An Overview: Water Resource Management Aspects in India

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Abstract The present chapter gives an overall understanding of water resource development and management aspects in India after a thorough review of several government publications, research papers, scientific studies, popular articles, and media reports. Water resources management has long been a major concern in India, owing to rising water demand as a result of population growth, agricultural development, industrial growth, worsening water quality, and expansion in other sectors. India has achieved remarkable growth in the water and agriculture sector in the post-independence period however the per capita water availability has been reducing constantly due to increasing demands. Despite having enormous water resources, there has always been a shortage of safe and quality water as per the specified standards for domestic and irrigation supply. Around 70% of India's population lives in rural areas, where agriculture, the most water-demanding sector, is the major source of income. Water demand has increased in both urban and rural areas as a result of the rising population and changing lifestyles. This demands the development of sustainable water resources in the country in order to bridge the rising demand-supply gap and provide enough water supply for domestic, agricultural, industrial, hydropower, and other uses. In India, the southwest monsoon contributes

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the majority of the country's rainfall, supplying massive amounts of water to rivers, lakes, reservoirs, and groundwater. However, the country's significant spatial and temporal variation of rainfall are the primary causes of water scarcity due to recurrent droughts.

Although India has a huge network of rivers for the development of surface water resources, the most desired source of water is groundwater. In India, there are still certain regions where surface and groundwater resources may be developed further. Extreme events like floods and droughts are posing threat mainly to water, agriculture, livelihood, economy, and other sectors. More than half of the geographical area can be considered as drought-prone contrarily major part of the country is flood-prone affecting 33 million population. The extent and risk of these extreme events may increase further due to climate change. To address these floods and droughts under climate change scenarios, it is critical to analyze droughts, devise mitigation plans, flood management, policy development, a systematic scientific methodology, and a sustainable water resource development strategy. Water quality is one of the concerns that threaten freshwater availability and poses major health risks owing to surface and groundwater contamination which has to be addressed immediately across the country. Because India is an agricultural-based country with agriculture as the primary profession of the people, the country must prepare to ensure that water is accessible for irrigation to improve food production and satisfy rising food demand. In the 1970s and 1980s, the Green Revolution resulted in remarkable improvements in agricultural and food grain production, which may further be sustained with systematic and scientific techniques for water resource development and management in the country.

Keywords Water resources management · Water availability · Droughts · Floods · Climate change

1 Introduction

Water is one of the most vital and valuable elements on the earth. It is necessary for the survival of human civilization, living creatures, and the natural environment. Water resource development and management are critical to satisfy rising household, agricultural, industrial, and hydroelectric needs. Water resources are equally useful for transportation, recreation, animal husbandry, and commercial uses. Due to its numerous advantages and the difficulties caused by its excesses, shortages, and deterioration in quality, water as a resource needs special attention. Total water availability on a worldwide basis is around 1600 million cubic kilometers. Although there is a vast amount of water available on the planet, 97.5 percent of seawater is saline, which contributes nothing to human usage. Only approximately 0.26 percent of the remaining 2.5 percent fresh water is available in rivers, lakes, and ponds, the majority of which is deep and in a frozen state in Antarctica and Greenland. The present article is an attempt to discuss and elaborate on different aspects of water availability and water resources management in India. It covers land and water resources, current and future water needs, precipitation, river systems, and water availability in terms of surface and groundwater resources. The chapter also covers droughts, floods, climate change, India's action to mitigate climate change, water quality, agriculture, and irrigation development in India. With a total size of 3.28 lakh km^2, India is the world's seventh biggest country. India's water resources have immense potential; the country's total utilizable water supply is estimated to be 1123 billion cubic meters (BCM). The per capita water availability at a national level was 5178 m^3 in 1951 and decreased to an estimated 1820 m^3 in 2001. Given the current pace of population growth, per capita water availability is expected to fall below 1000 m^3 by 2025, potentially indicating a water shortage situation [1]. The monsoon season rainfall pattern in India is highly variable, with 55 percent of precipitation falling on an average in only 15 rainy days and nearly 90% of river flows during just four monsoon months. To cope up with the situation, India has generated a storage capacity of 212.78 BCM through major, medium, and minor irrigation projects [2]. The country's irrigation potential has been assessed to be about 139.9 Mha without inter-basin water sharing, and 175 Mha with inter-basin water sharing [3]. The Central Ground Water Board (CGWB) estimates that taking up rainwater harvesting and artificial recharging of groundwater across the 45 Mha area through excess monsoon runoff may enhance groundwater availability in the country by around 36 BCM. The Indian land and water resources [4] are summarized in Fig. 1.

India has an average annual precipitation of 1170 mm, which equates to roughly 4000 km^3 of water and can provide about per capita 1720 m^3 of freshwater each year. Around 80% area falling in the semi-arid and sub-humid region in the eastern portion of the country receives 750 mm or more of annual rainfall. This rainfall, on the other hand, has an unequal distribution and a lot of variation in space and time. The monsoon seasons rainfall (June to September) account for the majority of India's rainfall, with the north-eastern and northern region receiving considerably more rainfall than the southern and western region. Besides the rainfall, the melting of snow in the Himalayas throughout the winter season feeds the northern rivers to various degrees results in flooding in certain months. The southern rivers, on the other hand, have higher flow fluctuation throughout the year [5]. Despite its large network of the river system, India has a lack of safe, clean potable water and also irrigation water supplies for sustainable agriculture. It has tapped only a tiny portion of its surface water resource which are accessible and recoverable. In 2010, India harnessed 761 km^3 of water, accounting for 20 percent of its total water resources, some of which come from groundwater which is not sustainable [6]. Figure 2 shows the availability of water resources in India [7].

The water sector in India faces numerous challenges, including combating the growing gap between demand and supply, providing adequate water for food production, matching with competing demands, meeting the growing demands of big cities, wastewater treatment, inter-basin transfer, water sharing with neighbouring countries and inter-state disputes, and so on [8]. Figure 3 shows the future water demands of major sectors such as irrigation, drinking water, industry, energy and other purposes in India, as anticipated by the Ministry of Water

