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Present status and future scenario of water security in the Barind area of Bangladesh

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Abstract

The present study assessed the spatial and temporal dynamics of water security from 1988 to 2021 and projected the future scenarios for 2026 and 2031 in the Barind area of Bangladesh. Geospatial techniques such as, weighted overlay method with composite weight levels ranging from 1 to 5 (representing very low to very high water security), were applied to delineate and identify water security conditions across specific locations within the Barind area. A total influence of 100 was distributed among key variables based on their relative importance. Using GIS and remote sensing software, rainfall, temperature, groundwater, and surface water conditions were processed, estimated, and predicted based on collected datasets. The findings reveal a significant deterioration in water security from 1988 to 2021, with a noticeable expansion of both very low and low water security conditions. Very low water security, nearly negligible in 1988, affected 17.08% of the region by 2021. Low water security increased from 12.22% in 1988 to 27.39% in 2021. Moderate water security, initially covering a substantial portion of the region, declined to 41.06% by 2021, while high water security areas dropped sharply from 44.06% in 1988 to just 12.29% by 2021. Throughout this period, very high water security conditions remained consistently limited, covering only 2.18% of the region by 2021. Projections for 2026 and 2031 suggest a further decline in water security, with very low water security predicted to affect 30.42% of the region by 2031 and low water security expected to cover 36.72%. High water security is projected to shrink to just 4.47% of the region, while very high water security will remain stable but limited, covering only 1.43%. These trends signify the pressing needs for improved water management strategies such as surface water conservation, sustainable irrigation practices, managed aquifer recharge and afforestation to mitigate increasing water scarcity and ensure sustainable resource use in the Barind area.

Keywords: Climate change, future prediction, ground water, water security, weighted overlay

Introduction

Water is a critical natural resource that sustains life and is integral to socio-economic development across regions (UN 2021, FAO 2020, IPCC 2022). It is essential for agriculture, energy production, and ecosystems, making it fundamental for both human well-being and economic stability (Ahmad *et al*. 2023). The negative impacts of climate change, especially global warming, have significantly exacerbated the global reduction in water resources (IPCC 2022, UN 2021). Similarly, these effects have been observed and documented at the regional level. However, water security, which indicates the capacity of a population to access adequate water of acceptable quality for human well-being, socio-economic development, and environmental sustainability (UN-Water 2013), is increasingly at risk in Bangladesh (Adeel 2017) it is ambitious as it aims to fix major global problems in a 15-year span. It signifies a paradigm shift in international development that emphasizes the role of national governments and other domestic stakeholders. Water security is a keystone element in achieving the 2030 Agenda – not just for Sustainable Development Goal (SDG. The broader implications of climate change, including altered precipitation patterns, higher temperatures, and rising sea levels, have serious consequences for Bangladesh's water resources (Hossain *et al.* 2012) Government of People' Republic of Bangladesh. Climate Change Cell, Dhaka, 2007. The country ranked 7th in the Global Climate Risk Index 2020, is one of the most climate-vulnerable regions globally (Eckstein *et al.* 2020). With frequent floods, cyclones, and droughts, the nation's hydrological risks are compounded by desertification, riverbank erosion, and salinization, further straining agriculture and food security (Rahman 2015). These challenges necessitate robust policy responses, as reflected in the government's efforts through various frameworks such as the National Adaptation Programme of Action (NAPA) 2005 and the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) 2009 (MoEF 2009). More recent policies include the Bangladesh Climate Change Action Plan (BCCAP) 2021-2025, which extends the BCCSAP and provides updated strategies for managing climate impacts and enhancing resilience (MoEFCC 2023). Additionally, the National Adaptation Plan (NAP) 2021 builds on the NAPA 2005 to outline long-term adaptation strategies for managing climate risks and improving resilience across various sectors, including water management (MoEFCC 2023). Furthermore, the Delta Plan 2100 addresses long-term water management and climate change challenges in the delta region, focusing on sustainable water use and resilience-building (Bangladesh Delta Plan 2018).

