Geography of the Physical Environment

Firuza Begham Mustafa *Editor*

Methodological Approaches in Physical Geography

Springer

Geography of the Physical Environment

The *Geography of the Physical Environment* book series provides a platform for scientific contributions in the field of Physical Geography and its subdisciplines. It publishes a broad portfolio of scientific books covering case studies, theoretical and applied approaches as well as novel developments and techniques in the field. The scope is not limited to a certain spatial scale and can cover local and regional to continental and global facets. Books with strong regional focus should be well illustrated including significant maps and meaningful figures to be potentially used as field guides and standard references for the respective area.

The series appeals to scientists and students in the field of geography as well as regional scientists, landscape planners, policy makers, and everyone interested in wide-ranging aspects of modern Physical Geography. Peer-reviewed research monographs, edited volumes, advance and undergraduate level textbooks, and conference proceedings covering the major topics in Physical Geography are included in the series. Submissions to the Book Series are also invited on the theme 'The Physical Geography of…', with a relevant subtitle of the author's/editor's choice. Please contact the Publisher for further information and to receive a Book Proposal Form.

Firuza Begham Mustafa
Editor

Methodological Approaches in Physical Geography

Springer

Editor
Firuza Begham Mustafa
Department of Geography
University Malaya
Kuala Lumpur, Malaysia

ISSN 2366-8865 ISSN 2366-8873 (electronic)
Geography of the Physical Environment
ISBN 978-3-031-07112-6 ISBN 978-3-031-07113-3 (eBook)
https://doi.org/10.1007/978-3-031-07113-3

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2022
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Cover image by Sonja Weber, München

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

Preface

A research methodology is the foundation of a study. This book is a collection of selected geographic research methodologies. It includes chapters that describe research methods for physical geography. This book is appropriate for final-year students and postgraduate students who want to begin writing a thesis in a higher institute or University. This book is a collection of selected methods from the author's team of academics in South Asia and South East Asia who specialize in the field. I hope you find this book useful and happy reading.

Kuala Lumpur, Malaysia — Ass. Prof. Dr. Firuza Begham Mustafa

Contents

Editor and Contributors

About the Editor

Firuza Begham Mustafa is an Associate Professor at the Department of Geography, Faculty of Arts and Social Sciences, University of Malaya. She specialized in agriculture geography, environment management and geophysical fields. She has produced more than 110 publications including in journals, conferences papers, IPs and posters. She has also written chapters on many international books and published several scientific books. She served in the Editorial Board Water Conservation Management (WCM), Editorial Board of Geology, Ecology and Landscapes (GEL), International Journal of Creative Industries (IJCREI) and Editorial Board of the Malaysian Journal of Tropical Geography (MJTG), University of Malaya. She was appointed as Visiting Fellow of Qinghai National University, China. She actively participated in Theo Murphy High Flyers Think Tank of Australia in 2011 and 2012. She is also Council Member of the International Geographical Union Commission on Commission Marginalization, Globalization, and Regional and Local Responses-C16.29, a member of International Geographical Union for Commission on Geographical Education, a member of the Southeast Asian Geography Association (SEAGA) and the Centre for Global Geography Education (CGGE) training by Association of American Geography (AAG). She is an Associate Fellow (AFMSA) of the Malaysian Scientific Association (MSA). She served as Auditor for Malaysia Qualification Agency (MQA) since 2009 for Geography and Environmental subjects.

Contributors

Adelalu Gabriel Temitope Department of Geography, Taraba State University, Jalingo, Nigeria

Anand Subhash Department of Geography, Delhi School of Economics, University of Delhi, Delhi, India

Atta-ur Rahman Department of Geography, University of Peshawar, Peshawar, Pakistan

Bibi Khadija Department of Geography, University of Peshawar, Peshawar, Pakistan

Chattopadhyay Srikumar Government of Kerala, ICSSR National Fellow, Gulati Institute of Finance and Taxation, Thiruvananthapuram, India

Chua Lloyd H. C. School of Engineering, Faculty of Science Engineering and Built Environment, Deakin University, Geelong, Australia

De Aparajita Department of Geography, Delhi School of Economics, University of Delhi, Delhi, India

Dissanayake Lalitha Department of Geography, University of Peradeniya, Peradeniya, Sri Lanka

Ezekiel Benjamin Bwadi Department of Geography, Taraba State University, Jalingo, Nigeria

Gideon Didams Department of Geography, University Malaya, Kuala Lumpur, Malaysia

Gul Shehla Department of Geography, University of Peshawar, Peshawar, Pakistan

Hermon Dedi Professor of Disaster Geography, Department of Geography, Universitas Negeri Padang, Padang, Indonesia

Hettiarachchi C. S. Department of Geography, University of Peradeniya, Peradeniya, Sri Lanka

Irvine Cameron A. Grand River Conservation Authority, Cambridge, Canada

Irvine Kim N. Faculty of Architecture and Planning, Thammasat University, Bangkok, Thailand

Manawadu L. Department of Geography, University of Colombo, Colombo, Sri Lanka

Mustafa Firuza Begham Department of Geography, Faculty of Arts and Social Sciences, University Malaya, Kuala Lumpur, Malaysia;
Department of Geography, Gombe State University, Gombe, Gombe State, Nigeria

Nagarale Virendra Department of Geography, SNDT Women's University, Pune, Maharashtra, India

Rajapaksha R. M. G. N. Faculty of Animal Science and Export Agriculture, Uva Wellassa University, Badulla, Sri Lanka

Rekha Nianthi K. W. G. Department of Geography, University of Peradeniya, Peradeniya, Sri Lanka

Siddique Fareeha Department of Geography, University of Peshawar, Peshawar, Pakistan

Telang Piyush Department of Geography, SNDT Women's University, Pune, Maharashtra, India

Wickramasooriya A. K. Department of Geography, University of Peradeniya, Peradeniya, Sri Lanka

Wijeratne V. P. I. S. Department of Geography, University of Colombo, Colombo, Sri Lanka

Yusuf Bakoji Mohammed Department of Geography, Taraba State University, Jalingo, Nigeria

1 Epistemology of Geography

Dedi Hermon

Abstract

Geography science aims to observe the dynamics in describing the earth's surface as a place and space for humans to carry out their lives, starting from simple identification to using recording and sketching models then utilizing tools such as maps, satellite imagery, statistics and Geographic Information Systems (GIS). In the development of geography science, it is appropriate to explain the phenomena of the earth in the present context along with the process of developing science and technology. Geography science as a synthetic science certainly views geosphere phenomena with a spatial, environmental and region approach with an orientation to problem-solving as a consideration for policymakers for the welfare of mankind. In epistemology, geography science uses quantitative and qualitative methods. This is because in studying the physical and human aspects the combination of the two methods is highly recommended so that the results of the geographic study are more comprehensive. Meanwhile, in axiology, the existence of geography science is increasingly important today to support sustainable development.

Keywords

Geography science · Epistemology · Development · Methods · Sustainable

1.1 Introduction

Geography science can be divided into three branches, i.e., natural sciences, life sciences and social sciences (Marsden 2001; Hermon 2010). Where in scientific studies, geography science is included in the natural sciences and social sciences. The difficulty of analysis is faced in geography science with existing material objects because each one is developed with a different philosophy and paradigm, especially when the quantitative revolution occurs (Sáez 1989; Khabazi 2018). Geography as a specific science about the geosphere in social science studies emphasizes human activities as its main aspect. This concept is "anthropocentric" in terms of the development of pure science geography which tends to natural sciences. Serdyukov (2017) explains in the development of science, specialization is required so that science can make a more meaningful and profound contribution, although cooperation between various scientific disciplines is often required to solve increasingly

D. Hermon (✉)
Professor of Disaster Geography, Department of Geography, Universitas Negeri Padang, Padang, Indonesia
e-mail: dihermon006@gmail.com

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

F. B. Mustafa (ed.), *Methodological Approaches in Physical Geography*,
Geography of the Physical Environment, https://doi.org/10.1007/978-3-031-07113-3_1

complex problems. Geography science no longer needs to only be concerned with debating the position of geography in the scientific structure, but more emphasis is placed on finding a format for the development of science as a specific science (Hermon 2010).

Johnston (2011), Aksa (2019) added that geography science is a very complex science. Geographical material objects are very broad. This sometimes makes geographers (especially in Indonesia) trapped in geography aids and often intersects with other disciplines (Suharsono and Budi 2006). Yunus (2008) suggests that this condition is exacerbated by the increasing tendency of specialization in geography science which includes physical, social and technical geography. As a result, geography is no longer interpreted as a complete science. These conditions make geography seem uniquely distinguished and marginalized.

Geography science introduced by Herodotus, Strabo, Humbolt, Ritter and Darwin is considered to be "environmental determinism", placing geography science related to location factors about the overall surface of the earth (West 1990). Brunhes (1920), who rejects determinism, puts humans as the main factor because nature offers possibilities that give birth to probabilism, which contains elements of interrelationships between nature and humans in structures, patterns and processes on earth according to place and time, the focus of human emancipation studies, and anthropocentric geography (Lozovsky 2000; Johnston et al. 2007).

Epistemology is an aspect that discusses philosophical knowledge. This aspect discusses how we seek knowledge and what that knowledge looks like. The term epistemology in English is known as "Theory of knowledge". Epistemology comes from the words "episteme" and "logos". Episteme means knowledge and logos means theory. There are several definitions of epistemology expressed by experts which can be used as a basis for understanding what epistemology is Steup (2005). According to Runes (2001), epistemology is a branch of philosophy that discusses the sources, structures, methods and validity of knowledge. Meanwhile, Azra (2005) adds that epistemology is a "science that discusses authenticity, understanding, structure, methods and validity of science". So, Epistemology can be defined as a branch of philosophy that studies the origin or source, structure, method and validity (validity) of knowledge.

Geography science with the approach used is expected to be able to play a role in planning and development to realize human welfare in harmony with nature. In a broad scope, the spatial approach includes spatial processes, spatial structures, spatial patterns, spatial interactions, spatial organization, spatial associations, spatial comparisons and trends in spatial development (Griffith 2007) (Fig. 1.1).

The environmental approach (Castree et al. 2016) as a study of the interaction between living organisms and the environment is referred to as the ecology of an ecosystem. The interaction of human life with its physical factors forms a spatial system that connects regions to other regions studied in geography science. The environmental approach is a method for approaching, analyzing and analyzing a symptom or problem by applying ecological concepts and principles. This approach is an analysis of the relationship between human variables and environmental variables. Ecological views and analysis are directed at the relationship between humans as living things and the natural environment, for example, in the ecological approach that a settlement is viewed as a form of the ecosystem as a result of the interaction between human distribution and activity with its natural environment.

The region approach (Dermendzhieva and Doikov 2017) is a combination of spatial analysis and environmental analysis, often called complex analysis of areas. The character of geography science is different from other disciplines that strictly group in science that focuses attention on

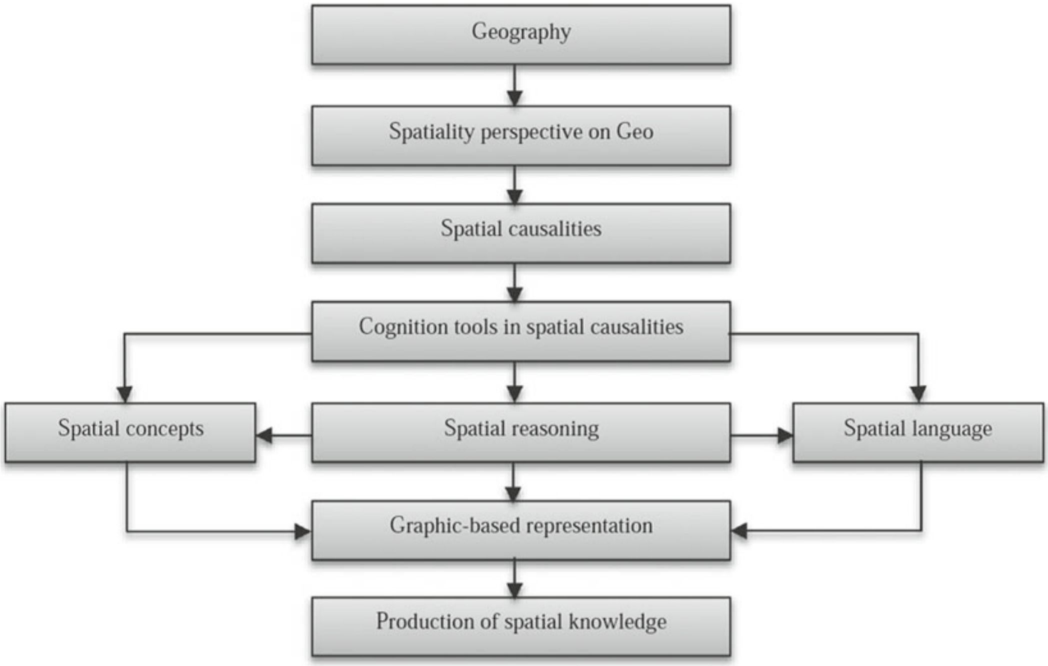


Fig. 1.1 The nature of geography and production of geographic knowledge (Shoorcheh 2019)

natural elements and scientific groups that focus on the study of humans with all their behavior and activities.

1.2 Objectives

Epistemology is the central core of every worldview. It is a parameter which can map, what is possible and what is not possible according to its fields, what might be known and what should be known, but it is better not to know and what not to know at all (Koltko-Rivera 2004). Epistemology can thus be used as a filter for objects of knowledge and not all objects need to be explored with human knowledge. The objective of scientific epistemology in geography science is a combination of rational and empirical thinking (White 1988). The two ways of thinking are combined in the study of natural phenomena to find the truth because science in epistemology uses two human abilities to study nature, i.e., the mind and the senses. Therefore, epistemology is an attempt to interpret and prove that we are aware of a reality other than ourselves. The attempt to interpret is the application of rational thought, while they attempt to prove it is the application of empirical thinking.

1.3 Methods

In research (epistemology), geography science and geography education use quantitative and qualitative analysis. Quantitative analysis techniques in the research of geography developed rapidly in the mid-twentieth century when there was a quantitative revolution (Sheppard 2001).

Approach method of the geography of divided into four, i.e.,

(a) The spatial approach in the room approach is typical of geographic science approach (Hall and Page 2014). In implementing the spatial approach in this geographic science research, it must be based on the applicable geographical principles. Hermon (2010) adds these principles are the principles of dissemination, interrelation and description.

Meanwhile, according to Jennings and Zandbergen (1995), the spatial approach includes the topic approach, human activity, and regional. In theory, these approaches can be separated from one another but in practical reality, they are related to one another.

(b) The ecological approach to geography science is not the only approach. This ecological approach is a complementary approach to approach problems that cannot be approached or analyzed by other methods (Díaz and Cáceres 2001). Ecological views and studies are directed at the relationship between humans as living things and the natural environment (Milner-Gulland 2012). In the ecological approach of a settlement area, the settlement area is viewed as a form of an ecosystem resulting from the interaction of human activity and distribution with its natural environment.

(c) The historical approach (chronological approach)

Hartshorne (1979) argues the importance of the historical dimension in geography science. If the dimension of place explains its spatial interrelation, then the historical dimension can explain the dimension of time and can explain its growth and development. In the study of geography science, a methodology using the dimension of time sequence or historical dimensions is known as the historical approach or the chronological approach. Through this historical approach, we can study the dynamics and development of a geographical phenomenon in a particular area or region, meaning that by using a map of regional developments based on the time sequence, we will be able to see the trend toward which the city is growing and what its supports.

(d) The system approach

The main criterion of a system is that the components or subsystems that make up the system must form a series or an inseparable unit (Wilbanks 1994). In a system, the set of components is of higher value than the separate components. Klapka et al. (2010) added that the systems approach is a synthetic thinking method that is applied to problems that are a system, whereas what is meant by synthetic thinking mode is a mode of thinking based on the doctrine of expansionism. The doctrine of expansionism is a way of viewing an object or thing as part of a large whole. Symptoms related to the main symptoms can be defined as a subsystem of the main symptoms. The approach and analysis of the main geography phenomena with its subsystems are viewed as a roundness that is inseparable from one another (Zheng 2020). As an illustration, for example, we examine a type of agriculture that we define as a system. The systems approach as above can be assigned to industrial, residential, urban, port, transportation communication networks and others.

1.4 Procedure/Steps

Things that must be mastered by people who are involved in geographic research include field observations, making and using various maps, using and compiling documentation, compiling and making models and others. As for geography science (Pabundu 2005), research steps are as follows, i.e., (1) Formulation and statement of research problems; (2) Research formulation and objectives; (3) Formulation of research hypotheses; (4) Determination of population and sampling; (5) Data collection technique; (6) Data analysis and interpretation and (7) Concluding research results.

1.5 Description/discussion

1.5.1 Principles of Geography Science

In the study of geography science, like other sciences, the underlying principles are used which are called geography principles. This principle serves as the basis for description, assessment, disclosure of geographic factors, variables and factors. Principles can be considered as “souls” when we approach the object we are studying. According to Nursid Sumaatmadja (1981), Gabler et al. (2006), there are four principles of geography science, i.e., distribution, interrelation, description and chorology.

(a) The principle of distribution
Geographical facts and symptoms, whether related to physical, human or a combination of the two, are scattered on the surface of the earth. The distribution of symptoms and facts in each location or place on the earth’s surface varies. Some are evenly distributed, uneven or clustered. By observing and describing the spread of these symptoms in a certain space or place, we can reveal the spread, both related to other symptoms and trends that can be used for future predictions.

(b) The principle of interrelation
The principle of interrelation is used to examine by studying geographical facts and symptoms. The principle of interrelation is a symptom or fact that occurs in a certain place. After knowing the spread of geographical symptoms and facts in that location, the next step is to reveal the relationship between the symptoms or facts that exist in that place. The disclosure of the relationship can come from the relationship between physical symptoms and physical symptoms, humans and humans or physical symptoms with humans. Based on the relationship between these geographical symptoms, the characteristics of the place can be determined. By using quantitative (statistical) methods, the interrelation of symptoms or facts can be measured mathematically.

(c) The principle of description
If the interrelationships between symptoms, factors or facts can be known, the next step is to explain the causes and effects of the interrelationships between geographical symptoms. Explanations, description and image are one of the basic principles of the study of geography science. The description principle serves to provide a more detailed description of the symptoms, facts or factors and problems under study. This principle not only explains the event in words and depicts it with maps, but is also supported by diagrams, graphs, tables and the results of overlapping symptoms through computer analysis using geographic information systems. These forms of writing, maps, diagrams, tables, graphs and others will provide explanation and clarity about what is being studied and is being researched.

(d) The principles of chorology
This principle is one of the principles of geography that is comprehensive because it is a combination of several other geographical principles. The principle of chorology is characteristic of the study of modern geography science. In this chorological principle, geographic symptoms, factors and problems are viewed in terms of the spread of geographical symptoms, facts and problems in space. Both the spread, interrelation and interaction between symptoms, facts and problems are known in spatial. The causes and effects of a symptom, fact and problem cannot be separated from the space in question. The understanding of the earth as spatial is not only part of the earth in contact with the air and parts of the outside of the earth, but also includes the lowest layer of the atmosphere which affects the earth’s surface and rock layers to a certain depth, including organisms that exist on the earth’s surface. Also, it includes land and sea waters that are spread over the earth which is known as the life layer. Thus, this chorological principle takes into account the distribution and interaction of all elements on the earth’s surface as a space that forms a unitary function.

1.5.2 The Development of Geography Views

To obtain a chronological picture of the development of geographical views, it is felt necessary to elaborate a little on the history of geographic views from century to century (Lilley 2011), i.e., (1) classical geographical views; (2) geographic views in the middle ages and renaissance; (3) modern geographic view; (4) geographical view of the late nineteenth and early twentieth centuries; and (5) a current geography view.

1.5.2.1 Geography Views in Classical

In the times of Homerus and Hesodius, some people think that knowledge about the earth is still heavily influenced by mythology. Gradually the influence of mythology waned and the influence of natural sciences grew since the sixth century BC so that the nature of knowledge about the earth in that century began to have the basis of natural and exact science. Since then the investigation of the earth has been carried out using logic. Meanwhile, the view of Thales (640–548 BC) considers that the earth is in the form of a keeping cylinder floating on the water and half a hollow ball above it. This opinion was lost a century later after Parmenides expressed his opinion that the earth has a sphere. Then Heraclides (± 320 BC) argued that the earth rotates on its axis from west to east. Apart from that, it was also known that there were several climatic zones, although at that time it was not known that this was a result of the tilted position of the earth's axis (Mason and de Blij 2016).

Claudius Ptolomeus wrote a book entitled "*Geographike Unphegesis*". His book, which was circulated in the middle of the second century, explains that geography science is a presentation with a map of a portion of the earth's surface that shows the general appearance contained in it. Furthermore, it is explained that geography is different from choreography because chorography discusses a particular region or region and presents it in depth. Chorography prioritizes the original footprint of an area and not its size. Meanwhile, geography prioritizes quantitative and not qualitative matters. The opinion of "Ptolemy" is the source of modern geography.

1.5.2.2 Geographical Views in Medieval and Renaissance (Daniels 2001)

Many religious groups paid attention to geography science at the beginning of the middle ages for the sake of religious propagation, trade and war waged by religious propagators. People who felt the need for an arrangement about geography science were Bernhardus Veranius (1628–1650 BC) who had published a book entitled "Geographia Generalis in Amsterdam" in 1650. Veranius argued for dualism in geography. On the one hand, geography studies natural processes and phenomena such as those that occur in the lithosphere, hydrosphere and atmosphere; besides that, it also studies the relationship between the sun and the earth, on the other hand, geography studies socio-cultural phenomena.

Because of this dualism, Veranius distinguishes between general geography or "geographia generalis" and specific geography or "geographia specialists". General geography deals with natural phenomena, while special geography studies areas or regions whose characteristics are obtained from interactions between humans and natural processes. Although Veranius' book entitled "Geographia Generalis" only talks about general geography science. Medieval geography or the geography of the Veranius era was characterized by dual dualisms, i.e., (1) general geography (geographia generalis) and special geography (geographia specialist); (2) physical geography and human geography. To simplify it, Veranius proposed that general geography (geographia systematic) and topical geography study physical elements which could be explained by law, while special geography (geographia regional) which involved humans was difficult to predict and had to be descriptive.

1.5.2.3 Geography Views in Modern (Ribas and Vitte 2009)

Like Veranius, Immanuel Kant (1724–1804) had regarded geography as a scientific discipline. According to Kant, science can be viewed from three different views. First, science classifies facts based on the type of object under investigation. Second, the science which views the relationship of facts throughout the ages. Third, science studies facts associated with space.

1.5.2.4 Geography Views in the Late 19th and Early Twentieth Centuries

In the late twentieth-century geography science focused on climate, plants and animals, and especially on landscapes. Most of the geographers of this period deepened geology and used geological methodology in their investigations and on the other hand human geography is becoming weaker and weaker. Human geography at the end of the nineteenth century is still characterized by Ritter geography where this geography imagines humans about the environment, without any new perspectives. This may be due to Ritter's position as a geographic figure at the University of Berlin after his death in 1859 for a long time and no one has replaced him. Likewise in England since the resignation of the geographer Alexander Maconochie in the 1830s, causing the country's geography to underdevelop.

Apart from that Friedrich Ratzel (1844–1904) has studied the influence of the physical environment on human life. The first volume of his book Anthropogeographie was published in 1882. Ratzel added that apart from the natural environment, human activity is an important factor in life in an environment. Apart from geography, Ratzel also studied, he thought that comparisons were made between different groups of people, it must be that humans themselves determine and especially the conditions that result from their cultural environment. Unlike the first anthropogeography volume, the second volume book (1891) emphasizes the description of population distribution and density, settlement formation, population migration and cultural dissemination. To explain this, Ratzel does not emphasize the influence of the environment on humans but these two phenomena are equal. At that time Ratzel had a great influence on geographers in the United States.

1.5.2.5 Geography Views in Cutting-Edge

Indonesian geographers are faced with a variety of geographical science environmental conditions the diverse. The concept of geography science relates its knowledge to various "mazhab" or concepts that are accepted in other places outside Indonesia, where we have to be smart in choosing which one is suitable for solving the problem. The link between one discipline and another and the link between one problem and another requires that modern geography should not separate itself from other disciplines. As also happens in other disciplines, recent geography has used statistics and quantitative methods in its research and has even used computers to store, process and analyze data. A major problem has arisen in geography science, i.e., whether physical and social aspects should be integrated into geography science. From geography writings during the last 30 years (Ian 2010), the unifying concept has not been seen even though the analysis used in geography has developed rapidly.

1.5.3 Epistemology of Geography Science

Epistemology is a branch of philosophy that emphasizes the study of how to get knowledge correctly. In this case, the epistemology aspect in geography science is the same as other scientific clusters, i.e., using inductive and deductive methods. It aims to obtain comprehensive data on the study of geosphere phenomena. Also, the epistemology of geography science uses quantitative and qualitative analysis. Quantitative analysis techniques in the study of geography science developed rapidly in the mid-twentieth century when there was a quantitative revolution (Sáez 1989). At that time, most geography studies used quantitative analysis. However, along with the development of the scientific paradigm of geography, geographers believe that quantitative analysis in the study of geography has not been able to satisfy and solve and answer geographic problems that arise. This is because as a science that studies natural and human aspects, it is not enough to only use quantitative analysis. Therefore, it also needs to be analyzed qualitatively.

Currently, geographers believe that by using inductive and deductive methods as well as quantitative and qualitative analysis, studies of natural problems that are included in the study of geography are increasingly comprehensive. Every problem that is studied provides useful results for the development of science today. By using this method, the results of geography research provide the characteristics that differentiate it from other sciences. One example in studying landslide disasters, geographers can use quantitative analysis by utilizing geospatial technology to map the affected areas. The results of the analysis provide benefits to stakeholders in making decisions. Also, with qualitative analysis, landslide disaster research examines aspects of human activities around the hillside slopes. The landslides that occur certainly do not only hurt people's lives around the hilly slopes. However, it also provides blessings for the surrounding community. Landslide material can be used by the community as a building material and at certain times it will open up new land for development (especially in agriculture).

There are three kinds of ways to investigate the reality on the earth's surface (according to Hartshorne 1958), i.e., (1) Systematically, which is looking for classifications, categories, similarities and conditions of the phenomena that exist on the surface of the earth. There were sciences such as biology, physics, chemistry (classified as natural sciences), and sciences such as sociology, psychology, economics, politics (classified as social sciences); (2) Chronologically (chronos = time); i.e., investigating the phenomena on the surface of the earth in chronological order (palaeontology, archaeology, history); and (3) chronologically (choora = region); i.e., investigating phenomena about earth space (geography, geophysics, astronomy).

Of the three (3) kinds of approaches, geography science uses (prioritizes) the chronological approach. The use of maps is a manifestation of this chronological approach. So there are geographers who say, "Geographers are people who work with maps to produce maps" (Murphy 2000). People who are involved in geography science at least must take two types of approaches, i.e., those that apply to spatial (corological) systems and those that apply to ecology or ecosystems. Even to study the development and dynamics of a symptom and/or a problem, one must also use a historical or chronological approach (Sumaatmadja 1981).

1.6 Conclusion, Advantages and Disadvantages

The geography notion or geography definition is the science that describes the earth. Furthermore, due to the development of geographical thinking from time to time, the definition of geography has developed and changed according to the insights and developments of society or experts. Some of the definitions of geography science put forward by several experts are as follows, i.e., (1) Geography science, on the one hand, is part of earth science, on the other hand, geography is part of social science; (2) Geography science focuses on the human spatial organization and how the ecological interrelationships in the environment; (3) Geography science is closely related to the diversity and richness of the earth's area. Nevertheless, there is a "common thread" in common, i.e., the reciprocal relationship between man and earth (a reciprocal relationship that affects each other between humans and the earth's environment). There are two objects of geographic science study, i.e., material objects and formal objects. Material objects include physical aspects (environment), human aspects and aspects of human relations with the environment. In summary, the material object of geography includes the phenomena that occur on the earth's surface. The formal object of geography science is a way of looking at and thinking about these material objects in terms of geography, i.e., in terms of spatial, environmental and regional complexes. The principles used in the study of geography science, i.e., the principles of distribution, interrelation, description and corology. These four principles are used to analyze natural or social phenomena in a certain area so that the characteristics of the area can be recognized. As for advantages in geography is helping us know the many places and conditions of an area. Geography science makes us realize how vast the world is. Geography helps us know the location, conditions and characteristics of different countries. Geography lets us know that there are many places and life in other parts of the world. As for disadvantages in geography is Indonesia lacks geography scholars. Currently, Indonesia only has two Geography Faculties. The Indonesian Geographers Association (IGI) proposed the addition of several Geography Faculties at several universities, where Indonesia only has a Geography Teaching Faculty with 23 Faculties. Plus several small Geography study programs, the number of Geography graduate graduates is less than 200 people a year. Geographical graduates (geographers) are increasingly important in line with the increasing threat to territorial boundaries and increasing environmental damage due to the management of natural resources in the State of Indonesia.

Acknowledgements The material for this paper was prepared with the help of academics at Universitas Negeri Padang, especially the Rector for contributing ideas, and also academics (Lecturers, Students and Alumni) in the Geography Department of Universitas Negeri Padang.

References

Aksa FI (2019) Geografi dalam perspektif filsafat ilmu. Maj. Geogr. Indones. 33(1):43–47

Azra A (2005) Reintegrasi Ilmu-ilmu dalam Islam Zainal Abidin Bagir (ed) Integrasi Ilmu dan Agama. Interprestasi dan Aksi, Bandung: Mizan

Brunhes J (1920). Human geography: an attempt at a positive classification. Trans. IC LeCompte. George C. Harrap, London

Castree N, Demeritt D, Liverman D, Rhoads B (eds) (2016) A companion to environmental geography. Wiley

Daniels PW (2001) Human geography: issues for the 21st century

Dermendzhieva S, Doikov M (2017) The regional approach and regional studies method in the process of geography teaching. Acta Sci Nat 4(1):106–117

Díaz S, Cáceres DM (2001) Ecological approaches to rural development projects. Cad Saude Publica 17: S201–S208

Gabler R, Petersen J, Trapasso L (2006) Essentials of physical geography. Cengage Learning

Griffith DA (2007) Spatial structure and spatial interaction: 25 years later. Rev Regional Stud 37(1):28–38

Hall CM, Page SJ (2014) The geography of tourism and recreation: Environment, place and space. Routledge

Hartshorne R (1958) The concept of geography as a science of space, from Kant and Humboldt to Hettner. Ann Assoc Am Geogr 48(2):97–108

Hartshorne R (1979) Notes toward a bibliobiography of the nature of geography. Ann Assoc Am Geogr 69 (1):63–76

Hermon D (2010) Geografi Lingkungan: Perubahan Lingkungan Global. UNP Press, Padang

Ian H (2010) An introduction to geographical information systems. Pearson Education India

Jennings PD, Zandbergen PA (1995) Ecologically sustainable organizations: an institutional approach. Acad Manag Rev 20(4):1015–1052

Johnston R, Poulsen M, Forrest J (2007) The geography of ethnic residential segregation: a comparative study of five countries. Ann Assoc Am Geogr 97(4):713–738

Johnston R (2011) Arild Holt-Jensen, geography. History and concepts: a student's guide. Singap J Trop Geogr 32(2):267–268

Khabazi M (2018) Regional geography and quantitative geography: compare and contrast

Klapka P, Frantál B, Halas M, Kunc J (2010) Spatial organisation: development, structure and approximation of geographical systems. Morav Geogr Rep 3 (2010):53–66

Koltko-Rivera ME (2004) The psychology of worldviews. Rev Gen Psychol 8(1):3–58

Lilley KD (2011) Geography's medieval history: a neglected enterprise? Dialogues Hum Geogr 1 (2):147–162

Lozovsky N (2000). "The earth is our book": geographical knowledge in the Latin West Ca. 400–1000. University of Michigan Press

Marsden WE (2001) The school textbook: geography, history, and social studies. Psychology Press

Mason JA, de Blij H (2016) Physical geography: the global environment. Oxford University Press

Milner-Gulland EJ (2012) Interactions between human behaviour and ecological systems. Philos. Trans. r. Soc. b: Biol. Sci. 367(1586):270–278

Murphy AB (2000) Geography's expanding place in American education. Coll Board Rev 2–6

Pabundu TM (2005) Metode penelitian geografi. Bumi Aksara, Jakarta

Ribas AD, Vitte AC (2009) O Curso de Geografia física de Immanuel Kant (1724–1804): cosmologia e estética na Construção epistemológica da ciência geográfica. Raega-O Espaço Geográfico em Análise 17

Runes DD (ed) (2001) The dictionary of philosophy. Citadel Press

Sáez HC (1989) The history of science and the history of the scientific disciplines, vol 84. Edicions Universitat Barcelona

Serdyukov P (2017) Innovation in education: what works, what doesn't, and what to do about it? J Res Innov Teach Learn

Sheppard E (2001) Quantitative geography: representations, practices, and possibilities. Environ Plan d: Soc Space 19(5):535–554

Shoorcheh M (2019) On the spatiality of geographic knowledge. Asian Geogr 36(1):63–80

Steup M (2005) Epistemology: Stanford encyclopedia of philosophy

Suharsono S, Budi TP (2006) Penajaman dan Kejelasan Objek Kajian dalam Disiplin Ilmu Geografi. Maj Geogr Indones 20(2):187–201

Sumaatmadja N (1981) Suatu Pendekatan dan Analisa Keruangan. Penerbit alumni Bandung

West RC (1990) Pioneers of modern geography: translations pertaining to German geographers of the late nineteenth and early twentieth centuries

White AJW (1988) A critique of the epistemological basis of human geography in education (Doctoral dissertation, Institute of Education (University of London)

Wilbanks TJ (1994) "Sustainable development" in geographic perspective. Ann Assoc Am Geogr 84(4):541–556

Yunus HS (2008) Dinamika wilayah peri-urban: determinan masa depan kota. Pustaka Pelajar

Zheng Y (2020) Rediscovering continentalism: the new geographic foundations of Chinese power. Int Polit 1–35

Dedi Hermon is a Professor in the Disaster of Geography Department at Universitas Negeri Padang, Indonesia, and a graduate of the Natural Resources and Environment Management of Bogor Agricultural Institute (IPB) in 2009. Since 2008, the Author has been an active writer of books and articles related to natural resources, geography, disasters, and environment science.

2 Site Selection Method Using the Geographic Information System (GIS) and Analytic Hierarchy Process (AHP)

Benjamin Bwadi Ezekiel, Firuza Begham Mustafa, Gabriel Temitope Adelalu, and Bakoji Mohammed Yusuf

Abstract

Site selection is a major factor in aquaculture activities as it affects both the success and sustainability besides resolving conflicts between different land users and making rational use of the land. The objective of this study centres on the methodical approaches for selecting a suitable site for freshwater aquaculture using the GIS and the AHP. A case study of giant freshwater prawn farming in Negeri Sembilan of Malaysia was adopted to elaborate on the approaches. Twelve factors were selected to determine suitable sites for prawn farming based on water quality factors (distance to source of water, water temperature, water pH, distance to source of pollution) land characteristics factors (land use types, slope, elevation, soil texture) and infrastructure facilities factors (distance to market, distance to roads, distance to electricity, distance to fry source). These variables were selected based on expert's opinion and review of relevant literature on prawn farming. At the first stage, a resource inventory and a list of prawn farming criteria were developed using the AHP technique. At the second stage, GIS methods were used to determine the ranking of different locations based on the set criteria, and therefore selecting the most suitable sites The result displayed areas of varying suitability of each factor classified as most suitable moderately suitable and not suitable for freshwater aquaculture. The methodology used was very useful in site selection for freshwater aquaculture by linking the criteria considered relevant with the actual land resources in the study area.

Keywords

Aquaculture · Freshwater · Site selection · GIS · AHP

2.1 Introduction

Identifying suitable sites by means of the conventional methods has been very unsuccessful because these traditional methods are time-consuming, slow, costly and cover only a small area of land, that is, only considered the sampled area. The traditional method has been the most commonly practised in Negeri Sembilan. Identifying a suitable site needs ready access to appropriate, reliable and up-to-date data and information for the work to be

B. B. Ezekiel (✉) · G. T. Adelalu · B. M. Yusuf
Department of Geography, Taraba State University, PMB 1167, Jalingo, Nigeria
e-mail: bwadiben@gmail.com

F. B. Mustafa
Department of Geography, Faculty of Arts and Social Sciences, University Malaya, Kuala Lumpur, Malaysia
e-mail: firuza@um.edu.my

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

F. B. Mustafa (ed.), *Methodological Approaches in Physical Geography*, Geography of the Physical Environment, https://doi.org/10.1007/978-3-031-07113-3_2

performed. As much of the data and information may likely have spatial components. Geographic information systems (GIS) have relevance for this task (Bonham-Carter 2014). By utilising GIS, it is not only time and cost-effective but also in realising comprehensive and integrated treatment of prawn farming criteria, which is not easy through the conventional techniques alone (González et al. 2011).

Site suitability analysis for crops is a significant prerequisite for sustainable aquaculture development. It must be performed to assist decision-makers as well as aquaculture development planners (Stelzenmüller et al. 2017). Information on the water quality, the topography, soil and the climatic condition occurring in an area is important for the selection of fish to be grown and the aquaculture practices to be employed. Previous studies conducted in the study area, have been focusing on the ecological zone and the need to delineate areas for agricultural land based on different biophysical attributes of farmer's field where crop can be grown.

> Ahmed et al. (2017) used GIS-based multi-criteria to identify a suitable site for rubber crop cultivation in Seremban district of Negri Sembilan, Malaysia. The study revealed that most of the suitable sites are in southern part of the district including Lenggeng, Pantai and Setul area. The study focused on the biophysical and the ecological factors for determining suitable agricultural land use. The result validation process in this study was somehow weak to seek an integrated information management system through analysing expert's opinion and people' perception.

2.2 Objective

The objective of this study centres on the methodical approaches for selecting a suitable site for freshwater aquaculture using the GIS and the AHP. The study uses a case study of freshwater prawn farming in Negeri Sembilan area of Peninsular Malaysia.

2.3 Method/Equipment/Instrument/Software

2.3.1 Data Used and Thematic Maps

The data used were collected to evaluate indicators of land use at various levels. Primary data were collected from field surveys, and the secondary data were collected from various institutions and organisations as presented in Table 2.1. Collected materials include statistical data, fisheries report at the state level and other related literature on prawn farming research and projects.

At the initial stage interview and questionnaires were used to collect the primary data during the field survey. Experts were chosen based on their prior experienced and knowledge on site suitability, the opportunities, challenges for sustainable prawn farming and GIS spatial analysis. Global Positioning System (GPS) receiver was also used in the field survey for the collection of farm locations and places in the Negeri Sembilan area.

Data from the secondary sources are mainly from the Department of Survey and Mapping Malaysia (JUPEM). These include the land use data, topographic and the Digital Elevation Model (DEM) of Malaysia, from the Shuttle Radar Topography Mission (SRTM) website (www.strm.org) for the digital elevation models used in the slope and elevation sub-model. Soil data was obtained from the Department of Soil, Ministry of Agriculture and Agro-based Industry Malaysia. Temperature and rainfall data was collected from the Malaysian Meteorological Department (MMD). Data for water quality assessment were collected from the Negeri Sembilan raw water quality assessment report prepared by the Department of Irrigation and Drainage (DID) for the Water Resources Commission of Malaysia in 2016 (NIWA Tideda JPS Ampang 2016).

Table1 Summary features of major data collected

Name of Theme	Main Custodian institution(s)	Primary data format	Data set(s)
Boundary map	Department of Survey and Mapping, Malaysia (JUPEM)	Line data as ASCII	National Region District Division
Land use map	JUPEM	Land use shapefiles \ARC/INFO polygons/lines 1:250,000	Land use types Built areas Land surface Roads Electricity lines Agricultural land and farms ponds Reserved areas Hatcheries Market
Climate data	Malaysia Meteorological Department	Point data as ASCII	Rainfall—year and monthly Temperature, year and monthly
Hydrology Water quality data	Department of Irrigation and Drainage (DID)	Point data as ASCII	Principal river basins Rivers Water bodies
Soil data	Department of soil Ministry of Agriculture and Agro-base Industries Malaysia	ARC/INFO polygons Shapefiles	Soil type/texture
DEM	SRTM (www.strm.org)	DEM shapefiles	Contour lines Elevation zones
Population statistics	Department of Statistics Malaysia Official Portal	ARC/INFO polygons	population and housing census report
Fisheries Reports	Department of Fisheries Malaysia	ARC/INFO Polygons	Prawn statistics

A large part of the information presented in the database was derived nationally from mapped/surveyed/compiled data layers in an original shapefile database put together by the above-listed institutions (Table 2.1). Other secondary data sources that were used in this study include statistical data obtained from various reports and the results of socio-economic surveys. Prawn statistics report from the Department of Fisheries (DoF). The Malaysia Statistical Services 2012 population and housing census report at Malaysia at a glance web page (https://www.statistics.gov.my) for updated information on populations and growth rates (Department of Statistics Malaysia Official Portal).

The thematic maps were produced, edited, overlaid and visualised using the ArcGIS 10.1 software about the land suitability analysis for prawn farming in the study area (Fig. 2.1). It is required that all the different map layers need to be converted to the same coordinate system, to be able to overlay the thematic map layers through the application of GIS to establish land suitability for prawn farming database.

2.3.2 Software Used for Data Management

The software used in this study includes the AHP online calculator, the ArcGIS 10.1 software version, the Global Positioning System (GPS), the Microsoft Excel and the Microsoft Word. The AHP online calculator was used for the multi-criteria analysis (compute the weight) based on Saaty (1980) AHP method. The ArcGIS 10.1 was used to analyse all the factors represented by GIS thematic layers and to generate the land suitability map for prawn farming, data processing, preparation of the layers and

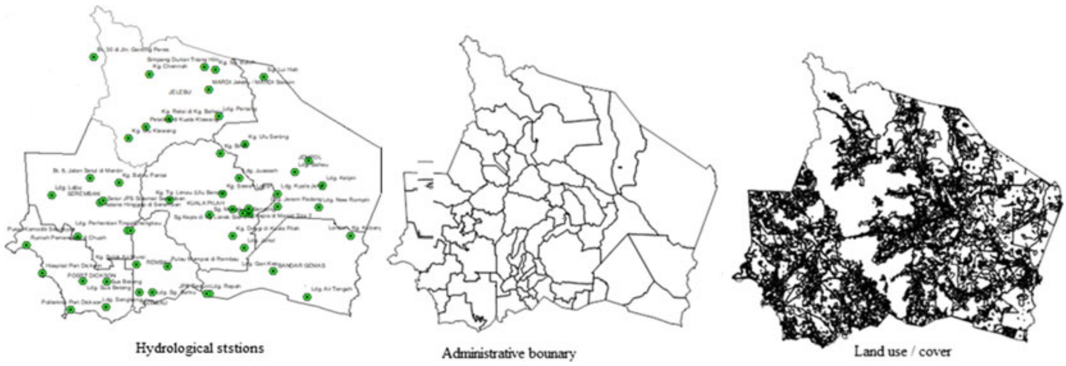


Fig. 2.1 GIS-based data layers used in the suitability analysis for prawn farming

performed the modelling. The GPS was used for taking the coordinate of the farm locations. The map overlay method was used following the Weighted Linear Combination (WLC) concept. The Microsoft Excel was used for the database processing, while the Microsoft Word for the preparation and write up.

2.4 Procedure/Steps/Method

2.4.1 Interview

The interview was performed to collect the primary data used in this study using a questionnaire as early stated which is one of the primary social research methodologies. Direct and indirect unstructured interview was also conducted with the expert during the field study. Formal and informal interviews and group discussions were carried out for additional information. The first round of the survey was to meet and identify the priority criteria and the factors for the land suitability analysis for prawn farming in Negeri Sembilan. The information obtained from this interview was used to produce the set of decision criteria and factors for identifying suitable sites for prawn farming in Negeri Sembilan. It was also applied to identify the challenge in the study area. The conclusion was derived from the attribute data. The final round of the questionnaires interview was applied to identify and prioritise the suitable prawn farming sites in Negeri Sembilan.

2.4.2 Distribution of Questionnaires to Experts

Weights are needed to be assigned to the parameters involved in the study before producing a land suitability map. The AHP was used to determine these factor weights and class weight. The expert primarily determines the priority of each factor involved in the AHP analysis. The AHP pairwise comparison method was applied to simplify the preference rating amongst the criteria. The initial step in this technique is to make the pairwise comparison between the factors for each of the criteria. Table 2.2 present the standard scale for the pairwise comparison matrix.

Designing of experts' questionnaires Table 2.3 is the first step in the analysis where expert opinions were required to determine the relative importance of the criteria and factors involved. The results for each of the pair factors from the comparison were defined in relations to a number from 1 as equal value to 9 with extreme importance. That is, the higher number means the selected factor is regarded more important than the other factor being compared within the matrix. Furthermore, to ensure the reliability of the expert's judgments of the relative importance applied, AHP offers measures to check the inconsistency of the judgments. In this study, expert's questionnaires were distributed and follow up interviews were performed to ensure that the respondents have understood the contents of the questionnaires.

Table2 AHP scale of 9 points used in the paired comparatives (intensity of importance)

Importance	Explanation
1	Equal importance
2	Between equal and moderate
3	Moderately
4	Between moderate and strongly
5	Strongly
6	Between strongly and very strongly
7	Very strongly
8	Between very strongly and extremely strongly
9	Extremely strongly
1/2, 1/3,1/5,…	Reciprocal values

Table 2.3 Questionnaires design for effective criteria pairwise comparison

Factor scoring (or weighting)			
Factor A - Importance - or Factor B?		**Equal**	**How much more?**
○ C1	or ○ C2	○ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
○ C2	or ○ C3	○ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
○ C3	or ○ C1	○ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9

After carrying out all the pairwise comparison with the experts, the individual judgments were aggregated using the geometric mean as suggested by Saaty (1990). The judgments were based on the information gathered through the questionnaires. The results are then combined by applying the geometric mean. The online AHP calculator and the AHP extension in ArcGIS software provide the options for comparing factors/criteria/ sub-criteria/alternatives.

2.4.3 The Degree of Suitability Classes

The FAO guidelines for land evaluation (FAO 1976) serve as the basis for this study. These were used by analysing land suitability for prawn farming potential to lay the foundation for collecting, evaluating and analysing information. The identification of suitable land classes based on the different factors is stated below:

a. Land suitability order indicates the types of suitability: S (Suitable) and N (Not suitable).
b. Land suitability classes that indicate the degree of suitability in the following MS3 (most suitable) MS2 (moderately suitable) and NS1 (not suitable).

2.4.4 Field Survey

A field survey was conducted for the period of ten months from August 2016 to May 2017. During the primary data collection, a combination of qualitative and quantitative methods was used, comprising (1) questionnaires interview, (2) key informants interview, and (3) analytical hierarchy process (AHP).

The criteria of AHP were developed based on the questionnaire survey and informant interview. Pairwise comparison matrix at each level of the hierarchy was applied by relating rating to differentiate the ranking of criteria. The judgments of the experts determined the AHP ratings of the criteria. A face to face questionnaire interview and AHP with fisheries experts from the study area in Negeri Sembilan was carried out. Several visits were made to the area to survey farms to determine and verify the quality of the suitability maps of the land for prawn farming.

2.4.5 Sample Size

Experts from the study area were interviewed to determine the criteria and factors, their relevance and level of importance to land suitability analysis, the opportunities and challenges for prawn farming in Negeri Sembilan. Thirty (30) experts were selected for informant interview from the study area. However, out of these 30 experts, only 20 experts were used due to consistency in their judgement. These experts were selected from the Department of Fisheries Malaysia who has useful information in fields thought to be related to prawn farming and aquaculture development to brain stomp amongst experts to assign values to the criteria and factors.

The AHP is a subjective technique, and so it is not mandatory to involve a large sample (Wong and Li 2008). Furthermore, the survey process may be unrealistic with large "cold-called" sample, as the respondents may tend to provide arbitrary answers, leading to a very high degree of inconsistency (Cheng and Li 2002). In a situation where it turns out that if an expert is experienced and well vested in an area, he can be sufficient to provide the judgement instead of diluting the accuracy with the participation of other experts who may not be as good (Saaty and Özdemir 2014). Saaty further suggested 7 to 8 experts as the best sample size for AHP comparative analysis. This study selected 30 experts in case of consistency and if any may be absent during interview.

Additionally, the significance of sample size for probability sampling in multiple criteria analysis is uncertain (Harrison and Qureshi 2000; Sahin and Mohamed 2013). Therefore, AHP is a decision-making method, which provides objective mathematics in solving complex decision-making problem. Thus, the smaller sample size is adequate for applying the AHP method.

2.4.6 Recruitment and Training of Interview Enumerator

Two enumerators were recruited from the master student from the Department of Geography, University of Malaya to assist in carrying out the interview. The enumerators were selected based on their background in social science data collection, their ability to communicate both in Malay and English Languages, hardworking and familiarity with the environment. They are natives of Peninsular Malaysia who were able to translate the questionnaire from the English language to the Malay Language and the ability to interpret the questions in the native. The enumerators were trained to be well informed and knowledgeable about the concepts and meaning of the questions.

Two days before the field survey the enumerators were trained. The aim of the training was to (a) Give orientation on the purpose and objectives, and organisation of the survey, (b) Offer instruction on how to ask a question and effectively communicate with the respondent, clarified some questions on the interview questionnaire, elaborate on the content and the information required for each question. The training was conducted by going through each question, interpreting the intention and the expected answer.

2.4.7 The Application of the AHP

The study employed AHP to measure the data collected. The primary aim of this study is to deal with the AHP for analysing the factors of land for prawn farming integrated with the Geographic information system (GIS) approaches with the participation of experts to determine the suitability of sites for prawn farming development. The AHP was applied to determine a suitable site for prawn farming in the study area.

The AHP is an MCDA technique introduced by Saaty (1990) that has been used in agriculture and aquaculture planning (Ahmed and Flaherty 2013; Akıncı et al. 2013). It is a method that can integrate and converts spatial data into a decision (Malczewski 2006). The AHP is an active tool that combined both qualitative and quantitative data for planning purpose. It is a multilevel hierarchy structure of objective, criteria, sub-criteria and alternatives. It is established on three major principles: that is decomposition of the overall goal, (prawn farming site suitability), comparative or relative judgment of the criteria, and synthesis of the priorities (Baniya 2008). Individual preferences and judgment are expressed using the fundamental 9-scale points employed by the AHP (Table 2.2). Generally, an individual can concurrently compare and consistently rank nine objects at most. It presumes by the score of differential scoring that the row criterion is of equal or greater importance than the column criterion. In a situation where the row value is less important than the column criterion, the reciprocal values (1/3, 1/5, 1/7, 1/9) have been used.

To ensure the reliability of the relative importance applied, the AHP provides a particular measure to determine inconsistency of the judgments. The consistency ratio (CR) can be calculated based on the priorities of the reciprocal matrices. $CR < 0.10$ indicates that the level of consistency in the pairwise comparison is acceptable. However, where the $CR > 0.10$ it means that there are inconsistency in the evaluation process and the process need to be computed else the AHP may not yield meaningful results (Saaty 1980).

2.4.8 Application of AHP in Decision Support

Structure of the decision problem and the standardisation of data will be considered here.

- Structure of the decision problem

  Some fundamental steps are involved in the application of AHP to a decision problem (Bunruamkaew and Murayam 2011).

  a. Specification of the Model: First of all, possible prawn farming alternatives (most suitable, moderately suitable and not suitable) are identified then followed by the identification of criteria for the assessment of alternatives. The criteria are further categories into logical groups, e.g. grouping to water qualities criteria, land characteristic criteria and infrastructure facilities criteria.
  b. Pairwise comparison of criteria: The criteria and factors were ranked in order of importance using the matrix structure. The values are from Saaty's 9-scale as stated early.
  c. Weighting (rating) prawn farming alternatives: all prawn farming alternatives are rated with respect to each criterion. Qualitative and quantitative ratings are possible. The qualitative rating applied the comparison matrix to rate non-measurable performance such as intangible data with respect to criteria. In case of quantitative criteria, data is available for instance in the form of estimated water temperature or pH, and the value can be rated or assigned weight.
  d. Prawn farming ranking: Finally, ranking or ratings of the alternatives is combined with the criteria that shares an overall rating for each prawn farming alternative. The alternative with the higher weight is ranked as the most preferred choice taking into consideration the relative importance of every criterion and the relative

attractiveness of the alternatives with regard to every criterion.

- Data standardisation

  Most of the GIS have less capability for integrating geographical information and decision-maker's preferences. Bunruamkaew and Murayam (2011) recommend that the combination of MCDA and GIS offer a basis for integrating into GIS process. The essential issues in determining the data model for the combined system is the compatibility of the data constructs between the GIS and the MCDA modelling system.

  The AHP method requires standardisation of the input data; this is because of the necessity to integrate into the evaluation process data measured not only in the different unit but also in different scale of measurements, such as nominal, ordinal, interval and ratio scales. Standardisation of data is not designed to make the multi-criteria score independent from the absolute values of the criteria. In fact, the value functions are not independent of a positive linear transformation of individual values. According to Yıldırım and Güler (2016), standardisation aims to:

  a. Harmonise or convert the scores of the criteria to a common base, which is to ensure all scales which may comprise nominal or ordinal scale are transformed to a common value scale with interval properties.
  b. Account for the possibly non-linear or even non-monotonic character of the relationship between nature and the value scale.

2.4.9 GIS Application to Freshwater Aquaculture and Prawn Farming

The application of GIS has been used in aquaculture research as well as that which relate to prawn aquaculture planning, sustainable aquaculture planning, coastal aquaculture management and identifying suitable site selection technique. Additionally, in recent time, analysts have begun using GIS in aquaculture and fish marking potential. Generally, this technology uses aquaculture research to obtain specific benefits as a supporting tool for decision-making (Nath et al. 2000). GIS is used in aquaculture to characterised aquaculture locations by using points, lines and polygon, particularly in different lands. Point features signify individual aquaculture farm ponds. More precisely, 'GIS can be used to map out fish farms', 'monitor activities', and 'predict suitable site for different fish species'(Stelzenmüller et al. 2017). GIS can minimise conflict in the case of allocating land resources between conflicting demands, needs and their ability to identify relationships based on specific criteria to support decision-making. It is important in site selection in prawn farming. For example, by using suitable site identification tools and topology, it is simply possible to identify potential locations for prawn farming (Hossain and Das 2010).

In prawn farming planning, the first concern that arises is the land and its sustainability. Prawn farming site must be in no way developed without planning regarding land resource concern. Hossain and Das (2010), applied GIS in identifying suitable sites for prawn farming in Bangladesh. At the first stage, a resource inventory and list of prawn farming criteria were generated. The next stage was the application of GIS methods to calculate the ranking of different sites according to the set criteria and, then, identify those with the highest potential.

2.4.10 The Conceptual Framework and Flowchart of the Analysis

Four significant steps were outlined to create a land suitability map for prawn farming in the study area, and these are as follows:

(a) identifying suitable factors to be used in the analysis,
(b) assigning factor priority weight and class weight,

(c) producing land suitability map of prawn farming, and
(d) determining potential areas for prawn farming.

The steps involved in the conceptual framework are presented in Figs. 2.2 and 2.3, respectively.

The AHP is a multi-criteria decision analysis approach applied to incorporate decision-maker's judgment and preferences. The technique includes the selection of the criteria for spatial Multi-Criteria Evaluation (MCE) method for land suitability analysis for prawn farming. This is with respect to the standardisation of the criteria maps and the relative importance of the class of each criterion. The aggregation of the relative weights obtained at each level of the hierarchy to calculate the suitability index is the final step involved in the AHP process. The ArcGIS is utilised to integrate the spatial data with suitability index so that a continuous land suitability map is created. A land suitability map for prawn farming is the output of the process. The concluding part is concerned with the recommendation to determine the potential area for prawn farming development and expansion.

The step-by-step analytic flowchart of the study is presented in Fig. 2.3. The preliminary study is the first part of the study which comprises study site selection and the literature review of the indicators and criteria for land suitability analysis of prawn farming in Negeri Sembilan. The second step is the data collection (spatial and non-spatial data) and spatial database construction so that criteria maps for land suitability analysis for prawn farming can be created. According to Malczewski (2004), GIS-based multi-criteria evaluation can be considered as a process that combines and transforms spatial and spatial data (input) into a resultant decision (output). In this study, the approach followed integrates GIS-based spatial analysis and MCDA methods for multiple assessments. The third step is the data analysis and the synthesis which deals with multi-criteria of land suitability analysis for prawn farming.

2.4.11 Determination of Criteria and Factors

The criteria and factors of decisions are analysed based on the physicochemical properties and infrastructure facilities of the land suitability analysis for prawn farming. Based on the data obtained, the MCE is performed based on three criteria as an indicator of land suitability within the environment of Negeri Sembilan: (1) water quality, (2) land characteristics and (3) infrastructure facilities. Furthermore, the analysis process for prawn farming site was conducted based on 12 relevant factors. The factors are (1) Distance to source of water, (2) water temperature, (3) water pH, (4) distance to sources of water pollution, (5) land use type, (6) slope, (7) elevation, (8) soil texture, (9) distance to road, (10) distance to market (11) distance to electricity and (12) distance to fry sources (Fig. 2.4). Expert's opinion, experience and expertise and information from the various literature were used to select these criteria and factors. Discussion with experts from the Department of Fisheries Negeri Sembilan regional office of Malaysia, survey of authenticated literature and analysis of historical data was accomplished to acquire knowledge related to prawn farming. Decision-maker's judgment and preference were incorporated into the MCDA to evaluate regarding the AHP method. A weight and score were given to each factor which represents the relative importance in the suitability analysis. The pairwise comparison matrix recorded the overall results.

Setting the objective that is to identify and prioritise the potential prawn farming sites is the first level in the hierarchy. Decision criteria and factors of the study in the hierarchy are based on the physicochemical and infrastructure (socio-economic) factors. On the second and the third levels, the criteria and factors of the study are evaluated based on the three (3) decision criteria and the twelve (12) factors for the land suitability for prawn farming. These are water qualities (distance to sources of water, water temperature, water pH, and distance to sources of water pollution). Land characteristics (land use types,

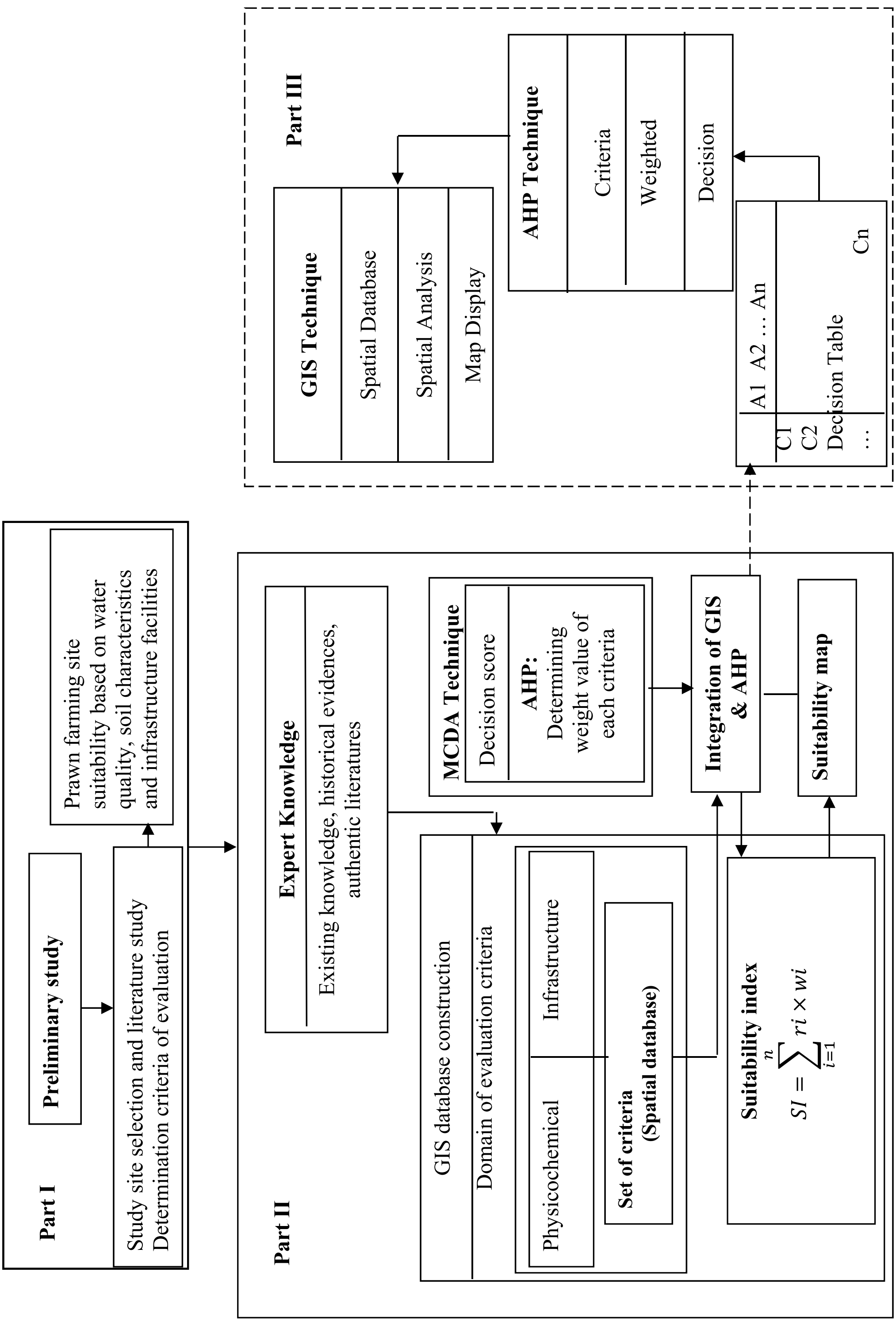


Fig. 2.2 Conceptual framework of the study (*Source* adopted from Laskar (2003)

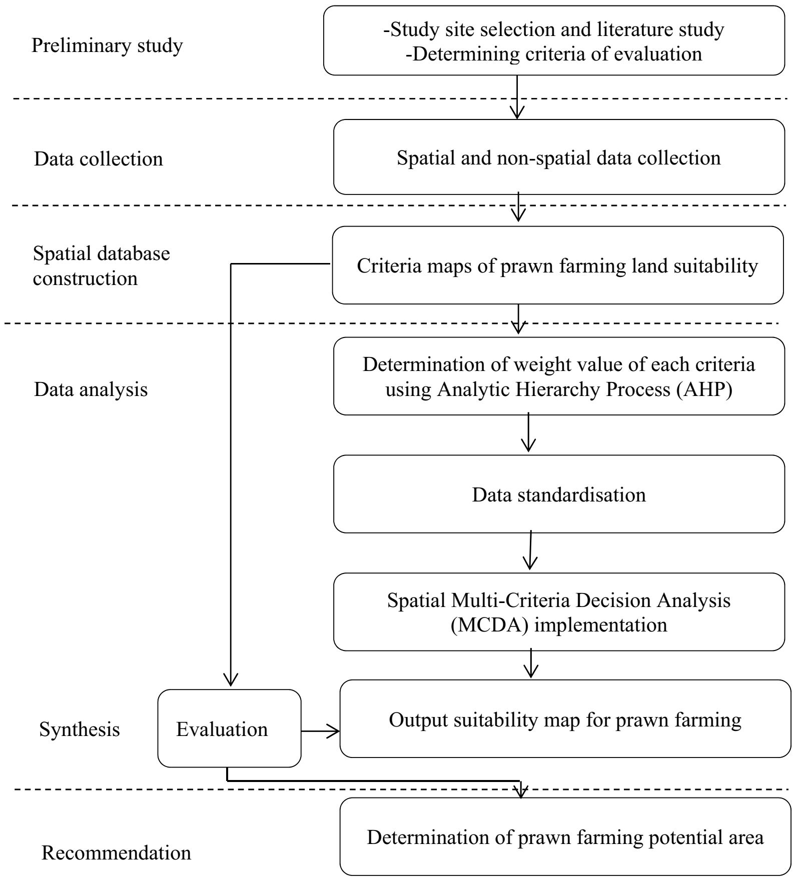


Fig. 2.3 The schematic diagram for modelling suitable site for prawn farming in Negeri Sembilan area

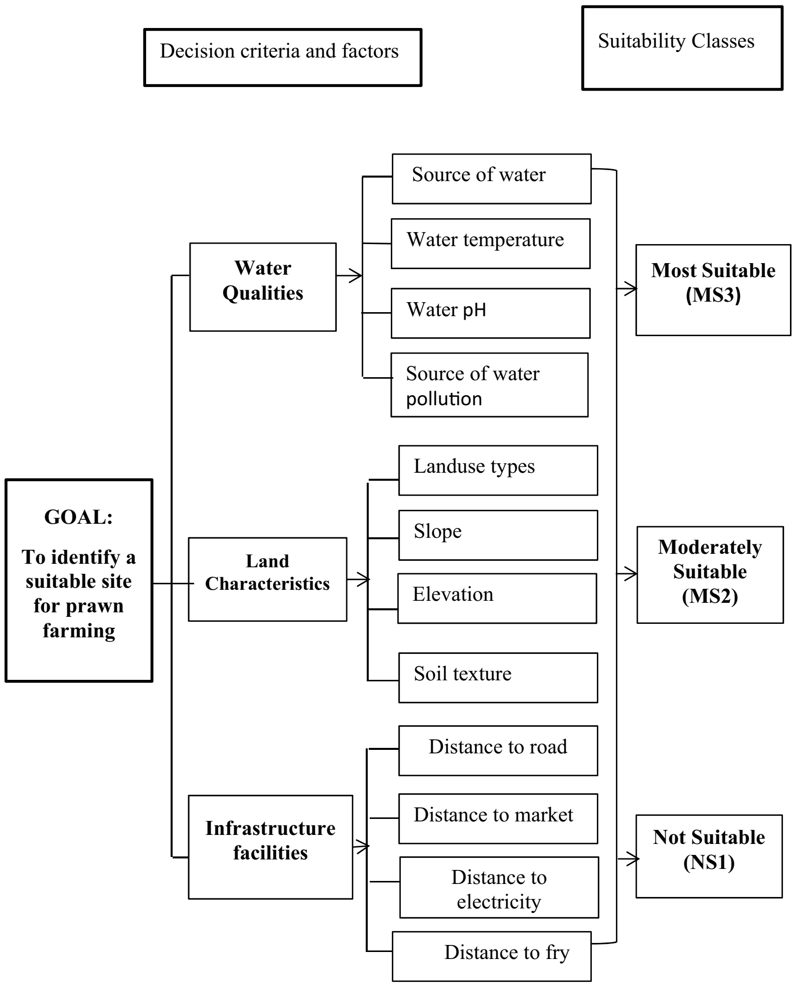
slope, elevation and soil texture), and infrastructure facilities (distance to road, distance to market, distance to electricity and distance to fry source). The fourth level is the degree of suitability of each factor classified as most suitable (MS3), moderately suitable, (MS2) and not suitable (NS1).

2.5 Description/Discussion/Elaboration

2.5.1 Water Quality

Water source, quality and quantity are very significant factors in any prawn farming site selection because any aquaculture system requires water to be available for both initial and future needs. In this study four water quality were analysed, the sources of water, water temperature, water pH and distance to sources of water pollution. The major sources of water from the study area include, rivers, streams and springs, which are supply by rainfall were considered to be good quality because they tend to be well oxygenated and are usually less expensive to develop than the groundwater sources. The mean annual rainfall in the area ranges from 1500 to 2500 mm which was regarded as suitable for prawn farming. The water source was analysed based on the presences or absence of rivers, and the proximity of the rivers to the prawn farms any farm located within the distance 1 km to the source of water is regarded as the most suitable. Mean annual water temperature from the area ranges between 25 °C and 31 °C was considered appropriate for prawn farm. The temperature was assessed based on the heat the water can hold at a

Fig. 2.4 Schematic diagrams for the evaluation process of the criteria for land suitability for prawn farming in Negeri Sembilan area



particular period. Water pH was assessed to determine the acidity and alkalinity level of the water. The range of an acceptable pH is 6–9ppt for the water. Distance to sources of pollution was assessed by determining the proximity of the prawn ponds to the source of pollution. The major pollution source from the area was from agricultural farms, residential and industrial sites. Any farm located within the range of 4–12 km away from the sources of pollution was considered most appropriate for prawn farming.