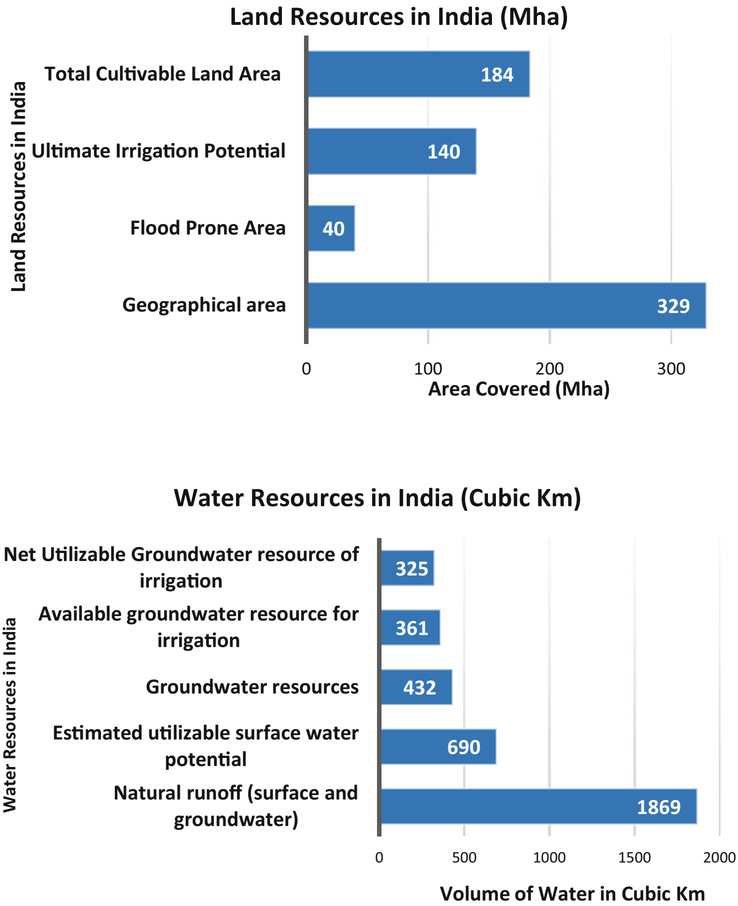


Fig. 1 Land and Water Resources in India

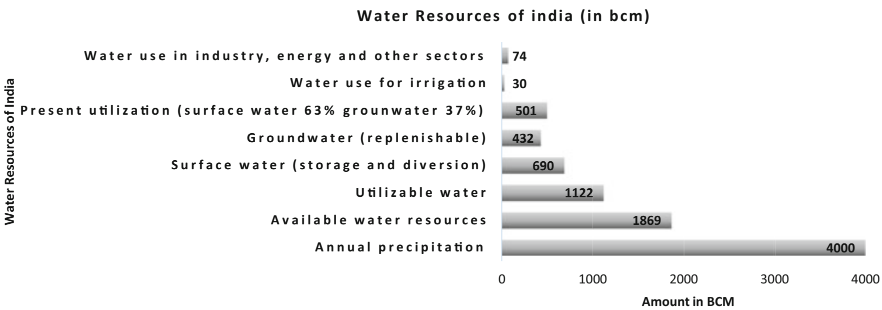


Fig. 2 Water Resources status in India

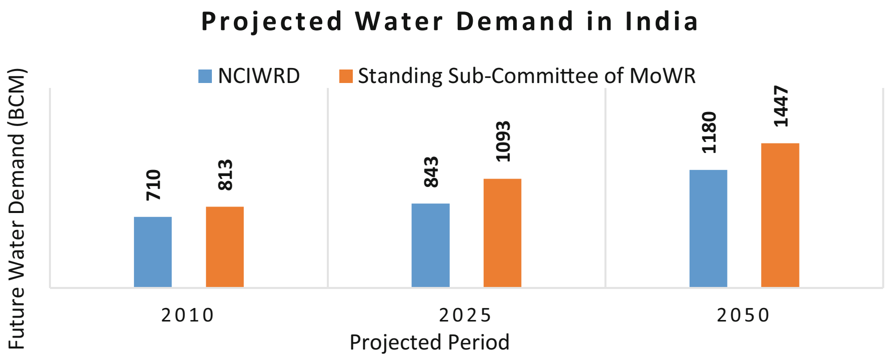


Fig. 3 Water Demand (in BCM) for various Sectors

Resources (MoWR) and the National Commission on Integrated Water Resources Development (NCIWRD) [9].

The NCIWRD and the Ministry of Water Resources have calculated India's future anticipated water consumption with a minimal difference, indicating a large imbalance between supply and demand by 2050. According to the NCIWRD and the Ministry of Water Resources, India's total water consumption would rise to 843 and 1093 BCM by 2025, and 1180 and 1447 BCM by 2050 respectively. As a result, finding new resources, managing existing supplies, and finding innovative ways to meet future water demand will be important concerns.

2 Precipitation in India

India has typical monsoon climatic conditions. Complete reversal of surface winds between January to July, resulting in two types of monsoon systems in India. During the winter, cold and dry air from northern latitudes flows in the southwest direction, creating the northeast monsoon, whereas, during summer, the warm and humid air rises from the sea and flows typically in the opposite direction, causing the southwest monsoon, which accounts for 75 to 90% of yearly rainfall. The southwest monsoon covers a major portion of India from June to September. However, the northeast monsoon influences much of the rainfall in the southern region of the east coast, such as Tamil Nadu and surrounding districts, during October and November [10]. Different climatic regions in India are shown in Fig. 4.

The country's average annual rainfall is about 1170 mm, however, there is a lot of temporal and geographical variance. Rajasthan's northwest desert receives less than 150 millimeters of rain each year on average. The average annual rainfall across the wide region from Central India to the peninsular region is typically less than 600 mm. The Khasi hills in the northeastern area, on the other hand, get more than 10,000 mm of rainfall in a short duration. The average annual rainfall in the west

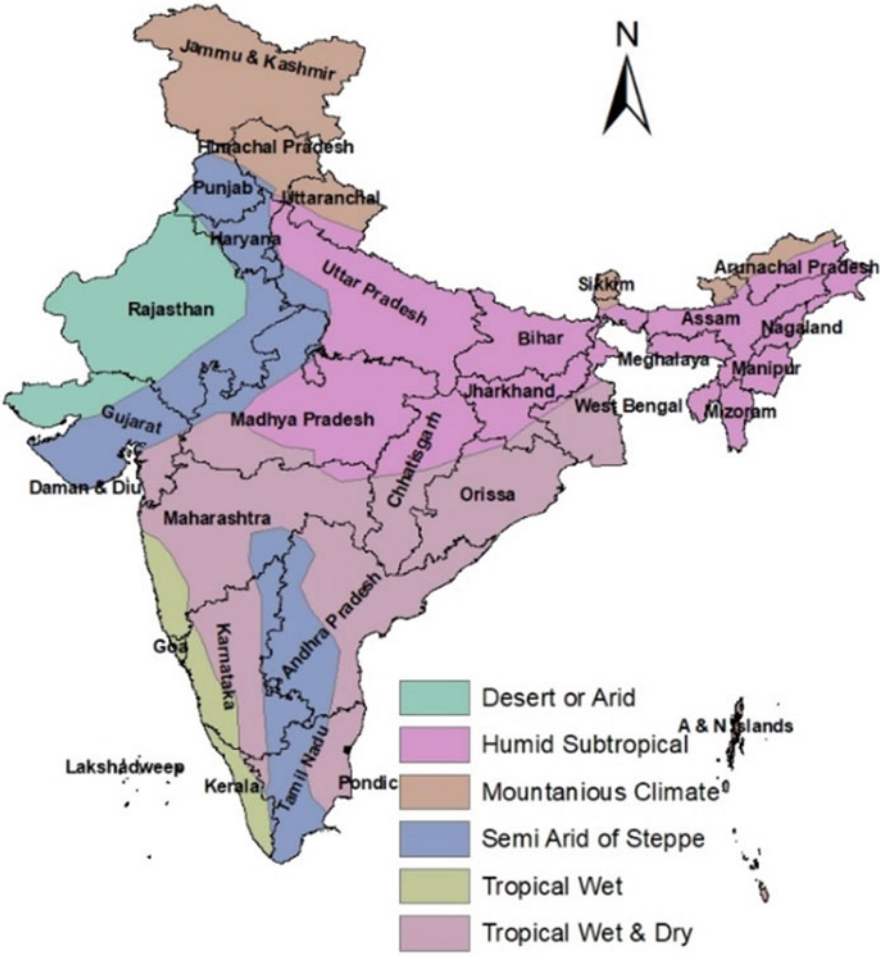


Fig. 4 Different climatic regions in India

coast states of Assam, Meghalaya, Arunachal Pradesh, and sub-Himalayan West Bengal is around 2500 mm.

Despite the fact that the seasonal monsoon dominates the Indian climate, regional variances in microclimate are attributable to different terrain and the impact of the oceans. Because of the Himalayas and the Indian Ocean, the nation has both a tropical and a continental climate. Temperatures in India range from sub-zero at high altitudes in the winter to 48 °C in the summer. The typical maximum temperature in northern India during the coldest months is 21 °C, whereas it ranges from 38 to 43 °C during the summer. The extreme southern part of the nation has less temperature fluctuation than the rest of the country. The Indian Meteorological Department (IMD) categorized four typical climatological seasons: October to February—winter season, April to June—summer or pre-monsoon, July to September—rainy or monsoon season from, October to November—post-monsoon or autumn season, all are based on average weather conditions.