There is substantial research evidence of reduced surface and groundwater levels across different regions of Bangladesh (Shaw *et al.* 2013). In particular, the Barind area of northwestern Bangladesh is experiencing the brunt of these changes, with rising temperatures, droughts, and depleting groundwater supplies (Hossain *et al.* 2020, Ahmed *et al.* 2022, Rahman *et al.* 2023). Studies have documented that groundwater abstraction has rapidly increased in Bangladesh, depleting reserves and pushing the water table further down (Basharat 2014, Zahid 2015, BGS 2015). The impacts of such over-extraction are particularly felt in water-stressed regions such as Barind area, where agriculture, which consumes nearly 90% of the country's water, depends heavily on groundwater (Reza *et al.* 2020b, UNDP 2017). As one of the climate-induced hotspots designated in the Bangladesh Delta Plan 2100, the Barind area exemplifies the growing threat of water insecurity exacerbated by climate change (Bangladesh Delta Plan 2018). The groundwater and surface water levels in Bangladesh, particularly in regions like the Barind Tract, have been continuously declining due to both climatic and anthropogenic factors (Sujan *et al.* 2023). Recent studies have confirmed these trends. For example, the Bangladesh Water Development Board (BWDB) has reported ongoing groundwater depletion, primarily driven by intensive agricultural irrigation (Islam *et al.* 2021). Additionally, global data from NASA's GRACE satellites highlight a significant drop in terrestrial water storage across the country, particularly over the last two decades, reinforcing the role of climate change in exacerbating water scarcity (Ahmed *et al.* 2020). Furthermore, a comprehensive analysis by the Asian Development Bank (2022) underscores the link between increased demand for irrigation water and declining aquifer levels in the region. The Barind Multipurpose Development Authority (BMDA), established to alleviate these water challenges, has made strides in afforestation and water extraction through deep and shallow tube wells (Reza *et al.* 2020a). Despite these interventions, groundwater depletion continues, posing a major concern for long-term water security in the region (Islam *et al.* 2017, Ahmed *et al.* 2020 and Rahman *et al.* 2022). The Barind area, marked by erratic rainfall, over-extraction of groundwater, and poor water management, faces exacerbated water stress due to both population growth and climate change (Hosenuzzaman *et al.* 2024, Raza and Khan 2022) untreated industrial effluents, improper disposal of domestic waste, and agricultural runoffs. Furthermore, the availability of surface water is not consistent because of seasonal variation. Due to shortage and inconsistencies in surface water supplies, groundwater acts as the mainstay for agriculture, industrial use, and household consumptions. The depleting groundwater level and contamination from different sources have become a great challenge for Bangladesh. This chapter will highlight the major causes of surface and groundwater contamination along with the potential water management strategies through human and policy intervention nexus.

A complete scenario of recent water pollution status, challenges of safe water, and management approaches will provide insights and help in policy-making to address water scarcity c7hallenges in the delta region of Bangladesh. The population of the Barind area is projected to increase from 18.9 million in 2019 to 23.3 million by 2030. This growing demand for water, combined with climate-induced stressors, is expected to worsen existing challenges (BBS 2020). Moreover, the intensifying impacts of climate change, such as prolonged dry spells, increased evaporation, and saline intrusion, are likely to further deplete groundwater resources (Islam *et al.* 2017). The literature review indicates that water security in the Barind area has not been covered extensively in previous research. Hence, the present study is an endeavor to evaluate the current and future water security in the Barind area of Bangladesh by examining the changes in climatic parameters in the study area.

Study area

The Barind area, encompassing the districts of Rajshahi, Chapai Nawabganj, Naogaon, Joypurhat, Bogra, Sirajganj, Pabna, and Natore in the Rajshahi Division, as well as Thakurgaon, Dinajpur, Panchagar, Rangpur, Kurigram, Nilphamari, Lalmonirhat, and Gaibandha in the Rangpur Division, features a diverse topography. Predominantly a flat plateau with gentle slopes, the region's elevation ranges from 20 to 30 meters above sea level. This elevated terrain is interspersed with small hills and undulating areas. The soil varies from sandy loam to clayey loam, supporting extensive agricultural activities. The drainage system, characterized by a network of rivers, canals, and natural depressions, plays a crucial role in flood management and irrigation. The region's subtropical climate, with distinct wet and dry seasons, impacts water availability and agricultural productivity. Understanding these spatial features is essential for addressing water security challenges and implementing effective policies for the Barind area (Figure 1).

Materials and methods

Modelling current water security: The study used geospatial approach to identify the trends of water security conditions in the study area. Hence, a weighted overlay method was applied in ArcMap (Version: ArcMap 10.3) in which a set of climatic and hydrological parameters was used (Figure 2). The parameters were selected based on a through literature review and adopting opinions from experts in the relevant fields. Previous data on rainfall, temperature, groundwater levels, and surface water in the Barind area have provided valuable insights into the region's water availability, quality, and overall environmental dynamics over the studied periods. Using a weighted overlay method, these variables were combined to produce annual assessments of water security in the Barind area of Bangladesh.

The following weighted overlay method was applied to assess water security for the years 1988, 1997, 2006, 2016 and 2021, using composite weight levels ranging from 1 to 5 (very low to very high) for each variable. The total influence of 100 was distributed among the variables based on their importance, as established by previous research. A total of four variables—rainfall, temperature, groundwater, and surface water—were considered to delineate and identify the water security conditions and the specific locations within the Barind region (Figure 2).

$$\text{Composite Weight} = \text{Weight}_{\text{Temperature}} \times \text{Influence of Temperature} + \text{Weight}_{\text{Rainfall}} \times \text{Influence of Rainfall} + \text{Weight}_{\text{Groundwater}} \times \text{Influence of Groundwater} + \text{Weight}_{\text{SurfaceWater}} \times \text{Influence of Surface Water} + \text{Weight}_{\text{Vegetation}} \times \text{Influence of Vegetation}.$$

Prediction of future water security: For the prediction of water security, data from 2016 and 2021, along with spatial variables, were utilized. A change matrix was developed to illustrate the differences in water security indicators between those years. A relational transition model was established to identify patterns and correlations between the change matrix and spatial variables. Using an Artificial Neural Network (ANN), water security for 2026 was simulated and validated. This process was iterated for 2021 and 2026 to predict water security for 2031. Finally, the results for 2026 and 2031 were visualized in maps.

