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Interplay of Climate Change and Water Stress in Bundelkhand Region of Madhya Pradesh: Risks, Resilience and Adaptation Strategies

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ABSTRACT: The Bundelkhand area of Madhya Pradesh, India, contends with a dynamic interaction between climate change and water stress, greatly harming its socio-economic and ecological balance. The study examines the connections between these occurrences, highlighting the circumstances of Bundelkhand's water-related problems. The study attempts to address complex threats, resilience mechanisms, and adaptation and action techniques relevant to the area by drawing on a thorough interdisciplinary lens spanning environmental, social, economic, technological, and policy dimensions. Based upon a comprehensive literature review, the study uses qualitative and quantitative secondary work evidence from empirical research, policy analyses, official reports, and community-based studies. It applies a system-oriented perspective to evaluate vulnerability, adaptive capacity, and resilience mechanisms that combine traditional knowledge with modern interventions. Unpredictable precipitation patterns, warming temperatures, and growing water demand amid agricultural growth are some of the variables that come together to cause water stress in Bundelkhand. The synthesis indicates that climate-driven shifts in temperature and precipitation contribute to intensified groundwater depletion, increased surface-water variability, and ecosystem degradation with cascading effects on agriculture and water-dependent livelihoods. To promote resilience and guarantee the region's water security in the face of changing climate conditions, policymakers, governmental organizations, and stakeholders are encouraged to adopt a comprehensive approach and give community engagement, sustainable water management techniques, and ecosystem restoration projects top priority. This study adds to the larger conversation on climate change resilience and sustainable water management by illuminating Bundelkhand's water-related problems and adaptation needs. It also provides insightful information and guiding principles for the creation of policies and grassroots initiatives in the region.

INTRODUCTION

Water is the quiet conductor of life, guiding ecosystems, fostering development, and maintaining life. Nature and mankind are forever intertwined in a never-ending cycle of reliance and rejuvenation, and this dynamic vitality shapes landscapes, cultures, and economies. Promoting the health of people by guaranteeing them access to safe drinking water. All life on Earth depends on water, and it is also crucial for long-term prosperity. Water is inherently linked to the international climate change disaster. The impacts of climate change involve a rise in the frequency and intensity of extreme weather occurrences. Higher average temperatures and changed patterns of precipitation constitute a danger to ecosystems, economies, and human livelihoods around the world (IPCC, 2022).

Water stress, defined as insufficient supply, poor quality, and unpredictable availability, is one of the most pressing issues, especially in semi-arid and drought-prone areas (UN-Water, 2021). When the mean and/or fluctuation of a climate's attributes alter over an extended duration, typically spanning decades or longer, climate change has occurred. Both internal and external influences, including fluctuations in solar cycles, volcanic activity, and the persistent impact of human endeavours on the atmosphere and land utilisation, may play a role in climate change. The Framework Convention on Climate Change (UNFCCC) articulates in Article 1 that climate change refers to alterations in climate that are directly or indirectly caused by human actions affecting the global atmospheric composition, alongside natural climate fluctuations observed over similar timeframes." (IPCC, 2014, p. 5).

Hydrological disruptions caused by climate change are expected to increase the already high population of over 2 billion people living in water-stressed regions (UN-Water, 2021). According to Sumthane et al. (2026), there is concern that current water management techniques are not strong enough to handle the consequences of climate change on aquatic ecosystems, health, agriculture, energy, and the dependability of water supplies. One of the most pressing issues affecting international politics and the economy today is climate change. Nearly all scientists (97%) acknowledge the problem's existence and say that it has become even more severe over the last two decades due to the industrial revolution's release of dangerous compounds into the air, water, and soil (Yakovlev & Belyaev, 2023, p. 1). Alterations in meteorological conditions and average planetary temperatures over prolonged durations are referred to as climate change. Natural phenomena, such as changes in solar radiation or significant volcanic eruptions, can lead to these shifts.

On the other hand, human activities have been the primary factor causing climate change since the 1800s (Nations, n.d.). While climate change has consistently been a facet of Earth's past, the alterations we currently observe are predominantly attributable to human activity. Unforeseen meteorological occurrences, reduced reliability of water supply, deteriorating water quality, and risks to sustainable development, biodiversity, and the fulfilment of human rights to safe drinking water and sanitation are all repercussions of climate change's influence on the hydrological cycle (UN-Water, 2019, p. 4). Recent estimates place the financial burden of climate change harm on poor nations, with estimates ranging from 70 to 80 percent (Yadav et al., 2023). Extinction of many planted species is probable because of altered weather patterns brought about by scarcity of water, increased melting of glaciers, and increasing mercury levels. (Abbass et al., 2022, p. 42542).

METHODOLOGY

This study employs a comprehensive literature review with the qualitative evidence drawn from the empirical research articles, policy documents and community-based studies relevant to the region's environmental, social, economic and policy context. The review process involved systematic identification, selection and analysis of scholarly publications and grey literature focusing on climate variability, water scarcity and adaptation strategies in the semi-arid region of Bundelkhand. Relevant databases and institutional databases were searched using keywords related to climate change, risk, resilience and adaptability.

