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Assessing Groundwater Dynamics and Potentiality in the Lower Ganga Plain, India

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Abstract: The present study intended to assess groundwater storage dynamics (GWS) and identify potential zones using the Multi-Criteria Decision Making (MCDM) method and geospatial technology in the Murshidabad district of West Bengal, India. The study district is located in the Ganga–Padma–Bhagirathi rivers' floodplain and covers approximately a 5324 km^2 area, comprising 26 blocks in five sub-divisions. The study portrayed a quantitative investigation of the pre-monsoon and post-monsoon season's variability of GWS from 2000 to 2020, taking Landsat TM/Landsat 8 OLI/SRTM satellite data. The geo-spatio-temporal analysis of groundwater storage variability for 20 years was carried out by such remotely sensed data with the geospatial method to portray the dynamics and uncover the potential zones of GWS using various cartographic and statistical techniques. We determined nine parameters for the study, and the analytical hierarchy process (AHP) method was employed for the computation. The present estimation and assessment include the MCDM method, covering assorted parameters and the variations and aspects of GWS in the pre- and post-monsoon seasons from 2000 to 2020. The outcome illustrates that a decline in water storage has taken place in most of the blocks of Murshidabad district on average during the study period, which indicates a water stress provison in the near future. However, the micro (block)-level scenario of the spatiotemporal dynamics of GWS and the potential zonation in the Murshidabad District were investigated to form a location-specific micro-level arrangement for the sustainable management of water.

Keywords: groundwater storage; spatiotemporal dynamics; MCDM; AHP; geospatial technology; lower Ganga plain; India

1. Introduction

Water is considered a chief, finite and precious natural resource globally, and groundwater has a high priority for drinking purposes and is crucial to prolonging agriculture and domestic and industrial advancement. The people of urban areas often have a high demand for groundwater, which is often overused due to its habitually cheaper nature. Furthermore, globally climatic confrontations, widespread groundwater mining and over-exploitation have promoted its depletion in numerous regions primarily due to population intensification. These affect the depletion of groundwater storage, the lowering of water table levels and enhancing water scarcity and water quality deterioration. Therefore, proper periodic assessment, monitoring, and management of such imperative resources is the decisive need of the hour. Globally, about 43% of the total consumption of groundwater accounts for irrigational exercise [1]. About 50–80% of domestic and 40–50% of irrigation water comes from India's groundwater [2,3]. In India, this resource has ubiquitously declined steadily [4], even though several regions have undetgone a rigorous water deficiency due to the unevenness and dissemination of precipitation (averagely 120 cm year^{-1}); still, no provincial estimation has been accomplished on such a depletion in most of these places. Groundwater contributes to about 35% of the total annual water supplies globally [5], while the availability of groundwater estimated for India is 339 billion/m^3 [6], and the withdrawal rate in India is approximately 251 km^3 [7].

Furthermore, nearly 85% of rural, 50% of urban and 65% of total irrigation draws from the groundwater in India [8]; thus, it becomes closely associated with the bio-physical, ecological and human environment. The groundwater has immense importance for agricultural activities, agro-based industries [9,10], and India's rural and urban domestic uses. The land-use changes due to intensive cropping, multi-cropping, high-yielding cropping [11,12] and related irrigation [13] demand more utilization of groundwater quantities [14], resulting in a declining trend in groundwater levels [15,16]. Some earlier studies disclosed that by 2015, India belonged to the water-stress zone, and by 2050, it would come under the water-scarce zone [17]. In India, June to September (monsoon) supplies approximately 80% of the annual rainfall [18]; subsequently, it has generated more prominent confirmatory anomalies of GWS between the pre- and post-monsoon season. Moreover, irrigation for agriculture in India consumes about 85% of water, about 1123 billion m^3, i.e., approximately 28% (4000 billion m^3) of rechargeable freshwater [19]. The study revealed that by 2050, the anticipated food production in India will be 250 million metric tons, which necessitates a sharp demand for water. Apart from this, the changes in the impending terrestrial water, the increasing rate of urbanization and their confrontation with water assets has led to groundwater depletion heterogeneously [20–23], and sustainable setting up and appropriate supervision of the groundwater must be encouraged to tackle the swelling demand for water for cost-effective advancement.

Groundwater assessments have been instigated chiefly via remote sensing worldwide since the 21st century [11,24–32]. Besides, numerous studies have concerted on groundwater recharge, flow, pattern, paths, etc., using several geochemical and numerical models [33–36], since groundwater's sky-scrapping requirement has resulted in scarcity and incongruity [37–40]. Ample studies have been conducted about diverse aspects of groundwater, considering the surface morphological features, and geological and climatic factors such as rainfall phenomena and hydrological settings [41–43], especially using geospatial datasets in India [44–52]. It revealed from some studies that RS- and GIS-based approached highly effective in the precise, accurate and detailed analysis of the complex milieu. The Multi-Criteria Decision Making (MCDM) approach is also usefully employed [53–60] to depict the interrelationships and association of diverse factors influencing groundwater's hydrological and geo-environmental settings. In this context, Analytical Hierarchical Process (AHP) is a widely used and accepted method of MCDM.

Some such studies have detected potential groundwater zones [60–66], but minimal works have been conducted on the spatio-temporal dynamics and identification of vulnerable and stress zones considering multi-criteria [51,67–70], particularly in the Murshidabad district of the lower Ganga plain. Hence, a research gap exists and there is pressing demand for studies investigating water mapping, the fluctuations of groundwater levels and their correlation with the utilization in the study area. Moreover, block-wise assessment is also required for sustainable groundwater management. Therefore, this study intended to depict the block-wise groundwater storage, fluctuations of groundwater levels and the status of groundwater extraction and irrigation implements in the study area. The prime objective of the study was to evaluate the groundwater potentiality in the study area. Apart from the remote sensing data, groundwater table information of numerous stations distributed in the whole district was employed and studied minutely for the current study. The present study region, i.e., Murshidabad district, belongs to the northern part of West Bengal. Very few studies have been published on water, but no such earlier works have been completed in this vicinity. Therefore, to address this research gap, the present attempt was designed to depict the troubles of water storage, oscillations, and changing dynamics in the pre- and post-monsoon season for a 20-year span (2000 to 2020) in Murshidabad district. The study emphasizes the block level scenario of groundwater to give a picture of micro-level conditions by using geospatial techniques through employing relevant remote sensing data and other secondary data. However, the present study discloses that groundwater depletion was established as a gigantic net water loss in a slower tempo, and this blemished its exploitation for irrigation, industrial, and other anthropogenic exercises, indicating water stress in the near future. Here, the active water supply is inadequate to meet the inhabitants, as well as agricultural, industrial, and municipal heaps, and possibly it will worsen over the imminent decades. The study also demonstrates the well-harmonized and collective role of RS and GIS in addressing the concern of groundwater dynamics. The spatiotemporal dynamics of groundwater storage, potentiality, and the identification of water stress zones in the Murshidabad district from 2000 to 2020 were designed to recognize the plausible aspects, numerous dependent criteria and to solve decision-driven problems that impacted groundwater; the RS, GIS and AHP (following Saaty 1980; 2004) [71,72] were altogether applied in the study. This kind of study is not accounted for in the study region; therefore, the present effort is pertinent and fresh for the rapid assessment of groundwater potential considering the MCDM using RS and GIS. Henceforth, the present study is imperative in the milieu of hurried population growth, unplanned urban expansion, changes in LULC, and extended irrigational use in the whole district, even at the micro-level. It will enable researchers uncover the path leading to the sustainable employment of groundwater and will assist in designing plans, policies, and in preparing a comprehensive framework.

2. Material and Methods

2.1. Study Area

The present study focused on the Murshidabad district (Figure 1) of the lower Ganga plain, located in the north-central part of the state of West Bengal, India. The area is enclosed between 23°43′ to 24°52′ N and 87°49′ to 88°44′ E, covering an area of 5324 km^2, and divided into 26 Community Development (C.D.) blocks [73]. The Bhagirathi and Jalangi and their distributaries are the main river systems here. River Bhagirathi divides the Murshidabad district into two parts; the eastern side is featured by shallow water table with the average depth of 4–7 mbgl in summer, while the confined and unconfined groundwater is noticed in the western side. Thus, most of the groundwater is found in the zone of alluvium and the aquifers made up of sands and gravels, the depth of which extends from 90–350 mbgl in the east to 140–150 mbgl in the west. The mono-aquifer condition has superior groundwater potentialities and it was found in the larger portion of the district; only the shallow aquifer contains high arsenic groundwater at places. The aquifer is separated by clay beds at depths in the confined condition and this is mostly observed in the Kandi, Khargram, Nabagram, Sagardighi, Raghunathganj and Samserganj blocks. In the Bhagirathi basin area, there is clay and sandy clay of 20–30 m thickness, below which sands and clay lenses in the shallow aquifer within 60m depths were found. The groundwater development is poor in Rarh region but it was good in Bagri region and therefore, 10 blocks belongs to the safe stage were selected, and 17 blocks under the semi-critical stage [74]. Geographically, this region is divided into two broad zones, namely Rarh and Bagri. The Rarh region found in the western part of the district is the continuation of the sub-Vindhyan region. This region is composed of laterite soil and the topography is slightly high, and undulating in its nature. The eastern part, Bagri lies between the Ganga-Bhagirathi basin and is composed by alluvial soil. According to the geological time scale, the district has the emblem of three eras: Jurassic, Pleistocene and recent and lies between the Rajmahal–Meghalaya gap. Owing to the location, geographical and geological characteristics, the district belongs to a tropical wet-and-dry climate and receives maximum rainwater from south-west monsoon winds during the monsoon season. The temperature during the summer season is between 27 to 40 °C, and during the winter season it ranges between 12 and 23 °C. The mean annual rainfall ranges from 1168 to 1500 mm, and the aquifers of this region mainly recharge during the monsoon season. Agriculture is the dominant economic activity of this region and in the eastern part rice, wheat, mustard, masur, potato, til, gram, khesari, maize, jute, and mangoes are the major crops and extensive mulberry cultivation is dominated in the western part of the district.

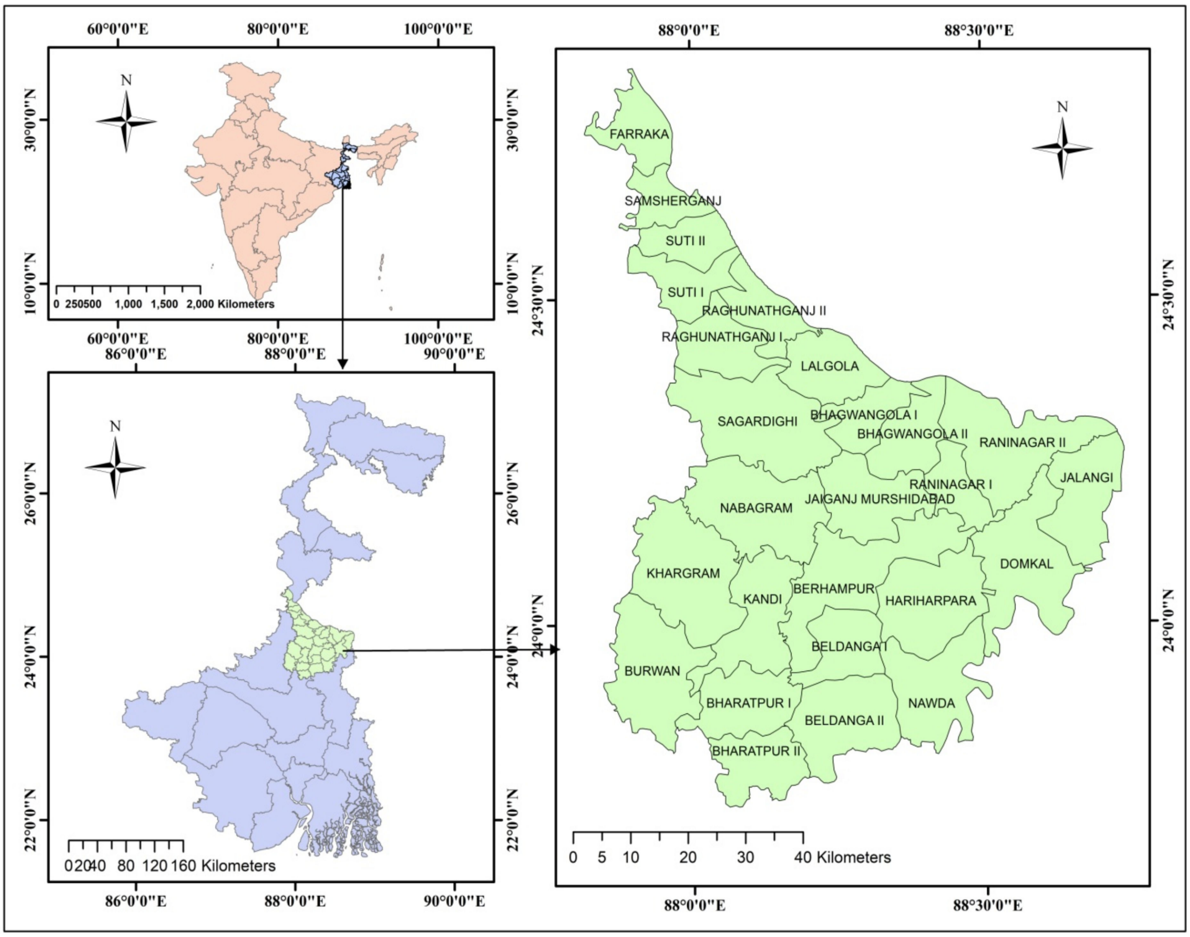


Figure 1. Location of the study area.