Data used in the study: The study incorporated meteorological data (i.e. rainfall and temperature)

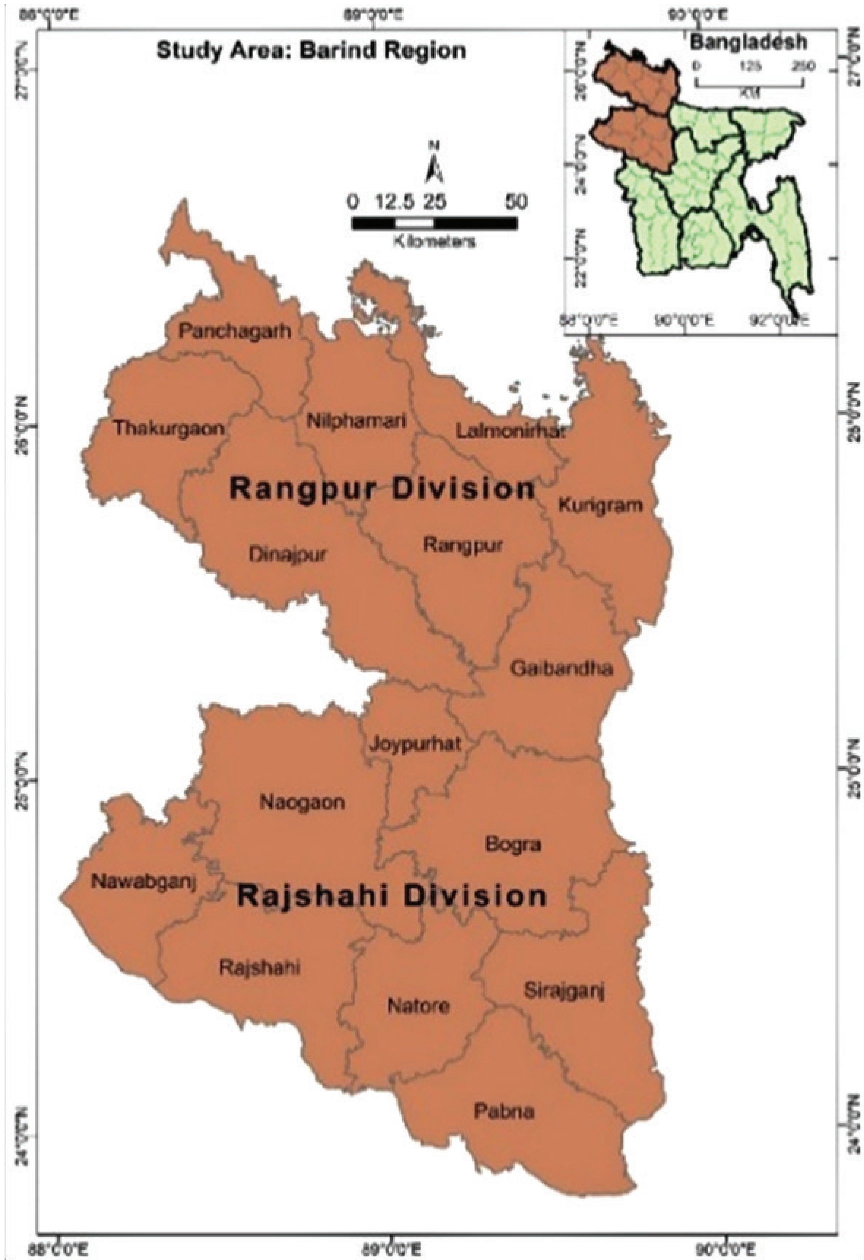

Figure 1. Location of the study area (Barind area) in Bangladesh.

from Bangladesh Meteorological Department for a period spanning 40 years, from 1977 to 2017, as well as groundwater data from the Bangladesh Water Development Board (BWDB) for the years 1997 to 2021. Additionally, USGS GloVis satellite data from 1988 to 2021 were utilized as key variables. The rainfall and temperature variables offer insights into the historical patterns of rainfall and temperature in the Barind area during the selected timeframe. Variations in these variables can impact water availability and quality within the region. Data on groundwater levels measure the depth of underground water in the Barind area over the selected period. Changes in groundwater levels indicate shifts in water availability and storage in the region. Surface water measurements in the Barind area were determined using the modified normalized difference water index (MNDWI)