2.5.2 Land Characteristics for Constructing Prawn Pond

The suitability of a site is significant and determines if there is a potential of land to construct and manage prawn ponds. The section aims to identify areas that are suitable for the construction of prawn ponds. Land use types, slope, elevation and soil texture were the criteria factors used in this category. For land use, aquaculture lands are the best land use preferred since aquaculture can be profitably integrated with agriculture while it performs well in agriculture lands. For slope, 0–5% was the most suitable range for constructing prawn ponds. While the preferred elevation also was between the range of 2 and 2.5 m. The soil texture is a vital aspect when selecting prawn farming site. The porous sandy soil was regarded as not suitable hence soils with 35% clay content were preferred.

2.5.3 Infrastructure Facilities

For a successful prawn farming, it must be sited in areas with easy access to infrastructure facilities and services such as roads, market, electricity and fry sources. Roads offer easy access to market and other services. For one to select a suitable site for prawn farming, this study analysed the proximity to all-weather roads and any ponds within the range of 0–2 km were considered to get a useful site. The market was assessed in terms of proximity to settlement and the population density of the area. Closeness to market within the range of less than 3 km was regarded as the most appropriate. Electricity supply to prawn farm was also essential in prawn site selection. Any prawn farm within the range of 0–3 km proximity to the significant electricity grid lines was regarded as most preferred. Nearness to prawn fry or seeds in prawn site selection is one key factor. This was assessed based on the distance travel to obtain the seeds. Prawn fry source located within the distance range of 0–3 km was considered the most appropriate for prawn farm.

2.5.4 Database Construction

Database construction has to do with the development of relevant criteria maps for the site suitability selection for prawn farming. Basic maps for most of the identified criteria were available in a shapefile form, for instance, rivers, elevation, slope, roads, electricity line, markets and the administrative map boundary of the study area. The first step in the database construction involves the preparation and processing of administrative boundary shapefile map to form the based maps of the study area. Followed by the creation of the criteria maps for prawn farming. The spatial data was made from different sources having different projection, features and measuring units. The final step was to georeferenced the spatial data to a standard reference frame to standardise the layer maps and therefore avoid multi-dimensional mismatch. The database for this analysis consists of twelve-factor layers early mention in Sect. 4.11.

2.5.5 Map Validation and Verification of the Result (Ground Truth)

The overall condition of the land suitability of the study area was observed to validate /verify (ground truth) the result of the predicted model in respect of prawn farming environment. Map verification was conducted to make a cross-comparison between the predicted suitable map and the current land use map, also the comparison between the predicted map and the current prawn farm sites in the study area. Seventeen (17) sites were identified using the purposive sampling of the prawn farms in the study area for visits and assessments (Hossain and Das 2010). Four days were used for the visit and the verification of the outcome of the GIS. The method was very suitable to verify each site after the GIS has been carried out to identify the suitable areas of land for prawn farming. The method aimed at comparing the location of current farm performance and the final predicted suitability map provided by the GIS. Site observations and interviews data were used to assess the performance of the land during the visit. The verification exercise aims to find out whether the current land site matched with the predicted suitability map or not. Bozdağ et al. (2016). The GPS coordinates of the locations were taken to combine them into the ArcGIS.

2.6 Advantages

In relation to the application of the methods in this study, the incorporation of AHP in GIS has been established to be useful for supporting the decision-making process. The method is valuable for identifying suitable sites for freshwater aquaculture and prawn farming. The development of prawn farming is further improved by geospatial and aquaculture planning. Moreover, prawn farming is an activity which strongly involves the geographical measurement. GIS was assumed to have an important potential as a tool for aquaculture site suitability application, analysis and quantification (Stelzenmüller et al. 2017). GIS has increasingly been an important tool for monitoring of physical resources in Malaysia (Aminu et al. 2017; Kamlun et al. 2016). This study revealed that GIS technology offers a set of efficient useful tools for prawn farming planning in Negeri Sembilan. GIS modelling methods can then afterwards assess the changing patterns of land use and identify the biophysical and socio-economic source that drive the perceived dynamic processes. It is as well recommended that GIS should be applied in prawn farming planning for sustainable development and policymaking.

The application of this study can be useful for planners and managers in the government both at the national and regional level and other non-governmental organisation concerned with prawn farming. GIS can play a significant role in assessing natural aquatic conditions, development and evaluating the suitability of resources for prawn farming, revealing conflicts and exposing cause-effect relationships (Rekha et al. 2015). As a result of this, GIS is offering new tools for promoting prawn farming management (Hossain and Das 2010). The application of GIS is not only useful for minimising time and cost of site selection, but also offers a digital database for site monitoring (Rawat and Kumar 2015; Tavares et al. 2009).

Furthermore, the reflection of the real situation of the study area is provided by the AHP Analysis. The details calculation of the factors and class weights for prawn farming were effectively performed by this analysis. Thus, the combination of the GIS and AHP integrates decision support approach which in turn aid the production of land suitability map for prawn farming. In addition, this study is valuable to those interested in GIS methodology, mapping and prawn farming suitability analysis. The study can serve as baseline information for evaluating the suitability of other areas for prawn farming. Moreover, it can be used as a reference point for more complex research in future taking into consideration those limitations encountered in this study. Amongst other methods that can be explored further is the addition of fuzzy AHP to this land suitability system.

References

Ahmed N, Flaherty MS (2013) Opportunities and challenges for the development of prawn farming with fish and rice in southeast Bangladesh: potential for food security and economic growth. Food Secur 5(5):637–649

Ahmed GB, Shariff ARM, Idrees MO, Balasundram SK, bin Abdullah AF (2017) GIS-based land suitability mapping for rubber cultivation in Seremban, Malaysia. Int J Appl Eng Res 12(20):9420–9433

Akıncı H, Özalp AY, Turgut B (2013) Agricultural land use suitability analysis using GIS and AHP technique. Comput Electron Agric 97:71–82

Aminu M, Matori AN, Yusof KW, Malakahmad A, Zainol RB (2017) Analytic network process (ANP)-based spatial decision support system (SDSS) for sustainable tourism planning in Cameron Highlands Malaysia. Arab J Geosci 10(13):286

Baniya N (2008) Land suitability evaluation using GIS for vegetable crops in Kathmandu Valley/Nepal. Humboldt-Universität zu Berlin, Landwirtschaftlich-Gärtnerische Fakultät

Bonham-Carter GF (2014) Geographic information systems for geoscientists: modelling with GIS, vol 13. Elsevier

Bozdağ A, Yavuz F, Günay AS (2016) AHP and GIS based land suitability analysis for Cihanbeyli (Turkey) County. Environ Earth Sci 75(9):1–15

Bunruamkaew K, Murayam Y (2011) Site suitability evaluation for ecotourism using GIS & AHP: a case study of Surat Thani province, Thailand. Procedia Soc Behav Sci 21:269–278

Cheng EW, Li H (2002) Construction partnering process and associated critical success factors: quantitative investigation. J Manag Eng 18(4):194–202

FAO (1976) Guidlines for land evaluation: soils bulleting 32. In: Food and agricultural organization of the United Nations (Ed.), FAO. Rome, Italy

González A, Gilmer A, Foley R, Sweeney J, Fry J (2011) Applying geographic information systems to support strategic environmental assessment: Opportunities and limitations in the context of Irish land-use plans. Environ Impact Assess Rev 31(3):368–381

Harrison SR, Qureshi ME (2000) Choice of stakeholder groups and members in multicriteria decision models. Paper presented at the Natural Resources Forum

Hossain MS, Das NG (2010) GIS-based multi-criteria evaluation to land suitability modelling for giant prawn (Macrobrachium rosenbergii) farming in Companigonj Upazila of Noakhali, Bangladesh. Comput Electron Agric 70(1):172–186

Kamlun KU, Arndt RB, Phua M-H (2016) Monitoring deforestation in Malaysia between 1985 and 2013: insight from South-Western Sabah and its protected peat swamp area. Land Use Policy 57:418–430

Laskar A (2003) Integrating GIS and multicriteria decision making techniques for land resource planning

Malczewski J (2004) GIS-based land-use suitability analysis: a critical overview. Prog Plan 62(1):3–65

Malczewski J (2006) GIS-based multicriteria decision analysis: a survey of the literature. Int J Geogr Inf Sci 20(7):703–726

Nath SS, Bolte JP, Ross LG, Aguilar- J (2000) Applications of geographical information systems (GIS) for spatial decision support in aquaculture. Aquacult Eng 23(1):233–278

Rawat J, Kumar M (2015) Monitoring land use/cover change using remote sensing and GIS techniques: a case study of Hawalbagh block, district Almora, Uttarakhand, India. Egypt J Remote Sens Space Sci 18(1):77–84

Rekha PN, Gangadharan R, Ravichandran P, Mahalakshmi P, Panigrahi A, Pillai S (2015) Assessment of impact of shrimp farming on coastal groundwater using Geographical Information System based Analytical Hierarchy Process. Aquaculture 448:491–506

Saaty TL (1990) How to make a decision: the analytic hierarchy process. Eur J Oper Res 48(1):9–26

Saaty TL, Özdemir MS (2014) How many judges should there be in a group? Ann Data Sci 1(3–4):359–368

Saaty TL (1980) The analytic hierarchy process: planning. Priority setting. Resource allocation. MacGraw-Hill, International Book Company, New York, p 287

Sahin O, Mohamed S (2013) A spatial temporal decision framework for adaptation to sea level rise. Environ Model Softw 46(Supplement C):129–141. https://doi.org/10.1016/j.envsoft.2013.03.004

Stelzenmüller V, Gimpel A, Gopnik M, Gee K (2017) Aquaculture site-selection and marine spatial planning: the roles of GIS-based tools and models. In: Aquaculture perspective of multi-use sites in the open ocean. Springer, pp 131–148

Tavares G, Zsigraiova Z, Semiao V, Carvalho MdG (2009) Optimisation of MSW collection routes for minimum fuel consumption using 3D GIS modelling. Waste Manag 29(3):1176–1185

Wong JK, Li H (2008) Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems. Build Environ 43(1):108–125

Yıldırım Ü, Güler C (2016) Identification of suitable future municipal solid waste disposal sites for the Metropolitan Mersin (SE Turkey) using AHP and GIS techniques. Environ Earth Sci 75(2):101

Benjamin Bwadi Ezekiel is an environmental Geographer. He is a Ph.D holder from the University of Malaya, and a lecturer in the Department of Geography, Taraba State University Jalingo, Nigeria. He has published several research papers in reputable journals and has participated in many workshops, seminars, and conferences in the field of Environmental Geography and aquaculture. His current research is mainly focused on freshwater aquaculture with specialties in land suitability analysis for freshwater prawn farming. Other areas of research interest include climate induces crises and drainage basin morphology. He was earlier involved in the sexual reproductive health issues; HIV and rural agricultural labour force.

Firuza Begham Mustafa is an Associate Professor at the Department of Geography, Faculty of Arts and Social Sciences, University of Malaya. She specialized in agriculture geography, environment management and geophysical fields. She has produced more than 110 publications including in journals, conferences papers, IPs and posters. She has also written chapters on many international books and published several scientific books. She served in the Editorial Board Water Conservation Management (WCM), Editorial Board of Geology, Ecology and Landscapes (GEL), International Journal of Creative Industries (IJCREI) and Editorial Board of the Malaysian Journal of Tropical Geography (MJTG), University of Malaya. She was appointed as Visiting Fellow of Qinghai National University, China. She actively participated in Theo Murphy High Flyers Think Tank of Australia in 2011 and 2012. She is also Council Member of the International Geographical Union Commission on Commission Marginalization, Globalization, and Regional and Local Responses—C16.29, a member of International Geographical Union for Commission on Geographical Education, a member of the Southeast Asian Geography Association (SEAGA) and the Centre for Global Geography Education (CGGE) training by Association of American Geography (AAG). She is an Associate Fellow (AFMSA) of the Malaysian Scientific Association (MSA). She served as Auditor for Malaysia Qualification Agency (MQA) since 2009 for Geography and Environmental subjects.

Gabriel Temitope Adelalu holds a B.sc. in Agrometeorology and Msc.in Environmental Resources Management and he is currently a doctoral student of Climatology in Modibbo Adama Federal University of Technology, Yola. He is working on the topic "Rainfall Analysis and Flood Vulnerability along Major Tributaries of River Benue in Taraba State, Nigeria. He is a member of many academic and Professional bodies such as the Nigerian Association of Hydrological Science, Nigerian Meteorological Society, and Association of Nigerian Meteorological Society. He has a solid publication record with 13 referred journal articles, 2 Conference papers and 1book chapter to his credit. The researcher's working experience started as a teacher at Government Science School, Jalingo, Taraba State in 2003. He began his academic career as an Assistant Lecturer in Geography Department at Taraba State University, Jalingo in February 2017. He was promoted to Lecturer II in 2019. He is fully committed to research. His research interests are Climate change and Climate induced challenges, Environmental and Water Resources Management.

Bakoji Mohammed Yusuf is a renowned Scientist in the field of Agriculture and Environmental Resources Management. He has a Doctor of Philosophy (Ph.D) in Agriculture and Environment from University of Malaya, Malaysia. He is presently a Senior Lecturer in the Department of Geography of the Taraba State University Jalingo, Nigeria. He has published more than 25 research papers in reputable journals and has participated in several workshops, seminars, and conferences in the field of Agriculture and Environment. He is equally involved in consultancy services at national and international levels.

3

The Application of a Data-Driven Method for Spatial Analysis and Prediction of Gully Erosion Susceptibility

Didams Gideon and Firuza Begham Mustafa

Abstract

Gully erosion (GE) is a major environmental problem that causes land degradation worldwide especially in arid and semi-arid regions. A crucial step to reduce and possibly reclaim areas degraded by GE is to predict potential susceptible areas using highly accurate predictive methods. This chapter demonstrates the suitability of a data-driven model (logistic regression) to this aim. The model was applied in South Gombe State, Nigeria, where land development is restricted by intense GE because of the semi-arid climate and physiographic conditions. A GE inventory was prepared from a total of 260 gully and non-gully locations compiled from interpretation of Google Earth images and field investigations. Besides, local environmental conditions and a 20 m DEM allowed the selection of soil texture, geology, land use, rainfall, and some topographical factors influencing GE susceptibility. Subsequently, the inventory data was randomly split into two datasets; 182% or 70% training, and 78% or 30% validation, while influencing factors independence was assessed via multicollinearity scrutiny. Results of forward stepwise regression for the relationship between GE and selected factors indicated that distance from road is key to gully formation. After running the logit function, the resultant susceptibility map revealed that 3.1% of the study area was relatively safe, 50.1% less, 23.3% moderate, 19.2% high, and 4.3% extremely susceptible. Validation assessment using area under receiver operating characteristic curve provided 92.3% prediction accuracy. This study further confirmed logistic regression as an excellent and accurate data-driven method for spatial analysis and prediction of GE susceptibility. The method can be applied elsewhere with similar physiographic characteristics.

Keywords

Gully erosion susceptibility · Data-driven method · Spatial prediction · Logistic regression · Gombe State

D. Gideon
Department of Geography, University Malaya, Kuala Lumpur, Malaysia
e-mail: gdamsviva@gsu.edu.ng

F. B. Mustafa (✉)
Department of Geography, Gombe State University, Tudun-Wada, Gombe, Gombe State, Nigeria
e-mail: firuza@um.edu.my

3.1 Introduction

Gully erosion (GE) is the "erosion process whereby runoff water accumulates and often recurs in narrow channels and, over short periods, removes the soil from this narrow area to

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

F. B. Mustafa (ed.), *Methodological Approaches in Physical Geography*,
Geography of the Physical Environment, https://doi.org/10.1007/978-3-031-07113-3_3

considerable depths" (Poesen et al. 2003). The channel formed from this erosion process is generally classified as a "gully". Because it is a geographically widespread phenomenon, it is also known by a variety of native names like Ravine, Uvrag, Wadi, Nuallah or 'Cho, Hakisan Gaung, Carcava or Arroyo, Donga, and Kwari (in Hausa language) in France, Russia, Arabic, India, Malaysia (Malay), Spain, South Africa, and Northern Nigeria, respectively, (Castillo and Gómez 2016; Maria and Nicolae 2017).

> Gullies are commonly classified as "permanent" and "ephemeral" gullies. A permanent gully is a wide and deep channel eroded by concentrated flow removing the upland soil and parent materials, which cannot be eliminated through conventional tillage operations. Whereas ephemeral gullies are formed by a concentrated overland flow which can be remediated by conventional tillage operations (Garosi et al., 2019). Ephemeral gullies are smaller than permanent gullies but larger than rill systems. Unlike rills, ephemeral gullies are formed in the same location each season.

GE is a threshold phenomenon that is controlled by numerous factors. Thus, gullies occur only after a threshold of runoff erosivity and soil erodibility has been crossed. In addition to rainfall, runoff erosive power depends on topography that controls the discharge, concentration, and velocity of overland flow (Conoscenti et al., 2013). Morphology, density, and development of gullies in a particular area are also substantially regulated by the underlying bedrock (Poesen 2011). The incidence of a gully is also governed by soil resistance, which is dictated by soil properties such as texture, bulk density, moisture conditions, and organic matter content (Poesen et al. 2003). GE is also related to the type and stage of crop production, as well as tillage direction and conservation practices (Li et al. 2016). Also, several studies have reported triggering of gullies or increasing of GE rates as being caused by land use changes, intensification of farming activities, and overgrazing (Conoscenti and Rotigliano 2020).

Once formed, gullies become major sediment sources and often cause environmental problems within their reach (on-site effects) and downstream (off-site effects). Generally, GE results in different consequences: (i) significant land degradation and loss of productive capacity, (ii) high sediment yields and sediment discharge, which can transport both nutrients and pollutants, and (iii) sedimentation of reservoirs (reducing the water capacity of the reservoirs) and damage to the infrastructure and transport routes. Ecologically, GE can cause associated ecological problems such as eutrophication and acceleration of desertification processes. Therefore, the prediction of gully erosion susceptibility is the first and most important step in averting the undesired effects of gullies and achieving sustainable development (Rahmati et al. 2017b).

According to Domínguez-Cuesta (2013), susceptibility reflects the condition of becoming weak or easily influenced. In natural hazards terms, susceptibility is related to the spatial dimensions of hazards. It refers to the tendency of a region to experience the consequences of certain dangerous activity (e.g., floods, earthquakes, erosion, etc.) without considering either the moment of occurrence or possible casualties and financial impacts. Thus, GES may be defined as the probability of spatial occurrence of GE based on the relationships between the distribution of gullies in the past and factors that influenced their occurrence.

The prediction of GES involves several qualitative (Knowledge-driven) and quantitative (data-driven) methods. The knowledge-driven methods depend on expert opinions. The most common types of these methods simply use GE inventories to characterize sites of similar geographical properties that are susceptible to GE. Certain knowledge-driven approaches, however, incorporate the idea of ranking and weighting and may evolve to be semi data-driven in nature.

Examples are the use of the analytic hierarchy process (AHP) of Saaty and Vargas (2012) by Arabameri et al. (2019b) and weighted linear combination (WLC) by (Sujatha and Sridhar 2019). AHP involves building a hierarchy of decision elements (factors) and then making comparisons between possible pairs in a matrix to give a weight for each element and also a consistency ratio. It is sustained by three principles: decomposition, comparative judgment, and synthesis of priorities. WLC is a concept to combine maps of GE influencing factors by assigning a standardized score (primary-level weight) to each class of a particular parameter and a factor weight (secondary-level weight) to the parameters themselves. Being partly subjective, the results of these approaches vary depending on the knowledge of experts (Arabameri et al. 2019c).

Data-driven approaches rely on statistical description of the relationship between GE and influencing factors. They statistically assess the combination of the influencing factors that are more closely related to the spatial distribution of existing gullies. Therefore, according to the prevailing terrain conditions (e.g., slope angle, slope shape, lithology, land cover) it is possible to quantitatively predict the likelihood of future gully occurrence even in non-gully affected areas. In this process, data from past and present gullies are used to evaluate the relative importance of the influencing factors and respective classes. Data-driven GES models are sustained by three major assumptions: (i) gullies can be recognized, classified, and mapped; (ii) GE influencing factors can be identified, registered, and used to build GE predictive models; and (iii) future GE occurrence can be spatially predicted (Arabameri et al. 2019c; Zêzere et al. 2017). In other words, following the Uniformitarianism principle, the past and the present are considered keys to the future, hence it is assumed that future gullies are more likely to occur under the same geologic and geomorphologic conditions that led to past gullies.

Data-driven methods can be grouped in bivariate statistical analysis (BSA) and multivariate statistical analysis (MSA) (Lucà et al. 2011). The BSA compares independently each influencing factor with the GE distribution. Weights of the GE influencing factors are assigned based on gully density using different methods such as information value, weights of evidence, among others. Bivariate statistical models do not consider the interdependence of predictive variables, and this is a major drawback of the method (Arabameri et al. 2019c; Zêzere et al. 2017). The MSA evaluates the combined relationship between the dependent variable and a set of independent variables.

Numerous MSA methods exist, but those commonly used to predict GES include linear and quadratic discriminant analyses and logistic regression. Linear and quadratic discriminant analyses have been used by Arabameri and Pourghasemi (2019) to predict GES in Iran. The method was also reported to be significant to define GES classes in the Pathro River Basin of India (Gayen et al. 2019). Logistic regression has been applied for susceptibility mapping by various researchers including Lucà et al. (2011), Conoscenti et al. (2014), Reza and Ronak (2015), Arabameri et al. (2018), Razavi-Termeh et al. (2020), and Arabameri et al. (2020c). However, the logistic regression model is the most widely used among the MSA approach. Compared with other MSA methods, its independent variables do not need to be linearly related or normally distributed, and can be categorical, continuous, or their mixture. In addition to this, the logistic regression model can effectively combine with other statistical analysis methods and/or knowledge-driven methods to improve GES prediction. Hence, the main objective of this study is to extend the application of logistic regression as a technique within data-driven methods. The method was applied in South Gombe State, Nigeria, where land development is restricted by intense GE because of semi-arid climate and physiographic conditions. Also, a thorough literature review to date shows that despite the high sensitivity of this area to GE, no comprehensive studies have been carried out to identify areas that are particularly susceptible to GE at all.

3.2 Materials and Methodology

3.2.1 The Case Study—Southe Gombe State (SGS), Nigeria

SGS occupies about 8023 km^2 and is located within Gombe State, Nigeria. It is bounded by latitude 9°30′ and 10°20′ N and longitude 10°40′ and 11°50′ E (Fig. 3.1). SGS is characterized by a semi-arid type of climate marked by two distinct seasons: a rainy season from April to October and a dry season from November to March. The average annual temperature is 27 °C, while the average annual rainfall is about 835 mm with much of it falling between June and September. The rains come in the form of intensive, violent showers of short duration, especially at the beginning and end of the rainy season. The early rains of April which come just after the dry season are very effective in the gullying process. The low relative humidity, characteristic of the dry season, leaves the surface of the soil dry and cracked at various points. These cracks and other human features like footpaths, are rapidly exploited by the runoff from storms of the early rains and greatly favor the inception and subsequent evolution of gullies. Rain in the area may fall continuously for two, three, or more hours—although most of it comes during the first 40 min of the period of fall. They are the type of rainfall that causes so much damage in a relatively short time, especially in places where the soil is bare or is partially covered by vegetation which is incapable of protecting it from the erosive impact of the rain.

The geology of the area comprises of the crystalline basement and Cretaceous sedimentary Formations (Ikusemoran et al., 2018) (Table 3.1).

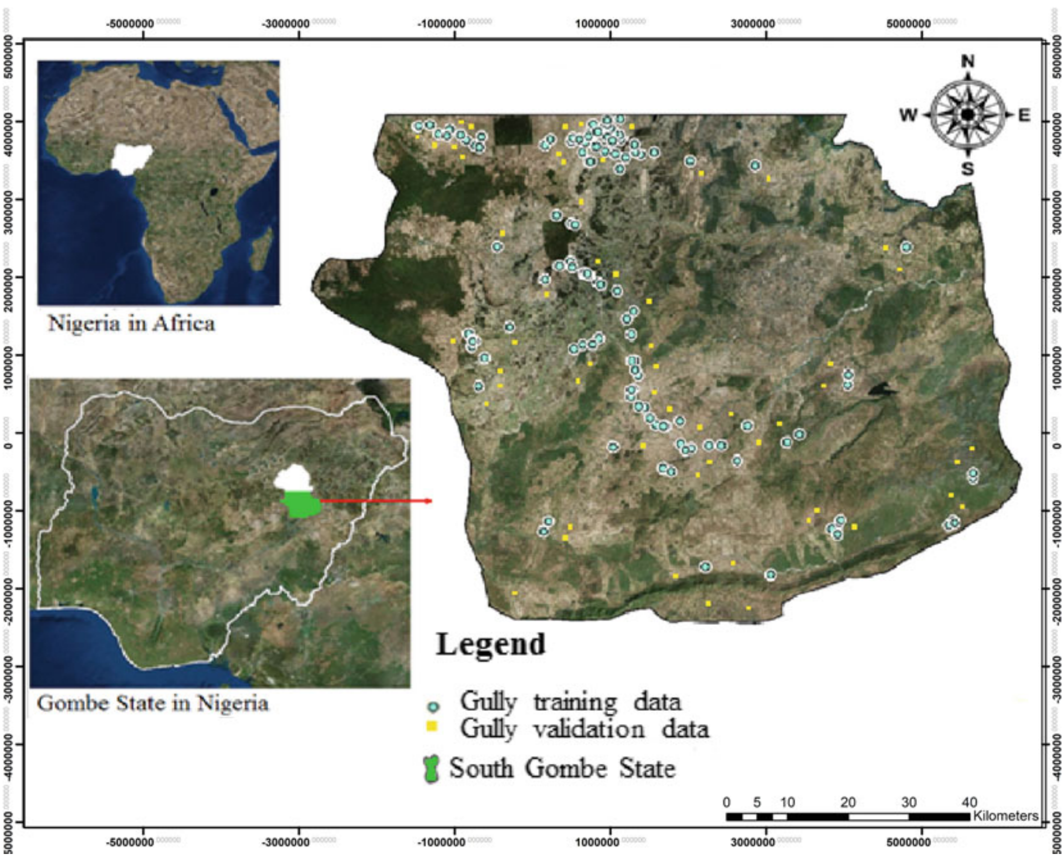


Fig. 3.1 Location of the study area and gully landforms distribution

Table 3.1 Geologic formations, lithological characteristics, and age of rock materials

Geologic formation	Lithologic units	Age
Alluvium	Alluvium	Holocene
Basalt	Basalt	Cretaceous
Kerikeri	Sandstone, shale, and clay	Palaeocene
Gombe	Sandstone, siltstone, shale, coal, and ironstone	Maastrichtian
Pindiga	Shale, limestone, and sandstone	Turonian
Yolde	Shale, limestone, and sandstone	Cenomanian
Bima	Sandstone, siltstone, and shale	Albian
Basement Complex	Porphyritic granite/coarse porphyritic biotite and biotite hornblende granite	Pre Cambrian
	Coarse, porphyritic hornblende granite	
	Undifferentiated granite, migmatite and granite gneiss	

The soils correlate with the underlying geology, and are mostly sandy, low in organic matter, and are characterized by low water-holding capacity. The only exception to this observation is the wetland (fadama) soils that are fine-textured with higher organic matter content and relatively higher water-holding capacity (Ikusemoran et al., 2016). Geomorphologically, the SGS is characterized by complex terrain and dominated by rugged hills of granite and sandstone, volcanic plugs, a sedimentary and volcanic plateau, and low, swampy plains; with elevation ranging from 200 m (a.s.l.) in the central parts to about 1170 m (a.s.l.) in the southern section. Land use in the area is characterized by livestock grazing, rain-fed farming, and dry season fadama (market gardening) cultivation.

3.2.2 Methodology

3.2.2.1 Spatial Data Used for the Study

The data used in this study was collected by integrating field data, remote sensing (RS) data, and geographic information system (GIS) applications. GIS data processing and computing can produce GE maps with low costs and acceptable accuracy. Also, GIS allows fast and easy representation and analysis of spatial data and can generally incorporate information layers from diverse sources (Arabameri et al. 2020d). Thus, the basic maps used in this study were satellite imageries archived by Google Earth, Landsat 8 images (spatial resolution 30 m), soil and geological maps (scale 1:100,000), and a Digital Elevation Model (DEM) with a spatial resolution of 20 m. Table 3.2 presents a summary of the data types used in the present study.

3.2.2.2 Spatial Analytical Process

Figure 3.2 displays the flowchart of the approach followed in this study and consists of the following steps: Spatial data collection which involves identification and extraction of permanent GE features (gully inventory data) and assembly of GEIFs; spatial data analysis comprising independence scrutiny (multicollinearity) among GEIFs, and random partitioning of the gully inventory data; susceptibility spatial prediction which involves a determination of the spatial relationship between GE and GEIFs, and estimation of the probability of gully occurrence and generation of GE susceptibility map; and Validation of results.

3.2.2.3 Spatial Data Collection

As described above, the assumption of susceptibility to GE is that past and/or present gullies are important for understanding the occurrence of future gullies, therefore, the acquisition and construction of GE inventory is considered an important step in geomorphological analyses and

Table 3.2 Summary of data used for the study

Data type	Sources	Uses
Gully inventory	Field surveys, Google Earth imagery, and NEWMAP	For identifying actual gully erosion locations in the study area
Rainfall	Gombe State University weather station, and the Nigeria Meteorological Agency (NiMet)	For classifying the amount of rainfall of the study area
Soil	Federal Department of Agricultural Land Resources (FDALR) Abuja, Nigeria	The base map for extraction of soil texture map of the study area
Geology	Nigeria Geological Survey Agency (NGSA)	The base map for extraction of the Geology map of SGS
Land use	Landsat 8 images with 30 m resolution—United State Geographical Survey (USGS)	For classifying and mapping land uses of the study area
Digital elevation model (DEM)	Developed from topographic maps (1:50,000) of the study area	For extraction of topographical factors related to the gully erosion formation in the study area

stochastic modeling like the present study. In this study, gully landforms (Fig. 3.3) were identified through the interpretation of Google Earth image taken in 2018, and comprehensive field surveys conducted in early 2019 using a global positioning system (GPS) to record coordinates of gullies. The gullies were mapped as polygons but later converted to points by considering the locations of the head-cut portion of each gully. An equal number of non-gully point locations were randomly selected and later combined with the gully locations.

As previously mentioned, GES is regulated by a variety of factors. However, it is difficult to use all factors at once (Arabameri et al. 2019a, b, c) and thus it is important to pick key factors that could theoretically affect GE in a specific area. Although, there is no standardized guiding theory for the selection of factors (Arabameri et al. 2018), comprehensive literature review, local environmental conditions in the study area, and multicollinearity checks were utilized to select 14 factors: rainfall, aspect, slope angle (SA), length of slope (LS), elevation, plan curvature (PC), topographic wetness index (TWI), stream power index (SPI), drainage density (DD), distance from stream (DS), distance from road (DR), geology, soil texture (ST), and land use (LU). After selecting and analysis of the GEIFs, it is essential to classify their numerical values for effective modeling, and when representing them on a map so that, visually, they can be as clearly understood as possible. For this reason, existing GISs are equipped with several methods for automatically performing the classification of susceptibility values. The commonly used ones include the quantile, equal interval, Jenks natural breaks, and geometrical interval classifications (Osaragi 2019). Those suitable for data used in this study have been applied.

3.2.2.4 Spatial Data Analysis

Partitioning of GE Inventory Data

Before its implementation, the logistic regression model must be trained and tested with two separate samples of data. But practice in early research on the implementation of logistic regression showed that for the percentage of training and testing samples, there is no clear rule of thumb. Nevertheless, it is suggested that the percentage for testing should be inversely proportional to the square root of the number of free adjustable parameters (Abdulkadir et al. 2020). Consequently, by using the unsupervised filtering procedures to avoid replications, the GE inventory data was divided into 70% training and 30% testing samples. This is consistent with the percentage of samples considered in related studies (Abdulkadir et al. 2020; Arabameri et al. 2020a; Rahmati et al. 2017a).

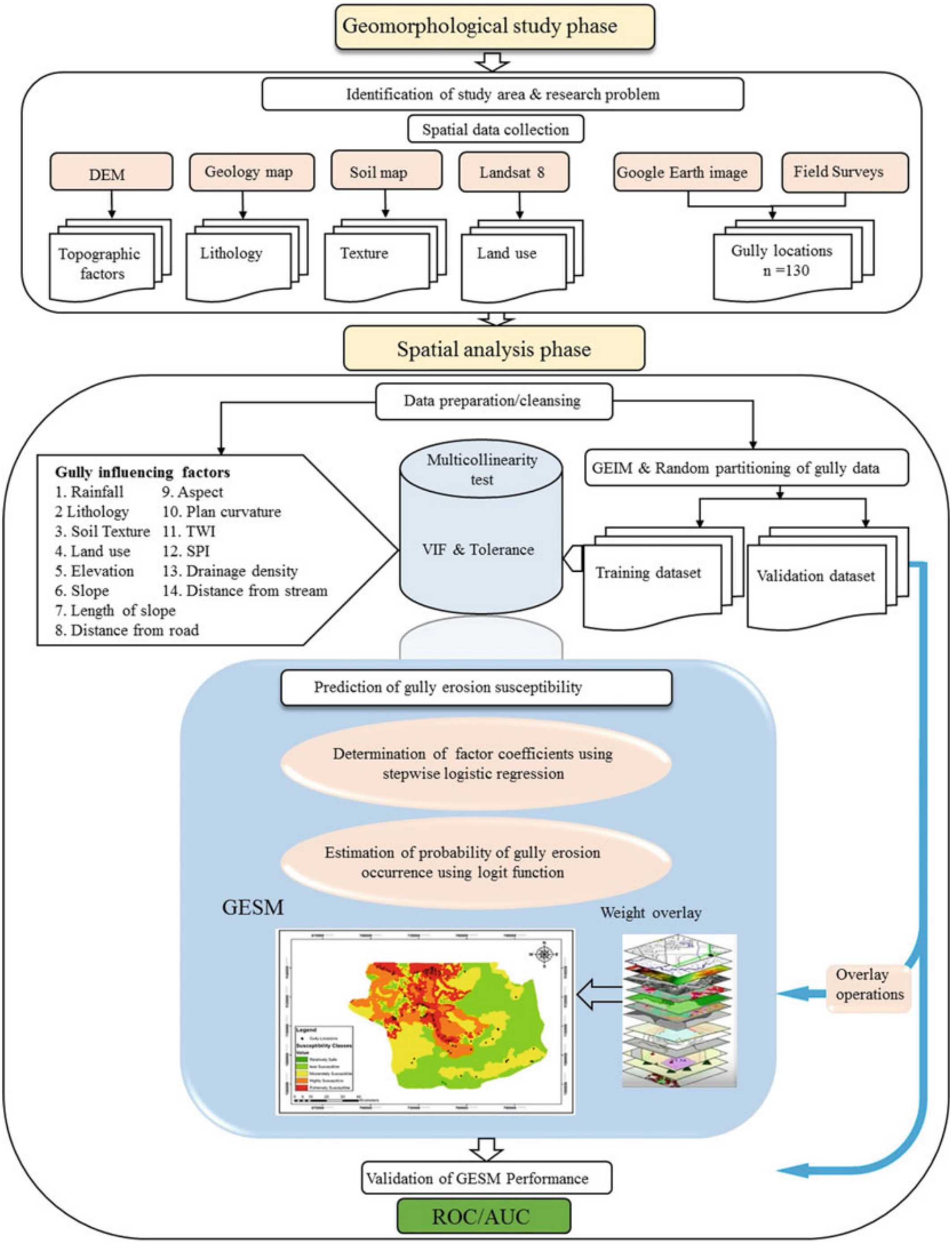


Fig. 3.2 Flow chart of data and procedures followed for the study

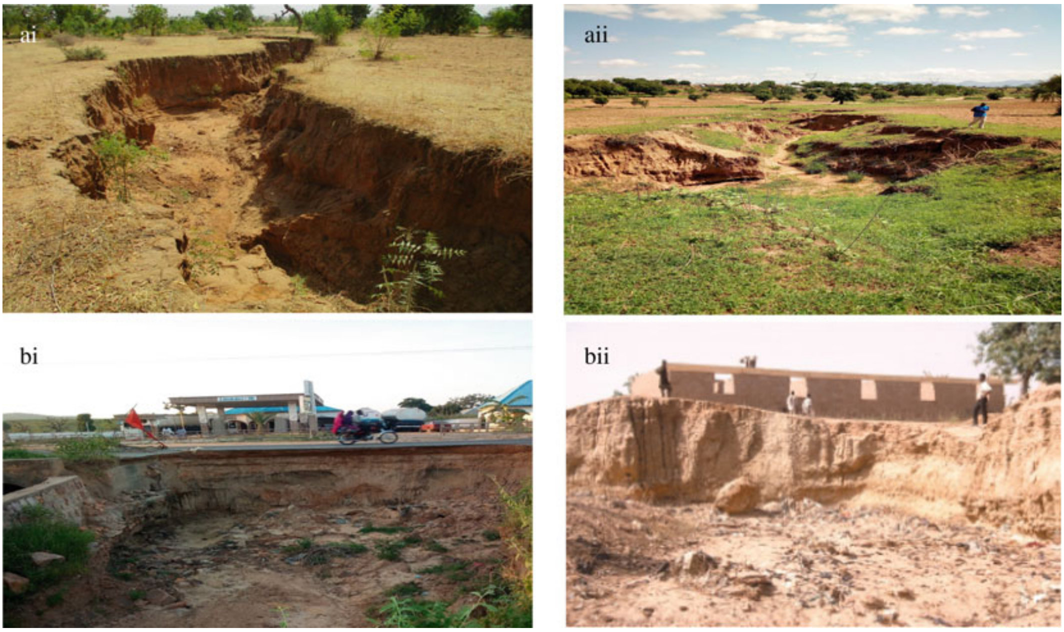


Fig. 3.3 Example of some identified gullies and their effects on (**ai** & **ii**) agricultural land (**bi** & **ii**), and on infrastructure in the study area

Extraction of GEIFs

Table 3.3 presents the methods of extraction and classification of GEIFs selected for the study. A Digital Elevation Model (DEM) with a spatial resolution of 20 m was produced from 1:50,000-scale topographic contour maps, and used for extraction of topographical factors: elevation, SA, LS, SPI, TWI, DD, DS, DR, aspect, and PC.

Elevation plays a significant role in determining vegetation cover type and to a large extend, precipitation characteristics (Gómez-Gutiérrez et al. 2015). Consequently, GE may occur in different elevations, depending on the initiating and developing mechanisms. SA plays a significant role in the dynamics of the processes controlling landscape development; it primarily affects surface runoff, DD, soil erosion, etc., (van der Meij et al. 2017). According to Conforti et al. (2010), steep SA facilitates high runoff velocity and consequent initiation of rill and gully. Hence, the SA is crucial for the prediction of GES. LS is the amalgamation of slope length (L) and steepness (S) of which L controls sediment detachment and generation, and S controls the movement of these sediments in response to intense rainfall and related runoff (Pradeep et al., 2014). It is a key variable used in GES assessment. Theoretically, areas with high LS values are prone to GE activity (Conoscenti et al. 2014; Lucà et al. 2011).

Stream power is an important factor considered in the assessment of GES. It is the potential for flowing water to perform geomorphic work and is used to measure the erosive power of water flow based on the assumption that discharge is proportionate to the catchment area. The index SPI is one of the main factors controlling slope erosion processes since the erosive power of running water directly influences slope toe erosion and river incision (Conforti et al. 2010). It is also indicative of the potential energy available to entrain sediment so that areas with high SPI have a great potential for erosion.

TWI relates local topographic slope to the upslope contributing area at any given location within a watershed. It is commonly employed as a proxy for the potential for surface and subsurface water accumulation due to runoff and lateral transmissivity (Raduła et al., 2018). Since the dynamics, location, and size of saturated source

Table 3.3 GEIFs and methods used for their extraction and classification

Factor	Extraction method/source	Classification method	Classes
Rainfall	Ordinary kriging interpolation	Natural break	< 950, 951–1000, 1001–1050, and >1050 mm (Fig. 4a)
Geology	Digitized from NGSA map (1:50,000)	Geologic units	Alluvium, Basalt flow, Bima, Gombe, Kerikeri, Basement, Pindiga, and Yolde (Fig. 4l)
ST	Digitized from soil characteristics map prepared by FDALR	Supervised classification	silt clay loam, silt clay, sandy, sandy loam, sandy clay loam, and loam sand (Fig. 4m)
LU	Extracted from Landsat 8 imagery	Supervised classification	bare surface, farmland, forest, built-up area, shrubland, waterbody, wetland, and woodland (Fig. 4n)
Elevation	Extracted from DEM using ArcGIS software with spatial analyst tool	Natural break	<300, 300–500, 501–700, and >700 m (Fig. 4b)
PC	Extracted from DEM	Natural break	flat, Concave, and Convex (Fig. 4k)
SA	Extracted from DEM	Natural break	<5°, 5–10°, 11–30°, 31–60°, and >60° (Fig. 4c)
Aspect	Extracted from DEM	Equal interval	flat, north, northeast, east, southeast, south, southwest, west, and northwest (Fig. 4j)
LS	Extracted from DEM using Moore and Burch, (1986) formula $\left(\frac{faXcellsize}{22.13}\right)\left(\frac{faXcellsize}{22.13}\right)0.4 \times \left(\frac{sin\alpha}{0.0896}\frac{sin\alpha}{0.0896}\right)^{1.3}\ldots$ (1) fa = flow accumulation; α = slope angle	Natural break	<3, 3–5, 6–10, 11–50, and >50 m (Fig. 4d)
SPI	Extracted from DEM using $AS\text{x}\tan\alpha\ldots(2)$ AS = catchment area; α = slope angle	Natural break	<30, 30–50, 51–100, 101–200 and >200 (Fig. 4e)
TWI	Extracted from DEM using Moore et al. (1991) formula: $\ln\left(\frac{As}{\tan\alpha}\frac{As}{\tan\alpha}\right)$ ...(3) AS = cumulative upslope area; α is slope angle	Natural break	<10, 10–12, 13–15, 16–18, and >18 (Fig. 4f)
DD	L/A…(4) L = Total length of streams A = size of catchment (Line Density Tool in ArcGIS)	Natural break	<0.5, 0.5–1.0, 1.1–1.5, and >1.5 km/km^2 (Fig. 4g)
DS	Euclidean distance tools in ArcGIS	Natural break	<50, 51–100, 101–300, 301–500 and >500 m (Fig. 4h)
DR	Euclidean distance and line density tools in ArcGIS	Natural break	<500, 501–1000, 1001–3000, 3001–5000 and >5000 m (Fig. 4i)

areas are controlled by subsurface hydraulic characteristics and watershed topography, TWI is frequently used to model GES. Technically, areas with larger upslope drainage areas and shallower slopes will produce larger TWI values, indicating a higher propensity for GE.

DD, also known as stream density, is the ratio of the total length of streams or channels in kilometer (km) to the size in km^2 of the area being studied. The measurement of DD is a useful numerical measure of landscape dissection and runoff potential. Hypothetically, a high DD

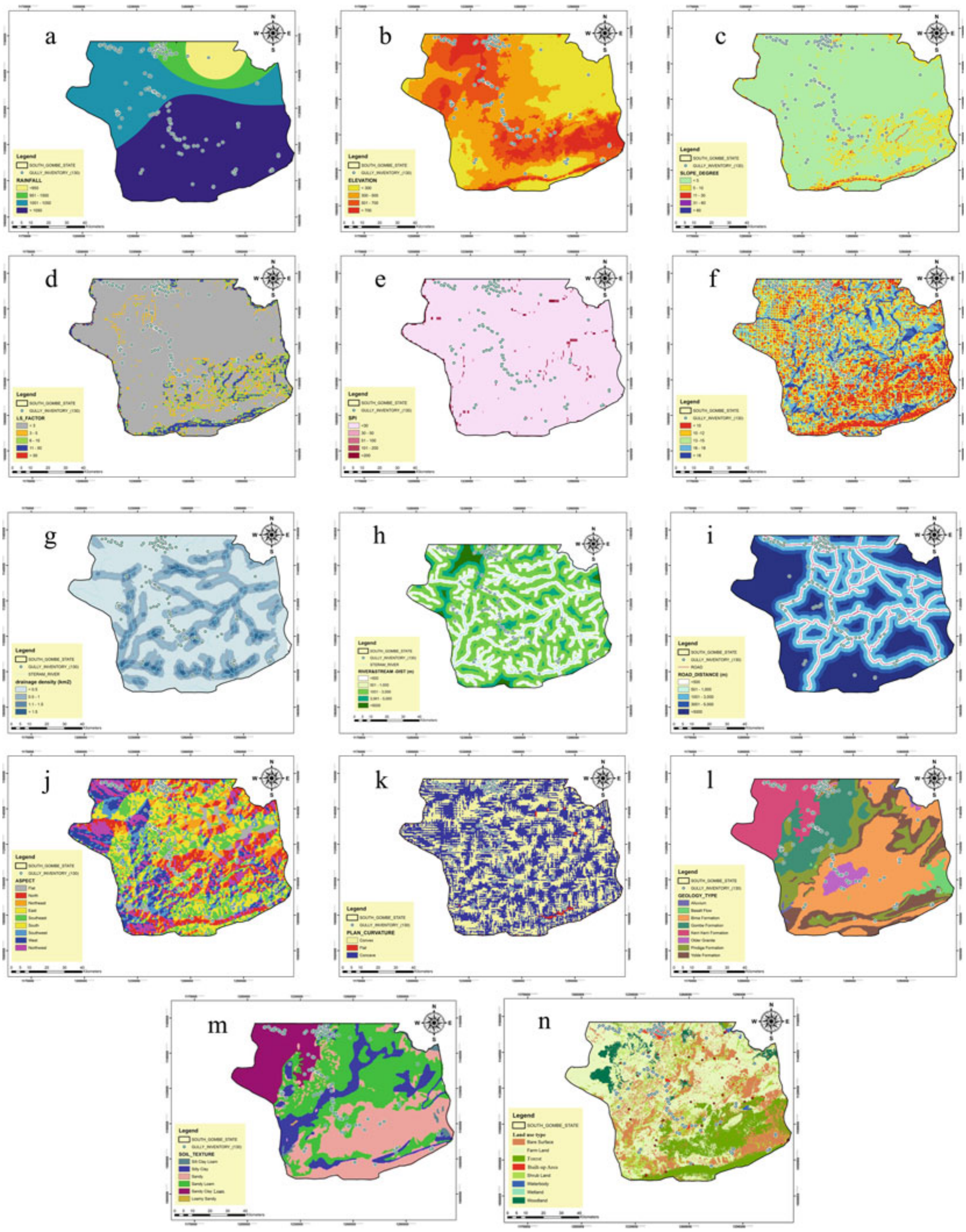


Fig. 3.4 GEIF Maps. **a** rainfall, **b** elevation, **c** SA, **d** LS, **e** SPI, **f** TWI, **g** DD, **h** DS, **i** DR, **j** Aspect, **k** PC, **l** geology, **m** ST, **n** LU

reflects a highly dissected drainage basin with a relatively rapid hydrological response to rainfall events, while a low DD entails a poorly drained basin with a slow hydrologic response (Charizopoulos et al. 2019). However, the critical value of DD per square km that may cause soil erosion by water is 0.90 km per square km of area (Surjit et al. 2015).

Gullies are generally connected to the stream network of an area, enabling the removal of the materials eroded from upland areas (Conoscenti et al. 2014). Joshi et al. (2019) observed that first- and second-order streams behave like gullies and accelerate soil erosion mechanism. These streams are normally located on greater elevations with steeper slopes and, thus, get conducive conditions for soil erosion. Further channel incision in those streams leads to their expansion and initiation of gullies in the nearby non-incised surface. For this reason, DS is recognized as a factor of gully development, with the assumption that the areas closer to existing first- and second-order streams are more susceptible to GE (Dube et al. 2014; Zakerinejad and Maerker 2015).

Roads play are important in rural and urban development; however, they have a significant impact on gully occurrence and distribution (Pourghasemi et al. 2017). Roads induce concentration of surface runoff, divert concentrated runoff to other catchments, and increase catchment size, which eventually leads to gully development (Conoscenti et al. 2014). Consequently, the spatial distribution of road networks was examined.

Aspect is a topographical attribute that is considered crucial in GES assessment. It is commonly referred to as the direction to which the slope face. Aspect is expressed in degrees from north and clockwise, ranging from 0 to 360. The value of negative one (−1) is used to indicate flat surfaces such as flood plains and fluvial terraces. According to Conoscenti et al. (2014) and Rahmati et al. (2016), aspect indirectly influences GE processes given its relationship with the duration of sunlight exposure, evapotranspiration, moisture retention, vegetation cover type, and distribution on slopes.

PC is described as the curvature of a contour line formed by intersecting a horizontal plane with the surface. The use of the word curvature technically defines the rate of change of SA or aspect, usually in a particular direction (Conforti et al. 2010). The influence of PC on slope erosion processes is the convergence or divergence of water during downslope flow. While assessing PC, positive values describe convexity, while negative values characterized the concavity of slope curvature. The values of the PC around zero indicate that the surface is flat.

Rainfall is a central factor that drives soil erosion and gully development through its potential ability (erosivity) to disintegrate soil aggregates and transport them downslope (Nearing et al. 2017). Rainfall erosivity is a function of the physical characteristics of rainfall (intensity and long duration). These aspects, in addition to those related to amount, drop size distribution, terminal velocity, and extraneous factors such as wind velocity and slope angle, determine rainfall erosivity (Rutebuka et al. 2020). Rainfall erosivity using annual rainfall distribution data from weather stations in SGS was analyzed.

Geological features and the weathering properties of material exposed or close to the earth's surface affect GE. Both soft and hard rocks are scourged by degradation through fluvial erosion, mass wasting, soil creeps, and landslides. Soft rocks are generally more susceptible to soil erosion than hard rocks. The extent of effectiveness of degradation is a function of the degree of consolidation or cementation among the different sedimentary types. GE in the areas underlain by rocks of the Basement Complex, including younger and older granites, usually occurs along modern and ancient water channels. These water channels have earlier been covered by alluvial deposits. Small scale gullies produced by fluvial action are generally associated with Basement Complex areas. Weathered zones of Basement Complex terrain are strewn with incipient and minor gullies running down slopes and generally oriented in all directions.

The Susceptibility of soil to GE is inclined to its characteristics which are closely associated with geologic settings and contribute expressively to soil infiltration, runoff rate, soil resistance to erosion, and gully occurrence (Rahmati et al. 2016). ST, organic content, structure, and permeability have been shown to influence soil erodibility. Predominantly, ST has a strong correlation with soil erosion as it controls the erodibility and cohesiveness of the soil (Pal 2015). Thus, ST was assessed for the present study.

LUs are among the major environmental factors regulating hydrological and geomorphological processes by controlling overland flow, runoff generation, and sediment dynamics. Naturally, barren lands and sparse rangeland are more susceptible to erosion than pastures and forests with dense cover, where the vegetation cover greatly cuts the erosive action of surface runoff. In fact, there is a negative association between the rate of erosion and the density of vegetation (Hayas et al. 2017). Figure 3.4 shows the 14 selected factors used for the study.

Multicollinearity Scrutiny

Multicollinearity is a statistical phenomenon that describes interdependency conditions among multiple independent variables. In other words, it is the lack of independence which is indicated by high intercorrelations among a set of variables. In GES assessment, numerous methods have been used to test for multicollinearity. However, the variance inflation factor (VIF) and tolerance (TOL) are frequently used for this purpose (Cama et al. 2017). Hence, the VIF and TOL are used in this study. A VIF $\geq$ 10 or TOL $\leq$ 0.1 indicates serious multicollinearity (Guo-Liang et al. 2017).

3.2.3 Susceptibility Spatial Modeling Using MLR

3.2.3.1 Determination of Spatial Relation Between GE and GEIFs

GEIFs have been assessed and their independence confirmed. However, there is the need to determine the relationship between the GEIFs and GE to identify the most influential factors, and successfully predict GES. To achieve this, the forward stepwise logistic regression was employed. Usually, stepwise logistic regression is most often used in situations where the important independent variables are not known, and their associations with the outcome are not well understood. It involves estimating the model with each variable entered in turn and looking at the change in the logarithm of likelihood when each variable is added. If the observed significance level (Wald test) is less than the probability for remaining in the model (0.05 in this study), the variable is entered into the model and the model statistics are recalculated to see if any other variables are eligible for entry. Finally, it becomes a model excluding all insignificant independent variables, and coefficients are allocated to the independent variable classes, correlated with the gully training data set. If a coefficient is positive, its transformed log value will be greater than one, meaning that the event is more likely to occur. If a coefficient is negative, the latter will be less than one, and the odds of the event occurring decreases.

3.2.3.2 Estimation of Probability of Gully Occurrence

The principle of logistic regression rests on the analysis of a problem, in which a result measured with dichotomous variables such as 0 and 1 or true and false, is determined from one to more independent factors. In the case of gully erosion susceptibility mapping, the goal of logistic regression is to find the best fitting model to describe the relationship between the presence or absence of gullies (dependent variable) and a set of independent parameters. Logistic regression generates the model statistics and coefficients of a formula useful to predict a logit transformation of the probability that the dependent variable is 1 (probability of occurrence of a gully event). Thus, in this study, binary Logistic regression estimates the probability (P) of the occurrence of a gully through the formula:

$$P = \frac{1}{1 + e^{-z}} \frac{1}{1 + e^{-z}} \tag{3.5}$$

where P is the probability of a gully occurring. Z is a value from $-\infty$ to $+\infty$, defined by the following equation;

$$Z = b_0 + b_1X_1 + b_2X_2 + \cdots b_nX_n \tag{3.6}$$

where b_0 is the intercept (constant) of the logistic regression model, n is the number of independent variables, and b_1, b_2, …, b_n are coefficients, which measure the influence or contribution of independent variables (X_1, X_2, …, X_n). In addition to the model statistics and coefficients, the outcome of the logistic regression process was obtained in ArcGIS as a predicted map of probability defined by numbers that are confined between 0 and 1. The predicted probability values were subsequently reclassified into five susceptibility classes using the Jenks natural classification method to produce the final gully erosion susceptibility map.

3.3 Validation of the GESM

Validation is the task of demonstrating that the model is a suitable representation of the actual system: that it reproduces system behavior with enough reliability to satisfy analysis objectives (Rahmati et al. 2017b). Without validation, the prediction model and image are ineffective and lack scientific significance. As a result, the final users would not be sure of the model outputs and are unlikely to use them for planning and decision-making. Normally, the validation of predictions is based on the comparison between the prediction results and the unknown target pattern, the areas affected by future gully erosion. The unknown target pattern is usually represented by a part of the known gully pattern. Usually, the comparison of the model results and observed data is represented through a confusion matrix (Table 3.4).

According to Table 3.4, TP (true positive) and TN (true negative) also known as sensitivity are the numbers of gullies that are correctly classified, whereas FN (false negative) and FP (false positive) referred to as specificity are the numbers of gullies that are incorrectly classified. Several approaches such as Efficiency, Kappa coefficient, Seed Cell Area Index (SCAI), Area Under Receiver Operating Characteristics (AUROC) among others have been used for validating GESMs. In this study, the AUROC is a graphical plot that illustrates the analytical ability of a model as its discrimination threshold is varied (Vakhshoori and Zare 2018). It is created by plotting sensitivity on the y-axis against specificity on the x-axis. The two parameters are derived as

$$\text{Sensitivity} = \frac{\text{TP}}{\text{TP}+\text{FN}}\frac{\text{TP}}{\text{TP}+\text{FN}} \tag{3.7}$$

$$\text{Specificity} = \frac{\text{TN}}{\text{TN}+\text{FP}}\frac{\text{TN}}{\text{TN}+\text{FP}} \tag{3.8}$$

The shape of the AUROC curve indicates the predictive performance of the model, where the predictive performance of the model is higher when the AUROC curve is closer to the upper left corner. The highest possible AUROC = 1 represents 100% specificity and 100% sensitivity. Furthermore, AUROC values of <0.6 indicate a poor, 0.6–0.7 a moderate, 0.7–0.8 a good, 0.8–0.9 a very good, and >0.9 an excellent model performance (Jiang 2020; Vakhshoori and Zare 2018).

3.4 Results and Discussion

3.4.1 Gully Erosion Inventory

The results of the interpretation of Google Earth imageries and field investigations confirmed that the study area is indeed affected by the GE phenomenon. A total of 130 critical gully

Table 3.4 Confusion matrix used for the evaluation of models

Observed	Predicted	
	Non-gully (−)	Gully (+)
Non-gully (−)	(−|−) True negative (TN)	(+|−) False-positive (FP)
Gully (+)	(−|+) False-negative (FN)	(+|+) True positive (TP)

eroding sites, covering 34,499.2 or 4.3% of the study area were identified and classified based on their position on the landscape and morphological hydraulic and geometry characteristic into three (3) main types of permanent gullies: continuous (35%), discontinuous (55%), and bank (10%). Generally, the gullies are characterized by incisions having near-vertical banks and are mostly large. Gully depth ranges from 0.9 to 12.2 m, less frequently up to 20 m and exceptionally even greater. The length reaches a maximum of 10,857 m on continuous, 497.2 m on discontinuous, and 1092.3 m on the bank gullies. Cross sections of the gullies are mostly U-shaped even though V-shaped gullies are also found. Spatially, it was observed in the northern parts of the study area, where Gombe and Kerikeri geologic formations are massively exposed that gully channels are mostly wide, U-shaped, and lack vegetation cover on the side slopes signifying active gullying stage. While in the mountainous southern part, narrow and V-shaped gullies are common with some vegetation growing on slopes indicating stabilization. However, the presence of falls on some of the channels indicated gully rejuvenation. Table 3.5 presents the morphometric characteristics of the identified permanent gullies in the study area.

3.4.2 Multicollinearity Scrutiny

The results of multicollinearity scrutiny as shown in Table 3.6 indicate that the highest value of VIF is 4.854 and the lowest coefficient of tolerance is 0.206, respectively. Therefore, there is no collinearity between these factors, and this allows the inclusion of all the factors in the final gully erosion susceptibility modeling process.

3.4.3 Susceptibility Spatial Prediction

3.4.3.1 Spatial Relationships Between GE and GEIFs

The results of the spatial relationship between GE and each GEIF obtained from the forward stepwise logistic regression are displayed in Fig. 3.5.

According to Fig. 3.5a, for all the rainfall classes, there is a positive relationship with GE occurrence since all the coefficient (β) values assigned to each class are positive. However, the rainfall classes 1001–1050 and >1100 with β values 2.261 and 1.183 exhibited a strong positive relationship when compared with the first two classes which were assigned weak positive association. The results suggest that the propensity of GE occurrence in the study area increases with an increase in rainfall amount. The result is in harmony with the findings obtained by Conforti et al. (2010) in the Turbolo catchment, Italy; Rahmati et al. (2016) in the Chavar region, Iran; and Makaya et al. (2019) in the upper uMgeni catchment in KwaZulu Natal, South Africa, who also showed that GE development generally occurs in regions with high rainfall amount.

Regarding elevation, regression analysis indicated that elevation has a positive but weak relationship with GE activity. From Fig. 3.5b it can be observed that an increase in elevation causes a corresponding increase in the probability of GE occurrence. This holds to the elevation class 300–500 m (β = 0.369) from which the

Table 3.5 Morphometric characteristics of the identified permanent gullies

Gully type	Length (m)			Width (m)			Depth (m)			Gullied area (ha)	Gully area (%)
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean		
Cont	2097	10,857	5550.7	6.4	68	31.4	1.4	20	12.2	21,950.1	64
Bank	777	1370	1092.3	4	43.1	6	0.9	13.4	1.8	8624.8	25
Discount	99.2	915	494.2	3.1	10.1	15.4	0.9	3.2	4.9	3924.3	11
Total										34,499.2	**100**

Table 3.6 Multicollinearity test results for the relationship among factors

Factor	Multicollinearity test		Factor	Multicollinearity test	
	Tol.	VIF		Tol.	VIF
Geology	0.578	1.730	Plan curvature	0.748	1.336
Soil texture	0.312	3.205	SPI	0.579	1.727
Land use	0.502	1.992	TWI	0.787	1.271
Aspect	0.906	1.104	Drain_density	0.206	4.854
Elevation	0.819	1.221	Dist_stream	0.872	1.147
Slope	0.613	1.631	Dist_road	0.287	3.484
LS	0.724	1.381			

relationship reverses and eventually becomes negative at the class >700 m (−0.299). This result agrees with the findings of numerous studies (Alireza et al. 2019; Arabameri et al. 2020d, 2019a; Rahmati et al. 2017b) who agreed that lower elevations are most susceptible to GE.

In the case of SA, a positive spatial correlation exists between gully formation and areas with SA below 30°. This is confirmed by the positive β values 1.387, 0.872, and 0.454 assigned to <5, 5–10, and 11–30 classes, respectively (Fig. 3.5 c). Conversely, for SA classes above 30°, β values were negative, indicating weak relationships and low probability of gully occurrence. This result is in agreement with Lazarus (2012); Adediji et al. (2013); Rahmati et al. (2016), (2017a); Debanshi and Pal (2018), and Arabameri et al. (2020d) who found most gullies occurring on lower slopes. According to these studies, the reason for this could be because lower SAs have greater soil depth, intensive rainfall impaction and greater runoff from upslope will decrease soil strength resulting in the development and extension of the gully channels.

The influence of LS on GE as shown in Fig. 3.5d revealed that the probability of gully occurrence increased with increasing LS. The highest probability was found where LS was 6–10 m (β = 1.262). However, immediately after this maximum level, the probability to host a gully abruptly decreased. The reason for this sudden decline was unclear, but it might relate to land use, vegetation, and other factors in the area. The result in this study confirms the findings of Bagio et al. (2017) and Zabihi et al. (2018) that a direct relationship exists between the LS and GE. Their result also implied that the higher the LS, the higher the probability of GE occurrence due to increased runoff velocity and a decreasing detachment and transport threshold of soil particles.

Concerning SPI, a significant positive association exists with GE. As shown in Fig. 3.5e a strong positive correlation was found in the class 51–100 (β = 3.456) and class 101–200 (β = 1.356). The remaining three classes had a low positive influence on GE. However, the results indicate that the probability to host a gully due to SPI increases with an increase in SPI. The outcome of this analysis is supported by the works of Shit et al. (2015); Rahmati et al. (2017a); Amiri et al. (2019); and Domazetović et al. (2019) who also observed that higher SPI values have higher erosion potential and often coincide with the appearance of soil removal and GE occurrence.

The bond between TWI and GE occurrence portrays an ascending pattern with the lowest class (<10) assigned the minimum β value (0.070) while the highest class (>18) got the maximum β value (3.112) (Fig. 3.5f). Thus, the result suggests that the probability of GE susceptibility intensifies with an increase in TWI. This result is similar to the study of Arabameri et al. (2020b) in the Chah Mousi watershed in Semnan province, Iran, that gully formation in the watershed is particularly favored in areas

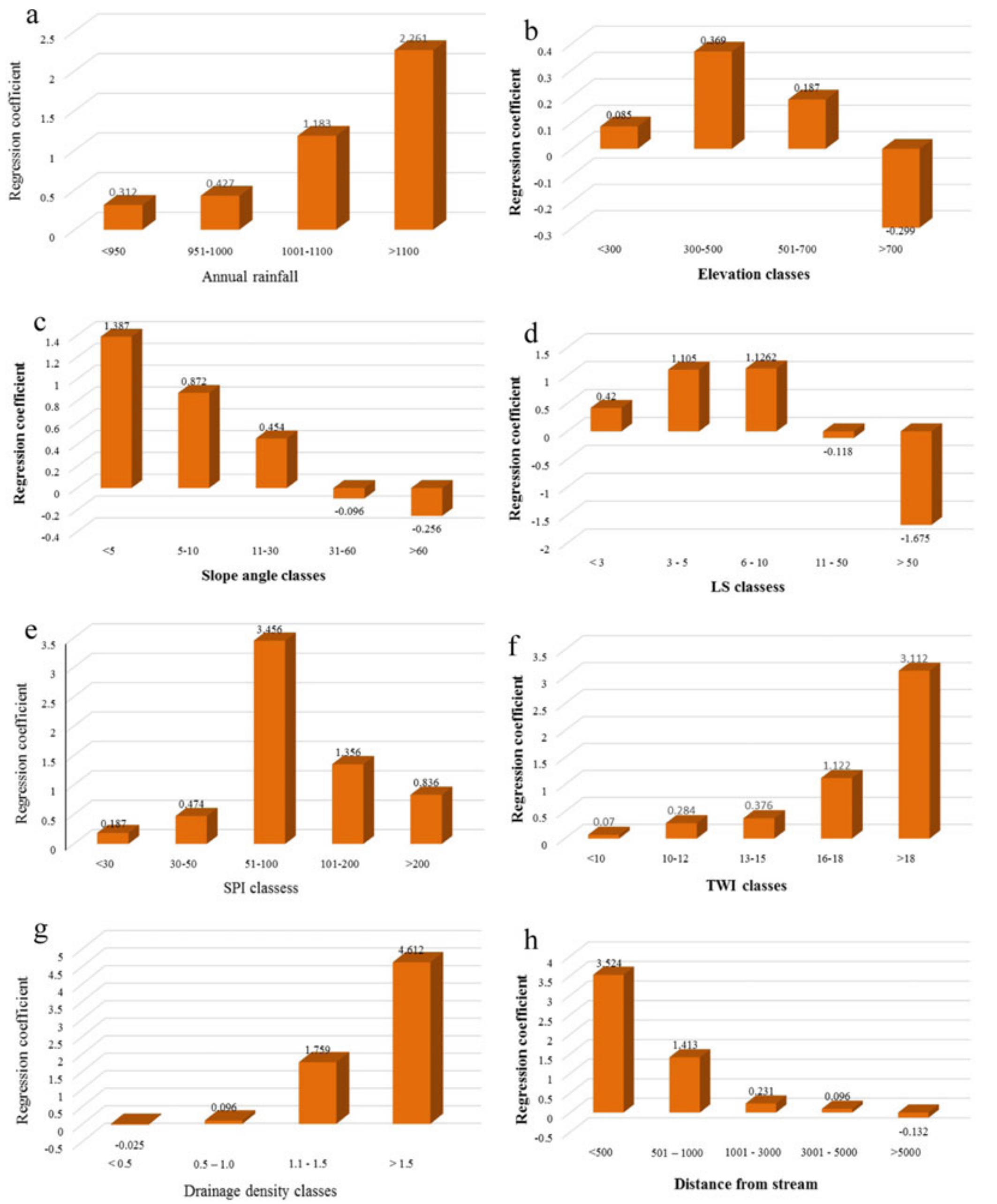


Fig. 3.5 Spatial relationships between GE and each class of GEIF **a** rainfall, **b** elevation, **c** SA, **d** LS, **e** SPI, **f** TWI, **g** DD, **h** DS, **i** DR, **j** Aspect, **k** PC, **l** geology, **m** ST, **n** LU

with high TWI values representing zones of saturation with high surface soil water along drainage paths. These saturated areas favor gully formation since the surface soils lose their strength as they become wet. Also, Zabihi et al. (2018) reported in their study in the Mazandaran province of Iran that, the greater the TWI factor, the greater is the potential for gully occurrence. High values of TWI increase the filtration rate and provide the conditions for piping and roof

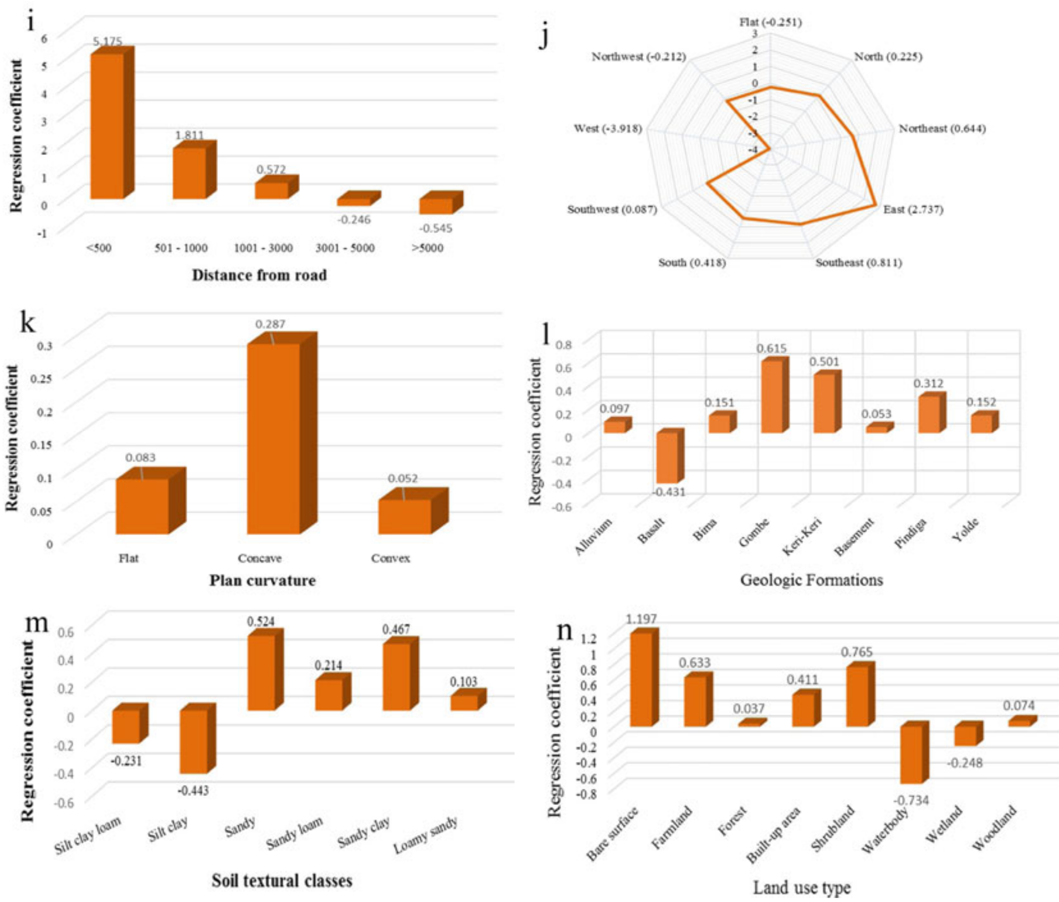


Fig. 3.5 (continued)

collapse, resulting in the development of gully tunnels and, eventually, the appearance of gullies on the surface.