3 River Systems in India

India has a 2.89 million km^2 network of river basin systems, with an average annual water flow output of 1900 BCM. According to the magnitude of their catchments, India's river system may be divided into four categories: major, medium, minor, and desert rivers [11]. All of India's major rivers originate in the Aravalli, Himalayas, Sahyadri, Vindhyan, and Satpura ranges. River systems in India can also be classified by their names, such as the Aravalli range river system, the Ganges, Brahmaputra, Indus river system, and rivers in Peninsular India. The majority of India's major rivers flow east, but the Narmada is the country's largest west-flowing river. Figure 5 depicts India's major river basins.

The Ganga, Yamuna, Brahmaputra, Godavari, Krishna, Kaveri, Narmada, Chambal, and other important rivers are among the major river system. There are around 44 medium river systems, with catchment sizes ranging from 2000 to 20,000 km^2 and a total area of 0.24 million km^2 within basins. These rivers have an annual average flow of 112 BCM, which irrigates just 0.08 million km^2 of cultivated land. Minor river basins, with a drainage area of smaller than 2000 km^2, are comes in the third category. These are mostly small streams that run into the sea from the eastern and western ghats. The catchment area of these rivers is 0.2 million km^2. These rivers are known for their ephemeral flow, steep slopes, and thick silt, which cause devastation from severe floods frequently. These rivers, on the other hand, are critical for coastal irrigation, notably in Kerala and Tamil Nadu. The overall estimated flow of minor rivers is 120 BCM, with the majority of the water going down small rivers that travel towards the west [11]. The fourth category includes rivers that flow for a short distance before disappearing in Rajasthan's desert. Their waters are utilized for irrigation, however, due to the erratic rainfall pattern, their flows are unpredictable in magnitude and timing. Desert rivers have a total basin area of roughly 1 lakh km^2 and an annual average flow of 10 BCM. Thus, in India, all river systems provide 1645 BCM of yearly water volume, with major rivers accounting for 85% of this, while medium and small rivers, as well as desert rivers, contribute 7% and 8%, respectively. The small rivers carry more water than the medium rivers [11].

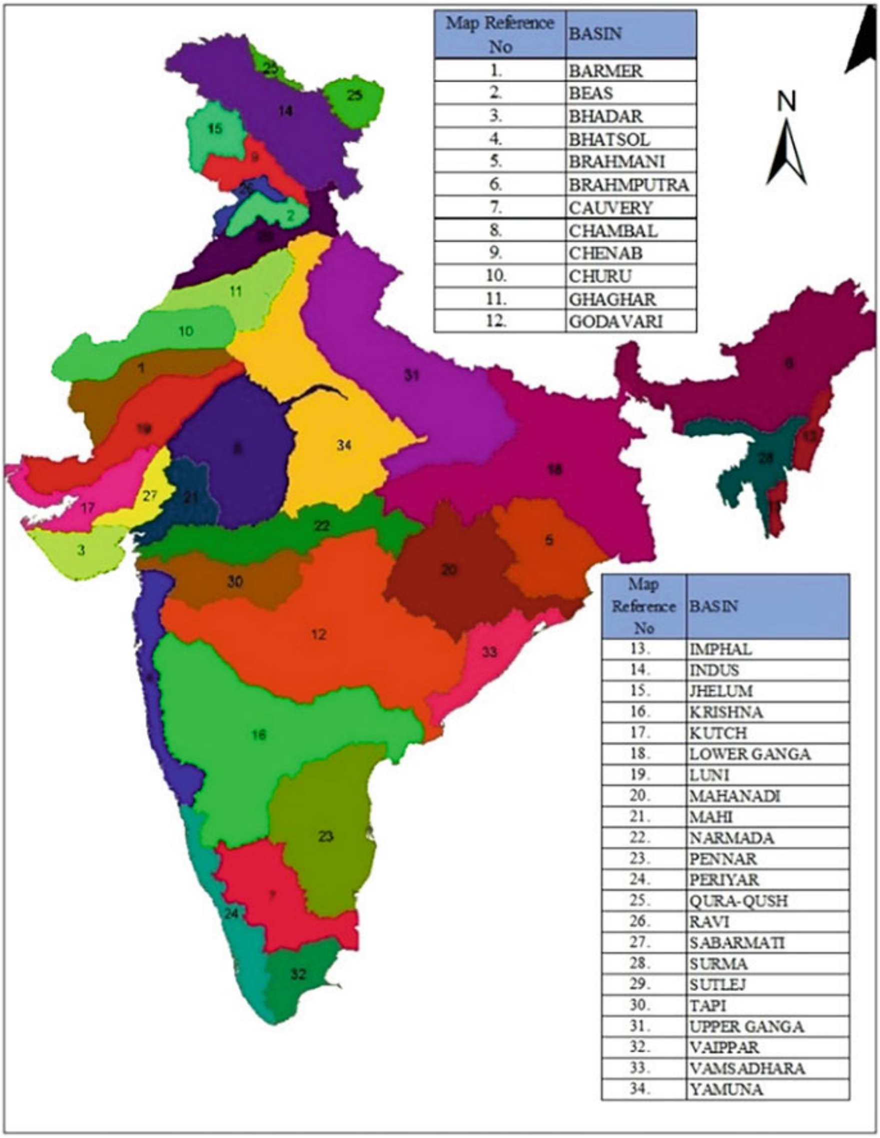


Fig. 5 Major river systems in India

4 Water Availability in India

In India, water availability is very uneven; almost 80% of the annual rainfall occurs in only four monsoon months from June to September. The Brahmaputra, Barak, and Ganga river basins contribute approximately 60% of total surface water resources.

On the other hand, water availability in the western and southern areas is limited. Years after years, this has resulted in the drought—flood—drought syndrome. As a result, the most difficult task is to prepare the plan, develop and manage water resources in order to increase water availability. India obtains 4000 BCM of total water from precipitation, leaving 1869 BCM of water accessible. Out of which there are 609 billion cubic meters of available surface water and 433 billion cubic meters of available groundwater. India covers 3.29 million square kilometers, or 2.4 percent of the world's land area, and is home to over 15 percent of the world's population. India sustains roughly one-sixth of the world's population, with one-fifth of the world's area and one-fifth of the world's water resources. India also has a 500 million-strong cattle population, which accounts for around 20% of the global livestock population. The country's total exploitable and utilizable water resources are estimated to be 1086 BCM [12]. Water resources are classed mostly depending on their available location, such as surface and groundwater resources, which are discussed further below.

4.1 Surface Water Resources

Several attempts have been made in the past to estimate water availability in India. Many researchers and government institutions worked in this area in order to get a true picture of the country's water resources. The average annual flow in Indian river systems was estimated to be 1953 km^3 by the National Commission for Integrated Water Resources Development. The utilizable water resource is the amount of water that can be taken away from its natural source. This utilization may be limited by physiographic circumstances and the socio-political context, as well as legal and constitutional limits and current development technology. It can be observed that there is still scope for improving further the water resource utilization from India's numerous river systems.