2.2. Database and Analysis

The current study combinely used remote sensing data and other relevant block-level secondary data [73]. Therefore, the study concentrated mostly on the secondary data for spatiotemporal analysis by using geospatial technology as the key technique for mapping. The required remote sensing data of Landsat 5 TM, SRTM and Landsat 8 OLI satellite imagery of 2000, 2010 and 2020 has been collected from the USGS website. While the ground-water-related block-wise data recorded groundwater level and storage, arsenic-related data have been collected from the government reports and district census handbook. The study also used slope, lithology, land cover and land use, lineament density, rainfall, soil, drainage density, topographic wetness index and topographic position index. Apart from these, geo-hydrology, vegetation (NDVI), irrigation, and cropping pattern were taken into consideration. Furthermore, relevant maps and graphs were prepared to find out the nature and cause of groundwater fluctuation, overutilization of water, anthropogenic inputs, apart from finding the groundwater storage, depletion and potential zonation using the GIS platform. The details of the used database are tabulated (Table 1).

Table 1. Source of database.

Attribute	*Data*	*Sources*
Slope, Drainage	SRTM DEM	USGS (https://earthexplorer.usgs.gov (accessed on 3 February 2022))
Lithology	GSI map [Scale—1:250,000]	Geological Survey of India
Land Use Land Cover	Landsat 5 TM, Landsat 8 OLI	USGS (https://earthexplorer.usgs.gov), accessed on 23 January 2022
Lineaments	SRTM DEM & GSI map [Scale—1:250,000]	USGS (https://earthexplorer.usgs.gov) & Geological Survey of India, accessed on 3 February 2022
Drainage Density	Landsat 8 O.L.I., SRTM DEM	USGS (https://earthexplorer.usgs.gov), accessed on 3 February 2022
Rainfall, Topographic Wetness Index (TWI), Topographic Position Index (TPI)	SRTM DEM CGWB data & Maps [Scale—1:1,000,000]	USGS (https://earthexplorer.usgs.gov) & Central Groundwater Board, Government of India, accessed on 3 February 2022
Soil	NBSS & LUP Maps [Scale—1:1,000,000]	National Bureau of Soil Survey and Land Use Planning, Kolkata
GWS, LULC, NDVI, TWI, TPI, DEM, Drainage, Slope, Lineament, Elevation, Aspect		Prepared using RS data
Lithology, Morphology, Geohydrology, Rainfall, Soil texture, Irrigation, Cropping map		Prepared using bibliographic data
GWPI map		Prepared using MCDM outputs

After the completion data collection, ArcGIS 10.3 and ERDAS IMAGINE 2014, Microsoft excel have been employed for data analysis and representation. A total of nine criteria, i.e., slope, lithology, land cover and land use, lineament density, rainfall, soil, drainage density, topographic wetness index, topographic position index, have been taken into consideration to prepare results of the groundwater storage, depletion and potential zone of the study area. Initially, the maps have been transformed into Universal Transverse Mercator (UTM) projections and finally prepared using the ArcGIS platform. The land use land cover (LULC) map was prepared applying the maximum likelihood classification method of supervised classification using Landsat 5 TM and Landsat 8 OLI satellite imagery for the respective years of 2000 and 2020.

2.3. Applied Methodology

The groundwater storage (GWS) and multi-criteria were mostly calculated from the remote sensing data using the ArcGIS and Edras Imagine software and were finally prepared by the ArcGIS software. The relevant formula that was used in the study is listed accordingly.

The GWS has been calculated using the formula (Rui and Beaudoing, 2018) [75]:

$$\text{GWS} = \text{TWS} - (\text{Root zone soil moisture} - \text{Snow water equivalent} - \text{Canopy Interception}) \quad (1)$$

where the values of GWS are extracted from the GLDAS-2 data using the inverse distance-weighting (IDW) interpolation method and thereafter the maps of the same are prepared by the ARC GIS platform; TWS = Total Water Storage, it is the sum of all above and below surface water storages.

The lineament density has been computed by this equation:

$$LD = (\text{km}/\text{km}^2) \quad (2)$$

The drainage density has been computed by this equation:

$$(\text{km}/\text{km}^2) \quad (3)$$

The Topographic Wetness Index (*TWI*) has been computed by this equation:

$$TWI = (\text{m}/\text{degree}) \tag{4}$$

The Normalized Difference Vegetation Index (*NDVI*) was calculated to represent the vegetation cover and watershed runoff prediction purpose. The following formula of *NDVI* calculation has been applied here:

$$NDVI = \frac{NIR - R}{NIR + R} \tag{5}$$

where *NIR* and *R* represent the near-infrared band and red band. In the case of the LANDSAT 8 data, the following equation has been applied:

$$NDVI = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4} \tag{6}$$

After preparation of thematic layers using integrated RS-GIS software, the Multi Criteria Decision Making (MCDM) has been employed by applying the AHP method to identify the potential groundwater zone. This AHP is the widely used multi-parametric evaluation method [71] in which a pair-wise comparison matrix was used to assign individual factors' weights. It also determines the Consistency Index (CI) and Consistency Ratio (CR) following the procedure of Saaty (1980) [71]. Thereafter, a weighted overlay analysis model has been performed to delineate the groundwater potential zones. The Groundwater Potential Index (*GWPI*) has been calculated using the formula [52]:

$$GWPI = [(SLw \times Slwi) + (Liw \times Liwi) + (LCLUw \times LCLUwi) + (LDw \times Ldwi) + (DDw \times Ddwi) + (TWIw \times TWIwi) + (TPIw \times TPIwi) + (Rfw \times Rfwi) + (STw \times Stwi)] \tag{7}$$

where, *GWPI* = groundwater potential index, *SL* = slope, *Li* = lithology, *LULC* = land use land cover, *LD* = lineament density, *DD* = drainage density, *TWI* = topographic wetness index, *TPI* = topographic position index, *Rf* = rainfall, *ST* = soil texture. The w and wi respectively refer to the normalized weight of a criteria and normalized weight of individual features of a criteria.

The application of the AHP method was carried out in the study, considering nine criteria, which included slope, lithology, lineament density, rainfall, drainage density, soil texture, land use/land cover, topographic wetness index (*TWI*), topographic position index (*TPI*), intended for the superimposed investigation using weights derived in the AHP method based on the experts' opinion, in order to indentify the Groundwater Potential Index (*GWPI*) of Murshidabad district.

The comparison between two criteria has been done using comparative magnitude scales between two criteria as recommended by Saaty (1980) [71], as it is broadly used in the AHP method. The attributing values from 1 to 9 are considered here (Table 2) and it determines the relative significance of the criteria in comparison with another.

Table 2. Saaty's Scale of relative importance.

Scale	Numerical Rating	Reciprocal
Extremely preferred	9	1/9
Very strong to extremely	8	1/8
Very strongly preferred	7	1/7
Strong to very strongly	6	1/6
Strongly preferred	5	1/5
Moderately to strongly	4	1/4
Moderately preferred	3	1/3
Equally to moderately	2	1/2
Equally preferred	1	1

The appliance of the AHP method discloses the groundwater potential analysis in a rational approach and the calculation steps are expressed below:

- **1st Step** is to construct the pairwise contrast between each criteria (Table 3). This comparison describes an integer value ranging from 1 (equally preferred) to 9 (extremely preferred), and the higher value signifies that the chosen criteria is considered to be more imperative, with superior implications.

- **2nd Step** is carrying out the matrix.
- **3rd Step** is normalization and determination of weight of each criteria.
- **4th Step** is calculating the Consistency Ratio (CR) (Table 4). This is calculated by the equation: ***CR*** *= Consistency Index (CI)/Random Index (RI)*

Table 3. The pair-wise comparison of multi-criteria evaluation by AHP.

Criteria	LULC	R	ST	DD	LD	TWI	TPI	L	S
Land use land cover (LULC)	1.00	1.00	5.00	5.00	3.00	3.00	3.00	0.33	0.33
Rainfall (R)	1.00	1.00	5.00	5.00	5.00	3.00	3.00	0.33	0.33
Soil Texture (ST)	0.20	0.20	1.00	3.00	3.00	4.00	4.00	3.00	0.33
Drainage Density (DD)	0.20	0.20	0.33	1.00	3.00	5.00	5.00	0.33	0.33
Lineament Density (LD)	0.33	0.20	0.33	0.33	1.00	3.00	3.00	3.00	5.00
Topographic wetness Index (TWI)	0.33	0.33	0.25	0.20	0.33	1.00	5.00	3.00	3.00
Topographic position Index (TPI)	0.33	0.33	0.25	0.20	0.33	0.20	1.00	5.00	5.00
Lithology (L)	3.00	3.00	0.33	3.00	0.33	0.33	0.20	1.00	5.00
Slope (S)	3.00	3.00	3.00	3.00	0.20	0.33	0.33	0.20	1.00

Table 4. Determination of Consistency Ratio of the multi-criteria by AHP.

Criteria	Priority	Rank	Weightage	Maximum Value	Consistency Index (CI)	Ratio Index (RI)	Consistency Ratio (CR)
Land use land cover (LULC)	14.25126	2	0.142513				
Rainfall (R)	15.56676	1	0.155668				
Soil texture (ST)	12.32186	3	0.123219				
Drainage Density (DD)	10.12936	4	0.101294				
Lineament Density (LD)	10.65556	5	0.106556	9.369829	0.046229	1.45	0.031882
Topographic wetness index (TWI)	8.846744	7	0.088467				
Topographic position index (TPI)	8.320544	6	0.083205				
Lithology (L)	10.65556	8	0.106556				
Slope (S)	9.252357	9	0.092524				

Here, if the *CR* < 0.01, then the value is acceptable. Here the CR value is 0.03, which signifies it is highly acceptable and logical and therefore, the judgement matrix was consistent.

The entire methodological framework of the present attempt is presented in a graph (Figure 2) which depicts the sequential steps. The execution of various secondary data has diverse sources such as RS data from USGS, demographic data from the census, groundwater data from the Central Ground Control Board (CGWB), and irrigation and crop data from the Irrigation and Waterways Directorate, Government of West Bengal and District Statistical Handbook. All these data were critically analysed and relevant maps and graphs were prepared using RS-GIS software and Microsoft Excel. The geospatial and MCDM technique, which includes the execution of the AHP method considering several influencing criteria of groundwater, were employed effectively in the effort.

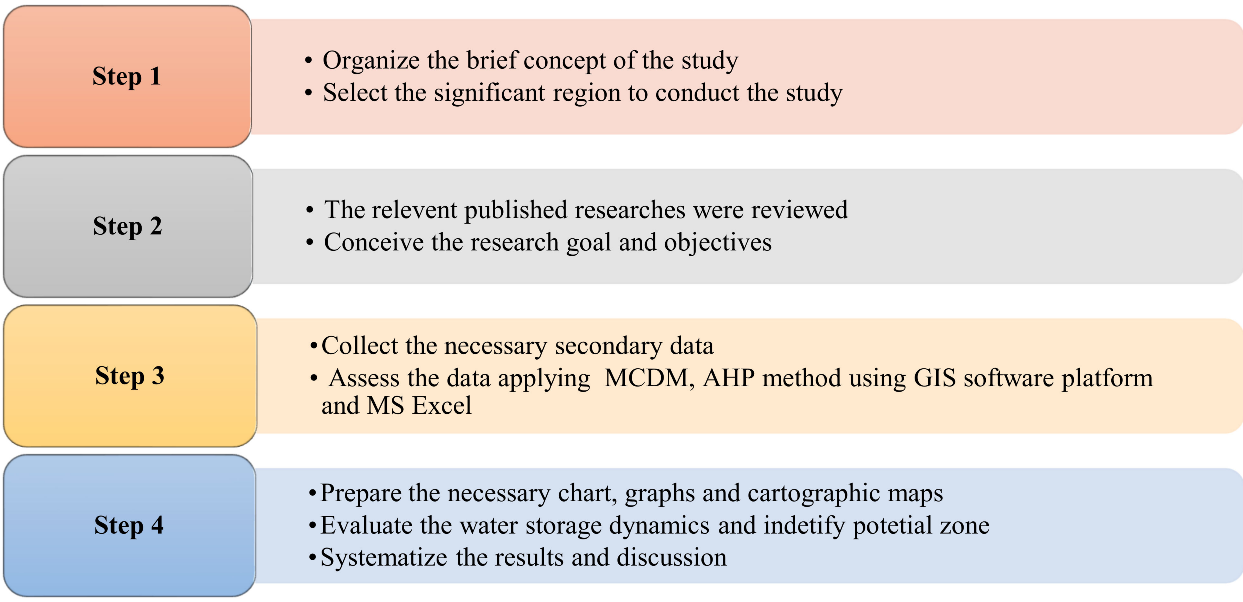


Figure 2. Skeleton of methodological stages.