Considering DD, the link with GE portrays an ascending pattern similar to the situation between TWI and GE. Positive relationships are observed in <1.5 ($\beta = 4.612$), 1.1–1.5 ($\beta = 1.759$), and 0.5–1.0 ($\beta = 0.096$) classes, while the class >0.5 ($\beta = -0.025$) exhibited a negative relationship (Fig. 3.5g). This means that susceptibility to GE due to DD increases with an increase in DD. Conoscenti et al. (2014); Dewitte et al. (2015); Rahmati et al. (2017a); Azareh et al. (2019); and Arabameri et al. (2020b) reported similar results.

The analysis concerning the association between DS and GE showed that GE increases as the DS decreases (Fig. 3.5h). In other words, locations at distances less than 500 m from a stream were more susceptible to GE. This finding conforms with reports by Dube et al. (2014), and Conoscenti et al. (2014) that close distances are more prone to gully development than on areas far from the stream. Like the case in DS, the relationship between GE and DR showed that the nearer the site to a road, the higher the potential for GE. Distances of less than 500 m from a road were positively correlated to gully locations (Fig. 3.5i), which highlights the importance of the roles of road development and disturbance of ground surfaces in promoting landscape degradation. This result is in consonant with findings of previous works ((Nyssen et al. 2002; Rahmati et al. 2017a; Seutloali et al. 2016) in that, when the distance from road increases, the probability of GE occurrence decreases. For aspect, positive correlation exists between east ($\beta = 2.737$), southeast ($\beta = 0.811$), northeast ($\beta = 0.644$), south ($\beta = 0.418$), north ($\beta = 0.225$), and southwest ($\beta = 0.087$) facing slopes. While west, northwest, and flat facing aspects exhibited negative relationships (Fig. 3.5j). This result implies that slopes facing north to southwest predominate and have a greater propensity to host gullies than slope aspect facing west. This is in agreement with Zabihi et al. (2018), who reported that eastward aspects in the Mazandaran province of Northern Iran are more susceptible to GE. This is so because the eastward facing slope aspects get more solar radiation in the northern hemisphere and, as a result, they experience more evaporation, higher soil porosity (total pore space), lower soil strength, and lower vegetation density.

The interpretation of the β values linking GE and PC classes revealed an all positive relationship (Fig. 3.5k). However, the concave class exhibited the strongest relationship with a β value of 0.287, followed by flat class (0.083), and convex class (0.021). There is a consensus between this result and the findings reported by Conforti et al. (2010) in the Turbolo catchment, Italy, and Rahmati et al. (2016) in the Chavar region, Iran, who also confirmed flat and concave curvatures are more prone to GE. About the connection between GE and geologic Formations, Fig. 3.5l showed that all Formations have a weak positive relationship with GE except Basalt Formation which had a negative relationship with the phenomenon. The positive relationship ranges from $\beta = 0.053$ on the Basement Complex to $\beta = 0.615$ on the Gombe sandstone. This confirms the study by Lazarus (2012) who concluded that the sandstones and shales that dominate Gombe States geology are more susceptible to GE than other geologic Formations in the area.

ST and GE revealed a significant relationship. However, among the six ST types (Fig. 3.5m), the sandy class had the highest positive β value (0.524), indicating the highest GE susceptibility, followed by sandy clay loam ($\beta = 0.467$), Sandy loam ($\beta = 0.214$), and Loamy sand ($\beta = 0.103$) accordingly. Contrarily, Silt clay loam and Silt clay obtained negative β values, showing the negative influence on GE incidence. A close look at the results also revealed that areas dominated by sandy loam and sandy clay loam hosted more gullies due to high sand contents that render them easily detachable. Similar work by Abdulfatai et al. (2014) and Igwe and Egbueri (2018) stated that the dominance of sand proportion in soils accelerates GE, while Silt clay loam and silt clay classes, due to sufficient and high clay content are resistant to soil erosion and gully development. Regarding LU (Fig. 3.5n), regression analyses established that bare surface, shrubland, farmland, built-up areas, and woodland have positive β values. The highest β value (1.197) was found on bare surfaces, followed by shrubland, which had a β value of 0.762. A negative relationship between LU and GE occurred in the wetland and waterbody classes, with waterbody having the lowest β value (−7.534). The finding is in harmony with previous studies (Amiri et al. 2019; Devátý et al. 2019; Shellberg et al. 2016), who concluded that protected locations like forest and rangelands experience less GE in comparison with bare surface regions.

3.4.3.2 The Relative Importance of the GEIFs

Following the stepwise regression allocation of β values to classes in all factors which confirmed their relationship with GES, the relative importance of each factor was determined based on the highest β value within the factor. The higher the β value, the stronger the effect of the given factor on GE occurrence. As shown in Table 3.7 and Fig. 3.6 DR, DD, DS, SPI, TWI, aspect, and rainfall had the strongest values and significantly contributed to GES whereas SA, LS, and LU exhibited moderate importance. In contrast, geology, ST, elevation, and PC were the least important and showed less impact in the gully occurrence in the study area, respectively. Therefore, this result suggests that among all the fourteen factors entered into the analysis, the DS factor by its highly significant β value is the most important single factor affecting GES in the study area.

Table 3.7 Relative importance and ranking of GEIFs

GEIF	β	Rank
DR	5.175	1
DD	4.612	2
DS	3.831	3
SPI	3.456	4
TWI	3.112	5
Aspect	2.737	6
Rainfall	2.261	7
SA	1.387	8
LS	1.262	9
LU	1.197	10
Geology	0.615	11
ST	0.524	12
Elevation	0.369	13
PC	0.287	14
Constant	−9.327	

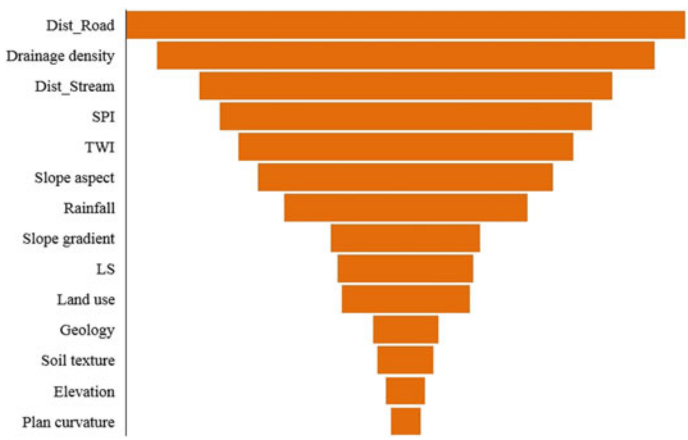


Fig. 3.6 Relative importance of GEIFs

3.4.3.3 GE Probability Mapping

After the influence of each factor class was determined, GES was predicted by computing the probability of gully occurrence in the study area. This was attained by executing Eq. 3.5 and 3.6. The value of z (Eq. 3.6) was computed by substituting b with the β values of the most important factors earlier determined. Because the highest positive significant coefficient in the analysis ($\beta = 5.175$) belongs to the DR factor class < 500, DR was introduced as the most significant determining factor for GE occurrence, thus assuming the rest of the factors are constant, for a unit change in DR, the probability of GE occurrence will be $e^{5.175}$ or 176.796 times. Hence, the β values of the most significant factors were inputted in the equation to compute z as

$$z = -9.327 + 5.175 * DR(Class1) + 1.811 * DR(Class2) + 4.612 * DD(Class1) + 1.759 * DD(Class2) + 3.831 * DS(Class1) + 1.413 * DS(Class2) + 3.456 * SPI(Class3) + 1.356 * SPI(Class4) + 3.112 * TWI(Class5) + 1.122 * TWI(Class4) + 2.737 * Aspect(east) + 2.261 * rainfall(Class4) + 1.183 * rainfall(Class3) + 1.387 * SA(Class1) + 1.262 * LS(Class3) + 1.105 * LS(Class2) + 1.197 * LU(baresurface) \quad (3.9)$$

Once the value of z was obtained, it was inserted into Eq. 3.10 and the probability of GE occurrence was calculated as

$$P(probabilityofgullyoccurrence) = \frac{1}{1 + e{-9.327 + 5.175*DR(Class1) + 1.811*DR(Class2) + 4.612*DD(Class1) + 1.759*DD(Class2) + 3.831*DS(Class1) + 1.413*DS(Class2) + 3.456*SPI(Class3) + 1.356*SPI(Class4) + 3.112*TWI(Class5) + 1.122*TWI(Class4) + 2.737*Aspect(east) + 2.261*rainfall(Class4) + 1.183*rainfall(Class3) + 1.387*SA(Class1) + 1.262*LS(Class3) + 1.105*LS(Class2) + 1.197*LU(baresurface)}} \quad (3.10)$$

The output of the above computation was subsequently transferred into the ArcGIS and the GESM with the probability (p) ranging from 0 to 1 was prepared. The produced map was then partitioned into 20 classes using a threshold of 0.05 equal probability intervals. After overlapping with the GE inventory map, a histogram representing the incidence of gullies and non-gully occurrence against the probability classes was plotted. Lastly, based on the histogram, the probability range was reclassified using the natural breaks classification method into five classes: 0–0.076, 0.076–0.494, 0.494–0.733, 0.733–0.898, and 0.898–1.00, representing relatively safe, less susceptible, moderately susceptible, highly susceptible, and extremely susceptible, respectively. Table 3.8 and Fig. 3.7 present the characteristics of the five susceptibility classes and the final GESM.

From a visual analysis of the final GESM (Fig. 3.7), it can be observed that most parts of the study area particularly the eastern and southwestern parts fall in the less and moderately susceptible classes, while the northwest and central parts fall in the highly and extremely susceptible classes. It was also observed from field observation that the areas within the high and extreme susceptibilities are mostly located near roads. This underscores the results of the relationship between GE and GEIFs of which DR

Table 3.8 Characteristics of the five GES classes

Susceptibility class	Susceptibility index	Surface area (ha)	Surface area (%)	No. gullies	% gullies
Relatively Safe	0–0.076	24,872	3.1	0	0
Less Susceptible	0.076–0.494	401,962	50.1	02	2.20
Moderately Susceptible	0.494–0.733	186,941	23.3	07	7.69
Highly Susceptible	0.733–0.898	154,045	19.2	16	17.58
Extremely Susceptible	0.898–1.00	34,500	4.3	66	72.53
Total		**802,320**	**100**	**91**	**100**

Table 3.9 Confusion matrix that presents results of the validation

Observed		Predicted			
		Gully (1)	Non-gully (0)	Total	% correct
	Gully (1)	37 (TP)	02 (FN)	39	94.87
	Non-gully (0)	04 (FP)	35 (TN)	39	89.74
	Total	41	37	78	92.31

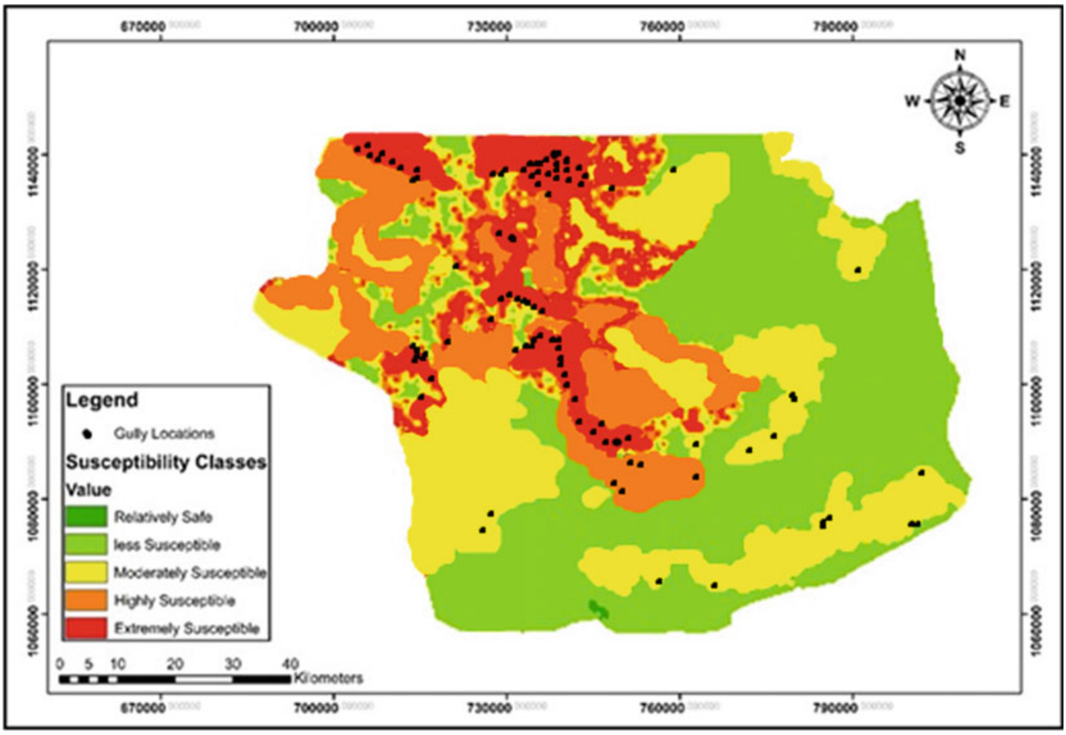


Fig. 3.7 Predictive GESM derived using the logistic regression model

(<500 m) is the most important single factor determining GE susceptibility in the study area

3.5 Validation

The predictive performance of the MLR model was evaluated using the validation data set (78). This was performed by calculating the values of sensitivity and specificity and then drawing the AUROC curve. As earlier indicated, sensitivity was computed using Eq. 3.7 as the fraction of locations hosting gullies that were correctly classified as susceptible, while specificity is derived from the fraction of areas free of gullies that were correctly classified as not susceptible using Eq. 3.8. Table 3.9 and Fig. 3.8 present the validation results and the AUROC curve. From Table 3.9 it can be seen that the model correctly classified 37 gully locations and 35 non-gully locations, representing 94.87% and 89.74%, respectively. Also, the overall predictive performance of the model as given by the value of AUROC (0.923% or 92.3%) indicates excellent performance.

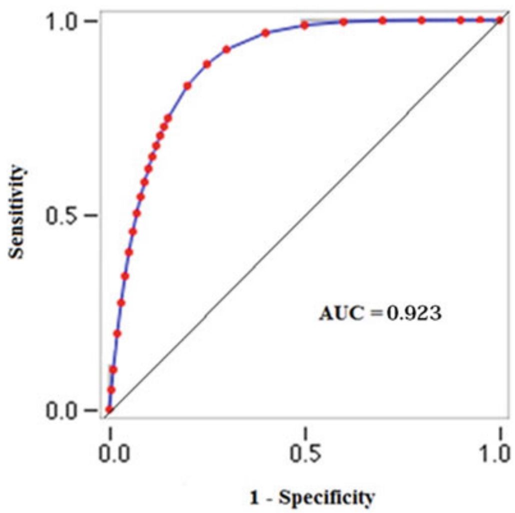


Fig. 3.8 AUROC curve for the final GESM

3.6 Conclusion

GE is the water erosion process that cuts soils and forms permanent gullies on the landscape that cannot be eliminated through conventional tillage operations. The formation and development of gullies is an important environmental threat throughout the world since it is responsible for land degradation, increase in sediment delivery, and reduction of water quality. It is also responsible for a decreased water travel time to rivers (and hence increased flooding probabilities), for the filling up of ponds and reservoirs, and for the destruction of infrastructure (buildings and roads). Therefore, the prediction of areas susceptible to GE is a crucial issue for environmental scientists, land managers, and decision-makers. To tackle this problem, researchers usually employ Knowledge-driven and Data-driven predictive methods. This study demonstrated the ability of data-driven logistic regression to accurately predict GES in SGS, Nigeria.

A GE inventory was prepared from a total of 260 gully and non-gully locations compiled from the interpretation of Google Earth images and field investigations. Besides, local environmental conditions and a 20 m DEM allowed the selection of soil texture, geology, land use, rainfall, and some topographical factors influencing GE susceptibility. Subsequently, the inventory data was randomly split into two datasets; 182 or 70% for training the logistic regression model, and 78 or 30% validation for validation of prediction results, while influencing factors independence was assessed using multicollinearity scrutiny. Results of forward stepwise regression for the relationship between GE and selected factors indicated that distance from road is key to gully formation. After running the logit function, the resultant susceptibility map revealed that 3.1% of the study area was relatively safe, 50.1% less, 23.3% moderate, 19.2% high, and 4.3% extremely susceptible. Validation assessment using area under the receiver operating characteristic curve provided 92.3% prediction accuracy. This study further confirmed logistic regression as an excellent and accurate data-driven method for spatial analysis and prediction of GE susceptibility. The method can be applied elsewhere with similar physiographic characteristics.

References

Abdulfatai IA, Okunlola IA, Akande WG, Momoh LO, Ibrahim KO (2014) Review of gully erosion in Nigeria: causes, impacts and possible solutions. J Geosci GeomatS 2(3):125–129

Abdulkadir TS, Muhammad RUM, Okeola OG, Khamaruzaman WY, Adelodun B, Aremu SA (2020) Spatial analysis and prediction of soil erosion in a complex watershed of Cameron Highlands, Malaysia. In: Shit P, Pourghasemi H, Bhunia G (eds) Gully Erosion Studies from India and Surrounding Regions. Advances in Science, Technology & Innovation (IEREK Interdisciplinary Series for Sustainable Development). Springer, Cham

Adediji A, Jeje LK, Ibitoye MO (2013) Urban development and informal drainage patterns: gully dynamics in Southwestern Nigeria. Appl Geogr 40:90–102

Alireza A, Artemi C, John PT (2019) Spatial pattern analysis and prediction of gully erosion using novel hybrid model of entropy-weight of evidence. Water 1129(11)

Amiri M, Pourghasemi HR, Ghanbarian GA, Afzali SF (2019) Assessment of the importance of gully erosion effective factors using Boruta algorithm and its spatial modeling and mapping using three machine learning algorithms. Geoderma 340:55–69

Arabameri A, Pourghasemi HR (2019) Spatial modeling of gully erosion using linear and quadratic discriminant analyses in GIS and R. In: Pourghasemi HR, Gokceoglu C (eds) Spatial Modeling in GIS and R for Earth and Environmental Sciences. Elsevier, pp 299–321

Arabameri A, Pradhan B, Lombardo L (2019a) Comparative assessment using boosted regression trees, binary logistic regression, frequency ratio and numerical risk factor for gully erosion susceptibility modelling. CATENA 183:104223

Arabameri A, Pradhan B, Rezaei K, Conoscenti C (2019b) Gully erosion susceptibility mapping using GIS-based multi-criteria decision analysis techniques. CATENA 180:282–297

Arabameri A, Rezaei K, Cerdà A, Conoscenti C, Kalantari Z (2019c) A comparison of statistical methods and multi-criteria decision making to map flood hazard susceptibility in Northern Iran. Sci Total Environ 660:443–458

Arabameri A, Chen W, Lombardo L, Blaschke T, Bui DT (2020c) Hybrid computational intelligence models for improvement gully erosion assessment. Remote Sensing 12(1):25

Arabameri A, Pradhan B, Bui DT (2020d) Spatial modelling of gully erosion in the Ardib River Watershed using three statistical-based techniques. CATENA 190:104545

Arabameri A, Pradhan B, Rezaei K, Yamani M, Pourghasemi HR, Lombardo L (2018) Spatial modelling of gully erosion using Evidential Belief Function, Logistic Regression and a new ensemble EBF–LR algorithm. Land Degrad Dev

Arabameri A, Blaschke T, Pradhan B, Pourghasemi HR, Tiefenbacher JP, Bui DT (2020a) Evaluation of recent advanced soft computing techniques for gully erosion susceptibility mapping: a comparative study. Sensors 20(2)

Arabameri A, Chen W, Blaschke T, Tiefenbacher JP, Pradhan B, Tien Bui D (2020b) Gully head-cut distribution modeling using machine learning methods—a case study of N.W. Iran. Water 12(16)

Azareh A, Rahmati O, Rafiei-Sardooi E, Sankey JB, Lee S, Shahabi H, Ahmad BB (2019) Modelling gully-erosion susceptibility in a semi-arid region, Iran: Investigation of applicability of certainty factor and maximum entropy models. Sci Total Environ 655:684–696

Bagio B, Bertol I, H, W. N., Schneiders, D., & Santos, M. (2017) Water erosion in different slope lengths on bare soil. Rev Bras Cienc Solo 41:e0160132

Cama M, Lombardo L, Conoscenti C, Rotigliano E (2017) Improving transferability strategies for debris flow susceptibility assessment: application to the saponara and Itala catchments (Messina Italy). Geomorphology 28852–65. https://doi.org/10.1016/j.geomorph.2017.03.025

Castillo C, Gómez JA (2016) A century of gully erosion research: Urgency, complexity and study approaches. Earth Sci Rev 160:300–319

Charizopoulos N, Mourtzios P, Psilovikos T, Psilovikos A, Karamoutsou L (2019) Morphometric analysis of the drainage network of Samos Island (northern Aegean Sea): insights into tectonic control and flood hazards. CR Geosci 351(5):375–383

Conforti M, Aucelli PPC, Robustelli G, Scarciglia F (2010) Geomorphology and GIS analysis for mapping gully erosion susceptibility in the Turbolo stream catchment (Northern Calabria, Italy). Nat Hazards 56 (3):881–898

Conoscenti C, Rotigliano E (2020) Predicting gully occurrence at watershed scale: comparing topographic indices and multivariate statistical models. Geomorphology 359:107123

Conoscenti C, Angileri S, Cappadonia C, Rotigliano E, Agnesi V, Märker M (2014) Gully erosion susceptibility assessment by means of GIS-based logistic regression: a case of Sicily (Italy). Geomorphology 204:399–411

Conoscenti C, Agnesi V, Angileri S, Cappadonia C, Rotigliano E, Marker M (2013) A GIS-based approach for gully erosion susceptibility modelling: a test in Sicily, Italy. Environ Earth Sci 70(3):1179–1195

Debanshi S, Pal S (2018) Assessing gully erosion susceptibility in Mayurakshi river basin of eastern India. Environ Dev Sustain

Devátý J, Dostál T, Hösl R, Krása J, Strauss P (2019) Effects of historical land use and land pattern changes on soil erosion—case studies from Lower Austria and Central Bohemia. Land Use Policy 82:674–685

Dewitte O, Daoudi M, Bosco C, Van Den Eeckhaut M (2015) Predicting the susceptibility to gully initiation in data-poor regions. Geomorphology 228:101–115

Domazetović F, Šiljeg A, Lončar N, Marić I (2019) Development of automated multicriteria GIS analysis of gully erosion susceptibility. Appl Geogr 112:102083

Domínguez-Cuesta MJ (2013) Susceptibility. In: Bobrowsky PT (ed) Encyclopedia of Natural Hazards. Encyclopedia of Earth Sciences Series. Springer, Dordrecht

Dube F, Nhapi I, Murwira A, Gumindoga W, Goldin J, Mashauri DA (2014) Potential of weight of evidence modelling for gully erosion hazard assessment in Mbire District - Zimbabwe. Phy Chem Earth Parts A/B/C 67(69):145–152

Garosi Y, Sheklabadi M, Conoscenti C, Pourghasemi HR, Van Oost K (2019) Assessing the performance of GIS-based machine learning models with different accuracy measures for determining susceptibility to gully erosion. Sci Total Environ 664:1117–1132

Guo-liang D, Yong-shuang Z, Javed I, Zhi-hua Y, Xin Y (2017) Landslide susceptibility mapping using an integrated model of information value method and logistic regression in Bailongjiiang watershed, Gansu Province, China. J Mountain Sci 14(2):249–268. https://doi.org/10.1007/s11629-016-4126-9.

Gomez-Guitierrez A, Conoscenti C, Angileri SE, Rotigliano E, Schnabel S (2015) Using topographical attributes to evaluate gully erosion proneness

(susceptibility) in two mediterranean basins: advantages and limitations. Nat Hazard 79(1):291–314. 1 https://doi.org/10.1007/s11069-015-1703-0
Gayen A, Pourghasemi HR, Saha S, Keesstra S, Bai S (2019) Gully erosion susceptibility assessment and management of hazard-prone areas in India using different machine learning algorithms. Sci Total Environ 668:124–138
Hayas A, Poesen J, Vanwalleghem T (2017) Rainfall and Vegetation effects on temporal variation of topographic thresholds for gully initiation in mediterranean cropland and olive groves. Land Degrad Dev 28 (8):2540–2552
Igwe O, Egbueri JC (2018) The characteristics and the erodibility potentials of soils from different geologic formations in Anambra State, Southeastern Nigeria. J Geol Soc India 92(4):471–478
Ikusemoran M, Didams G, Michael A (2018) Analysis of spatial distribution of geology and pedologic formations in gombe state, North Eastern Nigeria. J Geography Geol 10(1):83–108
Ikusemoran M, Wanah B, Mbaya L (2016) Geospatial techniques for terrain analysis of Gombe State, Nigeria. J Geography Environ Earth Sci Int 6(1):1–20
Jiang Y (2020) Receiver operating characteristic (ROC) analysis of image search-and-localize tasks. Acad Radiol
Joshi V, Susware N, Sinha D (2019) Estimating soil loss from a watershed in Western Deccan India using Revised Universal Soil Loss Equation. Landscape & Environ 10(1):13–25. https://doi.org/10.21120/le/10/1/2
Lazarus MA (2012) An assessment of gully erosion in Gombe Town, Gombe State, Nigeria. Unpublished Ph. D thesis. Department of Geography. University of Maiduguri, Borno State, Nigeria
Li H, Cruse RM, Bingner RL, Gesch KR, Zhang X (2016) Evaluating ephemeral gully erosion impact on Zea mays L. yield and economics using AnnAGNPS. Soil Tillage Res 155:157–165
Lucà F, Conforti M, Robustelli G (2011) Comparison of GIS-based gullying susceptibility mapping using bivariate and multivariate statistics: Northern Calabria, South Italy. Geomorphology 134(3–4):297–308
Makaya N, Dube T, Seutloali K, Shoko C, Mutanga O, Masocha M (2019) Geospatial assessment of soil erosion vulnerability in the upper uMgeni catchment in KwaZulu Natal, South Africa. Physics and Chemistry of the Earth, Parts A/B/C
Maria R, Nicolae R (2017) Gully erosion. In: Radoane M, Vespremeanu-Stroe A (eds) Landform Dynamics and Evolution in Romania. Springer Geography, Switzerland, pp. 371–396
Moore ID, Bruch GJ (1986) Physical basis of the length-slope factor in the universal soil loss equation. Soil Sci Soc America J 50:1294–1298
Moore ID, Grayson RB, Ladson AR (1991) Digital terrain modeling: a review of hydrological, geomorphological and biological applications. Hydrol Process 5:3–30
Nearing MA, Yin S-Q, Borrelli P, Polyakov VO (2017) Rainfall erosivity: an historical review. CATENA 157:357–362
Nyssen J, Poesen J, Moeyersons J, Luyten E, Veyret-Picot M, Deckers J, Govers G (2002) Impact of road building on gully erosion risk: a case study from the Northern Ethiopian Highlands. Earth Surf Proc Land 27(12):1267–1283
Osaragi T (2019) Classification and space cluster for visualizing geo information. Int J Data Warehousing Min 15(1):19–38
Pal S (2015) Identification of soil erosion vulnerable areas in Chandrabhaga river basin: a multi-criteria decision approach. Modeling Earth Syst Environ 2(1):5. https://doi.org/10.1007/s40808-015-0052-z
Pradeep GS, Krishnan MVN, Vijith H (2014) Identification of critical soil erosion prone areas and annual average soil loss in an upland agricultural watershed of Western Ghats, using analytical hierarchy process (AHP) and RUSLE techniques. Arabian J Geosci 8 (6):3697–3711
Poesen J (2011) Challenges in gully research. Landf Anal 17:5–9
Poesen J, Nachtergaele J, Verstraeten G, Valentin C (2003) Gully erosion and environmental change: importance and research needs. CATENA 50(2):91–133
Pourghasemi HR, Yousefi S, Komejady A, Cerda A (2017) Performance assessment of individual and ensemble data-mining techniques for gully erosion modeling. Sci Total Environ 609:764–775
Rahmati O, Haghizadeh A, Pourghasemi HR, Noormohamadi F (2016) Gully erosion susceptibility mapping: the role of GIS-based bivariate statistical models and their comparison. Nat Hazards 82(2):1231–1258
Rahmati O, Tahmasebipour N, Haghizadeh A, Pourghasemi HR, Feizizadeh B (2017a) Evaluating the influence of geo-environmental factors on gully erosion in a semi-arid region of Iran: an integrated framework. Sci Total Environ 579:913–927
Rahmati O, Tahmasebipour N, Haghizadeh A, Pourghasemi HR, Feizizadeh B (2017b) Evaluation of different machine learning models for predicting and mapping the susceptibility of gully erosion. Geomorphology 298:118–137
Radula MW, Szymura TH, Szymura M (2018) Topographic wetness index explains soil moisture better than bioindication with Ellenberg's indicator values. Ecol Indic 85:172–179
Razavi-Termeh SV, Sadeghi-Niaraki A, Choi S-M (2020) Gully erosion susceptibility mapping using artificial intelligence and statistical models. Geomat Nat Haz Risk 11(1):821–845
Reza E, Ronak S (2015) Evaluation of gully erosion susceptibility using logistic regression. in Salavat Abad, Kordestan Province. Arid RegNs Geogr Stud, 5(20)
Rutebuka J, De Taeye S, Kagabo D, Verdoodt A (2020) Calibration and validation of rainfall erosivity estimators for application in Rwanda. CATENA 190:104538

Saaty TL, Vargas LG (2012) Models, methods, concepts, and applications of the analytic hierarchy process, 2nd edn. Springer, US, p 346

Seutloali KE, Beckedahl HR, Dube T, Sibanda M (2016) An assessment of gully erosion along major armoured roads in south-eastern region of South Africa: a remote sensing and GIS approach. Geocarto Int 31 (2):225–239

Shellberg JG, Spencer J, Brooks AP, Pietsch TJ (2016) Degradation of the Mitchell River fluvial megafan by alluvial gully erosion increased by post-European land use change, Queensland, Australia. Geomorphology 266:105–120

Shit PK, Paira R, Bhunia G, Maiti R (2015) Modeling of potential gully erosion hazard using geo-spatial technology at Garbheta block, West Bengal in India. Model Earth Syst Environ 1(1–2)

Sujatha ER, Sridhar V (2019) Mapping of erosion susceptibility using a weighted linear combination model: a case study of a hill sub-watershed in Kodaikkanal, Western Ghats, South India. Remote Sens Appl: Soc Environ 14:34–45

Surjit S, Ravinder J, Satya PK (2015) Vulnerability assessment of soil erosion using geospatial techniques-a pilot study of upper catchment of Markanda River. Int J Adv Remote Sens, GIS Geogr 3(1):9–21

Vakhshoori V, Zare M (2018) Is the ROC curve a reliable tool to compare the validity of landslide susceptibility maps? Geomat Nat Haz Risk 9(1):249–266

van der Meij WM, Temme AJAM, Wallinga J, Hierold W, Sommer M (2017) Topography reconstruction of eroding landscapes—a case study from a hummocky ground moraine (CarboZALF-D). Geomorphology 295:758–772

Zabihi M, Mirchooli F, Motevalli A, Khaledi Darvishan A, Pourghasemi HR, Zakeri MA, Sadighi F (2018) Spatial modelling of gully erosion in Mazandaran Province, northern Iran. CATENA 161:1–13

Zêzere JL, Pereira S, Melo R, Oliveira SC, Garcia RAC (2017) Mapping landslide susceptibility using data-driven methods. Sci Total Environ 589:250–267

Zakerinejad R, Maerker M (2015) An integrated assessment of soil erosion dynamics with special emphasis on gully erosion in the Mazayjan basin, southwestern Iran. Nat Hazard 79(1):25–50. doi: https://doi.org/10.1007/s11069-015-1700-3

Didams Gideon is a Lecturer in the Department of Geography, Gombe State University, Tudun-Wada Gombe, Nigeria. He obtained both his Bachelor and Master of Geography degrees from the Federal University of Technology (now Modibbo Adama University of Technology (MAUTECH)), Yola Adamawa State Nigeria, and PhD in Physical Geography (Geomorphology) from the University of Malaya, Kuala Lumpur, Malaysia. He has over 10 years of teaching and research experience during which he has graduated several research students. He has also published research articles in reputable national and international journals and conference proceedings. His key research interests include soil erosion and modeling, watershed management and conservation, landscape reconstruction, application of machine learning algorithms, GIS, and remote sensing techniques in environmental geomorphology.

Firuza Begham Mustafa is an Associate Professor at the Department of Geography, Faculty of Arts and Social Sciences, University of Malaya. She specialized in agriculture geography, environment management and geophysical fields. She has produced more than 110 publications including in journals, conferences papers, IPs and posters. She has also written chapters on many international books and published several scientific books. She served in the Editorial Board Water Conservation Management (WCM), Editorial Board of Geology, Ecology and Landscapes (GEL), International Journal of Creative Industries (IJCREI) and Editorial Board of the Malaysian Journal of Tropical Geography (MJTG), University of Malaya. She was appointed as Visiting Fellow of Qinghai National University, China. She actively participated in Theo Murphy High Flyers Think Tank of Australia in 2011 and 2012. She is also Council Member of the International Geographical Union Commission on Commission Marginalization, Globalization, and Regional and Local Responses- C16.29, a member of International Geographical Union for Commission on Geographical Education, a member of the Southeast Asian Geography Association (SEAGA) and the Centre for Global Geography Education (CGGE) training by Association of American Geography (AAG). She is an Associate Fellow (AFMSA) of the Malaysian Scientific Association (MSA). She served as Auditor for Malaysia Qualification Agency (MQA) since 2009 for Geography and Environmental subjects.

Check for updates

4 Methods and Approaches of Flood Susceptibility Assessment and Mapping: A Review in Geographical Perspective

Khadija Bibi, Fareeha Siddique, Shehla Gul, Atta-ur Rahman, and Firuza Begham Mustafa

Abstract

Flood is one of the most common natural disasters having a devastating effect on human beings and their livelihood. Flood susceptibility assessment and zonation are necessary for flood prevention and mitigation strategies. To predict the probability and vulnerability of flood, essential steps are flood susceptibility mapping and zonation. The main objective of this work is to examine the application of different approaches that have been used for flood hazard assessment in different parts of the world. The major hydrological methods include statistical models, machine learning algorithms, and hybridized models. GIS and RS in integration with these models make it easier to predict future floods and identify the flood-prone areas. To overcome the limitations of a single method, hybridization of models has been introduced. This chapter is divided into six sections and the first section gives an introduction to the chapter. The second explains a global overview of flood disasters. Flood and flood susceptibility in Pakistan are discussed in the third section. The fourth portion of the chapter gives a detailed explanation of models and approaches used in the susceptibility mapping of flood hazards. The fifth section deals with the merits and demerits of the models, whereas the conclusion and way forward are illustrated in the last part of the chapter.

Keywords

Flood susceptibility modeling · Hydro-meteorological disaster · Geographic information system · Remote sensing · Flood susceptibility index

4.1 Introduction

Flood is "a huge amount of water that overflows the natural as well as artificial embankments of a river or other water body and spill onto the adjacent floodplain" (Rahman and Khan 2011). Globally, the frequency of hydro-meteorological disasters is increasing (Fendler 2008). Among various types of natural hazards, a flood is considered a destructive one (Doocy et al. 2013) and occurs with varying durations and different intervals (Tehrany et al. 2015).

Floods are divided into different types, based on their locations and causes. Kron (2005) classified floods into coastal floods, riverine floods, urban or pluvial floods, flash floods, landslide

K. Bibi · F. Siddique · S. Gul · Atta-ur Rahman (✉)
Department of Geography, University of Peshawar, Peshawar 25120, Pakistan
e-mail: atta-ur-rehman@uop.edu.pk

F. B. Mustafa
Department of Geography, University Malaya, Kuala Lumpur, Malaysia
e-mail: firuza@um.edu.my

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

F. B. Mustafa (ed.), *Methodological Approaches in Physical Geography*, Geography of the Physical Environment, https://doi.org/10.1007/978-3-031-07113-3_4

lake outburst floods (LLOFs), and glacial lake outburst floods (GLOFs). The events where, in the initial hours of heavy rainfall, a speedy increase in the water level is observed are flash floods (Das 2019). It causes the deaths of around 5000 or more people per year globally, making it four times greater than the rest of the flood events (Pham et al. 2020). Globally, about 50% of the human fatality and one-third of economic losses are caused by riverine floods (Zhang et al. 2008). The catastrophic release of water from glacial lakes is known as GLOF (ICIMOD 2011). With disastrous impacts, GLOFs are more frequent and repeatedly occur at the bottom of the mountains (Viviroli and Weingartner 2004). LLOFs are generated by the interaction of hydro-geomorphological and hydro-meteorological processes by temporarily blocking the river channel (Ruiz-Villanueva et al. 2017). These floods are very frequent in the Hindu Kush-Himalayan region due to the interaction of geomorphic processes, topography, climatic factors, and seismicity of the region (Hong et al. 2015).

Floods are generated as a result of both natural and human-induced factors (Barredo 2009). Natural factors include climatic variability, prolonged and heavy rainfall, glaciers and snowmelt, volcanic eruptions, and landslides, whereas rapid population growth, urbanization, unplanned changes in land use, poor dams and infrastructure construction, weak flood defense system, and management are included among the anthropogenic factors (Gaurav et al. 2011). Of all the factors, extreme rainfall has been considered the major cause of flooding (Hunter et al. 2005), and is intensified by the steep morphology and impervious surfaces (Van den Honert and McAneney 2011). The increase in the frequency of floods is related to the global climate change that occurs in recent decades (Rahman and Khan 2013).

Flood causes damage to crops, infrastructure, transportation, irrigation system, and population. Moreover, it erodes the soil, changes river morphology, and weakens the foundation of the building and settlements (Mahmood 2012). Flood has hit multiple areas of the world at different times, but after 1950, the frequency of flood has increased and the anthropogenic activities are considered an important factor for flooding (Yu et al. 2009). Researchers and planners have formulated a variety of flood management strategies that include forecasting, pre and postflood measures (Kourgialas and Karatzas 2011). The first step in flood management and mitigation is susceptibility mapping (Wu et al. 2010). These maps are advantageous in developmental planning, in the investigation of flood-prone areas, and in the selection of appropriate strategies. Thus, flood susceptibility mapping is a preparedness measure for flood risk remission and management (Ali et al. 2019).

4.2 Global Overview of Flood Disasters

Roughly, 2.3 billion people worldwide are affected by floods each year, which accounts for around 47% of all weather-related hazards (Uddin et al. 2013). Flood constitutes 31% of the global damages resulting from natural disasters (Yalcin and Akyurek 2004). More than one-third of the world's land surface is exposed to floods where about 75% of the population is living (Aksoy et al. 2016). Globally, the occurrence of floods has increased by 40% over the last decades (Hirabayashi et al. 2013). It was estimated that the number of people living in the flood zones would be around 1.3 billion in 2050 (Ligtvoet et al. 1991).

The changing climate and weather patterns are responsible for the increasing magnitude and frequency of the flood (Dobler et al. 2012). According to a report (UNISDR 2015), from 1996 to 2015, flood caused about 150,061 fatalities worldwide, representing 11.1% of global disaster mortality. Globally, about 99 million people per year were affected by a flood between 2000 and 2008. In 2010, almost 178 million people were influenced by flooding and the total losses recorded between 1998 and 2010 were more than $40 billion (Leskens et al. 2014). It was reported that during 2011–2012 flood caused an impact on the lives of nearly 200 million people and the total losses were about 95 billion dollars (Ceola et al. 2014). In the year 2013, damages caused by flooding were over 50 billion US$ worldwide. The average annual deaths caused by floods from 2006 to 2015 are 5,709. In 2016, the lives of almost 4,731 people were taken by floods worldwide (Wasko and Sharma 2017).

Recently, flood disasters have been reported on all the continents of the world. In Asia, about 90% of human deaths and 50% of economic losses are caused as a result of floods (Smith 2013). The major countries hit more frequently by floods in Asia are China, Indonesia, India, and Pakistan. The geographic location of Asian countries makes them more vulnerable to floods (Islam et al. 2016).

Globally, natural disasters cause irretrievable damages (Vorogushyn et al. 2012) and the planet earth has been a target of them majorly after the 1950s (McBean 2012). In the last 30 years, about 80% of the world's disasters hit nine countries, including Egypt, Somalia, Afghanistan, Yemen, Algeria, Sudan, Morocco, Iran, and Pakistan (UNISDR 2011). Therefore, the generation of appropriate hydrological models for flood analysis is the need of the hour (Fenicia et al. 2014).

4.3 Floods and Flood Susceptibility in Pakistan

Pakistan is a country in South Asia and its northern part is located within the highest mountainous region of the world. It has an area of 796,000 km^2 and holds a population of around 207.774 million. Pakistan is within the top ten countries that experience climate-related disasters. Our country is highly affected by floods, making it the fifth country in South Asia that is affected most by flooding (Price and Mittra 2016). It experiences floods almost every year (Shabbir et al. 2016). These events are of various magnitudes and are generated by both natural factors and anthropogenic activities (Rahman and Khan 2013). In the last decades, anthropogenic activities such as deforestation, a limited number of structural measures, changes in land use, and vicinity to the river coasts have intensified the flood occurrence (Qasim et al. 2016). The floods that come in rivers, both major (Indus, Jhelum, Chenab, Ravi, Sutlej) and secondary (Kabul, Swat) are responsible for a large amount of damage to communication networks and irrigation and cause land erosion by inundating low-lying areas around the rivers banks.

Pakistan has faced 25 disastrous floods (Table 4.1) since its creation in 1947 with both direct and indirect effects (GoP 2018). Due to these events, around 0.6 million km^2 of the land area is affected, more than 12,000 human fatalities, and thousands of villages were completely or partially damaged. In 2003, a 2-day wet spell caused a flood in the Sindh province and an urban flood in the Karachi area. In the year 2007, Baluchistan, Khyber Pakhtunkhwa (KP), and Sindh were hit by flood, displacing a population of above 20,000 and causing 152 deaths (GoP 2017). In 2010, Pakistan experienced a devastating flood (Table 4.1). The duration of this event was about 100 h with flood peak discharge ranging from 12 to 24 h (Asrar-ul-Haq and Zaidi 2011). This flood affected the Indus Basin and its major tributaries and was known as the worst flood that occurred in this region (Rahman and Khan 2011). Since 2010, Pakistan has been experiencing floods almost every year causing greater damages to both life and property (Table 4.1).

In Pakistan, work on flood susceptibility and hazard assessment was carried out in different river basins. Mahmood and Rahman (2019a) conducted a study on flash flood susceptibility modeling using geo-morphometric and hydrological approaches in Panjkora Basin, Eastern Hindu Kush, Pakistan. In this study, the outputs of both models were combined by using the weighted overlay analysis technique and a susceptibility map was obtained. Moazzam et al. (2020) carried out a study on flood susceptibility assessment in River Swat, District Charsadda,

Table 4.1 Flood events in Pakistan modified after Rahman and Shaw (2015) and GoP (2018)

S. no.	Year	Direct losses (US$ million)	Fatalities (Number)	Affected villages (Number)	Affected area (km^2)
1	1950	488	2,190	10,000	17,920
2	1955	378	679	6,945	20,480
3	1956	318	160	11,609	74,406
4	1957	301	83	4,498	16,003
5	1959	234	88	3,902	10,424
6	1973	5134	474	9,719	41,472
7	1975	684	126	8,628	34,931
8	1976	3485	425	18,390	81,920
9	1977	388	848	2,185	4,657
10	1978	2227	393	9,199	30,597
11	1981	299	82	2,071	4,191
12	1983	135	39	643	1,882
13	1984	75	42	251	1,093
14	1988	858	508	100	6,144
15	1992	3010	1,008	13,208	38,758
16	1994	843	431	1,622	5,568
17	1995	376	591	6,825	16,686
18	2010	10,000	1,985	17,553	160,000
19	2011	3730	516	38,700	27,581
20	2012	2640	571	14,159	4,746
21	2013	2000	333	8,297	4,483
22	2014	440	367	4,065	9,779
23	2015	170	238	4,634	2,877
24	2016	6	153	43	–
25	2017	–	172	–	–
Total		**38,171**	**12,502**	**197,273**	**616,598**

Pakistan, by using the statistical information value method. In this study, three different models were created based on the percentage of training and validation inventory data. The prediction rate curve and success rate illustrated that model with 70% training and 30% validation inventory data has more accuracy than the other. A similar study was conducted by Ullah and Zhang (2020), in Panjkora Basin, Eastern Hindu Kush, Pakistan using a relative frequency ratio method, and another by Ahmad et al. (2020) in the drainage basins of Dir Lower, Khyber-Pakhtunkhwa, Pakistan and by Mahmood and Rahman (2019b), in Ushairy Basin, Eastern Hindu Kush, Pakistan.

4.4 Methods and Approaches of Flood Susceptibility

Flood risks cannot be controlled permanently but their effects can be reduced by proper planning and by using appropriate structural and non-structural techniques. Susceptibility analysis considers many different standards to assess the related problems in different regions of the world. With the increasing criteria, the chances of the error have also increased (Tiryaki and Karaca 2018). To deal with this issue, GIS is a major tool that has been used globally to assess various types of data. Different research used different models and approaches to perform susceptibility analysis on the basis of their own interests and the data is collected from various sources (see, for example, Bui et al. 2019; Mahmood and Rahman 2019b; Rahmati et al. 2016). To predict future floods, it is necessary to analyze the historical flood events (Manandhar 2010). For susceptibility mapping, the construction of the flood inventory database is essential and is prepared by using a single or a combination of some techniques. The selection of the method is dependent upon the objectives of the research, condition of the study area, investigators' skills and experience, and availability of GIS and RS data (Van Westen et al. 2006; Fig. 4.1).

When assessing the probability of flooding during a particular time period and in a specific environment, it is essential to distinguish the conditioning factors and the situations that can cause the flood (Yalcin et al. 2011). The selection of causal factors is the primary step in developing a flood susceptibility map. These factors also have an impact on the accuracy of the final maps (Tehrany et al. 2014). They contribute to the occurrence of floods and vary from region to region. The most commonly used factors are slope, land use, curvature, distance from river, soil type, altitude, Topographic Wetness Index (TWI), rainfall, Stream Power Index (SPI), lithology, Stream Transport Index (STI), and Normalized Difference Vegetation Index (NDVI). However, there is no proper criterion for the selection of flood causal factors.

If all the relevant independent parameters are analyzed and used in modeling, the model will be very extensive and the output would deviate from the purpose of the research. It is thus important to determine which variable can be eliminated without harming the model's precision (Sanyal and Lu 2004). Recent studies have aimed to produce models that use the least number of data while achieving highly accurate results (Campolo et al. 2003).

Mapping of flood-prone areas is regarded as the most essential step of flood control and reduction. In order to handle complex data sets in a more effective way, different procedures and models have been introduced. Researchers have used integrated hydrological and hydrodynamic models, statistical models, machine learning (ML) algorithms, and vector machine (VM) models to investigate flood events (Pradhan and Youssef 2011; Tehrany et al. 2014). Some of the most commonly used models for flood susceptibility are discussed in the following sections.

4.4.1 Applications of Logistic Regression (LR) Model in Flood Susceptibility

LR is one of the most important multivariate statistical models and is used in various applications like mineral mapping (Xiong and Zuo 2018), landslides (Chen et al. 2017), earthquakes (Umar et al. 2014), land subsidence (Kim et al. 2006), groundwater mapping (Chen et al. 2018), and floods (Tehrany et al. 2017; Fig. 4.2b). This method was introduced by McFadden (1974), which measures the probability of any disaster in an area using a specific formula that is generated using the conditioning factors. LR assesses and distinguishes the link between the dependent variable and the independent variables, which may affect the probability of the event in one way or the other. Flood conditioning factors are considered as independent variables, whereas the flood event is a dependent variable (Tehrany et al. 2017). The mathematical expression of the LR model is given by (Eq. 4.1; Tehrany et al. 2014, 2017)

$$P = \frac{1}{1+e^{-z}} = \frac{1}{[1+e\{-(a_0+a_1x_1+a_2x_2+a_3x_3+\ldots+a_nx_n)\}]} \tag{4.1}$$

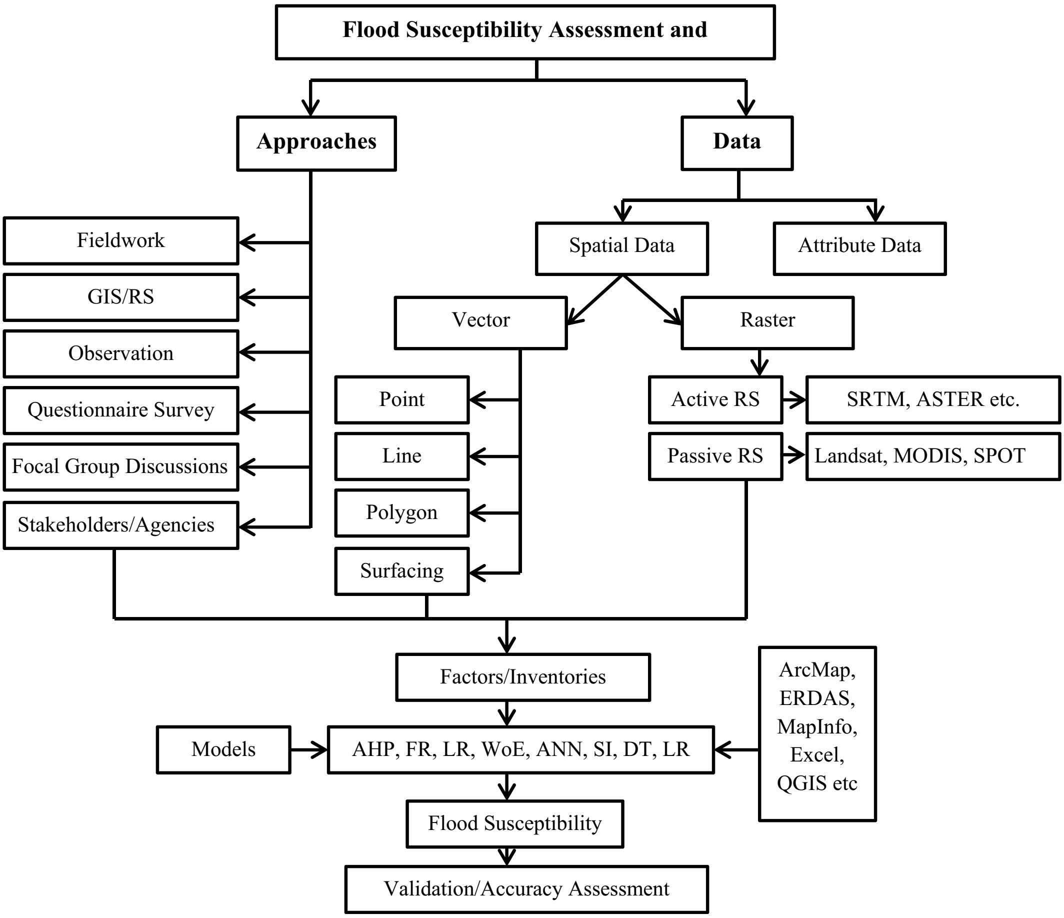


Fig. 4.1 Methods and approaches for flood susceptibility assessment and mapping

where P is the probability of occurrence or non-occurrence of a flood, a linear combination is represented by z, n is the number of conditioning factors, a_0 is the intercept of the model, a_i ($i = 0, 1, 2, \ldots, n$) is the regression coefficients of independent variables, and x_i ($i = 1, 2, 3, \ldots, n$) is the flood conditioning factors used in the model.

Different softwares are used to perform the analysis and to calculate the LR coefficient. The higher the logistic coefficient, the more will be the impact on the occurrence of flooding (Ayalew and Yamagishi 2005). In this method, the flood susceptibility map is generated from the flood inundation area and was considered as the dependent variable, where 0 represents the non-flooded areas and 1 represents the flooded areas (Rahman et al. 2019). This method is advantageous because it supports all kinds of data (scale, nominal, and categorical) and does not require any preanalysis assumptions (Tehrany et al. 2019). LR has the ability to instrument multivariate statistical analysis, but it is unable to assess the classes of causal factors.

4.4.2 Applications of Frequency Ratio (FR) Model in Flood Susceptibility

FR is a simple bivariate statistical model used to understand the relationship between the dependent and independent variables (Rahmati et al. 2016). It assesses the influence of each class of a conditioning factor on the occurrence of a

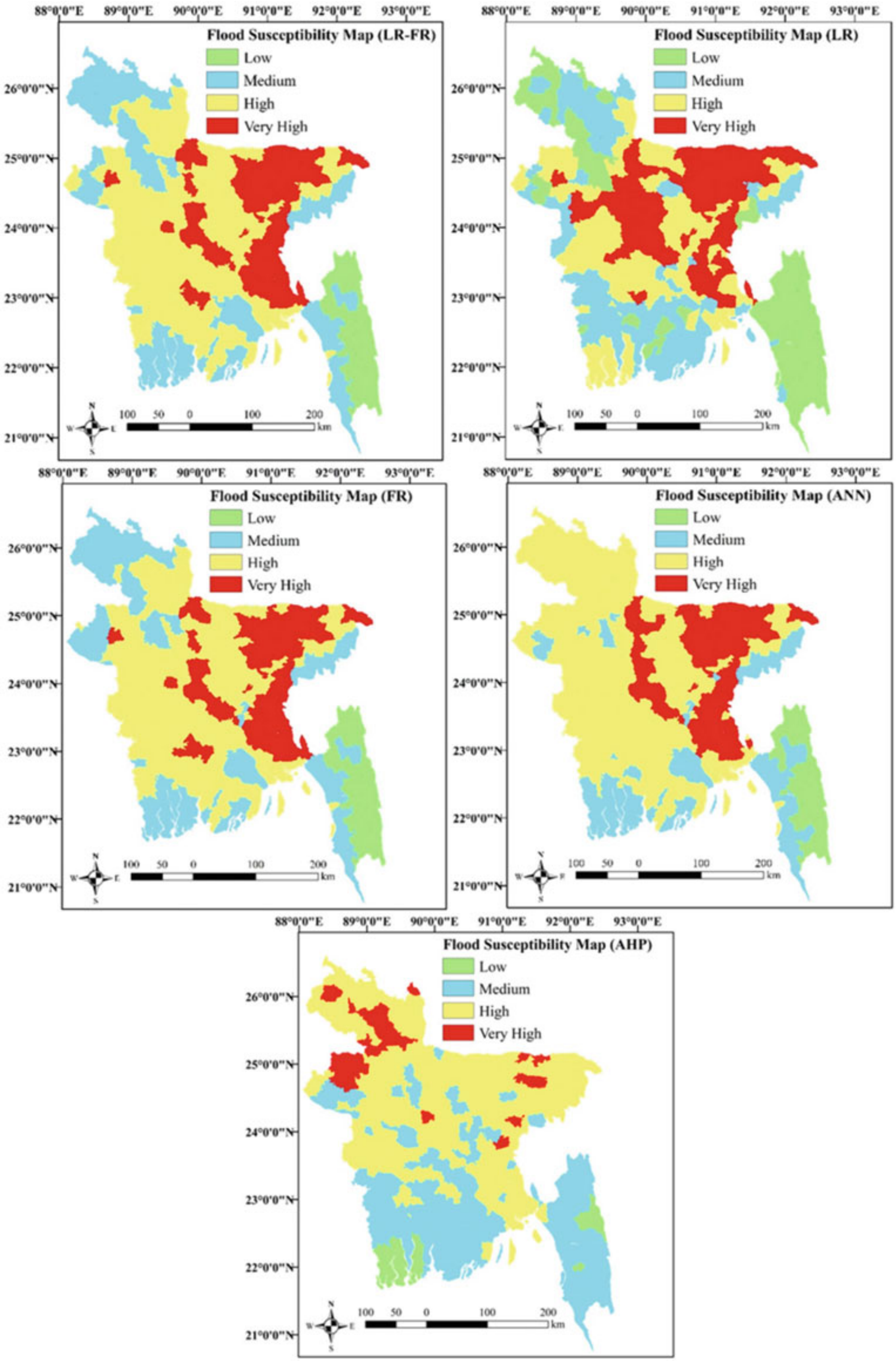


Fig. 4.2 Flood susceptibility zonations of Bangladesh **a** LR-FR, **b** LR, **c** FR, **d** ANN, **e** AHP after Rahman et al. (2019)

disaster (Lee et al. 2012). In order to calculate flood susceptibility mapping by using FR, three major steps would be followed: calculation of FR, production of susceptibility index, and the validation of the map. FR is the ratio between the probability of an occurrence to the probability of a non-occurrence for given attributes (Lee and Pradhan 2007). The higher ratio indicates a strong relationship between the flood event and the conditioning factors and vice versa. If the value is larger than 1 it means a strong relationship exists between the two and if it is less than 1 the relationship is weak (Pradhan and Youssef 2011). The rates are assigned to each class of a particular factor by using the following formula (Eq. 4.2; Bonham-Carter 1994).

$$FR = \frac{C/D}{X/Y} \tag{4.2}$$

where C represents the number of flooding pixels in each class, D is the total floods in the study area, X is the total number of pixels in each class, and Y is the total number of pixels in the study area.

The Flood Susceptibility Index (FSI) can be calculated by summing the FR of all the factors (Eq. 4.3):

$$FSI = \sum FR \tag{4.3}$$

where FSI is the Flood Susceptibility Index and FR is the frequency ratio for each factor.

Initially, this method was used for landslide susceptibility mapping but now, it is widely used for other hazards assessment like flood susceptibility mapping and zonation (Rahmati et al. 2016; Fig. 4.2c). This method is easy to understand and perform. FR can be quickly and easily applied to an area with limited data at a low cost. FR has the ability to analyze the effect of each conditioning factor on flooding (Lee et al. 2012). The weak point of this method is its inability to study the relationship between the variables (Ozdemir 2011).

4.4.3 Applications of Artificial Neural Networks (ANN) Approach in Flood Susceptibility

ANN is a machine learning method, which has been used in many hydrological applications due to its computational proficiency (Kia et al. 2012). This model consists of some elements known as neurons and three layers, including a hidden layer, input layer, and output layer (Zhang and Goh 2016). ANN helps to make a correlation between input causal factors and an output (Wan et al. 2010) and helps to demarcate flood susceptibility zones (Chowdhuri et al. 2020; Fig. 4.2d). ANN can handle all the input data which are uncertain to extract meaningful information (Lohani et al. 2012). This method has some drawbacks but many researchers have used it and have successfully provided flood susceptibility evaluations (Tehrany et al. 2015). The weak points of this model are dissimilar value ranges of the training, the validation of datasets, and weak prediction of dataset size. ANN has been used for flood susceptibility mapping in different parts of the world (Kia et al. 2012).

4.4.4 Applications of Analytical Hierarchy Process (AHP) Method in Flood Susceptibility

AHP is a simple mathematical model and was developed by Thomas L. Saaty in 1977, and has been extensively used for site selection, suitability analysis, regional planning, and susceptibility analysis (Rahim et al. 2018; Fig. 4.2e). It consists of four major steps: In step one, the factors were hierarchically arranged in the matrix. In step two, a pairwise comparison matrix (A1 matrix) was created to assign a numerical value to each factor on the basis of their importance compared to others. Following Saaty's (1977) scale these number was assigned based on literature and experts' knowledge. If the factors are in a direct relationship, the value between 1 and 9 is assigned by rating one factor against the other. Conversely, the values vary between the reciprocals of 1/2 and 1/9. The higher values should be assigned to the factors which are directly associated with flood and vice versa.

The A1 matrix values were multiplied and added to get a total weight matrix (A2 matrix). In the third step, A3 and A4 matrixes were calculated by means of the following equations (Eqs. 4.4 and 4.5);

$$A3 = A1 * A2 \quad (4.4)$$

$$A4 = A3/A2 \quad (4.5)$$

The average of the A4 matrix was used to calculate the rating value/eigenvalue and Consistency Index. For Consistency Index (CI) the following formula was used (Eq. 4.6; Saaty and Vargas 2001):

$$\text{Consistency Index} = \frac{\lambda\text{max} - \text{n}}{\text{n} - 1} \quad (4.6)$$

To validate the results, the consistency ratio (CR) was calculated by using the following formula (Eq. 4.7) given by Saaty (1977):

$$\text{Consistency Ratio} = \frac{\text{Consistency Index}}{\text{Random Index}} \quad (4.7)$$

In AHP, the weight of each parameter is determined by an expert opinion and has structural judgment. CR index is used, making the detection of the inconsistency in the process easy (Tehrany et al. 2014). Though this technique has a drawback of biasedness in expert opinion, still it could be efficiently used at the local and regional levels for flood assessment.

4.4.5 Applications of Decision Tree (DT) Approach in Flood Susceptibility

DT is a machine learning method used in modeling and classification (Bhaduri et al. 2008; Fig. 4.3a, b). It has a tree structure and consists of root nodes, internal nodes, and terminal nodes (Pradhan 2013). This method grouped the flood causal factors into homogeneous classes with varying levels of vulnerability. Those factors that would influence flooding significantly will be used in the process, whereas those that do not would be rejected (Tehrany et al. 2015). The major advantage of this method is that it does not require any strict assumption about data distribution rather; it allows all the available data formats to be used in analysis such as scale, nominal, etc., and its procedure is much easier than the rest of machine learning methods (Bou Kheir et al. 2010). The various available forms of DT are alternating decision trees (ADT), reduced error pruning trees (REPT), naïve Bayes trees (NBT), and logistic model trees (LMT) and can be used in spatial modeling and zonation (Khosravi et al. 2018). The choices of different DT algorithms and the requirement of statistical experts are the weaknesses of this technique (Tehrany et al. 2019).

4.4.6 Applications of Random Forest (RF) Method in Flood Susceptibility

Based on regression methods, the random forest model is a combination of statistical learning theory and machine learning method and/or a combination of techniques (Tatsumi et al. 2015). This method has been administered in a number of studies, such as remote sensing analysis, land-cover classification, flood hazard assessment, and risk studies (Breiman 2001; Wang et al. 2015; Fig. 4.3c).

Two of the most important advantages of this method are: the first is its ability to handle large datasets and shows the relationship between the conditional variables. This increases the accuracy of the prediction (Breiman 2001). Secondly, this method helps to link variables with the predicted outcomes and analyze their importance by selecting them randomly (Svetnik et al. 2003). RF model is very much appropriate for flood susceptibility modeling and mapping as it resolves the issue of multivariables.

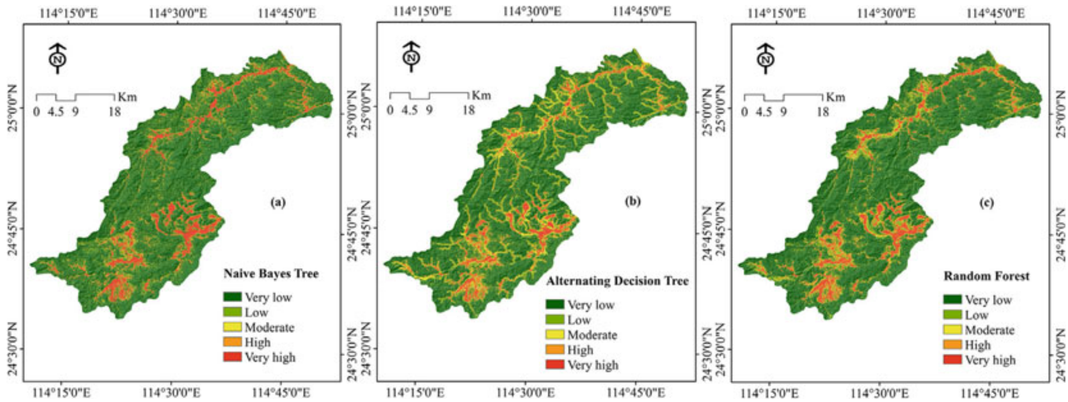


Fig. 4.3 Flood susceptibility maps of Quannan County, China. **a** NBTree, **b** ADTree, and **c** RF model after Chen et al. (2020)

4.4.7 Applications of Weight of Evidence (WoE) Model in Flood Susceptibility

WoE is a bivariate statistical model based on the Dempster–Shafer theory that was first introduced by Shafer (1976) and is a little more advanced than other bivariate methods (Rahmati et al. 2016). To use WoE, an important step is to calculate a negative weight (W−) and positive weight (W+) as the essential parameters. This method calculates the weight of each conditioning factor on the basis of the absence or presence of a disaster within the area and is calculated by using the following formula (Eqs. 4.8 and 4.9; Bonham-Carter 1994).

$$W^{+} = ln\frac{P\{X/Y\}}{P\{X/Y\}} \tag{4.8}$$

$$W^{-} = ln\frac{P\{X^{-}/Y^{-}\}}{P\{X^{-}/Y^{-}\}} \tag{4.9}$$

where ln is the natural log and P is the probability. X and X^{-} represent the presence and absence of the causal factor, respectively. Y and Y^{-} are the presence and absence of a disaster (Xu et al. 2012; Fig. 4.4a).

The positive weight indicates the presence of the causal factor at the disaster location, and the magnitude shows a positive relationship between the disaster occurrence and the causal factor. However, the negative weight shows the absence of the causal factor and represents a negative relation between the two (Regmi et al. 2013). The difference between the negative and positive weight, also known as the weight contrast, reveals the spatial relationship between the conditioning factors and the occurrence of disaster (Dahal et al. 2008). After the calculation, the weights are normalized in the range of 0 and 1.

