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Nagavinothini Ravichandran *Editors*

Climate Change Impact on Groundwater Resources

Human Health Risk Assessment in Arid and Semi-arid Regions

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Dedicated to our parents and all our teachers

Preface

Currently, two driving forces, namely climate change and man-made interference, are responsible the water crisis on Earth. Especially in semi-arid regions, hydrological activities are more complex, and they are more sensitive to human activities and climate change. Areas with the most water scarcity are generally defined as arid and semi-arid. Surface and groundwater regimes in these areas are intense and highly diverse, and they face great pressure to provide and manage freshwater resources. In recent years, water circulation has been severely affected by climate change, industrialization, urbanization, and desertification of usable lands (especially in urban areas). The socio-economic development of the population demands proper infrastructure development in and around their habitat resulting in natural water systems being subjected to severe denials. The main purpose of this chapters 1 to 5, is to identify the water source in semi-arid areas and to focus on the response mechanism and geographical modeling of the hydrological activities in those areas. The prime objective of this book is to provide insight into semi-arid regions' climatic and morphometric conditions through rainfall fluctuation and temperature variation studies, land use/landcover change analysis, morphometric analysis, and drought assessment studies and also demonstrate the modern remote sensing and GIS-based quantification and modeling approaches which are used to access the hydrological parameters such as rainfall-runoff, evapotranspiration, groundwater dynamic modeling, water level fluctuation study, water balancing, and aquifer properties.

This book deals with climate change challenges and their impact on groundwater quality, and human health risk assessment due to pollution of surface water and groundwater. To providing a stable outcome presentation by using recent trends in water resource management, pollution mitigation strategies techniques, modeling of groundwater quality and human health risk assessment in arid and semi-arid regions. Population growth has been raising an unparalleled demand for fresh water and also increasing human health risk due to water quality changes in arid and semi-arid regions. Currently, risk to groundwater and human health is very serious in the entire world, where several million people use contaminated surface and groundwater for drinking and irrigation purposes. Nowadays, every sector depends on surface water and groundwater. It is the most significant source of domestic, industrial, and irrigation water and also a limited resource. This book is a collection of chapters providing a multi-disciplinary overview for academics, administrators, scientists, policy makers, social scientists, and professionals involved in the various aspects of climate change impact on groundwater quality, hydrological process, pollution mitigation strategies and techniques, sustainable development, planning, and management. This book combines human health assessment, hydrological process, and groundwater quality monitoring techniques such as remote sensing and GIS techniques, entropy water quality index, weighted arithmetic water quality index, fuzzy logic application for water quality index and irrigation, saline water, and human health risk assessment planning of groundwater resources in arid and semi-arid regions. The main purpose of this book is to develop truthful outlines of major issues under the climate changes impact on groundwater resources and human health risk assessment, mitigation planning and management in arid and semi-arid region. Therefore, this book is organized into four sections.

This book includes research work by professors, planners, scientists, and research scholars from various universities, international organizations, and institutions in India as well as from other countries of world.

Dr. Balamurugan Panneerselvam
Dr. Chaitanya Baliram Pande
Mr. Kirubakaran Muniraj
Dr. Anand Balasubramanian
Dr. Nagavinothni Ravichanran

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About the Editors

Balamurugan Panneerselvam is a postdoctoral researcher in the Department of Civil, Architectural and Environmental Engineering, University of Naples Federico II, via Claudio 21, 80125, Naples, Italy. His current research interests include groundwater quality assessment for drinking, irrigation, and human health risk associated with major contaminants such as nitrate and fluoride in arid and semi-arid regions, and also groundwater related issues. He extended his research interest in the field of wastewater treatment using moving bed bioreactors and conducting performance evaluation of bioreactor in biogas units. He received his doctoral degree from Anna University, Chennai, in 2019. His thesis was based on the groundwater quality assessment using GIS techniques in Salem district, India. He has published more than 50 papers in international and national journals. He is privileged to act as technical reviewer in journals by Springer, Elsevier, and MDPI. With his immense interest in multidisciplinary research, his recent investigations are focused on parameter estimation using machine learning algorithms, innovative floating structures, and GIS-based potential assessment of photovoltaic systems in India.

Chaitanya B. Pande completed PhD in environment science from Sant Gadge Baba Amravati University, Amravati, and MSc in geoinformatics from Amravati University in 2011. He has more than 10 years of teaching, research, and industrial experience. He is a reviewer for several scientific journals of international repute and is editorial board member of the *American Journal of Agricultural and Biological Sciences*. He has published 57 research papers, 1 textbook, 1 edited book entitled *Groundwater Resources Development and Planning in the Semi-Arid Region* for Springer, 19 conference papers, and 5 book chapters with more than 840 citations. His research interests include remote sensing, GIS, Google Earth Engine, machine learning, watershed management, hydrogeology, hydrological modeling, drought monitoring, land use and land cover analysis, groundwater quality, urban planning, hydrogeochemistry, groundwater modeling, geology, hyperspectral remote sensing, remote sensing and GIS application in natural resources management, watershed management, and environmental monitoring and assessment of subjects.