As the attempt includes the execution of several pertinent maps and graphs, therefore a flow chart of this progression is graphed (Figure 3) to explore the data types, data sources, nature of analysis and to symbolize the decisive perspectives of the current endeavour.

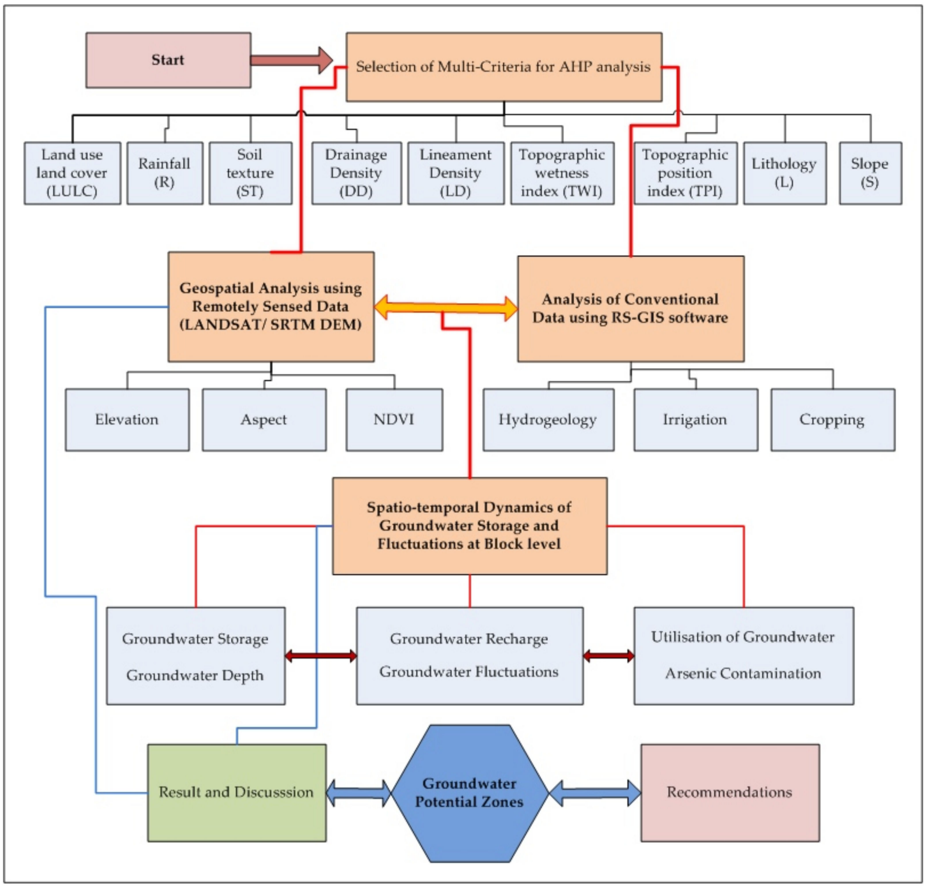


Figure 3. Methodology of the complete study in a flow chart.

2.4. Significant Contributing Factors and Multi-Criteria Analysis of Groundwater

2.4.1. Elevation and Aspect

The term elevation indicates the altitude above sea level. The different altitudes in a region are depicted on a topographic or elevation map. In relation to sea level, elevations are often expressed in meters or feet. The district has a mixed topography and terrain character with elevation ranges up to 55 m. The western part is known as Rarh, having undulating and rugged terrain due to the intersecting old rivers. This part is elevated towards the Rajmahal hill in the north-west and characterized by some isolated hillocks. The eastern part of the district is known as Bagri, and lies between Ganga and Bhagirathi river basin, which is a flat surface with existence of many swamps. Therefore, the broad slope of the entire district is towards east and south-east from the west and north-west sides. The whole district is divided into five sub-micro regions in terms of topographic variations, including Nabagram plain, Mayurakshi-Dwarka plain, Ganga-Bhagirathi basin, Jalangi-Bhagirathi Interfluve, and Raninagar plain. On the basis of the Digital Elevation Model (DEM) map (Figure 4), which displays the accurate picture of elevation of the entire district, a morphological map has been created (Figure 5). The plainland as mentioned and named earlier was grouped into three categories: alluvial plain, deltaic plain and flood plain. Among this, the deltaic plain covers the maximum area, followed by the alluvial plain, while the deltaic plain is located besides river Bhairab and it stretches from the north to south portion of the district. Moreover, a very small patch of pediment pediplain complex (Rajmahal hill) was found in the extreme north-west corner of the district. The main river Ganga (Padma) flows to the north-west to north and eastern side, while another main river Bhagirathi is flowing through the mid of the district, starting from the north-west towards the southern portion of the district.

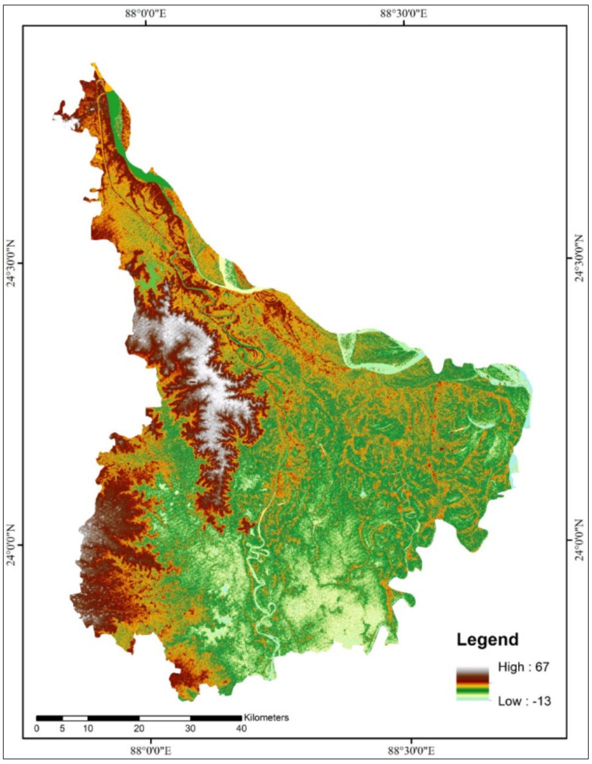


Figure 4. DEM Map.

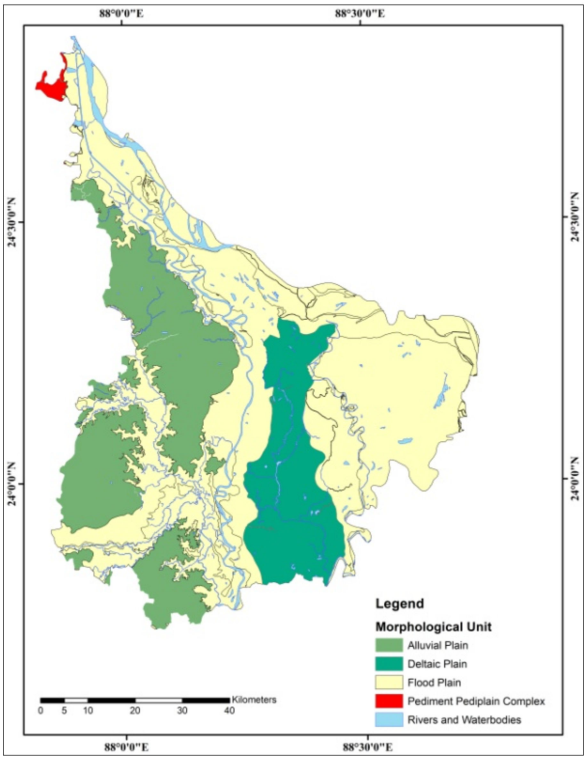


Figure 5. Morphological units.

The district has been grouped into five elevation zones (Figure 6) on the basis of its elevation. The highest elevation amount is about 55 m and the lowest elevation is 01 m; the most elevated landscape (>32 m) is identified in the western and north-western parts and it' gradually decreases towards the north-east and south-east corner of the district. The western part belongs to a highly elevated region when compared to the eastern part. A small division of the north- western bend of the district shows high relative relief, whereas the eastern and south-eastern part confirms the least relative relief.

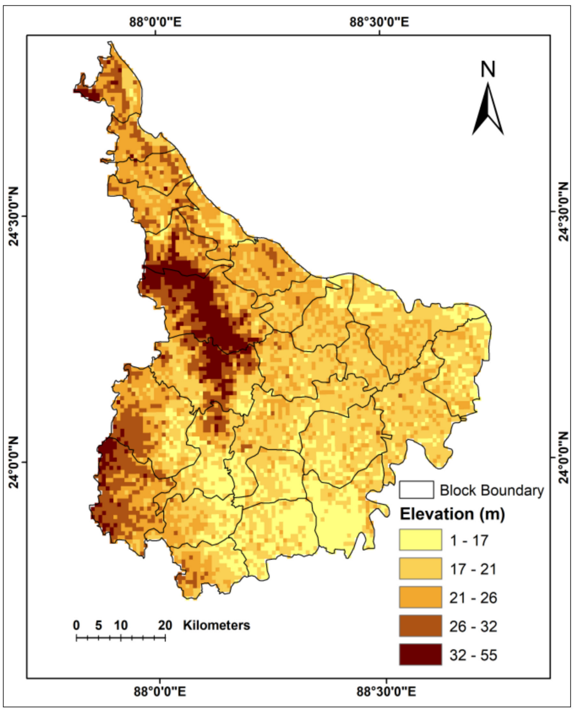


Figure 6. Elevation Map.

Aspect refers to the track of the slope in respect to geographical north. This aspect of the investigation is an imperative parameter as it reflects the attitude of rock bedding, moisture custody, vegetation and its connection to rain-containing wind. It can easily persuade the direction of river or stream; therefore, it was taken into consideration to identify the potentiality and storage fluctuation of groundwater in the study area (Figure 7). The aspect map affirms that the western and north-western part shows the south, east and south-east direction of the slope, which compelled most of the streams of this region to flow towards this direction. This aspect's variations helps to recharge the groundwater and, thus, this western, northern and north-western parts have comparatively larger grounwater storage than the other areas since 2000, and this has continued up to 2020 in pre- and post-monsoon seasons.

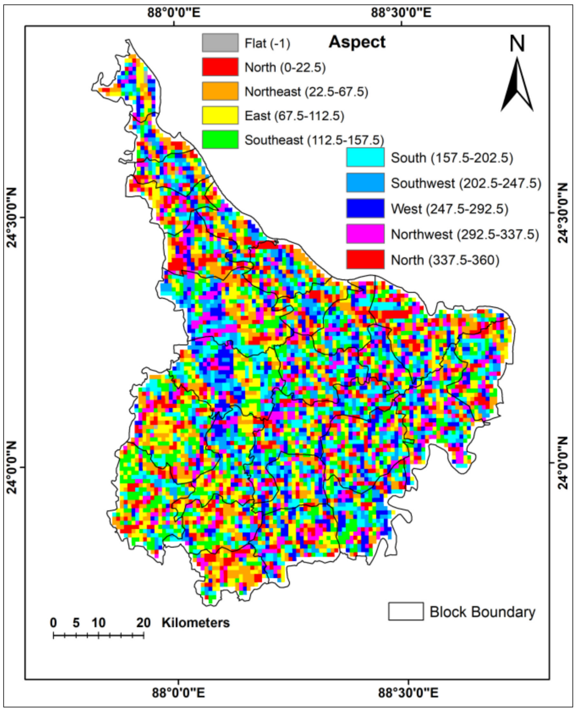


Figure 7. Aspect Map.

2.4.2. Hydrogeology

The hydrogeology of the Murshidabad district has a strong connection with the groundwater storage. The lithological formation of different geological times are thus depicted here (Figure 8). It reveals that Holocene, Jurassic, Cretaceous, and Pleistocene–Holocene formation are noticed here, among which the calcareous concretions (sand, silt, clay) of the Pleistocene–Holocene mostly covered the western part of the district; the other most part of the district is covered by the sand–silt–clay of the Holocene period. The central to north and west parts of the district are covered with high and very high GWS, while the east and south-east portions was covered by very low to low GWS and the fluctuations of the storage amount in the pre- and post-monsoon season were also largely impacted by such hydrogeological features.

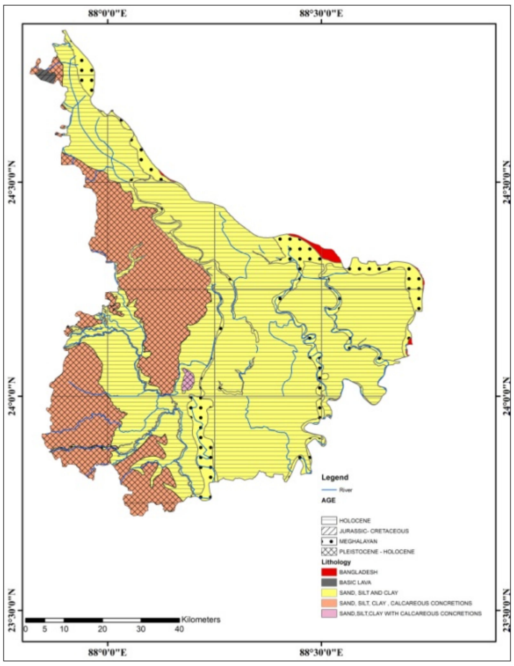


Figure 8. Hydrogeology.

