evaluated in food preparation, in relation to its influence on ADDs.

Social dimension: education, basic services, access to health services, solid waste management and social habits and practices: raising livestock at home, hand washing, hygiene, water boiling and filtering or another method of disinfecting water.

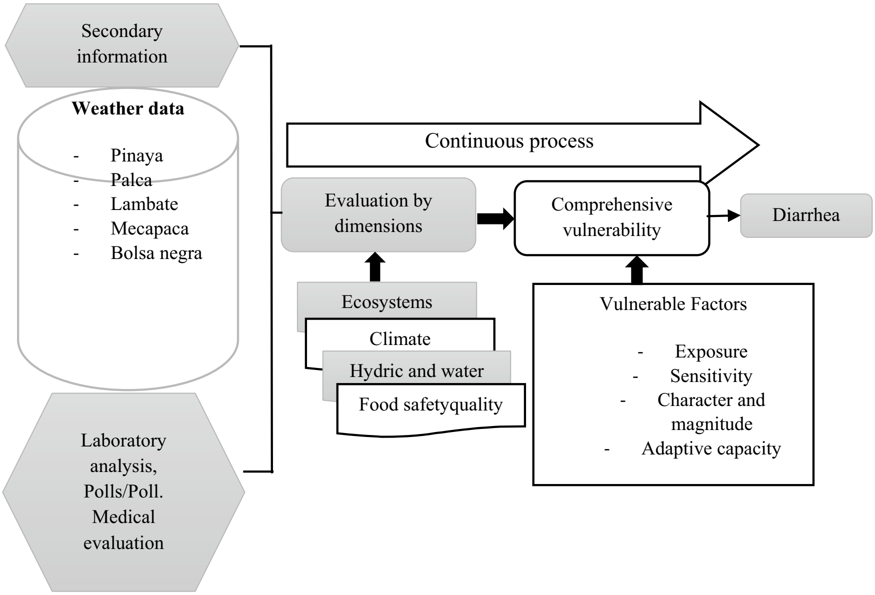


Fig. 22.2 Comprehensive analysis of health vulnerability to climate change. *Source* Own elaboration

Environmental Dimension, Ecosystems and Vegetation Types Existing in Each of Evaluated Communities Were Used

The indicators of vulnerability factors and dimensions were: maximum temperature, minimum temperature, temperature delta, precipitation, diarrhea cases, total population, water quality (Echericha coli, total coliforms) number of samples of water and sanitation, boiling and filtering water and hand washing. For statistical analysis, database was structured considering grouping of variables by vulnerability dimensions (Fig. 22.2).

ADD Climate Variability Assessment

The multi-causality of diseases complicates climate-health relationship, so we must consider "that many times studies of an epidemiological nature alone are not sufficient to estimate the role of climate by itself, in changes in population health states" (IPCC 2001). Climate variability has important geographical differences, where meteorological variables: temperature, rainfall, humidity, wind speed, solar radiation, etc., make up a particular scenario, which in turn will produce various effects on human health.

For variability analysis, a modified Climatic Index of Bulto Index (Ortiz 2004) has been used, which was modified for limited climatic information existing for Municipality of Palca. This index applies factor analysis techniques to simulate climatic anomalies on different space–time scales, or simulate epidemics occurrence and/or disease outbreaks due to climatic anomalies.

The indices allow determining how variables that comprise it are interacting, expressing phenomenon interrelationships of being studied (climate variability) with objects being described (disease).

IC1 Interpretation

The first index or factor reveals interaction between mean maximum temperature (TX) and rainfall (PP) variables, which describe thermal and pluviometric regime behavior. IC1 describes seasonal climatic characteristics. It reflects how atmospheric circulation determines seasonal variation of Palca climate and its space–time dynamics.

The positive values of indicator are associated with rainy season (November–April), while negative values are associated with dry season corresponding to southern winter (May–August).

IC2 Interpretation

The second index reveals interactions of mean minimum temperature (TN) and rainfall (PP) variables. This index reflects seasonal and interannual variations in minimum temperature regime pattern that coincides with rainfall, that is, low values of precipitation in southern winter combined with average minimum temperatures.

Universe and Sample

In coordination with La Paz Departmental Health Service, Health Network, and Palca Municipality authorities, 20 communities were selected as observation or analysis units, using a non-probabilistic stratified or convenience sampling. Therefore, the sample size was N° = 20. Based on watershed approach and special municipality characteristics, the Communities inclusion criteria were: that they are located in upper, middle and lower watershed areas (Table 22.1), which represent different ecosystems, that there are risk factors for water pollution, are accessible and have a representative number of people.