The major advantage of this method is its capability to handle incomplete datasets and produce predictive flood mapping zones and the degree of uncertainty of the same zone. However, this model has a few disadvantages. To use this model the flood conditioning factors should be transformed into evidential data layers to generate a flood susceptibility map. In addition, the output result of the Dempster–Shafer parameters (belief, disbelief, uncertainty, and plausibility) has to be defined as accurately as possible in order to achieve a reasonable final map (Dempster 1968).

4.4.8 Applications of Statistical Index (SI) Method in Flood Susceptibility

This method was introduced by Van Westen in 1977. SI is a bivariate statistical model and was primarily used in landslide hazards assessment

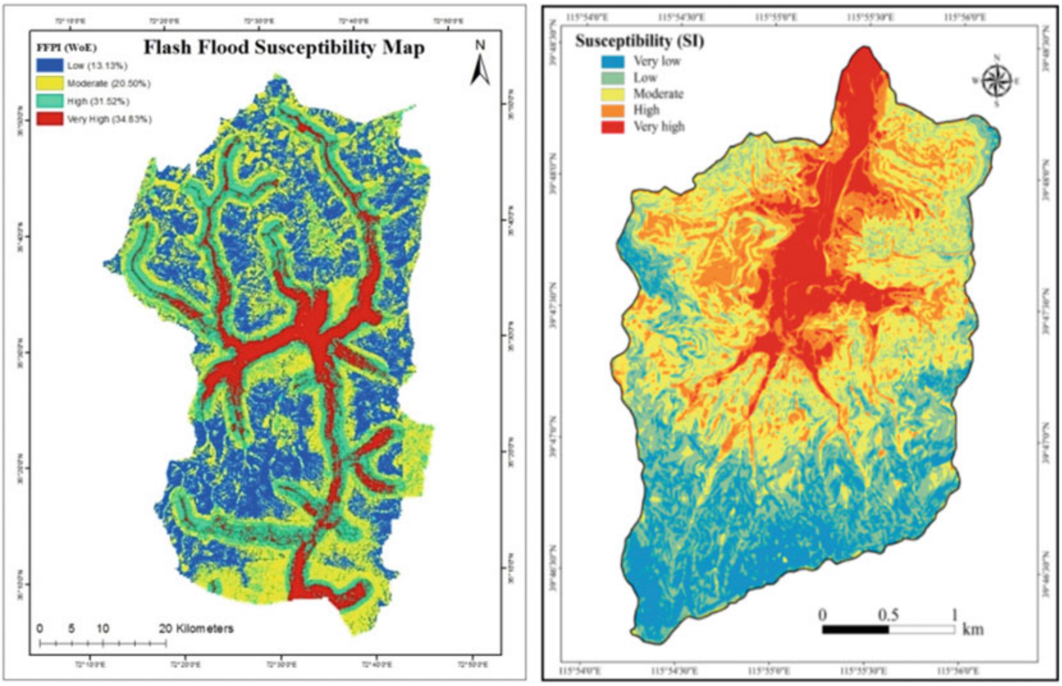


Fig. 4.4 **a** Flash flood susceptibility map of Upper Swat Valley, Pakistan using the weight of evidence model after Bibi (2019), **b** Flood susceptibility map of Xiqu Gully, Beijing using statistical index method after Cao et al. (2016)

(Wu et al. 2016). SI method uses the weight of factors' classes for final susceptibility by considering the flood point of a particular class and the total point in the whole selected area (Costache et al. 2019; Fig. 4.4b). The following formula (Eq. 4.10) is used to calculate the weights of each particular factor (Razavizadeh et al., 2017):

$$SIw = ln(dxy|d) = ln(Ixy\backslash It|Pxy\backslash Pt) \quad (4.10)$$

where *SIw* is the statistical index weight for class *x* of factor *y, dxy* is the flood density for the selected class, *d* is the total flood density of an area, *Ixy* is the number of flood for the *x* class of *y* factor, *It* is the total number of flood in the study area, *Pxy* is the number of pixel for a specific class and *Pt* is the total number of pixels of the whole area.

A positive *SIw* value indicates the presence of a significant relationship between flood distribution and the class of conditioning factors. If the *SIw* value is negative, it shows the presence of some irrelevant factor class in flood susceptibility (Pourghasemi et al. 2013).

4.5 Merit and Demerits of Flood Susceptibility Approaches

There are two main categories of flood hazard modeling; hydrological–hydraulic and geological geomorphological methods. On the basis of peak flows for specific events and their return period, the flood in the first group is analyzed and mapped (Cea and Bladé 2015). Floods in the second group are simulated through field surveys and remotely sensed data (Chapi et al. 2015).

For susceptibility mapping of natural hazards, the available methods and approaches which are based on the historical flood events and the conditioning factors have some disadvantages. The major drawback of statistical models is that they assume a predefined relationship between the causal factors of disasters and their occurrence (Dodangeh et al. 2020). For example, the

FR model is very sensitive to sample size and AHP is subject to uncertainties due to the biasedness in pairwise comparison (Choubin et al. 2019). To overcome the limitations of AHP, Laarhoven et al. (1983) developed fuzzy AHP to modify the original AHP and remove the biasedness in the pairwise comparison. Fuzzy AHP has a high precision than AHP and is therefore used for flood delineation.

Researchers are moving toward the machine learning (ML) method because it has the capability to handle the relationship between different variables and has a higher prediction performance (Bui et al. 2019). These methods are advantageous because it captures the information directly from spatial data without any assumption. It improves the speed of the data analysis and lessens the operating cost. ML models include adaptive neuro-fuzzy inference systems (ANFIS), support vector machines (SVMs), decision trees (DTs), artificial neural networks (ANNs), etc. But, these techniques also have one or more disadvantages. For example, due to the limitations of ANN, some other techniques such as the neural fuzzy method have been used and proposed in natural hazards applications (Chang and Tsai 2016). Neural fuzzy methods also have some limitations and restrictions like slow training speed and are unable to determine the weight of variables which substantially affects the model's prediction (Hong and White 2009). So, to cope with the limitations, the best-suggested option is to use hybrid methods in combination with GIS. Hybridization is a major trend in the prediction of flood susceptibility by identifying the regions that are vulnerable to floods. The studies conducted on flood susceptibility have incorporated the integration of a number of methods. In the areas of performance accuracy, uncertainty, robustness, and generalization, hybridization has gained remarkable progress (Zhang et al. 2018).

4.6 Conclusion and Wayforward

Globally, disasters are becoming more frequent, and flood is one of the most serious catastrophes that cause severe damage to the human population and their properties. It is a very complicated process and is intensified by many factors. In the last few decades, a lot of efforts have been made to detect flood-prone areas and control and mitigate the consequences of floods. A number of approaches have been used in order to gain further insight into flood susceptibility modeling and mapping. Hybridization of techniques has been introduced to deal with the limitations of an individual method.

Flooding is a complicated process and it varies from place to place and from country to country (Hong et al. 2018). Prevention measures for flood control are needed to reduce the possible damages. But it cannot be completely sidelined; rather, their harmful effects and consequences can be lessened through susceptibility analysis and proper planning.

Geographic information system (GIS) and remote sensing (RS) together with the latest modeling techniques made it easy to manage and predict floods. Several models have been used for flood susceptibility modeling and mapping in the literature. However, there is no method to assess which model has the greatest accuracy, as all the models have some advantages and disadvantages. Initially, statistical models were frequently used for flood mapping but now the researchers are moving toward the machine learning methods. ML methods are advanced computing approaches for flood studies and are based on mathematical algorithms for prediction and analysis (Bui et al. 2019). Though ML methods have some drawbacks, but greater accuracy can be achieved, because it uses post and prerunning strategies to overcome the associated problems. In contrast, statistical methods have some disadvantages. For example, poor estimation due to data scarcity or incomplete data, assume a predefined relationship between the conditioning factors and the disaster.

In order to overcome the drawbacks of all the methods to a certain limit, it is recommended to use hybridized method. Hybridization has several advantages, including robustness, reduction of noise and overfitting, ability to handle large datasets, interlink the variables, and provide good accuracy. Among different types of flood models presented in the literature, weight of evidence (WoE), frequency ratio (FR), decision trees (DT), artificial neural networks (ANNs), and logistic regression (LR) are more popular that have been utilized in flood susceptibility mapping.

References

Ahmad W, Nasir MJ, Iqbal J (2020) Flash flood susceptibility modeling for drainage basins of Dir Lower Khyber-Pakhtunkhwa: a comparative analysis of morphometric ranking and El-Shamy's approach. In: Remote sensing for agriculture, ecosystems, and hydrology XXII, Vol 11528, p 115280E. International Society for Optics and Photonics

Aksoy H, Kirca VSO, Burgan HI, Kellecioglu D (2016) Hydrological and hydraulic models for determination of flood-prone and flood inundation areas. Proc Int Assoc Hydrol Sci 373:137–141

Ali SA, Khatun R, Ahmad A, Ahmad SN (2019) Application of GIS-based analytic hierarchy process and frequency ratio model to flood vulnerable mapping and risk area estimation at Sundarban region India. Model Earth Syst Environ 5(3):1083–1102

Asrar-ul-Haq, Zaidi SM (2011) Flood 2010: the event, issue and way forward. Pakistan Eng Congr 32:53–74

Ayalew L, Yamagishi H (2005) The application of GIS-based logistic regression for landslide susceptibility mapping in the Kakuda-Yahiko Mountains Central Japan. Geomorphology 65(1–2):15–31

Barredo JI (2009) Normalised flood losses in Europe: 1970–2006. Nat Hazards Earth Syst Sci 9(1)

Bhaduri K, Wolff R, Giannella C, Kargupta H (2008) Distributed decision-tree induction in peer-to-peer systems. Stat Anal Data Min 1:85–103

Bibi K (2019) Flash flood potentials and assessment of susceptibility using weights of evidence model in Upper Swat Valley, Pakistan. Unpublished MPhil dissertation submitted to the department of Geography, University of Peshawar, Peshawar, Pakistan

Bou Kheir R, Greve MH, Abdallah C, Dalgaard T (2010) Spatial soil zinc content distribution from terrain parameters: a GIS-based decision-tree model in Lebanon. Environ Pollut 158(2):520–528

Breiman L (2001) Random forests. Mach Learn 45(1):5–32

Bonham-Carter GF (1994) Geographic information systems for geoscientists. Volume 13: Modelling with GIS (Computer Methods in the Geosciences)

Bui DT, Ngo PTT, Pham TD, Jaafari A, Minh NQ, Hoa PV, Samui P (2019) A novel hybrid approach based on a swarm intelligence optimized extreme learning machine for flash flood susceptibility mapping. CATENA 179:184–196

Campolo M, Soldati A, Andreussi P (2003) Artificial neural network approach to flood forecasting in the River Arno. Hydrol Sci J 48(3):381–398

Cao C, Xu P, Wang Y, Chen J, Zheng L, Niu C (2016) Flash flood hazard susceptibility mapping using frequency ratio and statistical index methods in coalmine subsidence areas. Sustainability 8:948

Cea L, Bladé E (2015) A simple and efficient unstructured finite volume scheme for solving the shallow water equations in overland flow applications. Water Resour Res 51(7):5464–5486

Ceola S, Laio F, Montanari A (2014) Satellite nighttime lights reveal increasing human exposure to floods worldwide. Geophys Res Lett 41(20):7184–7190

Chang FJ, Tsai MJ (2016) A nonlinear spatio-temporal lumping of radar rainfall for modeling multi-step-ahead inflow forecasts by data-driven techniques. J Hydrol 535:256–269

Chapi K, Rudra RP, Ahmed SI, Khan AA, Gharabaghi B, Dickinson WT, Goel PK (2015) Spatial-temporal dynamics of runoff generation areas in a small agricultural watershed in southern Ontario. J Water Resour Prot 7(01):14

Chen W, Li Y, Xue W, Shahabi H, Li S, Hong H, ... Ahmad BB (2020) Modeling flood susceptibility using data-driven approaches of naïve Bayes tree, alternating decision tree, and random forest methods. Sci Total Environ 701:134979

Chen W, Xie X, Peng J, Wang J, Duan Z, Hong H (2017) GIS-based landslide susceptibility modelling: a comparative assessment of kernel logistic regression, Naïve-Bayes tree, and alternating decision tree models. Geomat Nat Haz Risk 8(2):950–973

Chen W, Li H, Hou E, Wang S, Wang G, Panahi M, ... Xiao L (2018) GIS-based groundwater potential analysis using novel ensemble weights-of-evidence with logistic regression and functional tree models. Sci Total Environ 634:853–867

Choubin B, Moradi E, Golshan M, Adamowski J, Sajedi-Hosseini F, Mosavi A (2019) An ensemble prediction of flood susceptibility using multivariate discriminant analysis, classification and regression trees, and support vector machines. Sci Total Environ 651:2087–2096

Chowdhuri I, Pal SC, Chakrabortty R (2020) Flood susceptibility mapping by ensemble evidential belief function and binomial logistic regression model on river basin of eastern India. Adv Space Res 65 (5):1466–1489

Costache R, Hong H, Wang Y (2019) Identification of torrential valleys using GIS and a novel hybrid integration of artificial intelligence, machine learning and bivariate statistics. CATENA 183:104179

Dahal RK, Hasegawa S, Nonomura A, Yamanaka M, Masuda T, Nishino K (2008) GIS-based weights-of-evidence modelling of rainfall-induced landslides in small catchments for landslide susceptibility mapping. Environ Geol 54(2):311–324

Das S (2019) Geospatial mapping of flood susceptibility and hydro-geomorphic response to the floods in Ulhas basin, India. Remote Sens Appl: Soc Environ 14:60–74

Dempster AP (1968) A generalization of Bayesian inference. J Roy Stat Soc: Ser B (methodol) 30 (2):205–232

Dobler C, Bürger G, Stötter J (2012) Assessment of climate change impacts on flood hazard potential in the Alpine Lech watershed. J Hydrol 460:29–39

Dodangeh E, Panahi M, Rezaie F, Lee S, Tien Bui D, Lee C-W, Pradhan B (2020) Novel hybrid intelligence models for flood-susceptibility prediction: meta optimization of the GMDH and SVR models with the genetic algorithm and harmony search. J Hydrol 590:125423

Doocy S, Daniels A, Packer C, Dick A, Kirsch TD (2013) The human impact of earthquakes: a historical review of events 1980–2009 and systematic literature review. PLoS Curr 5

Fendler R (2008) Floods and safety of establishments and installations containing hazardous substances conclusions on a research project of the German Umweltbundesamt. Nat Hazards 46:257–263

Fenicia F, Kavetski D, Savenije HHG, Clark MP, Schoups G, Pfister L, Freer J (2014) Catchment properties, function, and conceptual model representation: is there a correspondence? Hydrol Process 28 (4):2451–2467

Gaurav K, Sinha R, Panda PK (2011) The Indus flood of 2010 in Pakistan: a perspective analysis using remote sensing data. Nat Hazards 59(3):1815

GoP (Government of Pakistan) (2017) Annual flood report, 2016. Ministry of Water and Power, Federal Flood Commission, Government of Pakistan, Islamabad

GoP (Government of Pakistan) (2018) Annual flood report, 2017. Ministry of Water and Power, Federal Flood Commission, Government of Pakistan, Islamabad

Hirabayashi Y, Roobavannan M, Koirala S, Konoshima L, Yamazaki D, Watanabe S, Kanae S (2013) Global flood risk under climate change. Nat Clim Change 3:816–821

Hong H, PanahiM, Shirzadi A, Ma T, Liu J, Zhu AX, Kazakis N (2018) Flood susceptibility assessment in Hengfeng areacoupling adaptive neuro-fuzzy inference system with genetic algorithm and differential evolution. Sci Total Environ, 621:1124–1141

Hong H, Pradhan B, Xu C, Bui DT (2015) Spatial prediction of landslide hazard at the Yihuang area (China) using two-class kernel logistic regression, alternating decision tree and support vector machines. CATENA 133:266–281

Hong YST, White PA (2009) Hydrological modeling using a dynamic neuro-fuzzy system with on-line and local learning algorithm. Adv Water Resour 32 (1):110–119

Hunter NM, Horritt MS, Bates PD, Wilson MD, Werner MGF (2005) An adaptive time step solution for raster-based storage cell modelling of floodplain inundation. Adv Water Resour 28:975–991

ICIMOD (2011) Report on the status of glaciers in the hindu kush-Himalayan region. Nepal, Kathmandu

Islam R, Kamaruddin R, Ahmad SA, Jan SJ, Anuar AR (2016) A review on mechanism of flood disaster management in Asia. Int Rev Manag Mark 6(1):29–52

Khosravi K, Pham BT, Chapi K, Shirzadi A, Shahabi H, Revhaug I, ... Tien Bui D (2018) A comparative assessment of decision trees algorithms for flash flood susceptibility modeling at Haraz watershed, northern Iran. Sci Total Environ 627:744–755

Kia MB, Pirasteh S, Pradhan B, Mahmud AR, Sulaiman WNA, Moradi A (2012) An artificial neural network model for flood simulation using GIS: Johor River Basin Malaysia. Environ Earth Sci 67(1):251–264

Kim KD, Lee S, Oh HJ, Choi JK, Won JS (2006) Assessment of ground subsidence hazard near an abandoned underground coal mine using GIS. Environ Geol 50(8):1183–1191

Kourgialas NN, Karatzas GP (2011) Flood management and a GIS modelling method to assess flood-hazard areas—A case study. Hydrol Sci J 56(2):212–225

Kron W (2005) Flood risk= hazard• values• vulnerability. Water Int 30(1):58–68

Laarhoven V, Peter JM, Pedrycz W (1983) A fuzzy extension of Saaty’s priority theory. Fuzzy Sets Syst 11(1–3):229–241

Lee MJ, Kang JE, Jeon S (2012) Application of frequency ratio model and validation for predictive flooded area susceptibility mapping using GIS. Int Geosci Remote Sens Symp 895–898

Lee S, Pradhan B (2007) Landslide hazard mapping at Selangor, Malaysia using frequency ratio and logistic regression models. Landslides 4(1):33–41

Leskens A, Brugnach MF, Hoekstra AY, Schuurmans W (2014) Why are decisions in flood disaster management so poorly supported by information from flood models? Environ Model Softw 53:53–61

Ligtvoet W, Witte F, Goldschmidt T, Van Oijen MP, Wanink JH, Goudswaard PC (1991) Species extinction and concomitant ecological changes in Lake Victoria. Neth J Zool 42(2–3):214–232

Lohani AK, Kumar R, Singh R (2012) Hydrological time series modeling: a comparison between adaptive neuro-fuzzy, neural network and autoregressive techniques. J Hydrol 442:23–35

Mahmood S (2012) Monitoring and assessment of 2010 flood disaster causes and damages in Upper Dir. Unpublished M.Phil thesis submitted to the

Sustainable Development Study Center, GC University, Lahore, Pakistan
Mahmood S, Rahman AU (2019a) Flash flood susceptibility modeling using geo-morphometric and hydrological approaches in Panjkora Basin, Eastern Hindu Kush Pakistan. Environ Earth Sci 78(1):43
Mahmood S, Rahman AU (2019b) Flash flood susceptibility modelling using geomorphometric approach in the Ushairy Basin, eastern Hindu Kush. J Earth Syst Sci 128(4):97
Manandhar B (2010) Flood plain analysis and risk assessment of Lothar Khola. Master of Science Thesis in Watershed Management. Tribhuvan University Institute of Forestry Pokhara, Nepal
McBean GA (2012) Integrating disaster risk reduction towards sustainable development. Curr Opin Environ Sustain 4:122–127
McFadden D (1974) The measurement of urban travel demand. J Public Econo, 3(4):303–328
Moazzam MFU, Lee BG, Rahman AU, Farid N, Rahman G (2020) Spatio-statistical analysis of flood susceptibility assessment using bivariate model in the floodplain of river Swat, District Charsadda, Pakistan. J Geosci Environ Protect 8(5):159
Ozdemir A (2011) GIS-based groundwater spring potential mapping in the Sultan Mountains (Konya, Turkey) using frequency ratio, weights of evidence and logistic regression methods and their comparison. J Hydrol 411(3–4):290–308
Pham BT, Avand M, Janizadeh S, Phong TV, Al-Ansari N, Ho LS, Das S, Le HV, Amini A, Bozchaloei SK, Jafari F, Prakash I (2020) GIS based hybrid computational approaches for flash flood susceptibility assessment. Water 12:683
Pourghasemi HR, Moradi HR, Aghda SF (2013) Landslide susceptibility mapping by binary logistic regression, analytical hierarchy process, and statistical index models and assessment of their performances. Nat Hazards 69(1):749–779
Pradhan B (2013) A comparative study on the predictive ability of the decision tree, support vector machine and neuro-fuzzy models in landslide susceptibility mapping using GIS. Comput Geosci 51:350–365
Pradhan B, Youssef AM (2011) A 100-year maximum flood susceptibility mapping using integrated hydrological and hydrodynamic models: Kelantan River Corridor Malaysia. J Flood Risk Manag 4(3):189–202
Price G, Mittra S (2016) Water, ecosystems and energy in South Asia making cross-border collaboration work. Chatham House, the Royal Institute of International Affairs, 10 St James's Square, London SW1Y 4LE, June. www.chathamhouse.org
Qasim S, Qasim M, Shrestha RP, Khan AN, Tun K, Ashraf M (2016) Community resilience to flood hazards in Khyber Pakhtunkhwa province of Pakistan. Int J Disaster Risk Reduct 18:100–106
Rahim I, Ali S, Aslam M (2018) GIS based landslide susceptibility mapping with application of analytical hierarchy process in district Ghizer, Gilgit Baltistan Pakistan. J Geosci Environ Protect 6:34–49
Rahman A, Khan AN (2011) Analysis of flood causes and associated socioeconomic damages in the Hindu Kush region. Nat Hazards 59(3):1239
Rahman A, Khan AN (2013) Analysis of 2010-flood causes, nature and magnitude in the Khyber Pakhtunkhwa Pakistan. Nat Hazards 66(2):887–904
Rahman A, Shaw R (2015) Flood risk and reduction approaches in Pakistan. In: Disaster risk reduction approaches in Pakistan. Springer, Tokyo, pp 77–100
Rahman M, Ningsheng C, Islam MM, Dewan A, Iqbal J, Washakh RMA, Shufeng T (2019) Flood susceptibility assessment in Bangladesh using machine learning and multi-criteria decision analysis. Earth Syst Environ 3(3):585–601
Rahmati O, Pourghasemi HR, Zeinivand H (2016) Flood susceptibility mapping using frequency ratio and weights-of-evidence models in the Golastan Province Iran. Geocarto Int 31(1):42–70
Razavizadeh S, Solaimani K, Massironi M, Kavian A (2017) Mapping landslide susceptibility with frequency ratio, statistical index, and weights of evidence models: a case study in northern Iran. Environ Earth Sci 76(14):499
Regmi AD, Devkota KC, Yoshida K, Pradhan B, Pourghasemi HR, Kumamoto T, Akgun A (2013) Application of frequency ratio, statistical index, and weights-of-evidence models and their comparison in landslide susceptibility mapping in Central Nepal Himalaya. Arab J Geosci 7(2):725–742
Ruiz-Villanueva V, Allen S, Arora M, Goel NK, Stoffel M (2017) Recent catastrophic landslide lake outburst floods in the Himalayan mountain range. Prog Phys Geogr 41(1):3–28
Saaty TL (1977) A scaling method for priorities in hierarchical structures. J Math Psychol 15(3):234–281
Saaty TL, Vargas GL (2001) Models, methods, concepts, and applications of the analytic hierarchy process. Kluwer Academic, Boston
Shafer G (1976) A mathematical theory of evidence. Princeton university press, Princeton
Sanyal J, Lu XX (2004) Application of remote sensing in flood management with special reference to monsoon Asia: a review. Nat Hazards 33(2):283–301
Shabbir AH (2016) The impact of flood on Economy of Pakistan. AgriHunt-A hunt for agricultural knowledge, July 22. http://agrihunt.com/uncategorized/the-impact-of-floodon-economy-of-pakistan
Smith K (2013) Environmental hazards: assessing risk and reducing disaster. Routledge
Svetnik V, Liaw A, Tong C, Culberson JC, Sheridan RP, Feuston BP (2003) Random forest: a classification and regression tool for compound classification and QSAR modeling. J Chem Inf Comput Sci 43(6):1947–1958
Tatsumi K, Yamashiki Y, Torres MAC, Taipe CLR (2015) Crop classification of upland fields using random forest of time-series Landsat 7 ETM+ data. Comput Electron Agric 115:171–179
Tehrany MS, Shabani F, Neamah Jebur M, Hong H, Chen W, Xie X (2017) GIS-based spatial prediction of flood prone areas using standalone frequency ratio,

logistic regression, weight of evidence and their ensemble techniques. Geomat Nat Haz Risk 8 (2):1538–1561
Tehrany MS, Kumar L, Neamah Jebur M, Shabani F (2019) Evaluating the application of the statistical index method in flood susceptibility mapping and its comparison with frequency ratio and logistic regression methods. Geomat Nat Hazards Risk 10(1):79–101
Tehrany MS, Lee M-J, Pradhan B, Jebur MN, Lee S (2014) Flood susceptibility mapping using integrated bivariate and multivariate statistical models. Environ Earth Sci 72(10):4001–4015
Tehrany MS, Pradhan B, Jebur MN (2015) Flood susceptibility analysis and its verification using a novel ensemble support vector machine and frequency ratio method. Stoch Environ Res Risk Assess 29 (4):1149–1165
Tiryaki M, Karaca O (2018) Flood susceptibility mapping using GIS and multicriteria decision analysis: Saricay-Çanakkale (Turkey). Arab J Geosci 11(14):364
Uddin K, Gurung DR, Giriraj A, Shrestha B (2013) Application of remote sensing and GIS for flood hazard management: a case study from sindh province, Pakistan. 2013 Am J Geogr Inf Syst 2(1):1–5
Ullah K, Zhang J (2020) GIS-based flood hazard mapping using relative frequency ratio method: a case study of Panjkora River Basin, eastern Hindu Kush Pakistan. PLoS ONE 15(3):e0229153
Umar Z, Pradhan B, Ahmad A, Jebur MN, Tehrany MS (2014) Earthquake induced landslide susceptibility mapping using an integrated ensemble frequency ratio and logistic regression models in West Sumatera Province, Indonesia. CATENA 118:124–135
UNISDR (2011) Global assessment report on disaster risk reduction. International Strategy for Disaster Reduction (ISDR)
UNISDR (2015) Global assessment report on disaster risk reduction. International Stratergy for Disaster Reduction (ISDR)
Van Den Honert RC, McAneney J (2011) The 2011 Brisbane floods: causes, impacts and implications. Water 3(4):1149–1173
Van Westen CJ, Van Asch TW, Soeters R (2006) Landslide hazard and risk zonation—why is it still so difficult? Bull Eng Geol Env 65(2):167–184
Viviroli D, Weingartner R (2004) The hydrological significance of mountains: from regional to global scale. Hydrol Earth Syst Sci Discuss 8(6):1017–1030
Vorogushyn S, Lindenschmidt K-E, Kreibich H, Apel H, Merz B (2012) Analysis of a detention basin impact on dike failure probabilities and flood risk for a channel-dike-floodplain system along the river Elbe, Germany. J Hydrol 436–437:120–131
Wan S, Lei TC, Chou TY (2010) An enhanced supervised spatial decision support system of image classification: consideration on the ancillary information of paddy rice area. Int J Geogr Inf Sci 24(4):623–642
Wang Z, Lai C, Chen X, Yang B, Zhao S, Bai X (2015) Flood hazard risk assessment model based on random forest. J Hydrol 527:1130–1141
Wasko C, Sharma A (2017) Global assessment of flood and storm extremes with increased temperatures. Sci Rep 7:7945
Wu SJ, Lien HC, Chang CH (2010) Modeling risk analysis for forecasting peak discharge during flooding prevention and warning operation. Stoch Environ Res Risk Assess 24(8):1175–1191
Wu Y, Li W, Wang Q, Liu Q, Yang D, Xing M, ... Yan S (2016) Landslide susceptibility assessment using frequency ratio, statistical index and certainty factor models for the Gangu County, China. Arab J Geosci 9 (2):84
Xu C, Xu X, Dai F, Xiao J, Tan X, Yuan R (2012) Landslide hazard mapping using GIS and weight of evidence model in Qingshui river watershed of 2008 Wenchuan earthquake struck region. J Earth Sci 23 (1):97–120
Xiong Y, Zuo R (2018) GIS-based rare events logistic regression for mineral prospectivity mapping. Comput Geosci 111:18–25
Yalcin A, Reis S, Aydinoglu AC, Yomralioglu T (2011) A GIS-based comparative study of frequency ratio, analytical hierarchy process, bivariate statistics and logistics regression methods for landslide susceptibility mapping in Trabzon NE Turkey. CATENA 85 (3):274–287
Yalcin G, Akyurek Z (2004) Analysing flood vulnerable areas with multicriteria evaluation (2004). In: Proceedings of the 20th ISPRS congress, Istanbul, Turkey, pp 359–364
Yu F, Chen Z, Ren X, Yang G (2009) Analysis of historical floods on the Yangtze River, China: characteristics and explanations. Geomorphology 113:210–216
Zhang Q, Xu CY, Zhang Z, Chen YD, Liu CL, Lin H (2008) Spatial and temporal variability of precipitation maxima during 1960–2005 in the Yangtze River basin and possible association with large-scale circulation. J Hydrol 353:215–227
Zhang T, Han L, Chen W, Shahabi H (2018) Hybrid integration approach of entropy with logistic regression and support vector machine for landslide susceptibility modeling. Entropy 20(11):884
Zhang W, Goh AT (2016) Multivariate adaptive regression splines and neural network models for prediction of pile drivability. Geosci Front 7(1):45–52

Khadija Bibi is a Ph.D. research scholar at the Department of Geography, University of Peshawar, Pakistan. She did her MSc in Geography with gold medal and MPhil in Geography from the Department of Geography, University of Peshawar. Her field of specialization is Flood Risk Modelling.

Fareeha Siddique is Lecturer in Geography at Government Postgraduate College Kohat, Pakistan. She did her MSc in Geography with gold medal and MPhil in Geography from the Department of Geography, University of Peshawar. Ms. Fareeha Siddique is working in the field of Peri-glacial environment of Himalayan region.

Shehla Gul is a Lecturer at the Department of Geography, University of Peshawar. She did her Ph.D. in Disaster Management from the University of Alberta, Canada and is actively participating in teaching and research activities in Disaster Management as well as a variety of different geographical fields. Her Ph.D. research is focused on gender and disaster management. She is publishing research articles in prestigious journals and contributing book chapters related to her field of specialization.

Atta-ur Rahman is Chairman and Associate Professor in the Department of Geography, University of Peshawar, Pakistan. He has recently completed his post-Doctoral studies on modeling disaster risk from Kyoto University, Japan. He has specialization in Applied Geography, Disaster Risk Reduction and Environmental Impact Assessment. He is working with international organizations on various aspects of Applied Geomorphology, DRR and supervising research students in the field of Applied Geography and Geomorphology. He is a member of the editorial board of reputed journals and has authored books and numerous research articles in prestigious journals.

Firuza Begham Mustafa is an Associate Professor at the Department of Geography, Faculty of Arts and Social Sciences, University of Malaya. She specialized in agriculture geography, environment management and geophysical fields. She has produced more than 110 publications including in journals, conferences papers, IPs and posters. She has also written chapters on many international books and published several scientific books. She served in the Editorial Board Water Conservation Management (WCM), Editorial Board of Geology, Ecology and Landscapes (GEL), International Journal of Creative Industries (IJCREI) and Editorial Board of the Malaysian Journal of Tropical Geography (MJTG), University of Malaya. She was appointed as Visiting Fellow of Qinghai National University, China. She actively participated in Theo Murphy High Flyers Think Tank of Australia in 2011 and 2012. She is also Council Member of the International Geographical Union Commission on Commission Marginalization, Globalization, and Regional and Local Responses- C16.29, a member of International Geographical Union for Commission on Geographical Education, a member of the Southeast Asian Geography Association (SEAGA) and the Centre for Global Geography Education (CGGE) training by Association of American Geography (AAG). She is an Associate Fellow (AFMSA) of the Malaysian Scientific Association (MSA). She served as Auditor for Malaysia Qualification Agency (MQA) since 2009 for Geography and Environmental subjects.

5 Digital Geography and Its Methods

Aparajita De

Abstract

The COVID-19 pandemic made many to suspend fieldwork for an unforeseeable future and compelled one to rethink on how they could practice geography, particularly carrying out geographical research in the face of mobility restrictions. This chapter attempts to explore the methodological possibilities and challenges that the pandemic has thrown us in order to conduct geographical research in digital fields using qualitative and ethnographic methods. It reflects on the larger conceptual and methodological challenges of connecting conventional notions of geographical space with new forms of spatialities that emerge due to digitalisation. These new forms often challenge traditional forms of representations of geographical space as well. The chapter critically examines the conceptualisation and identification of the field in geographical research and how digital media has not only expanded the scope of what constitutes the field but has redefined the field in itself and the practices of observing, knowing and analysing the real world. It has opened new ways of having direct, first hand experiences in the field but the possibility of conducting it remotely as well. Lastly, the chapter deals with the methods adopted to carry research in three steps—the first involves developing an overview of the digital landscape for the purpose of identifying appropriate sites in new media that addresses specific research questions related to one's study. The second step involves an unobtrusive and passive ethnographic observation about identified digital sites and the third involves taking field notes on observations made in the digital setting of the field.

Keywords

Digital geography · Digital ethnography · Digital fields · Research during COVID-19 · New media studies · Digital methods

5.1 Introduction: The Interconnecting Physical and Digital Worlds

After the first few months of the pandemic social scientists and geographers realised that not only had they to suspend fieldwork for an unforeseeable future but needed to rethink on how they could practice geography, particularly carrying out geographical research in the face of mobility restrictions put in force due to the pandemic. Under the circumstances in many Departments

A. De (✉)
Department of Geography, Delhi School of Economics, University of Delhi, Delhi, India
e-mail: ade.dse@gmail.com; ade@geography.du.ac.in

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

F. B. Mustafa (ed.), *Methodological Approaches in Physical Geography*,
Geography of the Physical Environment, https://doi.org/10.1007/978-3-031-07113-3_5

across the globe, like my own, dissertations and field-based project reports for the Masters and other programmes were dropped or were postponed. Research scholars too not just in India but world-wide were becoming increasingly anxious to get around the obstacle of the pandemic and trying to grapple with developing new and innovative methods that were in many ways challenging the already existing conceptual, analytical and methodological discourses within the discipline. Most importantly researchers were seriously considering the probabilities of conducting field work remotely and practicing geography from home (Goralska 2020). Much of the initial effort involved going online and using the digital ethnographic methods that included mainly online interviews and group discussions. These research methods, as Pink et al. (2015) has already pointed out, are existing methods that were being adopted in the new online-digital environments. Thus, the challenge here is not only to consider new and innovative methodologies that would also prove to be reliable but to examine the emergence of newer digital fields and methods. This chapter attempts to explore the methodological possibilities and challenges that the pandemic has thrown us in order to conduct geographical research in digital fields using qualitative and ethnographic methods.

As a geographer who researches on digital geography or digital media, I often encounter scepticism from my fellow 'old school' geographers and face questions like, 'But where is geography or space in new media (or social media as it is commonly referred to)? This is not even 'real' space it is all but virtual'. Almost hinting at digital geography being all but make believe. Or 'how can looking at Facebook, Instagram, Blogs, YouTube and WhatsApp be doing field work' or 'how can these new media platforms constitute as one's field?' These are real concerns for many geographers some of which I will try to address here. My most practiced answers, more like a series of counter questions really, is what do you do when you get lost? Or plan to travel in an unknown city or get stuck in a traffic jam on your way to office and have a particularly important meeting to attend? In most cases I see a sudden dawning of realisation that even while moving through or being in 'real' geographical space they are at the same time situated in virtual spaces by simply accessing the google map, google earth and google street view to explore and find their locations and their routes. One only needs to ask oneself—do I in my everyday life while living in a 'real' space simultaneously communicate, talk and connect with anyone in digital space through the many and popular new media platforms of Facebook, Instagram, or WhatsApp? The answer in most cases would be a resounding and overwhelming yes. If we just look around us we may observe that one may be conversing with our family members and yet at the same time may be scrolling through the news, Instagram or Facebook in our smart phones, or talking to someone on WhatsApp or watching a video on YouTube, Tiktok or even a film on the innumerable OTT platforms.

Students more often than not are in agreement that in today's world one cannot live without being present and connected to the digital world. Almost everything we speak of is digitised and available online and we often admit to finding, locating and accessing information through the simple act of 'googling' it. Commonly, search engines like google are referred to as 'guru', (guru in India refers to someone who is a teacher or an expert) who would immediately generate and provide you with wide ranging information and knowledge. Thus, by typing a word on google search engine we can access an extensive 'field' of information and knowledge. Take for example, if I google Malaysia I immediately have an overview about the country through Wikipedia, the top news stories and videos on

Malaysia. On further adding keywords like weather, culture and tradition, history, heritage and tourism one can get more focussed and related information on Malaysia. As an Indian who has never been to Malaysia, and likewise with regard to other geographical parts of the world that I have never been to, at a click of a button I have access to information on the society, polity, history and geography of Malaysia and if I so wish I could also make laksa or rendang, popular Malaysian food in my Indian kitchen by watching a few YouTube videos. So, it is possible to produce a taste and an experience of Malaysia both digitally and materially within the confines of my home in India. This example underlies the manner in which digital media opens up possibilities of experiencing and knowing geographical space not just by physically being present in them but digitally through social media as well.

Here, the larger conceptual question that trouble geographers are—how does one connect more conventional notions of geographical space with the new forms of spatialities that emerge due to digitalisation on one hand. On the other, these new forms often challenge traditional forms of representations of geographical space as well. For example, check-ins, geo-tagging, marking oneself safe during different hazards on Facebook or simply posting photographs of moments on Facebook and Instagram are different forms of visual representations and mapping of these moments lived in places. It leaves no doubt in my mind that digital media has rather insidiously crept in our everyday lives through the smart phone and devices that we seem to carry and how we are constantly connecting across time and space through simple everyday acts of checking our emails, and messaging on WhatsApp; posting and commenting on Facebook or Instagram; ordering food or multiple consumer products through the multiple digital platforms or Apps; reading reviews of films or web series that you may want to watch on Netflix to products that you maybe planning to purchase; locating the nearby retail outlet, reading and debating about the latest news not just in one's locality or country but anywhere, any place across the world and the list is seemingly endless (Hine 2015; Graham 2020; Leszczynski 2020; Richardson 2020; Sadowski 2020). And not to forget the landscapes created in the gaming world or the innumerable videos on YouTube or the blogs that create copious textual documents of our everyday lives (Murray 2020; Gill et al. 2009). Watching, scrolling and sensing the world around us through the many social or new media platforms have become an integral part of our everyday lives. In fact, the presence of the digital in our material world is so commonplace that 'one tends not to think about it but through it' (Markham 2017). The argument that I am trying to make here is how we are simultaneously traversing and locating ourselves in the real world as well as the digital one and how both these worlds are becoming increasingly interconnected and difficult to distinguish one from the other. Take for example, how many of us in the Universities around the world were and are taking and attending classes online from the real spaces of our homes and connecting/meeting with each other be that students and teachers alike in the digital realm. In fact, with the pandemic and ensuing lockdowns with norms of social distancing being put in place webinars and online video conferencing have increased many fold whether related to work or simply hanging out and getting together with friends, family and colleagues over Zoom, google meet, Facebook Live and video chats. After the first few months of the pandemic Facebook was inundated with posts of people in online video-conferences with grids of names and faces appearing either in large groups or in selective intimate groups of family and friends. The pandemic has perhaps made us take stock and re-examine how the real and digital; the online and offline worlds have fused together forming a digital-material realm. It is this inter-connectivity of the online with the offline, the real with the virtual, and the physical with the digital world that creates opportunities for using innovative methodologies which may be used to conduct geographical research that suits the current pandemic situation but opens us to the possibilities of a digital field and research methodologies that can be practiced well beyond the pandemic.

5.2 The Digital Field

At the outset of any geographical research that requires conducting fieldwork and collecting of primary data, one of the first things that we are trained to do is to identify the field. The identification of the field essentially involves and coincides with selection of a well-defined geographical area which is a site of inquiry that would provide primary data related to specific research questions raised, which in turn will be analysed to produce geographical knowledge (Geertz 1979; Katz 1994). Anthropologists Gupta and Ferguson (1997) point out that the idea of the field is largely a space, a location, or a territorially fixed site where social reality or the real world is to be observed, understood, written about and analysed. Hence, the first step of conducting field work addresses the question of 'where' is the field. The question of 'where' or the geographical location of the field is not only central to defining the research project at hand but is tied to the theoretical conceptualisation of space in itself. The defined geographical space of the field and the practice of doing field work within it thus involves direct and first hand experience of geographical phenomena and thereby exploring, unpacking and analysing through it the real world and its geographical spaces. Hope (2009) argues that direct experiences of the field facilitate active and deep learning typified by critical understanding of the real world on one hand. On the other, it enables one to connect theory with experience (Kent et al, 1997). The field, thus emerges as the sole site through which one can learn about the real world (Gerber and Chuan 2000). Not surprisingly, the location and the direct experience of the field is also the most important part of research design as it would legitimise the research project and geographical knowledge that it is to produce.

Clearly, within the discipline of geography to investigate and understand the real world through direct experience in the field is privileged over other forms of observing, understanding and analysing it. Thus, when referring to field data geographers tend to term it as primary data and all else as secondary data, and the latter plays a supportive or a supplementary role to the primary data. Nairn (2005) claims that the dominant underlying assumption in practising fieldwork within geography indicates that the only way to explore, analyse and uncover the truth about the real world is through the direct observations in the real field. It then tends to negate other forms of knowing, analysing and at the same time impedes different nature of fields emerging. In recent years advancement in technology particularly that of remote sensing, geographic information system and digital media has not only expanded the scope of what constitutes the field but has redefined the field in itself. Simultaneously, it has challenged the very notion and practice of observing the real world only through direct, first hand experiences in the field but the possibility of conducting it remotely as well. Stoltman and Fraser (2000: 37) suggested that 'fieldwork and virtual fieldwork are increasingly viewed as synonymous' at the research level.

It brings me back to the question of whether one can regard the digital field as a geographical space or not? To start with the digital field poses two fundamental methodological and conceptual challenges. First, it defies the concept of being a geographical space that can be considered as fixed, well defined and bounded, territorial location. Second, the impossibility of having a first hand experience of a non-specified, intangible space that does not exist in real geographical terms. Yet if one borrows Appadurai's (1996: 178) concept of locality as possessing a phenomenological quality that is constituted by 'social immediacy', 'technologies of interactivity', 'relativity of contexts' and extend it to digital media then it too is marked by similar characteristics. Digital media emerges as a place when we think of it has a socio-cultural space replete with instantaneous and multiple interactions and social relations (Jones 1995). Markham (2004: 362) argued that the digital space can be conceptualised as a place having dimension, comprising meaningful, structured places where things happen that have genuine consequences. She further adds it as a place where relationships and communities are formed on the basis of these interactions, the level of engagement, depth of involvement and the length of time spent online. Thus, like any place the digital space is also characterised by our ability to wander, travel, navigate through it and hold conversations, share feelings and opinions with others who are in it like us (Markham 2004). For instance, the WhatsApp group formed by the classmates of a school or college or students having studied in that school or college is a digital space where the classmates or schoolmates gather to meaningfully interact irrespective of their differing physical locations. Often, there are arguments and conflicts too within these spaces with members leaving and forming other groups too. On the other hand, constant interaction may lead to more intimate relationships being formed and members could also form another more intimate group comprising of fewer members. The following post by Rahul Sharma, member of the Facebook page The Himalayan Club found his life partner and the love of his life through the Facebook page, emphasises how these pages become actual spatial sites where people meet, interact and form relationships and the underlying 'real-ness' and complexity of these digital spaces (Floridi 2014):

> this post not related to group, but wish to say super thanks dilse [from my heart] & wish to share that this group gave me my life partner. we are from different countries and member of this group. i helped her while she was travelling with her mother in laddakh (thru this group). we started chat, than she invited me to visit russia and we started travel together. now we are blessed with a baby boy also and enjoying our life. this group given me my life and best life partner. BIG THANKS TO The Himalayan Club. [https://www.facebook.com/groups/48171250774/user/100000434760993, posted on 17/01/2021]

According to Airoldi (2018), the digital landscape is a constellation of highly fluid and liquid sites, a network of interconnected digital locations in a moving information stream. Let me go back to the example I gave at the start of this paper on the search result I got on Malaysia to elaborate on the networked interconnectedness of differing digital locations in digital spaces—the google search engine itself connects you to this myriad and varying digital sites on the basis of categories it makes like, All, Maps, News, Images, Videos and More, which is further categorised into Shopping, Books, Flights and Finance. Thus, a simple keyword or a #hashtag takes you to different digital locations along this information stream that moves in multiple directions covering wide ranging themes and topics on that keyword or #hashtag. Similarly, one often finds oneself simultaneously surfing, navigating or scrolling the digital space through different devices whether the smart phone or the computer/laptop or being on multiple social media platforms or apps at the same through different windows or tabs at the same time. The viral message on WhatsApp clearly elucidates the information stream and the interconnectedness of the different digital locations and platforms within it:

"Ordering a Pizza in 2022
CALLER: Is this Pizza Hut?
GOOGLE: No sir, it's Google Pizza.
CALLER: I must have dialled a wrong number, sorry.
GOOGLE: No sir, Google bought Pizza Hut last month.
CALLER: OK. I would like to order a pizza.
GOOGLE: Do you want your usual, sir?
CALLER: My usual? You know me?
GOOGLE: According to our caller ID data sheet, the last 12 times you called you ordered an extra-large pizza with three cheeses, sausage, pepperoni, mushrooms and meatballs on a thick crust.
CALLER: Super! That's what I'll have.
GOOGLE: May I suggest that this time you order a pizza with ricotta, arugula, sun-dried tomatoes and olives on a whole wheat gluten-free thin crust?
CALLER: What? I don't want a vegetarian pizza!
GOOGLE: Your cholesterol is not good, sir.
CALLER: How the hell do you know that?

GOOGLE: Well, we cross-referenced your home phone number with your medical records. We have the result of your blood tests for the last 7 years.
CALLER: Okay, but I do not want your rotten vegetarian pizza! I already take medication for my cholesterol.
GOOGLE: Excuse me sir, but you have not taken your medication regularly. According to our database, you purchased only a box of 30 cholesterol tablets once at Lloyds Pharmacy, 4 months ago.
CALLER: I bought more from another Pharmacy.
GOOGLE: That doesn't show on your credit card statement.
CALLER: I paid in cash.
GOOGLE: But you did not withdraw enough cash according to your bank statement.
CALLER: I have other sources of cash.
GOOGLE: That doesn't show on your latest tax returns, unless you bought them using an undeclared income source, which is against the law!
CALLER: WHAT THE HELL!
GOOGLE: I'm sorry sir, we use such information only with the sole intention of helping you.
CALLER: Enough already! I'm sick to death of Google, Facebook, Twitter, WhatsApp and all the others. I'm going to an island without the internet, TV, where there is no phone service and no one to watch me or spy on me.
GOOGLE: I understand sir, but you need to renew your passport first. It expired 6 weeks ago…

Welcome to the future".

In other words, this fluid and liquid nature of digital space also challenges the fixity of the dominant and prevalent notion of the territorial boundedness of the field. Here, I argue that if we deploy Massey's (2005: 9) definition of space as a product of interrelationships constituted through the interactions from the global to the local; of space being multiple and heterogeneous; and that space is always in the process of being made and never closed or bounded then the digital field is not aspatial or non-geographical and very much at the heart of the ever transforming and evolving contemporary real world.

5.3 Methods in Digital Geography

Methods in digital geography based on Markham (2020) can be distinguished in terms of (a) methods that are used due to the remoteness of the field or research area making the digital method a requisite or pre-requisite for the study, for example the use of remote sensing data; (b) methods that are used as a tool, for example GIS, or conducting online interviews and discussions in the current pandemic situation; and (c) methods that are developed to study the digital space or geography in itself. My paper focuses on methods, particularly qualitative and digital ethnographic methods that can be evolved in the study of digital spaces. Widespread internet connectivity, digitalization and smart devices that are almost physical extension of ourselves and which we carry everywhere in our everyday lives have rapidly transformed our material-digital worlds. It is imperative that we develop empirical approaches to understand these fast changing 'real' worlds.

In any given research they are multiple methods that can be employed depending on the research questions of the study and the digital environments and landscapes that are being studied. One of the major challenges in carrying research on digital geography is that the digital technologies rapidly change and evolve and have the ability to completely transform the digital space. This is clearly brought out by Markham (2020) when she discusses the five waves—Wave1—cyberspace from early to mid-1990s, Wave 2—Web2.0 from early 2000s, Wave 3—Platformization of social networking from mid to late 2000s, Wave 4—Big data from early 2010s and Wave 5—Algorithms and predictive analytics from mid to late 2010s, and the manner which each wave has shaped interpretive qualitative research methods. It also has to be kept in mind that these waves may have been experienced differentially across the globe. In case of India, social media platforms users have been increasingly growing and has the largest Facebook user base in the world and with more than 200 million users each for Facebook, YouTube, WhatsApp and nearly 150 million users for Instagram (Statista 2020; UNDP 2019). So, the third wave is still an overwhelmingly dominant one in India. In the backdrop of the popularity of social media platforms my study on the city of Kolkata conducted between 2016 and 2019 tried to unpack how Kolkata was being mapped through social media, particularly the colonial history and heritage of the city. What I had proposed to do in my study was to understand the practice of producing places in social media that cut across real and digital experiences of colonial Kolkata on the one hand. On the other hand, this production of place was participatory, open and public to both the producers and users of the content within the digital space of social media. Let me now outline the specifics of the methodology used in a step wise manner and explain the different elements of the individual steps.

Step 1

The first step or entrée (the term has been used extensively by Kozinets 2002, Kozinets et al. 2014) was to develop an overview of the entire digital landscape and look for and identify appropriate sites in social media that addresses my research questions. It also addresses my concern of locating and understanding where my field will be in the digital landscape. Since my main focus was on the mapping of colonial Kolkata, particularly on Facebook I navigated through Facebook pages, communities, groups that posted on colonial Kolkata, the history and heritage of Kolkata. I used hashtags and keywords like colonial Kolkata, history and heritage of Kolkata, old Kolkata, memories and nostalgia of Kolkata to enter and locate my digital field. I also closely examined the about section of each of these pages, communities and groups to develop an overview of my digital field. This overview also helped me in providing me the overall context in which mapping of colonial Kolkata was being done and also enabled me to compare the different pages, groups and communities and individual posts on Facebook and locate my field.

Step 2

The second step involved an unobtrusive and passive ethnographic observation to learn as much as possible about these pages, groups and communities and individual posts on Facebook and help in the identification of specific pages groups or communities. This step addresses my concern of what exactly constitutes my field, and what should be included in my field and the bases of selecting specific digital sites as my field. Kozinets (2002: 63) emphasises that selection of digital sites should be on the following basis: (1) are more “research question relevant”; (2) have a “higher traffic of postings”; (3) have larger numbers of discrete message posters; (4) have more detailed or descriptively rich data; and (5) have more between-member interactions of the type required by the research question. Following Kozinets, I have developed

Step 1	Locating the field	Where is the field?	Enlisting of the different digital sites based on keywords, hastags and brief description of the group
Step 2	Identifying the field	What is field?	Listing of specific digital sites based on date of establishment of the site; number of members/followers; content; public or closed site etc.
Step 3	Taking Field notes	Observations and reflections	Descriptive data; analytical data;

Sample Spread Sheet 1: Overview of Facebook Groups

Sr No.	Category of social media	Name	Year of establishment	Membership (as on 11.11.2017)	Url
1	Facebook Public Group	Calcutta memories	2008	4856 members	https://www.facebook.com/groups/26202763738/?ref=br_rs
2	Facebook Public Group	Anthony's Kolkata heritage tours	2015	1181 members	https://www.facebook.com/groups/KolkataHeritageTours/?ref=br_rs
3	Facebook Closed Group	Calcutta-photographs and memories	2009	42,866 members	https://www.facebook.com/groups/calcuttapnm/
4	Facebook Closed Group	Memories of Calcutta of the Raj	2012	99 members	https://www.facebook.com/groups/400876366599932/?ref=br_rs
5	Facebook Group	Calcutta Sikh history digital archive	2016	135 members	https://www.facebook.com/groups/864972783638699/about/
6	Facebook Group	Nostalgia Kolkata	2011	3744 members	https://www.facebook.com/groups/nostalgiakolkata/about/

Sample Spread Sheet 2: Overview of Facebook Pages

Sr No.	Category of social media	Name	Year of establishment	Membership (as on 11.11.2017)	Url
1	Facebook Page Commercial	Heritage Walk Calcutta	2016	7324 followers	https://www.facebook.com/heritagewalkcal/
2	Facebook Page Commercial	Heritage Kolkata	2013	32,096 followers	https://www.facebook.com/HeritageKolkata/
3	Facebook Community page	Photographs from the Raj era	2015	312 followers	https://www.facebook.com/pg/Photographs-from-the-Raj-Era-1421336284856253/about/?ref=page_internal
4	Facebook Community page	Calcutta Architectural Legacies	2016	2130 followers	https://scroll.in/magazine/845049/an-instagram-project-is-preserving-kolkatas-gorgeous-buildings-before-they-vanish-for-good
5	Facebook Community page	Photographs from the Raj era	2015	312 followers	https://www.facebook.com/pg/Photographs-from-the-Raj-Era-1421336284856253/about/?ref=page_internal
6	Facebook Community page	Calcutta Architectural Legacies	2016	2130 followers	https://scroll.in/magazine/845049/an-instagram-project-is-preserving-kolkatas-gorgeous-buildings-before-they-vanish-for-good
7	Facebook Page	The Tram Lovers Club of Calcutta	2013	1314 followers	https://www.facebook.com/The-Tram-Lovers-Club-of-Calcutta-450357788388427/

Sample Spreadsheet 3 Categorizing Content of Facebook Groups

Sr No.	Category of Facebook data	Outreach of data		Name	Form of content	Description	Types of content
1	Facebook Group	Public	Niche-On Kolkata	Calcutta Memories	Pictorial + Textual	Conversations on Calcutta-archival, personal experiences, particularly Anglo Indian Community	Documenting everyday experiences and histories of Kolkata,
2	Facebook Group	Public	Commercial—On Kolkata walks	Anthony's Kolkata Heritage Tours	Pictorial	Documents history through walks mainly conducted by the administrator	Documents colonial histories and alternative histories of Anglo Indians
3	Facebook Group	Closed	Niche- On Kolkata	Calcutta-Photographs and Memories	Pictorial	Visual Documentation of everyday Calcutta	Visual archiving of heritage of Calcutta
4	Facebook Group	Public	Commercial-Kolkata	Heritage Kolkata	Pictorial	Documenting everyday lives in Kolkata and historical	Everyday lives and historical archiving of Kolkata
5	Facebook Group	Closed	Niche- On Kolkata	Memories of Calcutta of the Raj	Pictorial + textual	Documents different aspects of colonial rule in Kolkata	Documenting colonial heritage in Kolkata
6	Facebook Group	Public	Project Group	Calcutta Siikh History Digital Archive	Pictorial	Digital documentation of Sikh history in Calcutta	Digital Heritage
7	Facebook Group	Public	Niche-On Kolkata	Nostalgia Kolkata	Pictorial + Textual	Posts on various news of Kolkata including documented histories	Documents various secondary data on Kolkata’s histories

Sample **Spreadsheet 4: Categorizing Content of Facebook Pages**

Sr No.	Category of Facebook data		Outreach of data	Name	Form of content	Description	Types of content
1	Facebook Page	Public	Commercial- On Kolkata walks	Heritage Walk Calcutta	Pictorial + textual	Documents experiences of colonial histories through commercial walks	Documenting heritage through personal experiences
2	Facebook Page	Public	Niche- On colonial rule in India	Photographs from the Raj era	Pictorial	Documenting memories of the colonial period of India	Documenting colonial heritage
3	Facebook Page	Public	Media Page	Calcutta Architectural Legacies	Pictorial	Conservation attempts of architectural buildings of late modern Kolkata	Conservation/ Heritage
4	Facebook Page	Public	Business venture	The Tram Lovers Club of Calcutta	Pictorial + Textual	Business venture providing transportation services and documents posts on transportation histories	Documents various posts on heritage transport system of Calcutta

four spread sheets that identifies specific Facebook groups and pages, taking into consideration their year of establishment, membership, whether they are open and public groups or closed and private groups, communities that were commercial or non-commercial in nature, brief description of their contents and the type and form of contents.

Step 3

The third step involves taking field notes on observations made in the digital setting of the field. There are two aspects of taking field notes—the first being descriptive and the second being analytical in nature (Schwandt 2015). The descriptive elements of field note include recording the factual information for example the date and time, a brief description of the data, comments made. The spread sheet below is an example of descriptive element of pictorial data that was observed.

The analytical aspect of the field note are the questions that immediately arise on observation of the data and any further reflection and analysis of these observations. For example, many of the pictures of the colonial period that have been posted were taken by British photographers, the landscape that was captured in the photograph equally captured the British and the natives. The comments on the photographs often expressed ‘amazement’, ‘shock’ and an acknowledgment of colonial heritage of Kolkata that was ‘fast disappearing’ and that needed to be preserved or how the posts brought to life the ‘hidden histories and heritages of Kolkata’.

Sample Spreadsheet 5

Sl. No	Content	Url	Description	Photograph retrieved from	Location	Nature of the photograph	Estimated time period of the site	Description Of People In the picture (If Any)	Comments Posted	Re-Imagined Knowledge From The Popular Imaginaries
1	View of the Town Hall	https://www.facebook.com/photo.php?fbid=10157450070434638&set=gm.10155569427197043&type=3	Rare documentation of the Eastern facade of the beautiful Town Hall, probably taken from the Raj Bhawan	Johnston & Hoffman	It's a colonial built royal administrative area of Raj Bhawan (present day residence of the Governor of West Bengal)	Black & White	1883 apprx	–	Constructive comments about the origin and the architectured buildings seen in the photograph	The Town Hall with ten windows Arched Gate of the Raj Bhawan Organised green space and Lawn
2	Esplanade East	https://www.facebook.com/photo.php?fbid=10211633281403356&set=gm.10155568651037043&type=3	View of a road crossing at Esplanade, Chowringhee and Dharramtolla	N.A	Semi crowded scene of Esplanade East with a stretch of European styled buildings on one side and open ground on the other side	Black & White	1903	Mostly people (particularly men are seen) wearing Dhoti Panjabi with a jhola(bag) in their hand are seen crossing roads, sitting beneath the trees, fixing street lights, coming out of the buildings, etc	People are amazed as well as shocked by the drastic transformation of the site in present time. Some say it's a change beyond recognition	New electric traction tram and tram lines Worker on ladder lighting decorative triple gas light lamp post in the middle of road crossing at Esplanade
3	Aerial view of Chowringhee	https://www.facebook.com/photo.php?fbid=10211636905253950&set=gm.	Aerial documentation of Chowringhee from Octerlony monument	N.A	Chowringhee encompassing various domains on one side of the	Black & White	1893	–	Describing the photograph with their knowledge about the site	A horse drawn tram on Chowringhee

(continued)

Sl. No	Content	Url	Description	Photograph retrieved from	Location	Nature of the photograph	Estimated time period of the site	Description Of People In the picture (If Any)	Comments Posted	Re-Imagined Knowledge From The Popular Imaginaries
		10155570008762043&type=3	depicting a religious building i.e. Shahi Masjid, etc		road like a mosque, mutty seal's market, newspaper office, new Bristol hotel, etc. and the other side is an open ground with trees and grasses					The mosque showing a relic architectural and cultural heritage Beautiful European architectured building of the Bristol hotel in the eastern side
4	View of newly built High Court building	https://www.facebook.com/photo.php?fbid=10157441682914638&set=gm.10155563519202043&type=3	Documentation of the newly built neo-Gothic styled High Court building in the Esplanade West shown	Johnston & Hoffman	Colonial built neo-Gothic styled High Court building in the Esplanade West near Babu Ghat	Black & White	1864	–	Adding significant informations of the before and after construction of the High court building	Neo-Gothic styled architectured building
5	St. John's Church, Calcutta	https://www.facebook.com/photo.php?fbid=10211615110229088&set=gm.10155562500302043&type=3	Documentation of the beautiful St. John's Church which is a large square structure in the Neoclassical architectural style	Samuel Bourne	A public building erected by the East India Company is located at the North-west corner of Raj Bhawan	Sepia	1860s	A women and a child is seen waiting at the entrance and two men, one wearing pants and jacket with a cap and other one	Posting recent pictures and commenting upon the changes that have occurred in all these years	The colonnade verandas which are the later additions in 1811 A stone spire 174ft tall is a

(continued)

Sl. No	Content	Url	Description	Photograph retrieved from	Location	Nature of the photograph	Estimated time period of the site	Description Of People In the picture (If Any)	Comments Posted	Re-Imagined Knowledge From The Popular Imaginaries
								sitting opposite to him with wearing probably a lungi and short kurta kind of clothing		distinctive feature Also the spire holds a giant clock
6	Tolly's Nullah	https://www.facebook.com/photo.php?fbid=10157447410619638&set=gm.10155567590762043&type=3	A view of Tolly's Nala (Aadi Ganga) with many hut type settlements are seen adjacent to it	Johnston & Hoffman	A native built compact kaccha settlement type is seen adjacent to the Tolly's Nala which is probably the Orphanganj	Black & White	–	Ferries are seen loaded with people (not clearly identifiable how many heads)	Comments are adding very important informations about the history of the place like the origin of the Orphanganj	A building more like a church is seen at the left corner of the photograph

Let me now give an example of making field notes from a ‘textual’ post and the comments made in response made on one of the Facebook pages. Navpreet Arora posts,

> While doing a research for a new walk, I suddenly realised that while lovers of Calcutta like me were busy exploring the farther parts of the city, streets and environs where we stay or work are often ***left unattended***.
> Sudder Street and its vicinity is a area where I have literally grown up and go there for work till date. Next few posts are an ***attempt to unearth the history of this street*** with some trivia of the adjoining lanes and by lanes.
> *Sudder Street* is an old thoroughfare which appears as *Ford Street* in *Wood's map of 1784*. Thereafter it came to be known as Speke Road after Peter Speke , a member of the Supreme Council from 1789-1801. He built a house in 1790, a building which still exists today in the Indian Museum complex. Speke's house was later let out to the Government for holding Sudder Dewani Adalat one of the first courts in British India. Instituted by Warren Hastings in 1772, the court saw many landmark legal battles. It was ultimately sold to the Government lending its name to the street . However, during Bentick's tenure, the Sudder Court was shifted to next to the present day P.G. Hospital. The Sudder Board of Revenue also occupied these premises for some time.
> This historical edifice was recently in news recently when 5 new support pillars were erected along with the old columns to provide support to the structure till the ongoing renovation is currently completed.

And the comments that followed:

> “B G It was in the same year, 1797, that an extraordinary and exciting scene took place in Sudder Street, just off Chowringhee Road, in a house which is now included in the buildings of the Indian Museum. This house was the property of Mr. Peter Speke, member of Council, who built it in 1790. The grounds extended to Kyd Street, and included the Kyd Street Tank, - Jhinjherrie Talao - sheet of water which may be readily found marked on the “Plan of Calcutta, 1742.” The public had the right of access to this tank, which Mr. Speke desired to keep private, and to surround with a garden; to obtain which purpose an ingenious scheme was devised. The “Plan of Calcutta, 1742.” The ghaut steps was removed from the east bank, to the south side, where the boundary was formed by the then new road, Kyd Street, named after General Alexander Kyd, who built and lived in the house which has been for so many years the United Service Club. The ghaut opened on this road, and over the steps an arch was thrown, and was built up with a perforated wall, which, while it allowed the water to flow freely through, effectually shut out the people who came to draw water from entering the tank, which was surrounded by a high wall. It was this perforated wall which obtained for the tank its native name of Jhinjherrie Talao (the “Mesh-work Tank ”).

In May, 1797, Mr. Speke had refused to receive a petition from a young Sikh, who, becoming importunate, was turned out of the house. Resenting this treatment, the unfortunate man, rushing into the house, killed two servants, and tried to enter Mr. Speke's room. His bearer with great presence of mind locked his master's door and misled the murderer, who, ascending the wrong staircase, reached the terraced roof, and was trapped. A party of sepoys—after trying in vain for some hours to reach the roof, the murderer keeping them at bay by pulling up the balustrades, and throwing the masonry on them in the narrow passage—broke loopholes in the wall of the staircase, and shot him dead, in the sight of an immense crowd gathered below.

The house was afterwards rented to Government by Mr. Speke for the Sudder Dewanny Court, and led to the name of the street being changed from Speke Road to Sudder Street, a name which it bears to this day.

The custom of naming streets after the most important resident has perpetuated his memory.

NDG Tagore s brother Jyotirendranath lived at 10 Sudder Street. He and his wife Kadambari often entertained the high society of Calcutta here, and the poet stayed with them on many occasions.

It was here, one day, while looking out of the window of his room, at the fountain in the courtyard, he wrote 'Nirjhorer Swapno Bhongo ', his renowned poem, and realised, poetry was his life s calling.

The poet has immortalized this incident in his memoirs.

At this house, the Tagore s entertained Bal Gangadhar Tilak and Gopalkrishna Gokhaley. Where the premises had to be 'sanitized' for the strict hindu vegetarians, because, much of Western society and the Tagores themselves, were fond of the good life and had no food taboos, thanks to their liberal outlook.

This was where they socialized.

NDG Navpreet Arora Is the house still there?

Navpreet Arora NDG it's there, converted into a hotel called Plaza.

Nothing of the old house exists.

NDG Navpreet Arora I started doing in Kolkata what you are doing after almost all my life, as a Bengali… Only last year. And I am much much older. I presume.

Discovered a lot of gems.

Guess, was too busy living life, to really see, what was in my own back yard…

BG The last House in Sudder Street on corner of Hartford lane, where R.N.Tagore as young boy lived and learnt music from Irish teacher IN 1883. A good picture can be seen in Calcutta Municipal Gazette, 1941 Tagore Memorial issue edited by Amal Home."

(Source: https://www.facebook.com/groups/1920995204893134/)

Navpreet Arora, BG and NDG are members of a Facebook page and where Navpreet Arora and BG are visual storyteller and NDG is a conversation starter as identified by Facebook. All three not only seemed familiar with the history of the Sudder Street but to the post brought to light little known history and mapped the evolution of the street over time. For example, they discussed as underlined in the above narrative the origin of the street from Ford street to Speke road to Sudder street and the adjoining Kyd Street and the history of the Street spanning over a period of hundred years marking the important buildings and structures on Sudder Street that contributed to the history and making of the Street. It is the little known histories that seem to fascinate the three commentators here as revealed through the narrative when they use phrases like – '***attempt to unearth the history of this street***', '***Discovered a lot of gems***', ***Guess, was too busy living life, to really see, what was in my own back yard..***'

Here while making the field notes the researcher also initiates the interpretative data analysis and also provides the context in which the data is to be interpreted. Based on the nature of the posts, likes and comments posted in response, and identity of the author of the content creator within the Facebook group, whether s/he is a virtual storyteller, conversation starter or admin one can then choose to conduct online interviews to generate further data and insights.

5.4 Conclusion

The current global pandemic has perhaps reinforced the relevance of the digital and computer mediated communications and its dominant presence in our everyday lives. Today young children who were perhaps not allowed any access to digital technologies are attending online classes whereas old people who were reluctant to use these new technologies are becoming familiar with them and trying to learn them. Thus, it has almost become necessary to explore and research on digital spaces with new innovative methods. The advantages of using digital methods are many, one being it is extremely flexible and adapts itself to changing digital contexts and technologies. The challenges too are innumerable in terms of what constitutes the field and fieldwork. It also requires the researcher to readjust her/himself with the nature of the field, which is online and on the screen. Thus, to communicate with the researched one needs to reorient oneself with regard to perhaps textual interaction through messaging where one may miss out on many of the non-verbal cues that a qualitative researcher relies on while doing fieldwork. Though online interactions could be audio-visual yet communication through the filter of a screen can be inhibiting for both the researcher and researched. Perhaps one of the biggest challenges that arises are large set of data and the task of managing, filtering and using the data. Ethical issues too are a major concern mainly with regard to the privacy of field participants and respondents.