4.2 Groundwater Resources

The near-universal availability, low capital cost, and more reliability make groundwater one of the most desired natural sources in different water user sectors in India. Because of the country's growing reliance on groundwater as a desired source of water, indiscriminate extraction has occurred in many regions of the country, with little consideration for aquifer recharge capabilities or other environmental concerns. On the other hand, despite the availability of sufficient resources, still there are regions of the country where groundwater development is not optimal, including canal command areas that are experiencing waterlogging and soil salinity as a result of the steady rise in groundwater levels [13]. According to the Central Groundwater Board, the yearly potential groundwater recharge occurring naturally from rainfall in

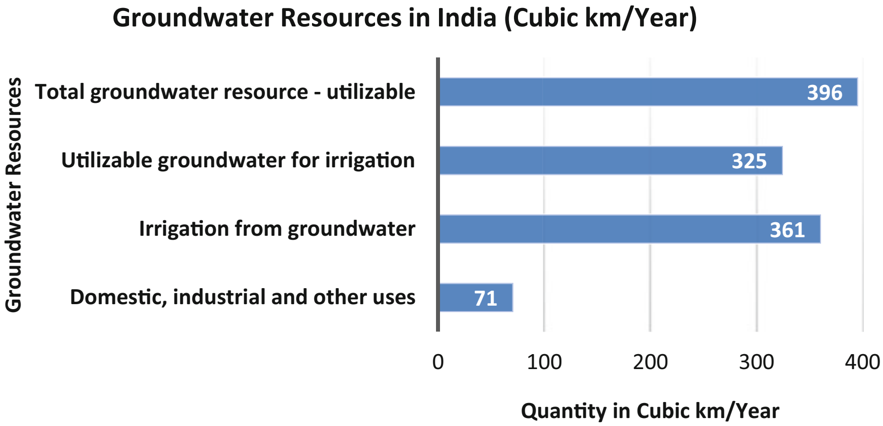


Fig. 6 Utilizable groundwater resources of India

India is around 342.43 km^3 which is around 8.56 percent of the country's total annual rainfall [14]. The canal irrigation system has an annual capacity for groundwater recharge improvement of about 89.46 km^3. As a consequence, the total replenishable groundwater resource for the country is calculated at 431.89 km^3. The rest of this quantity can be utilized for irrigation after 15 percent is set aside for drinking and 6 percent is set aside for industrial usage. Figure 6 shows the Central Groundwater Board's (CGWB, 1995) [14] estimates of total replenishable groundwater resources utilization for residential, industrial, and irrigation purposes, and future utilizable groundwater resources in India.

In the Indo Gangetic alluvial plain, there is a large area where the development of groundwater resources is sub-optimal and there is still scope for future development. Similarly, in water-stressed areas, immediate efforts are necessary to supplement groundwater artificially. However, in order to ensure the sustainable, judicious and appropriate use of groundwater resources, the focus on development activities must now be balanced by scientific planning and management systems [15]. Because groundwater development is mostly driven by demand, it may be boosted by appropriate agricultural, financial, subsidy, and energy policies, as well as the formation of appropriate markets. Furthermore, the flood plains along the country's major river systems provide excellent opportunities for groundwater development. Similarly, there are artesian conditions in some parts of the country that may be identified and appropriate development plans are to be developed. There is a need to create techniques for assessing the development potential of deeper aquifers in alluvial regions with multi-aquifer systems. For developing and implementing appropriate groundwater management plans in the country, there is a pressing need for scientific, integrated, and coordinated efforts by different Central and State Government departments, non-governmental and social service organizations, academic institutions, and stakeholders [13].

5 Droughts

Drought is referred to as the regional occurrence of relatively below-average water availability, whether in the form of precipitation, river flow, or surface and groundwater storages. It's a natural and common recurring phenomenon of climate that may happen everywhere on the earth, in any climate zone. Droughts are caused by a lack of precipitation as a result of natural climatic fluctuation in space and time [16]. Drought may affect each section differently, resulting in varying degrees of severity and impact. Drought has a subtle but long-lasting effect. Droughts may be divided into four categories. Meteorological drought is defined as a period when precipitation averages below the threshold level. Drought in agriculture refers to a shortage of soil moisture for crops, woods, rangelands, and cattle. A shortage of water in streams, tanks, and the aquifer is linked to hydrological drought. The fourth form of drought is socio-economic drought, which occurs when a lack of water impacts a region's social and economic activity. Droughts in India are caused by differences in the amount and distribution of monsoon season rainfall in time and place relative to the average value.

India has endured more than 14 significant droughts in the previous fifty years, out of which 1972, 1979, 1987, and 2002 droughts were the worst and affected almost half the geographical area of the country. Geographically, over 68% of India is vulnerable to drought, primarily covering the arid, semi-arid, and sub-humid climatic regions i.e. peninsular, central, western and north-western parts of India. Thus, in the planning and management of water resources and drought mitigation activities, determining the frequency, size, and persistence of droughts, as well as the susceptibility of an area to drought, is critical. Droughts influence both surface and groundwater resources, resulting in reduced water availability, worsened water quality, crop failure, reduced agricultural productivity, reduced power generation, disrupted riparian ecosystems, and halted recreational activities, among other things [17]. Droughts have an impact on water quality because mild climatic changes modify hydrologic regimes, which have a significant impact on river and lake chemistry [18].

Drought as the recurrent calamity has always threatened the Indian water and agriculture sector over decades and centuries. The detrimental impacts of drought are manifest in the sharp drop in agricultural production and farm income. It causes a reduction in rural employment imposing widespread economic impoverishment among farmers, farm laborers, rural artisans, and small rural businesses. Droughts are infamous for their complexity, thus the problems of preventing, mitigating, and managing this disaster need a scientific understanding of the symptoms, meticulous planning, concerted action, and cooperation amongst many concerned groups.

6 Floods

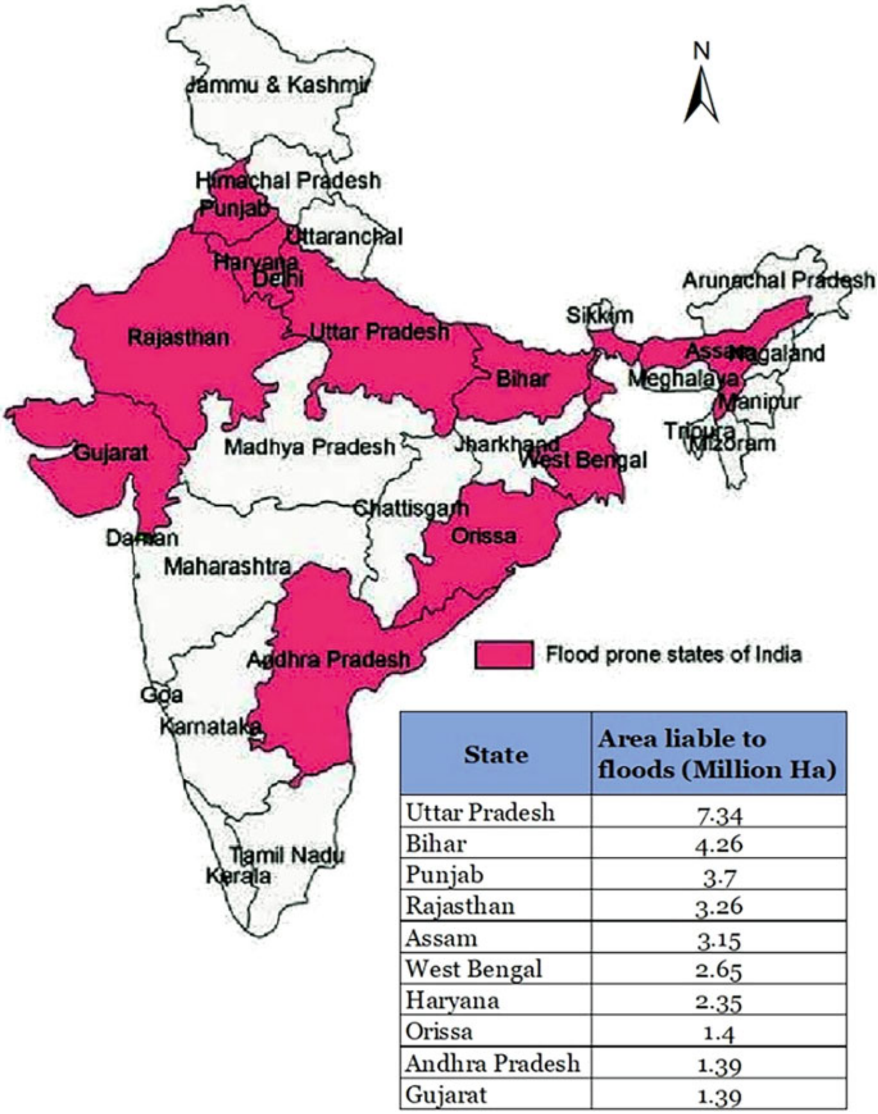
In India, floods are the most common natural disaster, with floods happening almost every year. Floods have lately wreaked havoc in India, particularly in the eastern states of Bihar, West Bengal, Orissa, and Andhra Pradesh. In India, the major causes of floods include a lack of capacity inside river banks to retain heavy flows, riverbank erosion, and riverbed silting. Landslides obstructing flow and changing the river's path, tidal and backwater effects delaying flow, inadequate natural drainage in flood-prone areas, cyclones and accompanying severe rainstorms or cloud bursts, snowmelt, and glacier outbursts, and dam-break floods are among the other factors. The material and intangible damages caused by floods in India are growing at an alarming rate, according to data provided by several government organizations. According to the Central Water Commission (CWC), which is part of India's Ministry of Jal Shakti, D/o Water Resources, the yearly average area impacted by floods in the country is 7.563 Mha. From 1953 to 2000, floods harmed around 33 million people on average. Due to the fast growth of the population and the growing encroachment of the flood plains for dwelling, farming, and other activities, this figure is certain to rise.

