

# Mapping for Groundwater Stressed Areas in Barind Region of Bangladesh and Its Implication on Water Management

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## Abstract

The combined effects of climate change, low rainfall, higher abstraction and less recharge due to thick upper clay layer are causing the depletion of the Groundwater level in Barind region of Bangladesh. This research aims to identify the water stressed area for better water resource management. For the purpose of mapping groundwater stressed area, water stress index for each union has been estimated using DRAHQEL method where seven parameters have been considered. The parameters are: 1) Depth to groundwater table [D], 2) Actual recharge [R], 3) Aquifer thickness [A], 4) Media of unsaturated zone [U], 5) Hydraulic conductivity of the aquifer [H], 6) Groundwater quality [Q], 7) Environmental issues [E], and 8) Trend of groundwater level [L]. It has been observed that in Rajshahi district, out of the total 71 unions, 13 unions show very high water stressed, 16 unions have high and 30 unions are moderate water stressed area. In Chapai Nawabganj district, out of the total 45 unions, 10 unions show very high, 10 unions show high and 14 unions are moderate water stressed area. In Naogaon district, out of the total 99 unions, 24 unions show very high water stressed, 14 unions show high and 22 unions are moderate water stressed area. These findings suggest that immediate attention should be given to these stressed areas to ensure sustainable water management and mitigate the impact of water stress on agro-socio-economic condition of Barind region.

## Keywords

Recharge, WSI, DGWT, Declining Trend, Low Water Consuming Crops,

## 1. Introduction

The Barind area is situated in the north-west region of Bangladesh and is a water-stressed area. Once, there was only one crops, *i.e.* rain-fed Amon rice. Under Barind Integrated Area Development Project in 1985, and later Barind Multipurpose Development Authority (BMDA) in 1992 used new water extraction technology and innovative management practices such as deep tubewells (DTWs) fitted with smart card-operated electric pumps to develop drought-resilient irrigation. The introduction of these projects helped to reduce the poverty and achieve self-sufficiency in rice production. BMDA introduced inverted DTWs and a prepaid smart metering system that has transformed agriculture into revolution. Cropping intensity has risen from 117 percent to 200 percent, higher than the national average of 175 percent [1]. The results have helped reduce poverty in the region from 57 percent in 2000 to 36 percent in 2010 [2].

Dependence on groundwater as a reliable source of water for irrigation and domestic uses has been increasing in many parts of the world [3] [4]. This is driven by the variability of surface water availability, exacerbated by changing hydrological patterns due to climate change [5]-[11].

Several countries in South Asia including India, Pakistan and Bangladesh rely on the groundwater resources available from the vast aquifers of the Indus, the Ganges and the Brahmaputra river basins for irrigated agriculture [9]-[12]. While these basins host several high yielding aquifers, continuous availability of safe and sustainable groundwater in the region is in serious doubt [13]-[16].

Bangladesh occupies a major part of the delta formed by the Ganga-Brahmaputra-Meghna river systems and has significant groundwater resources which have been exploited since the early 1960s with the advent of shallow and deep tube well technologies [5]. Limited availability of surface water during the dry season triggered the extensive development of groundwater in the last few decades [4] [17]. Groundwater recharge and discharge in Bangladesh has a seasonal dynamic driven by the monsoons. Groundwater recharge occurs predominantly during the wet or monsoon season (June to September) and predominant withdrawal occurs during the dry season (January to April) [18]. Towards the end of the wet season recharge period, the water table reaches close to the surface in much of the north-west region [19]. Groundwater withdrawal and other discharges result in lowest water levels by the end of the dry season. There are concerns about continuous declination of groundwater levels, resulting in a temporary halt in DTW expansion. The irrigation, in this area is mainly groundwater dependent and more than 97% of groundwater is used for agricultural purposes. However, for better management and protecting the area from any negative environmental impact, it is crucial for mapping the water stressed area.

Groundwater is a crucial natural resource for sustainable environmental development and high agricultural production. Groundwater levels have been steadily falling in several areas in the north-west region of Bangladesh in recent years, and the main causes are agricultural intensification, overexploitation, population increase, industrialization, insufficient recharge, low permeability and climate change [20]-[26]. In addition, factors like deforestation, impermeable surfaces, and rising global temperatures caused by climate change have an impact on groundwater recharge [6] [27]. The huge withdrawal of groundwater by millions of independent farmers is called the “Silent Revolution” as it happens to 70 percent of agriculture. In recent decades, climate change has an adverse negative impact on groundwater levels. Therefore, a significant change in the amount of groundwater might result from the uneven distribution of rainfall [28]-[30].