Acknowledgements This paper is based on ICSSR sponsored research project, "Popular Imaginaries and Discourses on Politics in India: Exploring Cultural Narratives as Sites of Knowledge Construction" conducted between 2017 and 2019. I would like to thank Arunima Ghoshal and Nandita Paul who worked as research assistant and research intern respectively in the project.

References

Airoldi M (2018) Ethnography and the digital fields of social media. Int J Soc Res Methodol 21(6):661–673

Appadurai A (1996) Modernity at large. Cultural dimensions of globalisation. University of Minnesota Press, Minneapolis

Floridi L (2014) The fourth revolution. how the infosphere is reshaping human reality. Oxford University Press, Oxford

Góralska M (2020) Anthropology from Home. Advice on Digital Ethnography for the Pandemic Times, Anthropology in Action 27(1):46–52, Berghahn

Geertz C (1979) From the Natives point of view: on the nature of anthropological understanding. In: Rabinow P, Sullivan WN (eds) Interpretive Social Science, Berkeley, C.A.: University of California Press, pp 225–41

Gerber R, Chuan GK (2000) Fieldwork in geography: reflections, perspectives and actions. Kluwer Academic Publishers, Boston

Gill AJ, Nowson S, Oberlander J (2009) What are they blogging about? Personality, topic and motivation in blogs, proceedings association for the advancement of artificial intelligence. http://www.nowson.com/papers/GillNowOber-ICWSM09.pdf

Graham M (2020) Regulate, replicate, and resist—The conjunctural geographies of platform urbanism. Urban Geogr 41(3):453–457

Gupta A, Ferguson J (1997) Discipline and practice: "The Field" as site, method, and location in anthropology. In: Gupta, Ferguson (eds) Anthropological locations: boundaries and grounds of a field science. University of California Press, Berkeley

Hine C (2015) Ethnography for the internet: embedded, embodied and everyday. Bloomsbury Academic, London

Hope M (2009) The importance of direct experience: a philosophical defense of fieldwork in human geography. J Geogr High Educ 33(2):169–182

Jones SG (1995) Understanding community in the information age. In: Jones SG (ed) Cybersociety: computer-mediated communication and community. Sage, Thousand Oaks, CA, pp 10–35

Katz C (1994) Playing the field: questions of fieldwork in geography. Prof Geogr 46(1):67–72

Kent M, Gilbertson DD, Hunt CO (1997) Fieldwork in geography teaching: a critical review of the literature and approaches. J Geogr High Educ 21(3):313–332

Kozinets RV, Dolbec P, Earley A (2014) Netnographic analysis: understanding culture through social media data. In: Flick U (ed) Sage handbook of qualitative data analysis. Sage, London, pp 262–275

Kozinets RV (2002) The field behind the screen: using netnography for marketing research in online communities. J Mark Res 39:61–72

Leszczynski A (2020) Glitchy vignettes of platform urbanism. Environ Plann D: Soc Space 38(2):189–208

Markham A (2004) The Internet as research context. In: Seale C, Gobo G, Gubrium JB, Silverman D (eds) Qualitative research practice. Sage, London, pp 358–374

Markham A (2017) Ethnography in the digital internet era: from fields to flows, descriptions to interventions. In: Denzin NK, Lincoln YS (eds) The sage handbook of qualitative research, 5th edn. Sage, London, pp 650–668

Markham A (2020) Qualitative inquiry in the digital age. In: The field of qualitative research, P Leavy (ed). Oxford University Press

Massey D (2005) For space. Sage, London

Murray S (2020) Horizons already here: video games and landscape. Art J 79(2):42–49

Nairn K (2005) The problems of utilizing 'direct experience' in geography education. J Geogr High Educ 29 (2):293–309

Pink S, Horst H, Postill J, Hjorth L, Lewis T, Tachchi J (2015) Digital ethnography. Principles and practice. Sage, London

Richardson L (2020) Coordinating office space: digital technologies and the platformization of work. In: Environment and Planning D: Society and Space, September 2020: 1–19

Sadowski J (2020) Cyberspace and cityscapes: on the emergence of platform urbanism. Urban Geogr 41 (3):448–452

Schwandt TA (2015) The sage dictionary of qualitative inquiry. Sage, Thousand Oaks, CA

Statista (2020) Number of Facebook Users in India 2015–2023 Statista. https://www.statista.com/statistics/

304827/number-of-facebook-users-in-india/. Last Accessed 15 July 2020

Stoltman JP, Fraser R (2000) Geography Fieldwork: tradition and technology meet. In: Gerber R, Chuan GK (eds) Fieldwork in geography: reflections, perspectives and actions. Kluwer Academic Publishers, Boston, pp 37–52

Social Media for Youth and Civic engagement in India, UNDP report (2019). file:///C:/Users/MY%20PC/Downloads/SOCIAL%20MEDIA%20REPORT.pdf. Last Accessed 15 July 2020

Aparajita De , is currently Professor at Department of Geography, Delhi School of Economics, University of Delhi. Her research largely falls within the scope of urban and media studies. Aparajita has worked and published on the theme of geographical imaginations and constructions of space in everyday lives. These include her publications on the socio-spatial construction of Hindu-Muslim identities in the backdrop of communal violence in Ahmedabad, Gujarat; digital practices of religion and the making of diasporic identities. She has also written on the need to critically examine the conceptual and analytical categories of space and the politics of knowledge creation. Aparajita's current research project examines the digital mapping, reimagining and story-telling of colonial Calcutta in new media, and the production of material-digital landscapes and spaces.

6 Automated in Situ Water Quality Monitoring—Characterizing System Dynamics in Urban-Impacted and Natural Environments

Kim N. Irvine, Lloyd H. C. Chua, and Cameron A. Irvine

Abstract

The application of in situ monitoring to characterize the dynamics of urban, peri-urban, and natural water environments from Southeast Asia, North America, and Australia is explored in this chapter. Focusing on water temperature, dissolved oxygen, turbidity, chlorophyll a, specific conductivity, and pH, important considerations in the deployment and maintenance of in situ monitoring systems is examined, followed by discussions of signature temporal trends (e.g. storm event versus dry weather, daily, seasonal) and specific spatial trends (e.g. land use impacts, water sensitive urban design (WSUD) performance, water column profiling). The value of in situ monitoring as a surrogate for other water quality parameters, such as nutrients, is explained; and finally, data analysis techniques are discussed, with a specific focus on deterministic modelling, geospatial modelling with GIS, and Artificial Intelligence (AI).

Keywords

Water quality time series · In situ monitoring · Water column profiling · Land use · WSUD · Mathematical modelling

6.1 Introduction

Automated, in situ water quality monitoring is now well established as a means to elucidate the dynamic characteristics of a diverse set of water environments (Glasgow et al. 2004) that include oceans, lakes, rivers, wetlands, Water Sensitive Urban Design (WSUD) features, drainage canals, sewers, and wastewater treatment facilities. The methods of assessment and data analysis are equally diverse. The objectives of this chapter are fourfold: (i) discuss techniques for the deployment of automated in situ instruments in a variety of water environments; (ii) examine issues related to maintenance of the instruments and data quality assurance; (iii) explore signature trends and characteristics of different water environments that have been identified using automated monitoring; and (iv) introduce and review common data analysis techniques. In addressing these objectives, we will rely extensively on our experience and publications with in situ

K. N. Irvine (✉)
Faculty of Architecture and Planning, Thammasat University, Bangkok, Thailand
e-mail: kim.irvine@ap.tu.ac.th

L. H. C. Chua
School of Engineering, Faculty of Science Engineering and Built Environment, Deakin University, Geelong, Australia
e-mail: lloyd.chua@deakin.edu.au

C. A. Irvine
Grand River Conservation Authority, Cambridge, Canada
e-mail: cirvine@grandriver.ca

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

F. B. Mustafa (ed.), *Methodological Approaches in Physical Geography*, Geography of the Physical Environment, https://doi.org/10.1007/978-3-031-07113-3_6

water quality monitoring over the past 25 years from locations in Southeast Asia, North America, and Australia.

We focus our review on instruments and sensors that we commonly have used in our monitoring efforts, YSI (https://www.ysi.com/products/multiparameter-sondes), Hydrolab (https://www.hydrolab.com/), Manta datasondes (https://www.waterprobes.com/), and SeaBird Sealoggers (https://www.seabird.com/about-sea-bird). This is not meant as an endorsement of these specific instruments, as other such instruments are available, but simply, they represent our experience. The sensor data examined herein represent conventional parameters, turbidity, chlorophyll a, dissolved oxygen, specific conductivity, temperature, and pH, although we do note that sensors for nutrient monitoring (and including lab-on-chip technology) are available (Beaton et al. 2012; Carey et al. 2014; Sherson et al. 2015; Pellerin et al. 2016), as are in situ methods for suspended sediment particle size analysis (Liss et al. 2005; Effler et al. 2008; Boss et al. 2018).

In situ monitoring offers several advantages over traditional, manual, grab sample approaches, foremost being that field teams do not have to be on call 24 h a day, 7 days a week to catch transient storm and pollution discharge events, and this maximizes understanding of system dynamics (Bourgeois et al. 2003; Irvine et al. 2005a; Wade et al. 2012; Skarbøvik and Roseth 2015). As will be discussed in detail later, the continuously monitored parameters can be used as surrogates for other water quality parameters that traditionally require laboratory analysis and this ultimately can incur cost savings (Irvine et al. 2002, 2019; Irvine and Murphy 2009; Gould et al. 2010). Furthermore, with the increasing availability of a wide array of low-cost sensors, Internet of Things (IoT), and data analytics, big data and environmental monitoring increasingly are becoming an important component of smart city development and resource management (Adamala 2017; Ascui et al. 2018; Bibri 2018; Chen and Han 2018).

6.2 Deployment, Maintenance, Downloading, and Data QA/QC

Datasondes can be deployed in a number of ways, depending upon study objectives. Typically, however, we have been interested in continuous time series data at a fixed water depth. There are a number of ways to deploy at a fixed depth, but the preferred installation for rivers and channelized flow is mid-channel from a bridge (e.g. Fig. 6.1), although creative solutions to deployment sometimes are necessary. For larger rivers and canals, we have deployed from floating buoys and even floating houses in the Mekong River (Fig. 6.2). When possible, for security and safety reasons, we prefer to deploy the datasondes inside of a capped and locked PVC pipe, with holes drilled in the pipe to facilitate water flow. In the case of the Alleghany River, Pennsylvania, bridges were not conveniently located, and we therefore fixed the PVC pipe to iron backhoe tread, which was of sufficient weight to keep the units in place, even under large storm events (Fig. 6.3). In the Tonle Sap Lake, Cambodia, we deployed two datasondes simultaneously, one approximately 1 m above the lake bed and the other approximately 1 m below the water surface. Here, we filled a car rim with cement and fixed a metal pipe into the rim. The PVC pipe that housed the bottom datasonde was attached directly to the pole. The near-surface datasonde was attached to the pole by a chain and was floated using empty plastic water containers (Fig. 6.4). Continuous monitoring of the Grand River in Ontario, Canada, is achieved by pumping water from an intake in the middle of the river to an indoor monitoring shed that houses the datasonde and an ISCO automated water sampler (Fig. 6.5). It is possible to monitor water-sensitive urban design (WSUD) features such as constructed wetlands, cleansing

Fig. 6.1 Datasonde deployment, together with a velocity meter, in a drainage/irrigation canal, Rach Gia, west coast of the Mekong Delta, Vietnam (photo by the authors)

biotopes, and retention ponds, as well as wastewater treatment ponds, provided the feature maintains a water source (Figs. 6.6–6.7). Alternative, smaller, IoT-based sensors have been developed primarily to monitor soil moisture and turbidity in rain gardens where the flow tends to be episodic.

In most of our continuous deployments, the measurements were recorded and stored automatically in the datasonde memory. Measurement time steps normally were 15 min, although in more remote locations, where battery life is of concern, the measurements may be every 30 min. Telemetry or Wi-Fi networks provide an option to transmit, store, and visualize water quality data in near real time on a data dashboard (e.g. Irvine et al. 2019), which allows for quick and easy data review and desktop QA/QC, although such networks for in situ research currently remain less common.

In some cases, spot measurements or vertical profiles are of interest (e.g. Irvine et al. 1997). These measurements can be taken from a bridge or a boat (Fig. 6.6) and often are manually recorded rather than stored in datasonde memory. SeaBird Sealogger profiling is an alternative to YSI or Hydrolab profiling. While SeaBird units can be used in moderately deep water (e.g. Fig. 6.8; Effler and O'Donnell 2001; Napieralski and Fraser 2010), they also have the capability of being deployed in much greater, oceanic depths. An option for rapid collection of spatial data along transects at different water depths is the use of a Remotely Operated Vehicle (ROV) with a datasonde (Fig. 6.9). The ROV transect coordinate pattern can be programmed, together with the collection time steps, so that deployment can be accomplished without continuous supervision. The ROV pattern also can be manually controlled from shore.

Fig. 6.2 Datasonde deployment from a buoy in the Black Rock Canal, Niagara River, New York (left), and on a floating house in the Mekong River, downstream of Phnom Penh, Cambodia (right) (photos by the authors)

Fig. 6.3 PVC pipe (with holes) fixed to a backhoe tread for weight (left) and installed in the Allegheny River, Pennsylvania (right). Datasonde is circled in red (photos by the authors)

Regardless of whether the datasondes are logging in situ or telemetrying the data remotely, routine calibration, cleaning, and maintenance of the sensors are essential. All sensors should be calibrated with commercially available and certified standards prior to initial deployment, although calibration of the chlorophyll a sensor is a particular challenge that may necessitate comparison with lab analysis. Even with laboratory analysis to generate fluorescence calibration curves, there can be scatter in the data related to the species of algae and biogeochemical conditions of the water body (Lawrenz and Richardson 2011; Roesler et al. 2017; Chaffin et al. 2018; Kuha et al. 2019), although Irvine and Murphy (2009) found a strong 1:1 relationship between lab measurements and a calibrated datasonde fluorescence sensor. Dissolved oxygen sensors that employ membrane

Fig. 6.4 Datasonde deployment in the flooded forest fringe of the Tonle Sap Lake, Cambodia, with the bottom unit (left) and the surface deployment floated with empty water containers (right) (photos by the authors)

Fig. 6.5 Monitoring station housing the datasonde and automated water sampler at the Grand River in Ontario, Canada (left). Inside the monitoring station, attached to the wall is the stainless-steel tank containing the datasonde and the ISCO automated water sampler in the foreground (right) (photos by the authors)

technology will tend to experience greater drift than optical or rapid response technology (e.g. Johnston and Williams 2006) and for this reason, our preference is to download, clean, and calibrate each datasonde on a routine weekly basis (Irvine et al. 2005b; Irvine and Murphy 2009), although in remote, inaccessible areas, the schedule might be extended to two weeks (Irvine et al. 2011). Routine cleaning is essential to prevent biofouling and poor sensor response, even in relatively clear water environments, despite the claims of manufacturers regarding long-term deployment with automated cleaning brushes. Routine downloading also minimizes the potential for data loss due to sensor fault or battery outage, as field response is more timely.

Fig. 6.6 Spot measurments in a canal, Selangor Nature Park, Malaysia (photo courtesy of Firuza Begham Binti Mustafa), and profiling from a boat in an aerated lagoon wastewater treatment facility, Cha am, Thailand (photo courtesy of Shwesin Koko)

Fig. 6.7 Installation of datasondes at an intake sump upstream of the cleansing biotope in Jurong Ecogarden, Singapore (left), and in the effluent sump from the cleansing biotope, with the biotope cells in the background (right) (photos by the authors)

Data must be routinely reviewed for QA/QC. In our experience, the most common suspect data are large spikes of turbidity, temperature, and conductivity for a single time step. Irvine et al. (2019) reviewed the QA/QC procedures undertaken by the Grand River Conservation Authority in Ontario, Canada, that include the identification of outliers and infilling of missing or outlier data.

Fig. 6.8 SeaBird MicroCAT profiler and Laser In Situ Scattering Transmissometry (LISST, for particle size and volumetric concentration of particles varying with depth) system being deployed from a boat in a Singapore reservoir (photos by the authors)

Fig. 6.9 Manual testing of an ROV-supported datasonde in Delaware Park Pond, Buffalo, New York (left), and National Institute of Education (Singapore) Year 4 Final Year Project students preparing to deploy an ROV in Lake Erie (right) (photos by the authors)

6.3 Water Environment Temporal Dynamics

6.3.1 Dissolved Oxygen

Dissolved oxygen is an important indicator of ecosystem health, and dissolved oxygen guidelines are used by many countries to help classify the best use status of a waterbody (Irvine et al. 2005b; Irvine 2017). During non-event periods, dissolved oxygen frequently exhibits a diurnal pattern (Fig. 6.10) that is driven by the relative balance of primary productivity and photosynthesis with respiration patterns and has been observed in wetlands, lakes, retention ponds, canals, and rivers in Southeast Asia, North America, and other locations throughout the world (e.g. Mulholland et al. 2005; Moraetis et al. 2010; Visoth et al. 2010; Price et al. 2011; Irvine et al. 2011; Viswanathan et al. 2015; Dodds et al. 2018). The pH levels of water bodies frequently mirror the diurnal dissolved oxygen pattern, as CO_2 is released during respiration, resulting in a lower pH at night when photosynthesis ceases and respiration is dominant (Irvine 2017).

As originally outlined by Odum (1956), the rate of change of dissolved oxygen in an aquatic system primarily is a function of gross primary production, the rate of respiration, and the rate of oxygen uptake by diffusion, expressed as (after McBride and Chapra 2005)

$$\frac{dD}{dt} + k_a D = R - P(t) \tag{6.1}$$

where D is the dissolved oxygen deficit, mg/L, calculated as C_{sat}–C, with C being the dissolved oxygen concentration (mg/L) and C_s its saturated value; t is time (day); k_a is the first-order stream reaeration coefficient (per day); R is the respiration rate (mgO/L/day); P(t) is the time-varying plant primary production (photosynthesis) rate (mgO/L/day). System metabolism has been characterized by examining values for P(t), R, and k_a, often calculated using the approximate delta method (McBride and Chapra 2005; Price et al. 2011), which is based on the difference between the maximum and minimum dissolved oxygen levels, while the primary production rate is described by a half-sinusoid within the photoperiod. Other methods to calculate dissolved oxygen and system metabolism have been developed (e.g. Song et al. 2016) and Holtgrieve et al. (2013) used a state-space oxygen mass balance model with continuous dissolved oxygen measurements to assess gross primary productivity (GPP) and ecosystem respiration (ER) for the Tonle Sap Lake, Cambodia.

While a diurnal pattern in dissolved oxygen is common, it is not universally observed. For example, Fig. 6.11 shows diurnal patterns for two tributaries (Buffalo Creek and Cazenovia Creek) located 6.5 km north of the monitoring site in the main Buffalo River, Buffalo, New York. No diurnal pattern can be discerned in the Buffalo River itself, possibly because of local urban discharge sources, but more likely because of high sediment oxygen demand from contaminated sediment and navigational dredging which has artificially deepened the river, reducing flow velocity, and thereby increasing residence time. These hydraulic conditions have produced a more stable water column in which thermal stratification occurs, resulting in reduced mixing of dissolved oxygen (Irvine et al. 2005b). Dodds et al. (2018) also noted the importance of local disruptions on the diurnal pattern for some rivers. Although the Tonle Sap Lake exhibits a diurnal pattern (Irvine et al. 2011), the Tonle Sap River near Phnom Penh does not exhibit such a pattern. This may be a combination of local impacts from Phnom Penh and water-based peri-urban communities as well as an influence from the Mekong River flow. The blackwater streams draining the North Selangor peat swamp forest of Malaysia (Fig. 6.12) had low dissolved oxygen (averaging 0.31 mg/L) and pH (averaging 3.63) (Irvine et al. 2013), which is consistent for blackwaters in Southeast Asia that are high in tannins. There was no observable diurnal pattern in the dissolved oxygen, likely because blackwaters of the North Selangor peat swamp forest tend to have low blue-green algae levels and photosynthetic activity (Yule and Gomez 2009). Wastewater in Phnom Penh, Cambodia, is not

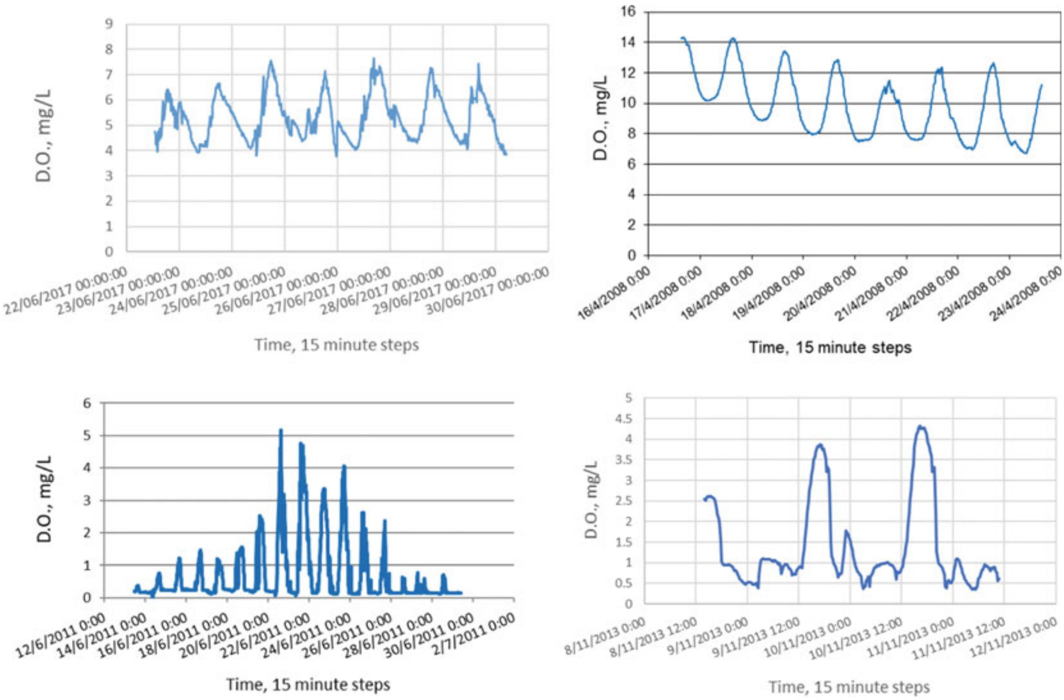


Fig. 6.10 Jurong Ecogarden, Singapore, outlet of stormwater retention ponds and cleansing biotope WSUD, (upper left); Cayuga Creek, Niagara County, New York, downstream site (upper right); Rangsit Canal, Pathum Thani, Thailand (lower left); and canal in Rach Gia, Vietnam, shown in Fig. 6.1 (lower right)

treated by a conventional treatment plant, but instead is treated by natural wetlands to the north and south of the city. Figure 6.13 shows a clear diurnal dissolved oxygen cycle at the outlet of the 1,500 ha Boeng Cheung Ek treatment wetland to the south of the city. However, the wetland area in the vicinity of the wastewater discharge inlets does not exhibit a diurnal pattern, but a pattern that is influenced by pump operations; dissolved oxygen levels are reasonably high for wastewater because of aeration by the pump activity, moving the sewage from the open sewer canals into the wetland. The algae and aquatic plants have not yet had the opportunity to establish a photosynthesis/respiration cycle at the head of the wetland system, as they do at the wetland outlet (Visoth et al. 2010).

In addition to a diurnal cycle, dissolved oxygen levels can exhibit seasonal trends. The Tonle Sap Lake is an interesting freshwater pulsing system, as between late May and late September (rainy season), it is not hydraulically possible for all flow to reach the South China Sea via the Mekong and Bassac Rivers. Excess flow goes up the Tonle Sap River to fill the lake. During this time, the surface area of the lake typically increases from about 2,500 km^2 to about 15,000 km^2 and depth increases from around 1 m to approximately 7–9 m (Koponen et al. 2005; Irvine et al. 2011). During the dry season, as flow on the Mekong River declines, water reverses direction, draining from the lake, down the Tonle Sap River, to the Bassac/Mekong system. Irvine et al. (2011) showed that in the flooded forest fringe area of the Tonle Sap Lake, dissolved oxygen levels could increase from daytime peaks of approximately 1–4 mg/L to 7–9 mg/L in association with the freshwater pulse. Warmer water also has a lower oxygen-holding capacity and as a result, summer conditions in temperate climates may exhibit lower dissolved oxygen levels (Fig. 6.14).

Fig. 6.11 Tributaries to the Buffalo River (Buffalo Creek and Cazenovia Creek) exhibit diurnal dissolved oxygen patterns that are absent in the dredged Buffalo River. Note that the Buffalo River experiences a generally lower level of dissolved oxygen

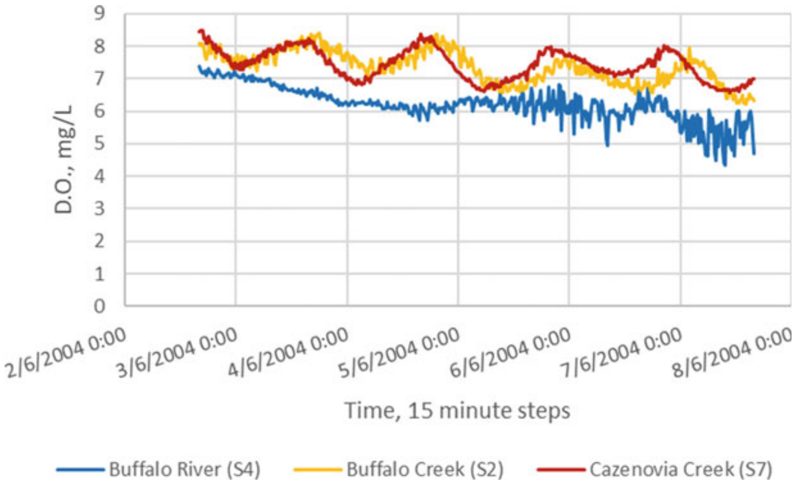
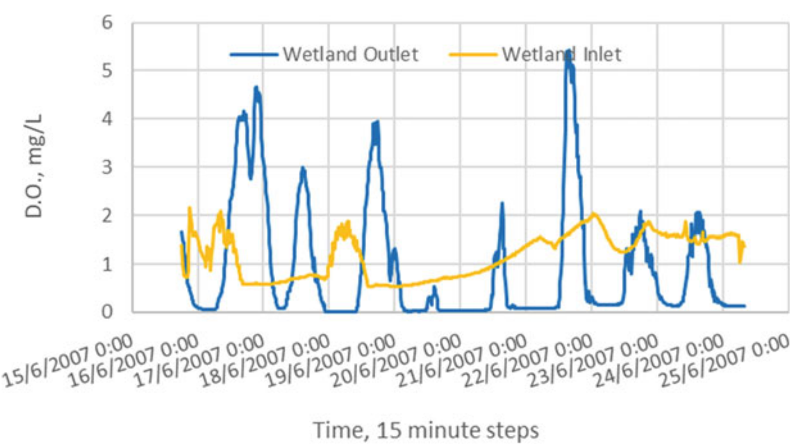


Fig. 6.12 Preparing the installation of a datasonde in a blackwater seep of the North Selangor peat swamp forest. The blackwater is contrasted with the main channel in the background (photo courtesy of Firuza Begham Binti Mustafa)

Fig. 6.13 Boeng Cheung Ek wastewater treatment wetland, Phnom Penh, Cambodia



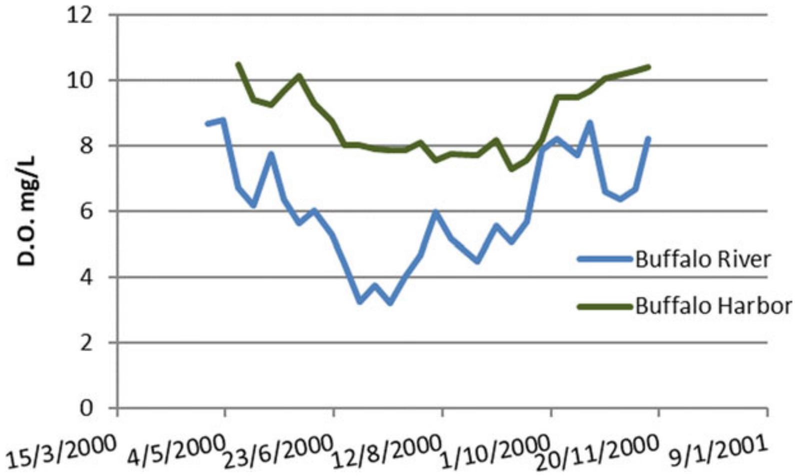


Fig. 6.14 Weekly mean dissolved oxygen for the Buffalo River and Buffalo Harbor, New York. The river dissolved oxygen is lower, primarily because of the hydraulics of the river and sediment oxygen demand, while the harbour is more reflective of dissolved oxygen at the eastern end of Lake Erie. Lowest dissolved oxygen levels are observed at both sites during the warm summer months of July through early September (from Irvine 2013)

6.3.2 Signature Characteristics of Storm Events

An increase in turbidity generally is observed during storm events due to soil, bed, and bank erosion as well as washoff of particulates from impervious urban surfaces (Fig. 6.15), and it follows that turbidity is related to suspended solids concentration. This event-based response will be discussed further, below. Frequently, however, there is an attendant dip in specific conductivity during storm events, reflecting a dilution of dissolved material in the runoff (Irvine et al. 2005b; McGrane et al. 2017; Wymore et al. 2019).

In some cases, a sag in dissolved oxygen may occur in association with storm events. Irvine et al. (2005b) noted that combined sewer overflows (CSOs) could produce dissolved oxygen sags in the Black Rock Canal, New York, but the CSOs discharging to the nearby Buffalo River had a relatively minor immediate impact on dissolved oxygen dynamics. It is possible that organic loadings associated with the CSOs could accumulate in bed sediment and produce a longer-term reduction in dissolved oxygen due to higher sediment oxygen demand (Miskewitz and Uchrin 2013; Riechel et al. 2016). Even in the absence of CSOs, it is possible that dissolved oxygen sags may occur in a waterbody and certainly the normal, dry weather diurnal dissolved oxygen pattern may be disrupted due to storm flow and presumably lower photosynthetic activity under cloudy conditions (Fig. 6.16). Interestingly, an opposite pattern also can occur in association with storm events, when oxygenated runoff from the urban surface flushes the more anoxic sanitary water within a combined sewer system (Fig. 6.17).

6.4 Water Environment Spatial Dynamics

6.4.1 Land Use Impacts

The impacts of water quality associated with different land uses can be evaluated using continuous monitoring (Halliday et al. 2015) and in this section, we will discuss how both continuous and spot measurements have been used to identify land use impacts. Gould et al. (2010) employed a combination of continuous datasonde measurements and the SWAT model to

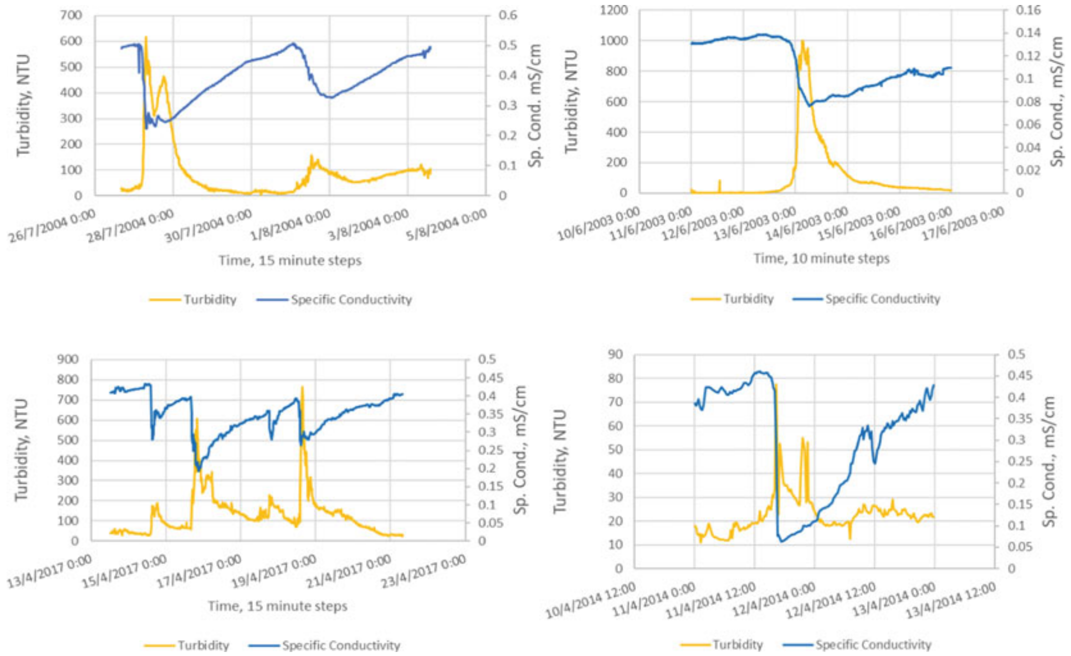


Fig. 6.15 Turbidity and specific conductivity signals associated with storm events, Buffalo Creek, Buffalo, New York (upper left); Allegheny River, Pennsylvania (upper right); Jurong Ecogarden, Singapore, outlet of stormwater retention pond downstream of a cleansing biotope WSUD (lower left); and inlet to Admiralty Park retention pond, Singapore, that receives combined flow from a rain garden discharge and public park runoff (lower right)

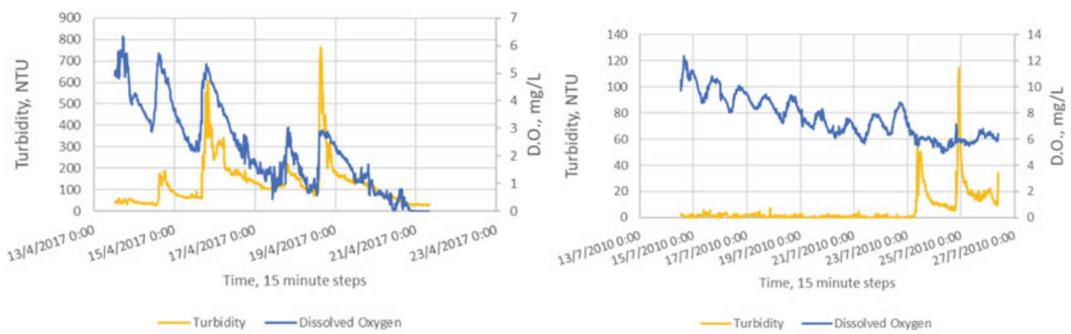


Fig. 6.16 Dissolved oxygen sag associated with four storm events in six days, Jurong Ecogarden, Singapore, outlet of stormwater retention ponds and cleansing biotope WSUD (left); and disruption of daily dissolved oxygen pattern associated with two storm events at the end of the sample period, Smokes Creek, New York (right)

explore how land use change between 1958 and 2005 might impact sediment yield in Cayuga Creek, Niagara County, New York. The model application is discussed in more detail, below. The continuous datasonde measurements revealed that mean turbidity for the monitoring period of 10 April through 15 July 2008, on average, was 135% higher at the downstream site compared to the upstream site, although storm events at the upstream site tended to have a slightly higher peak turbidity. The upstream site was primarily agricultural land use, while the downstream site was urbanized, including the Niagara Falls International Airport, and also

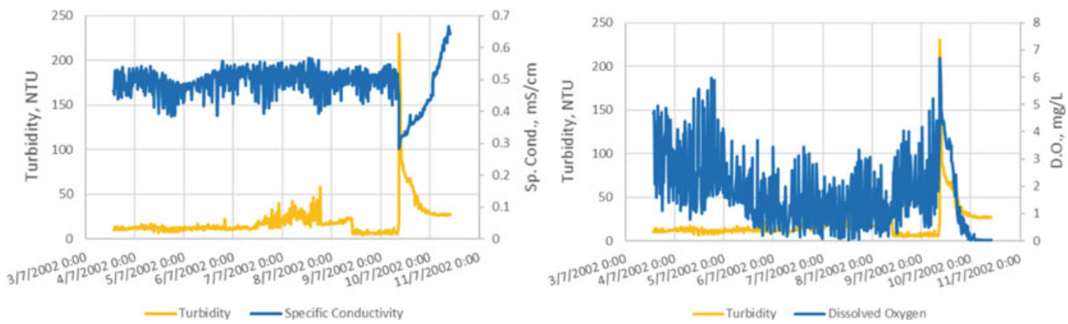


Fig. 6.17 Turbidity and specific conductivity from a combined sewer, Buffalo, New York (left), and turbidity and dissolved oxygen for the same site and time period (right). The storm event at the end of the time series is clear, with the signature increase in turbidity and dilution of specific conductivity. In this example, dissolved oxygen levels increase in association with the storm due to flushing of the more anoxic sanitary flow (compare 7/7/2002 and 10/7/2002)

received a significant permitted discharge from a limestone quarry. The higher peak turbidity associated with storm events at the upstream site likely is related to greater erosion rates from agricultural land use, while the day-to-day urban activities (including the airport and quarry discharges) would have increased the mean turbidity level at the downstream site.

Gugino et al. (2006) used spot measurements with a datasonde to show that the mean dissolved oxygen level decreased significantly ($\alpha = 0.05$) as the Mae Kha River flowed through the heart of Chiang Mai, Thailand. In addition, E. coli levels and Cr levels increased progressively from the same peri-urban to urban sites at which the dissolved oxygen was measured, underscoring the impact of urban land use on water quality.

6.4.2 Water-Sensitive Urban Design (WSUD) Performance

WSUD is a naturalized, green approach to managing urban flooding problems and improving runoff quality (Irvine et al. 2014; Fletcher et al. 2015; Wang et al. 2017; Lashford et al. 2019). WSUD features include rain gardens, green roofs, porous pavement, bioretention swales, constructed wetlands, cleansing biotopes, preservation of urban trees, and rainwater harvesting. Datasondes were installed in the intake sump and effluent sump of a cleansing biotope at the Jurong Ecogarden in Singapore (Fig. 6.7). Cleansing biotopes essentially are a vertical flow constructed wetland and in this case, stormwater runoff from the CleanTech Industrial Park is managed by a treatment train that includes ponds both upstream and downstream of the biotope. A portion of the flow in the downstream-most pond is recirculated to the upstream ponds, constituting a second pass through the biotope. The in situ monitoring results for the first month of an ongoing study (Fig. 6.18) show the Jurong Ecogarden biotope is effective in mitigating levels of chlorophyll a and turbidity during both dry weather and wet weather conditions, with mean chlorophyll a and turbidity levels being reduced by 58% and 74%, respectively.

The city of Geelong, Australia, located approximately 75 km southwest of Melbourne, has actively implemented a WSUD program to manage urban runoff and now maintains more than 200 small streetscape scale and 150 large end-of-pipe WSUD assets. Discrete sampling and continuous in situ monitoring are ongoing in the constructed wetland of a new subdivision (Fig. 6.19). The in situ continuous monitoring is done in the wet zone close to the outlet of the constructed wetland using a datasonde with temperature, dissolved oxygen, pH, turbidity, and specific conductivity sensors. The monitoring period (Fig. 6.19, left) is in the summer months and the water temperature remains high, with inflows being modest due to the dry summer

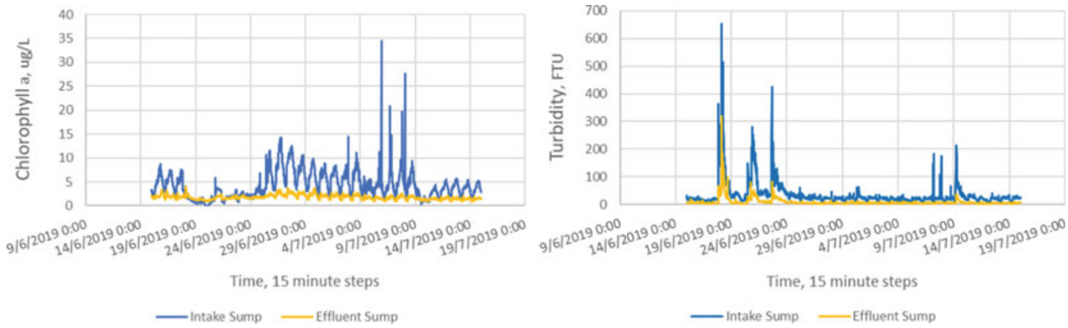


Fig. 6.18 Comparison of Intake Sump and Effluent Sump water quality at the Jurong Ecogarden cleansing biotope, for chlorophyll a (left) and turbidity (right). Note that the turbidity units of FTU are equivalent to NTU

conditions. Prolonged periods of low dissolved oxygen conditions also are evident during the drier summer months. In addition to allowing the water quality to be assessed, in situ measurements are providing the data necessary for the calibration of a mathematical model of the system.

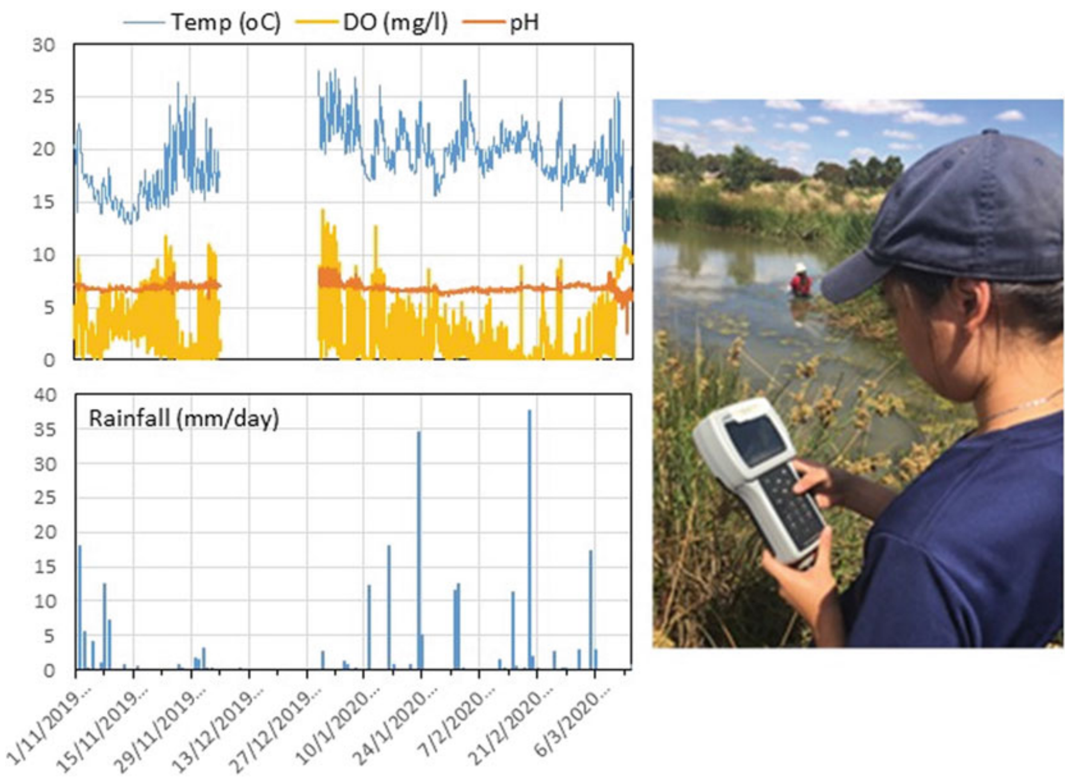


Fig. 6.19 Continuous in situ monitoring for a 4-month period in a Geelong constructed wetland (left). The instrument was removed in December for maintenance. Student wading to conduct discrete spot sampling in the wetland during the summer low water level period while readings are recorded onshore (right) (photo by the authors)

6.4.3 Water Column Profiling

Water quality trends in the vertical (z) direction can be assessed by progressively lowering a datasonde (or SeaBird Sealogger) through the water column and recording the data at specific depths for each x, y location. This technique can help to assess water column stability and degree of mixing.

In addressing ongoing questions regarding the spatial and temporal variability in water quality and system metabolism of the Tonle Sap Lake in Cambodia, we conducted a pilot program in 2010 that included water column profiling for three sites at the northwestern end of the lake near Siem Reap. To illustrate the water column profiling process, we will focus here on two of the sites, the first being in the flooded forest fringe (Site 1) and the other being in open water (Site 3) (Fig. 6.20). Profiling was done at 0.25 m increments from 0.1 m below the surface to a depth where the safety guard on the sensors gently rested on the lakebed. The profiling was done once per hour and generally took 10–15 min to complete. Water levels on the Tonle Sap at the time of sampling were lower than a typical dry weather year (as represented by 1992), but it was observed from the water level gauge at a government meteorological tower adjacent to Site 2 that the lake level rose 40 cm between 19 and 21 August 2010, during the profiling period, and the lake was beginning to experience the freshwater flush noted above.

Profiles for turbidity, dissolved oxygen, and temperature at Sites 1 and 3 are shown in Fig. 6.21. Turbidity generally increased from the flooded forest fringe (Site 1) to open water (Site 3). This increase in turbidity may be the result of the protection and filtering capacity of the vegetation associated with the flooded forest fringe at Site 1, as well as sediment resuspension by wind, wave, and boat traffic in the open lake. Generally, the profiles were uniformly mixed with respect to turbidity and overall, the turbidity levels were relatively high compared to other monitoring we have done on the lake (Irvine et al. 2011). Water temperature exhibited the effect of thermal warming from daybreak, through the day (Fig. 6.21). The thermocline extended to a depth of 1 m at Site 1 and 1.5 m at Site 3. However, even near the bed there was temperature variability throughout the day, with the difference between the maximum and minimum temperature being 0.62 °C at Site 1 and 0.45 °C at Site 3. The dissolved oxygen profiles at Site 3 exhibited slightly higher levels to a depth of 0.5 m, particularly during the day (Fig. 6.21) which likely is related to photosynthetic activity. Site 1 exhibited much greater dissolved oxygen variability than the open water sites (Fig. 6.21) and this may be the result of more complex biological and hydraulic interactions at the flooded forest fringe/open lake interface, including the periodic movement of dense floating mats of water hyacinth (Fig. 6.20).

6.5 In Situ Monitoring as a Surrogate

As noted in the Introduction, one of the benefits of in situ monitoring is cost savings related to labour and laboratory analysis that can be realized through the use of continuous datasonde sensor time series as a surrogate for other analytes of interest. Probably, the most common surrogate application is turbidity (an optical property) to represent total suspended solids (TSS), a gravimetric property. While turbidity in and of itself can have environmental indicator properties (e.g. for fish that are visual feeders), frequently a rating curve using simple or multiple regression is developed between turbidity and TSS (e.g. Lewis 1996; Sun et al. 2001; Davies-Colley and Smith 2001; Irvine et al. 2002, 2011; Pfannkuche and Schmidt 2003; Stubblefield et al. 2007; Minella et al. 2008). Although this relationship can be strong, several environmental variables, including particle size distribution, particle shape, particle composition, and presence of humic acids can produce scatter in the data. As such, Sun et al. (2001) concluded that suspended solids–turbidity relationships may be both site- and time-specific, so that a relationship may be unique for a particular catchment and within a particular period of time, including

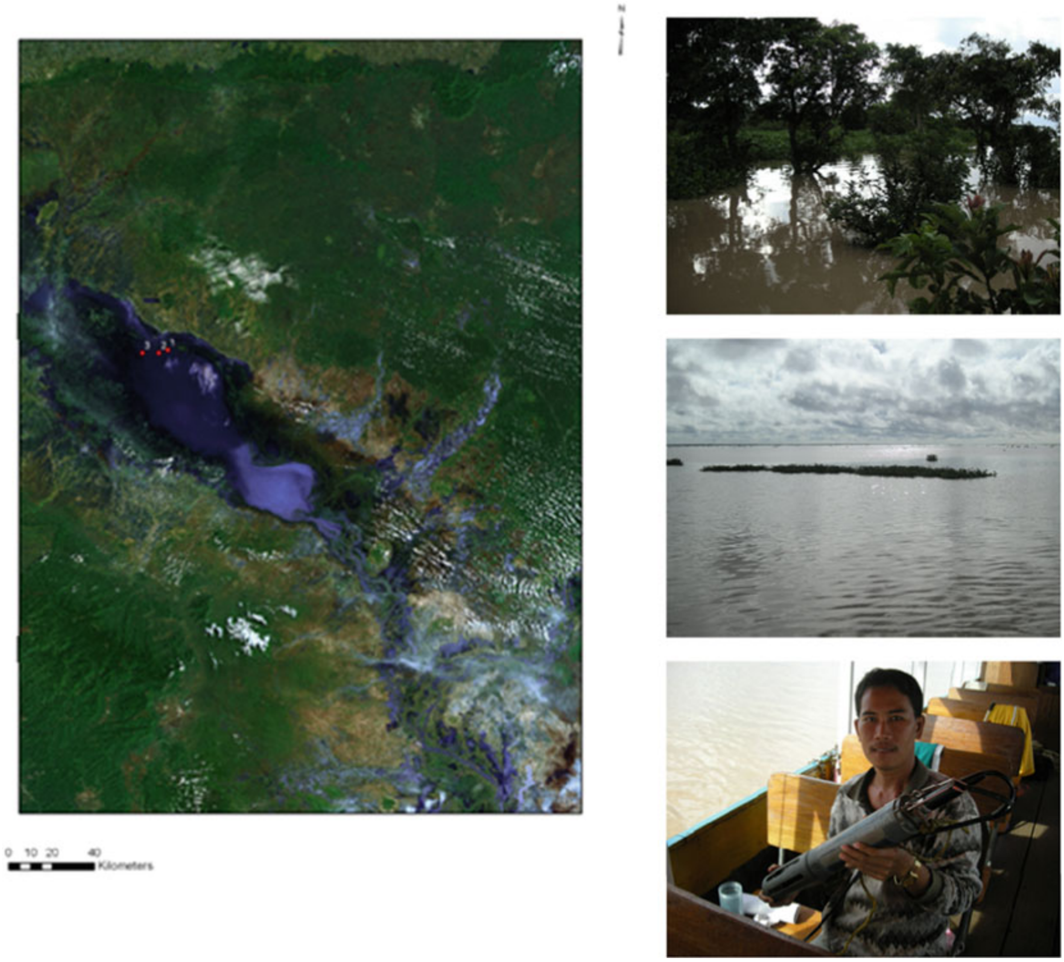


Fig. 6.20 Water column profiling in the Tonle Sap Lake, Cambodia, Sites 1, 2, and 3 (left); Site 1 (top), Site 3 (middle), and preparing the datasonde for profiling (photos by the authors)

seasonal differences (Irvine et al. 2019). Based on the strong turbidity-TSS rating curves ($r^2 \sim 95\%$) for Cayuga Creek, New York, Gould et al. (2010) converted the continuous turbidity data into TSS time series and used these to calibrate the SWAT model for estimating soil erosion under changing land use scenarios.

Turbidity also has been used as a surrogate for phosphorus (Stubblefield et al. 2007; Minaudo et al. 2017; Stutter et al. 2017; Lannergård et al. 2019). Irvine et al. (2019) examined how continuously measured parameters, namely turbidity and flow, might enhance understanding of total phosphorus dynamics in the Grand River, Ontario, Canada, to improve load reduction and eutrophication management programs for Great Lakes government agencies. Simple and multiple linear regression models were developed, with the explanatory variables including turbidity, flow, season, and flow condition (i.e. hysteresis). Hysteresis is a process that is common in streams and rivers, where the concentration of phosphorus (or TSS) is not linearly related to stream discharge but is time-dependent on whether the system is on the rising or falling limb of the hydrograph (Fig. 6.22). Understanding the hysteresis patterns of a river system can provide insight into the dominant transport mechanisms in the catchment. Clockwise hysteresis loops indicate that phosphorus (or TSS) is flushed early

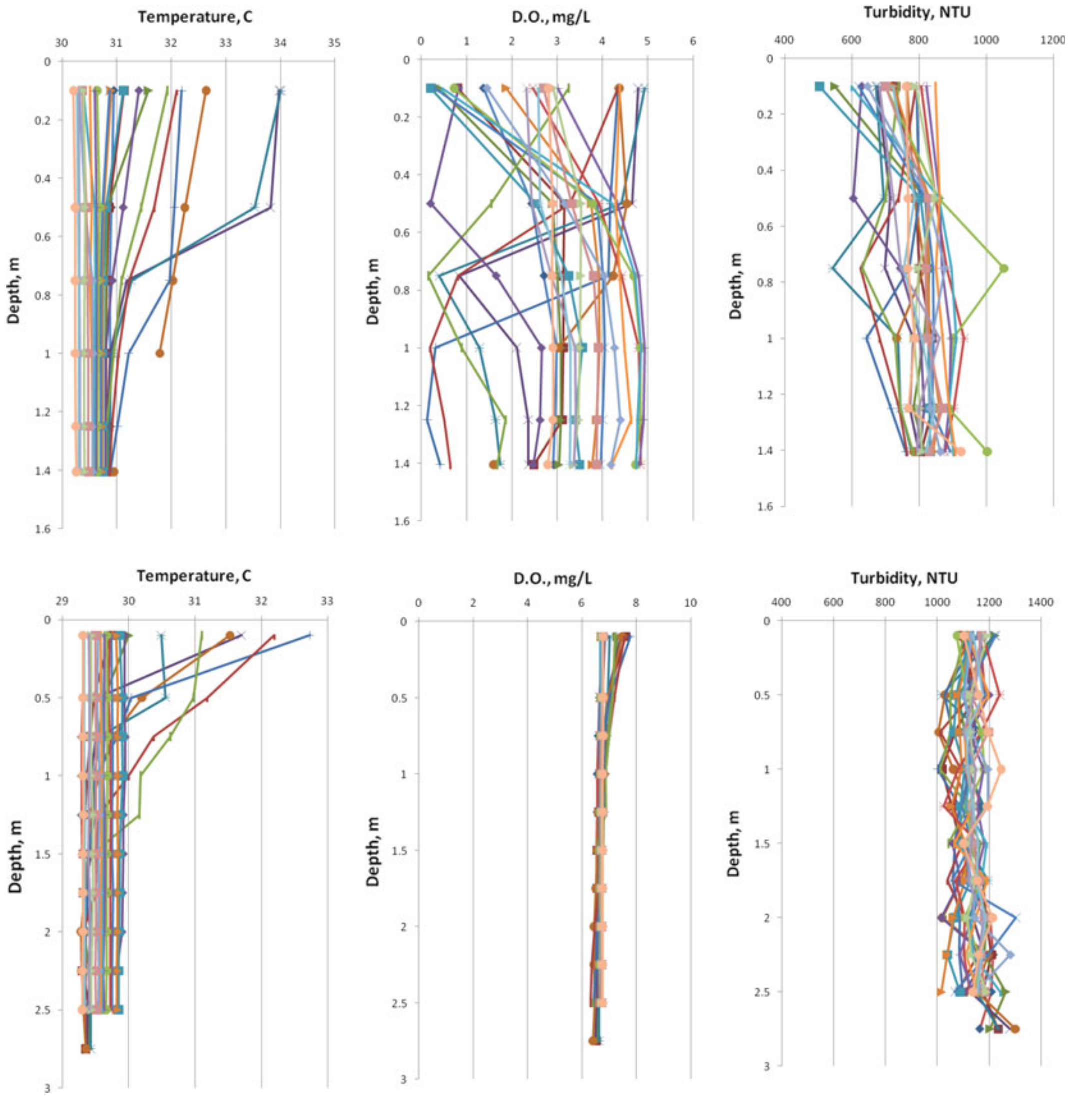


Fig. 6.21 Hourly water column profiling, Site 1, Tonle Sap Lake, Siem Reap (top), and Site 3 (bottom)

in the storm event, on the rising limb, while counter-clockwise hysteresis loops suggest that phosphorus or TSS is transport-limited (Lloyd et al. 2016). The models explained 63–65% of the total phosphorus variance, which is comparable to the results from other studies and it is a supplemental monitoring technique that is being considered for additional implementation within the Grand River.

Fluorescence is a surrogate measure for chlorophyll a, which in itself is an indicator of the potential for blue-green algae blooms and can continuously provide information on the trophic status of a waterbody. Irvine and Murphy (2009) conducted a literature review and found that average chlorophyll a levels for eutrophic waterbodies might be in the 8–30 µg/L range, while mesotrophic waterbodies may have average chlorophyll a levels of 2.5–8 µg/L. Irvine and Murphy (2009) also reported that the mean measured chlorophyll a level in a study on the Buffalo River, NY, was 3.3 µg/L and the level represented

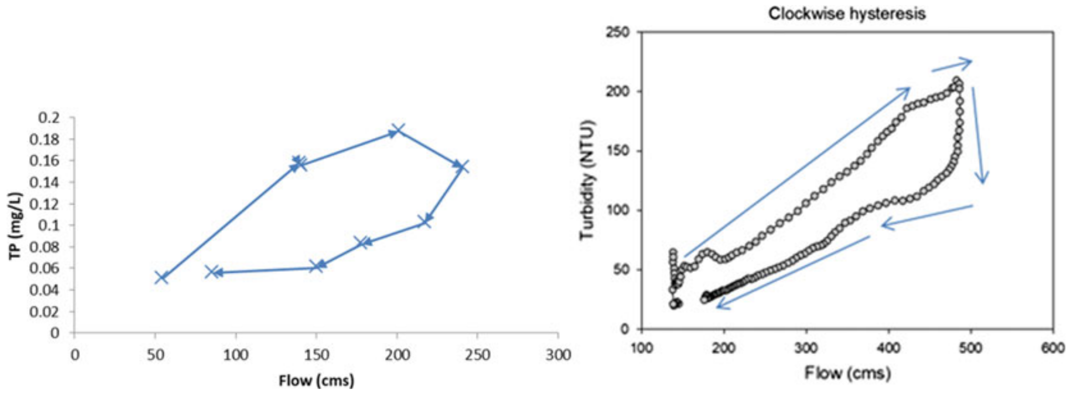


Fig. 6.22 Clockwise hysteresis loops for total phosphorus (TP) (left) and turbidity (right) with flow in the Grand River, Ontario, Canada (modified from Irvine et al. 2019)

by a datasonde fluorescence sensor was 3.5 μg/L. While strong relationships between fluorescence and chlorophyll a have been reported, strictly speaking fluorescence should be calibrated using site-specific chlorophyll a measurements; maintenance to prevent biofouling also is essential (Irvine et al. 2003; Roesler et al. 2017; Chaffin et al. 2018; Zolfaghari et al. 2020).

6.6 Data Analysis Techniques

The first step in any data analysis should be to draw a picture, or in other words, graph the data to visualize trends and provide a preliminary identification of relationships. Time series graphs shown in the previous sections of this chapter have been effective in exploring the water quality dynamics of different waterscapes. Summary statistics and simple univariate inferential statistics can go hand-in-hand with graphing to help quantitatively identify and differentiate processes and environmental conditions. However, while continuous monitoring can provide exceptional information on past and current system dynamics, frequently we are interested in extrapolating to future conditions and exploring how different environment (e.g. climate change) or development (e.g. land use change) scenarios may impact water quality. For this, we likely will choose some type of modelling approach, but here too, the continuous monitoring plays a valuable role in calibrating the models. Artificial Intelligence (AI) numerical approaches, including adaptive-network-based fuzzy inference system (ANFIS), artificial neural networks (ANN), general regression neural networks (GRNN), and support vector machine (SVM), increasingly are being employed to identify complex and subtle system interactions and predict future system trends based on historical data that may help to make near-real-time water management decisions (e.g. Deng and Wang 2017; Shamshirband et al. 2019; Liu et al. 2019). These numerical approaches can be highly automated, have minimal parameterization, and provide accurate results for stationary systems, and while they are data-intensive, the trend towards IoT and low-cost sensors within smart city frameworks makes this modelling approach attractive. However, these models essentially are black boxes that provide no insight into the processes operating within a water environment system and are of limited value in exploring scenarios associated with environmental change (e.g. changing land use patterns).

Alternatively, to better understand system dynamics and explore environmental change, some type of physically based, process-oriented, conceptual, deterministic model may be employed. This type of modelling seeks to represent the rate of change and continuity of mass, energy, momentum, etc. in a 1D, 2D, or even 3D framework. For example, Yang et al. (2022) used

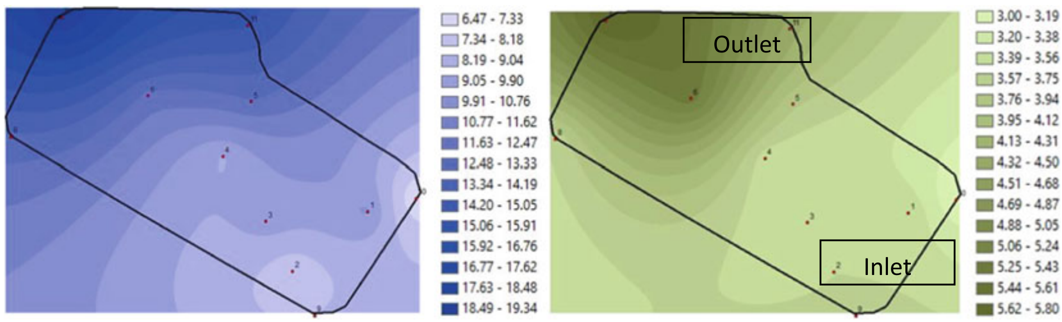


Fig. 6.23 Ordinary Kriging visualization of dissolved oxygen, mg/L in the upper 0.5–1.0 m of the Aeration Pond in the Cha am Aerated Lagoon system (left); and dissolved oxygen near the bottom of the pond (∼2.5 m) (right) (from Koko et al. 2017)

a 3D reservoir model (ELCOM-CAEDYM, Estuary, Lake and Coastal Ocean Model—Computational Aquatic Ecosystem Dynamics Model) to assess the potential impacts of a floating solar panel system on the water quality in a drinking water reservoir in Singapore. Datasondes helped to calibrate the model for both open water areas and for areas beneath a 1 ha pilot-scale project that then were used to model impacts from a planned ∼42 ha full-scale project. The model results for the full-scale project indicated, for example, that dissolved oxygen levels would decline by up to 15% with the solar panel installation, which may require mitigation.

Finally, we note that GIS is a useful analytical and visualization tool that can be used to reveal spatial trends associated with in situ monitoring. For example, Koko et al. (2017) employed Ordinary Kriging (OK) interpolation in ArcGIS10.1 to map the spatial distribution of dissolved oxygen at different depths of an aerated lagoon wastewater treatment facility in Cha am, Thailand, based on datasonde profile measurements (Fig. 6.6, right). OK showed that the highest dissolved oxygen concentrations were near the surface (0.5 m–1.0 m), averaging 18.53 mg/L, 20.5 mg/L, 17.31 mg/L, and 9.7 mg/L in the four ponds that make up the entire system. However, the dissolved oxygen concentrations also could be <2 mg/L near the bottom of some ponds. The spatial trend of dissolved oxygen shows, for example, that concentrations are lower at the inlet of the aeration pond than at its outlet even though mechanical aerators are operated for part of the day near the inlet (Fig. 6.23). It was recommended that the operation of the mechanical aerators could be shifted to start in the early morning, a time when dissolved oxygen was at a minimum.

6.7 Conclusion

This chapter has demonstrated the multiple types of applications in both natural and urban-impacted waterbodies that can be undertaken using in situ monitoring. These applications can both improve our understanding of water environment dynamics and improve management decision-making for such environments. It is important to calibrate and routinely maintain in situ instruments for quality-assured data and also to think creatively about how to deploy the instruments effectively. The technologies for in situ monitoring are improving and becoming more sophisticated, as are data analytics. New applications, particularly with smart cities and big data, await to be unlocked.

References

Adamala S (2017) An overview of big data applications in water resources engineering. Mach Learn Res 2 (1):10–18

Ascui F, Haward M, Lovell H (2018) Salmon, sensors, and translation: the agency of big data in environmental governance. Environ Plan D: Soc Space 36 (5):905–925

Beaton AD, Cardwell CL, Thomas RS, Sieben VJ, Legiret FE, Waugh EM, ... Morgan H (2012) Lab-on-chip measurement of nitrate and nitrite for in situ analysis of natural waters. Environ Sci Technol 46 (17):9548–9556

Bibri SE (2018) The IoT for smart sustainable cities of the future: an analytical framework for sensor-based big data applications for environmental sustainability. Sustain Cities Soc 38:230–253

Boss E, Haëntjens N, Westberry TK, Karp-Boss L, Slade WH (2018) Validation of the particle size distribution obtained with the laser in-situ scattering and transmission (LISST) meter in flow-through mode. Opt Express 26(9):11125–11136

Bourgeois W, Romain AC, Nicolas J, Stuetz RM (2003) The use of sensor arrays for environmental monitoring: interests and limitations. J Environ Monit 5 (6):852–860

Carey RO, Wollheim WM, Mulukutla GK, Mineau MM (2014) Characterizing storm-event nitrate fluxes in a fifth order suburbanizing watershed using in situ sensors. Environ Sci Technol 48(14):7756–7765

Chaffin JD, Kane DD, Stanislawczyk K, Parker EM (2018) Accuracy of data buoys for measurement of cyanobacteria, chlorophyll, and turbidity in a large lake (Lake Erie, North America): implications for estimation of cyanobacterial bloom parameters from water quality sonde measurements. Environ Sci Pollut Res 25(25):25175–25189

Chen Y, Han D (2018) Water quality monitoring in smart city: a pilot project. Autom Constr 89:307–316

Davies-Colley RJ, Smith DG (2001) Turbidity suspended sediment, and water clarity: a review. JAWRA J Am Water Resour Assoc 37(5):1085–1101

Deng W, Wang G (2017) A novel water quality data analysis framework based on time-series data mining. J Environ Manag. https://doi.org/10.1016/j.jenvman.2017.03.024

Dodds WK, Higgs SA, Spangler MJ, Guinnip J, Scott JD, Hedden SC, ... Evans-White MA (2018) Spatial heterogeneity and controls of ecosystem metabolism in a Great Plains river network. Hydrobiologia 813 (1):85–102

Effler SW, O'Donnell DM (2001) Resolution of spatial patterns in three reservoirs with rapid profiling instrumentation. Hydrobiologia 450(1–3):197–208

Effler SW, O'Donnell DM, Matthews DA, Perkins M, O'Donnell SM, Gelda RK, ... Mayfield JD (2008) Insights for the structure of a reservoir turbidity model from monitoring and process studies. Lake Reserv Manag 24(1):69–86

Fletcher TD, Shuster W, Hunt WF, Ashley R, Butler D, Arthur S, ... Mikkelsen PS (2015) SUDS, LID, BMPs, WSUD and more–The evolution and application of terminology surrounding urban drainage. Urban Water J 12(7):525–542

Glasgow HB, Burkholder JM, Reed RE, Lewitus AJ, Kleinman JE (2004) Real-time remote monitoring of water quality: a review of current applications, and advancements in sensor, telemetry, and computing technologies. J Exp Mar Biol Ecol 300(1–2):409–448

Gould JJ, Irvine KN, Perrelli MF, Reth K (2010) Exploring impacts of land use change on sediment erosion in the Cayuga Creek Watershed, Niagara Falls, New York, using BASINS SWAT. J Water Manag Model, R236–14. https://doi.org/10.14796/JWMM.R236-14, https://www.chijournal.org/R236-14

Gugino H, Irvine K, Ngern-klun R, Sukontason K, Sukontason K, Prangkio C, Thunyapar P (2006) Impacts of the urban environment on area water source: The Klong Mae Kha-Chiang Mai, Thailand. In: Poster presentation proceedings, the 4th international symposium on southeast Asian water environment, Asian Institute of Technology, Bangkok, pp 85–88

Halliday SJ, Skeffington RA, Wade AJ, Bowes MJ, Gozzard E, Newman JR, ... Jarvie HP (2015) High-frequency water quality monitoring in an urban catchment: hydrochemical dynamics, primary production and implications for the water framework directive. Hydrol Process 29(15):3388–3407

Holtgrieve GW, Arias ME, Irvine KN, Lamberts D, Ward EJ, Kummu M, ... Richey JE (2013) Patterns of ecosystem metabolism in the Tonle Sap Lake, Cambodia with links to capture fisheries. PLoS One 8(8): e71395

Irvine CA, Backus S, Cooke S, Dove A, Gewurtz SB (2019) Application of continuous turbidity sensors to supplement estimates of total phosphorus concentrations in the Grand River, Ontario Canada. J Great Lakes Res 45(4):840–849

Irvine KN (2013) Climate change and urban hydrology: Research needs in the developed and developing worlds. J Water Manag Model R246–11. https://doi.org/10.14796/JWMM.R246-11, https://www.chijournal.org/R246-11

Irvine KN (2017) Teacher handbook of water quality for the Singapore geography curriculum. National Institute of Education, Singapore, 92 p, https://www.researchgate.net/publication/319819863_Teacher_Handbook_of_Water_Quality_for_the_Singapore_Geography_Curriculum.