Table 22.1 Climate change vulnerability matrix. *Source* Own elaboration

Factors	Dimensions			
	Epidemiological	Hydrological	Socio-economic	Enviromental
Exposition	3	2	1	3
Sensitivity	3	2	2	3
Nature and magnitude of change	3	3	2	3
Adaptability	1	1	1	1

Results

Diseases have a multifactorial origin, that is, internal and external factors are combined to produce persons or communities' diseases, such as their disease perceptions, prevention activities, people behaviors, migrations, or population movements, socioeconomic situation in addition to their organizational, institutional and community capacity and response to diseases. Added to these factors are climate change direct and indirect effects, including its variability.

Our climate change diarrhea vulnerability, assessment followed IPCC definition (2007b), "as condition of natural or human system with a propensity to be adversely affected by character and magnitude of change in climatic patterns", to study direct and indirect effects of climate on diarrheas.

To assess Climate Change (VCC) Health Vulnerability for Acute Diarrheal Diseases (ADDs), the water availability reduction degree and contamination was analyzed as global warming effect, for which Palca climate and natural water reservoirs tributaries temporal/spatial evaluation was carried out. Additionally, was realized determination of type and degree of physical/chemical and bacteriological contamination of water bodies and distribution systems.

The correlation between levels and types of contamination and reduction of water availability with diarrheas was sought, also extreme events, food safety, solid waste, sewage, personal hygiene deficits were evaluated in relation to ADDs.

A comparative analysis between communities was not carried out due to low degrees of freedom; but they present differences between each variable studied by category. Multiple connection models were used, where diarrheas number was correlated with described variables and which parts of vulnerability dimensions were of overlapped with vulnerability factors. Each variable is correlated from correlation matrix with diarrhea confirmed cases number over 10 to avoid null values, a technique recommended by Calzada-Benza (1989). The hydrological variables annual precipitation, delta precipitation and minimum and maximum temperature were integrated. For social dimension, considering qualitative variables, they were parameterized in fixed arbitrary scales: education, access to health services, boiling water, etc.

Then:

$$Y = \beta_0 + \beta_1 X_1 + \cdots + \beta_n X_n + \varepsilon$$

Where:
Y: is the number of cases

$$\beta_0, \beta_{1,1} + \cdots + \beta_n\text{: Correlation coefficients}$$

X1,2,3,..n: son los variables seleccionadas por cada dimensión de vulnerabilidad.

$$\varepsilon\text{: random error}$$

The calculation was made in correspondence to matrix correlation, where direct or inverse correlations were obtained, which favored the occurrence or blocked disease presentation. DDA communities correlation matrix which show that exposure increases with increasing temperatures, however mean temperature correlation increase (DTx) with cases number is only 0.55, while for total coliforms, the correlation is 0.98 and not so for Eschericha coli that does not present correlation with the number of cases. Similarly, correlations were obtained for all vulnerability dimensions and factors variables considered for Acute Diarrheal Diseases.

The categories of double-entry matrix represented in Table 22.2 indicate: first three vulnerability factors (Exposure, Sensitivity, Character and magnitude of change) contribute to increase in vulnerability to climate change, it is represented by value 3 as a high vulnerability (black color) 2 as medium (gray color) and 1 as low (white color). And ability to adapt is quotient of other factors, being inverse to vulnerability. Therefore, based on institutional, individual, organizational (corporate and union) capacities and municipal income, it reaches the lowest level represented by the value "1" in black, 2 in gray and 3 in white, these last two adaptation capacities only occur in municipal level.

Current climate change sanitary vulnerability is high for Acute Diarrheal Diseases (VCCADD), in all evaluated communities of three parts of watershed, mainly related to water quality, which, although it complies with physical and chemical characteristics of Bolivian Standard for Water Quality, presents high levels of total coliforms and *Eschericha coli,* with Cebollullo community exception. In addition, chronic malnutrition is high in children under five years (Fig. 22.3).

Palca Climate Change Sanitary Vulnerability will go from high to Very High for Acute Diarrheal Diseases (VCCADD), due to increase in population, reduction in long-term water availability, with consequent deterioration of its quality (also favored by rising temperatures) (Fig. 22.4).