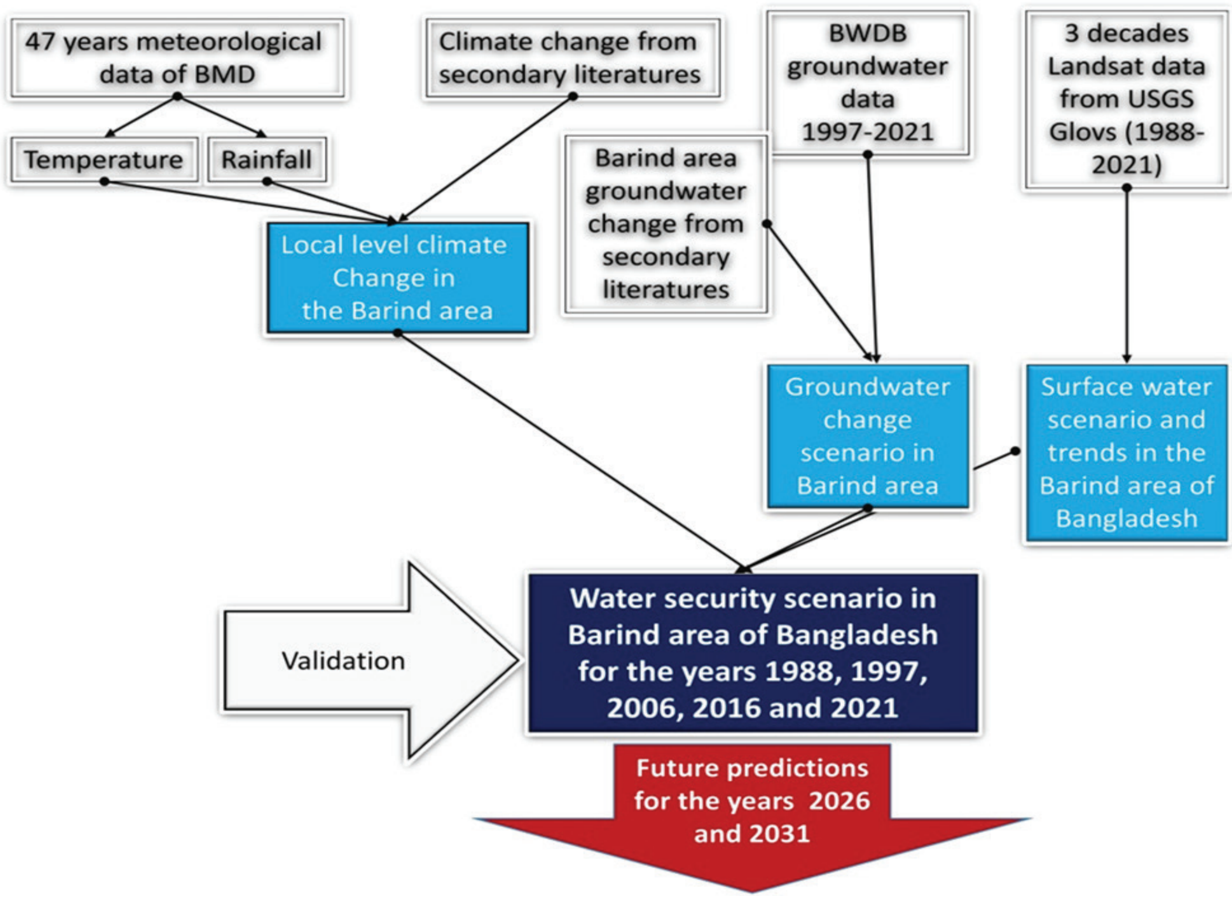

Figure 2. **Methodological flow chart of the study.**

by analyzing Landsat satellite images from 1988 to 2021. These measurements provide an accurate assessment of surface water availability in the region from 1989 to 2022, serving crucial needs for irrigation, industrial applications, and domestic use. Analyzing trends in surface water offers valuable insights into water security and the overall status of the region.

Validation of the results: The study conducted an accuracy assessment for the variables of surface water and vegetation coverage changes in Google Earth Engine. Among the datasets, temperature, rainfall, and groundwater were observed data collected from the government agency. However, the final model results were thoroughly validated by consulting relevant stakeholders, such as the Water Resources Planning Organisation (WARRPO), Bangladesh Water Development Board (BWDB), Bangladesh Agricultural Development Corporation (BADC), Soil Resource Development Institute (SRDI), Department of Agricultural Extension (DAE) and local communities.

Results

Condition of present water security : The water security across the Barind area, measured to pixel/cell values on a scale of 1-5, reveals a significant downward trend between 1988 and 2021. Districts such as Pabna, Natore, and Lalmonirhat with strong negative correlations close to -1.00, show sharp declines in water security, as reflected in their mean pixel values. For instance, a reduction of pixel value for Pabna district from 3.45 in 1988 to 2.27 in 2021, indicates a significant reduction in water availability. This consistent decline is strongly supported by the perfect negative regression (-1.00), indicating a steady worsening of water availability over time (Table 1). Water security was also moderately worsening in districts such as Rajshahi, Joypurhat, and Nawabganj, with negative correlation values ranging between -0.70 and -0.90. These districts exhibit substantial drop in water security. Rajshahi, for example, experienced a decline from 2.45 in 1988 to 1.42 in 2021, marking severe deterioration, as reflected by its correlation coefficient of -0.86. The regression trends in these districts suggest an overall declining trend in the area.