Literature Review

Climate change is making water scarcity worse in India, a nation whose agriculture is highly dependent on the monsoon. Water stress, which manifests as shortage, unreliability of supply, and diminishing quality, presents a substantial obstacle to sustainable development in India, where around 59% of the population relies on agriculture (FAO, n.d.). Agriculture uses more than 80% of the freshwater that is available. The lives of rural residents and their ability to get food are greatly affected by unpredictable monsoons and extended droughts (Krishnan et al., 2021). There are 690 billion cubic meters (BCM) of surface water and 447 BCM of groundwater that the nation may use each year. India relies heavily on groundwater resources for its daily needs, even though it has surface water resources as well. India is now confronted with the problem of meeting its demand with its current, diminishing resources (Aayog, August 2019, p. 1). Temperature rises, changes in precipitation and snow cover, and an increase in the frequency of floods and droughts are all impacts of climate change that threaten water supplies and, by extension, agriculture (Foundation, 2021).

Study Area

The semi-arid Bundelkhand area, which includes portions of both Uttar Pradesh and Madhya Pradesh, has a long history of water shortage. The effects of climate change, such as changes in rainfall patterns, higher average temperatures, and more frequent droughts, are making these problems worse (Jatav S. K., 2024, p. 253). The six districts of Bundelkhand Sagar, Damoh, Chhatarpur, Tikamgarh, Panna, and Datia encompass an expanse of 29,000 km² and accommodate a population of 7.5 million. Eighty-two percent of this population depends on rain-fed agriculture (Jatav & Bharati, 2023). The specific biophysical and socioeconomic characteristics of the geographically isolated area of Bundelkhand make it very susceptible to the effects of water scarcity and climate change. The landscape is mostly undulating, with rocky plateaus and thin, dark soils that don't hold much water, making the effects of unpredictable rains much worse (Pradesh, 2020, p. 2). According to Jatav and Bharati (2023), who developed the Environment Vulnerability Index for the Bundelkhand Region in India, the area has a semi-arid environment and receives a large amount of precipitation during the monsoon season.

As a result, the region is quite vulnerable to drought and dry spells. Adaptation solutions are suggested, threats to agriculture and livelihoods are assessed, community resilience is evaluated, and the impact of climate change on water stress in Bundelkhand, Madhya Pradesh, is examined in this research.

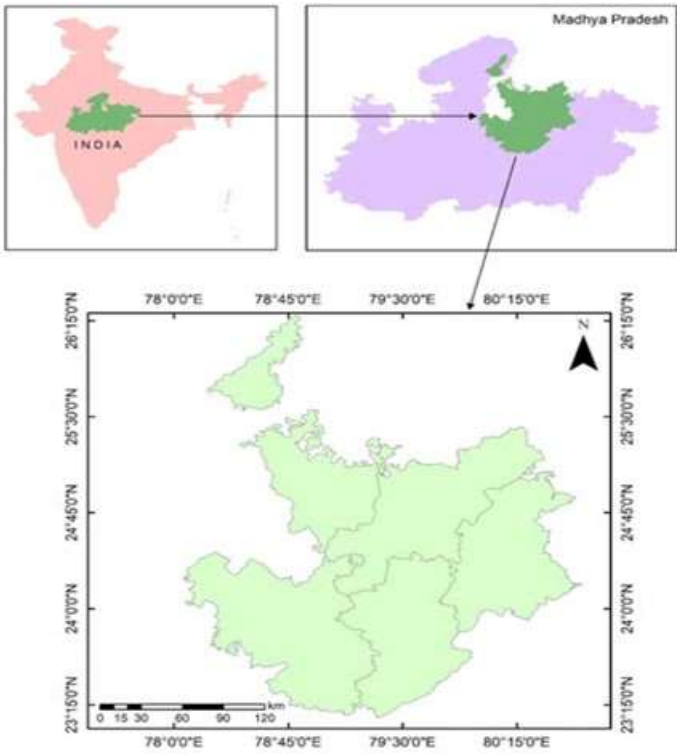

Fig. 1. Location map of study area
Source: (Yadav, 2020, p. 526)

History of climate change in Bundelkhand

Historically, the Bundelkhand area has been vulnerable to the effects of climate change. Between 1968 and 1992, the frequency of droughts increased to three times what it had been in the 18th and 19th centuries (TERI, 2018, pp. 22-23). As of late, droughts seem to happen almost every year (Moro et al., 2025, pp. 1-2). The area saw below-average precipitation every year from 2004 to 2022. There was a 30% drop in food grain yield because 40% of the net seeded land remained uncultivated due to the chronic lack of precipitation (Singh S., 2020, p. 3). Drought and temperature fluctuations have also made homes more susceptible. According to data released by Jatav and Singh in their 2023 publication "Determinants of Climate Change Adaptation Strategies in Bundelkhand Region, India," the average and maximum temperatures saw a 0.28°C rise from 1969 to 2017 when compared to the baseline period of 1960-1990. The

water resources of Bundelkhand and the lives of those who rely on them are under increasing danger because of a combination of these innate vulnerabilities and the changing climate stressor.

