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Research Article

GROUNDWATER MANAGEMENT THROUGH PARTICIPATORY RURAL APPRAISAL (PRA) AND MODELLING APPROACH IN THE BARIND TRACT

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Abstract

Groundwater is a vital source for drinking and agricultural purposes in Chapainawabganj district. The scarcity of water in surface water bodies causes high dependency on groundwater resources. Despite being a riverine country, Bangladesh faces growing concerns over its water resources, as revealed in a comprehensive study across 45 unions in five upazilas of Chapainawabganj district. The aim of this paper is to investigate the aquifer system and groundwater level up to union level of Chapainawabganj district. Existing historical data has been collected from BWDB, BMD and other relevant agencies. Rainfall data has been collected for the duration of 1985 to 2023. Existing hydro-geological data that includes groundwater level, lithologs and aquifer properties has been collected from available secondary sources. In addition, to fulfill the data gap, a comprehensive field investigation program has been conducted that includes exploratory drilling at 19 locations. Borelog data indicates that the aquifer system mostly falls under two physiographic units: Barind Tract and Ganges Flood plain. Through participatory rural appraisal (PRA), local communities shared critical insights into the state of water resources, complemented by hydrological investigations of both surface and groundwater. The area holds 5,184 surface water bodies, including 4,944 ponds and 240 beels. Groundwater table depths vary annually from 3.0 to 27.5 meters, with recharge rates ranging between 193 and 727 mm per year. Transmissivity values range from 89 to 4,648 m^2/day, while storage coefficients for the first aquifer vary from 0.0000748 to 0.1781. Water scarcity levels differ across the region, with 11 unions experiencing very low scarcity, 14 facing moderate, 10 high, and another 10 enduring very high scarcity. Notably, very high-water stress affects 1 union in Chapainawabganj Sadar, 5 in Gomostapur, and 4 in Nachol, while high stress is observed in 3 unions each in Chapainawabganj Sadar and Gomostapur, and 4 in Shibganj. Alarmingly, excessive groundwater extraction for agriculture-particularly in Nachol and Gomostapur-has led to significant declines in groundwater levels, signaling urgent need for sustainable water management practices.

Introduction

Water is a primary natural resource that is required for various activities, including industrial, agricultural, drinking, household, recreational, and environmental ones (Iqbal & Gupta, 2009; Raju et al., 2011 & Dhanasekarapandian et al. 2016). Globally, irrigation activities and industrial as well as domestic water supplies are largely dependent on the ground water reserve (Adhikary et al., 2011; Hoque et al., 2007 & Abida and Sajol, 2023). However, this resource, like many other valuable natural resources, is being exploited at an alarming rate all over the world. Therefore, development and management of this useful resource is an important subject matter in the field of modern hydrogeology (Hoque et al., 2007; Elango and Sivakumar, 2005; Butler, 2000).

Water is one of the scarce resources in the southwestern and northwestern regions of Bangladesh during the drought season due to insufficient annual rainfall (Hossain & Siddique, 2015). Despite this, awareness

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and adoption of water-saving irrigation techniques such as Alternate Wetting and Drying (AWD) remain limited among local farmers (Kabir et al., 2019). Rain water is the only source of recharging groundwater because almost of the area is flood free (IWM, 2012 & Rahman et al., 2012). Agricultural practice covers 77% of the area, but only 7% covers surface water bodies which mostly dries up during summer seasons (Islam, 2017). Ground water has been the source of irrigation in the agro based Barind area by installation of deep tube wells (DTWs) and shallow tube wells (STWs). Expansion of irrigated rice (Boro) cultivation causing the excess withdrawal of groundwater (Abida and Sajol, 2023). Besides, farmers used 20.2% excess water than required in Boro rice cultivation which causes excess withdrawal of groundwater (Hossain et al., 2016). But the thick top clay layers restrict the percolation of storm water to the groundwater (Hossain et al., 2019) and low infiltration capacity (2-3 mm/day) (Adham et al., 2010) causes the lessening of the natural recharging of groundwater (Jahan et al., 2015).