Climate change scenarios for Acute Diarrheal Diseases may become a reality in the near future, considering:

– Reduced water quality, which currently has high total coliforms levels and *Echericha coli*, which could be favored by reduced water availability and increased temperatures.
– Water quality deterioration as a result of flow variation, could generate contaminants concentration increment, due to a water bodies decrease dilution capacity,

Table 22.2 Laboratorial water quality results. *Source* IIS evaluation

Communities	Parameter				
	Residual chlorine NB 512 Maximum value allowed 1	Total coliforms (CFU/100 ml) NB 512 Maximum value allowed <1	*Escherichia coli* (CFU/100 ml) NB 512 Maximum allowed value <1	Physical–chemical quality	Bacteriological quality
Cotaña	0	883	95	Not drinkable	Not drinkable
Palca	0	149,25	4,67	Not drinkable	Not drinkable
Huanca Pampa	0	149	<1	Not drinkable	Not drinkable
Pacuani	0	28,5		Not drinkable	Not drinkable
Amachuma Grande	0	149	<1	Not drinkable	Not drinkable
Choquecota	0	229,5	<1	Not drinkable	Not drinkable
Tacapaya	0	1900	4	Not drinkable	Not drinkable
Camiraya	0	19	<1	Not drinkable	Not drinkable
Lacayani	0	361,8	101	Not drinkable	Not drinkable
Quillihuaya	0	1900	20	Not drinkable	Not drinkable
Pinaya	0	231,5	<1	Not drinkable	Not drinkable
Llujo	0	2900	<1	Not drinkable	Not drinkable
Cohoni	0	400	4	Not drinkable	Not drinkable
Cebollullo	0	1213,3	3	Not drinkable	Not drinkable
Tahuapalca	0	855	13,5	Not drinkable	Not drinkable

with consequent effects on human health, particularly in minors of five years old children, which would increase morbidity and mortality of the most vulnerable population.

- Unhygienic habits and lack of water bodies' protection, disposing of solid waste in water, can increase contamination, favoring diarrheal diseases spread.
- Droughts, landslides and floods or other extreme events favored by global warming, due to increased infectious and parasitic contamination, in addition to neglect of hygienic habits, will potentially increase episodes of diarrheal diseases.
- Soil contamination due pesticides and fertilizers municipality use, in addition to mining, which is exerting additional pressure on water resources, and may contaminate groundwater, reducing its quality.
- The water scarcity increase, combined with growth in food demand, and/or water irrigation use, can will affect for high temperatures result as climate change. Areas with low sanitary coverage could practice uncontrolled reuse of water contaminated and even sewage.

- Analysis of vulnerability dimensions

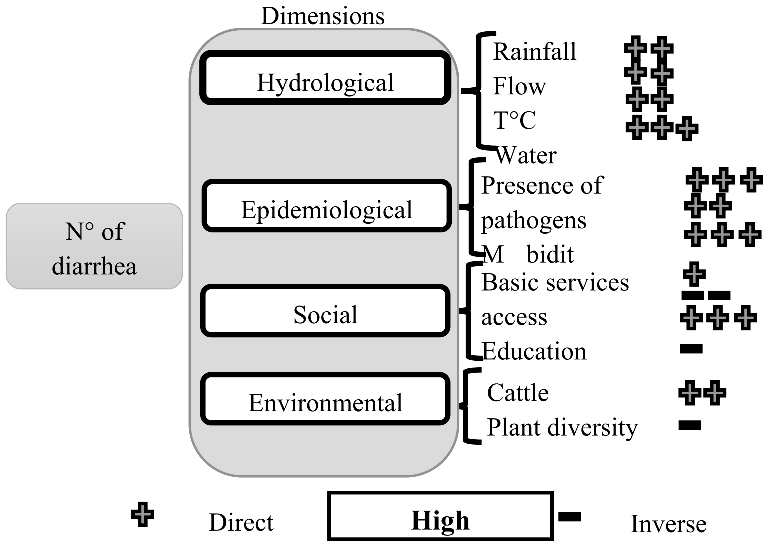


Fig. 22.3 Current climate change sanitary vulnerability. Graphic representation of current ADD vulnerability factors and dimensions in Palca. *Source* Own elaboration

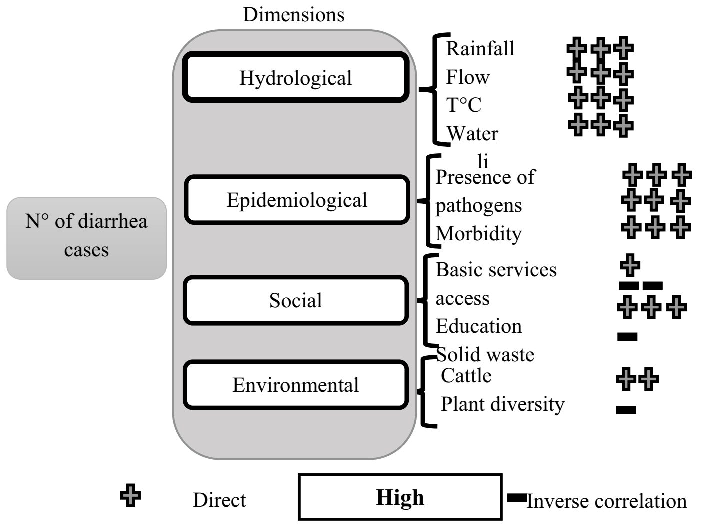


Fig. 22.4 Future climate change sanitary vulnerability. Graphic representation of current ADD vulnerability factors and dimensions in Palca. *Source* Own elaboration