Water-related Challenges

Numerous water-related issues have had a devastating impact on the economic, social, and ecological well-being of the people living in the Bundelkhand area of Madhya Pradesh. Anthropogenic pressures, such as excessive water consumption, insufficient infrastructure, the decline of conventional methods of water management, and soils with low water retention capacities, combine with natural factors, such as a semi-arid climate and unpredictable rainfall patterns, to create these problems (Ms. Harshita Bisht, 2014). Here are some of the key water-related challenges faced by the Bundelkhand region:

Erratic rainfall and drought: Water shortage and recurrent droughts are symptoms of Bundelkhand's low and unpredictable rainfall. The region is facing.

a. Floods: The Bundelkhand region has been in a state of chronic water shortage for three years running; nevertheless, in 2016, when the monsoon season came, the area was inundated due to climate change (Deep, 2016). Agricultural losses were also reported in the Chhattarpur and Tikamgarh districts in 2019 due to heavy rains (India, 2019). The area of Bundelkhand is notorious for its droughts, but in August 2021, it was the floods that caused houses to fall, livestock to perish, and fodder to be devastated (Singh A. G., 2022).

b. Groundwater depletion: Groundwater levels are falling across all districts, making an already precarious situation worse for water-dependent businesses, farmers, and the regional economy (Sharma A., 2023). The Central Ground Water Board reports that the Bundelkhand region's groundwater level has been falling by about 3–4 meters since 2020–21. (Board, 2021).

c. Water quality degradation: The Bundelkhand region's groundwater quality has been negatively impacted by the increased fluoride levels (Jhariya, 2020). The surface water of the Bundelkhand area is contaminated due to runoff from agricultural fields and other human-made influences. (Schmidt, 2022).

d. High rate of runoff: Surface runoff accounts for around 84.72 percent of total precipitation, according to CGWB (Jhariya, 2020). A long-term fix is required since this problem hinders water resource management efforts and reduces agricultural output.

e. Inadequate water infrastructure: Dams, reservoirs, ponds, and canals are insufficient in Bundelkhand, making it difficult to distribute and store water efficiently and making water stress even worse (Jhariya, 2020).

f. Climate change impacts: Climate change increases temperatures, alters precipitation patterns, and intensifies extreme weather events, all of which worsen the region's water stress. A rise of two to three degrees. The United Nations Institute for Training and Research (UNITAR) predicts that temperatures will reach 5°C by the end of this century. The area of Bundelkhand has been devastated by the monsoon's failure, which has brought with it the twin dangers of drought and floods (R. Ranjan, 2021).

g. Socio-economic implications: Agriculturally reliant rural populations of Bundelkhand are especially vulnerable to the social and economic effects of water shortage. Communities in the area often encounter issues such as crop failures, revenue losses, and migration in pursuit of water and better livelihood opportunities (Singh A. G., 2022).

h. Gender disparities: Social and cultural pressures, coupled with a low sex ratio, make women more vulnerable to the effects of climate change. This is because, in most households, women are primarily responsible for meeting fundamental needs, such as ensuring the safety of drinking water (Prem Prakash, 2021).

Climate Change and Water Stress in Bundelkhand Region

Climate trends

According to Dwivedi, Kumar, and Khare (2024), the state of Bundelkhand is known for its low annual rainfall of less than 800 mm, considerable variability in rainfall ranging from 27 to 30 percent, and frequent droughts. On record, catastrophic droughts occurred every 16 years throughout the 18th and 19th centuries. According to the Standardised Precipitation Index

(SPI), the frequency of droughts in the Bundelkhand region has been on the rise, especially in the past ten years. Droughts in this region have been more severe in recent years due to factors such as higher temperatures, which cause evaporation rates to rise, which in turn increases water demand and speeds up soil moisture loss (Patidar, Pingale, Khare, & Dayal, 2024). From 1951–1970, the highest annual temperature was 32.35°C; from 2011–2020, it rose by 0.19°C. Also, according to Jatav and Bharati's (2023) Development of Climate Vulnerability Index for the Bundelkhand Region in India, maximum temperatures have been rising at a quick pace during kharif and a more moderate rate during rabi. The already water-scarce area is confronted with a triple threat: increasing temperatures, shorter rainfall intervals leading to more runoff and less groundwater recharge, and the overexploitation and improper management of the region's groundwater resources. (Richhariya & Jaiswal, 2023).

Climate change and water stress history

There is an innate vulnerability to climate change in the semi-arid Bundelkhand region of Madhya Pradesh (Ms. Harshita Bisht, 2014, p. 4). Compared to the period between 1960 and 1090, the mean maximum temperature in this climatic hotspot rose by 0.28 degrees Celsius between 1980 and 2005 (Jyotsna Richhariya, 2023). According to Saini (2023), the annual rainfall in Bundelkhand decreased by 60% between 2013 and 2018 because of climate change affecting rainfall patterns. Based on forecasts, August will now be the rainiest month, rather than July. According to Prajapati, Singh, and Upadhayay (2018, p. 90), this modification causes a delay in planting, which in turn causes harvests to be postponed and, in dry years, perhaps reduced yields. The water shortage that Bundelkhand has been experiencing since independence has worsened dramatically in the last few decades (Radhika Singh, 2021). According to Chen et al. (2026), the frequency of severe droughts in this area increased threefold between 1968 and 1992, compared to 16 years in the 18th and 19th centuries. The area has seen eight significant droughts in the last fifteen years, with the frequency of these events on the increase (Saini, 2023). Bundelkhand has little natural groundwater recharge because of its hilly landscape. To tackle this, the Chandelas and Bundelas constructed reservoir networks that rapidly refilled shallow aquifers, thereby decreasing the amount of runoff caused by rain (Group, 2018).