At a local scale, the problems of water scarcity in the Barind region continue unchecked. Even though installation of new public irrigation wells has been stopped and existing irrigation and drinking water wells are being abandoned or operate at reduced capacity, the water table continues to fall. Awareness of the problems inside and outside the region, is increased but initiatives to reverse the lowering trends of groundwater are piecemeal, inadequate, and not coordinated. The participatory rural appraisal (PRA) approach, when integrated with hydrological investigations, offers a promising strategy for localized groundwater management by engaging local communities in identifying problems, mapping resources, and planning sustainable interventions (Chambers, 1994; FAO, 2016). Therefore, the paper examines to investigate the PRA approach and hydrological investigation for groundwater management in Chapainawabganj district.

Methodology

Study Area

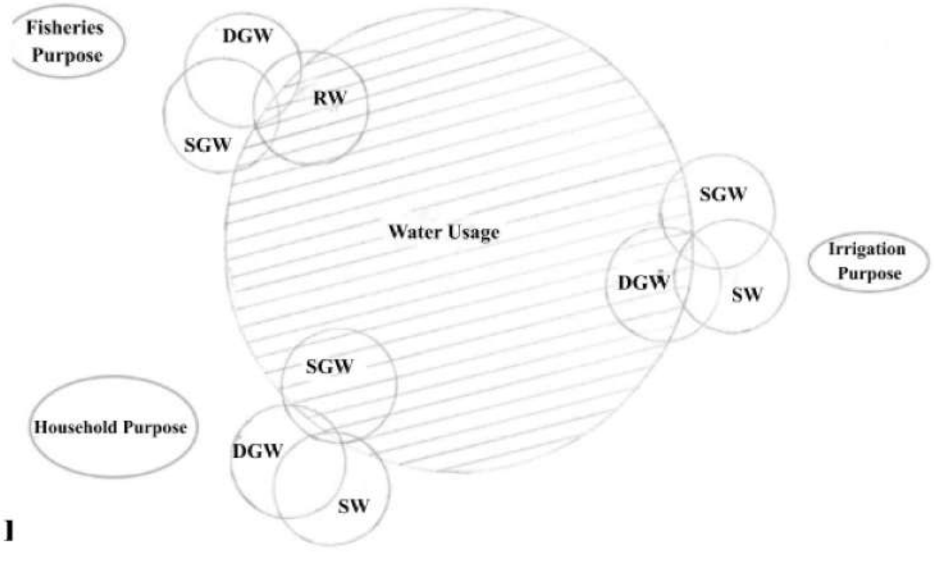
The study was conducted in the five upazilas (e.g., Nachol, Bholahat, Shibganj, Chapai Nawabganj Sadar and Gomastapur) four municipalities and 45 unions of Chapainawabganj district. This study area belongs to the dry humid zone with average annual rainfall varies from 1200mm to 1400mm. There is a decreasing trend of rainfall that has been observed. Rice is the predominant crop in all season. Three types of rice such as aus, aman, boro are grown in this area. Among them, boro rice is fully irrigated rice that is mostly fulfilled by groundwater. Regarding the livelihood in the district about 57.13% people depends on agriculture. The main crop cultivation in this area is rice. The study area is shown in Figure 1.

Figure 1. Study area map.

PRA Approach

The local community shared a comprehensive overview on state of water resources which reveals valuable information/data on the resources existing in the village. The PRA data were been collected from both primary and secondary sources. The sample size was determined based on the total number of mouzas within the project area and the total number of focus group discussions (FGDs) conducted. A total of 13 FGDs were carried out, each representing 40 mouzas. From each mouza, one participant or representative from different professions was selected to participate in the FGD process. Among the 40 participants in each FGD, approximately one-third were women, ensuring gender-inclusive participation and diverse perspectives in the data collection process. During the field visits the identified potential respondents and selected appropriate locations for conducting focus group discussion (FGD) through participatory rural appraisal (PRA) relation to gather information for fulfilment of the study objectives. In the primary data collection campaign, attempts have been made to collect information on present condition of water uses for domestic, irrigation, agriculture and future situation of the area.