Kirubakaran Muniraj is a civil engineer and has completed MTech in remote sensing at Anna University Regional Campus, Tirunelveli, TN, India, and is currently pursuing PhD in the Faculty of Civil Engineering, Anna University, Chennai, TN, India, in the area of microwave remote sensing (InSAR). He has published more than 25 research articles in reputed international journals by Springer, Taylor and Francis, and Elsevier, which include *Environmental Research*, *Marine Pollution Bulletin*, *Environmental Geochemistry and Health*, *International Journal of Environmental Analytical Chemistry*, *Environmental Science and Pollution Research*, and *Human and Ecological Risk Assessment*. Kirubakaran's research broadly focuses on remote sensing and GIS applications for environmental issues, water resource management, air pollution, solid waste management, subsidence monitoring, disaster management, climatic change, and urban planning. He is privileged to act as technical reviewer for journals including *Applied Water sciences* (Springer), the *Asia-Pacific Journal of Regional Science*, *Proceedings of National Academy of Sciences Part A Physical Sciences*, and *Marine Georesources and Geotechnology*. He is a life member of the Indian Society of Remote Sensing, member of the International Society for Research and Development (ISRD), associate member of the Institute of Engineers (India), and life member of the Indian National Cartographic Association.

Anand Balasubramanian, MTech, PhD (KIT-Kalaignar Karunanidhi Institute of Technology, Coimbatore), has completed his BTech in geotechnology and geoinformatics in the Centre for Remote Sensing at Bharathidasan University, Tiruchirappalli, and MTech in remote sensing and GIS at the Regional Centre of Anna University, Tirunelveli, and he also completed his PhD in remote sensing and GIS with the specialization in hydro informatics. Anand has worked in the NRDMS-DST Project as a JRF/SRF for 3 years. He has more than 5 years of research and 1 year of teaching experience. He has expertise in the field of remote sensing, GIS, and hydro informatics with respect to water resources management, natural resources mapping, landslide mapping, and agricultural crop management. He has published more 10 research articles in reputed national and international journals. He is privileged to act as a technical reviewer in journals by Springer and Elsevier. Currently, he has been working in the field of agriculture engineering with respect to remote sensing, GIS, and geoinformatics applications.

Nagavinothini Ravichandran is a postdoctoral researcher in the Department of Ocean Engineering at the University of Naples Federico II, Italy. Her current research interests include computer-aided analysis of structures, earthquake engineering and structural control, floating photovoltaic systems, and machine learning applications in engineering problems. She received her PhD in ocean engineering from the Indian Institute of Technology Madras in 2019. Her thesis is based on the dynamic analysis of offshore structures under environmental and accidental loads. She was a university first-rank holder and gold medalist in her undergraduate and postgraduate studies. She has published in approximately 50 international journals and conferences. In addition, she co-authored a textbook titled *Offshore*

Compliant Platforms: Analysis, Design, and Experimental Studies. Nagavinothini is an associate member of the American Society of Civil Engineers and a life member of the Indian Society for Technical Education. With her immense interest in multidisciplinary research, her recent investigations are focused on parameter estimation using machine learning algorithms, innovative floating structures, and GIS-based potential assessment of photovoltaic systems in India.

Chapter 1
Introduction

Chaitanya B. Pande, Balamurugan Panneerselvam, Kirubakran Muniraj, and Nagavinothini Ravichandran

Abstract Climate change and human health risk is a main important for the human and environment, these are factors continue affecting the groundwater resources, water quality and ecosystem in the semi-arid region. This book deals with the climate change impact on groundwater quality and human health risk assessment due to pollution of surface water and groundwater. This book discusses about the climate change factors that affect the quality of surface water and groundwater in the arid and semi-arid regions. Recent trends in management and pollution mitigation strategies, modelling, groundwater quality, and human health risk assessment in arid and semi-arid regions. Population growth has resulted in an unparalleled demand for freshwater and an increase in human health risks due to water quality parameter changes in the arid and semi-arid regions. Groundwater and human health risk condition is a most serious issues in the entire world, where several million people based on contaminated surface and groundwater resources. Nowadays, every sector depends on surface water and groundwater. They are the most significant sources of water for domestic, industrial, and irrigation purposes; however, these resources are limited. This book is a collection of chapters providing a multidisciplinary overview for academics, administrators, scientists, policy-makers, social science researchers, and professionals involved in the various aspects of climate change impact on groundwater quality, hydrological process, pollution mitigation strategies and techniques, sustainable development, planning, and management. This book is a combination of human health assessment, hydrological process, and

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groundwater quality monitoring techniques such as remote sensing and geographic information system (GIS) techniques, entropy water quality index, weighted arithmetic water quality index, Fuzzy logic application for water quality index and irrigation purposes, saline water, and human health risk assessment planning of groundwater resources in arid and semi-arid regions. The main purpose of this book is to develop truthful outlines for climate change impact on groundwater resources and for human health risk assessment planning and management on the earth's surface. Therefore, this book will help the readers understand climate change impact on groundwater resources and human health risk assessment in arid and semi-arid regions.