Hydrological impacts

The geology of Bundelkhand is hard rock, which means that groundwater recharge is limited. The majority of the rainfall in the region falls between July and August, and it typically comes as heavy rains that create runoff (Chourasia & Jhariya, 2020, p. 2). Groundwater overexploitation, unpredictable precipitation, and deforestation are the main causes of the acute water problem in the Bundelkhand area. As a result, farming, availability of potable water, and environmental conditions have all suffered. The ecological equilibrium of this area is greatly threatened by water shortages due to the relatively low average rainfall in this region (Chauhan, 2024, p. 351).

Water poverty index

The Water Poverty Index comprises five main components, which are access to water, water availability (quantity), water quality, the distribution and allocation of water use across households, food production and other economic activities, and the overall capacity for water management, including environmental sustainability (Sayyar et al., 2022, p. 2). In Sagar district, the WPI score is highest, followed by Damoh, Datia, Chhatarpur, Panna, and Tikamgarh. Since the water resources of Tikamgarh, Datia, Damoh, and Chhatarpur districts are in such bad shape, water resource management in these districts is crucial. When it comes to the Resource and Access component, Tikamgarh district is in a terrible state. While Panna has a very poor condition in the Access, Use, and Capacity components. The accessibility component is in very bad shape in the Chhatarpur district (Yadav, 2020, p. 533).

Risk associated with water stress

Risk is the possibility that a climate-related hazard may have negative effects on both natural and human systems, because of the interplay between the hazard and the exposed and vulnerable state of the affected system. Risk considers both the possibility of being exposed to a danger and the severity of that danger's effects. "Risk" may also refer to the possibility of unfavourable outcomes from climate change adaptation or mitigation efforts (IPCC, 2018). Climate change poses risks to human health via several pathways. Various scenarios for future emissions of greenhouse gases, as well as different predictions of climate change, were shown to be associated with these climate-health linkages (Bununu et al., 2023).

Potential impacts of climate change on major water sectors focusing on water scarcity

Food security issues are made considerably worse in this semi-arid area by a lack of water, poor soil quality, and low agricultural production. Since more than 90% of Bundelkhand's rural income comes from crop production, livestock husbandry, and seasonal migration, the region suffers greatly from the frequent droughts (R. Ranjan, 2021).

Table 1. Impact of water scarcity on different sectors

Sector	**Impacts**
Environment	Reduced environmental flow Lowering groundwater tables Drying wetlands Forest fires Water pollution, saltwater intrusion
Agriculture/ aquaculture	Declining fisheries Loss of crops and livestock Reduced aquaculture production Salinization
Water supply and sanitation	Shortage of drinking water Reduced hygiene Disease outbreaks Waste accumulation
Energy /Industry	Reduced hydropower capacity Lack of cooling and production water Concentration of pollutants
Infrastructure	Disruption and destruction of infrastructure Limited navigation

Source: (Cap-Net, 2018, p. 18).

Socio-economic Impacts

Water scarcity and climate change are having far-reaching consequences that threaten public health and social stability as well as the agricultural and environmental sectors. Poverty, social instability, and outmigration may result from unstable agricultural earnings and livelihoods, which disproportionately affect women and the elderly. Women in low-sex ratio societies are more vulnerable to the effects of climate change because of the cultural and societal pressures they face. According to Prakash and Mishra (2021, p. 211), women in the area often do the most fundamental household tasks, like gathering firewood and fodder and finding a reliable source of drinking water. By altering the amount of physical exposure to temperature levels, climatic elements are anticipated to influence the patterns of mortality and morbidity (Singh, Avashia, Bhati, & Garg, 2022, p. 4).

Ecological Degradation

Natural habitats in Bundelkhand are deteriorating due to the combined effects of water scarcity and climate change. Due to increasing temperatures and protracted dry spells, wetlands and other bodies of water might dry up, threatening aquatic biodiversity. Because of their sensitivity to the effects of climate change, the distribution and composition of forest resources in the Bundelkhand area are vulnerable to climatic uncertainty. Loss of habitat and changes to the local fauna are further outcomes. Similarly, the loss of soil fertility in this semi-arid terrain is a direct result of climate change, which will inevitably impact the wasteland condition. (Prakash & Mishra, 2021, p. 213).