In the PRA process, local stakeholder expressed their opinion regarding available sources of water usage for their purposes such as, household, irrigation, and fisheries. This was provided in venn diagram as shown Figure 2. In PRA, a venn diagram uses a simple closed curves drawn on a paper to illustrate simple issues (sets in statistics). Following the participatory rural appraisal (PRA) surveys, a two-tier validation process was undertaken to ensure the reliability and accuracy of the collected information. First, PRA validation workshops were organized at the upazila level to verify and refine the findings through stakeholder participation and local feedback. Second, the validated data were cross-checked and confirmed by the relevant departments at the upazila level for consistency and technical soundness. In total, five PRA validation workshops were conducted across the study area.



Water Use, Demand and Scarcity

In estimation water use for domestic's purpose, the collected information during FGDs like water use per person for different purposes – drinking, cooking, washing, cleaning, bathing, gardening, including use for cattle etc. in a year. Based on the opinions and information obtained from the PRA survey, the quantity of water used in the agricultural sector was estimated by considering three key parameters: (i) the irrigation water requirement for crop cultivation, (ii) the total cultivated area, and (iii) the additional water demand beyond irrigation needs. Crop water demand has been calculated upazila wise using CROPWAT version 8.0 (FAO 2014). After calculating crop water demand, irrigation water requirement (IWR) for different crops for different upazilas have been estimated. The water demand has been estimated based on people's perception of the increasing trend of different uses like domestic purposes, fish farming and industrial sector. Different sectoral water demand for the study area has been calculated and verified during PRA study through FGD.

Hydrological Investigation and Modelling Approach

Hydrological investigation and modelling of the state of surface and groundwater resources is a set of activities were carried out to assess the state of surface and groundwater resources based on physical data analysis. Physically based hydrodynamic modelling has been used to develop the surface water model. The surface water model comprises a hydrological (rainfall-runoff) model and a hydrodynamic (river/channel/floodplain hydraulics) model. MIKE 11 of MIKE Zero platform developed by the DHI Water & Environment. Both the rainfall runoff model (NAM) and hydrodynamic (HD) model have been calibrated and validated against observed data. Then the HD model has been coupled with groundwater model of the study area to get the groundwater and surface water interaction and to see the impact of groundwater abstraction. MIKE-SHE modelling tools have been used to develop the coupled model. Another purpose of developing the model is to assess surface water resources in the study area. For the hydrological investigation, hydro-meteorological data were collected for the study, including rainfall, evaporation, temperature, relative humidity, and sunshine hours. Rainfall data have been collected for 1985 to 2022. Existing hydro-geological data that includes groundwater level, lithology and aquifer properties have been collected from available secondary sources. In addition, to fulfill the data gap, a comprehensive field investigation program has been conducted that includes exploratory drilling depth varies from 200 m to 433 m at 3 m intervals at 16 locations. To assess the aquifer geometry of the different aquifer systems existing in and around the study area, 24 lithological logs were collected from the Bangladesh Agricultural Development Corporation (BADC), Barind Multipurpose Development Authority (BMDA), Bangladesh Water Development Board (BWDB), and Department of Public Health Engineering (DPHE). The depth of the collected lithological data ranged from 39 m to 450 m.

For the estimation of aquifer properties, a total of 14 aquifer pumping tests were conducted at different locations within the Chapainawabganj district. The pumping test data were analyzed using the AQTESOLV software, applying Theis's method, Cooper–Jacob method and Theis's recovery method, wherever applicable.

Groundwater Level Trend Analysis

To perform the groundwater level trend analysis the annual maximum and minimum water table depths were extracted from the database and a linear regression was performed on each set. From the trend analysis of groundwater level data at 32 locations, it was found that there are 10 nos. wells have strongly declining levels in both minimum groundwater depths and maximum groundwater depths, 07 nos. wells where the dry season minimum groundwater depth is declining and the wet season induced recharge top-up appears insufficient to fully restore groundwater levels, 11 nos. wells where the maximum depth is declining but there is no decline in the minimum depth indicating occurrence of insufficient recharge to compensate abstractions in most part of the study areas which is very alarming and for the remaining wells, both the minimum and maximum groundwater depths showed no discernible trend, indicating relatively stable groundwater conditions over the observation period. Different classes of groundwater level variation or 'Trend Types' is shown in Table-1.