The northwest region is often referred to as the food bowl of Bangladesh given the intensive irrigated agriculture of rice and other food crops in the region [8]-[33]. The northwest region of Bangladesh has the largest cropping areas in Bangladesh which rely on availability of fresh groundwater for irrigation, especially during the dry seasons [13] [31]. Groundwater use dominates irrigation water supply in many areas with up to 97% of irrigation water supply coming from groundwater in this region. Intensive groundwater use for irrigation has been believed to be the reason for observed trends in groundwater level declines in some areas of north-west Bangladesh [34] [35]. Declining groundwater levels, especially in the Barind area [8] [14] [32] have necessitated development of policy and management measures such as rainwater harvesting and recharge schemes, reduced groundwater use and conjunctive management for the sustainable use of water resources particularly groundwater resources.

Several researchers have performed many techniques to identify the groundwater potentiality and susceptibility zonation mapping. Multi-criteria decision analysis (MCDA) is an important GIS-based method that is used extensively not only for groundwater level detection, but also used in many hazards, risk, and susceptibility assessments [36] [37]. Analytical hierarchical process (AHP) is a subjective method of MCDA technique used by scholars in various countries [10] [39] etc., were used in groundwater-based research. But for groundwater stress zonation, there is still insufficient work although it is essential to identify it worldwide.

Several factors affect the recharge potential of groundwater which include topography, land use, and precipitation. Studies have shown that areas with higher elevations and lower levels of land use tend to have higher recharge potential. Additionally, areas with higher precipitation tend to have higher recharge potential. Ahmed [40] developed a spatio-temporal Groundwater method for determining vulnerability which considered 18 factors including six climatic factors. Adham [41] also determined Recharge Potential on the whole Barind Tract using WLC method. Nowreen [42] developed a potential map for groundwater abstraction using WLC and Water table fluctuation techniques. IWM [26] suggested for crop diversification with less water consuming crops for the area.

Identifying groundwater stressed areas in the Barind region is crucial for implementing sustainable water management practices, such as conjunctive water use and managed aquifer recharge or artificial recharge, which mitigate declining groundwater levels, prevent over-extraction for irrigation, and enhance water security for the region.

This study aims to identify the groundwater stressed areas and classify the stressed areas based on its recharge potential and abstraction for the purpose of better management of water resources in this area and protecting the areas from negative environmental impact as well as reducing the declining trend of groundwater.

## 2. Study Area

The study area comprises of Rajshahi, Chapai Nawabganj and Naogaon Districts. The elevation of the study area is plain in the eastern part, dissected and undulating in the middle and western part. Elevation of the area varies from 9.00 m PWD to 47.0 m PWD. The Atrai, Mahanada and the Punorbhaba are the major rivers in study area. The study area appears to be well drained because of these rivers and several small rivers. The study area is shown in **Figure 1**.