Depletion and Degradation of Water Resources

The water resources of Bundelkhand are being greatly affected by the changing climate, both in terms of quantity and quality. Surface water flows in rivers and other conventional bodies of water, such as talabs, tanks, and wells, are expected to decline due to lower rainfall and changing precipitation patterns (Chauhan, 2024). At the same time, the region's groundwater aquifers are being alarmingly depleted due to the rising dependence on groundwater for irrigation, which is being pushed by rainfall unpredictability and the growth of irrigated agriculture (Desnavi, 2024). Small and marginal farmers are hit the hardest by the increased expense of pumping caused by a declining water table. Agricultural runoff and sediment pollution of water sources, as well as soil erosion, may result from more intense rainfall events, which in turn affects water quality and poses health hazards to the population. In addition to heightening social tensions, the lack of accessible, clean water supplies may spark disputes over who gets to share the resource.

Agricultural Risk: The agricultural challenges faced by the Bundelkhand area include shallow red soils, undulating terrain, severe weather, and frequent droughts. As a result, crop intensity is low, crop production is poor, and soil loss due to erosion and runoff is significant. It is challenging to grow crops on leftover moisture after a rain since the soils in the area do not have a high ability to store moisture (Kumar et al., 2022). Prakash and Mishra (2021, p. 206) estimate that 90% of the agricultural population falls into one of three categories: small, marginal, or landless. Reduced agricultural output and fewer livelihood choices are two negative outcomes of climate change. Also, it's making things worse for things like food insecurity, fuel, wool, and fodder shortages, biodiversity loss, and human migratory patterns. In the Bundelkhand region, seasonal migration, animal husbandry, and agriculture make up the bulk of rural revenue. (Jatav S. S., 2024, p. 3).

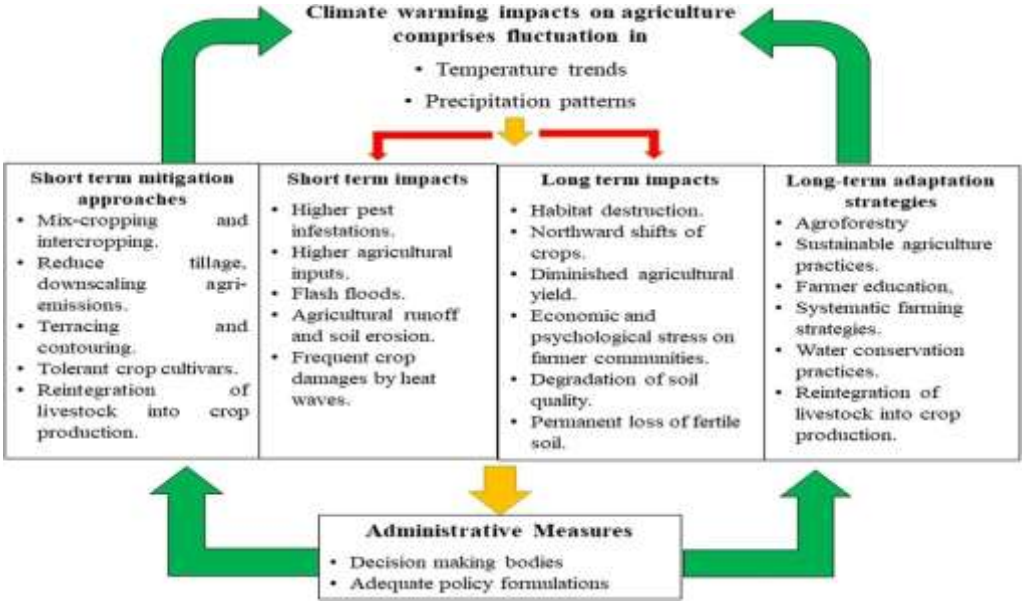

Fig. 2. Climate warming impact on agriculture. **Source**: (Abbass et al., 2022, p. 42546).

Resilience Mechanisms

A resilient social, economic, or environmental system is one that can quickly and effectively absorb, adapt, transform, and recover from the impacts of a hazard that is, one that can do so while preserving and restoring its essential basic structures and functions and while also retaining the ability to adapt, learn, and transform (UN-Water, 2020, p. 30).

Traditional Knowledge and Practices

Traditional water collecting and management strategies in Bundelkhand have a long history of helping to alleviate water shortage. To collect and store rainwater for later use in irrigation, household uses, and cattle, structures such as talabs, bandhis, and baoris were constructed. Conventional farming methods include growing crops that can withstand dry conditions (such as local millets). The area has a long history of cultivating drought-resistant crops, including mustard, gram, and legumes, which are characterised by their extensive root systems. A change, however, occurred during the Green Revolution when high-yielding seed types were adopted. Soybean, cotton, and wheat farming ensued in Bundelkhand, an area already struggling with water constraints. Worsening the already-present water issue, the growing use of chemical fertilisers and water further depleted already-scarce water supplies and hastened environmental deterioration (Desnavi, 2024).

Community-Based Initiatives

In Bundelkhand, a plethora of community-driven projects are springing up to deal with water scarcity and adapt to unpredictable weather. For more fair distribution and management of water, they include forming water user groups (Pani Panchayats) and bringing back traditional water harvesting infrastructure. Sustainable agricultural techniques, such as organic farming and water-efficient irrigation, as well as the development of small-scale water collection structures and afforestation initiatives, are advocated for in the context of participatory watershed management. Water conservation and sustainable livelihood choices are greatly advanced by self-help groups (SHGs), especially when women are involved.