Table 1. Different Classes of Groundwater Level Variation or 'Trend Types'

Types	Rate of Variation (maximum depth)	Rate of Variation (minimum depth)	Description
Type-1	falling @ > 0.00 m/yr	falling @ > 0.15 m/yr	These wells have strongly declining levels in both minimum groundwater depths and maximum groundwater depths.
Type-2	falling @ 0.00 to 0.58 m/yr	falling @ 0.025 to 0.15 m/yr	Groundwater trends where the dry season minimum groundwater depth is declining and the wet season induced recharge top-up appears insufficient to fully restore groundwater levels.
Type-3	falling @ 0.025 to 0.30 m/yr	falling @ 0.025 to rising @ 0.08 m/yr.	Groundwater trends where the maximum depth is declining but there is no decline in the minimum depth.
Type-4	falling @ 0.025 to rising @ 0.025 m/yr	falling @ 0.025 to rising @ 0.025 m/yr	Both minimum depth and maximum depth show no trend.

Safe Yield Assessment

The union wise safe yield level of groundwater resources was calculated based on actual recharges using mathematical modelling techniques. A method named Successive Simulation Method has been conducted for model (MIKE 11, MIKE-SHE, Groundwater and Surface water interaction) simulation (in average hydrological condition) to visualize whether the groundwater table regains to its original position for a number of pre-defined locations. As groundwater tables in most of the area are declining (falls under Type 1, 2, 3 or 4 shown in Table-1), yearly actual recharge (instead of potential recharge) has been estimated to find out safe yield level for the study area. According to the National Water Management Plan (NWMP, 2004) guideline and other literature review, 75% of actual recharge has been taken as safe yield level for the study areas.

Water Stress Area (WSA) Identification

Water stress area has been identified using an index-based groundwater vulnerability method, DRAHQEL, specifically developed for this particular study, following similar methodology and justifications as have been used in the very popular groundwater vulnerability method named modified DRASTIC (Magdaleena et al. 2023). The method has been introduced for this study, with Water Stress Index (WSI) estimated from ratings and weightages for the 8 parameters (D: Depth to Water Table; R: Recharge; A: Aquifer Thickness; U: Media of Unsaturated Zone; H: Hydraulic conductivity of the Aquifer; Q: Groundwater Quality; E: Environmental Issues; L: Trend of Groundwater Level).

Water Stress Area Index at any cell or polygon on the map has been determined as:

Water Stress Index (WSI) = $DrDw + RrRw + ArAw + UrUw + HrHw + QrQw + ErEw + LrLw$

According to WSI values, the study area has been classified into five zones- Very high-water stress area (WSI >160), high water stress area (WSI 140-160), Moderate water stress area (WSI 120-140), Low water stress area (WSI 100-120), and very low water stress area (WSI <100). In the high-water stress area, no additional abstraction should be allowed so that it would limit the groundwater table not exceeding the safe yield level and would keep the static water level in present condition. In the low stress area, some abstraction exceeding the present limit might be allowable.

Results and Discussion

PRA Survey

From PRA survey, the primary stakeholders opined that the water level has gone down in most areas of Chapainawabganj. As a result, the people of this area are in acute shortage of food and water. Most of the areas have to collect water from deep tube wells. At the individual level, submersible pumps are used to extract water, so it is not possible to extract water through ordinary tube wells. Besides, there is not much rainfall in the area. At present only drinking water is being supplied to that area. In addition, the drying up of Mahananda river has created more problems in agriculture.

Surface Water Resources Assessment

The number of surface water bodies in Bholahat, Chapai Nawabganj Sadar, Gomostapur, Nachol, Shibganj is 155, 827, 1144, 2017, 801 ponds having sizes >25 decimals respectively and 240 beels which higher number of ponds is in Nachol Upazila and lower number of ponds is in Bholahat upazila.