Following the devastating floods of 1954 in India, a nationwide flood management program was established. The Indian government has implemented a variety of flood-prevention measures, formulated policies from time to time, established working groups, task forces and committees to address flood-related issues. This includes Policy statement in 1954, high-level committee on flood in 1957, policy statement in 1958, ministerial committee on flood control in 1964, ministerial committee on flood and flood relief in 1972; working groups on flood control for five-year plans; Rashtriya Barh Ayog, National Water Policy in 1987, National Commission for Integrated Water Resources Management in 1996, Regional Task Force in 1996, and National Water Policy in 2002 and 2012 [19]. The government's committees and commissions have made useful suggestions on a variety of flood management concerns. To limit the damage in flood plains, a variety of structural and non-structural solutions have been used. In certain Indian states, structural interventions such as the construction of levees, embankments, spurs, and other similar structures have been adopted. The entire length of built embankments is 16,800 kilometers, while the total length of drainage canals is 32,500 kilometers. Flood protection is now in place for 1040 cities and 4760 villages. These have given reasonable safety and protection to an area of roughly 15.07 Mha, except for occasional breaches in embankments. A huge number of reservoirs have been built, and the intensity of floods has decreased as a result of these reservoirs. Non-structural flood management strategies, such as flood forecasting, flood classification based severity and flood warning, mass awareness, scientific studies on Dam break analysis and Emergency Action Plans are also being used. Flood forecasts and warnings in Delhi for the Yamuna River began in 1958. It has grown to encompass the majority of India's interstate river basins which are flood-prone and vulnerable. The Central Water Commission of India has established a large flood forecasting system that spans 62 major rivers and has over 157 stations, allowing it to give flood predictions for nearly all flood-prone states in the country. The response from all the state governments to the action on the flood plain zoning has been seen as encouraging. Although some states, such as Manipur and Rajasthan, Bihar, Uttar Pradesh have passed flood legislation on plain zoning, however the other flood-affected states, such as Himachal Pradesh, Goa, Sikkim, and Assam are yet to take action on this.

Flood control methods must be more concentrated and aimed at the predetermined goals within a set time frame. Methods for flood plain zoning must be developed in cooperation with local governments in order for flood plain zoning laws to be approved. As proposed by the Working Group of the tenth five-year plan, any concerns about the difficulty of writing legislation should not be used to dismiss the concept of flood plain zoning. One of the most essential aspects of flood catastrophe preparedness is flood forecasting. Technical progress in a well-planned flood forecasting and warning system can assist provide more lead time for the prompt response. The creation of suitable flood storage in reservoirs is widely acknowledged as a long-term solution to flood concerns. In India, completed projects have a total live storage capacity of around 174 km^3. A good flood management scheme necessitates a substantial flood storage area in reservoirs. Flood management also necessitates community involvement. Flood management is something that farmers, professional bodies, companies, and non-profit organizations must be aware of. Participation of the public in disaster preparedness, flood control, and disaster response is essential. Radio, television, newspapers, and social media platform may all play a part in flood control. Due to the fact that India shares river systems with six bordering nations, namely Pakistan, Bangladesh, Bhutan, Nepal, Myanmar, and China bilateral cooperation for flood control is required. The Indian government has taken some steps in this direction, but more active engagement is necessary. Figure 7 depicts India's major flood zones.

7 Climate Change

Climate change has been well defined by the United Nations Framework Convention on Climate Change (UNFCCC) as a change in climatic conditions caused directly or indirectly by anthropogenic activities that alter the global atmosphere's balance, in addition to natural climate variability seen over long time periods. Climate change is a long-term, continuous shift in average weather conditions that is either rising or decreasing. It may result in more frequent and severe extreme events like floods and drought, wreaking havoc on the region's agriculture, water supplies, livelihood, and economy. Unlike year-to-year fluctuation, climate change is a slow and steady process. Climate change is now broadly acknowledged as one of the most serious problems facing the world in the twenty-first century. Measurements over the past 157 years reveal that temperatures at the surface have risen globally, with considerable regional differences, according to the Intergovernmental Panel on Climate



State	Area liable to floods (Million Ha)
Uttar Pradesh	7.34
Bihar	4.26
Punjab	3.7
Rajasthan	3.26
Assam	3.15
West Bengal	2.65
Haryana	2.35
Orissa	1.4
Andhra Pradesh	1.39
Gujarat	1.39

Fig. 7 Major flood zones of India

Change (IPCC) report [20]. Over the previous 25 years, the rate of warming has accelerated, with 11 of the 12 hottest years on record occurring in the last 12 years. In general, this warming exacerbates the global hydrological cycle [21], and it is well documented that the earth's mean surface temperature has been rising since the last glacial maximum 21,000 years ago [22], resulting in increased globally averaged precipitation, evaporation, and runoff.

Biotic activities, variation in solar energy received by the planet, plate tectonics, and volcanic eruptions all contribute to climate change. Temperature and rainfall intensity has increased, indicating that the world and local climates are changing. Human activities have also been recognized as important contributors to climate change in recent times, often known as “global warming,” which has the potential to have a wide-ranging, complex, and unpredictable influence on the environment. Climate change will have a significant influence in the future, according to IPCC assessments, which predict a decrease in freshwater availability as a result of climate change. This has also indicated that by the middle of the twenty-first century, yearly average runoff and water availability will perceive decrease by 10–30% [20]. A change in a region’s long-term weather patterns, such as temperature, wind, and precipitation, is referred to as global climate change. According to the IPCC’s fourth assessment report, rising the mean seasonal temperatures will have an impact on agriculture, water, and the global economy. Due to its agrarian economy, India is one of the most vulnerable countries to climate change, with 70% of its population reliant on agriculture for a livelihood.