Government and Non-Governmental Interventions:

Bundelkhand is the target of several initiatives launched by federal and state governments to combat water scarcity and encourage adaptation to climate change. Initiatives such as PMKSY, watershed development programs, large-scale irrigation projects (which frequently encounter issues with equity and efficiency), and agricultural extension services' attempts to disseminate information on climate-resilient farming practices are all part of this category. To improve water management and sustainable agriculture, mobilise communities, advocate for policy changes, and help people connect with government initiatives, NGOs are essential. In addition to studying the effects of climate change on the area, research institutes are working on drought-resistant agricultural types. Inadequate money, a lack of interdepartmental coordination, a lack of community involvement in planning and execution, and difficulties in last-mile delivery are common problems that restrict the efficacy of these initiatives.

Technological Interventions

A growing body of evidence suggests that technological interventions, including solar pumps and drip irrigation, might help farmers in Madhya Pradesh's drought-prone Bundelkhand area better withstand the effects of climate change. There is much promise for water savings from drip irrigation systems, which use a system of pipes and emitters to supply water directly to plant roots. For agriculture to become more water efficient, techniques such as drip and sprinkler irrigation, rain-gun, micro-sprinklers, and subsurface drip systems are essential (Mohan et al., 2024, p. 2). Solar-powered pumps have also become popular, allowing farmers to irrigate crops during crucial development phases. These pumps provide a sustainable energy source for extracting groundwater, and they are especially useful in rural regions without reliable power. Since these methods have substantial upfront costs and are not readily available for financing or subsidies, just 5% of farmers in Bundelkhand use drip irrigation. The region's hard rock geology restricts the supply of groundwater for solar pumps, and there is a lack of technical know-how and maintenance issues. According to NITI Aayog, to scale these interventions, specific governmental backing is needed, including subsidies that cover 50-70% of the installation costs and training programs that increase farmer capacity (Aayog, 2021).

Adaptation Strategies

According to the United Nations World Water Development Report 2020: Water and Climate Change (p. 30), adaptation is the process by which natural or human systems are altered in reaction to current or future climate stimuli or their impacts, with the goal of mitigating negative impacts or making the most of positive ones. In response to real or anticipated climatic stimuli and their impacts, ecological, social, or economic systems undergo adaptation (Chen et al., 2026). The process of changing current processes, practices, and systems to mitigate the effects of climate change or capitalise on its opportunities is known as adaptation. To put it simply, countries and communities will need to discover strategies to adapt to the

circumstances to deal with the current and future repercussions of climate change (Adaptation and resilience, n.d.). Actions done to mitigate the negative consequences of climate change and make the most of its positive aspects are collectively known as adaptation (UN-Water, 2020, p. 30).

Protecting people, livelihoods, and ecosystems from the long-term effects of climate change requires a comprehensive strategy that includes adaptation. When planning for and implementing adaptation, it is important to draw from a variety of sources, including current scientific understanding as well as traditional wisdom, indigenous knowledge, and local knowledge systems (Adaptation and resilience, n.d.). Adaptation and mitigation activities that prioritise equality, social justice, climate justice, rights-based approaches, and inclusiveness may lead to more sustainable outcomes, fewer trade-offs, support for transformational change, and advancement of climate-resilient development (IPCC, 2023, p. 31).

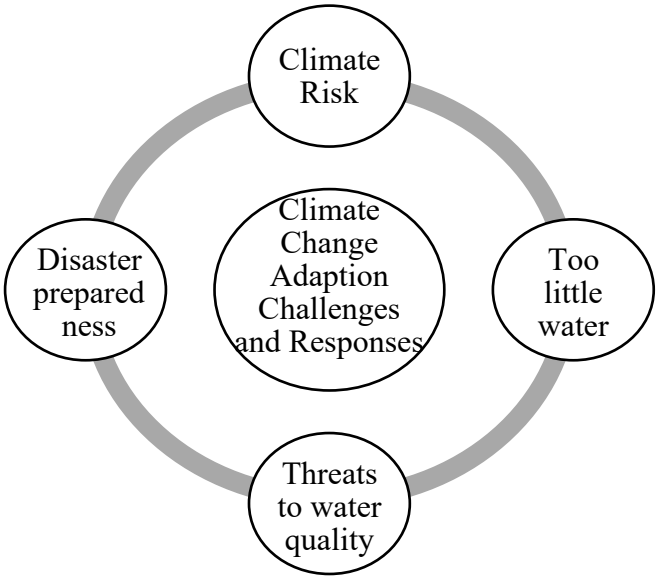

Fig. 3. Climate change adaptation challenges related to water. **Source**: (Cap-Net, 2018, p. 16)

Adaptive methods are ineffective in mitigating climate change. To lessen the toll on human health and slow the spread of illnesses, impacted regions should see more financing for adaptation and coping initiatives (Schmidt, 2022).