2.4.3. NDVI

The vegetation amount is closely related with the groundwater in various aspects, thus, the NDVI map was prepared (Figure 9a,b). The calculated values were grouped into nine classes and they range from −0.199 to 0.8 in the year 2000 and 0.199 to 0.814 in the year 2020. It is revealed from the map that the eastern portion has a high NDVI value, which signifies the higher storage of groundwater. This situation indicates the position of the GWS as well as probable potential zones of groundwater in the district.

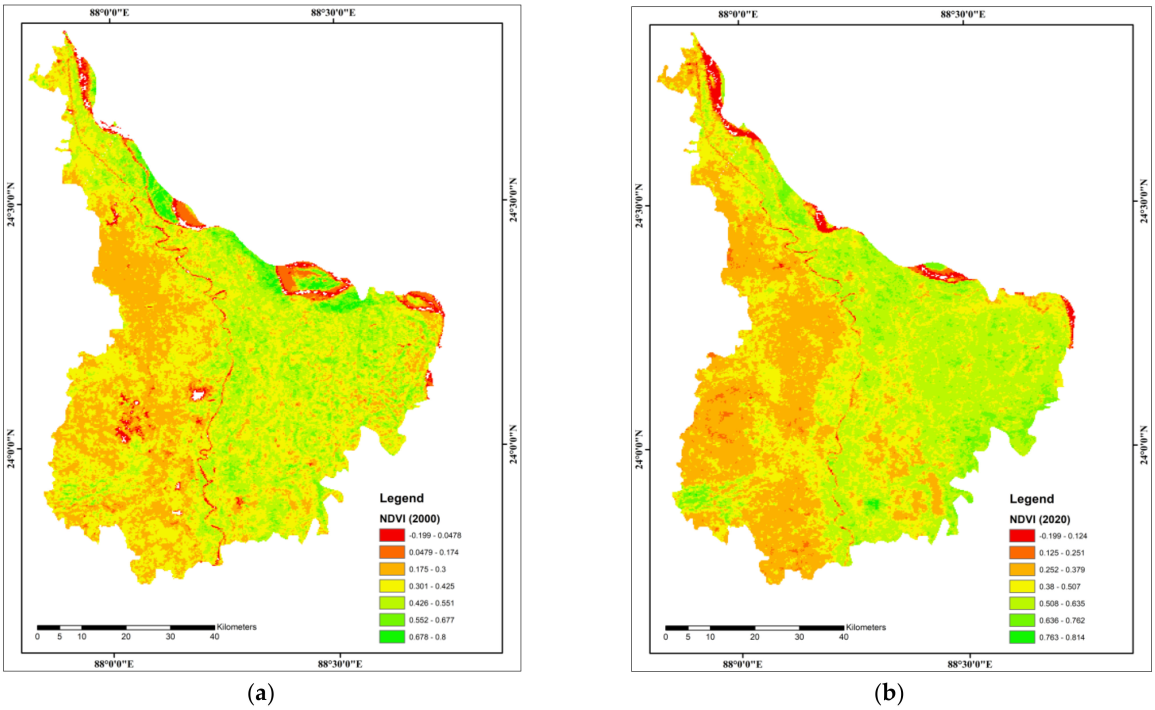


Figure 9. (**a**) NDVI Map (2000). (**b**) NDVI Map (2020).

2.4.4. Irrigation and Cropping

The block-wise irrigational status of the district was noticed (Figure 10) and it was observed that a huge amount of GWS was employed in irrigation and, according to the irrigated area, the west to eastern part (about 10 blocks) was covered by high (approx. 2700–9600 hectares) irrigation, while the north-west to south-eastern parts (about 10 blocks) were covered by a moderate amount (approx. 9600–17,300 hectares) of irrigation. Moreover, it was revealed from the source of irrigation map (Figure 11) that canal, tank, river lift irrigation (RLI), deep tube well (DTW), shallow tube well (STW) and other sources of irrigation were recorded in the district. The eastern parts of the district are mostly dependent on DTW and other sources of irrigation while the western and north-western parts mostly use canal (mostly by Mayurakshi canal command), tank water and other sources for irrigation. Apart from these, some blocks of central to southern and northern blocks are also using RLI for irrigation. Currently, a paradigm shift was observed from rain dependency to the mechanical lift of groundwater in the district. The well/bore well provides about 132,550 hectares among the total arable land of about 365,000 hectares. The use of tank irrigation (49,916 ha), as well as deep and medium tube wells (19,200 ha), increased by about 40% than before, which was very significant.

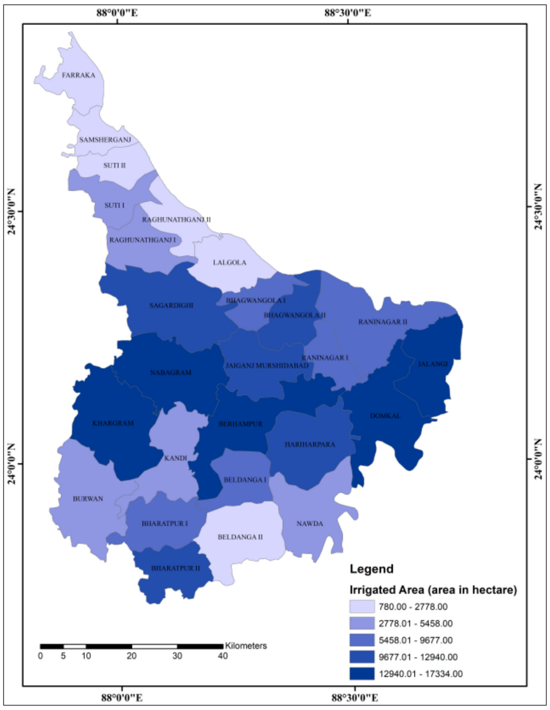


Figure 10. Irrigated area.

The cropping area was mapped (Figure 12) to observe its connection with the irrigational features of the district. It revealed that the all the blocks cultivate rabi and kharif crops and apart from the north-western blocks, most of the blocks have a good proportion of rabi and kharif cropping area. Most of the western and central blocks have more rabi crops than the kharif while most of the eastern blocks have more kharif than rabi crops. Among the rabi and kharif crops, rice, jute, oilseeds, wheat, barley, and mulberry are chief crops of the district. The non-monsoonal rabi crops (such as wheat, boro, mustard, masur, potato, til, gram, khesari, maize) are known for their high consumption of water, which only be catered for by the use of groundwater. Moreover, the HYV boro paddy needs a huge amount of water and thus the groundwater becomes stressed.

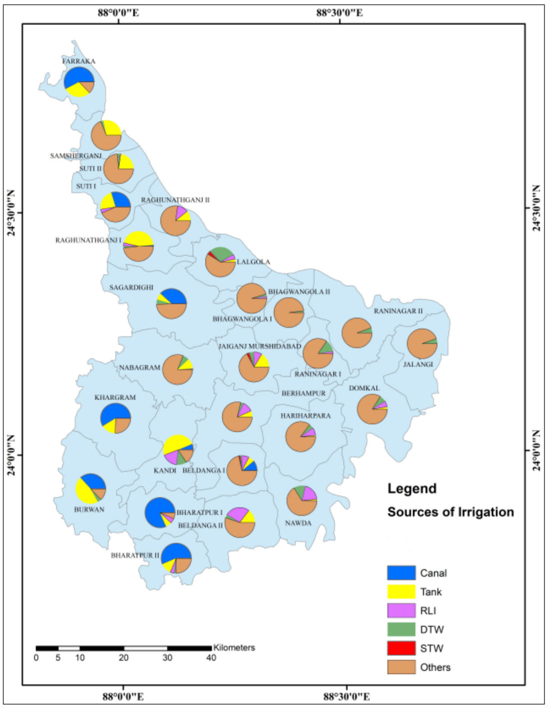


Figure 11. Sources of irrigation.

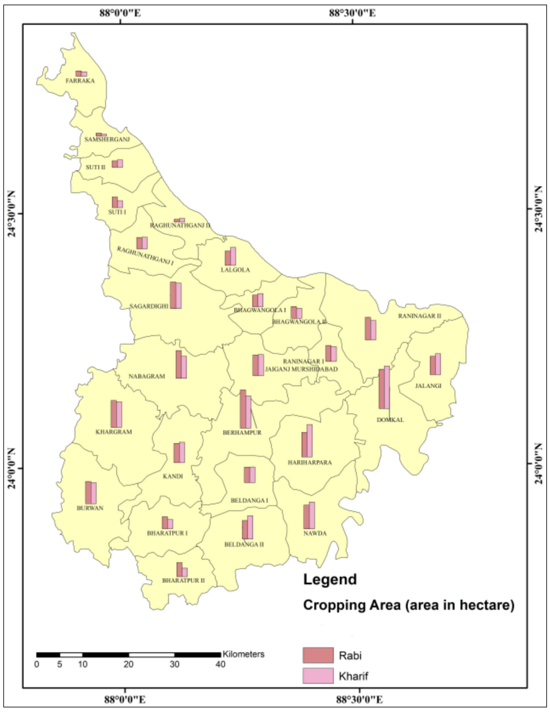


Figure 12. Cropping area.

2.4.5. Slope

The storage and recharge of groundwater largely depends on the slope; therefore, this is considered as a significant criterion in the study. Using the spatial tool in Arc GIS software, the slopes of the region was created based on the SRTM DEM. The slope angle of the map has been categorized into five zones (Figure 13), and the highest slope is found in the western part (>5°), while the lowest slope (<1°) is noticed in the eastern, northern and north-western divisions of the district. The entire district is mostly covered by a low slope, the value of which is less than 3°, as well as a few notches of comparatively higher slopes (3° to 6°) distributed abruptly in the district. Geologic uplift, rock structure, erosional rate, and the valley deposition of fluvial process are the main causes of slope variations in the region. As the study area belongs to a lower plateau and plainland, this is why it has less slope variability. Moreover, by the observations during the field visit, it is stated that this slope variability probably occurred due to dissimilar geologic rock arrangements, a dissimilar rate of erosion, and a few anthropogenic gestures, such as deforestation, grazing etc.

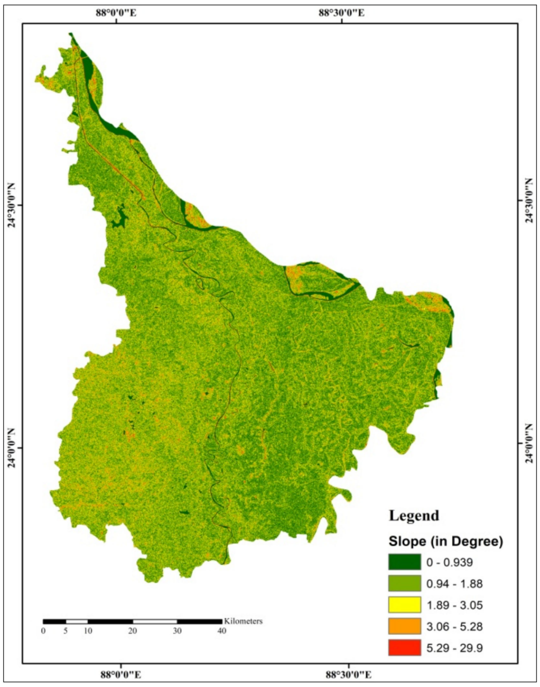


Figure 13. Slope Map.

2.4.6. Lithology

As the district is blanketed by sediments of diverse origin, therefore, its formation is grouped into three major categories, 1. Rajmahal trap of Jurassic period, 2. Older alluvium and lateritic clay of Pleistocene times, and 3. The newer alluvium of recent times. The oldest part of higher elevation with mostly basaltic rock of the Jurassic and Cretaceous period was observed in the north and north-western part of the region, while the older alluvium and lateritic clay of Rampurhat formation in Pleistocene times was found in the western sides [74]. It is considered as the continuation of the sub-Vindhyan region and therefore, the nodular limestone and lateritic clay are scattered in the region. The residual part of the district is featured by the recent alluvium of Bhagirathi formation, composed by sands and clay developed by the Bhagirathi river flood plains. The lithological setting governs the groundwater storage and its distribution, as it controls the landforms, their geomorphic features, and hydrogeological composition and features. Based on the Geological Survey of India (GSI) resource map series, the lithological sketch of the district was accurate. It revealed (Figure 14) that the district mostly contains alluvium and sandstone; thus, the entire district is covered by sand, silt, clay or sand, silt, and clay calcareous concretions. A very small patch of basal lava was observed near the hilly region of the north-west corner.

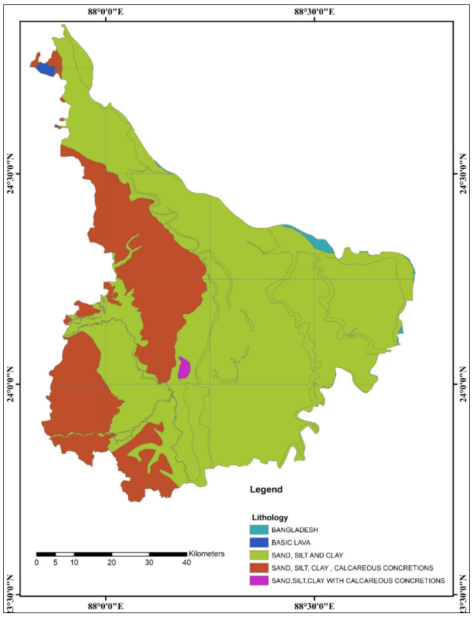


Figure 14. Lithology Map.