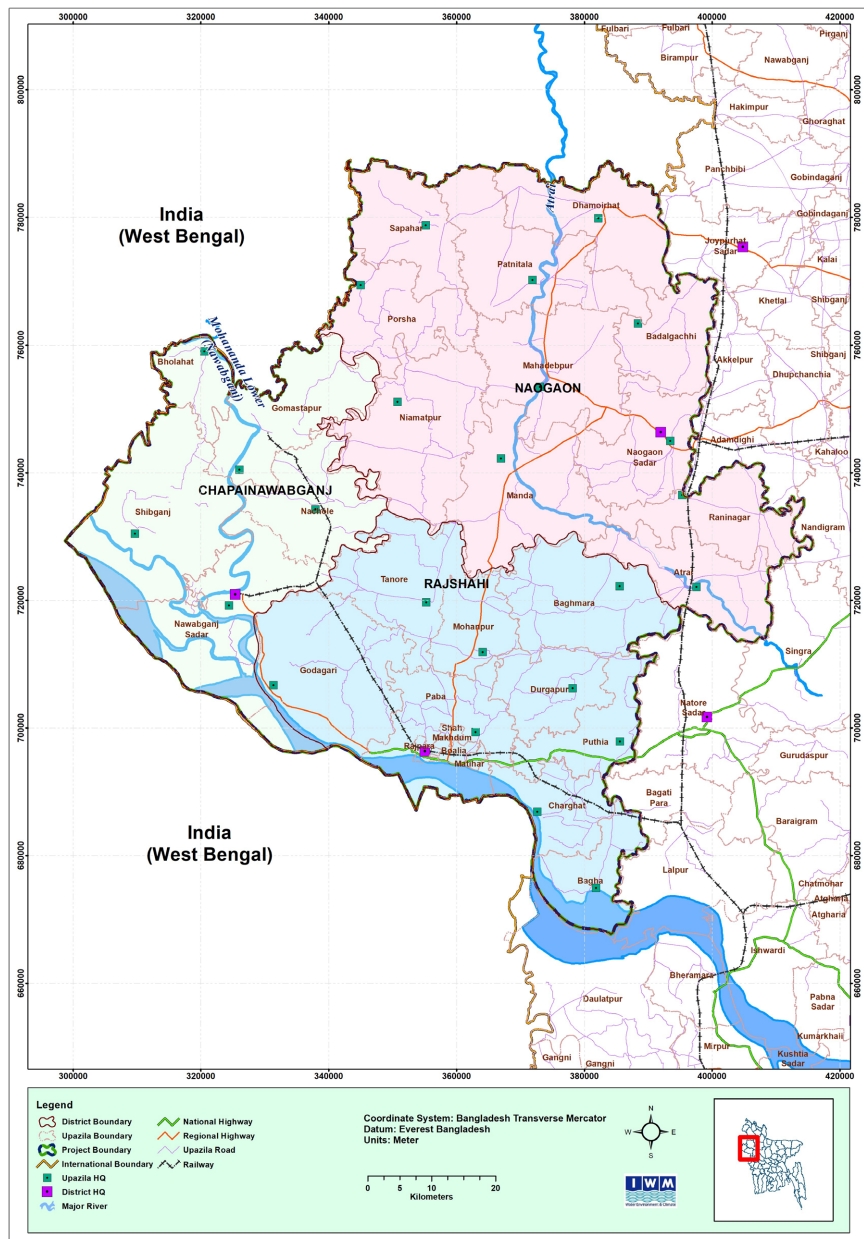
**Climate:** The study area experiences a tropical humid monsoon climate and the temperature varies from 35.7°C in summer to 10°C during winter. The annual average rainfall is around 1500 mm. The relative humidity varies from 46% to 83%.

**Aquifer System in Barind Area:** According to UNDP-BWDB [11], classifications of aquifer of Bangladesh are described as:

1) **Upper Aquifer or the Composite Aquifer:** It represents the uppermost water bearing zone over the country. This aquifer is mainly comprising of very fine to fine sand, in places inter bedded or mixed with medium sand of very thin layers and it exists underlined by the upper clay and silt unit. The thickness of this aquifer ranges from a few meters in the northwest to a maximum of 60 m in the south.

2) **Main Aquifer:** This aquifer mainly consists of medium to coarse grained sediments, in places inter bedded with gravel. This aquifer is either semi confined or leaky or consists of stratified interconnected, unconfined water bearing zones. This aquifer is considered the main water bearing zone and groundwater is withdrawn predominantly from this aquifer that occurs at depths ranging from less than 5 m in the north-west to more than 75 m in the south and most of the country.

3) **Deep Aquifer:** This aquifer is composed of medium to coarse sand, in places alteration with fine sand, silt and clay. The deeper unit is separated from the overlying main aquifer by one or more clay layers of varied thickness and extent. Deep aquifers are generally based on depth and water bearing formation deeper than 150 - 200 m are being exploited on limited quantity in the coastal zone to cater the need of municipal water supply and in the rural areas for drinking purpose.



Source: IWM.

**Figure 1.** Location map of the study area.

The aquifer system of the study area has been described based on the output of the studies carried out by [11] and [43]. Two different aquifer units have been identified based on lithological data available in the study area. The aquifers are classified as (a) upper shallow Aquifer and (b) lower shallow aquifer. The upper shallow aquifer consists of very fine to fine sand with lenses of fine to medium grained sand and occasionally with clay, silt and trace mica lenses and the thickness varies from 10 m to 30 m. The lower shallow aquifer consists of medium to coarse grained sand and occasional fine sediment lenses and the thickness varies from 20 m to 70 m. In most of the cases, these two layers are not separated as the

layer between the layers is not always continuous. That's why, it may be considered as a single layer.