Table 2. Adaptation strategies for Drought and Water Stress in Bundelkhand Region

Sr. No.	Adaptation Strategies
1	Modification in cropping patterns
2	Diversification into non-agricultural livelihoods
3	Adoption of short-duration crop varieties
4	Implementation of crop weather insurance schemes
5	Provision of institutional credit and financial assistance
6	Seasonal out-migration for alternative income
7	Balance and judicious application of bio-inoculants
8	Integrated crop- livestock farming systems
9	Intercropping

10	Promotion of drought-resistant crop varieties
11	Rejuvenation of traditional water bodies

Crop Diversification

Multiple studies have shown that farmers can successfully adjust to the unpredictable climate change. As an example, in response to increasingly frequent weather fluctuations, farmers in some locations have adjusted their farming patterns.

More efficient irrigation systems are one example of how farmers have embraced contemporary technology in their fight against drought (Rianti, Hindarti, & Maula, 2024, p. 2). Due to the present climate, where water shortages and climate change are creating obstacles to the production of wheat and rice (Joshi, Deepa, Joshi, & Sharma, 2023).

To create climate resilience projects that are successful, widely accepted, and have an impact, it is crucial to understand the factors that influence farmers' views on the unpredictability of weather conditions. Rural smallholder farmers are more susceptible to weather extremes since they are less able to adjust and rely on rainfed agriculture (Bitew & Minale, 2024). Farmers have diversified their crops, conserved soil, shifted planting dates, and boosted irrigation, among other changes, to lessen the effects of climatic unpredictability, according to the study. Although factors including a lack of expertise and resources restrict their widespread application, these adaptations are propelled by access to climatic information, credit, and extension services. To make farmers in the area more resistant to the effects of climate change, the research stresses the need to increase access to weather predictions, strengthen institutional support, and encourage the use of inexpensive adaptation technology (Deressa, Hassan, & Ringler, 2011).

Policy and Governance

The role that government policies and assistance play in mitigating the effects of climate change is another topic that farmers may bring up. The accessibility of subsidies and financial aid for adopting climate-resilient activities may be an issue they raise. Farmers often consult agricultural extension specialists for advice and assistance in adjusting to the effects of climate change on their farming operations. Raza et al. (2023) emphasise the need for farmers, extension workers, and lawmakers to work together to improve agricultural resilience and production amid climate change. The government of India has entrusted the National Bank for Agriculture and Rural Development (NABARD) with the responsibility of carrying out adaptation initiatives funded by the National Adaptation Fund for Climate Change (NAFCC). Project creation, review, approval, funding distribution, oversight and assessment, and stakeholder capacity building, including state governments, would all fall under NABARD's purview under this arrangement. SAPCC would serve as the source of project ideas and concepts. Natural resource management; agricultural production; livestock and fisheries; and the establishment of institutional frameworks for the continuation and expansion of the planned activities make up the four main components of the interventions (Pratibha, 2019, p. 2).

Water Management

To make agriculture more resistant to climate change and water scarcity, water management techniques like micro-irrigation, water harvesting, and laser land levelling, in addition to practices like agroforestry and zero-tillage, greatly improve the efficiency with which water and nutrients are used, increase soil fertility, and decrease erosion. Water storage, groundwater recharge, and agricultural production may be further enhanced by community-driven measures such as desilting tanks, building farm ponds and check dams, and using in situ soil moisture conservation techniques (Rao, Bara, Manichandana, Jagadesh, & Karthik, 2024, pp. 141-142). Improved groundwater recharge, more irrigated land, higher crop yields, and increased resistance to climate change are all outcomes of Bundelkhand's water management practices, which include farm ponds, micro-irrigation, zero-tillage, and community tank restoration. These methods, which have the backing of NICRA, boost farmers' earnings and soil quality while cutting down on water and energy use. The lack of technical understanding, high prices, and governance deficiencies, however, prevent broad implementation. For the region's water management and agricultural resilience to be sustainable, community-based governance, coordinated methods, and targeted policies are crucial (S, G, M, M, & K, 2024).

Enhanced Irrigation Facilities

In Bundelkhand, where water shortage is a big problem, one important adaptation method is to improve the irrigation system. Drip and sprinkler irrigation are two examples of the micro-irrigation technologies that farmers are putting money into to help them save water. To further recharge groundwater and provide additional irrigation during dry times, community-led activities have been put in place, such as renovating traditional water gathering infrastructure (e.g., check dams, farm ponds and tanks) (Garg et al., 2020). For small and marginal farmers in particular, the revitalisation of old community tanks increased irrigated land, crop yields, and farm revenues. Rural communities' standard of living was enhanced as a result of tank repair since it created job opportunities and encouraged crop diversification. In order to guarantee sustainable agriculture in areas prone to drought, our results highlight the economic and ecological advantages of TCT rejuvenation and call for community-based water management (Umesh, Kambale, Reddy, & Jain, 2024).

Conservation Agriculture

Reversing the downward cycle of resource deterioration and making better use of natural resources is the goal of conservation agriculture (CA), a crucial environmentally beneficial practice. Research at CRIDA in rainfed areas using different cropping methods has shown that CA has lower yields in the first several years, but it might eventually surpass conventional tillage.