In contrast, districts such as Kurigram, Dinajpur, and Gaibandha are also facing water security challenges, but with weaker negative correlations between -0.50 and -0.70, indicating a slower decline in water security, as shown by their relatively higher pixel values. Kurigram, for instance, obtained a mean pixel value of 4.06 in 1988 and showed a relatively stable water security condition (i.e. 3.77) in 2021. Although the decline is present, the slower pace suggests these districts may have experienced less severe stress on water resources compared to other districts.

Overall, the regression trends and pixel values on the scale of 1-5 highlight widespread degradation of water security in the Barind area (Table 2 and Figure 3). Districts with higher negative correlations and lower pixel values have faced more severe water scarcity, while areas with weaker correlations have shown more resilience but still reflect a general downward trend. The combination of urbanization, deforestation, and climate change appears to be driving these regional declines, leading to critical impacts on water availability.

Table 1. Water security condition on a scale of 1-5 in the Barind area of Bangladesh

District Name	Mean Pixel Value (1988)	Mean Pixel Value (1997)	Mean Pixel Value (2006)	Mean Pixel Value (2016)	Mean Pixel Value (2021)	Regression
Pabna	3.45	3.14	2.95	2.58	2.27	-1.00
Natore	2.89	2.66	2.66	2.25	2.03	-0.97
Lalmonirhat	3.97	3.61	3.6	3.39	3.31	-0.95
Bogra	3.09	2.94	2.98	2.73	2.69	-0.94
Sirajganj	3.73	3.47	3.54	3.25	2.82	-0.93
Rangpur	3.83	3.6	3.56	3.56	3.39	-0.92
Rajshahi	2.45	1.89	2.25	1.7	1.42	-0.86
Joypurhat	2.9	2.25	1.79	1.92	1.85	-0.84
Nawabganj	2.59	1.47	1.68	1.54	1.32	-0.78
Nilphamari	3.98	3.25	3.48	3.38	3.12	-0.76
Panchagarh	3.79	3.06	3.51	3.3	2.73	-0.73
Naogaon	2.75	1.53	1.61	1.61	1.51	-0.71
Kurigram	4.06	3.81	3.75	3.85	3.77	-0.69
Dinajpur	3.42	2.97	3.25	3.25	2.89	-0.56
Thakurgaon	3.33	2.74	3.27	3.08	2.6	-0.55
Gaibandha	3.51	3.5	3.5	3.59	3.26	-0.52

Table 2. Trends of aerial coverage of different categories of water security conditions from 1988 to 2021 in the Barind area of Bangladesh

Condition of Water Security	1988		1997		2006		2016		2021	
	Area (in sq. km)	%	Area (in sq. km)	%	Area (in sq. km)	%	Area (in sq. km)	%	Area (in sq. km)	%
Very low	7.07	0.02	3793.7	11.09	3010.59	8.80	4930.99	14.42	5841.88	17.08
low	4180.7	12.22	6195.44	18.12	6520.05	19.07	7730.91	22.61	9364.68	27.39
Moderate	14774.63	43.17	16220.95	47.44	14638.07	42.81	11474.53	33.56	14040.9	41.06
High	15080.2	44.06	7488.88	21.90	9300.78	27.20	9419.22	27.55	4204.1	12.29
Very High	182.19	0.53	496.58	1.45	726.05	2.12	639.9	1.87	743.99	2.18