According to [11] aquifer system has transmissivity values range from 500 to 1500 m<sup>2</sup>/day in the study area. The specific yield values of the lithologies vary from 9.8% to 22% [43]. The study also calculated the values of transmissivity (T) and specific yield (S) of the aquifers using mathematical and graphical methods like Jacob [31] and Hantush [44]. The calculated transmissivity (T) values according to the graphical method of Jacob and Hantush range from 743 to 2108 m<sup>2</sup>/day.

The top clay layer ranges from 20m to 80m in the study area. The upper aquifer and lower aquifer are often interconnected as the clay layer in the middle is disconnected.

### 3. Study Methodology

#### 3.1. Data Collection

A comprehensive set of hydrogeological, climatic, and environmental data was collected from multiple organizations to assess groundwater stress in the Barind region. The datasets include:

- 1) Groundwater level data from 172 monitoring wells, collected from BMDA and BWDB. After quality screening, 122 wells were used for analysis.
- 2) Lithological and aquifer properties, such as aquifer thickness and hydraulic conductivity, obtained from BMDA, IWM, and previous studies (UNDP-BWDB 1982; IWM 2006).
- 3) Groundwater quality data (particularly Fe and Mn concentrations) collected from BWDB and BMDA.
- 4) Soil type and unsaturated zone characteristics from SRDI.
- 5) Environmental and surface water availability information, including conditions of ponds, wetlands, and drinking water accessibility.
- 6) Rainfall and recharge data, derived from available meteorological records and secondary studies.

All datasets were spatially referenced, cleaned, and processed for integration into a GIS-based analytical framework.

#### 3.2. Analytical Framework for Groundwater Stress Mapping

To identify and classify groundwater-stressed areas, the study applied a multi-criteria decision-making approach named the DRAHQEL method, a novel method developed for the main study "Hydrological Investigation and Modelling of the State of Surface and Groundwater Resources in the High Barind Region" from which this research paper is formulated, which incorporates seven hydrogeological and environmental parameters:

- D—Depth to Water Table.
- R—Actual Recharge.
- A—Aquifer Thickness.
- H—Hydraulic Conductivity.

Q—Groundwater Quality.

E—Environmental Issues.

L—Trend of Groundwater Level (10-year slope).

U—Media of Unsaturated Zone.

These parameters were selected based on their documented influence on groundwater availability, recharge dynamics, and extraction sustainability.

### 3.3. Weighting and Rating of Parameters

Each parameter was assigned a weight (1 - 5) reflecting its relative importance, and a rating (0 - 10) based on threshold values or categorical conditions relevant to the Barind region.

1) Recharge, unsaturated zone media, and trend of groundwater levels were assigned the highest weight (4).

2) Depth to groundwater, hydraulic conductivity, and groundwater quality were moderately weighted (3).

3) Aquifer thickness and environmental issues were given weights of 2.

Threshold ranges (e.g., depth to water table, recharge in mm, hydraulic conductivity) were categorized from low to severe stress conditions, and corresponding ratings were assigned based on **Table 1** of the manuscript.

**Table 1.** Weighting and rating of parameters.

Parameters	Weight	Parameters	Weight
Depth to Water Table	3	Hydraulic Conductivity	3
Actual Recharge	4	Groundwater Quality	3
Aquifer Thickness	2	Environmental Issues	2
Media of Unsaturated Zone	4	Groundwater Level Trend	4

### 3.4. Computation of Water Stress Index (WSI)

The Water Stress Index (WSI) for each union was calculated using:

$$\text{Index (WSI)} = DrDw + RrRw + ArAw + UrUw + HrHw + QrQw + ErEw + LrLw$$

## 4. Result and Discussion

### 4.1. Maximum and Minimum Depth to Groundwater

After checking the quality and consistency of the data, the groundwater level data of 122 monitoring wells out of 172 wells have been used for the analysis of depth to groundwater table. In order to see the spatial distribution of maximum depth to groundwater table (DGWT) with respect to ground surface, the contour maps have been prepared for the groundwater table of 30th April and 30th October. Analysis of present groundwater table data reveals that groundwater table varies from 4.95 to 31.1 m in Rajshahi, 5.52 to 35.2 m in Chapai Nawabganj and 4.54 to 29.2 m in Naogaon district in the month of April. In the month of October,

groundwater table varies from 1.81 to 29.4 m in Rajshahi, 3.13 to 34.2 m in Chapainawabganj and 1.7 to 18.3 m in Naogaon district. It is also noticed that maximum depth to groundwater table occurs at the end of April and minimum depth to groundwater table occurs at the end of October.