Climate Dimension and Extreme Events

Climatic-hydrological component: To evaluate, temporally/spatially, the climatic variables, the following procedure was followed:

Climate—The local climate was comparatively characterized, in series of 30 years from 1960 to 1990, for temperature and precipitation, in relation to current climate (1991–2008). With information from Palca stations, Mecapaca, Pinaya, Lambate Laikakota and El Alto Downscaling climate scenario B2 was analyzed from 2020 to 2030, according to the "Providing REgional Climates for Impacts Studies" model (PRECIS).

The climatology of Palca Municipality is governed by both an Amazonian climate, which are the air masses that come from the watershed windward side, and the high plateau climate, which is governed by Palca area altitude at which it is located.

The analysis of current and historical climate shows warmer summers and less cold and drier winters, with significant increases in average maximum and minimum temperatures, which implies that current climate is warmer than the last 25 years. With an increase of 0.10 and 0.11 °C per decade since 1939 and the last 25 years warming rate is increasing between 0.32° and 0.34 °C per decade.

Five record years of high temperatures were recorded (1983, 1995, 1998, 2010 and 2014) and three with low temperature records (1985, 1986 and 1997). Precipitation shows decreasing trends and rainy season delayed start. Seasonally, the dry season has a significant reduction in rainfall, so winters are drier, followed by spring, which also shows decreasing trends, but not as important as in winter. During the summer, where more than 60% of the annual precipitation occurs, there is no reduction in rainfall.

The Palca communities are exposed to extreme weather events, whose impacts are different according to their location in the upper, middle or lower part of watershed. Snowfall, frost and hail storms affect more the populations located in watershed headwaters and floods those located in lower part of watershed, causing losses in agricultural production, homes damage and human health (mental health, traumatism, and others). Rain, wind and hail storms generate important erosion processes.

Facing floods, reactive adaptation measures have been generated, such as construction of defenses, retaining walls and canalization to prevent rivers overflow, which are not usually very effective, considering climate variability and Palca high vulnerability condition to climate change.

Extreme Events Related to Climate

The extreme events during the last 30 years were characterized, following IPCC methodology, identifying 3 years as rainy events (1984, 2001 and 2012) and 6 characterized as droughts (1985, 1989, 1998 and 2005). The precipitation behavior index curve shows more recurrent extreme events (Fig. 22.5). A direct relationship with ENSO events is not appreciated; however, the ENSO events of greater intensity cause episodes of greater or lesser precipitation. The precipitation concentration occurs in rainy periods marked by ENSO episodes in their positive phase (obvious for years 1998 and 2000), which implies water losses due to surface runoff.

The extreme events of quarterly precipitation with respect to annual precipitation show that highest precipitation is concentrated in the rainy season quarters (December, January and February). Appreciating three marked peaks in 1998, 1999 and 2002, which exceed 300 times the annual precipitation, which is more evident for Lambate station. Watershed high areas present at least 1 hailstorm event per year (according to communities) which, depending on intensity, can generate losses of 30% of food production.

Seasonally, during the spring there is a tendency to reduce precipitation. However, it is not austral summer significant, which is the season that has more than 60% of annual precipitation. The autumn months (MAM) present a slight increase in rainfall, during the last years; however, dry season shows a significant reduction in rainfall, which causes drier winters.

The irregular behavior, seasonality changes and intensity and patterns rainfall variations, demonstrate important modifications in hydrological cycle as climate change result. Additionally, tropical storms, droughts and floods have been increment in frequency. Pinaya, Lacayani, Quillihuaya Llujo and Choquecota Communities have a rainfall deficit, which is remedied with meltwater.