Keywords GIS · Groundwater · Human Health · Hydrological Process · Water Quality Index; Semi-arid

1.1 Introduction

Groundwater is water that exists beneath the earth's surface and makes up 30% of the world's freshwater supply. It is an extremely valuable natural resource that plays a critical role in any country's economy. For a long time, people from all over the world have relied on subsurface water to meet a variety of their needs such as drinking and washing (WWAP 2009; Pande et al. 2021a; Pande et al. 2021b; Rajesh et al. 2021). Due to large-scale human activities, changes in lifestyle, and consumerism, poor drinking water quality has become a severe concern in many countries; thus, groundwater quality evaluation is required, particularly for groundwater sustainable management (Todd and Mays 2005; Pande 2020). The varied properties of water, atmospheric precipitation, inland surface water, and subsurface geochemical activities all contribute to groundwater quality (Khadri and Pande 2016a, b). The majority of research works correlated their observed parameter values with the individual suggested parameter values according to the World Health Organization (WHO) guidelines (Cude 2001). Water quality indices (WQIs) are the most often used instruments for assessing groundwater excellence; they summarize a large number of groundwater quality parameters into a single numerical value (Rawat et al. 2019). The need for freshwater in Tamil Nadu's semi-arid districts has risen in recent years (Pande et al. 2017). Furthermore, due to a decline in groundwater and surface water owing to overextraction, as well as a general lack of public awareness of groundwater quality, systematic management strategies cannot be developed. Groundwater quality is influenced by soil permeability features as well as rock–water interaction, lithological background, and water residence time (Balamurugan et al.2020b; Kirubakaran et al. 2016; Balamurugan et al. 2020c). Increased concentrations of nitrate, fluoride, and arsenic in water are currently responsible for 82.5% of waterborne infections in India (Pande et al. 2019).Therefore, the objectives of this book is measured to variations in the concentration of nitrate under climate change and an evaluated the risk of nitrate contamination on human health, climate change impact on groundwater resources, and human health risk assessment by using GIS, remote sensing, and statistical approaches. The findings will aid in the proper planning and management of groundwater resources as well as in the development of novel techniques to prevent continuous water deterioration in semi-arid areas (Panneerselvam et al. 2021a, 2020b, Shanmugapriya et al. 2021).

1.2 Sections of This Book

This book is divided into four sections: (I) hydrological processes in semi-arid regions; (II) hydrochemical properties of surface water and groundwater; (III) human health risk assessment; and (IV) recent trends in the management and pollution mitigation strategies.

1.2.1 Hydrological Processes in Semi-arid Regions

Currently, the two driving forces, namely, climate change and man-made interference are the main reasons for water crisis on Mother Earth. Especially, hydrological activities are more complex in the semi-arid region as well as more sensitive to the effects of human activities and climate change on it. Areas with the most water scarcity are generally defined as arid and semi-arid. Surface water and groundwater regimes in these areas are intense and highly diverse, and they face great pressure to provide and manage freshwater resources. In recent years, water circulation has been severely affected by climate change, industrialization, urbanization, and desertification of usable lands (especially in urban areas). The socioeconomic development of the population demands proper infrastructure development in and around their habitat, resulting in natural water systems being subjected to severe denials (Batabyal & Chakraborty 2015; Balamurugan et al. 2020d; Kirubakaran et al. 2015; Kumar and Balamurugan 2019, 2018; Panneerselvam et al. 2020a). The main purpose of this chapter is to identify the water source in semi-arid areas and to focus on the response mechanisms and geographical modelling of the hydrological activities in those areas. The prime objective of this section is to provide insights into the semi-arid regions' climatic and morphometric conditions through rainfall fluctuation and temperature variation studies, land use/land cover change analysis, morphometric analysis, drought assessment studies, etc. and also to demonstrate the modern remote sensing and GIS-based quantification and modelling approaches, which are used to access hydrological parameters such as rainfall runoff, evapotranspiration, groundwater dynamic modelling, water-level fluctuation study, water balancing, aquifer properties, etc.

1.2.2 Hydrochemical Properties of Surface Water and Groundwater

In this chapter, the primary mechanisms governing the quality of surface water and groundwater in the arid and semi-arid regions are discussed. Over the past five decades, geochemistry has been significantly contributing to the field of hydrogeology, thus helping in the study of the geological, structural, and behavioural properties of minerals and their lithological effects on water quality. Surface and subsurface sources of water are drastically deteriorated due to rapid increase in population, industrialization, and changes in the methods of the modern agricultural system. The change in climatic conditions, inadequate rainfall, and improper maintenance of water sources are the major reasons for reducing the usage of surface water. Increase in population density and modernization are the primary reasons for excess utilization of groundwater than surface water. The main intention of this study is to evaluate the quality of surface water and groundwater for drinking purposes using various indices, namely, the entropy water quality index, weighted arithmetic water quality index, Fuzzy logic application for the water quality index and for irrigation purposes, sodium adsorption ratio, residual sodium carbonate, percentage sodium, permeability index, magnesium hazard index, residual sodium bicarbonate, potential salinity, synthetic harmful coefficient, and the amount of exchangeable sodium percentage. The result of the study clearly describes the present nature of the groundwater and the sources of contamination in the study area.