#### 4.2. Rating of Parameters

Considering the ranges or significant media types which has an impact on water stress, the relative significance (rating) for each parameter of DRAHQEL has been determined and is given in **Table 2**. For the trend of groundwater level, here the declining slope for the last 10 years has been considered. For groundwater quality, here only the range of iron (Fe) and Manganese (Mn) have been considered. For the environmental issue, it has been considered whether 1) the water table (WT) is within the suction limit and available in ponds and wetlands, 2) the water table (WT) is beyond the suction limit but available in ponds and wetlands, and 3) drying out of ponds/wetlands & hard to reach for drinking water.

**Table 2.** Ratings for DRAHQEL parameters for Barind region.

[D] (m)		[R] (mm)		[A] (m)		[U]	[H] (m/day)		
Range	Dr	Range	Rr	Range	Ar	Range	Ur	Range	Hr
<3	0	>600	0	>30	0	Medium to Coarse Sand	0	>30	0
3 - 7	2.5	500 - 600	2.5	15 - 30	2.5	Fine Sand	2.5	20 - 30	2.5
7 - 20	5	400 - 500	5	7 - 15	5	Very Fine Sand	5	10 - 20	5
20 - 30	7.5	300 - 400	7.5	4 - 7	7.5	Silt	7.5	5 - 10	7.5
> 30	10	<300	10	<4	10	Clay/Silty Clay	10	<5	10
[Q]		[E]		[L] (m/yr)					
Range (Fe)	Qr	Range (Mn)	Qr	Range	Er	Range	Lr		
<1	0	WT within suction limit and water available in pond/wetlands	0	<0.01	0	<1	0		
1 - 2	2.5	WT beyond suction limit, but available in pond/wetlands	5	0.01 - 0.05	2.5	1 - 2	2.5		
2.0 - 3.5	5	Drying out of pond/wetlands & Hard to reach for drinking water	10	0.05 - 0.1	5	2.0 - 3.5	5		
3.5 - 5	7.5			0.1 - 0.3	7.5	3.5 - 5	7.5		
>5	10			>0.3	10	>5	10		

Assessment for Water Stress Index: For assessing the Water Stress Index (WSI) within hydrogeological settings, numerical ranking has been used in the DRAHQEL parameters. There are 3 significant parts-Weights, Ranges, and Ratings. The value of weightage of different parameters have been considered as 1 - 5 and ratings of different parameters have been considered as 0 - 10. Summation of the product of

weight and rating for each parameter give the final Water Stress Index (WSI). A water stress area map has been prepared based on the estimated WSI value. The higher the WSI value, the higher the stress area. According to WSI values study area has been divided into five zones: Very high-water stressed area (WSI > 160), high water stressed area (WSI 140 - 160), Moderate water stressed area (WSI 120 - 140), Low water stressed area (WSI 100 - 120) and very low water stressed area (WSI < 100). For the purpose of better understanding, the mapping has been done union wise for Rajshahi, Chapa-Nawabganj and Naogaon districts. The upazila wise number of water stressed union for Rajshahi district is given in **Tables 3-5** and shown in **Figures 2-4**.

**Table 3.** Upazila wise number of water stressed union for Rajshahi district.

Sl No.	Upazila	Number of Unions					% of Very High Stress Union
		Very High Stress	High Stress	Moderate Stress	Low Stress	Very Low Stress	
1	Bagha	0	2	4	0	0	0
2	Bagmara	0	1	8	4	3	0
3	Charghat	0	1	4	1	0	0
4	Durgapur	0	3	2	2	0	0
5	Godagari	3	3	3	0	0	33.33
6	Mohonpur	1	4	1	0	0	16.66
7	Paba	3	1	4	0	0	37.5
8	Puthia	0	0	4	1	1	0
9	Tanore	6	1	0	0	0	85.71

**Table 4.** Upazila wise number of water stressed union for Chapainawabganj district.

Sl No.	Upazila	Number of Unions					% of Very High Stress Union
		Very High Stress	High Stress	Moderate Stress	Low Stress	Very Low Stress	
1	Bholahat	0	0	4	0	0	0
2	Chapainawabganj Sadar	1	3	2	0	8	7.14
3	Gomostapur	5	3	0	0	0	62.5
4	Nachol	4	0	0	0	0	100
5	Shibani	0	4	8	0	3	0