Aquifer System Based on Lithological-Logs

The study area mostly falls under three physiographic units: Ganga River Floodplain, Teesta Floodplain and Barind Tract. Nachol, eastern part of Chapainawabganj Sadar and Gomostapur upazilas fall under the unit of Barind Tract where there is one thin aquifer existed in the shallow depth throughout the area except part of Nachol pourashava area. The thickness of the aquifer varies from 6 to 18 m which is the only drinking water source for these areas. At Nachol pourashava there is only one thick aquifer that exists down to the drilling depth of 432 m. The groundwater table varies from 30 to 32 m which dropped down beyond the suction limit (7 m) that may create a very alarming situation for this area. Due to the less thickness of aquifer, the groundwater table condition of Nachol, Kosba, Fatehpur, Jhilim, Parbatipur, Rohanpur and Radhanagar unions are very alarming where the groundwater table varies from 27 to 35 m which dropped down to the suction limit. On the other hand, Bholahat, western part of Gomostapur, western part of Chapainawabganj and Shibganj upazila falls under the unit of Ganga River Floodplain and Teesta Floodplain where there is one thick aquifer present in the area except Shibganj pourashava area. The Thickness of aquifer varies from 18 to 60 m. At Shibganj pourashava there are two very fine to fine sand aquifers exist up to the drilling depth of 265 m. The groundwater table condition of Shibganj, Monakasha, Chakkirti, Mobarakpur, Ranihati, Bholahat and Shahabajpur unions are relatively good. Lithologic cross sections with groundwater table of different upazilas under Chapainawabganj district are shown in Figure 3.

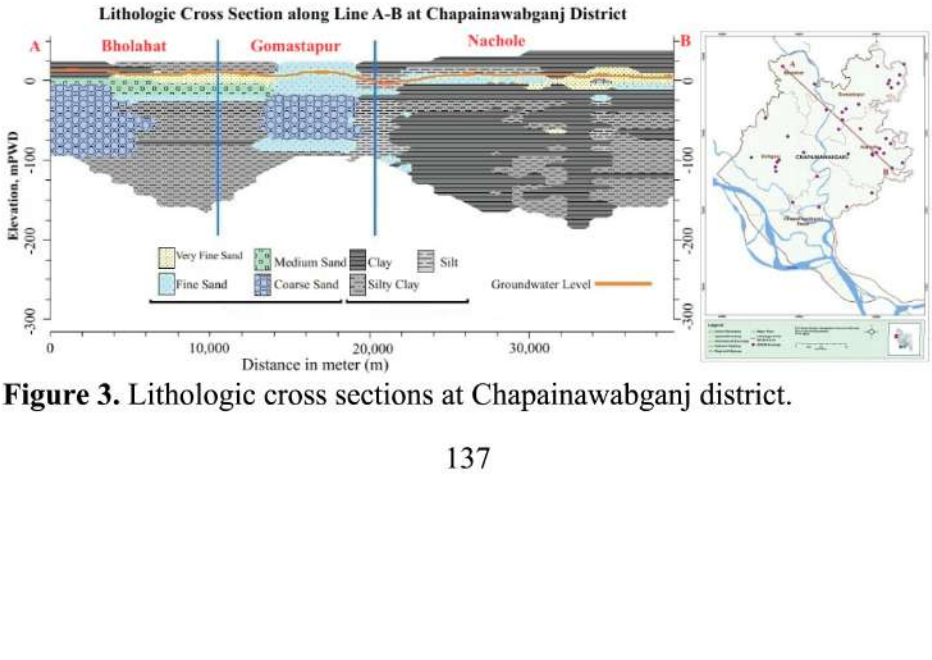


Figure 3. Lithologic cross sections at Chapainawabganj district.