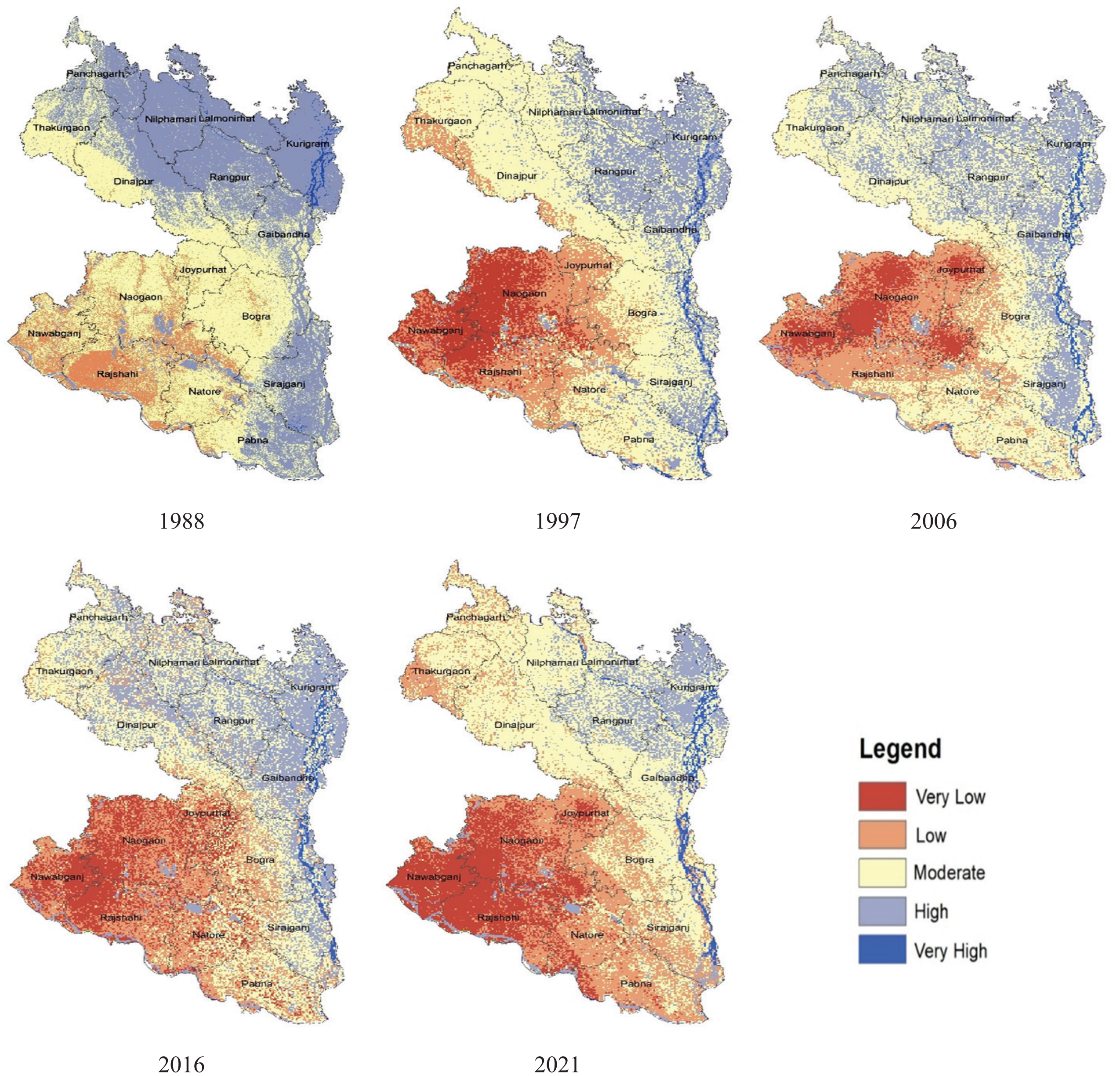

Figure 3. **Potential water security condition in the Barind region of Bangladesh from 1988 to 2021.**

Scenario of future water security : By 2026 and 2031, water security in the Barind area is expected to worsen, with the "very low" and "low" categories expanding significantly. The "high" category would be shrink, while the "very high" category will remain stable. Hence, an effective water management is crucial to address the anticipated shortages and ensure sustainable resource use.

In 2031, several districts are projected to face "very low" water security, indicating severe water scarcity. Naogaon (mean pixel value 1.19), Nawabganj (1.22), Rajshahi (1.27), Joypurhat (1.35), Natore (1.53), and Pabna (1.75) are the most affected, underscoring critical water availability challenges. The areal predictions highlight that by 2026, approximately 8,771.38 square kilometers might fall into this category, covering 25.65% of the region. This area is expected to expand significantly to 10,402.53 square kilometers by 2031, representing 30.42% of the total region (Table 3 and Figure 4). The "low" water security category also shows concerning trends. Districts such as Thakurgaon (mean pixel value 2.03), Bogra (2.11), Panchagarh (2.21), Dinajpur (2.30), Sirajganj (2.34), Nilphamari (2.66), Lalmonirhat (2.79), Gaibandha (2.86), and Rangpur (2.92) are experiencing challenges in maintaining a sustainable water supply. The areal expansion for this category is forecasted to cover 12,115.75 square kilometers in 2026, which constitutes 35.43% of the region. By 2031, this area is expected to increase to 12,557.70 square kilometers, making up 36.72% of the region. However, only one district, Kurigram (mean pixel value is 3.21), was projected to fall into the "moderate" water security category in 2031. This indicates relatively better water availability compared to other districts. The areal prediction for this category shows a coverage of 8,886.09 square kilometers in 2026 (i.e. 25.98% of the region), which is expected to increase slightly to 9,220.64 square kilometers by 2031, representing 26.96% of the region. While this reflects a more balanced water situation, continuous monitoring and management are crucial to maintain these conditions. The "high" water security category is projected to see a significant reduction. In 2026, this category might be anticipated to cover 3,935.31 square kilometers, accounting for 11.51% of the region. By 2031, it is expected to contract to just 1,527.69 square kilometers, or 4.47% of the region. However, the "very high" water security category remains stable. It is expected to cover 489.17 square kilometres in both 2026 and 2031, representing 1.43% of the region.