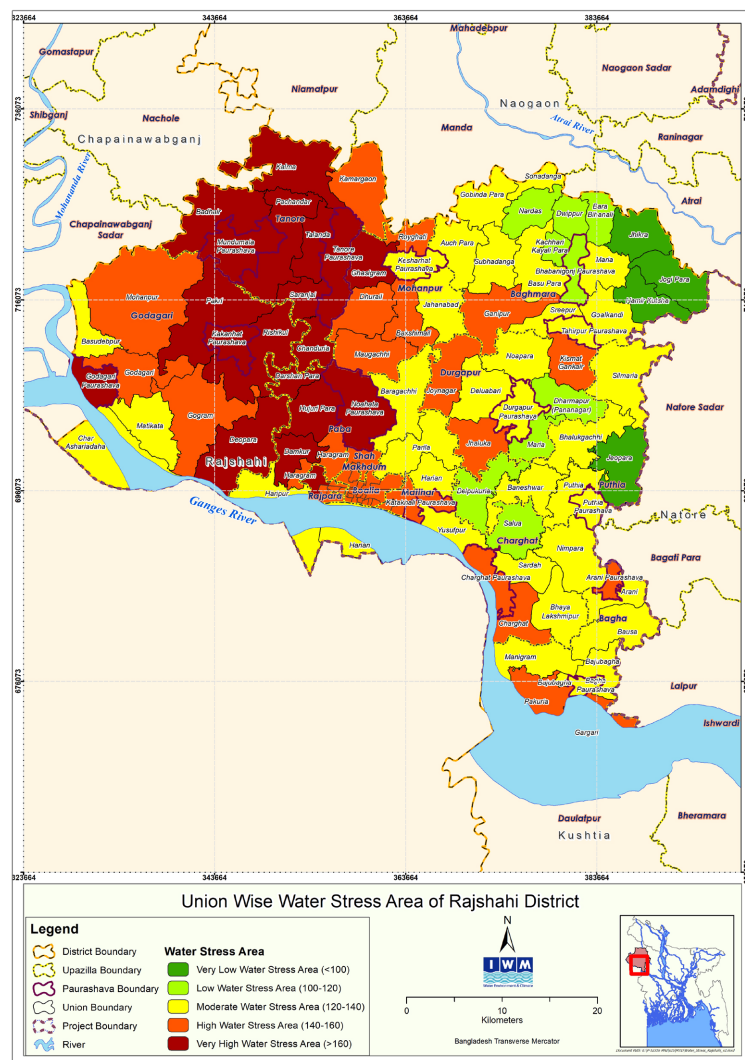
**Table 5.** Upazila wise number of water stressed union for Naogaon district.

Sl No.	Upazila	Number of Unions					% of Very High Stress Union
		Very High Stress	High Stress	Moderate Stress	Low Stress	Very Low Stress	
1	Atrai	0	1	2	0	5	0