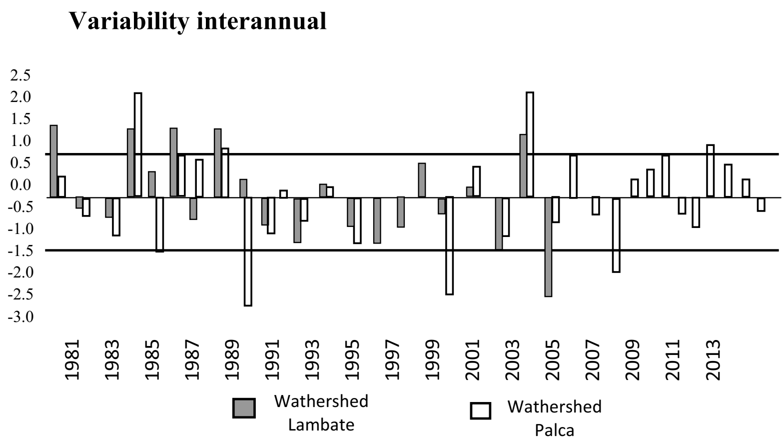


Fig. 22.5 Precipitation index interannual variability at Palca Meteorological Stations. *Source* Own elaboration based on SENAMHI data

Hydrological Dimension and Water Quality

Precipitation and temperature were temporally characterized, calculating Interannual and Seasonal Variability Indices and Analysis of frequencies and intensities. The area water balance was carried out in relation to surface water. For water resources calculation, they were quantified and potential evapotranspiration was used, Rational Method was used and runoff coefficient and intensity of rain were obtained, HEC-HMS model was applied, which is designed to simulate precipitation process and runoff in watershed, in addition to Watershed Model to represent physical part of watershed and Meteorological Model to calculate precipitation required in a sub-watershed. Palca is situated at Mururata and Illimani snow-capped peaks foot. Tropical glaciers are highly sensitive to increased temperatures and changes in rainfall patterns, currently increasing the flow of surface and groundwater from melting ice.

The differences between precipitation of current and historical climate, presents a significant reduction in precipitation. However, they do not affect the availability of water for human, productive and ecosystem consumption, due to summer contribution of melting glaciers, present in Palca. In dry season, is complex provide water to communities, so their glacier retreat plus decrease in rainfall could increase watershed communities health vulnerability. What can be aggravated, considering that current climate is warmer than baseline, In the future, negative effects would probably be generated for population located downstream, when the inflection point between water inlet and water outlet of system occurs.

The storage tanks and the water distribution system have been in a regular state of maintenance and cleanliness since their construction. This coincides with water microbiological analysis results. It presents total coliforms and *Escherichia coli* above the national norms, with Cebolullo community exception. Therefore, the quality of water is mainly affected by poor maintenance of intake works, storage tanks and water distribution network.

The catchment works and storage tanks of some communities do not have adequate protection since they do not have a fence that delimits and protects the access of animals or people outside population and contaminate drinking water. The tanks operate continuously throughout years and above them are booths for disinfection process, which in very few cases have hypochlorinators (which apparently have not been used since the construction of water system). The piping and accessories of storage tank and water connection systems are in fair condition.

It was possible to verify in situ that there is no presence of Free Residual Chlorine in distribution system in any of study communities, which means that there is no chlorine water treatment. Therefore, it allows pathogenic organisms' reproduction and diarrhea cases in different communities.

Another source of contamination is surface runoff due to low levels sanitation coverage, which contamination from non-localized sources contributes significantly to high level of pathogens in surface water bodies, which, added to deficiencies in hygiene, they would also be contributing to groundwater contamination.

Waters bacterial contamination is favored by increase in temperatures, of 0.32ºC in minimum temperatures and 0.34 °C in maximum temperatures per decade, in addition to greater intensity and frequency of extreme events that produce floods. in lower parts, or droughts due to reduced rainfall, which produce diarrhea due to contamination of water for human consumption, in case of floods, and cases of drought, due to an intensification of deficit of washing hands, fruits, vegetables and other hygiene measures.

To the above are associated weaknesses in maintenance of works of intake and system and water conduction. No significant reduction in water availability was observed, despite the downward trend in rainfall, because the communities receive water provided by high mountain glaciers found in municipality: mainly Illimani and Mururata, which show accelerated glacial retreat.

Choquecota, Tacapaya, Pinaya Llujo and Cohoni have the best water quality due to its chemical properties, given the best watershed head state of conservation. Amachuma Grande, Camiraya Lacayani have hard waters with high electrical conductivity, which implies salts high amounts presence. Although in general pH is within the Bolivian standard parameters. Pacuaya and Amachuma Grande Communities have less turbidity in water due to good vegetation cover. Choquecota, Tacapaya, Pinaya, Llujo and Cohoni have lower amounts of water dissolved solids (Table 22.2).

Food Insecurity

The Palca food security is sensitive to climate change impacts. Where subsistence agriculture is being replaced by commercial agriculture, which is associated with soil degradation, because region is subject to periodic rain, wind and hail storms, which occur between December and February. The losses in agro-diversity are increased by market pressure that is promoting commercial products monoculture such as lettuce. On the other hand, warming produces pressure on food production due to emergence of pests, loss of soil fertility, crop diseases, which is associated with soil and water contamination due to use of pesticides. In watershed lower part, floods cause losses in agricultural production.