Although numerous climatic factors influence water supplies, temperature and precipitation are the two most important. The hydrological cycle, which is a thermally driven system, is projected to accelerate as a result of global warming. Warmer temperatures will cause more precipitation to fall as rain rather than snow. In the long run, this will result in glacier shrinkage and a reduction in snow and glacier melt. There may be variations in the process of run-off production and its timing in areas such as India’s northern plains, where significant river flows are generated by Himalayan snow and glacier melt. Increased evapotranspiration from crops, plants, and land surfaces, as well as greater water needs, may result from rising temperatures [23]. Extreme weather events such as floods, droughts, and rainstorms are projected to become more common as a result of global warming. The precipitation pattern is likely to alter in two ways: temporal patterns, such as the monthly distribution of yearly precipitation, and geographical patterns, such as some places getting high precipitation receiving less and vice versa. The three sorts of effects are distinct and need distinct adaptive responses, but they are also intricately linked [8]. Climate change in India may have an impact on long-term rainfall patterns, reducing water supply and raising the risk of droughts and floods. Climate change in India, notably the South-West monsoon, would have a substantial influence on agricultural productivity, water management, the general economy, and the country’s livelihood sector. During the non-monsoon months, the great concentration of rainfall in the monsoon months leads to a scarcity of water in this area of the nation. Droughts may become more common when yearly rainfall decreases and wet days increase, despite increased rainfall and decreasing rainy days.

7.1 Climate Change and India's Actions

In 2007, India's emissions were expected to be in the range of 1331.6 million tonnes of carbon dioxide equivalent to Green House Gas (GHG) emissions. The emissions have seen increased by 4.2 percent each year since 1994. India's CO_2 emissions, on the other hand, account for just around 4% of total world CO_2 emissions and much less than the historical concentrations taken into consideration. Nonetheless, India has been aware of the worldwide threat of climate change. India has agreed to communicate information about the Convention's implementation in accordance with the obligations imposed on parties to the United Nations Framework Convention on Climate Change (UNFCCC). In 2012, India presented the UNFCCC with its Second National Communication (NATCOM). In 2004, the first National Communication was submitted by India. According to India's Second National Communication to the UNFCCC, the annual mean surface air temperature rises by the end of the century are expected to range from 3.5 to 4.3 degrees Celsius, while sea level along the Indian coast has been increasing at a pace of around 1.3 millimeters per year on average.

In 2006, the Government of India outlined the National Environment Policy as a critical component of India's response to climate change, with the goal of identifying India's key vulnerabilities to climate change, including impacts on water resources, forests, coastal areas, agriculture, and health, as well as assessing the need for climate change adaptation and encouraging Indian industry to participate in the Clean Development Mechanism (CDM). Later, India's Prime Minister established a High-Level Advisory Group on Climate Change, which includes both government and non-government members. The Council organizes national action plans for climate change assessment, adaptation, and mitigation. Since 2008, the Ministry of Environment and Forests has been implementing the National Action Plan on Climate Change (NAPCC) through nodal ministries in key sectors. State governments are also drafting State Action Plans on Climate Change, with the help of the federal government, to build institutional capacity and undertake sectoral actions to combat climate change. So far, 21 states have prepared State Action Plan on Climate Change (SAPCC), including Manipur, Meghalaya, Mizoram, Nagaland, Assam Arunachal Pradesh, Tripura, Sikkim, Jammu & Kashmir, Andaman and Nicobar, Lakshadweep, Delhi, Odisha, Punjab, Rajasthan, Uttarakhand, Andhra Pradesh, Karnataka, Kerala, West Bengal, and Madhya Pradesh.

8 Water Quality

In India, the degradation of water quality due to pollution is a serious environmental problem. The majority of India's rivers, lakes, and surface water are contaminated. The most significant sources of water pollution in India are untreated sewage from cities and industrial effluents. Unregulated small-scale enterprises and agricultural

Fig. 8 Picture showing the severity of pollution in Ganga

runoff are two further causes of pollution. The condition of India's rivers, lakes, and ponds is under growing threat as a result of population growth, urbanization, and industrialization. The quality of water degrades every time it is utilized for something. Unfortunately, the country's reverence for rivers does not guarantee that they are clean.

The severity of water pollution varies by region, based on the density of urban growth, agricultural and industrial activities, and wastewater collection and treatment infrastructure. India's Central Pollution Control Board (CPCB) has identified some of the contaminated river lengths as well as potential pollution sources. The majority of the contaminated regions are found in and around metropolitan cities. Water pollution is a significant problem in India, with biological, toxic, chemical, and inorganic pollutants contaminating almost 70% of its surface water resources and an increasing percentage of its groundwater reserves. The high frequency of severe contamination near urban areas suggests that the contribution of the industrial and residential sectors to water pollution is considerably more than their proportional prominence in the Indian economy suggests. In terms of total influence on water quality, agricultural activities also have a role. Aside from a rapidly falling groundwater table in various regions of the country, the government is also dealing with a severe groundwater pollution problem that has afflicted 19 states, including Delhi. Groundwater has been contaminated by geogenic pollutants such as salt, iron, fluoride, and arsenic in over 200 districts across 19 states. More than 70% of our country's pure water in liquid form has been rendered unsuitable for human use. Other countries, in addition to India, are dealing with the same issue. The numerous sources of pollution such as sewage discharge, industrial effluents, and agricultural runoff, as well as their potential, have been identified as the primary danger to water pollution in India [24]. Figure 8 depicts the current state of water contamination and the decline of water quality.

Water pollution may have a significant negative impact on the health of any life form that lives near a polluted water body or uses water that has been contaminated to some level. In reality, in India, contaminated water is one of the primary causes of the country's poor health, particularly in rural regions. Cholera, TB, dysentery, jaundice, diarrhea, and other illnesses can all be caused by contaminated water. Ingesting contaminated water is responsible for around 80% of gastrointestinal problems in India. At a certain point, contaminated water may harm crops and diminish soil fertility, affecting the agricultural industry as a whole and the country as a whole. When saltwater is contaminated, it has a negative influence on marine life. The most fundamental consequence of water pollution is the quality of the water, which can cause a variety of illnesses if consumed.

In India, water contamination has reached a catastrophic level. Almost every river system in India is now significantly polluted. Water quality evaluation and other elements of water pollution in major and small Indian rivers have been studied by several researchers in India. Nearly 70% of India's water is contaminated, according to experts at the National Environmental Engineering Research Institute (NEERI) in Nagpur [25].

The influence of sewage water entering the river Yamuna, bacterial pollution in Delhi, and river water quality in Agra have all been studied by researchers [26–28]. The biological characteristics of the river Yamuna are seen far inferior to those of the Ganga. A number of scientists have investigated pollution in the Ganga River. Studies were carried out at Mirzapur and Varanasi to investigate the Physico-chemical characteristics of the river Ganga [29, 30]. Both investigations come to the same conclusion: the physicochemical characteristics of Ganga water have been degrading over time and are continuing to do so. The studies point to the existence of a significant number of pathogenic and non-pathogenic microorganisms in concentrations much above their maximum permissible levels. Blue-green algae were studied in the Gomati river in India [31], and similar investigations were done in the Mahanadi river in Orissa state [32]. The Tungabhadra reservoir has also been the focus of extensive water quality investigations [33].

9 Agriculture in India

Agriculture accounts for about 46% of the gross national product in India, and it is also the people's primary occupation and the government's primary concern, with the responsibility of providing adequate food for a population that accounts for about 16% of the world's population while holding only 14% of the world's total agricultural potential [34]. India's agricultural achievements during the last four decades have been outstanding. The agricultural industry has done a good job of keeping pace with the growing food demand. Increasing land area under agricultural production has that important over time, and recent output increases have been nearly exclusively attributable to increased productivity [35]. Agriculture has made a significant contribution to overall progress in the country in recent decades. Increased production has helped feed the poor, increased agricultural revenue, and given direct and indirect job possibilities.