Continued

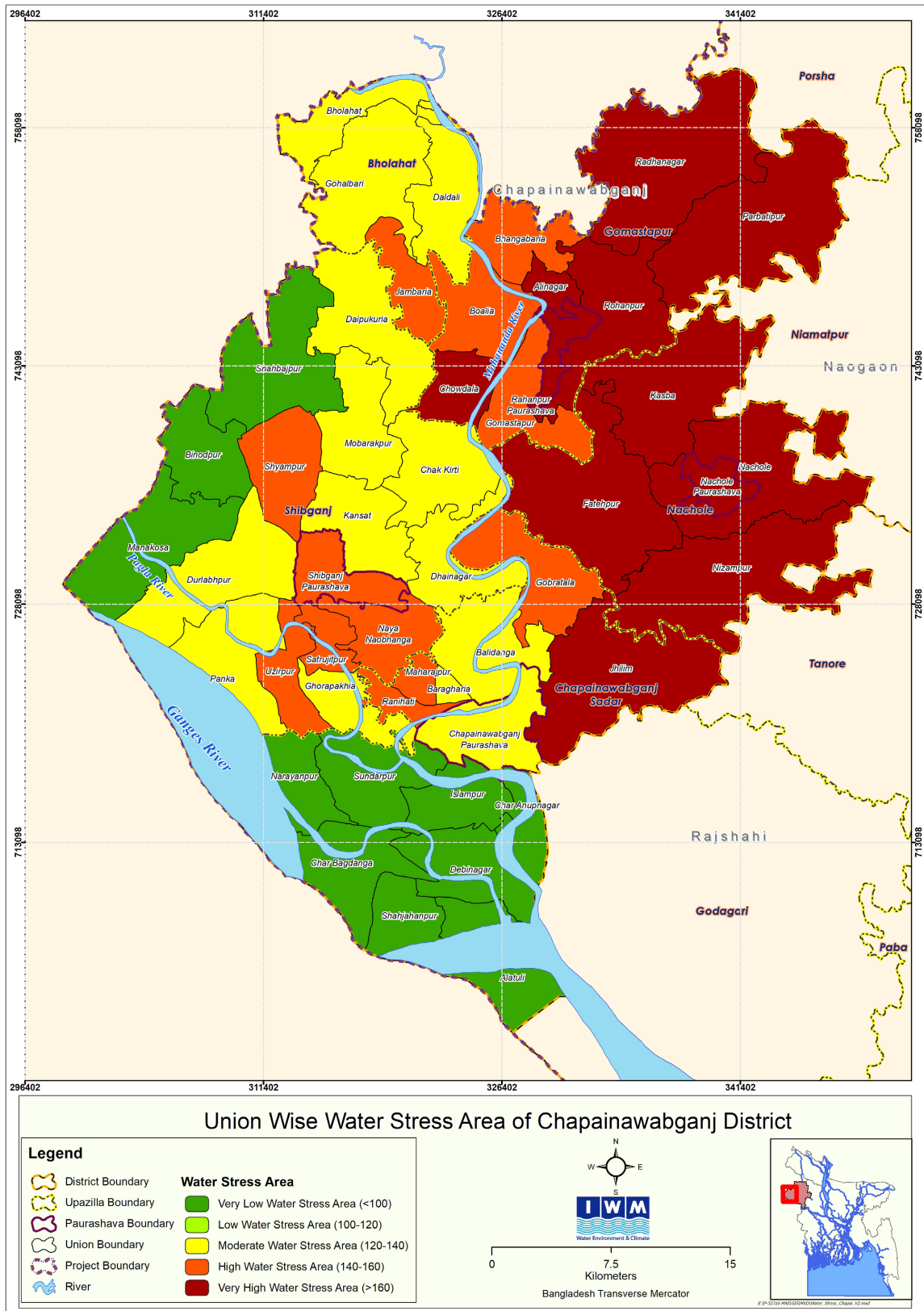
2	Badalgachi	0	0	0	2	6	0
3	Dhamoirhat	0	0	1	3	4	0
4	Manda	0	3	5	5	1	0
5	Mohadevpur	0	1	0	8	1	0
6	Naogaon Sadar	0	2	7	3	0	16
7	Niamatpur	6	1	1	0	0	75
8	Patnitala	7	2	2	0	0	63.63
9	Porsha	6	0	0	0	0	100
10	Raninagar	0	3	4	1	0	0
11	Sapahar	5	1	0	0	0	83.33

Source: IWM.