1.2.3 Human Health Risk Assessment

The Environmental Protection Agency commonly uses risk assessment to evaluate and characterize the nature and degree of health risks to humans and also ecological receptors such as birds, fish, and wildlife in arid and semi-arid regions. Human health risk exposure the injection of toxic materials such as food and drinking water (Pratap et al. 2021). The main objective of this chapter is to define human exposure to a contaminated environment and its severe effects due to continuous consumption. Nowadays, nitrate and fluoride are the major ions that are easily contaminated by natural and anthropogenic activities and also affect human well-being. Continuous consumption of elevated concentrations of nitrate- and fluoride-containing water causes methemoglobinemia, heart problems, and bone and teeth issues in the human body. It also affects the livestock in the same environment. The health risk evaluation has divulged that more information is needed for policy-makers and government and non-governmental agencies to take remedial measures to avoid contamination and to create awareness on the use of fertilizers and pesticides in agricultural fields.

1.2.4 Recent Trends in Management and Pollution Mitigation Strategies

The water resource-related challenges in the present situation have bestowed a greater responsibility and duty on engineers and scientists dealing with the environment to protect, preserve, and enhance our natural resources in order to deliver a sustainable future. In a market economy, a country's economic growth is forced to move towards industrialization, taking into account the country's gross domestic product (GDP), especially as the resources of developing countries are greatly depleted. Therefore, in recent years, more emphasis has been placed on environmental issues, especially in developed countries (Panneerselvam et al. 2021b, c; Ramalingam et al. 2022). However, due to the economic and technological deficits of many developing countries, the impact of surface/subsurface water pollution and the importance of appropriate control measures are faltering. Therefore, this chapter elaborates on the modern trends of water resources engineering to maintain sustainable water consumption of the available precious resources with more economic concern for a clean environment (Balamurugan et al. 2020a; Colins et al. 2016). Through this chapter, the reader can get a clear explanation of how to deal with the integrated method in the monitoring and mitigation activities of key techniques such as promotion of artificial recharge, identification of urban water body encroachments, deployment of sustainable supply and consumption methods, regulations and legalization activities, industrial pollution source control measures and modern Internet-of-Things (IOT)-based monitoring systems.

This book contains 25 chapters. Chapter 1 discusses about the climate change impact on groundwater resources in semi-arid regions. Chapter 2 discusses the factors that influence the hydrological process, with a climate and land use/land cover perspective in the semi-arid and arid regions. Chapter 3 discusses the climatic changes affecting groundwater quality in the semi-arid region of central India with a special reference to the major cities of Madhya Pradesh.. Climate change views rainfall research as more important for semi-arid regions. Chapter 4 is dedicated to the spatiotemporal analysis of rainfall trends in the semi-arid regions of India over the last 36 years. Chapter 5 discusses the assessment of groundwater quality for drinking and irrigation, citing a case study of the Kattar micro-watershed in Tamil Nadu. Chapters 6 and 7 focus on the hydrogeochemistry and the WQI. Chapter 6 investigates the groundwater hydrochemistry of the shallow aquifers of the Cuddalore coast, South India. Chapter 7 describes Human health risk exposure the injection of toxic materials such as food and drinking water quality index (EWQI) in semi-arid regions in India. Chapter 8 describes a study on the seasonal variation of groundwater quality for irrigation purposes in semi-arid regions in Tamil Nadu, India. The geographic information system is an effectively proved instrument to check the water quality and for WQI research. Chapter 9 discusses the evaluation of groundwater quality and its suitability for drinking and cultivation practices in and around the deltaic regions of South India using the drinking water quality index (DWQI), irrigation water quality index (IWQI), and GIS. Chapter 10 discusses the groundwater quality assessment using GIS-based multi-criteria decision analysis for the Pattukkottai Taluk in Tamil Nadu. Chapter 11 focuses on the study of heavy metal contamination at the Durgapur Barrage site, Damodar River. Chapter 12 explains the heavy metal assessment of groundwater on the periphery of a semi-urban solid waste dumpsite and the mitigation strategy used. This is highly essential for understanding the climate change impacts of nitrate contamination on human health, as discussed in Chap. 13. Chapter 14 describes the catastrophic effects of climate change on child health. Chapter 15 focuses on the mitigation measures of fluoride- and nitrate-contaminated regions. The hydrological system and process are important in semi-arid and arid regions, and, based on this view, Chap. 16 discusses hydrological modelling for ungauged basins, providing an overview of the past, present, and future directions. Chapter 17 focuses on appraising the groundwater potential of the Liddar sub-basin (western Himalayas) using geospatial techniques. Groundwater resources are the key factors in semi-arid and arid regions. In this context, Chap. 18 describes the groundwater potential zone (GPZs) delineation in the Dhamani River basin in Kolhapur district, Maharashtra, India, using remote sensing (RS), geographical information system (GIS), and multi-criteria decision analysis (MCDA) techniques (Chap. 19). Chapter 20 discusses the assessment of groundwater potential zone mapping for development of semi-arid regions through analytical hierarchy process (AHP) and GIS techniques. Chapter 21 describes a study of the assessment of groundwater potential zones in Adigrat town and its surrounding areas using geospatial technology. Rainfall trend analysis is important for arid regions. Chapter 22 describes a study on the computation of rainfall infiltrates into the coastal soil of Andhra Pradesh, India. Chapters 23 and 24 focus on rainwater harvesting activities and rainwater conservation in semi-arid and arid areas. In this view, Chaps. 23 and 24 focus on the feasibility assessment of low-cost filters to be adopted in rooftop rainwater harvesting (RWH) prioritization of sub-watersheds through morphometric analysis of the Amaravathi watershed using geoinformatic techniques. Overall, all these chapters give comprehensive ideas about the importance of climate change impact on groundwater resources for human health risk assessment in arid and semi-arid regions.