Discussion

The validation of the results identified an accuracy rate of about 99 percent for each year. During this validation process, the findings were found to be an alignment with the field perceptions of the respective organizations and the local stakeholders. However, Very Low water security conditions in the Barind area of Bangladesh has shown a concerning upward trend from 1988 to 2021. In 1988, Very Low water security was almost negligible, affecting only 0.02% of the region. However, by 1997, this situation had changed significantly, with Very Low water security affecting 11.09% of the region, reflecting a marked decline in water availability. This worsening trend persisted, with Very Low water security covering 8.80% of the region in 2006 and expanding further to 14.42% by 2016. By 2021, Very Low water security had deteriorated alarmingly, affecting 17.08% of the region

Table 3. Areal expansion of water security predicted for the year 2026 and 2031 in the Barind area

Predicted water security condition	2026		2031	
	Area (km^2)	%	Area (km^2)	%
Very low	8771.38	25.65	10402.53	30.42
Low	12115.75	35.43	12557.7	36.72
Moderate	8886.087	25.98	9220.64	26.96
High	3935.31	11.51	1527.69	4.47
Very High	489.17	1.43	489.17	1.43

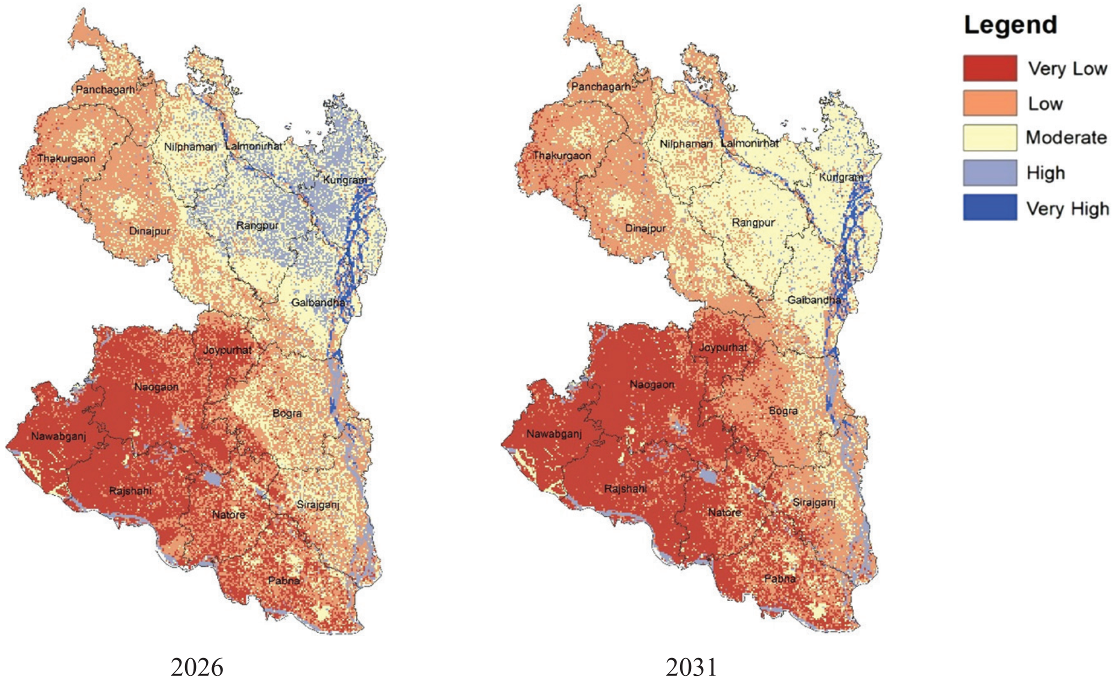

Figure 4. **Areal expansion of water security predictions for the years 2026 and 2031.**

(Table 2 and Figure 3). This significant increase highlights the growing severity of water scarcity, driven by factors such as climate change, urbanization, and environmental degradation, which have led to critical challenges in water management and availability across the Barind area.

Low water security condition in the Barind area of Bangladesh has demonstrated an upward trend from 1988 to 2021, reflects an increasing water stress. In 1988, Low water security affected 12.22% of the region, covering 4,180.7 sq. km, indicating that a moderate portion of the area faced some degree of water scarcity. By 1997, the situation worsened significantly, with Low water security areas expanding to 18.12%, encompassing 6,195.44 sq. km. The trend continued into 2006, with Low water security areas rising to 19.07% (6,520.05 sq. km). In 2016, Low water security further increased to 22.61% (7,730.91 sq. km), reflecting a continued decline in water availability and quality across a larger portion of the region. By 2021, the extent of Low water security had expanded to 27.39% (9,364.68 sq. km), marking a significant rise in areas experiencing substantial water stress. This persistent increase underscores the growing challenges in managing water resources, likely exacerbated by urban expansion, climate change, and environmental degradation. The trend reflects a critical need for improved water management strategies to address the expanding regions facing low water security.