2.4.7. Drainage Density

The drainage density is the proportion of the sum length of every stream and its corresponding area and it has an extremely imperative responsibility in surface run off, influencing the land use pattern and the intensity of torrential floods. Moreover, it has a direct effect on topography and geomorphic landforms and has an inverse relation with the permeability and therefore is heavily related with the groundwater potentiality. Therefore, drainage density (Figure 15) was produced from the DEM using ArcGIS software. The computed density has been classified into five classes and ranges from 0 to 33/km^2. The middle and eastern parts of the region demonstrate high drainage density and some parts of the western and northern segment confirm the least drainage density, mostly due to the physical properties of the underlying rock, enveloped by vegetation cover and patchy relief assets. The middle to southern parts of the region have the highest drainage density values.

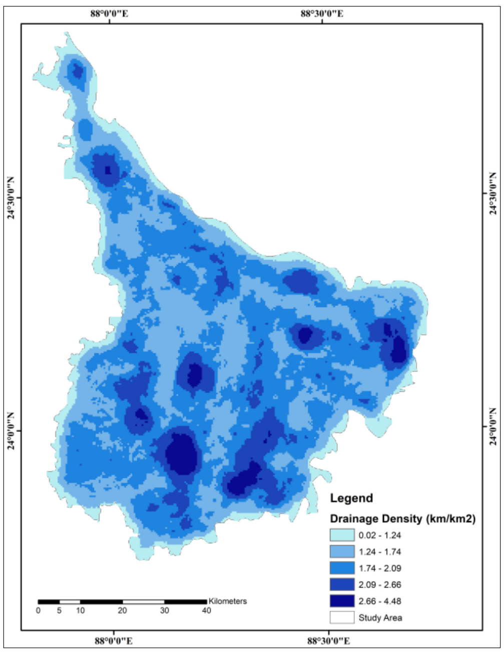


Figure 15. Drainage Map.

2.4.8. Lineament Density

The lineament density has an effective connection with groundwater recharge and flow; therefore, the lineament density map has been prepared (Figure 16) using the Landsat 8 OLI remote sensing data with the help of the DEM map using Edras Imagine and Arc GIS software. The density ranges from 0 to 1.46 km/km^2 and the higher to moderate value is positioned in the western to the north-western parts of the region, which signifies the higher water inflow and recharge.

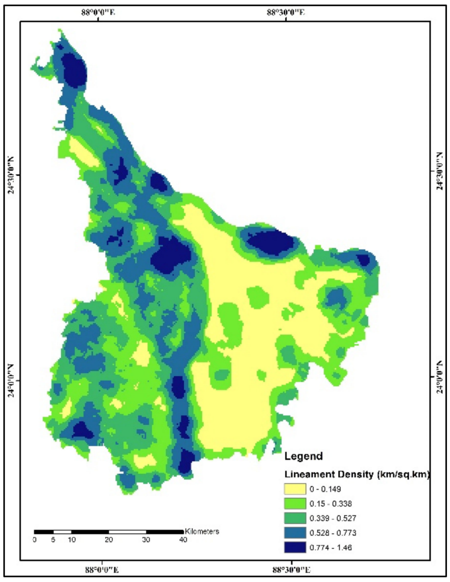


Figure 16. Lineament Map.

2.4.9. Topographic Wetness Index

The topographic wetness index is the ratio between the slope and catchment area and therefore, the spatial allocation of moisture is expressed by the TWI, which was initially used by Baven and Kirkby (1979) [43,50,51]. The TWI has been widely used in the groundwater studies as the behavior and movement of water, water accumulation, etc., are directly related to TWI and the groundwater incidence is directly proportional to the TWI. The calculated TWI was grouped into six classes (Figure 17) and the value rages from 4.35 to 22.95. The entire district is mostly covered by low ranges (<10) of TWI and the higher ranges are concentrated in a few pockets.

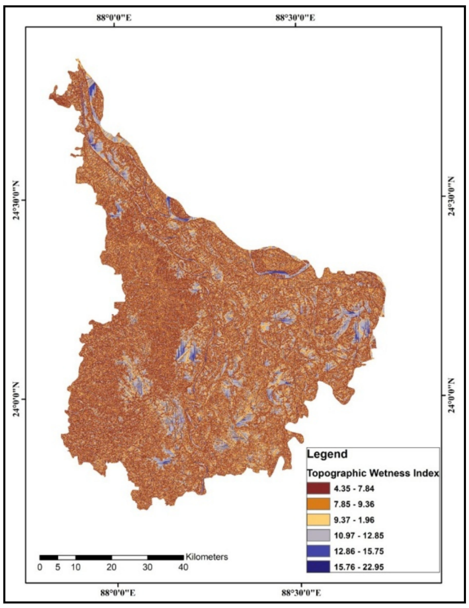


Figure 17. Topographic Wetness Index Map.

2.4.10. Topographic Position Index

The TPI is the scale-dependent phenomena of the positioning of upslope and downslope attributes and it is generated from the DEM by detecting the rise and proximity around it. The area is classified into five groups based on the TPI value (Figure 18) and the highest TPI value (>6) is observed in the western part, while the lowest TPI values (−4 to −14) were found dispersed in the eastern, central and northern side. As a higher TPI signifies a hilly, plateau or terrain surface and a lower TPI value signifies a flat surface, therefore, the eastern side of the study area having a lower TPI value is considered as the groundwater potential.

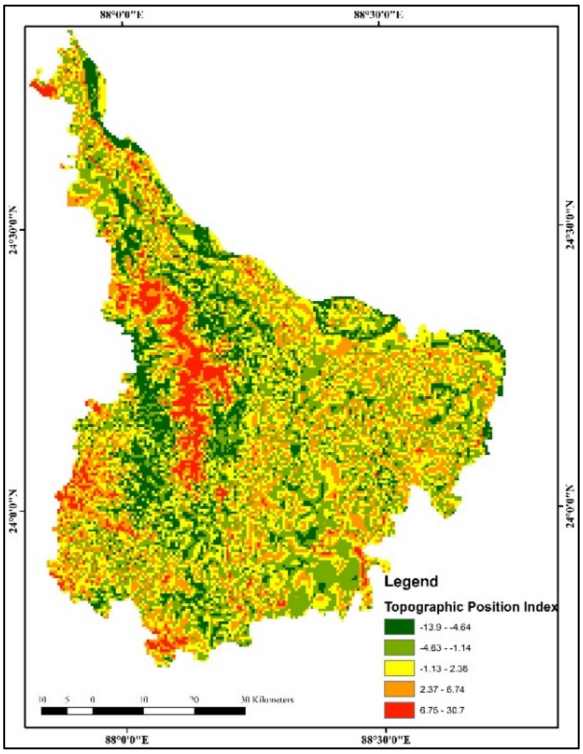
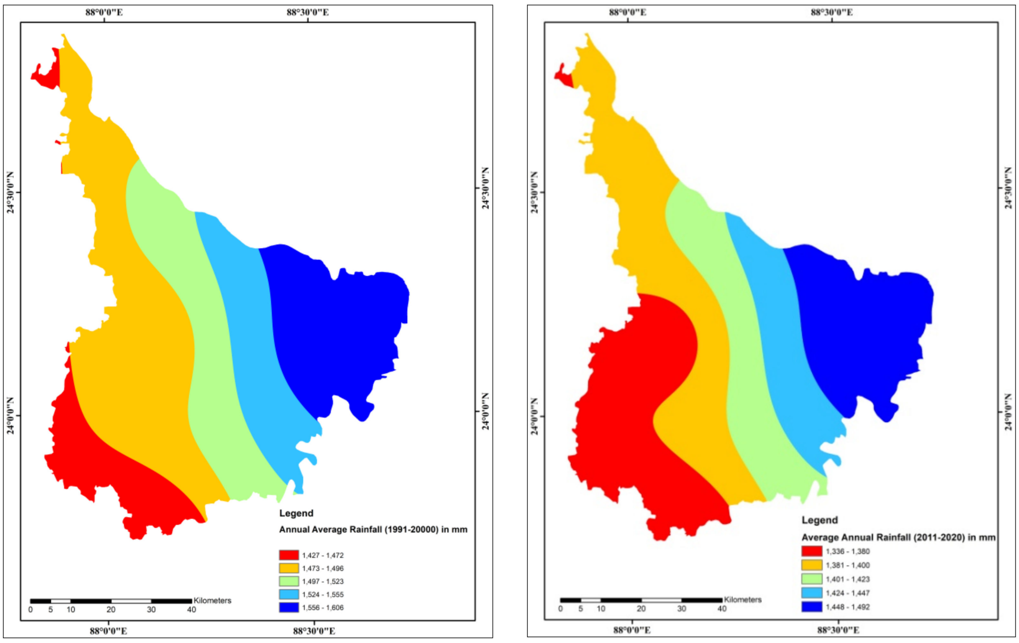


Figure 18. Topographic Position Index Map.

2.4.11. Rainfall

The rainfall is strongly connected with the groundwater recharge, therefore the average annual rainfall map (Figure 19a,b) has been prepared using the IDW interpolation method using the geospatial technology in ArcGIS based on the IMD data and SRTM DEM. It reveals that the eastern part of the region receives substantial amount of rainfall annually. From 1991 to 2000, the average annual rainfall ranged from 1427 to 1606 mm; while it declined to 1336 to 1492 mm in the period 2011 to 2020. The spatial distribution pattern of both the periods were almost the same, where the very low to low average annual rainfall was observed in the central to western parts of the district, followed by the moderate amount and the high to very high amount being noticed in the central to eastern parts. This rainfall amount has a strong connection with the groundwater potentiality, as it was found in most of the cases that a high rainfall amount often produces a high potentiality of groundwater.



(**a**) (**b**)

Figure 19. (**a**). Rainfall Map (1991–2000). (**b**)**.** Rainfall Map (2011–2000).

2.4.12. Soil Texture

The soil is also connected with groundwater flow, recharge, discharge and movement. The soil of the eastern part is mainly dark clay, which is very fertile, while the western part, the left bank of River Bhagirathi, is mostly clay and laterite clay, grey or reddish in colour. The whole district in characterized by clay, loamy, laterite soils which are mostly grouped into two categories; a. Sub-Vindhyan alluvial soil and b. New alluvial soil, found in the flood plains. The coarse, fine and very fine loamy soil are the major loamy soil types of the region as per the NBSSLUP records. Thus, the soil map (Figure 20) has been prepared and the outcome was grouped into four classes. The description of such a set is important to relate it with the groundwater dynamics.

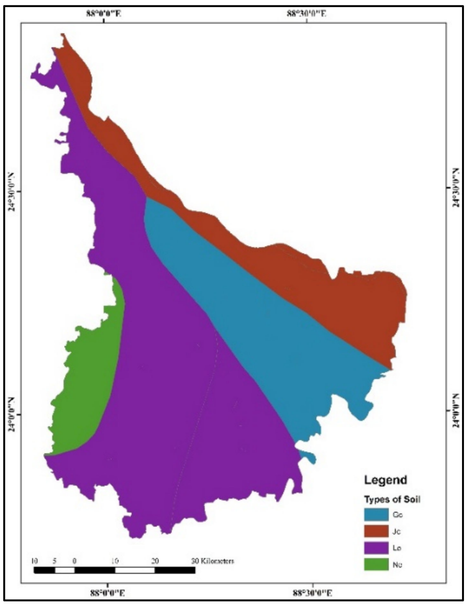


Figure 20. Soil Texture.