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Chapter 2
Climate Change Impact on Groundwater Resources in Semi-arid Regions

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Abstract Groundwater is one of the significant freshwater resources and provides essential freshwater supply, chiefly in dry regions where surface water availability is limited. However, groundwater-related problems are among today's most acute and complex technical problems. The climate change outcomes connected to water resources are an increase in temperature, variation in precipitation patterns, snow cover, and a probable increase in the frequency of flooding and droughts. Due to this, climate change intensifies the global hydrological cycle and affects the quality and quantity of groundwater resources. Climate changes also disturb the hydrological cycle, directly increasing the evaporation level of accessible superficial water and vegetation transpiration and affecting the amounts of soil infiltration and deeper percolation. Subsequently, these variations can directly affect evaporative demand over land, rainfall rate, timings, and concentration rates and indirectly affect the flux and storage of water in surface (i.e. lakes, rivers, seas) and subsurface (i.e. groundwater storage (GWS)) reservoirs. In addition, there are other related factors such as groundwater contamination, seawater intrusion, and water scarcity. Climate changes affect surface water resources through climate variants such as air temperature, rainfall, and vegetation transpiration variations, and these variations also affect groundwater storage. Larger rainfall variations directly affect surface water levels and seawater intrusion and result in a drop in water storage. These variations directly affect groundwater storage depending on the percolation rate, volume, and distribution of groundwater recharge. We need to find out the solution on the impact of

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climate change and groundwater resources and exact estimation of groundwater recharge in the semi-arid region. For understanding climate variations, several global climate models (GCMs) are available. GCMs help detect quantification of groundwater recharge and provide a suitable adaption scheme to protect groundwater storage from climate change. This study shows the impact of climate change on groundwater resources and the methodology used to measure this impact.

Keywords Groundwater · Climate · Groundwater recharge · Hydrological cycle

2.1 Introduction

Water is the most useful and renewable resource for people. Without water, no life can exist, as water is a life-characteristic of air. Two-thirds of the human body are estimated to be made up of water (Priyan 2021). Water is essential not only for the survival of human but also for the survival of animals, plants, and all other ecosystems. Sustainable quality and quantities are threatened by different factors such as agriculture production and polluted water etc. As a result of climate change, there are uncertainties about water supply and management (Lal and Datta 2021; Balamurugan and Balakumaran 2015; Balamurugan and Kumar 2016). Climate change directly affects surface water resources through changes in major long-term climate variables such as precipitation, evapotranspiration, and temperature of the atmosphere. There are more complicated and misunderstood relations between groundwater resources and climate change. Kumar (2016) have said that if greater precipitation change can lead to higher or lower groundwater levels. Furthermore, because it increases sea level and reduces resources on the earth surface. The atmosphere varies by way of soil moisture, percolation, and groundwater systems. Hydrological cycling can influence the amount of soil infiltration, thus resulting in deeper percolation and in the recharge of groundwater (Wu et al. 2020; Kumar and Balamurugan 2018; Panneerselvam et al. 2021b). Effects on precipitation, such as increased precipitation variability and weather, can also lead to prolonged drought and flooding periods that openly affect groundwater availability and dependency (Rane and Jayaraj 2021). According to the International Groundwater Resources Assessment Centre (IGRAC), climate change is becoming a greater concern, and, although this issue is rightly receiving a lot of attention, its impact on groundwater is still underappreciated (Pande et al. 2022). The IGRAC estimates that climate changes also affect groundwater quality, for example, a rise in sea levels may lead to saltwater intrusion into coastal aquifers, affecting groundwater quality (Gaur et al. 2021; Sharief and Zakwan 2021). In order to accurately anticipate future supplies, the groundwater resource management team will increasingly need to factor in the effects of global climate change. Several studies have found that groundwater streamflow is sensitive to climate change in watersheds all around the world (Fathi et al. 2021; Kumar and Balamurugan 2019; Muniraj et al. 2021).

2.2 Background of Research

The findings suggest that a smaller percentage of winter rainfall will fall as snow as the temperature rises. As a result, the spring snowmelt peak is lowered, whereas the winter overflow threat is almost certain to increase. In summer, significant quarterly soils and stream fluxes are reduced by up to 50%, mainly due to water quality, groundwater withdrawals, and hydropower generation problems (Eckhardt and Ulbrich 2003).