Irvine KN, Murphy TP (2009) Assessment of eutrophication and phytoplankton community impairment in the Buffalo river area of concern. J Great Lakes Res 35 (1):83–93

Irvine KN, Droppo IG, Murphy TP, Lawson A (1997) Sediment resuspension and dissolved oxygen levels associated with ship traffic: implications for habitat remediation. Water Qual Res J 32(2):421–438

Irvine KN, Somogye EL, Pettibone GW (2002) Turbidity, suspended solids, and bacteria relationships in the Buffalo river watershed. Middle States Geogr 35:42–51

Irvine KN, Murphy TP, Tang T, Romano LM, Walters D (2003) Spatial and temporal trends in chlorophyll a nutrients and sediment in relation to avian mortality. Whitewater Lake, Manitoba, Canada. In: Sediment quality assessment and management: insight and progress, Ecovision World Monograph Series, Aquatic Ecosystem Health and Management Society, pp 271–86

Irvine KN, Perrelli MF, McCorkhill G, Caruso J (2005a) Sampling and modeling approaches to assess water quality impacts of combined sewer overflows—The importance of a watershed perspective. J Great Lakes Res 31(1):105–115

Irvine KN, McCorkhill G, Caruso J (2005b) Continuous monitoring of conventional parameters to assess receiving water quality in support of combined sewer overflow abatement plans. Water Environ Res 77 (5):543–552

Irvine KN, Richey JE, Holtgrieve GW, Sarkkula J, Sampson M (2011) Spatial and temporal variability of turbidity, dissolved oxygen, conductivity, temperature, and fluorescence in the lower Mekong River-Tonle Sap system identified using continuous monitoring. Int J River Basin Manag 9(2):151–168

Irvine K, Vermette S, Firuza BM (2013) The “black waters” of Malaysia: Tracking water quality from the peat swamp forest to the sea. Sains Malaysiana 42 (11):1539–1548

Irvine K, Chua L, Eikass HS (2014) The four national taps of Singapore: a holistic approach to water resources management from drainage to drinking water. J Water Manag Model C375:1–11

Johnston MW, Williams JS (2006) Field comparison of optical and Clark cell dissolved oxygen sensors in the Tualatin River, Oregon, 2005. US Geological Survey

Koko S, Irvine K, Jindal R, Thongdara R (2017) Spatial and temporal variations of dissolved oxygen in cha-am municipality wastewater treatment ponds using GIS Kriging interpolation. J Water Manag Model 25: C427. https://doi.org/10.14796/JWMM.C427

Koponen J, Kummu M, Sarkkula J (2005) Modelling environmental change in Tonle Sap Lake, Cambodia. Int Ver Theor Angew Limnol: Verh 29(2):1083–1086

Kuha J, Järvinen M, Salmi P, Karjalainen J (2019) Calibration of in situ chlorophyll fluorometers for organic matter. Hydrobiologia, 1–11

Lannergård EE, Ledesma JLJ, Fölster J, Futter MN (2019) An evaluation of high frequency turbidity as a proxy for riverine total phosphorus concentrations. Sci Total Environ 651:103–113

Lashford C, Rubinato M, Cai Y, Hou J, Abolfathi S, Coupe S, ... Tait S (2019) SuDS & sponge cities: A comparative analysis of the implementation of pluvial flood management in the UK and China. Sustainability 11(1):213

Lawrenz E, Richardson TL (2011) How does the species used for calibration affect chlorophyll a measurements by in situ fluorometry? Estuaries Coasts 34(4):872–883

Lewis J (1996) Turbidity-controlled suspended sediment sampling for runoff-event load estimation. Water Resour Res 32(7):2299–2310

Liss SN, Milligan TG, Droppo IG, Leppard GG (2005) Methods for analyzing floc properties. CRC Press, Boca Raton, Florida, pp 1–21

Liu P, Wang J, Sangaiah AK, Xie Y, Yin X (2019) Analysis and prediction of water quality using LSTM deep neural networks in IoT environment. Sustainability 11(7):2058

Lloyd CEM, Freer JE, Johnes PJ, Collins AL (2016) Using hysteresis analysis of high-resolution water quality monitoring data, including uncertainty, to infer controls on nutrient and sediment transfer in catchments. Sci Total Environ 543:388–404

McBride GB, Chapra SC (2005) Rapid calculation of oxygen in streams: approximate delta method. J Environ Eng 131:336–342

McGrane SJ, Hutchins MG, Miller JD, Bussi G, Kjeldsen TR, Loewenthal M (2017) During a winter of storms in a small UK catchment, hydrology and water quality responses follow a clear rural-urban gradient. J Hydrol 545:463–477

Minella JP, Merten GH, Reichert JM, Clarke RT (2008) Estimating suspended sediment concentrations from turbidity measurements and the calibration problem. Hydrol Process 22(12):1819–1830

Minaudo C, Dupas R, Gascuel-Odoux C, Fovet O, Mellander PE, Jordan P, ... Moatar F (2017) Nonlinear empirical modeling to estimate phosphorus exports using continuous records of turbidity and discharge. Water Resour Res 53(9):7590–7606

Miskewitz R, Uchrin C (2013) In-stream dissolved oxygen impacts and sediment oxygen demand resulting from combined sewer overflow discharges. J Environ Eng 139(10):1307–1313

Moraetis D, Efstathiou D, Stamati F, Tzoraki O, Nikolaidis NP, Schnoor JL, Vozinakis K (2010) High-frequency monitoring for the identification of hydrological and bio-geochemical processes in a mediterranean river basin. J Hydrol 389(1–2):127–136

Mulholland PJ, Houser JN, Maloney KO (2005) Stream diurnal dissolved oxygen profiles as indicators of in-stream metabolism and disturbance effects: fort Benning as a case study. Ecol Ind 5(3):243–252

Napieralski J, Fraser G (2010). Visualizing the Impact of Storm Events on the Quality of the Buffalo and Niagara Rivers (NY). Open Geogr J 3(1)

Odum HT (1956) Primary production in flow waters. Limnol Oceanogr 1:102–117

Pellerin BA, Stauffer BA, Young DA, Sullivan DJ, Bricker SB, Walbridge MR, ... Shaw DM (2016) Emerging tools for continuous nutrient monitoring networks: Sensors advancing science and water resources protection. JAWRA J Am Water Resour Assoc 52(4):993–1008

Pfannkuche J, Schmidt A (2003) Determination of suspended particulate matter concentration from turbidity measurements: particle size effects and calibration procedures. Hydrol Process 17(10):1951–1963
Price J, Chaosakul T, Surinkul N, Bowles J, Rattanakul S, Pradhan N, ... Nguyen TV (2011) Surface water quality and risk analysis in a peri-urban area, Thailand. In: Proceedings, 9th international symposium on southeast Asia water environment
Riechel M, Matzinger A, Pawlowsky-Reusing E, Sonnenberg H, Uldack M, Heinzmann B, ... Rouault P (2016) Impacts of combined sewer overflows on a large urban river–Understanding the effect of different management strategies. Water Res 105:264–273
Roesler C, Uitz J, Claustre H, Boss E, Xing X, Organelli E, ... d'Ortenzio F (2017) Recommendations for obtaining unbiased chlorophyll estimates from in situ chlorophyll fluorometers: a global analysis of WET Labs ECO sensors. Limnol Oceanogr: Methods 15(6):572–585
Shamshirband S, Jafari Nodoushan E, Adolf JE, Abdul Manaf A, Mosavi A, Chau KW (2019) Ensemble models with uncertainty analysis for multi-day ahead forecasting of chlorophyll a concentration in coastal waters. Eng Appl Comput Fluid Mech 13(1):91–101
Sherson LR, Van Horn DJ, Gomez-Velez JD, Crossey LJ, Dahm CN (2015) Nutrient dynamics in an alpine headwater stream: use of continuous water quality sensors to examine responses to wildfire and precipitation events. Hydrol Process 29(14):3193–3207
Skarbøvik E, Roseth R (2015) Use of sensor data for turbidity, pH and conductivity as an alternative to conventional water quality monitoring in four Norwegian case studies. Acta Agric Scand B—Soil Plant Sci 65(1):63–73
Song C, Dodds WK, Trentman MT, Rüegg J, Ballantyne F IV (2016) Methods of approximation influence aquatic ecosystem metabolism estimates. Limnol Oceanogr Methods 14(9):557–569
Stubblefield AP, Reuter JE, Dahlgren RA, Goldman CR (2007) Use of turbidometry to characterize suspended sediment and phosphorus fluxes in the Lake Tahoe basin, California, USA. Hydrol Process 21(3):281–291
Stutter M, Dawson JJ, Glendell M, Napier F, Potts JM, Sample J, ... Watson H (2017) Evaluating the use of in-situ turbidity measurements to quantify fluvial sediment and phosphorus concentrations and fluxes in agricultural streams. Sci Total Environ 607:391–402
Sun H, Cornish PS, Daniell TM (2001) Turbidity-based erosion estimation in a catchment in South Australia. J Hydrol 253(1):227–238
Visoth T, Yim M, Vathna S, Irvine K, Koottatep T (2010) Efficiency of Phnom Penh's natural wetlands in treating wastewater discharges. Asian J Water Environ Pollut 7(3):39–48
Viswanathan VC, Molson J, Schirmer M (2015) Does river restoration affect diurnal and seasonal changes to surface water quality? A study along the Thur River, Switzerland. Sci Total Environ 532:91–102
Wade AJ, Palmer-Felgate EJ, Halliday SJ, Skeffington RA, Loewenthal M, Jarvie HP, ... Joly E (2012) Hydrochemical processes in lowland rivers: insights from in situ, high-resolution monitoring. Hydrol Earth Syst Sci 16(11):4323–4342
Wang J, Chua LH, Shanahan P (2017) Evaluation of pollutant removal efficiency of a bioretention basin and implications for stormwater management in tropical cities. Environ Sci: Water Res Technol 3 (1):78–91
Wymore AS, Leon MC, Shanley JB, McDowell WH (2019) Hysteretic response of solutes and turbidity at the event scale across forested tropical montane watersheds. Front Earth Sci 7:126
Yang PP, Chua LHC, Irvine KN, Nguyen MT, Low EW (2022) Impacts of a floating photovoltaic system on temperature and water quality in a shallow tropical reservoir. Limnology https://doi.org/10.1007/s10201-022-00698-y
Yule CM, Gomez LN (2009) Leaf litter decomposition in a tropical peat swamp forest in Peninsular Malaysia. Wetlands Ecol Manag 17:231–241
Zolfaghari K, Wilkes G, Bird S, Ellis D, Pintar KDM, Gottschall N, ... Lapen DR (2020) Chlorophyll-a, dissolved organic carbon, turbidity and other variables of ecological importance in river basins in southern Ontario and British Columbia, Canada. Environ Monit Assess 192(1):1–16

Kim Irvine received his B.Sc. in Geography from the University of Toronto in 1983; his M.Sc. and Ph.D. in Geography from McMaster University in 1985 and 1989, respectively. Currently he is an Associate Professor in the Faculty of Architecture and Planning, Thammasat University, Thailand. Between 2012 and 2020 he was an Associate Professor at the National Institute of Education, Nanyang Technological University (NTU), Singapore, and also a Cluster Leader with the Environmental Process Modelling Centre of the Nanyang Environment and Water Research Institute (NEWRI), NTU. Previously, he had been a Professor in the Department of Geography and Planning, Buffalo State, State University of New York. He is an Adjunct Professor in Environmental Engineering and Management at Asian Institute of Technology (2010-present). He received the NIE Excellence in Teaching Commendation, 2018, and was granted a Bualuang ASEAN Fellowship Award in 2020 to conduct research on water sensitive urban design in collaboration with the Faculty of Architecture and Planning, Thammasat University. Dr. Irvine has been a member of the Science Advisory Committee for the International Foundation for Science (IFS) since 2011. He has more than 140 peer-reviewed journal articles, book chapters, and conference proceedings and has been the PI or co-PI on more than $6.8 million USD of externally-funded research.

Lloyd Chua is currently an Associate Professor in Civil Engineering in the School of Engineering, Deakin University, Australia. He teaches subjects related to hydraulics, hydrology, numerical and water quality modelling. Besides teaching, he also holds the position of Associate Head of School (International) where he is in charge of international activities related to the School. Lloyd is/was also holding research positions in other institutions, including Adjunct Professor at Universiti Tenaga, Malaysia and a Research Affiliate at the School of Engineering, Massachusetts Institute of Technology (MIT), Boston, U.S. Prior to coming to Deakin, he held teaching positions at the School of Civil and Environmental Engineering, Nanyang Technological University, Singapore and research positions at Department of Informatics (LFB), Brandenburg Technical University, Germany and at the Department of Hydrodynamics and Water Resources (ISVA), Technical University of Denmark. He holds a Ph.D. (Civil Engineering) and M. Eng (Civil Engineering) from the Nanyang Technological University and B. Eng. (Civil Engineering) from National University of Singapore. He is reviewer for numerous journals and has published $>$ 100 papers in refereed journals and conference papers and has research interests in water quality monitoring, modelling and management, and flood modelling.

Cameron Irvine is an environmental professional currently working as the Subwatershed Planning Coordinator at the Grand River Conservation Authority in Cambridge, Ontario, Canada. He has more than 8 years' experience working in water resources and environmental science, specializing in water quality, watershed health, chemical and nutrient transport and statistical analysis with roles in the private and public sector. Cameron has both field and data analysis experience working on real-time water quality monitoring in the Grand River watershed in Ontario Canada. He completed a Master of Science (M.Sc.) from the University of Waterloo in the Department of Geography and Environmental Management where his research focused on land use and hydrophysical drivers of phosphorus and nitrate export in a mixed land-use watershed in Southern Ontario, Canada.

7 Research Methods and Techniques in Physical Geography

Virendra Nagarale, Subhash Anand, and Piyush Telang

Abstract

Scientific research uses a variety of tools and techniques and methods to explain the reasons for the problems and find out the solutions to them, proven to be scientific, i.e., there should be an adorable basis that may explain the solutions to the identified problem. It is, therefore, necessary for each research to stand alone in the field of research and to prove the fact that the research is new and there is no knowledge about it before the humans or it is not available in the literature. Hence each research is unique and it is considered to be unique on the basis of methods and techniques used for finding a solution to a problem. Geographers are more concerned about the spatial arrangements of a phenomenon, its pattern and geographical distribution. The contemporary physical and human spaces, their past arrangements and patterns are documented, and methods and models they have used before are explained to predict different aspects of the physical human world. After the twentieth century, new technologies have emerged which have made a remarkable contribution to the development of new methods in geography helpful in the collection of data and analysis. One of the major innovations is the use of GIS in geographical studies to emphasize mapping as a tool for exploratory research in geography. This chapter provides a structured pattern of research methods used deliberately in physical geography. It also discusses various case studies in accordance with some research methods.

Keywords

Research · Physical geography · Mapping · Survey · Analysis

V. Nagarale (✉)
Department of Geography, SNDT Women's University, Pune Campus, Karve Road, Pune, Maharashtra 411 038, India
e-mail: vnagarale@geographypune.sndt.ac.in

S. Anand
Department of Geography, Delhi School of Economics, University of Delhi, Delhi 110 007, India

P. Telang
Department of Geography, SNDT Women's University, Pune Campus, Karve Road, Pune, Maharashtra 411038, India

7.1 Introduction

Research is an ongoing process that seeks to find answers to certain problems or questions which have not been answered yet in the contemporary world. Research is simply 'a search for something new' that may be done for building theories and models. Research is useful not only to

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

F. B. Mustafa (ed.), *Methodological Approaches in Physical Geography*,
Geography of the Physical Environment, https://doi.org/10.1007/978-3-031-07113-3_7

innovate something new but to explore and find the reasons for already accepted beliefs and knowledge which have underpinned the traditions of humankind. This may be illustrated by taking the example of earth. In the dark age of Greek civilization from the twelfth to ninth centuries B.C. to the end of antiquity, the earth's shape was considered a flat or disc. Around 500 B.C. Pythagoras first proposed the idea of spherical earth mainly on an aesthetic basis without any physical or scientific evidence. Possibly, the first physical evidence was given by Aristotle (384–322 B.C.) for spherical earth shape which determines that hips disappear hull first when they sail over the horizon, Earth casts a round shadow on the moon during a lunar eclipse and different constellations are visible at different latitudes. The first person to determine the size of the Earth was Eratosthenes of Cyrene, who produced a surprisingly good measurement using a simple scheme that combined geometrical calculations with physical observations. The research process is helpful to find the solution to a problem through a set of processes, methods, tools and techniques. Each research is unique as it uses a certain set of principles and a set of different methods to arrive at a dependable solution to an identified problem. Scientific research uses a variety of tools and techniques and methods to explain the reasons for the problems and find out the solutions to them proven to be scientific, i.e., there should be an adorable basis that may explain the solutions to the identified problem. It is, therefore, necessary for each research to stand alone in the field of research and to prove the fact that the research is new and there is no knowledge about it before the humans or it is not available in the literature. Hence each research is unique and it is considered to be unique on the basis of methods and techniques used for finding a solution to a problem. A research method is different from a research methodology and it is very important to know the difference between both the words. Research methods usually refer to specific activities or tools and techniques designed to generate, classify, analyse and display the data (e.g. questionnaire data represented by choropleth maps). Research methodology is more about the understanding of the research strategy which an individual chooses to pursue their research. Research methodology is therefore a broad term which involves all the methods to be used along with other relevant information about the research (e.g. data sources).

7.2 Objective

Geographers are more concerned about the spatial arrangements of a phenomenon, its pattern and geographical distribution. The contemporary physical and human spaces, their past arrangements and patterns are documented, and methods and models they have used before are explained to predict different aspects of the physical human world. After the twentieth century, new technologies have emerged which have made a remarkable contribution to the development of new methods in geography helpful in the collection of data and analysis. One of the major innovations is the use of GIS in geographical studies to emphasize mapping as a tool for exploratory research in geography. They also helped us to develop the concerns about positionality which means how we position ourselves and are positioned by others and reflexivity that how humans reflect the nature. The innovative tools and techniques in the contemporary world made us rethink the traditional methods that had been used in the previous researches and also opened the ways to correct traditional methods into an evolutionary one. The evolution of remote sensing with the help of artificial satellites dramatically increased the data available for research in physical geography. This revolutionary change led to increased concerns about quantitative research methods rather than qualitative ones. Mostly the researchers who are concerned about the physical spaces used quantitative methods to find the solution to an identified problem. In this chapter, we have tried to elaborate on the common research methods that are mostly used in physical geography with the help of different case studies and researches.

7.3 Research Methods in Physical Geography

The research process is sometimes mistaken for just gathering data or information and documenting the facts.

> Research process involves a broad structure of the methods for collecting, analysing and interpreting data for communicating the findings that occurred in the specified areas. For this instance, there are three commonly used approaches in geography: qualitative, quantitative and mixed approach. Several research methods may be adopted to perform each type of research, whether it is quantitative or qualitative. These research methods may also be used in various degrees and different research environments. The purpose that drives the application of techniques in physical geography is the desire to undertake the research process.

Authors who write at length about methodology and techniques are usually agreed that methodology provides the general framework used to approach the research topic, and techniques or methods are the mechanisms used to carry out the research task itself. To avoid complexity in methods that are being used in the different phases of research, we have categorized the research methods that are commonly used in physical geography into five sections: the methods to conduct a literature review, methods for data collection, methods of analysis, methods of interpretation and methods for communicating results. Fig. 7.1 shows the categories of research methods used in physical geography research.

7.4 Methods of Literature Review

The first and foremost step towards conducting any research is the literature review or literature survey. Literature review refers to the critical evaluation of existing published resources like research papers, books, articles, journals etc. A literature review provides vast information related to the topic of research. In physical geography, a continuous review process becomes an important part of any kind of research because of the dynamic nature of the physical environment. To understand this let us take an example. A river changes its course with time and in accordance with the slope of the land. A slope, therefore, depends on the different internal as well as external factors of the earth's process. A researcher in the past may have studied any particular river and its various characteristics may change in due course of time. Hence it is required to continuously check whether there is any further research to take place related to the topic of research in physical geography. A literature review provides information about the present world simultaneously, allowing a researcher to find a gap in the chosen research topic. The literature review is important for knowing the past theories, models and methods that have been used in the previous researches. This actually gives an idea to a researcher to make an attempt to apply new methods or tools and omit the previously used or outdated methods.

A literature review is sometimes considered only as a written description of any document. But it is not true as it involves many steps that each researcher should know while proceeding with the research process. These five steps are:

1. Searching for appropriate literature: For any research, an appropriate literature has to be selected so as to minimize the lengthiness and ambiguity of the research. If a literature review is to be written as a section in the research paper or dissertation, then the literature is to be searched for relevant to the research questions or research problem.

Fig. 7.1 Research methods in physical geography

2. Assessment of literature foundation: Each research is unique in nature and probably you cannot read each and everything from the research; therefore you have to evaluate which sections are more appropriate to your topic of research. For each publication, you have to critically examine what type of problem the researcher has undertaken, which different methods have been a part of that publication, what approach is used to reach the conclusion and how the publication will contribute to your topic of research.
3. Identification of gaps: This is an important step while writing a review of the literature and giving status for your topic of research. The gaps can be found by evaluating the patterns and trends of approaches that have been used over a period of time in the field of particular research. Whether a particular approach is being used by many researchers and whether our approach is different while approaching a similar topic can give more weight to your research. What were the contradictions or debates in the literature and how we can minimize the criticism in your topic of research can also have an important role to play in finding the weaknesses or gaps in the literature.
4. Make a chart of literature review: It is the simplest way of organizing your literature survey of various publications. A proper organization of reviewed literature helps a researcher in the final writing of literature and references. The proper organization of literature may also be useful for the comparison of results and to see the differences in the variety of methods. As shown in Table 7.1, the literature survey can be organized in a similar way.
5. Writing literature review: While writing full texts of literature review, one should first start with an introduction that may clearly show the focus and purpose of the literature review. Depending on the format for the research publication for your topic of research one can write a literature review in different subsections. A literature review can be written according to the chronological order of the

Table 7.1 Sample table for the organization of literature

S. no.	Area/topic of research	Details of research publication	Aim and objectives	Database and methodology and study area	Main findings	Remarks
1	Development: Geographical perspectives on a contested concept	Author: Katie Willis Source: Geography, Vol. 99, No. 2 (Summer 2014), pp. 60–66 Published by: Geographical Association Stable URL: http://www.jstor.org/stable/43825382 Accessed: 09-04-2018 06:44 UTC	Aim of this article is to highlight how development cannot be seen as a neutral concept This article provides an introduction to three main ways in which geographers have approached the concept of development: modernization, Marxist analysis and post-structuralism A key argument in this section is that in order to understand different approaches to development, networks of economic resources, ideology and political power need to be recognized	Gross national income categories map: World Bank, 2012 Human development index world map: UNDP, 2013 Malawi, Mulanje district, South Africa	It highlights the duopoly of development concept as a goal and process as well and speaks about the "scale" that has to be considered in the geographical approach for defining the concept of development Describes Marxist ideology in geography by defining the turn from mapping to understanding inequalities	The argument is that development concept cannot be seen as a neutral concept and thus it has its own meaning according to the regional characteristics and the activities which are suitable for the particular region. It has been very well defined by a case study carried out by the author in Malawi, Mulanje district. Aleva stove within Malawian households provided a very different perspective on development but the consideration of only one factor for the dynamic concept like development would not be sufficient and it should be studied at any level taking various other parameters into consideration

publications reviewed (e.g. 2000, 2001, …, 2020), the thematic areas of the publications (e.g. social, economic and geographic), methodological ways (e.g. qualitative and quantitative) and according to the spatial levels (international, national and regional) of the publication. Anything is the way of writing though the literature review should be able to answer the questions that why do you chose a particular topic of research.

7.5 Methods of Data Collection

Physical geography consists of various sub-branches which deal with the physical phenomenon present on the earth. The physical phenomena are air, water and land, and on the basis of these physical elements, the physical geography is usually subdivided into geomorphology (the study of landforms), climatology (study of climate and weather) and hydrology (the study of water movement). There are various other sub-branches too in physical geography like oceanography, biogeography, soil geography etc., but all deal with different physical elements of the earth. The data collection methods change as per the source and sub-branches in this field. The data collection method can either be qualitative or quantitative. Quantitative data collection methods are often used in physical geography. In this section, we will elaborate on the contemporary data collection methods used in physical geography and simultaneously discuss the case studies.

7.5.1 Instrumental Surveys

A variety of instruments are used to collect the primary data on the physical aspects of the earth. Modern techniques have changed the data collection methods and proven to be very useful in applied research in the field of physical geography. In the past decades, many instruments were used in the ground surveys they are dumpy level, theodolite, plain table, prismatic compass etc. These instruments were proven to be very effective in the coastal surveys, land surveys etc. but the main disadvantage of using these instruments was the time required for the surveys and also the human resource. It was very difficult to have such a great team with a single researcher and therefore the new innovations took place. Nowadays, remote sensing is deliberately used to collect data from far distances without any modification or physical contact with the objects present on the earth. Apart from this, the instruments like total station, GPS, dGPS are now proven to be effective tools for collection of data on the physical aspects of land and its various features. In climatology, many facets of the Earth's climate are described using a variety of climatic elements like temperature, humidity, rainfall, wind speed, air pressure etc. A variety of instruments are used for the measurement of each aspect of the climate. They include cup anemometer, wet and dry thermometer, wind vane and many more. The modern techniques include remotely sensed data gathered using satellites basically devoted to observe the changes in climatic events. A popular soil data collection method in the contemporary world is automated data processing (ADP) in soil survey. ADP facilitates data collection and entry, data editing, and timely summaries, comparisons, and analyses of data that otherwise would be impractical or impossible to do. We will be discussing some commonly used instrumental survey methods in this chapter which are proven to be very useful to collect the data from the fields.

7.5.2 GPS Survey

Global positioning system (GPS) is an instrument used to determine the location of any point by calculating the transmission time of messages received from the GPS satellites which are accurate to 15 m. The GPS is very useful in ground surveys as it provides latitudinal, longitudinal and altitude information of a specific point. GPS is useful for tracking, mapping and navigation purposes. The GPS is also proven to be effective in urban planning and development. A recent study of smart city's utility services in Pune Municipal Corporation, Maharashtra, India shows how the urban utility services are distributed spatially with the help of the location information gathered by using a GPS survey. Maddison and Ni Mhurchu reviewed applications of GPS for monitoring human movement in sports while walking or running and in free-living physical activity. In sports applications, GPS was used to track players' movement, distance and speed. The free-living applications focused on active travel in urban areas and on the value of combining GPS with accelerometry. The second review by Duncan et al. focused on transport-related physical activity (TPA) using GPS in combination with accelerometers and/or GIS to identify activity patterns and to provide information on the spatial context of an activity.

7.5.3 dGPS Survey

Improvement in the technology and greater need for better accuracy led to the innovation of differential global positioning system (dGPS). The location information is calculated with great accuracy because the dGPS uses a base station and roving receiver. The best use of this instrument is in geomorphology for surveying and mapping. The main application of dGPS includes the recording of location for any particular feature or points of geomorphological interest; for example, generating continuous depth profiles (e.g. Joseph 2017) and assessing the dynamics of glaciers (e.g. Khromova et al. 2016). It can also be used for mineral exploration (e.g. Haldar 2018).

7.5.4 Total Station Survey

A total station is a digitalized upgraded instrument of theodolite. This instrument helps in measuring the horizontal and vertical angles as well as distances. A high-quality total station combines surveying, imaging and high-speed 3D scanning into one precise and reliable instrument. It blends the latest field technologies with advanced technical features to create a tool that is trusty and dependable in demanding field situations while producing accurate results for analysis in physical geography. The total station is helpful to conduct various types of land-based surveys like topographic surveys, land and title surveys, roadway and corridor surveys, design surveys, infrastructure surveys, volumetric surveys to measure stockpile volumes, power line inspections, utility design surveys, crash scene investigations, crime scene investigations, mine and quarry surveys, tank calibration or inspection and many more.

7.5.5 Remote Sensing

Remote sensing is a technique used to collect the information of any physical object with any physical contact with that object. Nowadays an extensive use of this remotely sensed data changed the facets of research in geography, particularly in physical geography. Remote sensing data can be obtained in the form of satellite imageries and aerial photos taken from the airborne platform. The digital format of these datasets allows the researcher or planner to extract the necessary information in an easy way so that it will be easy to analyse the same. The remote sensing data provide essential information that helps in monitoring various activities performed on the earth. It is important to know about the mineral potentiality of the area to be considered for mineral extraction during the pre-feasibility and feasibility stages of the mineral exploration. In such scenarios, satellite remote sensing-based mapping and its integration into a GIS platform help geoscientists to map the mineral potential zones easily by saving time. With the help of spectral analysis of satellite image bands, the scientist can quickly identify and map mineral availability through special indicators. This will enable exploration by the geologists to narrow their geophysical, geochemical and test drilling activities to high potential zones. The global population is increasing at a very faster rate, hence leading to an increase in the demand for more agricultural production. To do so, there is a firm need for proper management of the world's agricultural resources. To make this happen it is first necessary to obtain reliable data on not only the types but also the quality, quantity and location of these resources. Satellite imagery and geographic information systems (GIS) will always continue to be a significant factor in the improvement of the present systems of acquiring and generating agricultural maps and resource data. Agriculture mapping and surveys are presently conducted throughout the world, in order to gather information and statistics on crops, rangeland, livestock and other related agricultural resources. The result of a natural calamity can be devastating and at times difficult to assess. But disaster risk assessment is necessary for rescue workers. This information has to be prepared and executed quickly and with accuracy. Object-based image classification using change detection (pre- and post-event) is a quick way to acquire damage assessment data. Other similar applications using satellite imagery in disaster assessments include measuring shadows from buildings and digital surface models.

It is necessary to select an appropriate technique for doing a research, hence modern tools can be more helpful in doing research on physical geography. It is time-saving as well as the results we get from the reliable datasets can be more interpretable and helpful for building a model and construction of different theories.

7.6 Methods of Analysis

A critical step of any research is the analysis of gathered data. In physical geography, various analysis techniques are being used for meeting the objectives of the study. The analysis methods mainly include the statistical methods that are been applied to the numerical and graphical datasets. The graphical data mainly includes the satellite images that use a property of a unique identification number for each feature that has been presented in an image. With the help of various GIS-based software, the analysis is done for satellite images. Also, there are many computer-based software useful to carry out the statistical analysis like regression, ANOVA test, Chi-square test etc. The software includes MS-Excel, SPSS, R and many more. In this chapter, we will discuss some of the most used methods for analysis in physical geography.

7.6.1 Principal Component Analysis (PCA)

It is a popular dimensionality reduction technique used in physical geography. PCA compress information from a large set of variables into fewer variables by applying some sort of transformation to them. The transformation is applied in such a way that linearly correlated variables get transformed into uncorrelated variables. Correlation tells us that there is a redundancy of information and if this redundancy can be reduced, then information can be compressed. For example, if there are two variables in the variable set which are highly correlated, then, we are not gaining any extra information by retaining both the variables because one can be nearly expressed as the linear combination of the other. In such cases, PCA transfers the variance of the second variable onto the first variable by translation and rotation of original axes and projecting data onto new axes. The direction of projection is determined using eigenvalues and eigenvectors. So, the first few transformed features (termed principal components) are rich in information, whereas the last features contain mostly noise with negligible information in them. This transferability allows us to retain the first few principal components, thus reducing the number of variables significantly with minimal loss of information. In physical geography is technique is proven to be very useful for numerical as well as graphical datasets. For example, if we have a data for rainfall and we want to see the effect of the amount of rainfall on the vegetation, soil erosion and any other variable then PCA may be useful in determining the major principal component that is more impacted by the amount of rainfall in the study region. The application of this technique can also be useful to obtain information about land-use and land-cover (see Estornell et al. 2013).

7.6.2 Simple Linear Regression and Correlation

Regression describes the co-variation of two variables measured on an interval/ratio scale. A simple regression means there is only one independent variable. Correlation describes the closeness or strength of that co-variation. If the points in the scatter diagram appear to follow a straight line, then such a line that describes the average relationship can be fitted to the points. Linear regression is finding the equation of the line that best fits the scatter. The equation for a regression line has the form: $Y = a + bx$.

$Y\hat{}$ is the predicted value given the value of X. The subscript "i" refers to the ith observation of X and Y. The parameters "a" and "b" are called the constant and the regression coefficient, respectively. The constant is the predicted value of Y where X is zero; it is also called the intercept and can be read off the Y-axis at that point. The regression coefficient is also called the slope because it is the slope of the line. It is also a measure of the predicted change in Y if the value of X is increased by one unit. The regression coefficient would be negative if Y decreases as X increases, describing an inverse relationship. The application of regression analysis in physical geography can be helpful to see the relationship between precipitation with altitude, latitude and distance from the coast (see Taylor 1980) or it can also be used with GIS-based land-use regression model (see Rosenlund et al. 2008).

7.6.3 Factor Analysis

Factor analysis is a statistical method used to describe variability among observed, correlated variables in terms of a potentially lower number of unobserved variables called factors. For example, it is possible that variations in six observed variables mainly reflect the variations in two unobserved variables.

7.6.4 Statistics and the Computer

The calculation of statistics on paper can be slow and error-prone. Fortunately, there are ways around this. Many pocket calculators are programmed to calculate standard deviations and other descriptive statistics. Computers offer a wider range of facilities. Spreadsheets allow their users to perform descriptive statistics, and dedicated statistical packages like SPSS and Minitab provide a range of inferential statistics. If you become a serious user of statistics you will almost certainly want to explore these facilities. Not only do they save time and reduce the chance of error in routine calculations, but they offer facilities which hand calculation could not realistically provide. Although computers have revolutionized the handling of statistics, it is sensible at this point to make it clear that there are some problems with computerized statistics. The first is that the use of the computer brings 'overheads' with it. One of these is the time cost of familiarization. The training needed to make a statistical package do exactly what you want may take far more time than the hand calculation of a simple test! Even a seasoned user might find that in the case of simple tests it is faster to use a pocket calculator and paper than to set up the data and command files needed by the package.

The computer should never be treated as a black box which magically produces correct results. As a user, you should be confident that the chosen test will be appropriate before any computer analysis is carried out. When the analysis has been performed, it is important to check the work to make sure that it matches expectations. If the same analysis is to be performed on several sets of data, it is a good policy to carry out a hand calculation on one set to ensure that the instructions given to the package have been appropriate.

The very traditional conception of quantitative methods. Reviews descriptive statistical measures (mean, variance, higher-ordered moments and correlation), classic statistical models (regression, analysis of variance, principal components, factor analysis and multidimensional scaling), nonparametric approaches and spatial statistical subareas: point pattern analysis, spatial autocorrelation, spatial statistical models and exploratory spatial data analysis—techniques unique in quantitative geography.

7.7 Methods of Communication

These are also the methods of representation of results obtained from the analysis of different datasets. In physical geography, many methods have been used to display the data in an appropriate way. The following Figure 7.2 depicts the various forms of data representation or communication results to the research community. The first form of representation of data is in plain text or descriptive information regarding a landform, or any other characteristic information. The tabular arrangement is useful when data is vast and it cannot be shown by using other forms of representation. In this technique, the data is arranged in rows and columns where the top row and extreme left column depict the characteristics of the data. The semi-tabular arrangement of data is little used in physical geography. An effective technique or method for data representation in geography is by using various graphical devices like graphs, diagrams and most importantly the different types of maps.

7.7.1 Graphs and Diagrams

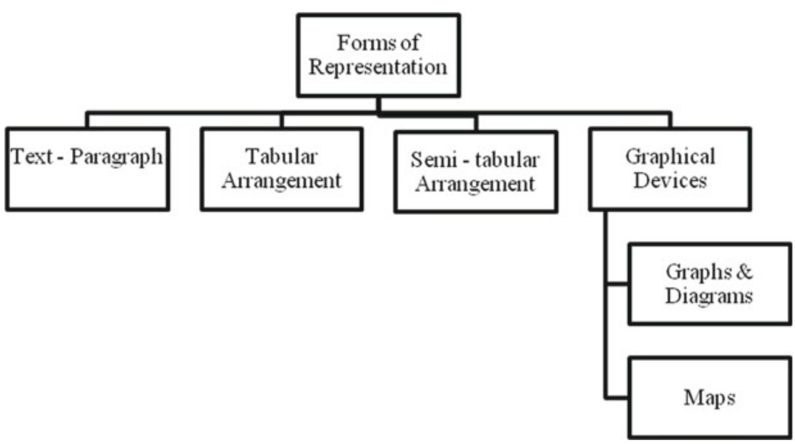
There are different types of graphs and diagrams in mathematics and statistics which are used to represent data in a pictorial form. Among the various **types of charts or graphs**, the most common and the most widely used ones are given and explained below.

(i) **Bar graphs**: These are the pictorial representation of data (generally grouped), in the form of vertical or horizontal rectangular bars, where the length of bars is proportional to the measure of data. They are also known as bar charts. Bar graphs are one of the means of data handling, in statistics. The types of bar charts are as follows:
   a. Vertical bar chart
   b. Horizontal bar chart
   c. Range bar chart

(ii) **Line graph**: Linear means straight and a graph is a diagram which shows a connection or relation between two or more quantities. So, the linear graph is nothing but a straight line or straight graph which is drawn on a plane connecting to points on x and y coordinates. We use linear relations in our everyday life and by graphing those relations in a plane, we get a straight line.

(iii) **Pie chart**: A pie chart is a type of graph that represents the data in a circular graph. A pie chart requires a list of categorical variables and numerical variables. Here, the term "pie" represents the whole and the "slices"

Fig. 7.2 Forms of data representation



represents the parts of the whole. In this article, we will discuss the definition of a pie chart, its formula, an example to create a pie chart, uses, advantages and disadvantages in detail.

(iv) **Maps and mapping techniques**: Maps have traditionally been one of the geographer's primary tools and most geographers have training in map-making, although the production of high-quality finished maps is normally done by specialist cartographers. All maps are attempts to represent patterns in geographical space, but as we will see later, there is a very wide range in the types of patterns portrayed and the methods used.

a. Choropleth maps: These are technically quantitative areal maps that show the spatial distribution of the intensity or density of an element with help of graded shading or colour, drawn following the boundaries of the administrative units.
b. Isopleth maps: These are quantitative real maps where quantities are indicated by lines of equal value. These maps are predominantly used in physical sciences.
c. Diagramatic maps: These maps, as the name suggests, show the representation of statistical data over the map by means of suitable graphs and diagrams.

All the above-mentioned methods are deliberately getting used in the display of data. Particularly, the maps are created using different GIS-based platforms like Arc map, Erdas, Autocad etc. These softwares are very useful in creating different layers of the map and also for data extraction purposes. GIS is therefore an effective tool for the generation, analysis and display of different kinds of a dataset in a single entity of a map.

7.7.2 Methods of Interpretation

The usual step in proceeding with data analysis is interpretation. Interpretation involves attaching meaning and significance to the analysis, explaining descriptive patterns, and looking for relationships and linkages among descriptive dimensions. Interpretation refers to the task of drawing inferences from the collected facts after an analytical and or experimental study. In fact, it is a search for a broader meaning of research findings. The task of interpretation has two major aspects, viz., the effort to establish continuity in research through linking the results of a given study with those of another, and the establishment of some explanation concepts.

"In one sense, interpretation is concerned with relationships within the collected data, partially overlapping analysis. Interpretation also extends beyond the data of the study to inch the results of other research, theory and hypotheses". Thus, interpenetration is the device through which the factors that seem to explain what has been observed by the researcher in the course of the study can be better understood and it also provides a theoretical conception which can serve as a guide for further research. Interpretation is essential for the simple reason that the usefulness and utility of research findings lie in proper interpretation. It is being considered a basic component of the research process because of the following reasons;

a. It is through interpretation that the researcher can well understand the abstract principle that works beneath his findings.
b. Through this one can link up his/her findings with those of other studies, having the same abstract principle, and thereby can predict the concrete world of events.
c. Fresh inquiries can test these predictions later on. This way the continuity in research can be maintained.
d. Interpretation leads to the establishment of explanatory concepts that can serve as a guide for future research studies.
e. It opens new avenues of intellectual adventure and stimulates the quest for more knowledge.
f. A researcher can better appreciate only through the interpretation of why his findings are, what they are and can make others understand the real significance of his research findings.

7.7.3 Methods of Data Interpretation

i. Direct visual observations of raw data
ii. After organizing the data in tables
iii. After making graphical representations
iv. After calculations using numerical/statistical methods
v. After mathematical modelling
vi. Interpretation of the findings.

The interpretation of the findings of an exploratory research study often results in hypotheses for experimental research and as such interpretation is involved in the transition from exploratory to experimental research. Since an exploratory study does not have a hypothesis to start with, the findings of such a study have to be interpreted on a post factum basis in which case the interpretation is technically described as a 'post factum' interpretation.

7.8 Technique of Interpretation

The task of interpretation is not an easy job, rather it requires great skill and dexterity on the part of the researcher. Interpretation is an art that one learns through practice and experience. The researcher may, at times, seek guidance from experts for accomplishing the task of interpretation. The technique of interpretation often involves the following steps:

a. Researcher must give reasonable explanations of the relations which he/she has found and he/she must interpret the lines of relationship in terms of the underlying processes and must try to find out the thread of uniformity that lies under the surface layer of his diversified research findings. In fact, this is the technique of how generalization should be done and concepts be formulated.
b. Extraneous information, if collected during the study, must be considered while interpreting the final results of the research study, for it may prove to be a key factor in understanding the problem under consideration.
c. It is advisable, before embarking upon final interpretation, to consult someone having insight into the study and who is frank and honest and will not hesitate to point out omissions and errors in logical argumentation. Such a consultation will result in correct interpretation and, thus, will enhance the utility of research results.
d. Researcher must accomplish the task of interpretation only after considering all relevant factors affecting the problem to avoid false generalization.
e. He/she must be in no hurry while interpreting results, for quite often the conclusions, which appear to be all right at the beginning, may not at all be accurate.

7.8.1 Precautions in Interpretation

One should always remember that even if the data are properly collected and analysed, the wrong interpretation would lead to inaccurate conclusions. It is, therefore, absolutely essential that the task of interpretation be accomplished with patience in an impartial manner and also in correct perspective. For correct interpretation the researcher must pay attention to the following points:

i. At the outset, the researcher must invariably satisfy himself that
a. the data are appropriate, trustworthy and adequate for drawing inferences;
b. the data reflect good homogeneity; and that
c. proper analysis has been done through statistical methods.
ii. The researcher must remain cautious about the errors that can possibly arise in the process of interpreting results.

Errors can arise due to false generalization and/or due to wrong interpretation of statistical measures, such as the application of findings beyond the range of observations, identification of correlation with causation and the like. Another major pitfall is the tendency to affirm that definite relationships exist on the basis of confirmation of particular hypotheses. In fact, the positive test results accepting the hypothesis must be interpreted as "being in accord" with the hypothesis, rather than as "confirming the validity of the hypothesis". The researcher must remain vigilant about all such things so that false generalization may not take place. He/she should be well equipped with and must know the correct use of statistical measures for drawing inferences concerning his study. Researchers must always keep in view that the task of interpretation is very much intertwined with analysis and cannot be distinctly separated. As such he must take the task of interpretation as a special aspect of analysis and accordingly must take all those precautions that one usually observes while going through the process of analysis, viz., precautions concerning the reliability of data, computational checks, validation and comparison of results. Researchers must never lose sight of the fact that their task is not only to make sensitive observations of relevant occurrences but also to identify and disengage the factors that are initially hidden from the eye. This will enable him to do his job of interpretation on proper lines. Broad generalization should be avoided as most research is not amendable to it because the coverage may be restricted to a particular time, a particular area and particular conditions. Such restrictions, if any, must invariably be specified and the results must be framed within their limits. The researcher must remember that "ideally in the course of a research study, there should be constant interaction between initial hypothesis, empirical observation and theoretical conceptions. It is exactly in this area of interaction between theoretical orientation and empirical observation that opportunities for originality and creativity lie". Researchers must pay special attention to this aspect while engaged in the task of interpretation.

As we have seen there are various methods used in physical geography, especially in dealing with the physical phenomena and hence mostly use quantitative methods to describe the multidimensional aspects of nature, society and interrelationships among the different physical aspects. Physical geography is dynamic in nature; therefore it is very important to understand that some aspects cannot be measured even quantitatively, so some qualitative measures may be applied to such conditions. The models developed in a certain region at a certain period may not necessarily be useful for other regions in the contemporary period of time. The methods and techniques described above are the common ones used in all the disciplines of physical geography. There are many such methods and techniques that can be developed and used in physical geography and each researcher has to study as many techniques as possible to gain the comprehensive knowledge of these methods or techniques.

References

Estornell J, Marti Gavilá J, Sebastiá MT, Mengual J (2013) Principal component analysis applied to remote sensing. Model Sci Educ Learn 6(2):83–89. https://doi.org/10.4995/msel.2013.1905

Gomez B, Jones JP (2010) Research methods in geography. United Kingdom. Wiley-Blackwell Publications. ISBN 978-1-4051-0710-5

Haldar SK (2018) Chapter 3—Photogeology, remote sensing, and geographic information system in mineral exploration. In: Haldar SK (Eds) Mineral exploration (2nd Ed), Elsevier, pp 47–68. ISBN 9780128140222. https://doi.org/10.1016/B978-0-12-814022-2.00003-4. http://www.sciencedirect.com/science/article/pii/B9780128140222000034

Joseph A (2017) Chapter 7—Citadel-building: tiny creatures in the oceans—Corals. In: Joseph A (Eds) Investigating seafloors and oceans. Elsevier, pp 377–442. ISBN 9780128093573. https://doi.org/10.1016/B978-0-12-809357-3.00007-2

Khromova T, Nosenko G, Muraviev A, Nikitin S, Chernova L, Zverkova N (2016). Chapter 2—Mountain area glaciers of Russia in the 20th and the beginning of the 21st centuries. In: Greenwood GB, Shroder JF (Eds) Developments in earth surface processes. Elsevier, Vol 21, pp 47–129. ISSN 0928-2025, ISBN 9780444637871. https://doi.org/10.1016/B978-0-444-63787-1.00002-0

Maddison R, Ni MC (2009) Global positioning system: a new opportunity in physical activity measurement. Int J Behav Nutr Phys Act 6(1):73

Rosenlund M, Forastiere F, Stafoggia M, et al (2008) Comparison of regression models with land-use and emissions data to predict the spatial distribution of traffic-related air pollution in Rome. J Expo Sci Environ Epidemiol 18:192–199. https://doi.org/10.1038/sj.jes.7500571

Taylor P (1980) A pedagogic application of multiple regression analysis: precipitation in California. Geography 65(3):203–212. Accessed 7 December 2020. http://www.jstor.org/stable/40569273

Virendra Nagarale is Professor in the Department of Geography at SNDT Women's University Mumbai, Pune Campus (INDIA). He has 25 years of teaching experience at undergraduate and postgraduate level. He has guided 14 M. Phil. and 10 Ph.D. students successfully and currently guiding four Ph.D. students. Besides guiding research students, he has published more than 35 research papers in reputed journals and presented more than 40 research papers. He has completed two research projects funded by UGC and currently working as a Project Director in the ICSSR research projects.

Subhash Anand is currently Associate Professor of Geography at Department of Geography, Delhi School of Economics, University of Delhi. He has to his credit 20 Years of Teaching and Research experience, 8 books and 70 research papers published in books and journals. Dr. Anand is specialised in Agricultural Planning, Urban Solid Waste Management and Planning. He is the recipient of Dr. Rajendra Prasad Award by the International Eminent Educationist Forum of India.

Piyush Telang is a Ph.D. research scholar in Savitribai Phule Pune University and a former Research Associate in Department of Geography S. N. D. T. Women's University, Karve Road, Pune under ICSSR Project. His current research interest areas are development and sustainability especially urban sustainability. Other research areas include Infrastructural development and other allied disciplines. His specialization in the masters is climatology and has taught different subjects in Geography.

8 The Methodological Approaches in Physical Geography

K. W. G. Rekha Nianthi, A. K. Wickramasooriya, Lalitha Dissanayake, C. S. Hettiarachchi, and R. M. G. N. Rajapaksha

Abstract

Physical geography is the branch of natural science which deals with the study of processes and patterns in the natural environment such as the atmosphere, hydrosphere, lithosphere, biosphere, in the geosystem. This chapter considers some selected methodological approaches for hydrology, climatology, geomorphology and biogeography. The hydrology section of this chapter recommended to apply the most suitable method to estimate missing precipitation. Three methods are introduced as a simple arithmetic mean method, normal ratio method and inverse distance method. The methods of estimating missing precipitation, which are described in this subsection, are very useful for researchers who engaged with hydrological and climatological research utilizing precipitation data in gauging stations facing difficulties to collect continuous precipitation due to unavailability of data. The techniques of climate section are devoted to discuss the selected statistical techniques that are vastly applicable in many climate-related assessments. Time series analysis plays a significant role in analysing and modelling climatological data. There are several software packages that support time series data analysis. Out of them R is a widely used statistical package that provides an environment for statistical analysis and the production of clear graphics in time series analysis. Four main components frequently perform in a time series analysis are trends, seasonality, cycles and irregular fluctuations. All are applicable to climate data and result in meaningful outputs. The geomorphological section introduced how to derive the particle size distribution of soils. There are some advantages; of the sieving method in particle sizing, it is fast and easy handling of the instrument, accurate and reproducible, a time-saving method and the cost of the instrument is lower than other methods, but it works only with dry particles. Biogeography is a discipline with a long intellectual heritage that considers where and why different types of organisms occur over the face of the globe. In Biogeographical survey methods measuring Biodiversity is one of the main tasks.

K. W. G. Rekha Nianthi (✉) · A. K. Wickramasooriya · L. Dissanayake · C. S. Hettiarachchi
Department of Geography, University of Peradeniya, Peradeniya, Sri Lanka
e-mail: nianthi@pdn.ac.lk

A. K. Wickramasooriya
e-mail: ashvin@pdn.ac.lk

L. Dissanayake
e-mail: dissanayakela@pdn.ac.lk

C. S. Hettiarachchi
e-mail: shantha@arts.pdn.ac.lk

R. M. G. N.Rajapaksha
Faculty of Animal Science and Export Agriculture, Uva Wellassa University, Badulla, Sri Lanka
e-mail: gayanir@uwu.ac.lk

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

F. B. Mustafa (ed.), *Methodological Approaches in Physical Geography*,
Geography of the Physical Environment, https://doi.org/10.1007/978-3-031-07113-3_8

Keywords

Physical geography · Hydrology · Climatology · Geomorphology · Biogeography

8.1 Introduction

Physical geography is the branch of natural science which deals with the study of processes and patterns in the natural environment such as the atmosphere, hydrosphere, biosphere and geosphere, as opposed to the cultural or built environment, the domain of human geography. Physical geography can be divided into several branches. This chapter considers hydrology, climatology, geomorphology and biogeography selected techniques which are more important to the undergraduate and postgraduate studies. The early studies in geomorphology are the founder for pedology one of two main branches of soil science. In this chapter, soil geography is also considered special for the distribution of soil across the terrain. The hydrology mainly concerns with the amount and quality of water moving and accumulating on the land surface and the soils and rocks near the surface and the hydrological cycle. It encompasses water in river, lakes, aquifers and to a glacier. Climatology is the study of the climate scientists defined as the weather conditions average over a long period of time. Climatology examines both the nature of micro and macroclimates and the natural and anthropogenic influences on them. Geomorphology concerns the surface of the earth and the processes by which it is shaped in the present and past form. This geomorphology has several subfields that deal with specific landforms of various environments. Biogeography is the science which deals with geographic patterns of species distribution and the process that results in these patterns. This chapter considers some selected methodological approaches for the above-mentioned four subjects.

8.2 The Selected Methodological Approaches in Hydrology

8.2.1 Introduction

Precipitation is one of the main parameters considered in climatological and hydrological studies. However, sometimes researchers may find it difficult to complete their research without having continuous precipitation data records at gauging stations. There are various reasons for not having continuous precipitation data at gauging stations, i.e. malfunctioning of precipitation gauges and other related instruments, gauges are damaged due to the effect of natural hazards and are not replaced for a long period, the absence of people in charge of reading and record of rain gauge stations, not available continuous precipitation data at gauging stations.

The researchers are interested to complete their research even though with the lack of precipitation data, and they use many alternative precipitation estimating methods to find missing precipitation at gauging stations. In that case, it is necessary to use the most suitable method to calculate the accurate missing precipitation, otherwise it will affect the analysis of their research. Thus, this sector addresses the appropriate methods which can be used to calculate missing precipitation data and understand their strengths and weaknesses.

8.2.2 Objective

The main objective of this section is to identify the different methods which can be applied to estimate missing precipitation at a station using available precipitation data at stations in and around that station. Further, this section explains the best method and conditions to be satisfied to estimate the most accurate missing precipitation data.

8.2.3 Methods

The sample data set of ten rain gauging stations which include national grid coordinations, the average annual precipitation data and available precipitation data are considered to explain different methods that could be applied for estimating missing precipitation of a station. There are three methods commonly use to estimate or calculate missing precipitation of a rain gauge station. These three methods are Simple arithmetic mean method, Normal ratio method and Inverse distance method.

8.2.3.1 Simple Arithmetic Mean Method

The simple arithmetic mean method can be applied when there is a similar normal annual precipitation that can be observed in all rain gauging stations considered for estimating the missing precipitation. Therefore, first it has to be checked whether the normal annual precipitation of all stations considered for the estimation of missing precipitation are within the 10% of the normal annual precipitation of the station of the missing precipitation to be estimated. If this condition is satisfied, simple arithmetic mean method could be utilized to estimate missing precipitation of the station 'X', i.e. P_x (Chow et al. 1988) and arithmetic mean of precipitation could be calculated using number of nearby stations (n) and precipitation of ith station (P_i) which are given in the following equation (Tabios and Salas 1985).

$$P_x = \frac{1}{n}\sum_{i=1}^{i=n} P_i$$

8.2.3.2 Normal Ratio Method

When the normal annual precipitation is not similarly distributed in rain gauging stations consider the estimate of missing precipitation, i.e. normal annual precipitation of stations do not fall within 10% normal annual precipitation of the missing station, normal ratio method could be used. The missing precipitation of station 'X', i.e. P_x could be calculated using no of surrounding stations (m), precipitation of rain gauges used for estimation (P_i), normal annual precipitation of X station (N_x) and normal annual precipitation of surrounding stations (N_i) as mentioned in the following equation (Singh 1994).

$$P_X = \frac{1}{m}\sum_{i=1}^{m}\left[\frac{N_X}{N_i}\right]P_i$$

8.2.3.3 Inverse Distance Method

When the normal annual precipitation data of gauging stations are not available and distances to gauging stations from the station with missing precipitation or (x,y) coordinates of all stations are available, inverse distance method could be used to estimate the missing precipitation of the station. The equation used to estimate missing precipitation of station 'X' i.e. P_X using this method is given below (Lam 1983) which includes precipitation of each station use for the estimation (P_i), distance from each location to station with missing precipitation (di) and the number of surrounding stations (N).

$$P_X = \frac{\sum_{i=1}^{N}\left[\frac{P_i}{d_i^2}\right]}{\sum_{i=1}^{N}\left[\frac{1}{d_i^2}\right]}$$

If the distances are known from the station with missing precipitation, directly those distances could be assigned for the above equation. However, if distances are unknown and if the coordinates of each station are known, distances in metres could be calculated using the following equation.

$$d_{1,2} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

where $d_{1,2}$ is the distance between station 1 and station 2 and (x_1, y_1), (x_2, y_2) are coordinates of station 1 and station 2, respectively. However, $d_{1,2}$ has to be divided by 1000 to convert distance into km.

8.2.4 Procedure

Three methods of estimating missing precipitation explained in the above could be understood by the following examples. To explain procedure of three methods following sample data set could be used (Table 8.1). Assume that the researcher needs precipitation data of all ten stations on 01 September 2020. However, this data is not available in stations S_2, S_5 and S_8. Therefore, he/she could use the most suitable method out of three methods introduced in the above to estimate missing precipitation data. The researcher should consider the following criteria to estimate missing precipitation of station S_2, S_5 and S_8.

8.2.4.1 Estimate of Missing Precipitation at S_2 Station

The coordinations are missing at station S_2 and therefore, distances from S_2 station to other stations cannot compute. Thus, inverse distance method cannot apply to estimate missing precipitation. The normal annual precipitation of station S_2 is 104.8 mm and 10% of it is 10.48 mm. To check whether the normal annual precipitation of other stations are within 10% of the normal annual precipitation of S_2 station, the following calculations could be done.

$$\text{Maximum normal annual precipitation} = 104.8\ \text{mm} + 10.48\ \text{mm or } 115.28\ \text{mm}$$

$$\text{Minimum normal annual precipitation} = 104.8\ \text{mm} - 10.48\ \text{mm or } 94.32\ \text{mm}$$

All available normal annual precipitation of stations are within 94.32 mm and 115. 28 mm. Therefore, simple arithmetic mean method could be used to calculate the missing precipitation at station S_2, i.e. P_{S2} as mentioned below

$$P_{S_2} = (22.4 + 8.9 + 3.8 + 18.7 + 7.3 + 18.6 + 20.5)\text{mm}/7 = 14.31\ \text{mm}$$

Table 8.1 Sample data set of rain gauging station

Station Name	X-Coordination	Y-Coordination	Normal annual precipitation (mm)	Precipitation on 01/09/2020
S_1	156,956	345,284	111.8	22.4
S_2	Not available	Not available	104.8	Not available
S_3	166,868	336,500	108.4	8.9
S_4	167,000	334,025	106.6	3.8
S_5	172,358	347,480	Not available	Not available
S_6	157,880	346,890	105.6	18.7
S_7	167,040	334,562	96.3	7.3
S_8	Not available	Not available	114.5	Not available
S_9	170,060	340,568	111.7	18.6
S_{10}	167,895	334,674	98.7	20.5

8.2.4.2 Estimate of Missing Precipitation at S_5 Station

The normal annual precipitation at station S_5 is missing and also it is needed to estimate the missing precipitation on 01 September 2020 at station S_5. As the normal annual precipitation at station S_5 is missing, it is not possible to check whether all station's normal average precipitation is within 10% of the normal average precipitation of S_5 station. Therefore, inverse distance method has to be used to calculate the missing precipitation of S_5 station (P_{S5}). However, as only coordinates are given in the table, distances to other stations from station S_5 have to be calculated using the following equation.

$$d_{1,2} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

Example: distance between S5 and S1 stations could be calculated as

$$d_{S_5,S_1} = \sqrt{(172358 - 156956)^2 + (347480 - 345284)^2} \Big/ 1000 \text{ km}$$
$$= 15.6 \text{ km}$$

Similarly, distances between other stations and station S_5 can be calculated and are shown in Table 8.2.

Precipitation on 01 September 2020 at station S_5, i.e. P_{S5} could be calculated as follows:

$$P_{S_5} = \frac{\left\{ \begin{array}{c} (22.4/15.6^2) + (8.9/12.3^2) + (3.8/14.5^2) + (18.7/14.5^2) \\ + (7.3/14.0^2) + (18.6/7.3^2) + (20.5/13.6^2) \end{array} \right\} \text{mm}}{\left\{ \begin{array}{c} (1/15.6^2) + (1/12.3^2) + (1/14.5^2) + (1/14.5^2) \\ + (1/14.0^2) + (1/7.3^2) + (1/13.6^2) \end{array} \right\}}$$
$$P_{S_5} = 15.25 \text{ mm}$$

8.2.4.3 Estimate of Missing Precipitation at S_8 Station

The normal annual precipitation at station S_8 is 114.5 mm. As there is no information about coordinates of this station, it is not possible to apply inverse distance method to calculate missing precipitation. Therefore, suitable method out of simple arithmetic mean method or normal ration method could be used. The 10% of the normal annual precipitation at station S_8 is 11.45 mm.

Maximum normal annual precipitation
$= 114.5 \text{ mm} + 11.45 \text{ mm}$ or 125.95 mm

Minimum normal annual precipitation
$= 114.5 \text{ mm} - 11.45 \text{ mm}$ or 103.05 mm

Normal annual precipitation of all stations are not within the range of 10% of the normal annual precipitation of the station S_8. For example stations S_7 and S_{10} received precipitation 96.3 mm and 98.7 mm respectively which are not in the range 125.95 mm and 103.05 mm. Therefore, simple arithmetic mean method could not apply to estimate precipitation on 01 September 2020 at station $S_{8,}$ and therefore, normal ratio method has to be used. Based on normal ratio method missing precipitation at station S8 could be calculated as follows:

$$P_{S_8} = \frac{1}{7} \times \left(\begin{array}{c} \frac{114.5}{111.8} \times 22.4 + \frac{114.5}{108.4} \times 8.9 + \frac{114.5}{106.6} \times 3.8 \\ + \frac{114.5}{105.6} \times 18.7 + \frac{114.5}{96.3} \times 7.3 + \frac{114.5}{111.7} \times 18.6 + \frac{114.5}{98.7} \times 20.5 \end{array} \right)$$
$$P_{S_8} = \frac{108.23}{7} \text{ mm}$$
$$P_{S_8} = 15.46 \text{ mm}$$

8.2.5 Advantages and Disadvantages

The methods of estimating missing precipitation which are described in this subsection are very useful for researchers who engaged with climatological and hydrological research utilizing precipitation data in many gauging stations and face difficulties to collect continuous precipitation due to unavailability of data. However, as these methods are used to estimate missing precipitation, it is recommended to apply the most suitable method to estimate missing precipitation otherwise, it will affect the outcome of the research or study.

Table 8.2 Distances between S_5 station and other stations

Station	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
Distance from the station S_5 (km)	15.6	–	12.3	14.5	–	14.5	14.0	-	7.3	13.6

8.3 The Selected Methodological Approaches in Climatology

8.3.1 Introduction

Field of climatology focuses on study of the atmosphere and weather patterns in a particular area over the period. The term weather describes status of the atmosphere for short term or various temporal scales. Climate is defined as averages of atmospheric or weather conditions in a particular area over a longer period. Commonly assessed climate variables are atmospheric temperature, precipitation, wind direction and speed, atmospheric pressure and humidity. Analysis of climate is important to quantify risks and trends of climate-related disasters as well as predict the future weather and climate status to minimize economic and social losses and adapt to the climate variations. Weather forecasting plays grate importance from a farmer to top-level policy-makers and planners since majority of the economic activities are directly or indirectly climate related or dependent. There are different aspects in quantification of climate data. Frequently analysed climate parameters are mean or average values, minimum and maximum, Coefficient of variance, range, standard deviation, and standard error, etc. of climate variables as descriptive statistics. However, selection of statistical methods is mainly depending on the objective/s of the study. Most climate studies are focused on spatial and temporal variations, trend analysis, seasonal variations, likelihood of occurrence of storms or flood peaks in an area and weather forecasting through statistical models.

Climate data can be analysed either subjectively in experience or objectively dealing with long-term reliable data series. Climate data are collected in meteorological stations by experienced climatologist in specific time intervals as specified for each climate variable. Rainfall data are usually collected on daily basis. All daily records are stored in electronically or manually in climate databases. Interested person can be accessed the official database and purchase either daily data or monthly mean or data as required. Modern world is highly depending on climate change impacts. Awareness of climate variations and changes is vital to plan future activities and minimize or get rid of climate change impacts. Reliable climate and weather assessments are purely depending on mathematical and statistical techniques.

8.3.2 Objective

This section has devoted to explain the statistical techniques that are vastly applicable in many climate-related assessments.

8.3.3 Methods

Time series analysis plays a significant role in analysing and modelling climatological data (Collischonm et al. 2005). There are several software packages that support to time series data analysis. Out of them R is a widely used statistical package that provides an environment for statistical analysis and the production of clear graphics in time series analysis. Four main components frequently perform in a time series analysis are trends, seasonality, cycles, and irregular fluctuations. All are applicable to climate data and result in meaningful outputs.

8.3.4 Procedures

There are prerequisite tests need to perform before the data series bring into the analysis to acquire some compulsory conditions in time series analysis. Further climate data series are depending on long-term data series; there might be a chance to having missing data and abnormal data in a series due to instrumental errors or other reasons. Therefore, to achieve reliable output, it is essential to follow correct statistical tests and procedures to analysis of climate data towards specific objective.

8.3.5 Homogeneity and Normality Testing

Testing of homogeneity of the data is essential for analysing climate data series to check instrumental, reading or data processing errors. Climate data analysis is indeed homogeneous data series unless it hides the true climatic signals specially trends, detect change points and forecasting. Normal distribution of the data series can be detected by the normal or Gaussian frequency distribution. Histograms, scatter plots, or probability– probability (P–P) or quantile–quantile (Q–Q) plots, Skewness and kurtosis are common statistical tests that can be used to assess normal distribution. None-normal data series need to transform the data series as required to get the series nearly normal. Transformed data also need to represent the same physical processes as the original data as well transformed data should safeguard the thorough conclusions. The most common data transformation methods are the square root, cube root, logarithmic and inverse transformations.

8.3.6 Missing Values

Climate data analysis are depending on continuous long-term data series. There might be a chance to loss some data in such long-term data series due to different reasons. To reach a reliable outcome of any analysis is essential to identify and replace the lost data before taking the data in to the analysis. Estimation allows an observed value to be compared to its neighbours in both time and space. Data estimation to be realistic and consistent when using essential applications of statistics and mean time need to consider physical properties of the system being considered. In some cases, the estimation of a missing value can be performed by a simple process, such as by computing the average of the values observed on both sides of the gap. Complex estimation methods are also used, considering correlations with other elements. These methods include weighted averages and linear regressions.

8.3.7 Time Series Plot and Moving Average Plot

General time series plots illustrate natural behaviour of the data series over the years. Most instances general time series plots are not enough to assess seasonality, cyclic patterns or trends exist in the time series. Therefore, further analysis methods are required to assess seasonal, cyclic and trend analysis. Especially lengthier time series data sets show noise and shield the true patterns.

As per the time series plots in Fig. 8.1, there is no clear trend of increasing or decreasing of

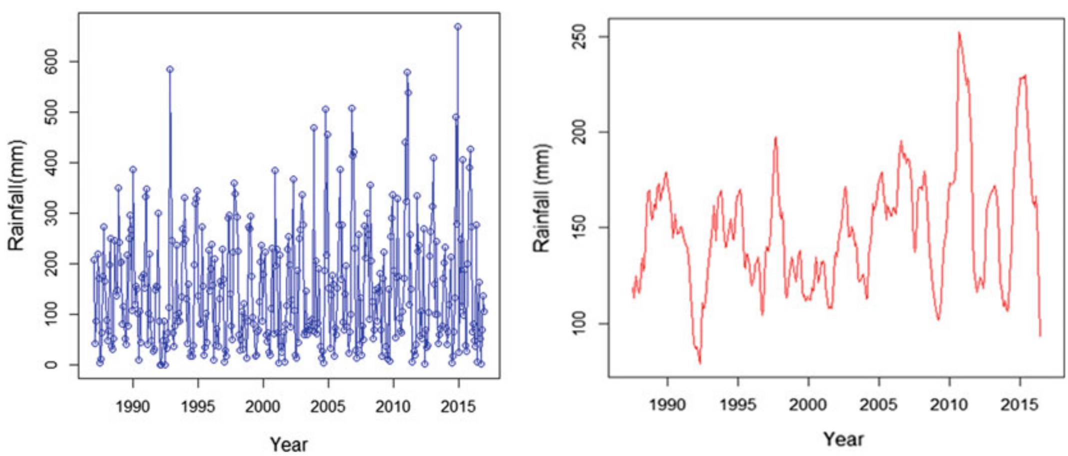


Fig. 8.1 General Time series plot and moving average plot illustrating monthly mean rainfall distribution over 1987–2016

rainfall during 1987–2016 period, but it visualizes that a seasonality pattern showing small and huge hikes representing rainfall fluctuations over the period. The expanded plots further visualize huge hikes are restricted towards year ends.