Water Use, Demand and Scarcity Estimation

Approximate yearly sector-wise water demand in MCM per year has been found for domestic in Bholahat, Chapai Nawabganj Sadar, Gomostapur, Nachol, Shibganj is 1.70, 6.77, 4.41, 2.48, 10.57 respectively (higher in Shibganj Upazila and lower in Bholahat Upazila). Approximate yearly sector-wise water demand in MCM per year has been found for agricultural (including Boro, Amon, Aus, Potato, Wheat, Others crops and Fisheries) with industries in Bholahat, Chapai Nawabganj Sadar, Gomostapur, Nachol, Shibganj is 74.56, 294.76, 178.24, 138.16, and 214.9 respectively (higher in Chapai Nawabganj Sadar Upazila and lower in Bholahat). Similarly, water demand has been estimated and it stands in Bholahat, Chapai Nawabganj Sadar, Gomostapur, Nachol, Shibganj is 76.39, 302.07, 183.02, 140.97, 226.22 MCM respectively (higher in Chapai Nawabganj Sadar Upazila and lower in Bholahat Upazila) for 2030 and 76.52, 302.66, 183.42, 141.31, 227.03 MCM respectively (higher in Chapai Nawabganj Sadar Upazila and lower in Bholahat Upazila) for 2041. Due to over exploitation, groundwater level is observed in a declining trend. It revealed that the depth to groundwater table varies from 3.0 to 27.5 meters in all upazilas of Chapai Nawabganj District. There are 56% union is less scarce; 9% union is moderate scarce; 13% union is severe scarce and 22 % unions is scarce free in Chapainawabganj district which is shown in Figure 4.

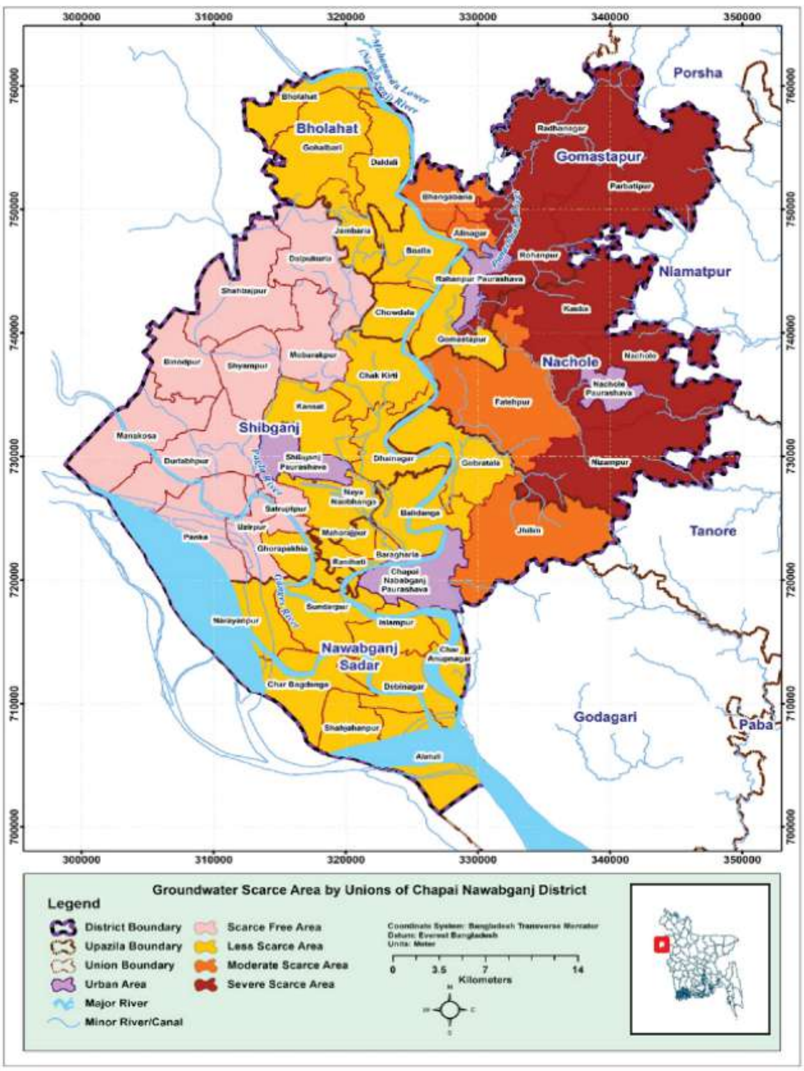


Figure 4. Groundwater scarce map of Chapainawabgabj district from PRA study.