An integrated hydrological model was developed in Belgium, aiming to study the influence of climate change on the hydrological cycle of representative basins and to mainly examine groundwater flows modelled using a spatially dispersed system (Bohidar and Ahmad 2021; Balamurugan et al. 2020a; Panneerselvam et al. 2020a). Results on the progress of groundwater and groundwater reserves in relation to climate change were discussed. Using this model, investigate how the levels and resources of groundwater about climatic differences are being reduced. The Geer Basin aquifer has been verified situations and display no effects of seasonal variations on the groundwater levels (Brouyère et al. 2003).

Use for the effect of climate change impact on the streamflow of the upper Mississippi river basin of RCM (regional climate), and Hydrology Model and SWAT (solar and water model). Model could give information about the climate change effects. This survey showed that the repeated fluid variation significantly exceeded the joint modelling system's bias with an 18% bias. Our results also show that the relationship between annual flux and annual precipitation may lead to a change in future climatic conditions, as every per-unit rainfall increase will lead to more significant stream fluctuations (Jha et al. 2004; Balamurugan et al. 2020c; Panneerselvam et al. 2021a). In a case report in East Anglia, Great Britain, researchers explained the direct and indirect impacts of groundwater recharges on climate and socioeconomic change. Many factors will disturb the recovery of groundwater, such as the changing rules of precipitation and temperature, coastal flooding, urbanization and sealing, forest creation, cropping and change in rotation, etc (Shahid et al. 2021). Usually, the direct impacts of climate situations are more important locally than socioeconomic ones. But, despite the several worries have involved in the usage of circumstances, and an exclusively attend to the direct impacts of climate change like those arising from temperature and rainfall variations are negligence the theoretically significant part of social ethics and economic procedures in determining the overhead landscape aquifers (Holman 2006).

The research outcomes specify that the total amount of groundwater recharge is predicted to grow due to climate change. A higher concentration and rainfall rate will also contribute significantly to surface runoff, even though global warming may result in improved evapotranspiration rates. Warmer winter temperatures will decrease the level of ground frost and alter the spring melt from spring towards winter, permitting extra water to penetrate the ground. Although numerous earlier climate change impact investigations have been attentive to the time-based variations in groundwater recharge, outcomes of other studies have recommended that the effects have high spatial changeability (Jyrkama and Sykes 2007; Balamurugan et al. 2020b; Panneerselvam et al. 2020).

Scientists have stated that it is essential to try and identify the problem with persistent research, based on a good set of quality meteorological and hydrological information, which is currently far from satisfactory, to overcome the current and future water and ecological problems. It is crucial that ecosystems such as those that defend recharging areas, wetlands, and mountain forests are secured and reinstated. The gap between the water supply and demand must be reduced, through more energy-efficient irrigation systems, farmers' training, wastewater recycling, public consciousness, and groundwater preservation. More effective irrigation systems, farmers' training, wastewater recycling, water conservation through public awareness, and groundwater regulation are all needed to close the gap between supply and demand for better groundwater management (Dragoni and Sukhija 2008).

The effects of climate change on groundwater recharge as well as baseflow were investigated in the upper catchment area of Ssezibwa in Uganda. For this study, ancient data, which certainly exposed indications of climate change based on fluctuations detected in temperature and discharge rate, were first studied. For this investigation, the Statistical DownScaling Model (SDSM) was used to infer upcoming climate change situations, which were obtained from the UK HadCM3 climate model. The equivalent increase in temperature ranged between 1 and 4 °C, and these temperature changes were expected to strengthen the hydrological cycle. Between the 2020s and 2080s, the existing mean annual daily baseflow of 157 mm/year (69% of discharge) is predicted to increase by 20–80%. From the present 245 mm/year, the comparable increase in recharge ranges from 20% to 100%. The findings lay the groundwork for further research into climate data downscaling and sensitivity analysis for virtual hydrological fluctuations in the catchment area (Nyenje and Batelaan 2009).

An approach for estimating the average changes in groundwater recharge under future climates is described. This approach is used in Australia's Murray–Darling Basin (MDB), which covers 1,060,000 km^2. Climate sequences were created using the outputs of 15 global climate models and 3 scenarios for a 2030 climate compared to a 1990 climate. Owing to the discrepancies between the climate sequences provided by the 15 various global climate models, predicting the direction, much alone the extent, of the shift in recharge for a 2030 climate is problematic (Crosbie et al. 2010; Balamurugan et al. 2020; Panneerselvam et al. 2021).

The results show that recharging is precisely proportional to rainfall in the examined area, even when substantial soil moisture shortages are projected. This means that the water recharging behaviour is controlled by privileged and/or localized flow processes (Abraham and Priyadarshini 2021). In this area underlain by lateritic soils, soil moisture balance and source-responsive models (SMBMs) and unsaturated flow models based on uniform flow guided by the Richards equation are found to be ineffective in estimating recharge. Concerns have been expressed about the use of such models for recharging estimation, and hence for examining future patterns owing to climate or land use change, unless they are backed up by enough hydraulic data to confirm the recharge processes (Cuthbert and Tindimugaya 2010).