Smoothing is a technique that is used to reduce random fluctuations or noise in a time series and results in sharp clear pattern of the original data series. Moving average is one of the smoothing techniques that are commonly used for time series analysis and time series forecasting. Moving Average smoothers, the data by averaging consecutive observations in a series. The average plot shows clear random fluctuations than in general time series plot.

8.3.8 Decomposition

Method of Decomposition provides useful information about the time series as decomposition transforms an original time series into multiple different time series as trend component, random component, and seasonality component either additively or multiplicatively (Fig. 8.2). There are four components are shown separately in Fig. 8.2 within four panels. First panel illustrates observations that depict the behaviour of rainfall variation in the original data series over the time. The second panel illustrates trend component. According to this example, there is no visual trend pattern. Overall trend throughout the period is not increased or decreased over time. Third panel shows seasonal component. There is a clearly identified seasonal component illustrated in panel 3. The residual component shown in the bottom panel that is leftovers when the seasonal and trend-cycle components have been subtracted from the data series. Fairly random behaviour is shown in residuals over the period. Further decomposition analysis gives in figure, whether the seasonality and the trend are true or false.

8.3.9 Trend Analysis

Trends are the long-term underlying movements representing growth or decline in a time series over an extended period. Either smooth continuous curve or a straight line represents the trend

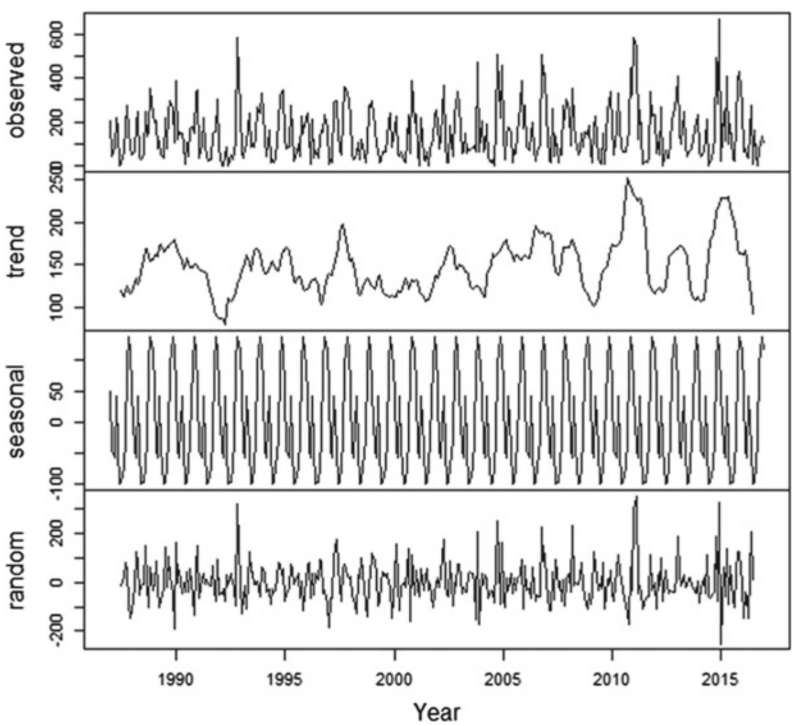


Fig. 8.2 Time Series decomposition plot showing rainfall behaviour during 1987–2017

in a graph that is captured using time series regression, double exponential smoothing, moving average methods and Mann–Kendall trend test.

8.3.10 Mann–Kendall Trend Test

The Mann–Kendall trend test is completely nonparametric. Before applying the Mann–Kendall test to the time series, need to be investigated whether the time series data are serially correlated (Wickramaarachchi et al. 2020). If they are serially correlated need to be used the Mann–Kendall test in conjunction with block bootstrapping method in order to account for the serial correlation and if they are not serially correlated they could apply the Mann–Kendall test without performing block bootstrapping.

Examining the autocorrelation (ACF) and partial autocorrelation (PACF) plots for the time series data set suggests that the autocorrelation and partial autocorrelation present in this series are significant. If most of the vertical spikes in the ACF and PACF plots fall out of the horizontal band defined by the blue dotted lines indicates presence of significant autocorrelations (Fig. 8.3).

Once the Mann–Kendall test is performed the resulting Tau value is inside the 95% confidence interval levels, we can conclude that trend of time series is not significant and if Tau value is out of the limits of confidence interval then the trend is significant. Sign of the Tau value indicates the direction of the trend. Magnitude of the trend can be estimated by Sens' slope estimation test. The used time series data are not shown significant trend (Fig. 8.4).

8.3.11 Time Series Forecasting Using ARIMA Model

8.3.11.1 ACF & PACF Analysis

There are different climate forecasting methods. The Box-Jenkins **A**uto **R**egressive **M**oving **A**verage (ARIMA) models possess many desirable features allowing the analyst to depend only on historical data series to forecast future events without depending on other related time series data. There are few steps behind to build up the ARIMA model. Seasonality, trend components as well correlations are need to remove by converting the data series as stationary if it is a non-stationary series. There are several conditions that must be satisfied for the stationarity of a series. They are the mean, and the variance of the series should not be time dependent and the covariance of time series and lagged time series should depend only on the difference of the time. Differencing is the technique that is commonly used to remove non-stationarity in a data series. If the series is non-stationary due to non-constant mean, then the lag differencing can be performed. This differencing technique results in three parameters as p, d and q. Plots of Auto

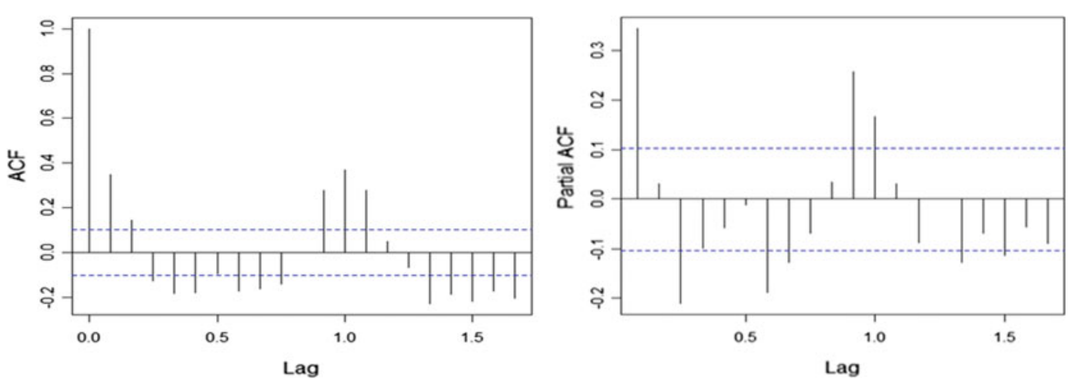


Fig. 8.3 ACF and PACF Plots showing autocorrelations

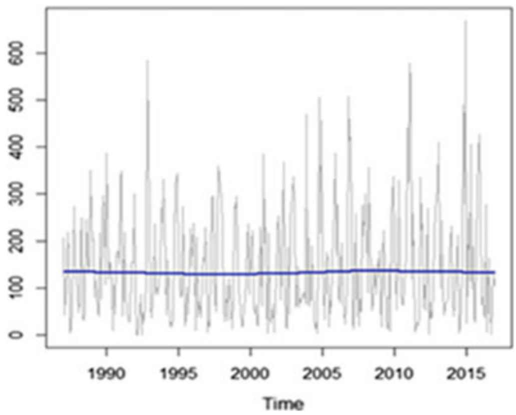


Fig. 8.4 Trend plot

Correlation Function (ACF) and Partial Auto Correlation Function (PACF) result in the parameters p,d,q. ACF Plot is used to get Moving Average (MA) parameter (q, Q), PACF Plot is used to get Auto Regressive (AR) parameter (p, P) (Meher and Jha 2013).

In ACF and PACF plots, lag represents the years and single spike represents a month in a year. Within one lag there are 12 spikes are displayed. Horizontal blue lines are indicated critical lines. Spikes within the critical lines indicate that absence of autocorrelations and spikes extending beyond the critical line signifies the presence of significant autocorrelations (Fig. 8.5a).

The ACF plot showing in illustrates a significant spike at lag 4 for MA parameter and the sinusoidal curve indicates that seasonality of annual (m = 12) and PACF plot indicates a significant spike at lag 1 for AR parameter. Therefore, the rainfall data series used in this example is non-stationary because it shows seasonal effects as revealed by the ACF and PACF plots and needs to transform it into a stationary series by adjusting the seasonality.

Figure 8.5b illustrates the seasonality adjusted ACF and PACF plots. As per Fig. 8.6, ACF and PACF plots have not shown significant spikes. Most autocorrelations and partial autocorrelations are within the critical level. Hence can be confirmed that the original rainfall data series have converted to stationary data series and the data series is now capable to apply in ARIMA modeling.

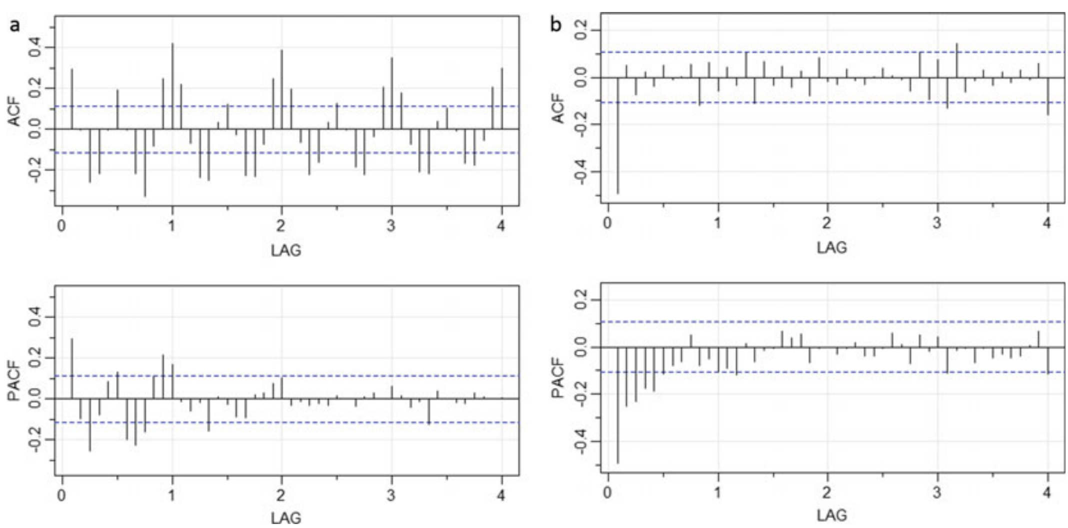


Fig. 8.5 **a** ACF and PACF plots and **b** Seasonality adjusted ACF and PACF plots

8.3.12 Ljung-Box Test and Augmented Dickey-Fuller Test (ADF Test)

Stationarity of data can be assessed by the Ljung-Box test statistics. The Augmented Dickey-Fuller Test (ADF test) is another confirmation test that is used to confirm the conversion of data series into a stationary series. As per the ADF test results, we have enough evidence to reject null hypothesis since p-value is less than 0.05. The tested data series has seasonality adjusted and converted to stationary series and applicable for the ARIMA modelling. The data series that contains seasonal component must be modelled as a Seasonal ARIMA model. Seasonal ARIMA model is a combination of non-seasonal ARIMA model and seasonal ARIMA model. If the data series is separated into two parts such as seasonally adjusted component and seasonal component due to the existence of seasonality, then the ARIMA model used in both components can be identified as SARIMA model. The SARIMA model is denoted by SARIMA (p,d,q) (P,D,Q)s, where first bracket and second bracket denote the seasonally adjusted and seasonal factor series respectively. As per the results of the Ljung-Box test, associated p-value is greater than 0.05 confirms the acceptance of null hypothesis which said that 'the model does not exhibit lack of fit'. Therefore, the developed model is fine and better forecasts the future rainfall. Pattern visible in the residuals time plots, lag spikes of the frequency in the ACF plots and the Gaussian shape of the parametrically measured residuals all suggested that there is no correlation and models are capable of capturing future variation of the rainfall (Fig. 8.6).

Stationary series use to fit the SARIMA model and then the statistical programme fits all the possible models as a result. The Akaike Information Criterion (AIC) is mostly used to choose the best model out of many resulted models, best model will be a model that has lowest AIC value. When the most appropriate model selects, the model parameters can be estimated using the least squares method. The diagnostic checking of the residuals from the fitted model is the next stage of the process, usually by correlation analysis with the aid of ACF plots. If the residuals are correlated, the model will need to be revisited. Further, inspecting the normal probability plot and the histogram of residuals are the common test that can be performed to assess fitness of the ARIMA model and to check the behaviour of the residuals of the fitted model, respectively. As per the results of the Ljung-Box test, if associated p-value is greater than 0.05 it confirms the not rejection of null hypothesis which is 'the model does not exhibit lack of fit' and in other words model is fine. Pattern visible in the residuals time plot, lag spikes of the frequency in the ACF plot, and the Gaussian shape of the parametrically measured residuals (Fig. 8.7) all suggest no correlation or model is capable of capturing variation of the rainfall using this time series data.

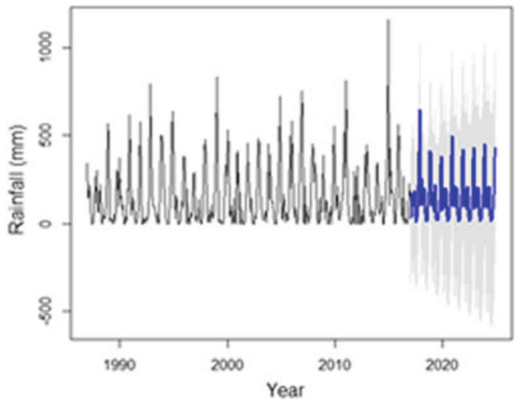


Fig. 8.6 Time series forecast plot

8.3.13 Advantages of Climate Data Analysis

Climate information are relevant for several fields. Agriculture, Aquaculture, Food processing industries, construction designers, management of public finances, assets, insurance needs and health and much more different fields depend on understanding of future climate. Potential climate models are useful tool to predict the climate variations in future. Reliable analysis and modelling techniques are essential to provide

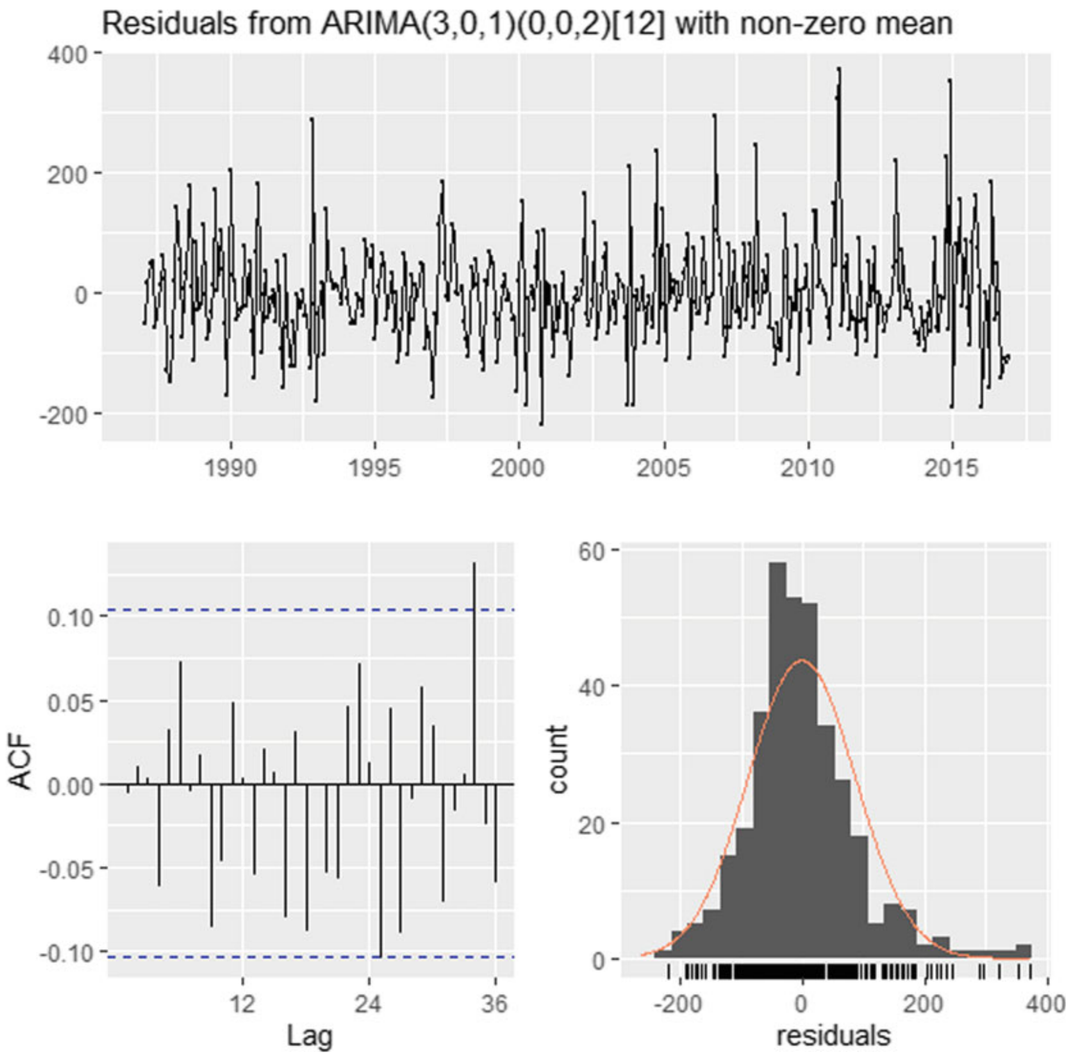


Fig. 8.7 Pattern visible in the residuals from ARIMA models

information to parties who rely on the climate conditions in their business.

8.4 The Methodological Approaches in Geomorphology

8.4.1 Introduction

In the last two decades, the management of land surface has developed into the form of a multi-functional procedure built upon the holistic base that unites scientific knowledge Lehotský and Grešková (2007). The section methodological approaches in geomorphology present a review of the methodology of soil texture analysis based on key techniques. The term 'texture' refers to the degree of coarseness or fineness of the mineral matter in the soil. It is determined by the proportion of sand, silt and clay particles Waugh (2006).

8.4.2 Objectives

The purpose of the analysis is to derive the particle size distribution of soils. Soil tests are conducted for several purposes such as agricultural, engineering (geotechnical), geochemical or as an ecological investigation. Soils supply most of the mineral nutrition for plants through the plant's root system. Therefore, the most widely conducted soil tests are to estimate the plant nutrients for the purpose of determine fertilizer recommendations in agriculture. In agriculture, soil tests are generally referred to as the 'analysis of a soil sample'. This field and laboratory soil sample tests are basically for determining physical properties of soil such as soil colour, consistency, moisture, porosity, bulk density and particle density, structure and texture. In addition to that, this also constitutes for measuring some chemical properties; particularly the soil pH and salinity.

8.4.3 Method

Soil test is comprised of four steps: Collection of a representative soil sample, Laboratory analysis of the soil sample, Interpretation of analytical results and recommendations based on interpreted analytical results. Soil sampling is the critical first step in a soil testing. Laboratory testing will utilize the analysis procedures which appropriate for determining soil conditions. Lab tests frequently include professional interpretation of results and recommendations. This method is constituting those four steps that relates to the above main physical and chemical properties of soil. The records of soil properties are useful for determining the soil management strategies and maintaining soil fertility for the ecological balance. Soil texture analysis is used to measure proportions of various sizes of the soil particles. The three major groups of soil particles are sand, silt and clay. These three groups are commonly referred to as the soil separates and soil texture is defined as the relative proportions of each class. The size measured in the particles are depending upon system use to define soil particle size classification. U.S. Department of Agriculture (USDA), World Reference Base for Soil Resources (WRB) and several other researchers and research institutions have introduced soil particle size classifications (Table 8.3).

According to this classification, particles less than 2 mm belong to sand, silt and clay. These fine grain particles are much more important in chemical reactions, release of nutrient elements and retention of soil moisture than a large volume of coarse gravel or sand. And also, soil texture is important to identify soil's responses to environmental and management conditions such as drought or calcium requirements. There are different methods to identify soil texture. 'Feel method' is a way to determine soil texture by rubbing soil between fingers. 'Separation by sedimentation' is depends upon *Stokes' Law*. 'Sieve analysis' is used to assess the particle size distribution and particularly it is used for coarse grain fraction. 'Pipet method' is often used as the standard to which other methods are compared and it is used for defining fine grain fraction which is less than 0.063 mm diameter. Generally, the grain size distribution is combined method of

Table 8.3 Soil particle size classifications (USDA & WRB)

Name of soil separate	Diameter limits (mm) (USDA classification)	Diameter limits (mm) (WRB classification)
Clay	Less than 0.002	Less than 0.002
Silt	0.002–0.05	0.002–0.063
Very fine sand	0.05–0.10	0.063–0.125
Fine sand	0.10–0.25	0.125–0.20
Medium sand	0.25–0.50	0.20–0.63
Coarse sand	0.50–1.00	0.63–1.25
Very coarse sand	1.00–2.00	1.25–2.00

Source Soil Survey Field and Laboratory Methods Manual (2009) this mechanical sieve and pipet analysis. The Hydrometer method is predominant method which is associated with this laboratory test.

8.4.4 Procedure

See Figs. 8.8 and 8.9.

8.4.5 Determination of Soil Texture by Using Hydrometer Method

This method is used to determine sand, silt and clay concentrations without separating them. Hydrometer method is similar to pipet method except for the manner of determining the concentration of solids in suspension (Fig. 8.10; Table 8.4).

8.4.6 Discussion

Results are reported as percentages of the mineral fraction, 42.5% sand, 42.5% silt and 15% clay. Soil texture is based on the USDA textural triangle. This soil sample indicates 'loam' texture according to this soil texture triangle. Loam soils generally contain more nutrients, moisture and humus than sandy soils. It has better drainage and infiltration of water and air than silty soils. And also, it can be easier to till than clay soils. This soil can be basically recommended for the plant growth. In addition to the fine grain texture, this soil sample indicated small amount of coarse grain soil particles and considerable higher amount of fine grain particles. These fine grain particles are much more important in chemical reactions, release of nutrient elements and retention of soil moisture than a large volume of coarse gravel or sand. It is further important in determining the fertility and tillage characteristics of soils that is used as one of the primary characteristics for classifying soil horizons and soil profiles. This soil sample is representing the loam (Fig. 8.11).

8.4.7 Advantages and Disadvantages

The advantages of the sieving method in Particle Sizing: The analysis includes fast and easy handling of the instrument. The results of particle sizing are accurate and reproducible. It is a time-saving method, and the cost of the instrument is lower than other methods. The disadvantages of the sieving method in Particle Sizing: It works only with dry particles. The minimum limit of measurement is 50 μm, and there is a possibility of further reduction in size, which can cause errors.

Acquired representative soil sample put in oven until it become constant weight. In here, soil sample is in the metal cylinder and it put to oven keep with tray. It's weight record in 1st day as 726. 51g (weight with tray). Second day it shows constant value as 726.04g. Therefore, weight of the dry soil is 168.98 g (without weight of tray and metal cylinder).

Weight of Dry soil (without tray and metal cylinder)	= weight of dry soil (with tray and metal cylinder)	-	(weight of tray + weight of metal cylinder)

Weight of dry soil (without tray and metal cylinder) = 726.04g – (235.25g+321.81g)

= 168.98g

Fig. 8.8 Method of drying soil sample

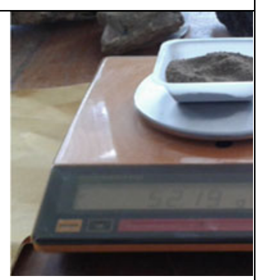
Step 1	Crush the soil sample which is in metal cylinder and put it into bowl. Then it crushes further by using small pestle. (Specially to note that, gravels and stones are not toughly crush; due to those are want to separate as coarse grain soil particle)	
2	Then this soil sample put into 2 mm diameter sieve and sifts well. (It will help to grain size separate). Sieve will keep soil particles which more than 2 mm diameter (coarse grain soil). Coarse grain soil particles (>2 mm diameter)	
3	Fine grain soil particles (< 2 mm diameter) are drop onto the paper Fine grain soil particle (<2 mm diameter)	
4	Then we can measure the weight of fine and coarse grain soil samples. -In here, weight of coarse grain soil particles is 19.13 g.-Total weight of fine grain particles is 149.85 g. 50 g of fine grain soil particles should separate for the 'hydrometer method of soil analyses.	
5	In here weight of measuring cup is 2.19 g. Therefore weight should take as 52.19 g. %0 g of fine grain soil sample put into the beaker. Weight of remain fine grain soil sample is 99.85 g (after the separate 50 g soil sample for hydrometer analysis).	

Fig. 8.9 Steps for fine and coarse grain size separation by using Sieve

1	First, take 50 g of separated fine grain soil sample beaker, then Prepare a solution of sodium hexametaphosphate. In here, 25 g of sodium hexametaphosphate take for soak soil sample. Then, soil sample soak overnight in this sodium hexametaphosphate solution. It will chemically separate the soil sample.	
2	Then, soil mixture should pour into the cylinder by adding distilled water as the cylinder fill up to the volume of 1 liter.	
3	Next hydrometer reading taken after the five hours and 55 minutes. Hydrometer reading at that time (4.00 p.m) was 0.1g/L.	
4	Then put hydrometer into the cylinder. Hydrometer reading at that time indicated as 0.8g/L. [hydrometer reading at 9.05 a.m. (50 sec after to fill up cylinder)]	

Fig. 8.10 Steps for hydrometer analysis

Table 8.4 Calculations for soil texture analysis

Temperature corrections
Add 0.2 units to the readings of the sample due to it in above 67 In here, temperature was 26 (88). Therefore should add 0.2 unit to the readings
Percent Clay: % clay = Corrected hydrometer reading at 5 h, 55 min. * 100/ wt. of sample = (0.1 + 0.2 g/L)*100/50 g = 15%
Percent Silt: % silt = Corrected hydrometer reading at 50 s. * 100/ wt. of sample−% clay = (0.8 + 0.2 g/L)* 100/50 g−15% = 42.5%
Percent Sand: % sand = 100%−% silt−% clay = 42.5%

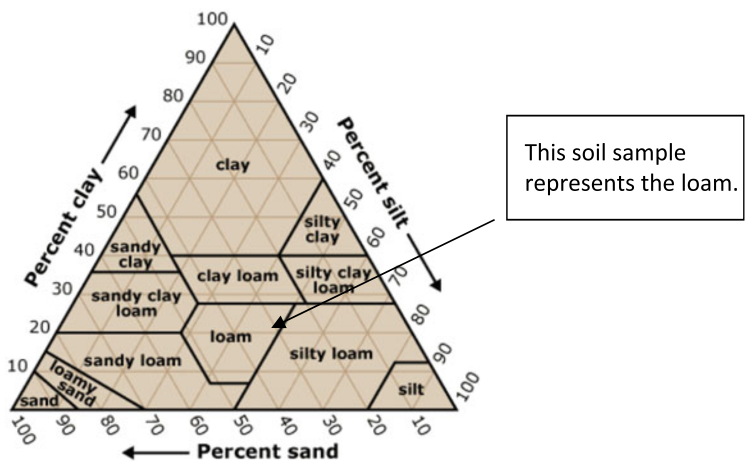


Fig. 8.11 Soil texture analysis: the use of a triangular Graph. *Source* Waugh (2006)

8.5 The Methodological Approaches in Biogeography

8.5.1 Introduction

Biogeography is the study of the distribution of species and ecosystems in geographic space and through geological time. Organisms and biological communities often vary in a regular fashion along geographic gradients of latitude, elevation, isolation and habitat area. Biological diversity is a central theme of Biogeographical theory and has been the subject of many discussions. Currently, researchers have developed a large number of parameters for the measurement of biodiversity as an indicator of the state of ecological systems, with practical applicability for purposes of conservation, management and environmental monitoring (Magurran 1988).

8.5.2 Objectives

There are large number of parameters that are used to measure the biodiversity, for example, measuring Genetic Diversity, Species Diversity, Taxonomic Diversity, Patterns in Time, Dimensionless Patterns, etc. This chapter is mainly focused on measuring Species Diversity.

8.5.3 Methodology

There are two main aspects in Species Diversity namely, Species Richness and Species Abundance. Species richness is the number of species in an area; often the only information available depends on baseline taxonomic data. Species abundance is relative commonness of species, or evenness; requires baseline ecological data.

8.5.4 Procedure

Although there are several methods used to measure the Species Diversity below-mentioned methods are used commonly.

8.5.4.1 Simpson's Diversity (D)

Used to measure mainly Species Richness.

$$D = \frac{N(N-1)}{\sum n(n-1)}$$

D = Diversity, N = Total number of organisms of all species found, n = Number of individuals of a particular species

8.5.4.2 Shannon-Weiner Index (H)

$$\mathbf{H} = \sum -(\mathbf{P_i} * \ln \mathbf{P_i})$$

H = the Shannon diversity index, P_i = fraction of the entire population made up of species i.

S = numbers of species encountered, $\sum$ = sum from species 1 to species S.

$$\text{For this community, } N = 32 + 18 + 12 = 62$$

$$D = \frac{N(N-1)}{\sum n(n-1)}$$

$$D = \frac{62 \times 61}{(32 \times 31) + (18 \times 17) + (12 \times 11)} = \frac{3782}{1430} = 2.64$$

Table 8.5 Example 01

Species	No.of Individuals
Vigna mungo	32
Glycine max	18
Vigna radiata	12

Table 8.6 Example 02

Plant Species	N_i	P_i	ln P_i	$-(P_i$*ln $P_i)$
Artocarpus nobilis	96	0.96	−0.041	0.039
Dipterocarpus zeylanicus	1	0.01	−4.61	0.046
Mangifera zeylanica	1	0.01	−4.61	0.046
Syzygium rotundifolium	1	0.01	−4.61	0.046
Shorea stipularis	1	0.01	−4.61	0.046

$$\text{Shannon} - \text{Weiner Index (H)} = (0.039 + 0.046 + 0.046 + 0.046 + 0.046) = 0.223$$

8.5.5 Advantages and Disadvantages

If Simpson's Diversity is high the area may be a stable ancient site. Low Simpson's Diversity may suggest pollution, recent colonization or agricultural management. The Shannon index is sensitive to the presence of rare species, and the Simpson's index is more responsive to the dominant species.

References

Chow VT, Maidment DR, Mays LW (1988) Applied hydrology. Mc Graw Hill Book Company. ISBN 0-07-010810-2.

Collischonn W, Haas R, Andreolli I, Tucci CEM (2005) Forecasting river Uruguay flow using rainfall forecasting from a regional weather predicted model, J hydrol305(1–4):87–98

Lam NS (1983) Spatial interpolation methods review. Am Cartogr 10:129–149

Lehotský M, Grešková A (2007) Fluvial geomorphological approach to river as-sessment—methodology and procedure. Geografický časopis 59, 2, 22 tabs., 44 refs

Magurran AE (1988) Ecological diversity and its measurements. Princeton University Press, New Jersey, NJ, p 179

Singh VP (1994) Elementary hydrology. New Delhi, Prentice Hall of India

Soil Survey Staff (2009) Soil survey field and laboratory methods manual. In: Burt R (Ed) Soil survey investigations report No. 51, Version 1.0. U.S. Department of Agriculture, Natural Resources Conservation Service

Tabios GQ, Salas JD (1985) A comparative analysis of techniques for spatial interpolation of precipitation. Water Resour Bull 21(3):365–380

Waugh D (2006) Geography: an integrated approach. 3rd Edition and Supplement Set

Wickramaarachchi WWUI, Peiris TUS, Samita S (2020) Rainfall trends in the North-Western and Eastern coastal lines of Sri Lanka using non-parametric analysis. Tropical Agric Res 31(2):41–54

K. W. G. Rekha Nianthi is a Professor in Geography at the University of Peradeniya, Sri Lanka. She obtained her M.Sc. from AIT-Thailand, Ph.D from NEHU, India and Postdoctoral qualification from the University of Minho, Portugal under the Erasmus Mundus Scholarship. She was a visiting scholar at Kyoto University, Japan and a research fellow at Mainz University, Germany, under the Presidential Scholarship. Her main research interests include climate change, adaptation, and disaster management. She serves as the consultant for various projects, authored many research papers and participated in many conferences. She was the project coordinator of the Building Resilience to Tsunami in the Indian Ocean: ADRRN-UNISDR-EU and the project leader of the EU funded UN4DRR Erasmus+Project, UoP and the member of the SAADRI-Indian Institute of Technology.

A. K. Wickramasooriya is a Senior Lecturer in the Department of Geography, University of Peradeniya. He received his B.Sc. special degree in Geology and the Master of Philosophy degree from University of Peradeniya, Sri Lanka. He is an author to several publications and won a Merit Award for Scientific Publication in 2010 by the National Research Council, Sri Lanka. He is the Founder Chairman of Sri Lanka Earth Science Olympiad competition and the National Geography Olympiad competition of Sri Lanka. His research interest includes geoinformatics applications for disaster management, natural and anthropogenic activities on variation of coastal geomorphology and coastal erosion, influence of geological conditions, hydrological and hydrogeological processes on surface water and groundwater contamination.

Lalitha Dissanayake is an Associate Professor in the Department of Geography at the University of Peradeniya, Sri Lanka. She obtained her bachelor's degree from the University of Peradeniya, her MPhil degree from NTNU, Norway, and her Ph.D. from the University of Salzburg, Austria. Her Ph.D. research focused on stream corridor restoration. She is a renowned scientist in the field of geography, and her research interests are headwater streams, waste management, and urban ecological planning. She has presented her various research outcomes in national and international research forums and published that work in reputable international conference proceedings, journal papers, and book chapters. She was invited by the European universities and local government authorities to exchange teaching and research experiences. She is also an advisory member of Europe's Society for Urban Ecology (SURE).

C. S. Hettiarachchi is a Senior Lecturer at the Department of Geography, University of Peradeniya. She received her doctorate in 2015. Her research interests include the areas such as Biogeography, Botany, Environmental Science, Microbiology, Molecular Biology & Biotechnology. Her ongoing research work includes investigation of the relationship between land use and soil quality -A case study in the Lower Hantana, Sri Lanka and Identifying the spatial variations and distribution of invasive plant species *Myroxylon balsamum* species in Udawattakele Forest Reserve, Sri Lanka.

R. M. G. N. Rajapaksha is a Senior Lecturer attached to the Aquatic Resources Technology degree programme under the Department of Animal Science in Uva Wellassa University of Sri Lanka. She has completed her M.Phil. in Earth Science from the University of Peradeniya, Sri Lanka and BSc from Faculty of Applied Sciences, Rajarata University of Sri Lanka. Her research interests are mainly focused on surface water hydrology, aquatic ecology and climate impacts on aquatic ecosystems.

9

Urban River Restoration: A Methodological Discourse with Examples from Kerala, India

Srikumar Chattopadhyay

Abstract

Urban river restoration is an emerging challenge across the world. Several countries are in the process of executing various restoration programmes. However, often the thrust of restoration activities is on technical measures with little or no scope for social interventions. This has not produced desired results, and the need for a paradigm shift is globally felt. It is realised that social and ecological issues are equally important as most of the ecological problems are of societal origin. The co-evolutionary approach advocated in recent years stresses the consideration of both social and ecological issues and stakeholder participation. Examining two case studies from Kerala, India, this paper argues that the participatory approach has the potential to emerge as the viable alternative for urban river restoration under the co-evolutionary framework. The methodological challenges are context-specific, however, there is a need for a broad policy framework and strategic plan covering a wide range of activities from the campaign, conscientisation to plot-level intervention.

S. Chattopadhyay (✉)
Government of Kerala, ICSSR National Fellow, Gulati Institute of Finance and Taxation, Thiruvananthapuram, India
e-mail: srikumarc53@gmail.com

Keywords

Urban river restoration · Co-evolutionary approach · People's participation · Strategic plan

9.1 Introduction

The river valleys are the citadel of civilisations. Conurbations of human settlements and urban development flourished mostly in the riparian zones since the dawn of settled human history. The riparian zones provide unhindered and easy access to drinking water, facilitate movement through water transport, support agriculture, crop production, energy generation, and other economic activities. All these services offer a congenial environment for the growth and development of urban centres. Over the years, urbanisation spreads a humanised/cultural landscape over the natural landscape and, in the process, triggers the transformation of the landscape itself. The ecosystem services based on which urban settlements originally developed cease to offer any further support. There is a disconnection between the river and the people living in the urban centres. People in cities hardly notice the utility of the rivers except to drain out wastes. It is a phenomenon noted worldwide and not limited to any specific country. Loss of ecosystem services of urban rivers is a matter of serious concern across the world. Urban river

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

F. B. Mustafa (ed.), *Methodological Approaches in Physical Geography*,
Geography of the Physical Environment, https://doi.org/10.1007/978-3-031-07113-3_9

restoration is a common response to ameliorate this situation and bring back ecosystem functions of the rivers. In general, the necessity of river restoration is widely felt and several countries, particularly the developed countries, are executing river restoration programmes due to serious impairments of their rivers. The urban river restoration brings additional challenges as each city is linked to different socio-political drivers and functions (Speed et al. 2016). Recently, approaches to river restoration activities are changing both in content and scope. Earlier, it was mainly technical interventions to address water quality problems by controlling point source of pollution. However, over the years, it is learnt that ecological restoration is not limited to improving water quality alone, rather it has to consider several other parameters. Moreover, technological interventions can temporarily restore the water quality or delay the process of degradation; it can never fully ameliorate the situation. Unless root causes of the problems are appropriately dealt with, and the principal drivers are controlled, the desired results of river restoration activities may be short-lived or may not be achieved at all. The restoration of urban rivers is now an essential component of urban water management irrespective of the country's position in the economic ladder. The emerging approach stresses that the restoration activities may be evolved along with the science–society interface. It should be socially driven with the involvement of the community and integrated with the urban water management and the urban area plan following the principle of sustainability science, which is trans-disciplinary, community-based, interactive, and participatory. The co-evolutionary framework provides the necessary scope to adopt this approach.

9.2 Impact of Urbanisation on the River Ecosystem

Urban development significantly impacts the river ecosystem and affects river health. The rivers being located at the lowest level in any given landscape receive all materials from human activities on land and atmosphere and are highly modified (Turner et al. 1993; Naiman et al. 1995; Naiman 2013). Numerous interventions of various magnitudes, in streams, within the floodplains and catchment areas have resulted in serious perturbations, and in many places, the fluvial system is disturbed beyond the resilience limit.

> Urbanisation impacts rivers in three broad areas: modification of geomorphological-hydrological interconnectedness, the diminished social value of rivers and ecological dysfunction/loss of habitat, and biodiversity (Bernhardt and Palmer 2007). The urban rivers are physically and ecologically most intensely affected/damaged with certain commonness for most of the urban areas. Several urban rivers experience alteration of hydrology and morphology, channelisation, artificial construction of river banks, dredging of river beds, disconnection of rivers from flood plains, low flow during the dry period and increased flood risk during monsoon, loss of riparian biodiversity, the preponderance of invasive species, degradation of water quality and similar negative impacts. Accordingly, the term 'urban stream syndrome' has been coined to describe river sections that are characterised by 'flashier hydrograph, elevated concentrations of nutrients and contaminants, altered channel morphology, reduced biotic richness, and increased dominance of tolerant species' (Walsh et al. 2005: 706). The impact of Urbanisation is not limited to urban boundaries. It is felt both upstream and downstream. While the urban centres draw water and hydro-energy resources from upstream, the downstream part receives urban effluents.

The impacts are, therefore, manifested in catchment processes, flow regime, habitat, water quality and sediment chemistry, and aquatic and riparian biodiversity (Table 9.1).

Table 9.1 Impacts of urbanisation on elements of river system

Items/elements	Increase	Decrease	Scale of intervention $
Catchment process			Catchment
Frequency of overland flow	*		
Pollution load	*		
Sediment load	*		
Infiltration		*	
River flow regime			Catchment & corridor
Frequency of erosive flow	*		
Magnitude of high flow	*		
Lag time to peak flow		*	
Rise and fall of stream hydrograph	*		
Change in habitat			Corridor & local
Channel width		*	
Pool depth	*		
Scour	*		
Channel complexity		*	
Connectivity		*	
Water quality and sediment chemistry			Catchment & corridor
Nutrients (N, P)	*		
Toxicants	*		
Temperature	*		
Nutrient uptake		*	
Aquatic and riparian biodiversity			Corridor & local
Abundance and diversity of aquatic lives		*	
Sensitive fish and invertebrates		*	
Tolerant invertebrates	*		
Eutrophic diatoms	*		
Oligotrophic diatoms		*	
Invasive species	*		

Source Speed et al. (2016): River Restoration—A strategic approach to planning and management, UNESCO. $ Level of intervention suggested by the present author

9.3 River Restoration as Part of Urban Water Management

Traditionally, urban water management was restricted to fulfil the demand for drinking water supply, sanitation, and disposal of wastewater. Rivers in urban areas are typically neglected and, in most cases, these natural watercourses have become drains and sewers. In the twentieth century, the scope of urban water management expanded to incorporate the management of floods and the spread of disease (Walsh et al. 2005). This scope has been further expanded in the twenty-first century to cover river health (Lloyd et al. 2002). There were attempts to examine the state of urban water evolution. Conceptually, three trends have been identified: ecology and evolutionary biology-related concept, earth science and engineering-related concept, and socio-ecological-related concept (Kaushal et al. 2015). Based on a review of Australian cities, six typologies have been developed to designate cities according to their state of water use (Brown et al. 2009). It begins with the water supply city when the thrust is on supplying secured drinking water. In the next stage, the disposal of wastewater and sewage management is important to safeguard and maintain public health. In the third level, water management expands to include floodwater drainage. Control of point source pollution and use of waterways as part of urban amenity form the next stage of waterways city. When city water management is based on the integration of all sectors or a total water cycle approach the city is designated as a water cycle city. The final stage is water sensitive city when all aspects of water management have been addressed and water ecosystem services restored so that future generations are not bereft of ecosystem services, and the city is also resilient to climate change-related problems. This typology is a good framework to assess the present state of city water management and to plan for the future course of action. It is also possible that water management services are different in different parts of the same city. Decentralised approach, spatial planning, and prioritisation are important to address the problems of such cities. The restoration of urban rivers is now an essential component of urban water management irrespective of the country's position on the economic ladder. There are also attempts to provide a conceptual and predictive framework for characterising stages, transitions, and mechanisms related to urban evolution. It is now being stressed that in urban river restoration, the focus should be on recovering, stabilising, and enhancing ecosystem functions and services of the rivers, and the restoration activities may be socially driven with the involvement of the community and integrated with the area plan following the principle of sustainability science, which is trans-disciplinary, community-based, interactive and participatory.

9.4 Urban River Restoration: A Brief Overview

River restoration as part of urban water management is being practiced in many countries. The most well-known example is the London River Action Plan (Anonymous 2009), which provided a guideline to help restore rivers for people and nature. The river Thames, which is an iconic symbol of London city, has been hugely improved. Five key features of this plan are (i) improve flood management using more natural processes, (ii) reduce the likely more negative impact of climate change, (iii) reconnect people to the natural environment through urban regeneration, (iv) gain better access for recreation and improved well-being, (v) enhance habitats for wildlife. However, many of its tributaries leave much to be desired. The present challenge is to restore and improve all London rivers with specific goals. Many other countries have also set similar goals (Cha et al. 2011). The European Union's Water Framework Directive (WFD) operationalised since 2000 provided a broad guideline for water management in all EU countries. Rivers in the USA are under severe stress. Earlier, efforts of restoration focused on improving water quality, more recently, the thrust is on the restoration of the aquatic system (NRC 1992) as part of the natural resource of economic, cultural, and spiritual importance. The National River Restoration Science Synthesis (NRRSS) in the USA compiled a database of 37,099 stream and river restoration projects distributed throughout the country (Bernhardt et al. 2005). Most of the projects in the USA, money, and effort-wise, are related to urban areas.

The case study analysis has brought out potential benefits and limitations of urban river restoration projects. Restoration of river segments/sections is useful to improve local river health to some extent; however, this type of localised efforts cannot remedy catchment level impairments (Lammers and Day 2018). There are cooperative conservation efforts with the involvement of Federal and State agencies, NGOs, and private sectors to restore environmental values. Experience from the USA brings out that partnership of stakeholders, multidisciplinary project teams and field personnel helps make successful design decisions in the field (Obropta and Kallin 2007).

Australia has several initiatives on river restoration. It has demonstrated the usefulness of the whole river approach and also the segment-wise approach in river restoration. However, river water pollution due to urbanisation is not so significant in Australia like Europe and the USA. Asian River Restoration Network (ARRN), Japan River Restoration Network (JRRN), and Foundation for Riverfront Improvement and Restoration (FRIR), Japan have documented river restoration works in various Asian countries, particularly in Japan, Malaysia, China, Taiwan, Korea, Cambodia, Philippines, and Singapore. All countries attempted restoration activities with various measures of success. The Asian River Restoration Network (ARRN) emphasised the linkage between river restoration and Integrated Water Resource Management (IWRM). As identified in the case of the USA, broadly, there are four phases in the evolution of river restoration activity. These are (i) the discovery phase, (ii) the conservation phase, (iii) the restoration phase, and (iv) effective integration of the actions phase (Naiman 2013). This progression from the scientific characterisation of a river in the first phase to the integration of conservation and restoration with broader social values and stressors in the fourth phase manifests changing perspectives and understanding the importance of science–society integration to address management problems of rivers.

9.5 Urban River Restoration: Importance and Changing Perspectives

Restoration of urban rivers is expected to address both ecological and social issues, although there are conflicting interests and priorities that are different based on the intensity of problems. River restoration plan may be conceived in three steps: identification of degradation factors, setting up degradation targets, and formation of restoration scenarios (Zhao et al. 2007). There are various attempts, mostly techno-centric, particularly in the developed countries to address these issues of river restoration singularly or in combination during the last several decades, although with varying degrees of success.

River restoration has evolved from a one-dimensional response to manage a single issue like water quality to a multidimensional approach addressing the ecosystem–human relationship, direct and indirect drivers/stressors, and policy measures governing human behaviour (Asian River Restoration Network 2007; Speed et al. 2016). There is a paradigm shift to integrate societal issues in addressing ecological problems. It has been conceptualised under the socio-ecological system advocated by the end of the twentieth century (Berkes et al. 2001). The emphasis is on viewing human and resource systems as parts of a common ecosystem, and therefore mutually interacting, re-enforcing, and coevolving. Socio-ecological perspectives envisage identification and analysis of relationships among four core subsystems: governance, resource users, resource units, and resource system (Berkes and Folke 1998; Ostrom 2009). Restoration of the urban river is therefore an exercise under the purview of social as well as ecological sciences. This approach calls for investigating and identifying relationships among social science issues of governance and actual users controlling human interventions on the river ecosystem on one hand, and, on the other hand, water and river systems, components of ecosystem science (Zingraff-Hamed 2018). This change in approach is potent to replace the principal thrust from technology transfer to knowledge sharing and exchange of experiences between developed and developing countries.

9.6 Concept of Co-Evolution

The concept of co-evolution owes its origin to the Darwinian theory of evolution. The evolution involves three basic processes: variation amongst the population, retention of characteristics from one generation to the next generation, and selection of favourable characteristics in relation to the environment. An evolutionary analysis tries to explain how these three processes function to produce varieties, to retain advantageous properties and pass them on to the future and why entities differ in their propagation (Hodgson 2010; Kallis and Norgaard 2010). The functioning of the natural systems is variously impacted by human intervention. The anthropogenic activities are so intense and penetrative that the upper part of the Holocene, particularly, since the beginning of the industrial revolution has been rechristened as the Anthropocene. Ecosystem functions are variously modified, and human intervention has emerged as the principal driver of environmental change.

There is a paradigm shift in research methods and the thrust is to analyse societal issues in addressing ecological problems. The ecological and social systems are assumed to coevolve through mutual interaction and casual influence that can be analysed following the co-evolutionary framework. This concept, although originally evolved and applied in biological sciences, has spread across a number of disciplines. In recent years, it is argued that this approach is well suited for research on organisation and natural environment (Porter 2006). The concept of coevolution also provides an opportunity to link other intellectual streams with the traditional concerns of mutual dependence between man and nature. It facilitates rich and complementary insights and understanding of the change in complex social-ecological systems.

The water resource system can be organised into four sub-systems (Loucks et al. 2005: 645): '(i) Natural resource system involving streams, rivers, lakes, and aquifers, (ii) Infrastructure system, such as canals, reservoirs, wells and pumping stations (including their operation rule) associated with technology, (iii) Socio-economic system related to water-using and water-related human activities, and (iv) Institutional system of administration, legislation, and regulation of water'. Each of these subsystems operates on a range of space–time scale and in addition, they are coupled to each other via numerous positive and negative feedbacks; this makes them collectively a co-evolutionary coupled human–nature system (Sivapalan and Bloschl 2015). The co-evolutionary approach is expected to deal with all these sub-systems, capture interactions among them, and analyse mutual interdependence.

9.7 People's Participation

Public involvement emerged as a key factor for the success of urban river restoration projects across the world. Water Framework Directive has spelt out the modalities for public participation and related issues (European Commission 2003). It is acknowledged that people's participation increases the acceptance of projects and helps to achieve social sustainability. Public participation is considered an essential component of the present-day development process. It is expected that active participation of stakeholders will help proper decision-making, effective policy formulation, and overcome hurdles during project implementation. To ensure active participation, there is a need for empowering local stakeholders or communities/groups, likely to be involved, particularly when long term engagement is envisaged in provisioning and monitoring of public services. Participation is multifaceted. It can be government-sponsored, donor backed, NGO inspired, civil society sponsored, and spontaneous (Van Buuren et al. 2019). Government-sponsored or donor-demanded participation is basically top-down participation as rules are set at the higher level as part of the project planning mechanism. As an alternative, bottom-up participatory initiatives are emerging in which the society or stakeholders themselves set the rules. River restoration projects in the USA now have the provisions to involve stakeholders; however, their involvement is subject to knowledge level and proximity to the project site (Larson and Lach 2010). Democratic decision-making and effectiveness of community participation appear to depend on the socio-spatial equity in participation (ibid). Participation in the case of the USA is more of stakeholder engagement (Van Buuren et al. 2019) whereas what we are proposing is that the participation is facilitated through continuous actions and the emphasis is much more on inclusiveness and empowerment drawing local people to take part in the development process.

In Kerala, people's participation in the planning process has been successfully demonstrated. Close cooperation, coherent action of urban and surrounding local bodies, information dissemination, consultation, and involvement of the local people including all users and concerned groups are necessary for successful planning and execution of projects (Chattopadhyay and Harilal 2017). Efforts should be there to involve citizens, NGOs, commercial associations, businessmen, institutions, and politicians. The resident associations, private property owners, nature conservation groups and individuals concerned with river restoration may be involved to contribute in site selection, providing ideas as well as in the planning and implementation of schemes. Tourism sectors can also be involved in the process as this sector is going to be the income-generating sector once the water bodies are cleaned and accesses are ensured. The Universities, Colleges, Schools, R & D centres, Employees' associations, and Trade Unions are also stakeholders. Politicians have a very definite role in restoration activity as it involves people and legislation and there is also a need to integrate river restoration programme with existing Government programmes. The second case study from Kerala has indicated such an approach.

Identification of proper stakeholders is an important step in the river restoration project. The stakeholder's involvement is context-specific. The people living in the area, affected groups, local opinion makers, and potential contributors for long-term programmes may be identified. In this context, local residents can help. Informing stakeholders about the conditions of a river or the need for a specific river rehabilitation project is very important. It helps confidence generation and to win stakeholder's support for the project, promotes stewardship, advocacy and initiates participation. Continuous dialogue and consultation are necessary. The information must be user-oriented and should refer to their specific problems. This will increase citizens' participation in the consultation processes. Local seminars and discussions at the level of Resident Association and small groups will help. Guided tour, river walk, lectures, presentations, exhibition, and press release from time to time will energise local people and students. By involving them in site selection for rehabilitation schemes, voluntary clean-up, and ensuring their participation through competition, surveys, workshops, and public meetings will help elicit information and ideas from the locality. It will help to document local knowledge, recounting local history, creating a timeline, and arrange for focus group discussion.

People can also be involved in the implementation and maintenance of the project and can be imparted training to monitor chemical and biological indicators of the water quality. Implementation of pilot schemes, maintenance, and monitoring can be taken over by universities or colleges or research institutes, or resident associations. Business houses/industries/public sector undertakings may also be involved. Annual or bi-annual voluntary clean-up can be taken up by schools and colleges.

It is important to develop stewardship and advocacy for rivers, primarily to generate active support for river enhancement, including acts of pleading or promoting river enhancement activities and projects. To achieve this, it is essential for the citizens and responsible agencies to know and understand the problems of urban rivers so that they are able to recognise sources of constraints and possible pathways of improvement. Advocacy and stewardship can be promoted through information and the involvement of stakeholders in projects. It has to continue after project completion, so as to establish a continuous awareness and to improve attitudes towards streams and their problems. Finally, people may be taken into confidence for forging a partnership, social auditing of the project, and create and nurture a healthy river environment.

9.8 Case Studies in Kerala, India

We present here two case studies describing the steps followed to prepare a restoration plan in two urban centres in Kerala, India. Before handling the case studies, it is pertinent here to concisely discuss river restoration activities in India.

9.8.1 Urban River Restoration in India

Government-level initiatives for river restoration started with the Clean Ganga project started during the 1980s involving all major cities on the bank of the Ganges. A special body, National Ganga River Basin Authority (NGRBA) has been constituted to coordinate the clean Ganga programme. All cities along the bank of the Ganges are required to take up pollution management measures. Nagpur Municipal Corporation is one of the cities to take up restoration activities of the Nag river based on a detailed restoration plan in 2013 (Puranik and Kulkarni 2014; Anonymous 2012). Chennai River Restoration Trust under the Government of Tamil Nadu has initiated ecorestoration of Adyar Creek, Adyar creek estuary, and Cooum river in Chennai city. The Sabarmati riverfront project was executed by the Ahmedabad Municipal Corporation in 1997. Academic studies have been conducted for the rivers of Madurai and Pune. Besides, there is the experience of Arghyam's (a public charitable foundation based in Karnataka) initiatives to introduce Integrated Urban Water Management in Mulbagal town in mid-2008. Rivers in Kerala are under stress and warrant immediate rejuvenation measures (Chattopadhyay and Mahamaya 2014). A river rejuvenation framework has also been developed for Kerala (Chattopadhyay and Harilal 2016). Central Pollution Control Board (CPCB) (2018), Government of India has identified 23 river stretches in Kerala flowing through 34 towns. The stretch of Karamana river draining Thiruvananthapuram city falls under the high priority category for restoration. The Rail India Technical and Economic Services (RITES) prepared a detailed project proposal for cleaning of Karamana river and Killi Ar in Thiruvananthapuram city. Several questions are often raised regarding these city-level initiatives about their wholesomeness and linkage with urban water management. River restoration activities in India are mostly limited to control of point source pollution from the industries and cities. India is largely in the stage of inventorying polluted river stretches through CPCB.

Case I: Karamana river restoration plan in Thiruvananthapuram city.

Thiruvananthapuram, at present the capital city of Kerala province of India, was the citadel of power of the Travancore princely state prior to the formation of Kerala in 1956 following the reorganisation of the States in India based on language. It was originally a religious city and its name had derived from one of the incarnations of Lord Vishnu, the deity of the Padmanabha Swamy temple. The foundation of Thiruvananthapuram as the capital city could be credited to the king Dharma Raja (1758–1798) and his eminent Diwan Raja Kesavadasa during whose time the capital of Travancore princely kingdom was shifted here from Padmanabhapuram near Nagercoil in Kanya Kumari district of Tamilnadu in the second half of eighteenth century (Poulose 1979). The name Thiruvananthapuram was anglicised as Trivandrum and only recently the city got back its original name in official records. The city that evolved as a religious settlement grew as an administrative centre. Subsequently, the character of the town changed both in its settlement pattern and economy. The service sector followed administration and gradually this town started catering to the surrounding rural areas and now it is emerging as an IT hub and a centre providing health services to the national and the international community. Trivandrum accounts for 45% of total state income from the IT sector.

By the end of the 1920s, when pipe water supply was planned the city covered an area of

29 km^2 and had a population of 65,000. At present, Thiruvananthapuram spreads over an area of 215 km^2 and houses 9.58 lakh people (2011) distributed in 100 Wards. The population density is 4454 persons/km^2. Thiruvananthapuram city enjoys relatively better services in the matter of drinking water supply and continuity of water supply among all state capital cities in India. However, in all other sectors of water services and overall environmental management, the performance of the city is far from satisfactory (Chattopadhyay and Harilal 2017). The Karamana river, its tributary Killi Ar and small streams like Pattom *thodu*, and Ulloor *thodu* drain Thiruvananthapuram city. The total stream length within the city is 180 km. Each Ward is drained by a stream (Fig. 9.1**).** Besides, there are the storm water drains diverging into these streams. The river Karamana is the main source of drinking water supply in the city. In 1928–33, a reservoir was constructed impounding the Karamana river in the outskirt of the city. This was designed to meet the demand till 1961. To meet further growth in subsequent years, another reservoir was impounded in 1976–77 further upstream. The city is not yet fully covered under the sewage system. Topographically, the city is undulated with alluvial valleys, and lateritic slopes and ridges. Traditionally, valleys were given for agriculture, and settlements are constructed along the slopes and ridges. As Thiruvananthapuram grew over the years, there was considerable pressure on land. The valleys used to accommodate storm water and functioned as spill areas of streams and rivers during monsoon are now filled up, and mostly diverted for settlement construction to meet the growing demand for housing and infrastructure development. The specialty of Kerala's urbanisation is spatial spread. According to the urban water typology proposed by Brown et al. (2009) part of the Thiruvananthapuram city falls under the category of drained city, with emphasis on flood mitigation and drainage channelisation. However, with only 40% coverage under the sewage system, a large part of the city may be categorised as sewered city requiring a proper sewage system ensuring public health protection.

Existing water bodies and rivers are under severe stress. Both the Karamana river and its tributary Killi Ar show urban river syndrome in their courses traversing the city. Water quality is significantly impaired. The water pollution level of Karamana is even noted at the national level. The Central Pollution Control Board, Government of India identified the urban segment of the Karamana river as one of the most polluted segments in Kerala and accorded the highest priority for rejuvenation (CPCB 2018). The State Pollution Control Board, Government of Kerala took initiative to prepare the Karamana restoration plan (Table 9.2).

Case Study II: Canal rejuvenation in Alappuzha Town.

The coastal town, Alappuzha, located at a distance of 160 km north of Thiruvananthapuram city, capital of the State of Kerala, India, is one of the oldest planned backwater towns of Kerala and is known as Venice of the East due to its intricate canal network crisscrossing the town. This town originally planned and developed in 1762 at the behest of Raja Kesavadasan, the erstwhile Diwan of the princely State of Travancore, was a major trade and commerce centre till the end 1920s, when the Cochin port started developing. Nevertheless, Alappuzha continues to be a major centre for trade of coir, copra, coconut oil, and fishing and marine products.

The Municipal town of Alappuzha spreads over an area of 48 km^2 of which around 40% is underwater and agricultural land. The town has a population of 1.75 lakh (2011 Census). The population growth rate in this town is the lowest among all municipal towns in Kerala. However, there is high pressure on infrastructure with the tremendous growth of backwater tourism. Due to the absence of the hinterlands and the presence of water bodies all around, the canals within the town are common dumping grounds for waste. There are heavy soil and water pollution causing health hazards. Disposal of municipal solid wastes turned out to be a major challenge. The political leadership took note of the situation and initiated a novel programme 'Clean Home Clean City' to treat the problem at the root itself, e.g. at the household

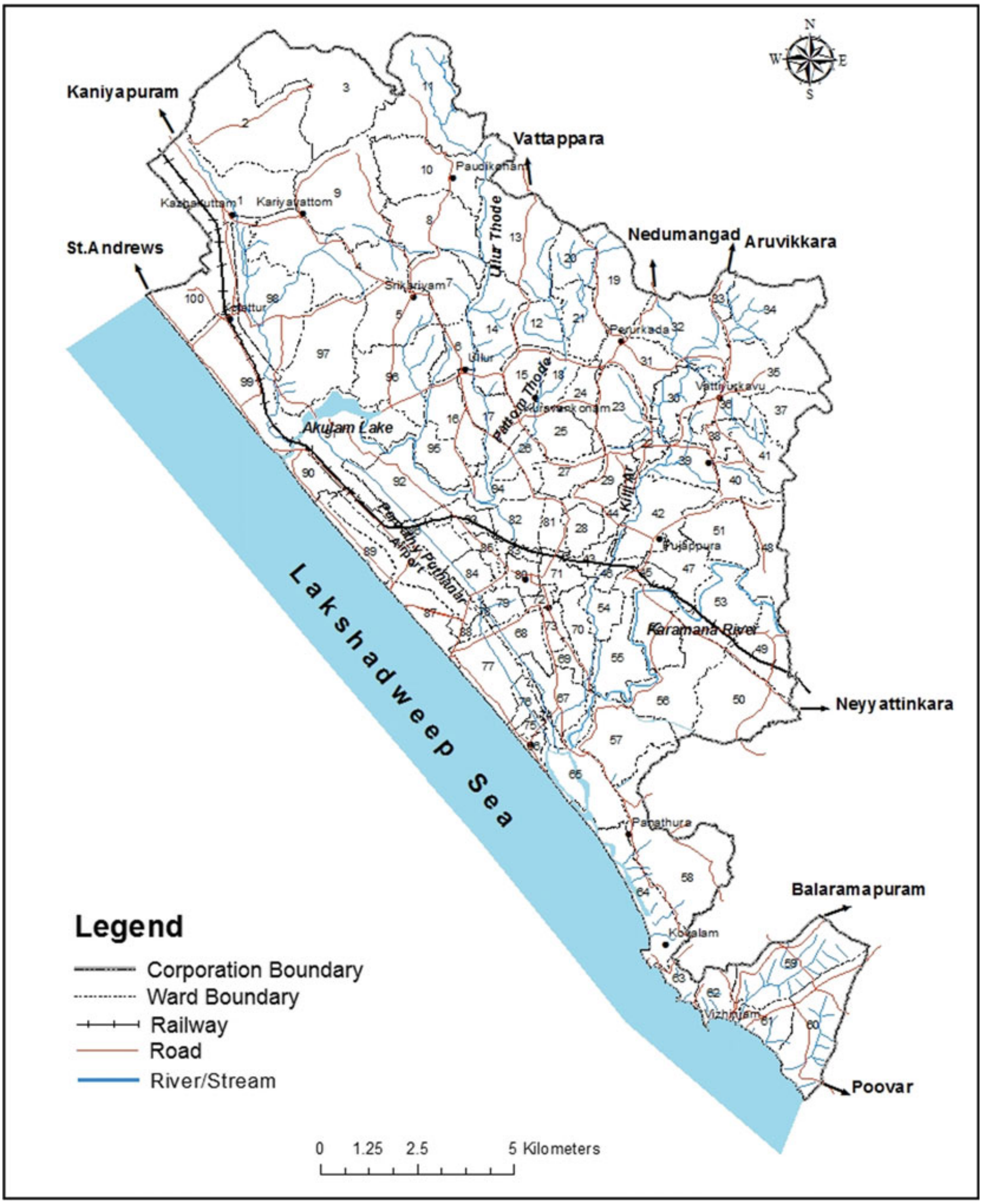


Fig. 9.1 Drainage network and Wards in Thiruvananthapuram city, Kerala, India

level. The programme involved students, their families, schools, and people. Water and sanitation clubs were formed at the schools. The programme began in 2012 and emerged as a successful intervention for decentralised solid waste management. In late 2017, United Nations Environment Programme (UNEP) recognised this programme, and Alappuzha town received the distinction to become one of the four cities in the World including Osaka in Japan for successfully executing decentralised solid waste management programme. Alappuzha town is yet to be covered

Table 9.2 Activities for river restoration in two urban centres in Kerala, India

Details of the programme	Thiruvananthapuram city	Alappuzha town
Lead agency	State Pollution Control Board	Local body
Objectives	Karamana river action plan	Cleaning of canals
Entry point/confidence building	Nil	Decentralised solid waste programme
Approach	Departmental/technocentric	Decentralised/people-centric
Activities	–Investigation of channel characteristics –Sanitation survey along the river banks, –Surface and groundwater quality analysis –Inventory on the source of pollution and gap identification –Action plan for pollution abetment in Karamana–Killiar river	–Mapping civil Engineering features of the canal network –Solid and liquid waste management at the household level—Status and Implications –Water quality analysis –Waste management in the commercial and industrial establishment –Pilot intervention for drainage and sanitary management
Partner organisations	–Department of Irrigation –Kerala Water Authority –Thiruvananthapuram corporation –Kerala State Remote Sensing and Environment Centre –Kerala Socio-Economic Foundation	–IIT, Mumbai –Cochin University College of Engineering, Kuttanad, –Kerala Institute of Local Administration (KILA)
Intervention projects/action plan	–Kerala State Pollution Control Board –Kerala Water Authority –Thiruvananthapuram Corporation –Irrigation Department –Budget for intervention	–Integrated approach to address both solid and liquid waste problems –Decentralised waste watertreatment system (DEWATS) –Four typologies for domestic waste management system under DEWATS –Pilot project –Cluster level treatment –Household-level treatment –Budget for pilot

Source KSPCB (2019), Narayanan et al. (2018), CDD (Undated)

under a separate sewage system and, thus, falls under the category of sewered city under urban typology.

The decentralised solid waste management programme was followed by a programme of cleaning canals in the Alappuzha town concentrating on the Vadai canal and the Commercial canal. The Indian Institute of Technology, IIT, Mumbai extended support by organising the Winter School, in December 2017 and the Summer School in June 2018 (CDD Undated; Narayanan et al. 2018). Cochin University College of Engineering, Kuttanad collaborated in this initiative. The Kerala Institute of Local Administration (KILA) extended support. The programme began with a detailed inventory of the canals, the status of waste generated at households, water quality analysis, waste management in commercial and industrial establishments, and pilot interventions. Recommendations following this analysis cover technical solutions for canal network, solid waste management, liquid waste management, water quality and public health, environmental regulation of industries and commercial establishments, and utility of canals and institution building. The pilot intervention project has brought out encouraging results. The CDD proposed an integrated approach for rejuvenation

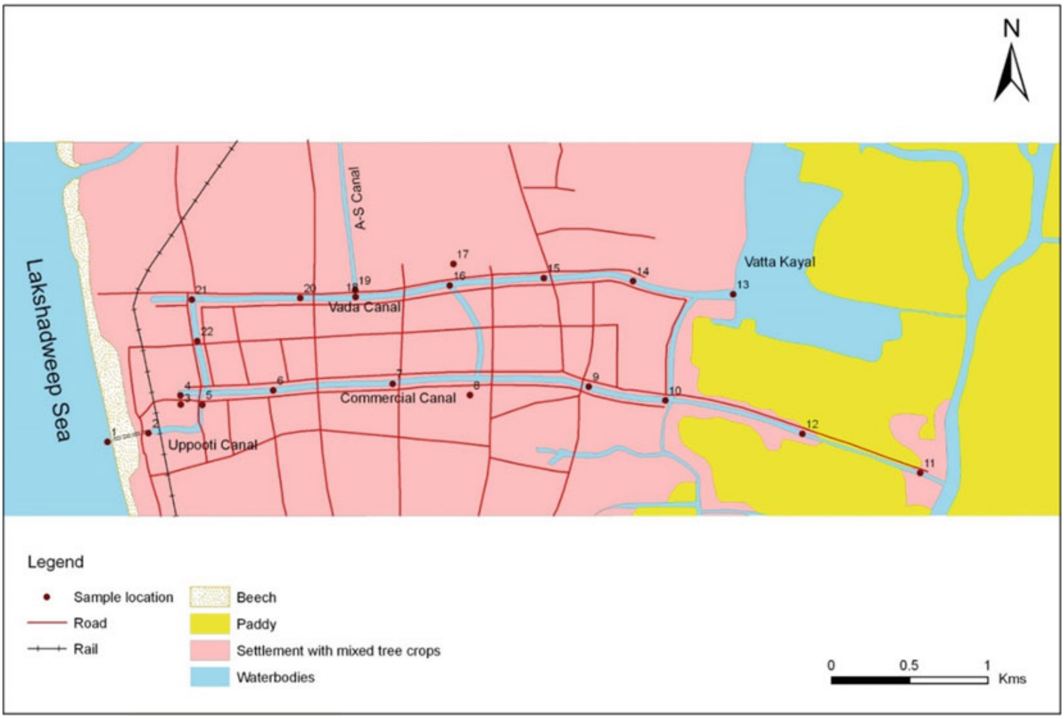


Fig. 9.2 Canal Network of Alappuzha town, Kerala, India

of the Municipal Colony Canal (Fig. 9.2) and a plan has been drawn with budget (Table 9.2). The thrust of this programme is the involvement of local people across the society, local institutions, and emphasis on decentralised management.