The success of India's agriculture may be credited to a series of events that led to the availability of farm technology, which resulted in substantial gains in production during the Green Revolution era in the 1970s and 1980s. The introduction of new varieties of crop, intensification of input usage such as fertilizers and manures in agriculture, and investments leading to extension of the irrigated area were the main sources of agricultural growth during this era [36]. Now the growth has been slowed in places where 'Green Revolution' technology had a significant influence in past. To push out the yield to new highs, use inputs more effectively, and diversify to more sustainable and higher value cropping patterns, and introduce new farming technologies. At the same time, if we are to fulfill agricultural growth and poverty reduction objectives, we must better harness the potential of rainfed agriculture and other less endowed areas with new techniques, schemes, and programs. Indian agriculture has a wide range of requirements, possibilities, and prospects due to the diverse agro-ecological settings. Future growth must be faster, more evenly dispersed, and more precisely focused. Agricultural research and scientific approach will be increasingly required to address community-specific problems; on the other hand, agricultural systems will have to position themselves in an increasingly competitive environment in order to generate and adopt cutting-edge technologies to address the problems that a large majority of poor farmers face [37].

Agriculture's long-term viability is contingent on soil management methods that provide healthy soils, and ecosystem services, as well as avoid resource degradation and ultimately enough food security. Conservation agriculture has provided a common thread for the application of five principles for sustainability—improved soil health, reduced use of agrochemical, sufficient use of water, adaptation to climate change, and doubling farmer income. The state's involvement in Indian agriculture must be based on the conservation agriculture method for food and ecological sustainability [38].

India would require 1498 BCM of water per year to meet agricultural water demand, according to the 2030 Water Resources Group Report [39]. Agriculture is expected to account for 80% of demand, with industry accounting for 13% and residential requirements accounting for 7%. India's current water supply is around 740 BCM, which is insufficient to meet this demand. As a result, unless the Ganga, Krishna, and Indus basins in India take coordinated action, most of India's river basins might face a severe shortfall of 758 BCM by 2030. Rice-wheat farming methods in Punjab and Haryana alone have resulted in a net loss of 109 BCN water yearly between 2002 and 2008 [40]. Agricultural water-productivity strategies help close the water gap by combining enhanced water application, soil moisture, and tillage management methods to produce 'more crops per drop', as well as improving crop yields through their relationship to soil health [41]. Surface flooding is the most common mode of irrigation water application in India and abroad, it is critical to enhancing the surface ridge-furrow irrigation system utilizing lay-flat gated pipes as soon as possible [42, 43]. Rolling toposequences must be pushed for pressurized sprinkler systems. Under marginal soil, water quality, and climate circumstances, a drip system works best which saves more water than gated pipes and sprinklers.

Direct dry seeding of Kharif crops before the rainy season begins can enhance production and decrease soil erosion risks. Dry rice sowing avoids puddling, saving at least 25 cm of irrigation water per hectare. Laser-assisted precision field leveling, surface seeding, dry planting, zero tillage, mulching, and other practices increase infiltration, reduce evaporation, conserve irrigation water, increase soil moisture and improve crop yield [41]. Improved soil health and reduced evaporation are still key alternatives for enhancing water productivity in areas with poor water productivity [44].

10 Irrigation Development in India

Agriculture is impossible to carry out without the presence of water. We must rely on rain to provide water for our farms, but rain does not fall throughout the year in the Indian region. India receives virtually all of its rain during the monsoon season, which runs from June to September and is not always consistent. Some areas receive modest rainfall, while others are left dry. Rainfall changes from year to year as well having huge temporal variation. In certain years, we receive a lot of rain, but in others, we don't get nearly enough. This demonstrates the need for water resource development, conservation, and optimal utilization. Indian irrigation infrastructure consists of a network of the major, medium, and minor canals originating from irrigation projects constructed on rivers, tanks, lakes, as well as well-based groundwater systems and other rainwater harvesting installations for agricultural purposes [45]. Groundwater wells can irrigate roughly 39 million hectares out of India's around 160 million hectares of cultivated land, while irrigation canals can irrigate another 22 million hectares [10]. Only approximately 35% of India's total agricultural area was reliably irrigated and the monsoon is the main source for around two-thirds of India's agricultural rainfed land. In the last 50 years, advances in irrigation infrastructure have helped India to reduce monsoon reliance, enhance food security, increase agricultural output, and generate rural job opportunities. Irrigation dams have also aided in the provision of drinking water to a rising urban as well as rural population, flood control, and the prevention of crops from drought-related damage.

10.1 History of Irrigation in India

In the early nineteenth century, according to irrigation sources, canal irrigation was 45 percent, irrigation from wells was 35 percent, tanks 15 percent, and from other sources, it was 5 percent. Famines in India in 1897–98 and 1899–1900 have prompted the British to create the first irrigation commission in 1901, specifically to report on irrigation as a way of famine prevention in India. The overall irrigated area by governmental and private works grew to 16 Mha in 1921 as a consequence of the first irrigation commission's suggestions. There was no substantial increase in tube well-irrigated areas from the beginning of the nineteenth century until 1921. Irrigation growth rates were projected to be 2.0 percent per year for government canal irrigation, 0.54 percent per year for well irrigation, and 0.98 percent per year for irrigation from all sources between 1910 and 1950.

10.2 Post-Independence Irrigation Development

India's irrigation development accelerated significantly after independence. The nation started on a large irrigation effort during the First Five Year Plan (1951–56). Hirakud, Bhakra Nangal, Chambal, Nagarjunasagar, Kosi, Kakrapar, and Tungabhadra were among the major and multipurpose irrigation projects undertaken. Simultaneously, under the Agricultural Sector, smaller irrigation initiatives, including groundwater, were given priority, with financial support from the Centre. New irrigation initiatives were established during the Second Five Year Plan (1956–61), the Third Five Year Plan (1961–66), and the three yearly plans (1966–69). During the Fourth Five Year Plan (1969–1974), the emphasis was moved to project completion, integrated surface and groundwater usage, effective management approaches, and modernization of existing systems. The Command Area Development Programme (CADP) was established during the Fifth Plan (1974–78) as a Centrally Sponsored Scheme with the goal of closing the gap between the irrigation potential developed and actual irrigation to make the best use of available resources. The program was designed as a way to bring all relevant activities under one roof in order to achieve these goals and initiated by the government with a 15 Mha of CCA of 60 major and medium projects.

Construction of new projects was continued during the year 1978–80 and the Sixth Five Year Plan (1980–85). By the conclusion of the Seventh Plan, there were 182 large and 312 medium active projects in the country. Due to huge investment and fund requirements in new projects in the period of 990–91, the Govt. of India changed its focus and started work of completing projects that were already well. This was continued up to the Eighth Plan (1992–97) and the Ninth Plan (1997–20). In 1996–1997, the Government established the Accelerated Irrigation Benefit Program (AIBP) scheme to expedite the completion of ongoing projects in the advanced stages of development. During the Eighth Plan period, irrigation potential of 2.22 Mha was developed at a rate of 0.44 Mha per year in the major and medium sectors. During the Ninth Plan period, this grew to 4.12 Mha, with AIBP accounting for 1.65 Mha (almost 40%). The importance of user engagement in large and medium irrigation systems was highlighted. Repairs and improvements to local irrigation projects were also encouraged as part of integrated micro-development. Later the sprinkler and drip irrigation systems, as well as the combined use of surface and groundwater, grew in popularity. According to the second irrigation commission's assessment, the total ultimate irrigation potential created in 1972 was 113.47 million hectares which include 58.47 million hectares from major, medium projects and

55 million hectares from minor irrigation (surface and groundwater). The total ultimate irrigation potential increased to 139.90 million hectares up to 2013–14 which include 58.47 million hectares from major, medium projects and 81.43 million hectares from minor irrigation (surface and groundwater) [46].