Understanding how climate change could influence groundwater systems is an essential component of sound long-term management of our water supplies. On the other hand, calculating how climate change could impact groundwater systems is complicated and forecasting upcoming groundwater situations would still be more complicated because of the multifaceted combinations of processes that have an effect on groundwater recharge, discharge, and quality. Enhanced interpretation, improved understanding of processes, and superior modelling capabilities will be needed to calculate and forecast the upcoming situations of this essential resource in the face of projected climate changes (Earman and Dettinger 2011).

Despite the fact that projections in place and time are burdened by means of doubt, researchers have discovered that the future intensity and frequency of dry periods combined with warming trends must be addressed in the status of groundwater supplies. Finally, the possible effects of groundwater on the global climate system are mostly unknown. All circumstances, changes to global change must include a smart organisation of groundwater as a renewable energy development. Since groundwater storage is already overtapped in many areas, previously untapped subterranean storage could be an option for satisfying the collective demands of agriculture, industry, municipal and domestic water supplies, and ecosystems during times of scarcity (Green et al. 2011; Orimoloye et al. 2022; Pande et al. 2018; Pande et al. 2021; Rajesh et al. 2021).

Frequently, rainfall is downscaled in climate change impact studies; on the other hand, the dependability of the downscaled outcome is frequently poor or variable, as there is a repeatedly small connection among the predictors. A reduced connection has been frequently observed in mesoscale processes occurring at a site scale, which are not represented in provincial models due to their representative spatial and temporal sizes in comparison to large-scale local rainfall. Mesoscale rainfall processes usually occur in the summer period from a variety of convective clouds, which are an outcome of local-scale evapotranspiration from elevated temperatures and solar radiation magnitudes. As an outcome, global-scale models may underestimate the summer precipitation measured at a site (Kumar 2012).

Scientists have stated that the meteoric rise of the nuclear underwater economy demands the development of a groundwater management scheme with convenient supply and demand strategies through brave new ideas and resource allocation policies. In the twenty-first century, the influence of climate change significantly exceeding India's management of hydroclimates is accepted. For instance, the Himalayan snowmelt has heavily loaded the Indo-Gangetic aquifer system. Aquifers react little by little to droughts and climatic variations than surface storage (Shah 2013).

In Eastern Canada, the likely impacts of future climate change on soil water recharge were investigated on a local scale for a watershed of 546 km. Infiltration model recharge was assessed by the Hydrological Depositional Performance Assessment (HELP). The results indicate that higher temperatures do not compensate for the huge increase in winter infiltration, resulting in increased evapotranspiration. Clear changes have been made to the different climate change situations with regard to specific water budget mechanisms (Rivard et al. 2014).

Climate changes have led to disadvantageous phenomena such as high precipitation, which could worsen soil erosion. Therefore, effective and qualitative monitoring of water resources to evaluate groundwater recharges, groundwater flows, and soil erosion is required. The study resulted in a 50% improvement in the usual soil recharge, 42% in baseflow, and a corresponding reduction of 72% in sediments. The recommended procedure thus contributes positively to the hydro-ecosystem and the reduction of muddy water in a steep, sloping water border (Min et al. 2014).

A study evaluated the impact of future climactic variations and sea-level increase on groundwater recharge and groundwater in the low and shallow waters of Hanko on the south coast of Finland and used groundwater flow modelling as an instrument of evaluation. There were strong correlations between groundwater recovery and sea levels with simulated surface leakage. The increase in sea levels will increase groundwater levels in future climates and lead to more surface leakage in low-lying areas, thus increasing the risk of winter and early spring surface floods (Luoma and Okkonen 2014).

The impact of climate change causes doubts about water supply and management. Although the impact of climate on the resources of surface water is directed at the most important long-term climatic variables, such as air temperature, precipitation, and evapotranspiration, it is more difficult and unsuccessful to connect the changing climatic variables to groundwater. Two more frequent periods of high or low groundwater can be caused by higher rainfalls, and saline intrusion into coastal waterfowl can increase and decrease in reserve (Kumar 2016).

For investigating climate change effects on recharges, model studies are helpful. Special effects on recharge for some aquifers have been projected and used for climate change. Predicted temperature and precipitation changes have been reasonably distributed side by side in each charging mechanism, producing approximate, qualitative calculations (not magnitude). Several solution patterns are derived from the research, for example, the standard 10–20% decreases in total refuelling of the southern aquifers are indicated by the available estimated figures but without a vast number of doubts. Second, small alterations are likely to be achieved in the northern aquifers including small increases in total charging. Reasons that contribute to major doubts in the approximation include the following:

1. Limited studies quantitatively coupling climate projections with recharge estimation methods using detailed, process-based numerical models
2. A generally poor understanding of the hydrological flow paths and processes in mountain systems
3. Difficulty in predicting the response of focused recharge to potential changes in the frequency and intensity of extreme precipitation events
4. Unconstrained feedbacks between climate, irrigation practices, and recharge in highly developed aquifer systems (Meixner et al. 2016).

Consequently, it is important to add to this selected standardization plan, where likely, that normal standardization information should include climatic excesses in the directive in order to minimize the standardization model bias. The results strongly recommend that climate forecast bands be fixed with hydrogeological models in order to provide reliable calculations and associated doubts (Moeck et al. 2016).