Soil and water conservation measures for various rainfall zones

The table below illustrates recommended soil and water conservation techniques tailored to different annual rainfall levels. These practices help reduce soil erosion, improve retention, and enhance agricultural productivity in rainfed regions. These measures are highly relevant for semi-arid regions like Bundelkhand, where rainfall is erratic and drought is common. Farmers can select appropriate techniques according to their local rainfall pattern to improve water use efficiency and reduce land degradation.

Table 3. Climate-Smart Soil and Water Management Practices in Low to High Rainfall Zones

Rainfall < 500 mm	**Rainfall 500-750 mm**	**Rainfall 750-1000 mm**	**Rainfall >1000 mm**
In-situ moisture conservation between rows	In-situ moisture conservation between rows	Vertical mulching in black soils	Vertical mulching in black soils
Contour cultivation	Live bunds	Contour cultivation	Field bunds
Dead Furrows	Contour cultivation	Dead Furrows	Graded bunds
Field bunds	Field bunds	Live bunds	Live bunds
Tie bunds	Tie bunds	Minimum tillage	
Mulching	Mulching	Graded bunds	
Ploughing across the slope	Dead Furrows	Cultivation of crops across the slope	
	Vertical mulching in black soils		

Source: Adapted from Pratibha (2019, p. 41).

Less Water-Consuming Crops

The semi-arid climate of Bundelkhand is ideal for water-efficient crops like pulses, sorghum, and millets; thus, farmers there are replanting these crops to combat water shortages. In addition to being drought-tolerant, these crops are economical since they need less input. According to Jatav and Singh (2023), decreasing rainfall and water tables have led farmers in the Bundelkhand region to shift their focus from water-intensive crops like wheat to less water-intensive crops like chickpea. Another important group of climate-resilient crops is millets, which thrive in (semi)arid regions.

DISCUSSION

Based on the synthesis of existing literature, it is evident that climate change and water stress are intricately linked in the Bundelkhand region. Rising temperatures, erratic rainfall patterns, and anthropogenic factors have intensified water scarcity,

which in turn adversely affects agriculture, livelihoods, and ecosystems. The following figure summarizes the key relationships identified through the literature review. It depicts the primary climate change drivers, resulting water stress factors, their socio-economic and environmental impacts, prevailing vulnerabilities and potential adaptation and resilience strategies.

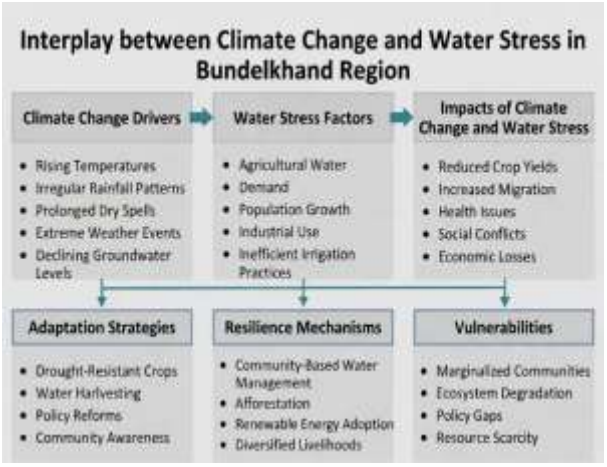

Fig. 4. Interplay between climate change and water stress in Bundelkhand Region

Climate change triggers water stress, which creates serious impacts and makes certain communities highly vulnerable. However, through proper adaptation strategies and resilience mechanisms, the region can reduce these negative effects and build a more sustainable future.

CONCLUSION

Climate change and water scarcity are interacting in a way that is having a devastating effect on the Bundelkhand area of Madhya Pradesh, threatening both the region's economy and ecology. Water shortage, groundwater depletion, and agricultural susceptibility are worsened in this semi-arid area because of climate-induced changes, according to this study. These changes include unpredictable rainfall, increasing temperatures, and frequent severe weather events. Women and smallholder farmers are among the most vulnerable populations, and they bear the brunt of these problems in the form of increased hazards like droughts and floods as well as socioeconomic stresses like crop failures, livelihood instability, and out-migration. Drip irrigation, community-led watershed programs, and indigenous water management methods like talabs and bandhis have helped Bundelkhand remain resilient in the face of these challenges. However, these approaches are not easily scalable due to factors including high prices, a lack of technical competence, and governance gaps.

This paper promotes a comprehensive adaptation framework to deal with the growing dangers and encourage sustainable development. Important measures include reviving and increasing irrigation efficiency with micro-irrigation systems, encouraging agricultural diversity with drought-tolerant types and old water collection buildings. Scaling up these approaches requires strengthening community-based governance, increasing access to climate information, and encouraging cooperation among politicians, NGOs, and local people. Further ways to strengthen resistance to climate change include making sure resources are distributed fairly and combining traditional knowledge with contemporary technology. Bundelkhand can provide water security and livelihood sustainability by prioritizing sustainable water management, ecological restoration, and inclusive policy initiatives. This would alleviate the detrimental consequences of climate change and water stress. This study adds to the existing body of knowledge on climate resilience and provides policymakers and stakeholders with practical insights to help create a future where Bundelkhand and other vulnerable places throughout the world can thrive despite the effects of climate change.

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