Medical evaluation

In all Communities evaluated in 2015–2019 period, 4,301 diarrhea cases were registered, of which 1,944 occurred in children under 5 years of age (45.6%) and 2,337 (54.3%) cases in others age groups. Therefore, children under 5 years old are the most affected age group, which coincides with Bolivian infant first cause of morbidity and mortality (Fig. 22.6).

Although there are improvements in Palca household's habitability, many houses present favorable conditions for diarrhea presentation, since 78.7% (3818) do not have sanitary service, bathroom or latrine. 3154 (65%) have a dirt floor and 860 (18%) do not have a separate kitchen for preparing food. The houses proximity to solid waste

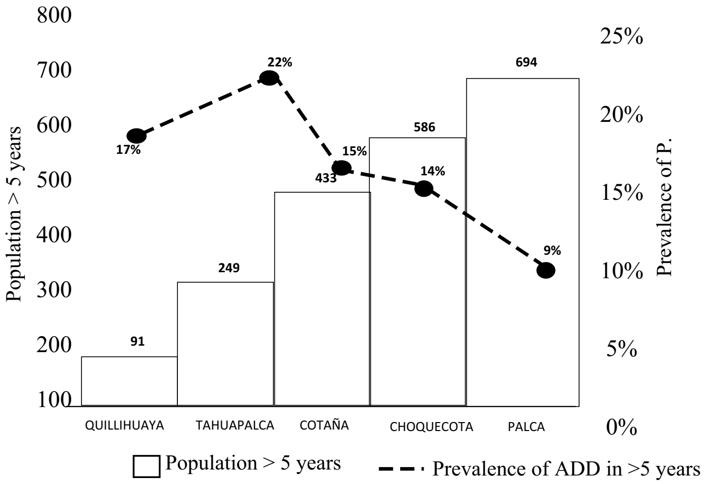


Fig. 22.6 Palca Communities ADD Prevalence in children under five years old. *Source* Own elaboration based on Palca Health Network data

deposit areas (garbage) is high in all ecological levels, predominantly in watershed lower part (56.4%), which favors children exposition and diarrhea presentation.

Parasitosis is the most frequent gastrointestinal disease in Palca three ecological levels with percentages greater than 87%, followed by dysentery and amebiasis, as causes of diarrhea.

The diarrheal episodes' frequency is 2–6 episodes per year (92%) in three Palca ecological levels, followed by 2–4 episodes per month, predominantly in Communities located in watershed lower part. Pearson's correlation analysis between water quality and diarrhea is significant at 1%, for Communities located in watershed lower part. This ecological floor is the most affected and most vulnerable to diarrhea, given that several risk factors are combined. Tahuapalca and Quillihuaya located in watershed lower part, present the highest diarrhea prevalence followed by Palca town for children under five years old, which corresponds to watershed middle part, and by Choquecota, which belongs to upper part of watershed.

Water quality and personal history of gastrointestinal disease at watershed medium part is significant (1% Pearson's correlation), as washing food before eating (5% of significant correlation). Hygiene is key in prevention, taking into account that bacteria and parasites "benefit" from high temperatures and high humidity concentration.

There are a set of determinants: safe water low levels coverage, poor drainage and sewerage, lack of coverage in latrines and urinals, low quality materials used in houses (such as dirt floors that favor the transmission of parasites), hygiene problems, little education levels and proximity and poor management of solid waste, which added to climate change and its variability effects, creating a high vulnerability for acute diarrheal diseases in Palca municipality, which can accentuate the risk of infant morbidity and mortality.

Climate Variability of Acute Diarrheal Diseases (ADDs) Epidemiological Patterns at Palca

Considering all risk factors, acute diarrheal diseases have traditionally been related to temperature variations. The fact that half of diarrhea positive cases correspond to viruses, and that cases produced by enterotoxigenic Escherichia coli (ETEC) and other bacteria are very numerous, allowed to relate its presentation to climate, considering that Diarrhea episodes caused by bacteria increases in warmer, rainier and more humid summer months, while diarrhea caused by viruses prevails in colder ones. Thus, climate acts as a factor that favors favorable conditions or not, to different microorganisms, among them viruses that cause diseases in man (Alemayehu et al. 2020; Chowdhury et al. 2018; Liang et al. 2021; Von Hildebrand et al. 2009).