In the West of Iran, Global Climate Models (GCM) and Hadley Centre is predicting the impact of climate change for soil charging in a dry environment (HADCM3). The study has been shown to assess the impact of climate change in an arid environment on natural recharge. For the aquifer examined, the recharge is reduced by the average of long-term precipitation in comparison with the recharge calculated. Based on the results, a GCM, HADCM3, was carefully selected as the best model to forecast the parameters of the weather conditions in the province of Ilam, west of Iran. The results of HADCM3 have shown that the mean annual precipitation in the study is about 3% lower, whereas the mean annual temperature is around 0.5 °C higher (Ghazavi and Ebrahimi 2018).

The effect of temperature variations on soil storage (GWS) could distress freshwater resources' sustainability. At the time, a fully interconnected climate model was used to study the variation in groundwater storage, and seven dangerous aquifers were found to be suggestively distracted by remote sensing observations. Researchers have assessed the potential impacts on GWS differences in a business-as-usual situation through the twenty-first century (RCP8.5). As a substitute, the trend may result from improved evapotranspiration and decay in snowmelt that together lead to a variety of GWS diagonal fluctuation reactions. The results show that the impacts of GWS on changes due to climate do not necessarily reflect the long-term trend of rains. Finally, the researchers compared the impacts of anthropogenic and climate-driven pumping. The decrease in GWS is mainly due to the mutual impacts of overpumping and climate effects; however, pumping contributions can simply go far beyond natural substitution (Wen-Ying Wu et al. 2020).

Researchers have presented a hypothesis that the quantitative recharging of groundwater and associated water temperature imprinting is primarily determined by infiltrating river-fed aquifers. Investigators showed that regular changes in the methods of groundwater charging could be a significant element of distressing future groundwater temperatures. Moreover, high runoff times are expected to powerfully influence groundwater temperatures through the connections of surface water and the recharging of groundwater. Thus, a shift of precipitation and flood actions from the summer to the winter months could be accompanied by a rise in groundwater recharge during relative winter season for the "business-as-usual" climate change scenario and by a tendency for "cooling down" groundwater resources during the winter season (Epting et al. 2021).

2.3 Impact of Climate Change on Groundwater Resources

Much of the impact of climate change on precipitation and surface water and ultimately on groundwater systems, as the area of groundwater saturation, is mostly charged by precipitation and surface water bodies (lakes, rivers). In addition, the impact on surface water quality and quantity is affected by climate change. Water managers have a major concern about surface water, and management is likely to either reduce or increase the value of groundwater. Groundwater is the main source of drinking water for human consumption and for agriculture. The potential impacts of climate change on groundwater systems are important to consider as part of the hydrological cycle, and groundwater systems are expected to be affected by recharging changes, including changes in precipitation and evapotranspiration and potential environmental changes of connections between groundwater and groundwater systems.

The hydrological cycle represents a continuous and repetitive water process from the earth's surface to the atmosphere and vice versa under the influence of solar heat. The circulation of water from the hydrosphere to the atmosphere and then to the lithosphere is mainly caused by solar heat. So, the impact of climate influence on the hydrological cycle also affects precipitation, soil moisture, evaporation, transpiration, runoff, groundwater recharge, and groundwater movement. Climate change affects evaporation and transpiration; however, warming global temperature increases the rate of evaporation and is causing more precipitation. Higher evaporation and precipitation rates are not uniformly circulated around the world. Some areas may experience heavier-than-normal precipitation, whereas some areas may undergo droughts due to the traditional locations of rain belts and desert shifts in response to a climate change (Fig. 2.1). Soil moisture is stored in the soil and affects precipitation, climatic conditions, solid properties, etc. Soil moisture is good for crop cultivation and farming. The content and output from these models are directly simulated by global climate models to indicate possible changes. However, the impact of climate change on soil moisture will vary not just from climate change to soil capability, soil quality, etc. The soil's water capability will affect possible soil humidity shifts. The lower the capacity, the greater is the climate change and its impact on groundwater resources. Climate change may also affect soil characteristics, perhaps through changes in water logging or cracking, which may affect soil moisture storage properties.

Climate change also affects aquifers, which are usually refilled by efficient rainfall and surface water bodies (Vidya et al. 2021). This water may percolate and reach the aquifer rapidly, through macropores, fissures, cracks, etc. and more gradually by infiltrating through soils and permeable rocks overlying the aquifer (Fig. 2.2). Climate change affects rainfall and will also affect groundwater recharge but so will alteration in the recharge period (Zakwan 2021). Increased rainfall is generally likely to result in increased groundwater recharge. Various types of aquifers include reclaims, such as unrestricted water, which is recharged from lakes, rivers, and plumes over distances ranging from a few kilometres up to thousands of kilometres using local rainfall and surface water bodies.

On the other hand, a confined aquifer features an impermeable overlying bed, and local rainfall has no impact on the aquifer. Charging rate is influenced by the overlying strata's hydrological features. "Rapid" charging can, in principle, occur whenever it rains, so if this process is dominated by charging, then it is more affected by rainfall changes than by soil variability seasonal cycles (Fig. 2.3). Therefore, changes in recharging are determined by changes in local flow times and the