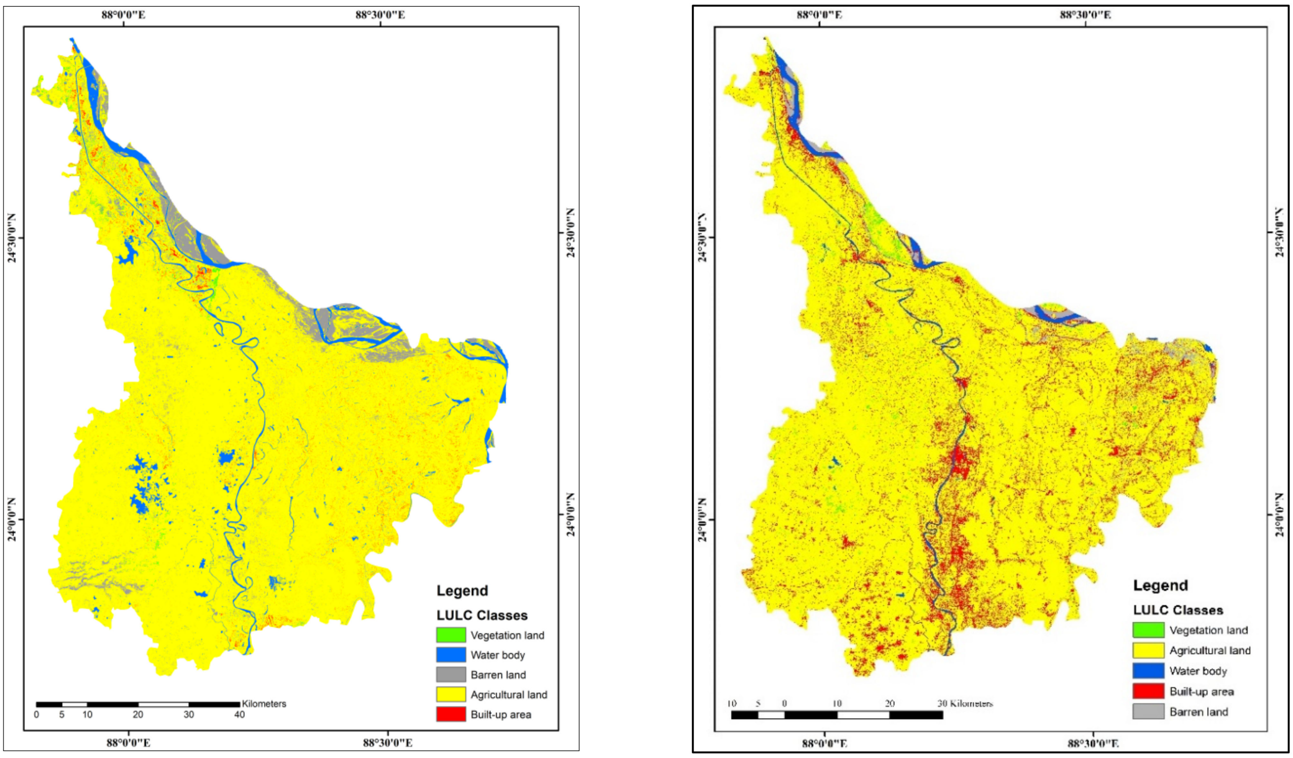
a. *Gc (Calcaric Gleysols)*—It shows hydromorphic properties of the surface (<50 cm); having only A, H, and B horizons with cambic or calcic or gypsic character.

b. *Jc (Calcaric Fluvisols)*—It is generated from fresh alluvial deposits with ochric or umbric or sulfuric horizons. Conditionally, they have high resilience and low sensitivity, but are much prized for intensive agriculture.
c. *Lo (Orthic Luvisols)*—It has a high pedestal saturation (>50%), which is seriously exaggerated by water erosion and thus has low organic matter.
d. *Ne (Eutric Nitosols)*—It is considered as the most excellent and fertile soils of the tropics as it can suffer acidity and P-fixation. It has modest toughness and a reasonable to stumpy compassion. It was found in the western parts of the district, which is not suitable for groundwater storage.

2.4.13. Land Use Land Cover (LULC)

Agriculture is considered as the foremost land use of the region, and apart from that, water body, open forest, built-up area and fallow land are observed as other land use types. About 76% area of the district is available for cultivation, where irrigation is considered as the main factor, and as per the 2011 census, about 65% cultivable land is under irrigation. The irrigated cultivation is mostly noticed in the eastern part and it was found to be highest in the Farakka block and lowest in the Suti-I block. The forest cover of the district is very insignificant (770 hectares). The settlements are distributed throughout the district with a special concentration in the Rarh region. The soil of the eastern part is mainly dark clay, which is very fertile and thus mostly used for paddy, jute, and rabi crop cultivation. The western part, the left bank of River Bhagirathi, is mostly clay and laterite clay, grey or reddish in colour. Some paddy, sugarcane, potato, oil seeds and vegetables are mainly cultivated in this region.

The utilization of groundwater and its rejuvenation is largely influenced by the LULC of the region. Therefore, the LULC map (Figure 21a,b) was prepared using the Landsat (five TM and eight OLI) remote sensing data in Arc GIS software and five classes of LULC have been identified, namely, vegetation, water body, barren, build up, agriculture. The LULC changed over the 20 years span, especially regarding the reduction of water bodies, vegetation cover, barren land and the increase in build up area and agriculture, and the impact of these changes can be correlated with the groundwater dynamics.



(**a**) (**b**)

Figure 21. (**a**). LULC Map (2000), (**b**). LULC Map (2020).

3. Results

3.1. Groundwater Potential Zone

The potential zones of groundwater of Murshidabad were identified (Figure 22a,b) through amalgamating the thematic layers of the selected criteria with respect to their relative prioritization through employing the geospatial operations in the Murshidabad districts. The area is divided into three potential zones, namely fair, good and excellent, and it is noticeable that the the whole district is enclosed by a good potentiality (middle to west part), followed by the excellent potentiality (middle to east part) of groundwater booth in 2000 and 2020. A negligible amount of fair potentially is dispersely distributed in the south, central and north-western parts of the district. This good to excellent potentiality is matched with the hydrogeological condition; comparatively more rainfall; a flat slope; existence of alluvial and flood plain; existence of sand, silt, clay; low to moderate drainage density; low to moderate lineament density.

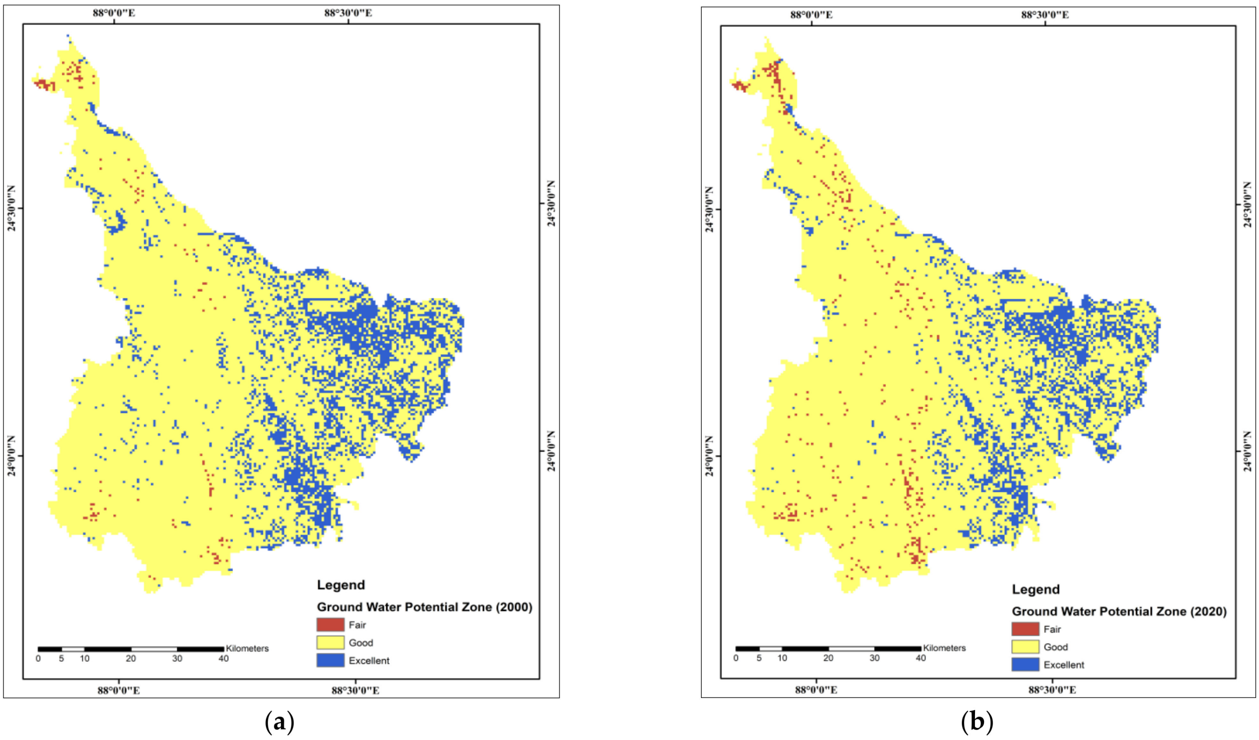


Figure 22. (**a**) Groundwater potentiality (2000). (**b**) Groundwater potentiality (2020).

3.2. Groundwater Storage

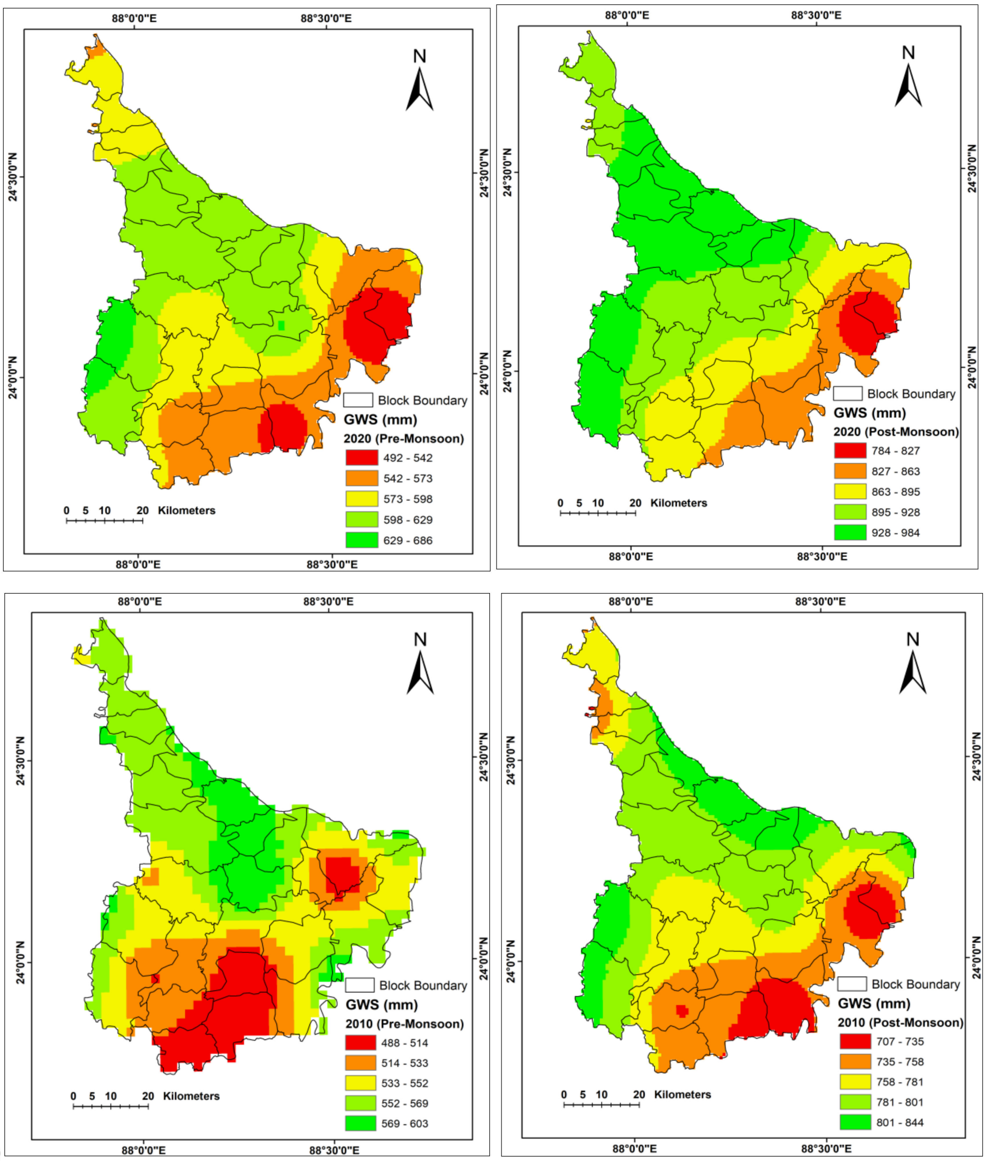
The eastern side of the River Bhagirathi of Murshidabad district is characterized by a shallow water table, while the western side is attributed by confined and unconfined groundwater and thus the groundwater development is good in Bagri region and poor in Rarh region [74]. As per the investigation (1996–2018) of the Central Groundwater Board (CGWB), the deepness of the water level in dug wells varies from 0.8 to 17.8 mbgl (pre-monsoon) and 0.8 to 15.38 mbgl (post-monsoon). The average depth of a dug well is 5.22 and 3.2 m in pre- and post monsoon, respectively. The depth of water intensity in tube wells varies from 2.15 to 26.9 mbgl (pre-monsoon) and 1.02 to 32.54 mbgl (post-monsoon) and the average depth is 10.1 and 7.24 m in pre- and post-monsoon periods, respectively.

The groundwater storage (GWS) amount of pre- and post-monsoon water of the year 2000, 2010, 2020 in the Murshidabad district is tabulated (Table 5) and we observed the spatial pattern and trend of fluctuation in the preceding years (Figure 23a–c). The groundwater storage is illustrated in a tabular format (Tables 6 and 7) which is self-explanatory.

Table 5. Levels of groundwater storage (GWS) range.