Safe Yield and Water Stress Area (WSA) Identification

From the analysis, it has been found that the estimated union wise actual recharge ranges from 193-727mm in 5 upazilas of Chapainawabganj district and 20 unions out of 45 unions are facing high and very high-water stress situation. Identified upazila wise number of water stressed unions and ranges of actual recharge is given in Table 2 and Figure 5.

Table 2. Upazila Wise Number of Water Stressed Union for Chapainawabganj District

Sl No.	Upazila	Upazila wise ranges of actual recharge (mm)	Upazila wise number of unions identified water stress areas					
			Very High Stress	High Stress	Moderate Stress	Low Stress	Very Low Stress	% of Very High Stress Union
1	Bholahat	494-683	0	0	4	0	0	0
2	C. Sadar	241-727	1	3	2	0	8	7
3	Gomostapur	193-579	5	3	0	0	0	63
4	Nachol	221-369	4	0	0	0	0	100
5	Shibganj	298-672	0	4	8	0	3	0

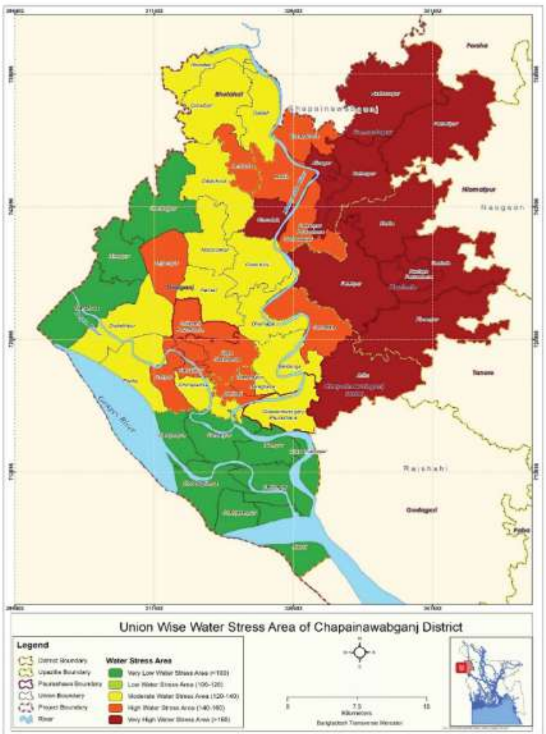


Figure 5. Union wise water stress area for Chapainawabganj district.

Conclusion

From analysis of groundwater table trend, it has been found that groundwater table in most of the area are declining. It is revealed that 20 unions of different upazilas of Chapainawabganj district has been identified as high or very high-water stress area. In the high-water stress area, no additional abstraction should be allowed as because it exceeds the safe yield limit and to keep the static water level in present condition. Notably, very high-water stress affects 1 union in Chapainawabganj Sadar, 5 in Gomostapur, and 4 in Nachol, while high stress is observed in 3 unions each in Chapainawabganj Sadar and Gomostapur, and 4 in Shibganj upaqzila. Present groundwater abstraction in Nachol and Gomostapur upazilas of Chapainawabganj district is quite alarming. Therefore, these upazilas should be brought under restricted/limited abstraction areas. The following attempts should be taken in high water stress areas for better water resources management; i) No addition abstraction of groundwater should be appreciate; ii) Supplying water from less water stress area to high water stress area; iii) Potential beels should be re-excavated; iv) Avoid dependency on ground water use and use of surface water should be increased; v) Crop with less water requirement should be practiced instead of HYV Boro rice; vi) MAR(Managed Aquifer Recharge) Strategy should be introduced if applicable. In all those unions which are identified as water stress area, relevant articles and rules of Bangladesh Water Act 2013 and Bangladesh Water Rules 2018 should be strictly followed before withdrawal of Groundwater.

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