Among viruses, rotaviruses undoubtedly exhibit pathogenicity mainly in children and young animals of various species, dissemination route being mainly fecal–oral route. Although virus is labile at pH below 2, it can easily withstand stomach pH above 3 (Piatkin and Krivoshein 1981), which would explain its transmissibility and survival in water and food.

Regarding ADDs, produced by bacteria, it prevails in communities that have low levels of access to safe water, environmental sanitation, personal hygiene and domestic refrigeration. Therefore, socioeconomic factors that condition family income deficiency, food insecurity and malnutrition, as well as generators of an immune deficit, will influence the development and maintenance of EDAs.

The concepts indicated, highlight importance that ambient temperature has on development of Acute Diarrheal Diseases, due to meteorological patterns variations, which occur during climatic variability events (El Niño, La Niña, etc.) and those due to global climate change, are evidencing their influence on incidence, prevalence and course these diseases predominantly in most vulnerable age group such as those under five years of age.

Palca ADDs present a marked seasonal fluctuation, according to Palca climate and variability variations. Disease epidemiological patterns show that greatest vulnerability manifests itself in two periods: the first and most important between October-December at summer months, and in some areas it may be earlier, such as September, or extend until February of following year, coinciding with abundant rainfall and higher temperatures, climate variables that favor water contamination, and greater bacterial and parasitic replication. And the second between April - August, mainly in July, coinciding with season of less precipitation (dry season), presence of extreme events, instability of temperatures or colder temperatures, coinciding with winter, and that would be related to diarrhea of viral etiology such as those caused by rotavirus (Fig. 22.7).

Tahuapalca diarrheas in children under five years of age have a unimodal presentation that begins in winter and continues in summer, with a maximum peak between June and July, which suggests a viral etiology. In those over five years of age, curve is bimodal, diarrhea increment in October and November would coincide with temperatures and rainfall raises read by IC_1. The decrease in cases is shown by IC_2, which

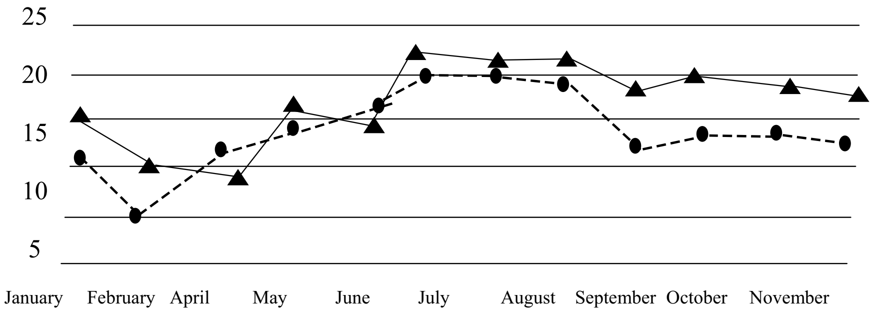


Fig. 22.7 Palca ADD seasonality by age groups, according to CI_1. *Source* Own elaboration based on SNIS, Palca Health Network and SENAMHI data

indicates high dependence in this Community on rains and high temperatures for EDA cases presentation. Cases from June to August coincide with lower rainfall and cooler temperatures, also shown by the IC_2.

Quillihuaya acute diarrheal diseases have unimodal presentation that begins in winter and continues in summer, with a maximum peak in September, which suggests bacterial and/or parasitic etiology. The diarrhea increase coincides with IC1, which represents temperatures and rainfall rises, coinciding with rainy and high temperatures season. In patients older than five years, the curve is bimodal, with a first peak from January to February and the second from November and December. For children under five years group, there is also a bimodal presentation in relation to IC2, first peak from January to March and second from October to December. The decrease in cases is shown by IC2, which indicates the high dependence on rains and high temperatures, and demonstrated because between April and September, which is dry and cold season, diarrhea cases decrease significantly.

The diarrheas Palca Community seasonality is unimodal with a peak between of September and December (reaching its maximum incidence in November) for both age groups. The increase in diarrhea cases coincides with CI_1, which represents temperatures and rainfall rises, coinciding with rainy season and warmer temperatures. CI_2 for group over five years of age shows a diarrhea cases bimodal presentation with a first peak from January to March and the second from November to December. These results would suggest a combination of cases of diarrhea of bacterial and/or parasitic etiology in the warmer and rainier months and of viral etiology in winter, which most strikingly affects children under five years of age.

The present study allowed us to verify that diarrheas present a marked seasonal fluctuation, according to Palca climate variations. The diseases epidemiological patterns show that greatest vulnerability manifests itself in two periods: the first and most important between October-December, and in some areas it may be earlier, such as September, or extend until February of following year, coinciding with rainfall, higher temperatures and climatic conditions that favor water contamination, and greater bacterial and parasitic replication, and the second between April - August, mainly in July, coinciding with season of less precipitation (dry season), presence of extreme events, instability of temperatures or colder temperatures, coinciding with winter, and that would be related to diarrhea viral etiology such as those caused by rotavirus.