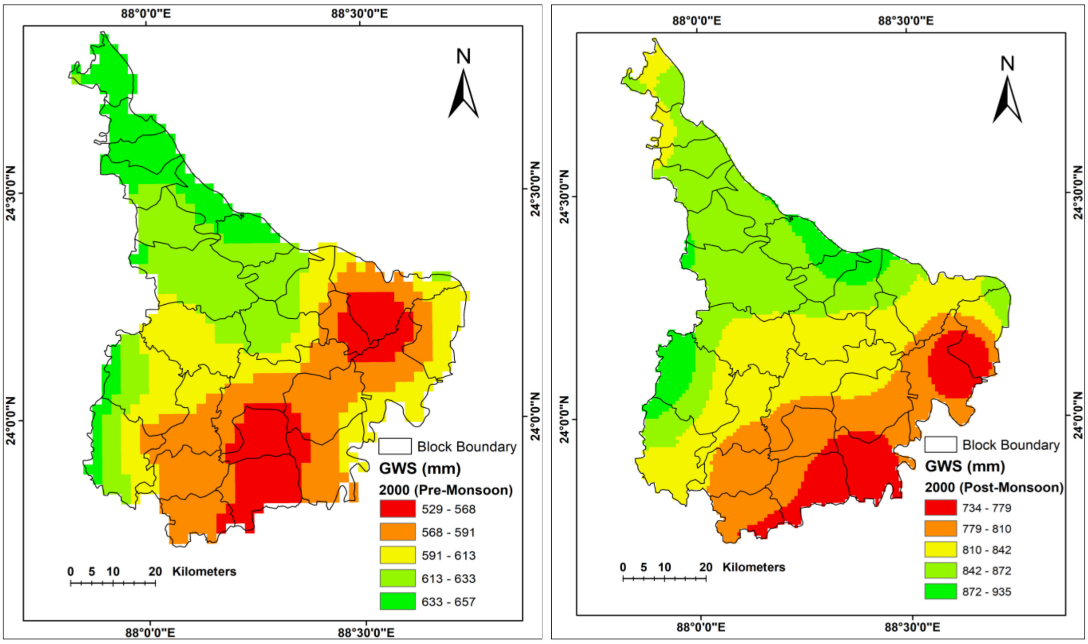
Seasons and Year	Water Storage Range (mm)				
Storage Level	Very Low	Low	Moderate	High	Very High
Pre-Monsoon					
2000	529–568	568–591	591–613	613–633	633–657
2010	488–514	514–533	533–552	552–569	569–603
2020	492–542	542–573	573–598	598–629	629–686
Post-Monsoon					
2000	734–779	779–810	810–842	842–872	872–935
2010	707–735	735–758	758–781	781–801	801–844
2020	764–827	827–863	863–895	895–928	928–984

Source: Authors.



(**a**) (**b**)

Figure 23. *Cont.*



(**c**)

Figure 23. Groundwater storage of 2000 (**a**), 2010 (**b**), 2020 (**c**) (pre-monsoon and post-monsoon).

Table 6. Variations of groundwater storage (GWS).

Year	*Period*	*Storage Level*	*Location in the District*	*Expressive Remarks*
2000	Pre-monsoon	Very High	West, North-West	The foremost parts of the district are enclosed by moderate to awfully stumpy GWS, positioned in the middle to lower segment. The high to very high GWS was found mostly in the upper part of the district. Here, the coverage of low and high GWS was almost equal and the storage amount range was 529 to 657 mm.
		High	Central to North, West	
		Moderate	Central to West, East, South-East	
		Low	East, South	
		Very Low	East, South	
2010	Pre-monsoon	Very High	North, West	The key portions belong to modest to extremely high GWS (middle to upper part), while the low to very low GWS is concentrated in the south. The storage amount declined from 2000 and it ranges from 488 to 603 mm.
		High	Central, North, West, North-West, South-East	
		Moderate	Central, East, South, West	
		Low	East to South	
		Very Low	East, South	
2020	Pre-monsoon	Very High	West	The moderate to very low GWS condition was noticed in the central to lower parts. It has extra anomalies than in previous times as the very high GWS is negligibly found in a small patch in the west. Here, the GWS deteriorated from high to moderate in the north-west corner of the districts. The storage amount ranges from 492 to 686 mm, which was greater than 2010 but lower than 2000.
		High	Central, North, West	
		Moderate	Central, East	
		Low	East, South	
		Very Low	East, South	

Table 6. *Cont.*

Year	*Period*	*Storage Level*	*Location in the District*	*Expressive Remarks*
2000	Post-monsoon	Very High	West, North	In 2000, the GWS of the post-monsoon season was predominantly found to be of moderate to very low quantity and concerted in the middle and lower parts of the region. Most of the pre- and post-monsoonal GWS disparities were noticed in the west and southern parts. The storage amount ranges from 734 to 935 mm.
		High	North to North-West	
		Moderate	Central, South-Central, small patch in East, North-West	
		Low	East to South, South-East	
		Very Low	East, South	
2010	Post-monsoon	Very High	West, North	Here the amount of GWS fluctuates mostly especially in the middle to lower parts of the region compared to the pre-monsoon condition. The location of different storage level remained almost same, as the low to very low GWS is concentrated in the south and south-east. The storage amount ranges from 707 to 844 mm, lower than in 2000.
		High	West, West to North, Central, East	
		Moderate	Central, South to South-East, North-West	
		Low	East to South, South-East, North-West	
		Very Low	East, South	
2020	Post-monsoon	Very High	West, North to West	The improved GWS was achieved in the whole district from the pre-monsoon condition in the central to north; the west parts were covered with high and very high storage. The storage quantity also became higher than its pre-monsoon provison. The very low to low GWS was noticed in the east and south-east portion. The storage amount ranges from 764 to 984 mm, greater than in 2000 and 2010.
		High	Central, North to West, North-West	
		Moderate	East to South	
		Low	East, South, South-East	
		Very Low	East	

Table 7. Block distribution in the Murshidabad district.

Direction-wise block allocation	**North (N):** Lalgola, Bhogobangola-I & II, Raninagar-I & II, Raghunathgunj-I & II, **South (S):** Bharatpur-I & II, Nawda, Beldanga-I & II, **East (E):** Jalangi, Domkal, **West (W):** Barwan, Khargram, Nabagram, Sagardihi, **Central (C):** Kandi, Berhampur, Hariharpara, Jiaganj Murshidabad, **NW:** Farakka, Samsherganj, Suti-I & II
Upper portion	Lalgola, Bhogobangola-I & II, Raninagar-I & II, Raghunathgunj-I & II, Farakka, Samsherganj, Suti-I & II
Middle portion	Kandi, Berhampur, Hariharpara, Jiaganj Murshidabad, Barwan, Khargram, Nabagram, Sagardihi, Jalangi, Domkal
Lower portion	Bharatpur-I & II, Nawda, Beldanga-I & II

It reveals that the GWS amount fluctuated largely throughout the district during the pre- and post-monsoon seasons and over the years from 2000 to 2020; the storage amount changed (Figure 24). In the year 2000, the pre-monsoonal storage amount ranged from 529 to 657 mm, this declined to the range of 488 to 603 mm. However, the storage amount recovered in 2020 and ranged from 492 to 686 mm, which was greater than 2010 but slightly lower than 2000. The same kind of trend was also noticed in the case of post-monsoonal storage, as in the year 2000, the storage amount ranged from 734 to 935 mm., but declined largely in 2010, where it ranged from 707 to 844 mm. In the year 2020, the post-monsoonal storage improved and the amount ranged from 764 to 984 mm, which was greater than in both 2000 and 2010.

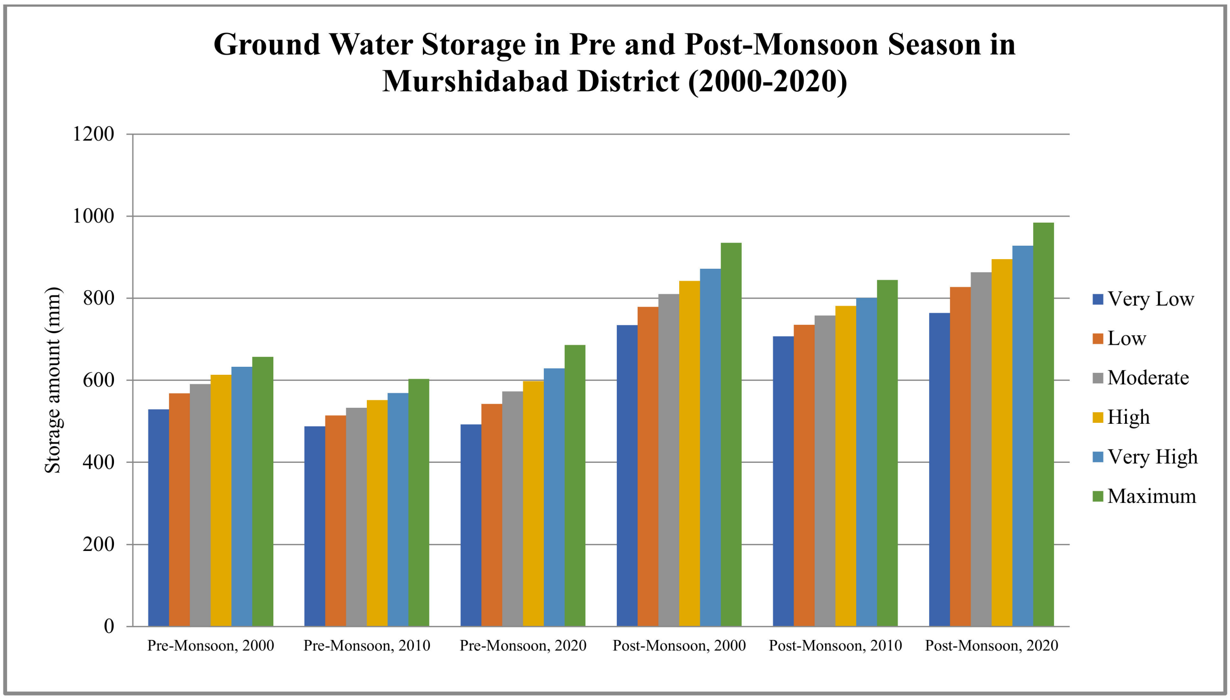


Figure 24. Seasonal groundwater storage.

3.3. Arsenic Contamination

A study revealed that in 2001, about 18 blocks, 354 villages and 1,343,866 people were affected by arsenic contamination in Murshidabad district. All these figures sharply increased in the year 2011 where 1721 villages and about 5.88 million people came under arsenic-affected regions, covering about 24 blocks belonging to above 50 µg/L, among which 17 blocks had above 300 µg/L [76].

The Murshidabad district was affected by the arsenic contamination in its groundwater and low to moderate arsenic concentration was observed in 18 blocks, which were spatially distributed throughout the district (Figure 25). The highest arsenic level (1.12 mg/L) was found in Raninagar-II block, followed by the Domkal, Berhampur, Jalagi, and Mushidabad-Jiaganj blocks (ranges up to 0.5 mg/L). Moderate ranges (0.05 to 0.3 mg/L) were found in rest of the blocks, while the lowest concentration level (0.05 mg/L) was observed in the Samserganj block.

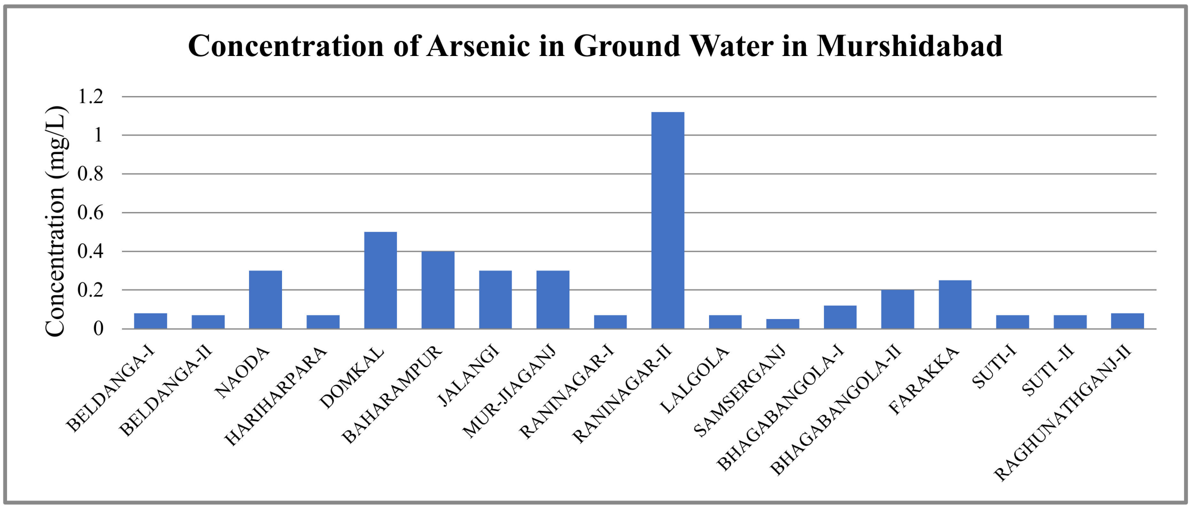


Figure 25. Concentration of arsenic in the groundwater in the blocks of Murshidabad district.

3.4. Groundwater Depth

The Rarh region has greater groundwater fluctuations than the Bagri region, which indicates a disparity in recharge and discharge in pre- and post-monsoon seasons. In 1980, the depth of the Rarh region ranges from 1.17 to 15.35 mbgl in pre-monsoon and 0.79 to 11.32 mbgl in post-monsoon months, while in the Bagri region this range was reduced to 3.5 to 9.5 mbgl post-monsoon in the year 2010 [74]. A small fluctuation was recorded in the period of 1980–1990. An incidence of flooding occurred in 2000 that was able to raise the water level to some extent in some blocks; afterward the water logging condition persisted mostly in Suti-I & II, Farakka and Samserganj block for three consecutive decades, but again the water level situation of most of the blocks were deteriorated in the preceding years [74].