9.8.2 Lessons from Case Studies

Important lessons can be learnt from these two case studies in Kerala. The case study on the Karamana river is a departmental approach with a thrust on technological interventions. One of the actions so far taken includes erecting fences along the upstream and downstream side of the bridges to prevent people to dump wastes within the rivers. The other proposed actions cover setting up a biodiversity park and walkway along some stretches of the river, construction of a check dam downstream of the Karamana river to prevent saltwater intrusion, integrated solid waste management plants near the popular religious site, known for the high congregation of people during festivals, maintenance of river stretch for washermen, raising of bund height to contain floodwater, desiltation of canals and streams, improvement of tanks/ponds in the catchment, construction of shutter and improvement of the most polluted section of a canal joining this river. Most of these action plans are structural interventions. These remedial measures may not provide the long-term solutions that are required for urban river restoration. Limitations of technological solutions are globally recognised. As the pollution problem compounds, the investment required for technological solutions escalates. The rich nations can manage to increase the investment and overcome the immediate stress without remedying the underlying causes of pollution; however, the developing nations continue to suffer (Vorosmarty et al. 2010). The lesson from the first case study is that the Government departments continue to follow the prevailing trend and try to address the pollution problem through technological solutions. The global change has hardly impacted these decisions.

The second case study on canal rejuvenation of Alappuzha town suggests a different approach. It is more akin to the emerging trend of a co-evolutionary approach addressing both social and ecological issues. The programme evolved as a natural corollary of participatory solid waste management and conscientisation executed over 5 years. It created the right platform to involve professionals, local institutions, students, and people across the society in planning canal restoration programme. The thrust is on decentralised approach and promoting local institutions. The action plan envisaged the construction of an artificial wetland for greywater management in one of the underprivileged colony. The project also suggested a pilot project. Establishing community institutions, the active affirmative role of political leadership, proper sensitisation of the government officials, and participation of local self-government institutions are important for the preparation and execution of successful canal restoration programmes.

9.8.3 Framework for Urban River Restoration

The proposed urban river restoration framework has been developed considering the emerging global trend and experiences from these two case studies in Kerala. The basic premise is that urban river restoration should form part of urban water management (Table 9.3).

It is now well established that an effective urban river restoration plan should be part of the total urban water management plan and followed socio-ecological analytical principles. The fragmented and ad-hoc approach will not produce desired results as is evident in the failure of many of the restoration activities introduced in several countries (Roni et al. 2002). The main thrust is to improve the ecological functions of water while maintaining the anthropogenic use of them. It warrants compatibility between society and ecology. The first step is to reverse adverse environmental impacts such as changes in channel morphology and water quality. This will improve the river health. There are also socio-cultural and aesthetic dimensions of river restoration. Balancing all these considerations is important to trade the path of sustainability. The rivers in urban areas are in different stages of degradation, based on which priorities may be assessed for initiating restoration programmes. Improvement of water quality, enhancement of summer water flow, and moderation of flood flow are parts of the catchment management activities. Design of intervention measures calls for micro catchment/watershed-based analysis and prioritisation. Therefore, urban river management plan should be developed considering watershed as well as site-specific intervention to achieve the desired goal.

The co-evolutionary approach proposed for restoration activities requires system-based strategic plan. It is necessary to address the fluvial system (physical process), socio-economic, political, cultural, and institutional dimensions of the social system enveloping the river basin. The fluvial system is dynamic and the processes function spatially at the multi-scale level. It is important to understand these dynamics to appreciate the trend of change. The restoration activities should respond to the nature of river ecosystem degradation, and the underlying drivers causing these negative impacts. Rivers are the main sources of freshwater for most of the areas and provide a variety of ecosystem services. River restoration is necessary to preserve the freshwater resource base and rejuvenate ecosystem services and strike a balance between human demand and the natural environment. River restoration requires a spatial framework, for which the flood plain provides a common

Table 9.3 River restoration and urban water management: basic principles

*River restoration as part of city planning and integrated with urban water management
*Sustain and enhance the water resource base of the cities
*Treating the causes of the problem
*Segment as well as whole river approach
*Developing technical and non-technical innovations
*Awareness, stakeholder engagement, capacity building
*Reconnecting people with the rivers
*Creation of socio–technical–political space for dialogue

base for documenting physical, biological, demographic, and economic characteristics along the river corridor (Gregory and Hulse, undated). Configuration of the channel, its position, and land use may change over time; however, the flood plain area usually inundated during monsoon/high rainfall remains relatively constant during the human time scale.

River restoration plan may be conceived in three steps: identification of degradation factors, setting up degradation targets, and formation of restoration scenarios (Zhao et al. 2007). The urban river restoration plan should follow a decentralised approach with a strategic plan spelling out technical and non-technical activities. There are various steps and activities involved in the restoration plan (Table 9.4).

The decisions are required at the local, regional, and national levels. The national-level strategic policy is necessary to provide an overarching frame for river restoration and to initiate actions at the regional and local levels. There are other set of activities, particularly related to prioritisation, fund allocation, inter-departmental coordination, etc., to initiate actions at the basin level. The river restoration plans indicating sites for restoration and the list of activities to be followed are developed at the local level. The whole river approach and segment level approach as followed in some countries can be linked to the regional and local level plan initiatives. Integration of river restoration plan with other sectors of water management is necessary. Quality improvement of river water contributes to river health management under river restoration plan. The stressors leading to water quality degradation are various human activities producing greywater. Controlling of the point and nonpoint sources of pollution form part of greywater management, handled by other departments like Pollution Control Board at the state and central levels. Similarly, stormwater management, an essential component of urban water management can be linked to river restoration plans. Apart from industries, each household, commercial establishments, and land plots that generate greywater and stormwater have a role in the restoration of urban rivers.

A comprehensive plan is necessary to initiate river restoration activity, which is a multidisciplinary programme and warrants the involvement of all stakeholders including the common people. It should begin with a vision and long-term goals. Restoration activity is a multi-stakeholder exercise with the deep involvement of people. People's participation will also help to inventory local knowledge and assimilate it with a restoration plan. It will be a learning exercise both for the experts and people and help create a congenial environment to share, adapt, and manage restoration activities. Participation is a process of empowerment. The type of restoration

Table 9.4 Steps for river restoration plan and level of activities

Steps for restoration plan	Level of activities
*Strategic plan	*Catchment/river basin
*Campaign	–Analysis of catchment and fluvial processes
*Conscientisation	–River health
*Investigation and database	–Ecosystem services
*Identification and analysis of stressors	–Anthropogenic activities within the basin
*Setting up restoration targets	*Urban segments/local level
*Identification of priority areas	–Improvement of channel character
*Preparation of plans	–Improvement of water quality
*Identification of best practices	–Rehabilitation of riparian vegetation,
*Formation of restoration scenario	–Flood mitigation, flow maintenance/improvement
*Modalities for execution	–Control of invasive species
*Monitoring and maintenance	–Flood plain reconnection
*Institution building	–Improve aesthetics,
*Household-level intervention plan	–Improvement of storm drainage
*Plot level intervention plan	–Improve community access and safe use
*Pilot intervention plan	–Improving resilience

activity will vary according to the nature of the problem and the land-use practices with due consideration to the existing urban landscape. There will be continuity. The restoration plan will ensure cumulative/aggregation of individual projects within a holistic frame and each activity will form part of the total programme.

9.9 Summary and Conclusion

Urbanisation impacts the river ecosystem adversely and this impact is not limited to urban boundaries. It is felt both upstream and downstream. While the urban centres draw water and hydro-energy resources from upstream, the downstream part receives urban effluents. The impacts are, therefore, manifested in catchment processes, channel configuration, flow regime, habitat, water quality and sediment chemistry, and aquatic and riparian biodiversity. A new term 'urban river syndrome' emerged in urban water management vocabulary to indicate changes in all these components together. The problems of urban rivers are globally noted. The urban river restoration has drawn wide attention and now being considered an essential component of urban water management. The focus of urban river restoration should be on recovering, stabilising, and enhancing ecosystem functions and services of the rivers.

A brief review of river restoration activities practised in some of the countries in the world brings out that the usual thrust on technical interventions is slowly yielding to a more comprehensive approach. The shift from the initial scientific characterisation of a river to the integration of conservation and restoration with broader social values and stressors manifests changing perspectives and understanding the importance of science–society integration to address management problems of rivers. It is felt that the root causes of the problems leading to river degradation should be dealt and the restoration activities may be socially driven with the involvement of the community and integrated with the area plan following the principle of sustainability science, which is trans-disciplinary, community-based, interactive and participatory.

An emerging paradigm is a co-evolutionary approach that proposes to cover both ecological and social issues as they are mutually dependent and co-evolved. The four sub-systems of the river ecosystems—the river water resources, infrastructure to harness the resources, resource users, and the governance operate on a range of space–time scale, and in addition, they are coupled to each other via numerous positive and negative feedback. The co-evolutionary approach is expected to deal with all these sub-systems, capture interactions among them, and analyse mutual interdependence. It stresses internalisation of social issues and people's participation. People's participation is multifaceted. The bottom-up approach of participation ensures spontaneity, identification of local knowledge, and continuous involvement of people. Advocacy and stewardship can be promoted through information and empowerment of the ground level stakeholders. Analyses of the two case studies in Kerala, India have highlighted the changing perspectives of river restoration in this part of the world and the importance of the participatory approach. Kerala is well known for participatory decentralised planning. The case study on canal cleaning of Alappuzha town has demonstrated the necessity of creating socio-political-technical space and decentralised approach for urban river restoration and water management. The approach proposed here calls for a strategic plan with a specific thrust on campaign, conscientisation, database development, and plan for pilot interventions. Activities will be both at the catchment level and local level. The catchment level interventions are necessary to improve overall river health, maintenance of flow, and to assess the demand for water. Urban segment level or local level interventions are needed to improve in-channel conditions and re-establish the people–river relationship. Regional level interventions are required to improve water quality by controlling point and non-point sources of pollution. The river restoration programme looks for synergy across the scale.

The methodological framework advocated in this paper broadly falls under the co-evolutionary approach. The scientific analysis and technological intervention should be supported by the community. The thrust is on decentralised management and the involvement of people from inventory to execution. Participation has to continue after project completion, so as to establish a continuous awareness and to improve attitudes towards streams and their problems. Finally, people may be taken into confidence for forging a partnership, social auditing of the project, and create and nurture a healthy river environment. People's participation in the approach followed in Kerala and advocated in this paper differs from the stakeholder's participation as envisaged in many of the developed countries. In Kerala, participation is a process of empowerment and to facilitate extending people's ownership of community resources. Although the methodological challenges are context-specific and each country, even locality has to evolve suitable measures, it is argued that experiences from Kerala will be useful for developing river restoration methodology.

Acknowledgements This paper is part of the ongoing research project under National Fellowship. The author is grateful to the Indian Council for Social Science Research (ICSSR), Government of India, New Delhi, for awarding the National Fellowship. Thanks are also due to Prof. K. J. Joseph, Director, Gulati Institute of Finance and Taxation (GIFT) for hosting the national fellowship and extending facilities to complete the work.

References

Anonymous (2009) The London Rivers Action Plan—A tool to help restore rivers for people and nature. www.therrc.co.uk/lrap.php

Anonymous (2012) Rejuvenation of Nag River and its tributaries in Nagpur city—Detailed Project Report, Vol III. Nagpur Municipal Corporation

Asian River Restoration Network (2007) River Restoration in Asia and connection between IWRM and River Restoration. Presentation by Akira Wada, Foundation for River Front Improvement and Restoration

Berkes F, Folke C (1998) Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. Cambridge University Press, New York, USA, p 459. ISBN 9780521785624

Berkes F, Colding J, Folke C (2001) Linking Social-Ecological Systems. Cambridge University Press, Cambridge, UK, p 45. ISBN 978-0521785624

Bernhardt ES, Palmer MA (2007) Restoring streams in an urbanizing world. Freshw Biol 52:738–751. https://doi.org/10.1111/j.1365-2427.2006.01718.x

Bernhardt ES, Palmer MA, Allan JD, Alexander G, Barnas K, Brooks S et al (2005) Restoration of U.S. rivers—a national synthesis. Science 308:636–637

Brown R, Keath N, Wong T (2009) Urban water management in cities: historical, current and future regimes. Water Sci Technol 59(5):847–855

Consortium for DEWATS Dissemination, CDD undated. Rejuvenation of Canal Network of Alappuzha. Project report for pilot phase. Inspiration, Kochi

Cha YJ, Shim Myung-Pil, Kim SK (2011) The four major rivers restoration project. UN Water International Conference, Zarogoza Spain, 3–5 October, 2011. In: Water in the Green Economy in the Practice: Towards Rio+20. pp 1–10

Chattopadhyay S, Harilal KN (2016) River restoration in Kerala: Developing a co-evolutionary framework and river restoration action plan for Trivandrum city. Project Report, Research unit, local self government (RULSG). Centre for Development Studies, Thiruvananthapuram

Chattopadhyay S, Harilal KN (2017) Emerging Challenges of Urban Water Governance: Case of Thiruvananthapuram city, India. Occasional Paper no 2017–1. Research Unit on Local Self Government, Centre for Development Studies, Thiruvananthapuram

Chattopadhyay S, Chattopadhyay M (2014) Rejuvenation of Kerala Rivers: Geoenvironmental Setting, Potentials, Problems and Recent Initiatives. Special Publication Geological Society of India, Bangalore, pp 1–12

Central Pollution Control Board, CPCB (2018) River stretches for restoration of water quality (State wise and priority wise). Ministry of Environment, Forest and Climate Change, Government of India, New Delhi

European Commission (2003) Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance document no. 8 Public Participation in relation to the Water Framework Directive

Folke C, Hahn T, Olsson P, Norberg J (2005) Adaptive governance of social–ecological systems. Annu Rev Environ Resour 30:441–473

Gregory S, Hulse D (undated) Conceptual and Spatial Framework for River Restoration. PNW Ecosystem Research Consortium

Hodgson GM (2010) Darwinian coevolution of organizations and the environment. Ecol Econ 69:700–706

Kallis G, Norgaard RB (2010) Coevolutionary ecological economics. Ecol Econ 69:690–699

Kaushal SS, McDwell WH, Wollheim WM, Johnson TAN, Mayer PM, Belt KT, Pennino MJ (2015) Urban evolution: the role of water. Water 7:4063–4087. https://doi.org/10.3390/w7084063

Kerala State Pollution Control Board (KSPCB) (2019) Karamana River Action Plan. Government of Kerala, Thiruvananthapuram

Lammers RW, Day C (2018) Urban River Restoration: Bringing Nature Back to Cities. Institute for Built Environment. Colorado State University, Fort Collins

Larson KL, Lach D (2010) Equity in urban water governance through participatory, place-based

approaches. Nat Resour JS 50:407. Available at: https://digitalrepository.unm.edu/nrj/vol50/iss2/8
Lloyd SD, Wong THF, Porter B (2002) The planning and construction of an urban storm-water management scheme. Water Sci Technol 45(7):1–10
Loucks DP, Van Beek E, Stedinger JR, Dijkman JP, Villars MT (2005) Water Resources System Planning and Management-An Introduction to Methods, Models and Application. UNESCO, Paris
Naiman RJ (2013) Socio-ecological complexity and the restoration of river ecosystems. Inland Waters 3 (4):391–410
Naiman RJ, Magnuson JJ, McKnight DM, Stanford JA, Karr RJ (1995) Freshwater ecosystems and management: a national initiative. Science 270:584–585
Narayanan NC, Sunil Kumar N, Rana N, Sridhar A, Pillai S (2018) Canal rejuvenation in Alappuzha town: a multidisciplinary study—findings and recommendations. Centre for Policy Studies (CPS), Indian Institute of Technology (IIT), Bomaby; Cochin University College of Engineering, Kuttanad (CUCEK), Kerala, and Kerala Institute of Local Administration (KILA), Kerala, p 127
National Research Council (NRC) (1992) Restoration of aquatic ecosystems: science, technology, and public policy. The National Academies Press, Washington, D.C., USA. https://doi.org/10.17226/1807
Obropta C, Kallin P (2007) The restoration of an urban floodplain in rahway, New Jersey. Ecol Restor 25(3): 175–182. Retrieved 3 Aug 2020, from: www.jstor.org/stable/43443071
Ostrom E (2009) A general framework for analyzing sustainability of social-ecological systems. Science 325(5939):419–422
Porter TB (2006) Coevolution as a research framework for organizations and the natural environment. Organ Environ 19(4):1–26. https://doi.org/10.1177/1086026606294958
Poulose KT (1979) Experiences and Experiments in Town and Country Planning. Pub. Mrs. C Mathews, Trivandrum. p 192
Puranik V, Kulkarni A (2014) Study of rejuvenation and restoration aspects of Nag river. Intern J Appl Res Stud 3(9):1–7
Roni P, Beechie TJ, Bilby RE, Leonetti FE, Pollock MM, Pees GP (2002) A review of stream restoration techniques and a hierarchical strategy for prioritising restoration in Pacific Northwest watersheds. North Am J Fish Manag 22:1–20
Saraiva M da GA (2008) Restoration of urban rivers as a challenge to sustainability. Are ecologic and social concerns compatible? In: Presentation in Expo Zarogoza 2008, Tribuna del Agua ST3 Agua para la Vida —Rios y Sostenibilidad. www.upv.es/contenidos/CAMUNISO/info/U0643700.pdf
Schanze J, Olfert A, Tourbier JT, Gersdrof I, Schwager T (2004) Urban river basin enhancement method (URBEN)-Existing Urban River Rehabilitation Schemes (Work Package 2) Final Report. Leibniz Institute of Ecological and Regional Development, Dresden (IOER) and Dresden University of Technology (TU Dresden), Dresden
Sivapalan M, Bloschl G (2015) Time scale interactions and the coevolution of humans and water. Water Resour Res 51:6988–7022. https://doi.org/10.1002/2015WR017896
Speed R, Li Y, Tickner D, Huang H, Naiman R, Cao J, Lei G, Yu L, Sayers P, Zhao Z, Yu W (2016) River Restoration: A Strategic Approach to Planning and Management. UNESCO, Paris
Turner BL, Clark WC, Kates RW, Richards JF, Mathews JT, Meyer WB (eds) (1993) The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years. Cambridge University Press, Cambridge (UK)
Van Buuren A, Van Meerkerk I, Tortajada C (2019) Understanding emergent participation practices in water governance. Int J Water Resour Dev 35(3): 367–382. https://doi.org/10.1080/07900627.2019.1585764
Vorosmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, Glidden S, Bunn SE, Sullivan CA, Liermann CR, Davies PM (2010) Global threats to human water security and river biodiversity. Nature 467(30 September): 555–561. https://doi.org/10.1038/nature 09440
Walsh CJ, Roy AH, Feminella JW, Cottingham PD, Groffman PM, Morgan RP (2005) The urban stream syndrome: current knowledge and the search for a cure. J N Am Benthol Soc 24:706–723
Zhao YW, Yang ZF, Xu F (2007) Theoretical framework of the urban river restoration planning. Environ Inform Arch 5:241–247
Zingraff-Hamed A (2018) Urban River Restoration: a socio-ecological approach. PhD thesis, University of Tours

Srikumar Chattopadhyay M.Sc & Ph.D in Geography formerly a Director grade scientist and Head, Resources Analysis Division of the National Centre for Earth Science Studies (CESS), Thiruvananthapuram, India is currently a National Fellow of Indian Council of Social Science Research (ICSSR) housed in the Gulati Institute of Finance and Taxation (GIFT), Thiruvananthapuram, India. A postdoctoral Fulbright Fellow and recipient of State and National awards, Dr. Chattopadhyay's work area covers natural and environmental resource management, terrain analysis, the human dimension of environmental change, participatory local level planning, and sustainable development. He has served as visiting fellow/professor in several Indian and Foreign Universities/Institutes, published more than 100 research papers, authored/edited eight books, one Atlas and completed 40 research projects. Dr. Chattopadhyay served in various committees, academic bodies and professional organizations both at the National and State level.

The Methodological Approach of Assessing Urban Vertical Expansion Using Satellite Remote Sensing Techniques

10

L. Manawadu and V. P. I. S. Wijeratne

Abstract

Recently, the change of urban landscape has been widely discussed and recognized that understanding urban change is vital for decision-makers to plan sustainable urban development in the future. Also, an in-depth understanding of current urban processes will help to formulate new urban policies. Identification of horizontal (2D) expansion is not enough to understand the urban morphological changes, and vertical expansion has become vital in urban studies. New digital geographic data sources and GIS applications can help the urban researchers receive more apparent concepts and obtain better measurements of the urban system's relevant attributes, such as urban densities and urban morphology. This study has proposed a methodology to estimate urban Surface Feature Heights (SFH) and Urban Volume (UV) to understand rapid urban morphological changes better. Even though many data sources are available to extract SFH and Urban Volume, this proposed methodology has mainly focused on the ALOS PRISM DSM open-source data. The Digital Terrain Model (DTM) values extracted using the Digital Surface Model (DSM) and SFH were estimated using derived DTM and DSM. The Root Mean Square Error (RMSE) was calculated for accuracy assessment of the estimated data using actual built-up heights obtained from the secondary databases and survey data collected using a range finder. When compared with other data sources, ALOS PRISM DSM is free, and the spatial and temporal coverages are very high. Therefore, researchers can easily access free spatial coverages of ALOS PRISM DSM data which provides more opportunities for urban researchers to incorporate the third dimension heights into the urban morphological analysis.

Keywords

Remote sensing · Surface feature height · Digital terrain model · Digital surface model · ALOS PRISM DSM

10.1 Introduction

One of the main challenges we face globally is the rapid urban growth of cities and continuous and drastic changes in the urban landscape. Urban areas directly consume land as their physical footprints expand, often resulting in complete landscape transformation (Güneralp et al. 2020). Cities are home to half of the earth's

L. Manawadu (✉) · V. P. I. S.Wijeratne
Department of Geography, University of Colombo, Colombo 03, Sri Lanka
e-mail: lasan@geo.cmb.ac.lk

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

F. B. Mustafa (ed.), *Methodological Approaches in Physical Geography*,
Geography of the Physical Environment, https://doi.org/10.1007/978-3-031-07113-3_10

population, and their architecture, structure, and ecology have a considerable impact on residents (Akristiniy and Boriskina 2018). Urbanization is showing an increasing trend all over the world, especially in developing countries. Estimates and projections of urbanization indicate that the future growth of the human population can be accounted for almost entirely by a growing number of city dwellers (World Urbanization Prospect: The 2018 Revision). In 1950, about two-third of the population worldwide lived in rural settlements and one-third in urban settlements. By 2050, we will observe roughly the reverse distribution, with more than 6 billion people living in the messy, burgeoning atmosphere of urbanized areas. Cities have always attracted people with their vibrancy, energy, and, most importantly, opportunities. Within the next minute, the global urban population will increase by 145 people. In 1800, about 2 percent of the world's population lived in cities. Now it is 50 percent. Every week, some 1.5 million people join the urban population through an amalgamation of migration and childbirth (Charles 2017). This has always put tremendous pressure on the city's resources, leaving no option but expanding. A city has three options: expand horizontally, build new cities, and expand vertically. Each approach has its pros and cons (Edam 2019). Natural population growth has been the prime contributor to this expansion. However, the exponential surge is also due to rural–urban migration motivated by the prospect of a higher standard of living, more significant employment opportunities, the opening up of industries, better health care, educational facilities, and increased overall well-being (Charles 2017). Urban growth generally includes both horizontal growth and vertical growth. When space is scarce, cities tend to grow vertically (Koomen et al. 2004), and the growth of urban areas is now dominated by the vertical expansion around the main urban areas and the horizontal expansion of the surrounding areas, which mainly can be seen in the suburban areas (McGee 2009).

Horizontal urban expansion and single house constructions continued until the 19th century, and some economic factors create unique preconditions for the development of vertical urban constructions. After the 19th century, urban areas were facing different environmental, socioeconomic problems, and there were no enough space to absorb population growth in city areas except horizontal expansion toward the suburbs. Therefore, vertical expansion was begun as a new construction solution in the cities. Figure 10.1 shows the factors contributing to the vertical city expansion. In addition to the growth, several other factors such as a comfortable environment and ecology come first in city planning, problems with fresh air, fresh food and traffic, etc. The urban areas' population is increasing day by day, and it creates many issues related to human livelihood. Also, overpopulation and the deployment of many industrial and transport equipment have greatly exacerbated the city's ecological situation. If most countries need to conserve resources and protect the environment, the development of horizontal cities does not always allow this to be done effectively, or it requires a lot of financial costs to replace engineering communication networks or transfer objects. Moreover, people desire comfortable living, people need parks, shopping places, communication, beautiful scenery from windows, and sports opportunities while moving as little as possible in the city. Therefore, vertical expansion of the city has become the best solution for these (Akristiniy and Boriskina 2018).

As United Nations 2015, from 1990 to 2016, the number of megacities in the world increased from 10 to 36. One-third of these megacities are located in East Asia, with 248 million residents. East Asia (including China, Hong Kong, Japan, Macao, Mongolia, North Korea, South Korea, and Taiwan) is one of the world's fastest growing regions. From 2000 to 2010, nearly 20 million people migrated to urban areas every year (Zhang et al. 2018). Urban Hub describes this booming situation precisely. "Think of urban growth like this: a city the size of Manhattan is being built every single day".

Moreover, much of that growth is vertical and tall. Since 2000, the number of 200+ meter skyscrapers being built has tripled. Another aspect of skyscrapers is that it is becoming an

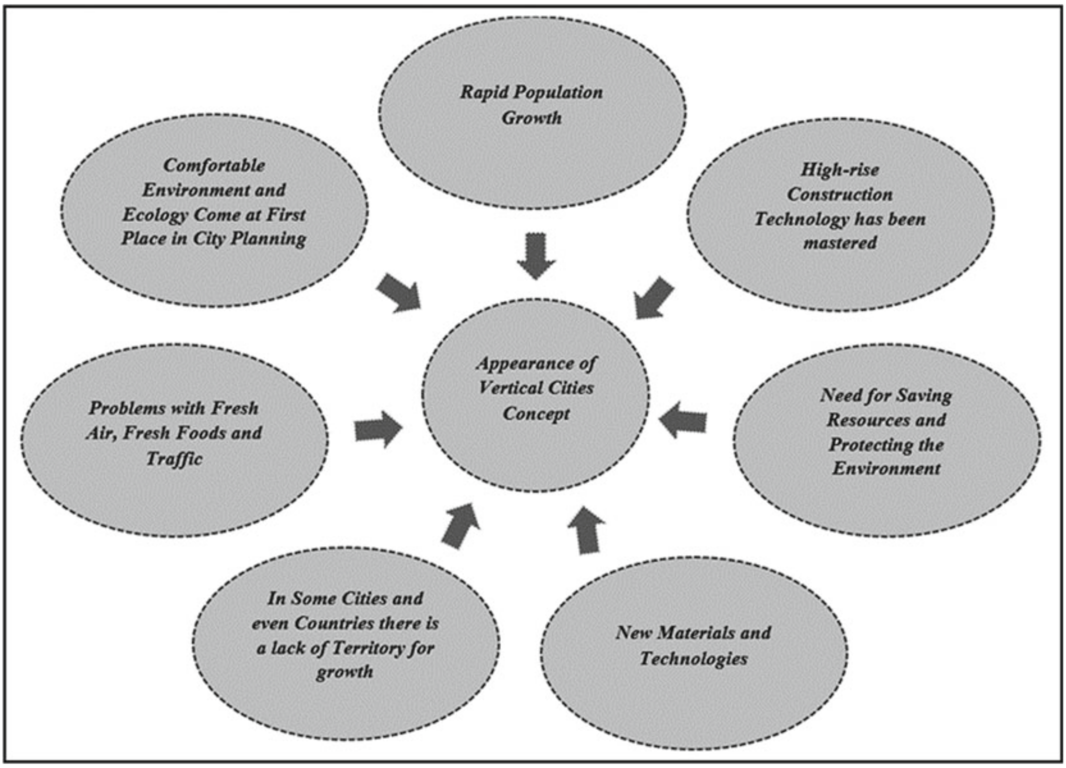


Fig. 10.1 Appearance of vertical cities concept. *Source* Akristiniy and Boriskina (2018)

economically viable investment source in both developed and developing worlds. According to the Global Tall Building Database of the CTBUH, China is the leading country by the number of tall buildings (more than 150+ meters), followed by the United States and Japan. Most of the Southeast Asian countries like South Korea, Thailand, Indonesia, Malaysia, and Singapore were ranked among the top 10 countries. India is in the 13th position being a South Asian country. Another aspect of these skyscrapers is now urban planners and architectures discuss and explore solutions for cul-de-sacs of mobility among the skyscrapers.

Many studies attempted to quantify the horizontal urban expansions globally, and different GIS and Remote Sensing (RS) methods have been applied. Remote sensing with relatively low cost, synoptic view, and repeatability has provided abundant, reliable, and multi-temporal data for urban monitoring and mapping at various spatial scales (Zhang et al. 2018). Urban vertical growth is the other significant aspect of urban growth, representing urban compactness, population growth, and residential lifestyle (Lin et al. 2014). It has been highlighted by urban geographers and researchers that the two-dimensional (2D)-level remote sensing-based data extraction which is good enough for studying urban horizontal expansion is not strong enough to examine the urban morphological changes and urbanist lifestyle changes. Therefore, the third dimension's spatial information is a crucial indicator of urban expansion in dense urban areas where multiple land use exist. However, recent studies have attempted to detect the vertical expansion of some urban cities globally. Remote Sensing (RS) technology has been a powerful tool to study both horizontal and vertical urban expansion, and many analysis on the urban growth pattern, mostly vertical urban expansion, has been done using different spatial analysis in GIS and satellite-based RS techniques (Zhang et al. 2018).

Remote sensing techniques applied for extraction of urban vertical expansion can be divided into two streams based on the methodologies or, more specifically, sensors, active sensors (SAR imagery, LiDAR data), and passive sensors (available optical imagery) (Zeng et al. 2014). Brunner and his research team estimated the building heights for a residential area in Dorsten, Germany, using SAR data in 2010. Literature evidence using LiDAR data building heights was estimated to apply the OLS-based growth model (Qiu et al. 2010). The study conducted by (Mathews et al. 2019) has done the satellite scatterometer estimation to detect the urban built-up volume validation which have been done using airborne LiDAR data. Moreover, they have mentioned that the Light Detection and Ranging (LiDAR) data provide the potential to monitor three-dimensional (3D) changes. Recent studies attempted to use Google Earth and OpenStreetMap as source data to extract the building's height or several floors. Cellular automata (CA) modeling has commonly been used to simulate horizontal urban sprawl over the world, but now it is being used to simulate UV and generate future growth scenarios. The use of medium resolution remote sensing data is becoming more and more popular among urban researchers in urban volume estimations. Advanced Land Observing Satellite panchromatic remote sensing instrument for stereo mapping digital surface model (ALOS PRISM DSM) provides a better opportunity for urban researchers to detect the urban landscapes' third-dimensional view of the world without relying on costly data.

Furthermore, Koomen et al. (2004) have proposed a new indicator to measure all urban form dimensions: urban volume, based on a combination of land-use maps and detailed elevation data. A new indicator of urban growth ("vertical-to-horizontal growth" ratio (VHG)) has been proposed by Zambon et al. (2019). Researchers pointed out that medium resolution imagery for detecting vertical urban growth is a relatively low cost, observable and repeatable (Zhang et al. 2018). Many studies have been conducted and elaborated on the potential methods to estimate the vertical urban expansion using different RS methods and data sources. Therefore, it is vital to understand the suitable methodological approaches to detect the vertical city growth, and identifying the accurate method to urban mapping expansion is a high priority in the proper allocation of resources and services and in solving environmental, socioeconomic, and geopolitical issues (Mathews et al. 2019).

10.2 Objectives

The main objective of this chapter is to develop a methodological approach to assessing the urban vertical expansion using satellite remote sensing and GIS techniques. The sub-objectives also were formulated to achieve the main objective as follows:

1. To extraction of the third-dimensional view of the urban landscape using space-born technology.
2. To introduce a method to validate the remote sensing-derived urban volume.
3. To examine the spatiotemporal density patterns of the vertical urban expansion.

10.3 Methods

The methodology of this study is elaborated under three subsections: data and data source, data extraction and analysis, and the validation of the results derived through the remote sensing techniques.

Data and data sources:

This methodology is mainly developed targeting the open-source digital data sources listed below:
1. ALOS PRISM Digital Surface Model Data.
2. Building footprint data.

ALOS PRSM DSM data was used as the primary dataset in this study, and data were obtained through the ALOS online website (https://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm) released by Japan Aerospace Exploration Agency (JAXA). ALOS Digital Surface

Model (3.1 new version dated 15th May 2020) was obtained with the horizontal resolution of approximately 30 m (basically one arc second) by the Panchromatic Remote Sensing Instrument for Stereo Mapping (PRISM), which was an optical sensor onboard the Advanced Land Observing Satellite (ALOS). Two datasets were downloaded; May 2015 and April 2020. The ALOS DSM-related details are shown in Fig. 10.2.

The DSM consists of both DTM and SFH values, and their graphical illustration can be shown in Fig. 10.3.

Building footprint data: 2015 and 2020 data were obtained from OpenStreetMap (OSM). This is also an open-source secondary dataset that can be obtained from the website of https://www.openstreetmap.org/ (Fig. 10.4). Also collected individual built-up surface and volume data (2020) from the Urban Development Authority, Sri Lanka, to validate estimated building heights.

Field survey, location-based randomly selected 60 building heights were measured using a range finder instrument. The range finder is an instrument that measures the distance from the observer to a target, as shown in Fig. 10.5.

10.4 Procedure of the Analysis

The procedures adopted of this study have been summarized under six steps.

Step 1: Data Preprocessing

The conversion of the downloaded data into the local coordinate system is the only technical aspect of preprocessing. Downloaded ALOS DSMs data was converted and projected to local coordinates; Kandawala Sri Lanka Grid. Additionally, no other specific preprocessing methods have been performed in the DSM. All other obtained data are also projected to the same coordinate system for further analyses.

Step 2: Digital Surface Model (DSM)-based Terrain Extraction (DTM)

The Digital Surface Model (DSM) refers to the earth's surface height, including all objects on the earth. Therefore, the DSM's elevation values refer to the upper tree canopy or the roof of human-made features. Unlike DSM, DTM represents the bare soil surface's elevation without any objects (plants and buildings). In this study, ALOS Global Digital Surface Model "ALOS World 3D—30 m (AW3D30)" was used to derive the Digital Terrain Model (DTM) of the

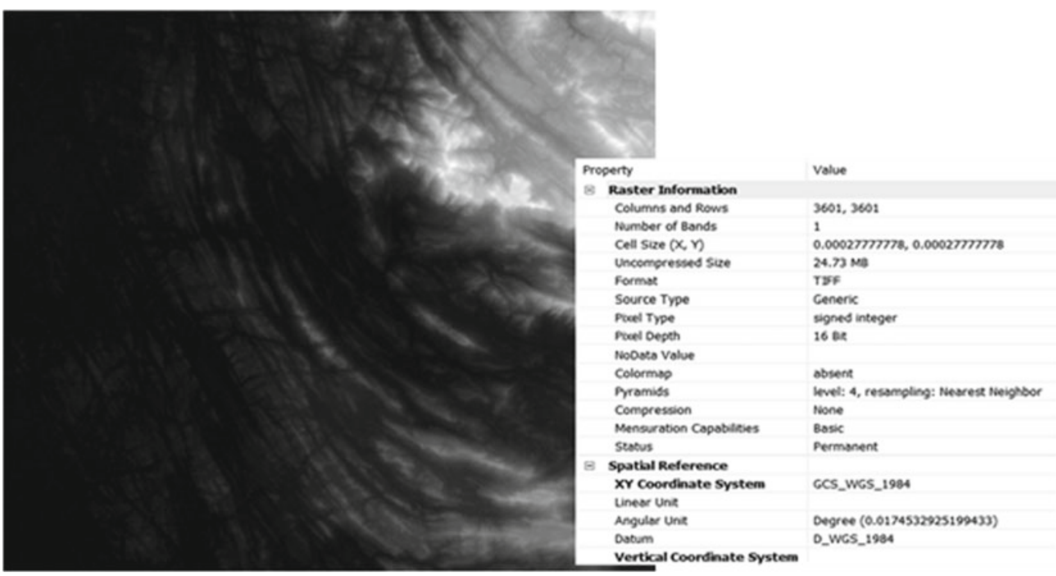


Fig. 10.2 ALOS DSM dataset and the metadata

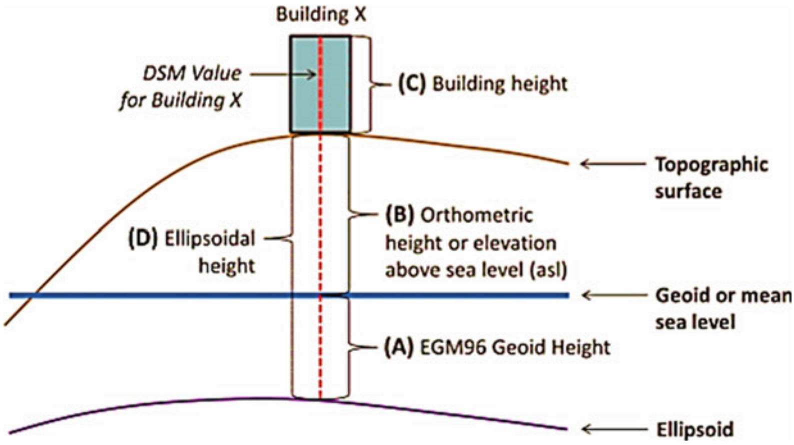


Fig. 10.3 The ALOS PRISM DSM, highlighting the DSM value of hypothetical building X (DSM = A + B + C = C + D). *Source* Estoque et al. (2015)

Fig. 10.4 Building footprint data obtained from the OSM

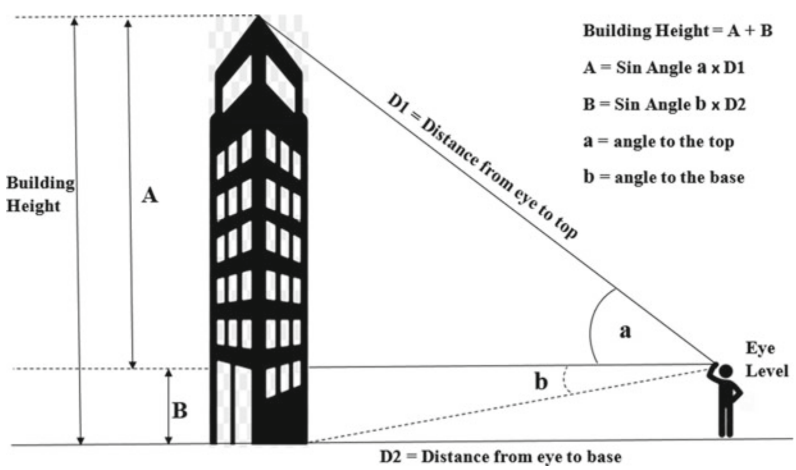


Fig. 10.5 The field survey method

area. The grid-based method proposed by Estoque et al. (2017a, b) was used to extract the DTM from DSM. Two main steps were adopted to derive DTM from DSM as describe below.

a. Generating sample points to extract DTM values from DSM

   Figure 10.5 summarizes the proposed methodology to derive the DTM from DSM and describes under two bullet points below.

   - **Generate sample points using 50 m*50 m grid**—50 m by 50 m grid was generated using the fishnet facility available in ArcGIS covering the whole study area (Fig. 10.6a) and identified the centroids of each cell as sample points (Fig. 10.6b). Relatively smaller grids are useful for generating more sample points and producing more detailed DTM (Estoque et al. 2015).
   - **Create buffer zones and eliminate unnecessary sample points**—The building footprint layer was used to filter the sample points (Estoque et al. 2017a, b). 5 m distance buffers were created around the building blocks, and centroid was overlaid on building buffers. Sample points located in the buffers were removed (Fig. 10.6c), considering those points are on buildings or within the shadow areas. This was useful to remove the output (pixel value) errors that can be happened due to the image shadows.
   - **Extract DTM values**—Finally, the selected sample points (using outside points of the buffers) were used to extract the DTM values using extract values to point tool in the ArcGIS software (Fig. 10.7).

b. Create a DTM surface cover using the spatial interpolation method.

The extracted values of sample points were used to create the surface map for DTM using the interpolation technique in GIS. There are different interpolation techniques in ArcGIS (IDW, Spline, Kringing, Natural Break, etc.), and the best interpolation method for extracted data was selected using the cross-validation method. Cross validation is a method used to assess the accuracy of estimated or model data in interpolation applications in GIS. Cross validation uses all the data points to estimate the accuracy of model data. It removes or omits one data point at a time

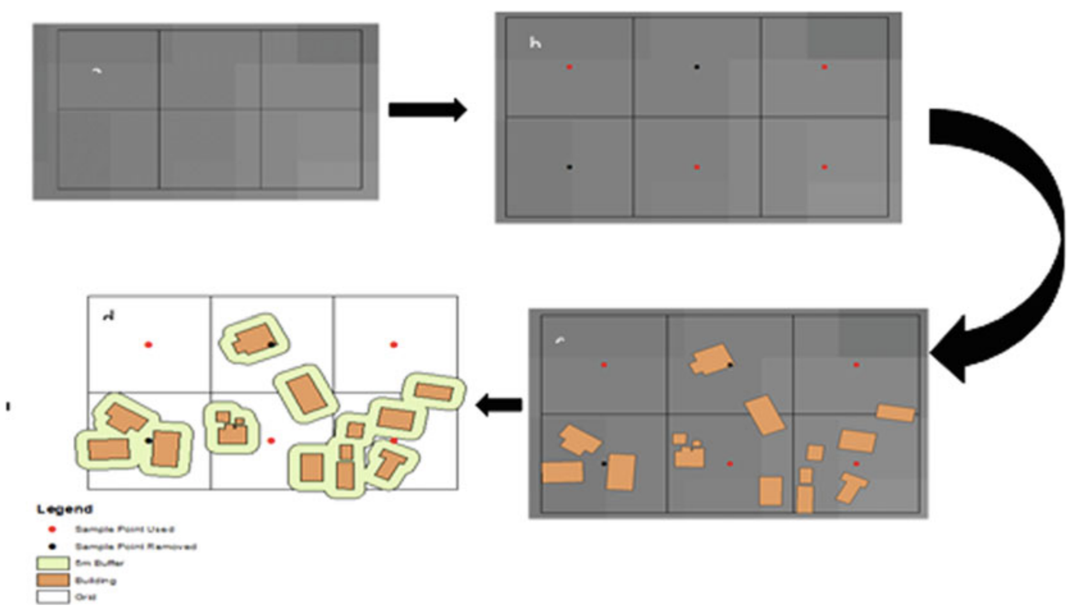


Fig. 10.6 **a** Created 50 m grid on the DSM, **b** sample point created for DSM; **c** building footprint on the DSM; **d** removed neighbor points and selected sample points for low-value extraction

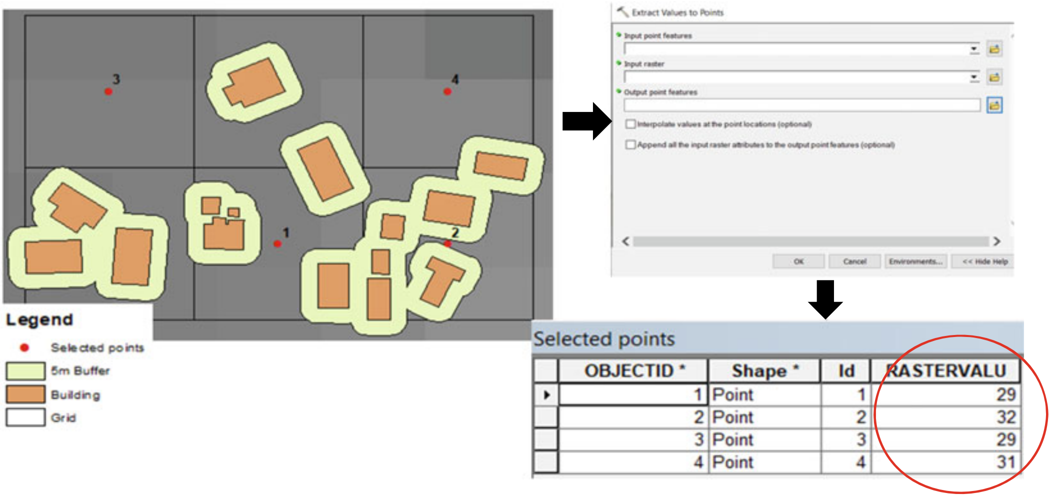


Fig. 10.7 Extract DTM values to selected points

and predicts the associated data. The predicted and actual values at the location of the omitted point are compared until the nth observation.

According to this method, one sample point from all sample points was deleted and interpolated using four interpolation methods (IDW, Spline, Kringing, and Natural Break) in ArcGIS. Secondly, the deleted location was used to extract the estimated DTM values from all interpolated surfaces. Then extracted estimated data were compared with the actual DTM value of the deleted observation. This process continued until the last observation and identified the most suitable interpolation method based on the minimum aggregated deviation (Fig. 10.8).

Kriging was identified as the most suitable interpolation method, as indicated in Fig. 10.8, considering the minimum gap between the actual values and the estimated values.

Step 3: Validation of Estimated DTM values

The sample elevation data obtained from the survey department were used to assess the accuracy of the estimated DTM values in an area. Estimated DTM values were compared against the obtained elevation values, and the Root Mean Square Error (RMSE) was calculated using Eq. 10.1 using Excel 2013, as suggested by Nikolakopoulos (2020).

$$RMSE = \sqrt{\frac{\sum_{i-1}^{n} (D_i - R_i)^2}{n}}, \quad (10.1)$$

where D_i is the actual elevation values, R_i is the estimated DTM value, and n is the number of sample points.

Step 4: Calculate Surface Feature Height (SFH) using DTM and DSM

Once the DTM was created, the Surface Feature Height (SFHp) was calculated using Eq. 10.2.

$$\text{SFHp} = \text{DSMp} - \text{DTMp} \quad (10.2)$$

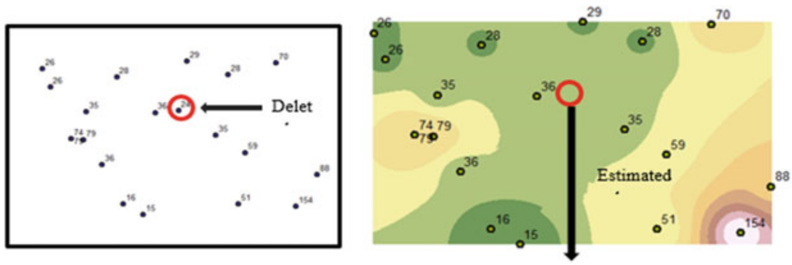
SFHp is the surface feature height of pixel, DSMp is the digital surface value of a pixel, and DTMp is the pixel's digital terrain value.

SFHp is the difference between Digital Surface Map (pixel) and Digital Terrain Map (pixel). The mathematical operation behind this is only subtraction. As both surfaces are in a grid format, a raster calculator in ArcGIS can be used to extract SFH values (Fig. 10.9).

Step 5: Validation of Estimated Surface Feature Height

The data obtained from Urban Development Authority and location-based randomly selected 60 built-up heights measured through the field survey were used to assess the accuracy of the

Fig. 10.8 Cross-validation method



Interpolation Method	Actual Value	Estimated Value
IDW		38.8
Kriging	24	28.3
Spline		32.2
Natural breaks		35.5

estimated SFH in an area. Estimated SFH values were compared against the field obtained height values, and the Root Mean Square Error (RMSE) was calculated using Eq. 10.3 using Excel 2013, as suggested by Nikolakopoulos (2020).

$$RMSE = \sqrt{\frac{\sum_{i-1}^{n} (D_i - R_i)^2}{n}}, \qquad (10.3)$$

where Di is the observed SFH value, Ri is the estimated SFH value, and n is the number of sample points.

Step 6: Urban Volume Estimation

Urban built-up volume (Fig. 10.10) was calculated using Eq. 10.4.

$$\text{UVp} = \text{ARp x SFHp}, \qquad (10.4)$$

where UVp is the urban volume of a pixel, ARp is the area of a pixel, and SFHp is the surface feature height of a pixel.

Step 7: Spatial and Temporal variability of Urban Built-up volume

Urban built-up volume is increasing day by day, and it is essential to understand the spatial and temporal variability of urban built-up volume in the study area. Concentric rings were created from the city center (Central Business District (CBD)) at the interval of 1 km distance to identify the spatial distribution pattern of urban volume charges from the city center to the periphery.

Estimated UVp data were summarized to concentric rings using (Fig. 10.11) zonal statistics option to access the spatial and temporal changes of built-up height variations from 2015

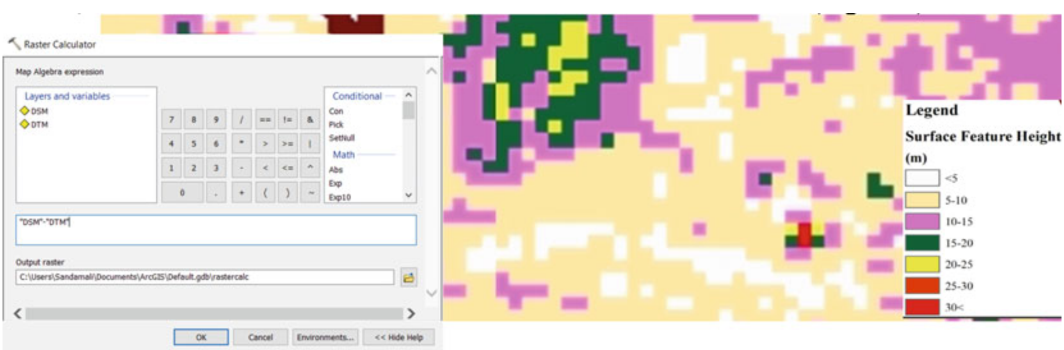


Fig. 10.9 Surface feature height

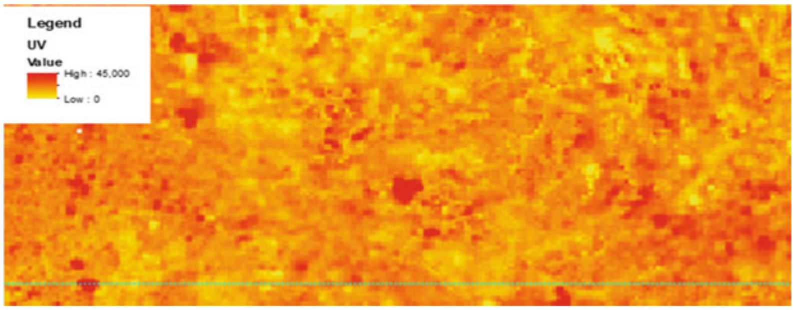


Fig. 10.10 Urban volume

to 2020. Finally, two cross sections were created to visualize the changes in urban volume estimated for 2015 and 2020.

The analysis carried out using ArcGIS 10.5 and Excel 2013 is summarized in Fig. 10.12 for easy understanding.

10.5 Discussion

One of the main characteristics of urban intensive land use is vertical expansion. When space is scarce, cities tend to grow vertically. Until recently, this third dimension usually does not exist in urban research (Koomen et al. 2004). Knowledge of urban growth, such as the spatial pattern of horizontal and vertical expansion in urban structure, is vital in urban morphology and sustainability. The population of the earth is growing rapidly. Every year, the world's population increases by 89 million, which means that more homes and facilities are needed every day worldwide (Edam 2019). Thousands of years, urbanization has been a phenomenon, but traditionally, it is accompanied by horizontal urbanization, that is, the city extends outward along the ground, increasing the total area of the city itself. However, the number of people living in urban areas will increase rapidly. Therefore, urban vertical expansion has become a vital urban management plan for the current urbanization happening worldwide. Since vertical urbanization encourages people to live very close to each other, it also has the potential to improve social cohesion, while horizontal urbanization may promote regional social division of labor (Edam 2019). Recently, researchers have attempted to describe the urban morphological changes over the world, while this new form of urban planning emphasizes less on the original urban landscape. Therefore, this research mainly attempted to introduce a suitable methodology to understand the vertical urban expansion in urban areas. Open-source data, GIS, and remote sensing applications have helped urban research analyses gain a clearer explanation and better measurement of urban growth and horizontal and vertical expansion.

According to the available literature, there are a few methods to analyze urban vertical growth.

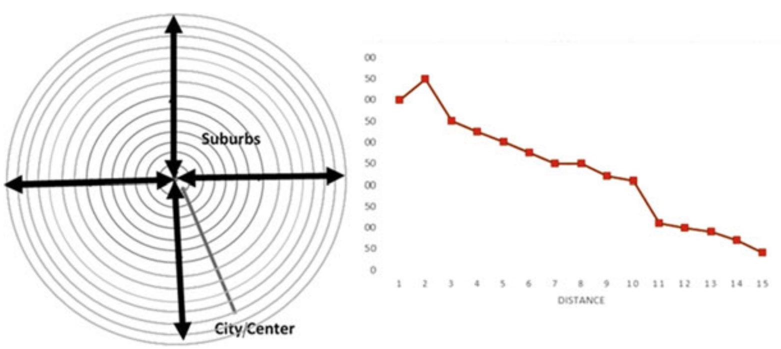


Fig. 10.11 Develop concentric zones from the city center

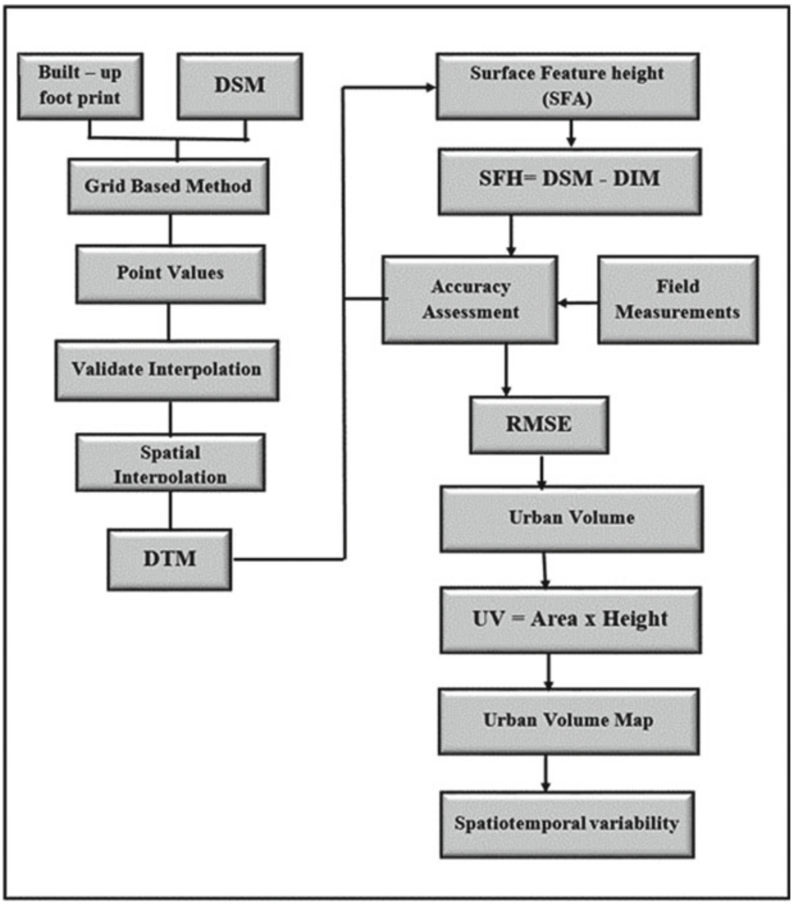


Fig. 10.12 Methodology of the study

Also, there is a long history of using urban models (land-use model, traffic model and urban sprawl model, cellular automata (CA), and agent-based city model) to understand the process and dynamics of urban development. However, the model is not a representation of reality but a simplification (DeMers 2002). Recently, most researchers have identified different remote sensing methods to obtain very accurate results for urban studies. Compared with the urban 2D expansion, the literature shows that the understanding and description of 3D expansion is relatively new.

The most straightforward method is to collect the vertical expansion of a city to obtain the data from a building height survey conducted by other organizations (Salvati et al. 2013). A range finder can be used to obtain the actual heights of the buildings. It is an instrument that measures the observer's distance to a target in a process called ranging. However, this is very time-consuming, and tedious work as information should be collected building by building. Official statistical sources such as Urban Development Authority, Survey Department, etc. also can provide building heights for analyses. However, limited spatial coverages and less repetitiveness are some of the limitations of such data. Researchers have recently used new technology to find the building heights and footprints of urban areas, i.e., Google Earth, OpenStreetMap (OSM), and Street View. At present, the most commonly used data source for studying building heights and their expansion is remotely sensed data. SAR imagery, LiDAR data, aerial imagery, SPOT imagery, QuickBird imagery, IKONOS imagery, VHR images, and Landsat images can be identified as the most common remote sensing data used for vertical analysis in the urban areas. Remotely sensed data sources applied to examine the vertical expansion studies can be divided into two groups, such as active remote sensing (SAR imagery, LiDAR, etc.) and passive remote sensing (general optical imagery).

Usually, SAR imagery (VHR) can estimate building heights with an automation simulator and a matching function. However, the most popular active remote sensing data source which applied estimating building heights is LiDAR data. Some researchers used a robust interpolation method that can separate LiDAR data into the building layer, and finally 3D models of buildings can be generated automatically. Simultaneously, estimating building heights and the reconstruction of the three-dimensional buildings' model using the shadow information of the VHR image is generally studied. Some researchers have also drawn attention to the sun-sensor shadow of the images to derive building heights and mostly use high-resolution images, such as SPOT, QuickBird, and IKONOS (Zhang et al. 2018). Although mostly for horizontal urban growth analysis, researches use medium resolution images, it is very rare in urban volume studies. However, the use of high-resolution images is costly, and sometimes spatial coverages are limited. Therefore, this chapter has discussed how to examine the urban vertical expansion using open-source global remote sensing data.

The proposed methodology mainly based on medium resolution satellite remote sensing data and ALOS PRISM Digital Surface Model (DSM) released by JAXA in 2015, and global DSM data can be accessed from anywhere in the world. This chapter has focused on the grid-based method, and Digital Terrain Model (DTM) values are also generated from the DSM. Furthermore, Surface Feature Height (SFH) data extracted using generated DTM and DSM and the data validation using actual built-up heights is discussed. Finally, this paper discussed the spatial and temporal variability of the urban vertical expansion using concentric rings created from the city center (Central Business District (CBD)) at the interval of 1 km distance to identify the spatial urban volume changes from 2015 to 2020.

This study's primary purpose is to identify a suitable method to estimate and identify vertical urban growth patterns using freely available satellite remote sensing data. The availability of ALOS prism DSM data provides an opportunity for urban researchers to incorporate the third-dimensional height into urban geographic analysis without relying on costly remote sensing data (Estoque et al. 2017a, b). As a free dataset, ALOS DSM can be recommended for urban vertical analysis, and it is available everywhere in the world. Therefore, this method can easily be applied to researchers in developing countries with limited access to reliable data sources. This method will help sustainable urban planning and policy over the world, especially in developing countries.

10.6 Advantages and Disadvantages

The number of megacities worldwide increased 10–36 between 1990 and 2016 (United Nations 2015). Urbanization leads to many social, economic, and environmental problems. As a result, governments worldwide have been taking strict measures to regulate urban expansion (Zhang et al. 2018). Both horizontal (2D) and vertical (3D) expansions are the major components of urban development, and when examining the past urban geography research, there were very few studies for urban vertical expansion. Therefore, it is essential to understand the particular vertical growth pattern of urban areas worldwide for better city planning and urban sustainability.

GIS and remote sensing can be identified as two main powerful analytical tools used for urban studies too. Remote sensing data sources became the most reliable data source for urban vertical estimation in the recent past as a low cost, highly reliable with repeatability. Remote sensing data provides extensive area coverage, and this study used ALOS DSM data, which is covering the whole globe.

Usually, remote sensing data and processes are relatively expensive, especially when applying for a small study area. However, remote sensing data can be obtained freely, and ALOS DSM is also free for everyone. Therefore, researches permit the easy collection of DSM data for urban analysis. Most previous studies focused on vertical urban growth have been done using active remote sensing high-resolution data (SAR imagery and LiDAR data), which are very expensive and analysis is also a bit time-consuming. Moreover, those data will be processed for special requirements, and images may not cover the whole globe and required a special kind of training for data processing and analysis. So, ALOS free DSM provides an excellent opportunity for urban studies, especially in developing countries.

The method proposed in this chapter is very straightforward and less time-consuming. Special training is not required except for fundamental knowledge of ArcGIS for the users, and it will be a cost-effective method. Therefore, time-saving is one of the prime benefits of this method and assists urban researchers in producing very reliable results with minimum effort and low cost.

This method can also be used for visualizing and quantifying the urban land-use changes and characterizing urban vegetation structure and supports ecological evaluation, green-economic estimation, and urban ecosystems research (Estoque et al. 2017a, b).

The main disadvantage of this method is the resolution of DSM data. The ALOS PRISM Global DSM data resolution is 30 m by 30 m. Therefore, it is not highly recommended for analyzing a very small urban area. Also, this study did not consider the canopy cover when the DTM values estimate. Normally, DSM consists of both canopy and building heights, and canopy cover also should eliminate for DTM calculation.

References

Akristiniy V, Boriskina Y (2018) Vertical cities—the new form of high-rise construction evolution. In: E3S Web of Conferences, vol 33(01041), pp 1–11

Charles A, (2017) Urbanization: insights in a global megatrend. Retrieved from Smart City Hub: http://smartcityhub.com/governance-economy/urbanization-insights-in-a-global-megatrend/

DeMers M (2002) GIS Modeling in Raster. Wiley, Newyork

Edam B, (2019). What is vertical urbanization, and what does it mean for our cities. Retrieved from Boon Edam Global: https://www.boonedam.com/blog/vertical-urbanisation

Estoque RC, Murayama Y, Tadono T, Thapa BR (2015) Measuring urban volume: geospatial technique and application. Tsukuba Geoenvironmental Sci 11: 13–20. Retrieved from: https://www.researchgate.net/publication/292228043_Measuring_urban_volume_geospatial_technique_and_application

Estoque RC, Murayama Y, Myint SW (2017a) Effects of landscape composition and pattern on land surface temperature: an urban heat island study in Southeast Asia's megacities. Sci Total Environ 577: 349–359. https://doi.org/10.1016/j.scitotenv.2016.10.195

Estoque RC, Murayama Y, Ranagalage M, Hou H, Subasinghe S, GonG H, Zhang X (2017b) Validation ALOS PRISM DSM derived surface feature height: implications for urban volume estimation. Tsukuba Geoenvironmental Sci 13: 13–22. https://doi.org/10.15068/00150209

Güneralp B, Reba M, Hales BU, Wentz EA, Seto KC (2020) The trend in urban land expansion, density, and land transitions from 1970 to 2010: a global synthesis. Environ Res Lett 15: 1–12. https://doi.org/10.1088/1748-9326/ab6669

Koomen E, Kaufholz P, Scholten H (2004) 3D-GIS and urban volume: applying the third dimension in a morphological study of the Amsterdam Urban Landscape. In: 7th AGILE Conference on Geographic Information Science, pp 139–147. Heraklion, Greece

Lin J, Huang B, Chen M, Huang Z (2014) Modeling urban vertical growth using cellular automata-Guangzhou as a case study. Appl Geogr 53: 172–186. https://doi.org/10.1016/j.apgeog.2014.06.007

Mathews AJ, Frazier AE, Nghiem SV, Neumann G, Zhao Y (2019) Satellite scatterometer estimation of urban built-up: validation with airborne lidar data. Int J Appl Earth Obs Geoinformation 77: 100–107. https://doi.org/10.1016/j.jag.2019.01.004

McGee T (2009) The Spatiality of Urbanization: The Policy Challenges of the of Mega-urban and Desakota Regions of Southeast Asia UNU-IAS. Working Paper No. 161

Nikolakopoulos KG (2020) Accuracy assessment of ALOS AW3D30 DSM and comparison to ALOS PRISM DSM created with classical photogrammetric techniques. Eur J Remote Sens 53 (Sup2):39–52. https://doi.org/10.1080/22797254.2020.1774424

Qiu F, Sridharan H, and Chun Y (2010) Spatial Autoregressive Model for Population Estimation at the Census Block Level using LIDAR-derived Building

Volume Information, Cartography and Geographical Inforation Science, 37(3):pages 239–257

Salvati L, Zitti M, Sateriano A (2013) Changes in vertical city profile as an indicator of sprawl evidence from a Mediterranean urban region. Habitat Int 38: 119–125. https://doi.org/10.1016/j.habitatint.2012.05.006

United Nations (2015) World urbanization prospects: The 2014 revision. Urban Development, DC. World Bank Group, East Asia's changing urban landscape: measuring a decade of spatial growth, Washington

Zambon I, Colantoni A, Salvati L (2019) Horizontal vs. vertical growth: understanding latent patterns of urban expansion in large metropolitan regions. Sci Total Environ 654: 778–785. https://doi.org/10.1016/j.scitotenv.2018.11.182

Zhang W, Li W, Zhang C, Hanink D, Liu Y (2018) Analyzing horizontal and vertical urban expansion in three East Asian megacities with the SS-coMCRF model. Landsc Urban Plan 177: 114–127

Zeng D, Liu K, Lai S, Zhou G, and Zhao J (2014) Relation classification via convolutional deep neural network. In Proceedings of the 25th International Conference on Computational Linguistics (COLING), pages 2335–2344, Dublin, Ireland

Manawadu, L. Dean of the Faculty, Faculty of Arts, University of Colombo and Chair Professor at the Department of Geography, University of Colombo, Sri Lanka. Earned his Ph.D from the University of Colombo and M.Sc. from the Asian Institute of Technology, Thailand. His areas of specialization are GIS and Remote Sensing, Settlement Studies, Environmental Studies. He has been involved in several national and international level consultancy projects which include five-year Development Plan for the North Western Province of Sri Lanka, Resettlement Action Plan for the Kelani River flood protection project.

Wijeratne, V. P. I. S. is a lecturer in the Department of Geography, University of Colombo, Sri Lanka and presently, she is a Doctoral candidate in Physical Geography at the college of Urban and Environmental Sciences, Northwest University, China. She received her M.Sc. in GIS and Remote Sensing from the Postgraduate Institute of Science, University of Peradeniya, Sri Lanka in 2014 and BA (Hons) First Class from the Department of Geography, University of Colombo, Sri Lanka in 2011. She is broadly interested in Eco-Hydrology, Social hydrology, GIS and Remote Sensing, Climate Change, Disaster Management and Environmental Management.