Health Promotion Activities Allowed

- We achieved population active participation in Project development with the aim of protecting and caring for their health.
- Interaction strategies with community were prioritized, to reinforce behaviors changes, attitudes and practices, in order to improve the understanding of health care in the face of Climate Change health risks.
- Community access to health care was promoted through medical and health care campaigns, motivating population to resort to Palca Health Centers.
- Community socialization of information, education and communication (IEC) was promoted, through IEC strategies, for its dissemination (Banners, Rolers and Triptychs) with messages and selected information related to climate change and health, for population in general awareness and vulnerable groups.
- Social community mobilization and health sector providers, was promoted to generate and implement climate change adaptation measures to.
- Through spots radio broadcast, awareness messages and information were broadcast, for climate change sensitive disease health care mainly for Acute Diarrheal Diseases.
- Activities through print media contributed to climate change and health information dissemination, Project results and human health prevention, through housing improvement, safe water availability and correct care of animals and ecosystems.
- Final Project results were presented at Palca Municipality Health Sector Workshop where the Project Proposal Climate Change and Health Intervention Plan, was presented.

Study Limitations

Research limitations are related to use of comprehensive methodology because although we included many sectors and variables, all of them are insufficient for describing health reality complexity. As an example, we did not include cultural aspects for describing climate change health vulnerability.

Before our study we identified a very little or no prior research on ADD climate change vulnerability, in this sense we had the need to develop an entirely new research typology. But now it can be considered an important opportunity to identify current research gaps and develop new methodology innovations for planetary health, more adequate for studying health, since complex thinking.

In rural areas, there is limited access to meteorological data because the national distribution of meteorological stations prioritizes areas with large population presence or with important airport's needs, for this reason, we had to use four meteorological stations data, two of them located at near cities.

Conclusions

Climate change and other global environmental changes are affecting the health of natural planetary systems with serious impacts on the most vulnerable human population, to despite the planetary health's targets: highest attainable standard of health, wellbeing, and equity worldwide. In this sense, is necessary to redefine new economic behaviors, adopt boundaries that guarantied social equity boundaries and identify multilevel (global–local) safe environmental limits to manage natural systems and avoid health prejudices to human systems.

The rural populations of less developed countries settled in mountain ecosystems are already suffering the impact of global warming on water resources, despite the contribution of tropical glaciers melting, also increased by climate change, so effects on food security and health are already evident. Acute diarrheal diseases are one of the main causes of morbi-mortality in children under five years old in these countries, which had not been fully resolved and now face a greater risk due to climate change effect, rendering local efforts useless and insufficient.

Palca Sanitary Vulnerability to Climate Change is high for Acute Diarrheal Diseases (VCCADD), in all evaluated communities, mainly related to water quality, which, although it complies with physical and chemical characteristics of Water Quality Bolivian Standard presents high levels of total coliforms and *Eschericha coli*, with Cebollullo community exception.

Waters bacterial contamination is favored by temperatures increment of 0.32 ºC at minimum temperatures and 0.34 °C at maximum temperatures per decade, in addition greater intensity and frequency of extreme events that produce floods in lower parts, or droughts due to reduced rainfall, which produce diarrhea due to contamination of water for human consumption, in case of floods, and cases of drought, due to an intensification of deficit of washing hands, fruits, vegetables and other hygiene measures.

Free Residual Chlorine is non-existent in samples taken from storage tanks and water distribution network, which indicates that there are not water treatment for human consumption. Human practices and behaviors as: animal husbandry, inadequate disposal of solid waste, mining contamination, almost non-existent sanitation services and deficits in hand washing and other hygiene measures, allow the acute diarrhea diseases in Palca.

Once research results were obtained, a proposal and intervention strategy for climate change adaptation (to understood as an active vulnerability reduction process) was developed, where sanitary, environmental and technological measures are suggested for exposed population vulnerability reduction (structural and non-structural) are proposed for Palca Municipal Development Plan, and others as a basis for policies generation. This document was submitted to Palca Municipal Government, SEDES La Paz and Ministry of Health, to prevent similar health effects in other country climate change vulnerable areas.

Without adaptation policies and measurements, Palca Climate Change Sanitary Vulnerability will go from high to very high for Acute Diarrheal Diseases (VCCADD), due to global warming, to increase in population, food insecurity, and reduction in long-term water availability, with consequent deterioration of its quality (also favored by rising temperatures).

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