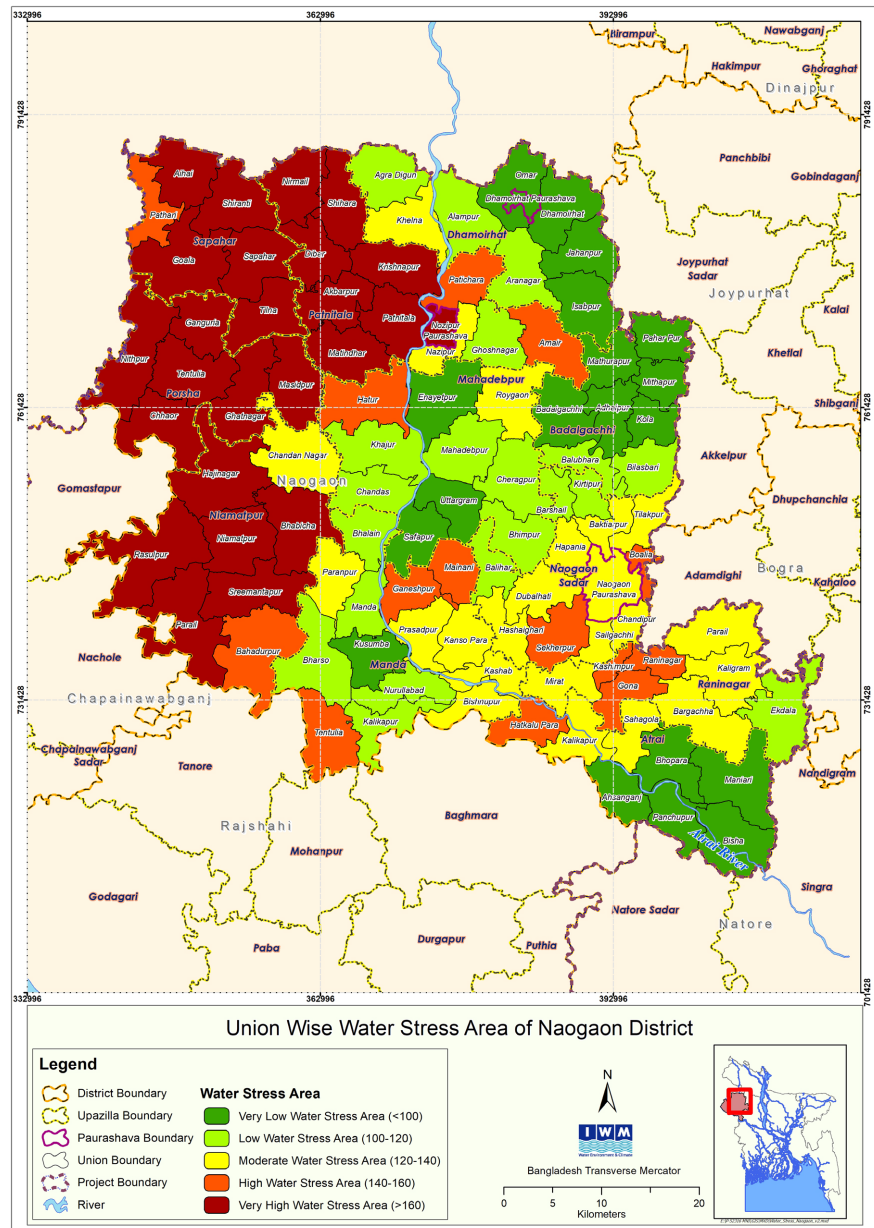
Source: IWM.

**Figure 2.** Union wise water stressed area for Rajshahi district.



Source: IWM.

**Figure 3.** Union wise water stressed area for Chapai Nawabganj district.



Source: IWM.

**Figure 4.** Union wise water stressed area for Naogaon district.

### 5. Conclusion & Recommendations

To estimate water-stressed areas, we look at factors like how deep the water table is (D), how much water is recharged (R), the thickness of the aquifer (A), how easily water flows through it (H), the quality of groundwater (Q), environmental concerns (E), and the trend of groundwater levels over time (L). Using the DRAH-QUEL method, the water stress index (WSI) has been estimated for each union of Rajshahi, Chapai Nawabganj and Naogaon districts in Barind region. Considering the weightage and rating of the different parameters water stress index for each union has been estimated and the mapping has also been done for better under-

standing. It has been observed that in Rajshahi district, out of the total 71 unions, 13 unions show very high water stressed, 16 unions have high and 30 unions are moderate water stressed area. In Chapai Nawabganj district, out of the total 45 unions, 10 unions show very high, 10 unions show high and 14 unions are moderate water stressed area. In Naogaon district, out of the total 99 unions, 24 unions show very high water stressed, 14 unions show high and 22 unions are moderate water stressed area.

Recommendation: In the high to very water stressed area, no additional abstraction should be allowed as it exceeds the safe yield limit and should be kept the static water level in present condition. The practice for conserving surface water to use in irrigation and less water consuming crops should be introduced for this area.

### Limitations

The present study has several limitations that should be considered when interpreting the results. The analysis is primarily based on secondary data collected from a limited number of groundwater monitoring wells, which may not fully capture local-scale spatial variability in groundwater conditions across all unions. The DRAHQEL-based multi-criteria approach involves expert judgment in assigning weights and ratings to different parameters, introducing a degree of subjectivity that may influence the computed Water Stress Index and zonation patterns. Due to the unavailability of reliable abstraction data, actual groundwater withdrawal was not explicitly incorporated; instead, groundwater level trends were used as a proxy, which may not adequately reflect spatial differences in pumping intensity. Furthermore, groundwater quality assessment was restricted to iron and manganese concentrations, excluding other important quality parameters such as arsenic, salinity, and nutrients that could contribute to groundwater stress.

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### Conflicts of Interest

The authors have no relevant financial or non-financial interests to disclose.

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