11 National Water Policy

The Ministry of Jal Shakti, Government of India (Formerly M/o Water Resources) has developed a National Water Policy to guide the planning and development of water resources as well as their optimal usage. In September 1987, the first National Water Policy was enacted. In 2002, it was re-evaluated and modified, and then again in 2012. It proposes connecting rivers to alleviate the country's water shortage. The major focus of the National Water Policy 2012 was to consider water as an economic good, with the goal of promoting its conservation and effective use, according to the ministry.

11.1 National Water Mission

A National Water Mission program has been developed to ensure integrated water resource management, which will aid in water conservation, waste reduction, and more equal distribution between and within states. The mission is to establish a framework to optimize water usage by increasing water use efficiency by 20% through regulatory mechanisms with differential entitlements and pricing, taking into consideration the requirements of the National Water Policy. It aims to ensure that a significant portion of urban water needs can be met by augmenting groundwater recharge through water harvesting measures and wastewater recycling. Similarly, the water needs of coastal cities with insufficient alternative water sources are met through the adoption of new and appropriate technologies, such as low-temperature desalination technologies that allow the use of ocean water. The National Water Policy is to be reviewed in coordination and cooperation with states to guarantee river basin level management plans to deal with climate change-related variations in rainfall and river flows.

The National Water Mission includes goals to improve surface and groundwater resources, storage, as well as rainwater harvesting, and fair and efficient management structures. New regulatory frameworks, as well as proper entitlements and pricing, are planned by the Mission. Its goal is to improve the effectiveness of existing irrigation systems, including the rehabilitation of deteriorated systems and, where possible, irrigation expansion, with a focus on increasing storage capacity. Water-positive, water-neutral technologies, enhancing subterranean water sources, and adoption of large-scale irrigation schemes relying on drip, sprinklers, ridge, and furrow irrigation will all be promoted through incentive structures. The

National Water Mission program has five goals: promotion of citizen and state actions for water conservation, augmentation, and preservation; focused attention on vulnerable areas, such as over-exploited areas, increasing water use efficiency by 20%; public domain for water database and an assessment of the impact of climate change on water resources [46].

12 Conclusions

After a thorough review of the number of government reports, research papers, scientific studies, popular articles, and media reports on the development and management of water resources in India, overall conclusions are drawn and summarised in this chapter to better comprehend the findings. In India, after independence water demand has grownup due to growing population, growth of agriculture, industry, and other sectors which resulted in decreased per capita water availability. Despite having abundant water resources, clean drinking water and agricultural water have always been in shortage. As a result, India must establish policies for long-term water management to bridge the widening gap between demand and supply, ensuring sufficient water for residential, agricultural, and industrial use.

A major portion of India receives rainfall from the southwest monsoon. It does, however, have a lot of temporal and spatial variation. India is blessed with a network of large, medium, and small river systems that contribute 1645 BCM of yearly water flow, with large rivers accounting for 85 percent of this total. The country has a further scope to improve its water utilization from its bestowed river systems. Groundwater is the most favored source of water in India's different consumer sectors; nevertheless, the country's growing reliance on it has led to indiscriminate extraction without consideration for aquifer recharge capacity. There is still scope at certain lares where groundwater resources might be developed further. However, urgent action is required for the augmentation of groundwater recharge in water scare and over-exploited areas in the country.

Droughts are extreme events posing threat mainly to water, agriculture, livelihood, economy, and other sectors. India has undergone a series of disastrous droughts that have affected over half of the country's geographical area, with more than half of the country classified as drought-prone. As a result, assessing droughts is critical for developing drought mitigation strategies and managing water resources. In India, floods are the most commonly occurring natural disasters. In India, the major causes of floods include a lack of capacity inside river banks to retain heavy flows, riverbank erosion, and riverbed silting. Due to fast population expansion and the growing encroachment of flood plains, about 33 million people in India are in danger of flooding, and this number is certain to rise as the country's population grows. The Indian government has adopted a variety of flood prevention and protection measures, including the creation of a National Flood-Prevention program.

A huge number of reservoirs have been built across large and medium rivers and the intensity of floods has decreased as a result of these reservoirs.

Due to its agrarian economy, India is one of the most vulnerable countries to climate change, with 70% of its population reliant on agriculture for a living. Climate change in India may affect rainfall patterns, reducing water supply and causing frequent droughts and floods. It would have a major influence on agricultural productivity, water management, and the country's general economy. In 2006, India's government announced its National Environment Policy as a critical component of the country's response to climate change, with the goal of identifying India's main vulnerabilities to climate change and laying out adaptation plans.

Water pollution is one of the severe problems in India, with organic, inorganic, biological, and toxic contaminants contaminating the majority of surface and underground water resources. The quality of water in rivers, lakes, and ponds is under rising threat as a result of population growth, urbanization, and industrialization. Untreated sewage, agricultural runoff, and uncontrolled small-scale industry are the most common sources of water pollution, with the majority of contaminated sections occurring in and near big metropolitan centers. Water quality issues must be addressed urgently to ensure clean and good quality freshwater supply for the expanding population.

Agriculture is the primary occupation of the people in the country, as well as the government's primary concern when it comes to providing enough food for a population. Over the last few decades, India has made significant strides in agriculture. India's agriculture industry has done a good job of keeping up with growing food demand. The Green Revolution period, which brought about substantial improvements in production in the 1970s and 1980s, is credited with India's agricultural prosperity.

One of the major factors contributing to India's green revolution was the rapid construction of irrigation infrastructure following independence. The government began a significant irrigation program, undertaking a number of multifunctional and big projects while also focusing on minor irrigation schemes, including groundwater, and implementing new irrigation programs. The Government of India created the Accelerated Irrigation Benefit Program (AIBP) to advance irrigation development by ensuring project completion, user involvement, minor irrigation project repairs, and improvements as part of integrated micro development, sprinkler, and drip irrigation programs, and the conjunctive use of surface and groundwater.

The Indian government has established a framework policy for the development, management, and planning of water resources through a series of policy documents, high-level committees, and missions. The Ministry of Water Resources developed a National Water Policy to guide the planning, development, and optimal use of water resources. A National Water Mission program has been developed to ensure integrated water resource management, which will aid in water conservation, waste reduction, and equal distribution between and within states.

13 Recommendations

Following are some recommendations based on a thorough study and evaluation of the state of water resource management in India, which will aid in the formulation of plans and the implementation of essential actions to meet challenges.

Despite India's enormous water resources, there has always been a scarcity of safe drinking and agricultural water. As a result, sustainable water resource development is critical in the country in order to bridge the growing gap between demand and supply, ensuring sufficient water for domestic, agricultural, and industrial use.

Groundwater is the most preferred source of water in India, and increased reliance on it has resulted in groundwater resource depletion in many parts of the country. Identification of potential areas for surface water resources development through a vast network of rivers and implementing programs for augmentation of groundwater recharge through natural and artificial means will be the key to tackle this issue.

The systematic scientific approach for assessment of water scarcity, droughts, formulate mitigation plan, assessment of extent and magnitude of floods, flood management, development of policies under climate change scenarios are key issues to tackle flood and droughts.

Agriculture is the main occupation of the people in the country and it accounts for the majority of rural livelihood. Policies, provisions, plans have to be made for assured water availability to meet irrigation demand, thereby increasing food production to meet the increasing food demand of the increasing population.

Deterioration of surface and groundwater quality is a major environmental concern in India. Immediate action is needed to implement policy options for reducing industrial water, industrial effluent treatment, and urban waste-water treatment for better handling of organic wastes.

Surface and groundwater quality degradation is a serious environmental problem in India. For improved handling of organic wastes, immediate action is required to adopt policy alternatives for decreasing industrial water, industrial effluent treatment, and urban waste-water treatment.

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