Moderate water security conditions in the Barind area of Bangladesh has undergone notable changes from 1988 to 2021. In 1988, a substantial portion of the region, 43.17% (14,774.63 sq. km), enjoyed moderate water security, indicating that a large area had a reasonably stable water supply. However, by 1997, this proportion increased to 47.44% (16,220.95 sq. km), suggesting a slight shift in water security conditions, with more areas falling into the moderate category as high water security areas declined. The trend continued into 2006, with moderate water security encompassing 42.81% (14,638.07 sq. km) of the region. This slight decrease from 1997 indicates a gradual shift away from high security but still reflects a considerable portion of the region maintaining a stable water supply. By 2016, moderate water security further declined to 33.56% (11,474.53 sq. km), reflecting a more pronounced reduction as areas with lower water security increased. In 2021, moderate water security accounted for 41.06% (14,040.9 sq. km) of the region, showing a partial recovery from previous lows but still indicating a general trend of declining water security. These changes highlight ongoing challenges in maintaining stable water resources amidst growing pressures from urbanization, climate change, and environmental changes.

High water security condition in the Barind area of Bangladesh has seen a significant decline from 1988 to 2021. In 1988, a significant percentage (i.e. 44.06%) of the region, covering 15,080.2 sq. km, was classified as having high water security, indicating that a large area enjoyed optimal water conditions. However, by 1997, this proportion had dropped sharply to 21.90% (7,488.88 sq. km), revealing a considerable decrease in areas with robust water security as pressures on water resources began to intensify. The decline continued into 2006, with high water security areas further shrinking to 27.20% (9,300.78 sq. km). By 2016, only 27.55% (9,419.22 sq. km) of the region maintained high water security, indicating that while there was a slight recovery, the overall trend remained downward. By 2021, the situation had worsened significantly, with high water security covering just 12.29% (4,204.1 sq. km) of the region. This stark reduction underscores a severe decline in regions with optimal water availability, reflecting the increasing impact of urbanization, climate change, and environmental degradation on water resources. The significant loss of high water security areas highlights the growing challenges in ensuring adequate water resources and managing water security effectively in the Barind area.

Very High water security conditions in the Barind area of Bangladesh has remained limited throughout the period from 1988 to 2021, reflecting a generally stable but small proportion of the region with optimal water conditions. In 1988, Very High water security covered 0.53% (182.19 sq. km) of the area, indicating that only a small fraction of the region had exceptional water availability. By 1997, the extent of Very High water security increased to 1.45% (496.58 sq. km), suggesting a modest improvement in certain areas but still representing a minor portion of the region. This trend continued into 2006, with Very High water security covering 2.12% (726.05 sq. km), reflecting a slight expansion but still indicating limited coverage. In 2016, Very High water security covered 1.87% (639.9 sq. km), showing a decrease from the previous period, which may reflect worsening conditions elsewhere or changes in measurement criteria. By 2021, Very High water security accounted for 2.18% (743.99 sq. km) of the region, indicating a marginal increase from 2016. Overall, the extent of Very High water security has been relatively small throughout the years, with only a small proportion of the region experiencing optimal water conditions. The limited coverage highlights that, despite some fluctuations, the number of areas with exceptionally high water security has remained consistently low, emphasizing the challenges in achieving and maintaining such ideal water conditions in the Barind area.

The aerial expansion of very low water security condition in future emphasizes the urgent need for effective water management strategies to mitigate the severe water scarcity (Table 3 and Figure 4). Similarly, the low water security category in future highlight the increasing difficulties in managing water resources across these districts. The noticeable decrease of high water security condition in future underscores the pressing need to preserve and enhance water security in areas currently enjoying higher levels of water availability. The static rate of very high category indicates that while some areas maintain optimal water conditions, the overall trend in water security is concerning, highlighting the need for continued efforts to manage and improve water resources across all categories. However, the local communities in water-stresses Barind area adopt to the shortage of water in a number of techniques. Among them, 'Da Jhoro' and 'Mulching' are two most efficient indigenous practices to retain moisture in their agricultural fields. Moreover, local government (e.g. DPHE) took several initiatives such as Deep Tube Well, Shallow Tube Well and Managed Aquifer Recharge to manage surface and ground water in the Barind area.

Conclusions

Over the past 40 years, the Barind area has witnessed significant variability in temperature and rainfall. Average temperatures have hovered around 34.75°C, with fluctuations of 1.23°C. Some districts, like Pabna and Bogra, have experienced rising temperatures, while others, such as Nilphamari, have seen cooling trends. Rainfall has varied widely, from a high of 25,722.63 mm to a low of 12,017.2 mm, averaging 18,765.04 mm. This variability has resulted in increasing rainfall in districts such as Panchagarh and Nilphamari, contrasted by decreasing trends in Naogaon and Rajshahi, with Pabna showing the most significant decrease. Looking ahead, water security is expected to worsen significantly by 2026 and 2031. The "very low" category has been projected to cover 25.65% of the region by 2026 and 30.42% by 2031, with severe shortages anticipated in districts like Naogaon and Rajshahi. The "low" category would also be expanded, reaching 35.43% in 2026 and 36.72% by 2031. These trends emphasize the urgent need for improved water management strategies to address the expanding areas of scarcity and to sustain current water conditions. The increasing decline of water resources indicates the pressing needs for improved water management strategies such as surface water conservation, sustainable irrigation practices, managed aquifer recharge and afforestation to mitigate increasing water scarcity and ensure sustainable resource use in the Barind area.

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