The depth of the groundwater of the blocks of Murshidabad ranged from 21 to 74 m. The highest and least depth ranges of the blocks were plotted (Figure 26) and it was found that the highest depth was observed in the Domkal block, while lowest depth was noticed in the Berhampur and Raghunathgunj-II blocks. It was also noticed that the blocks located in the northern and north-western parts have fewer fluctuations of the maximum and minimum depth, and the average depth range was 40 to 50 m. Besides, the blocks of the southern parts, where the amount of groundwater storage was very low to low in pre- and post-monsoon seasons, have larger fluctuations in the deepness range.

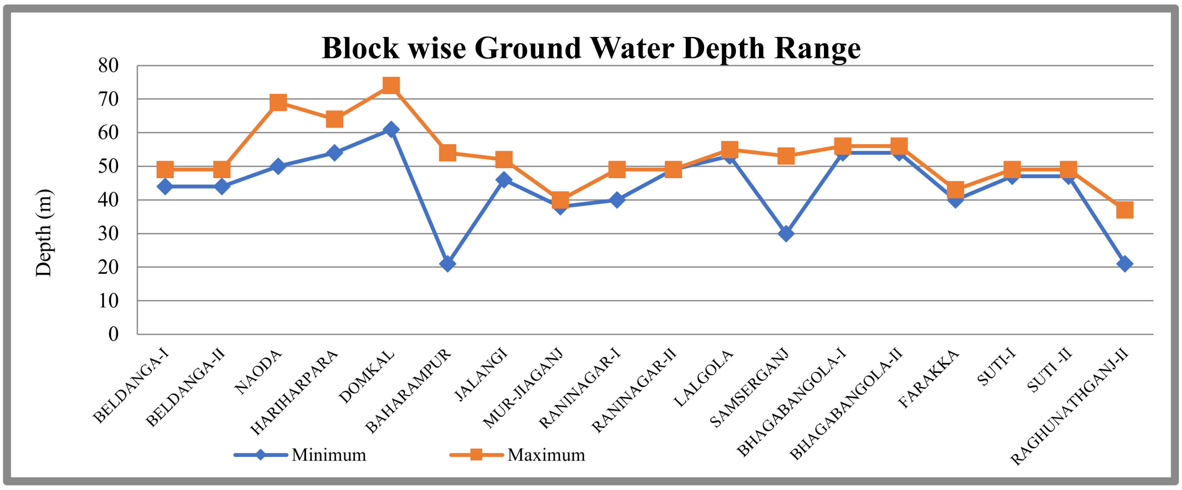


Figure 26. Groundwater depth range.

The block-wise fluctuations of groundwater levels in pre-monsoon (Figure 27) and post-monsoon seasons (Figure 28) of 2011 to 2017 were also studied. It was revealed that the average pre-monsoon values ranged from 5 to 45, while some of the blocks (Sagardighi, Nabagram, Khargram, Kandi, Barwan, Bharatpur-I & II) have values ranging from 16 to 160. The same pattern and nature was also observed in the post-monsoon season. During both seasons, the fluctuations of the groundwater level of most blocks are gradually increasing from 2011 to 2017.

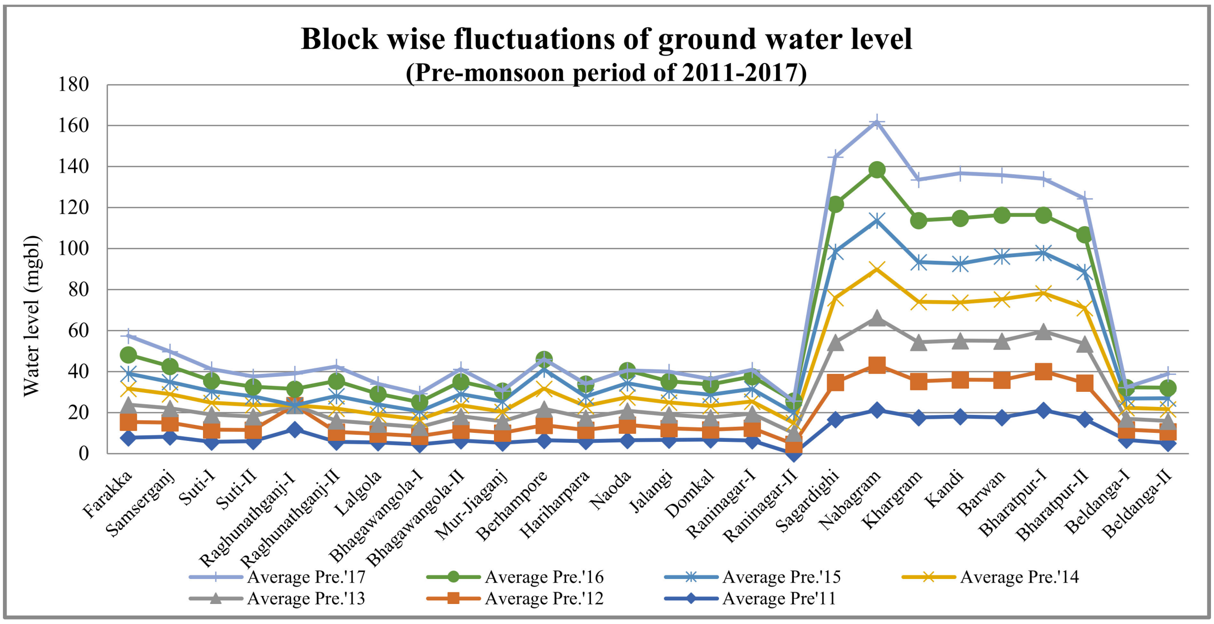


Figure 27. Groundwater fluctuations in pre-monsoon season.

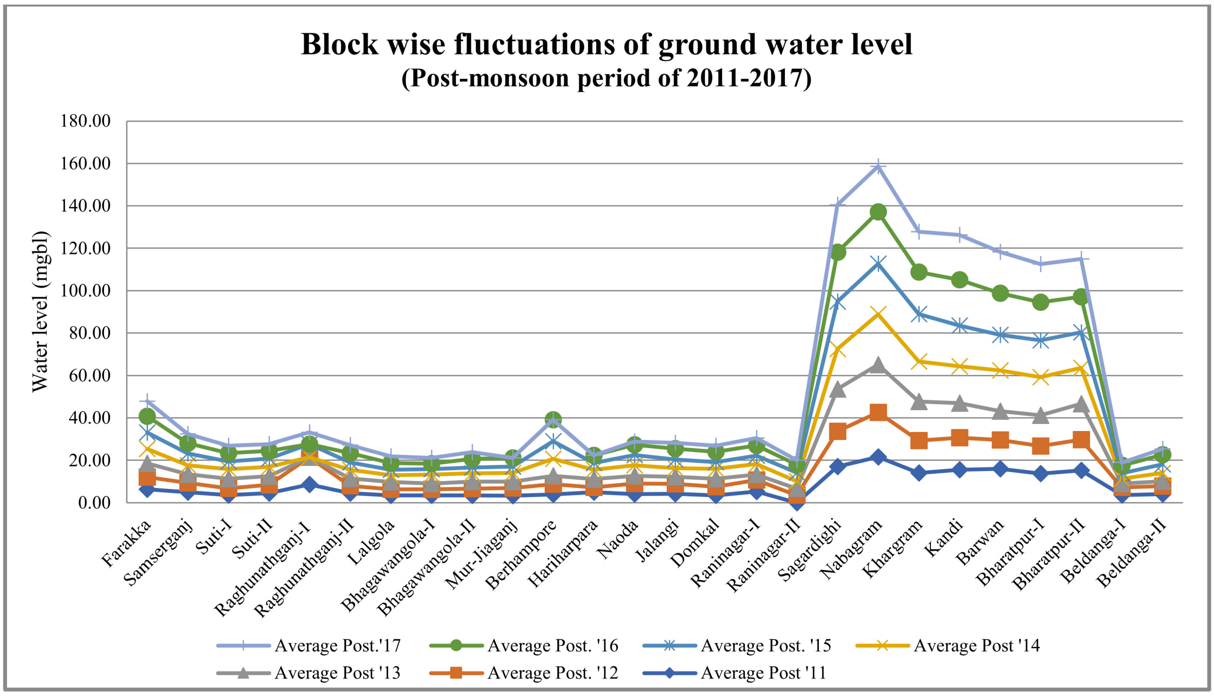


Figure 28. Groundwater fluctuations in post-monsoon season.

The fluctuations of the groundwater intensity of the pre- and post-monsoon seasons of 2019 were graphed (Figure 29) and it reveals that the average level varies in pre-monsoon seasons from 3 to 20 mgbl, where most of the blocks (number 15) have close to a 5 mgbl level. However, in the post-mosoon, due to groundwater recharge during monsoons, the level increases and thus the average level varies from 6 to 38 mgbl, and most of the blocks (number 17) have the level of 10 mgbl or more. Thus, it appears that the average fluctuation between pre- and post-monsoon was quite remarkable.

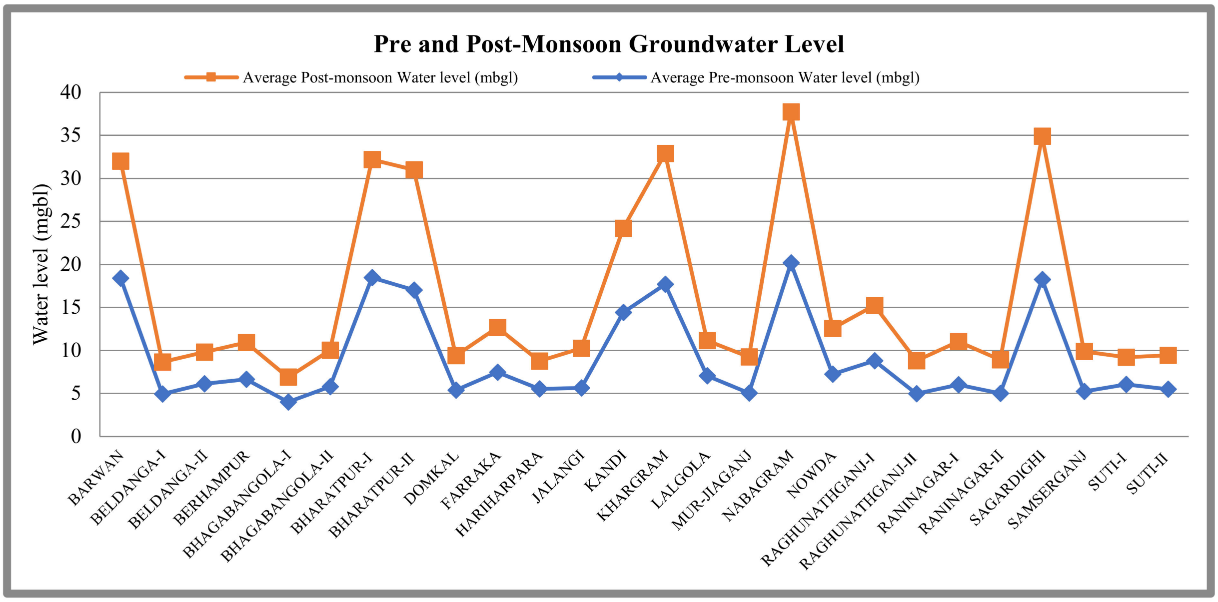


Figure 29. Fluctuations in the pre- and post-monsoon groundwater level, 2019.

3.5. Groundwater Recharge

The district mainly recharges openly through the penetration of rainfall (average annual rainfall is 912.96 mm) and that captured into the aquifer. Moreover, some other sources such as leakage from canals and tanks and return seepage from irrigation fields recharge groundwater [75]. The western part of the district (Kandi subdivision, which has five blocks) has high to very high GWS and it reveals that the area is characterized by clay layers on the top and bottom sides, and the confined and semi-confined aquifers were discontinued and interrupted by the pocket clay layers, which reduces the groundwater recharge amount [75].

The groundwater rechage status of the blocks was studied in terms of number of tanks/ponds and storage capacity in surface flow scheme (Figure 30). It reveals from that almost all the blocks have less than six ponds/tanks; only Burwan block has a high number, 157. Besides, the storage capacity was mostly 50 cubic meters in most of the blocks; only Nabagram block has 72,000 cubic meters, followed by Sagardighi (30,800 cubic meters) and Burwan (10,005 cubic meters) (Figure 31). The geographical area and the groundwater-recharge-worthy area of each block was noticed (Figure 32), and it was observed that most of the blocks have the same recharge-worthy area in respect to their geographical area, which range from 9400 to 34,600 hectares. The highest area was observed in Sagardighi block, while the lowest area was occupied by the Samserganj block. Only seven blocks have an area of greater than 25,000 hectares and more recharge-worthy area, and these blocks are mostly positioned in the western and northern parts, which have high groundwater storage; the only exception is Domkal block located in the eastern part, which has very low amount of storage.

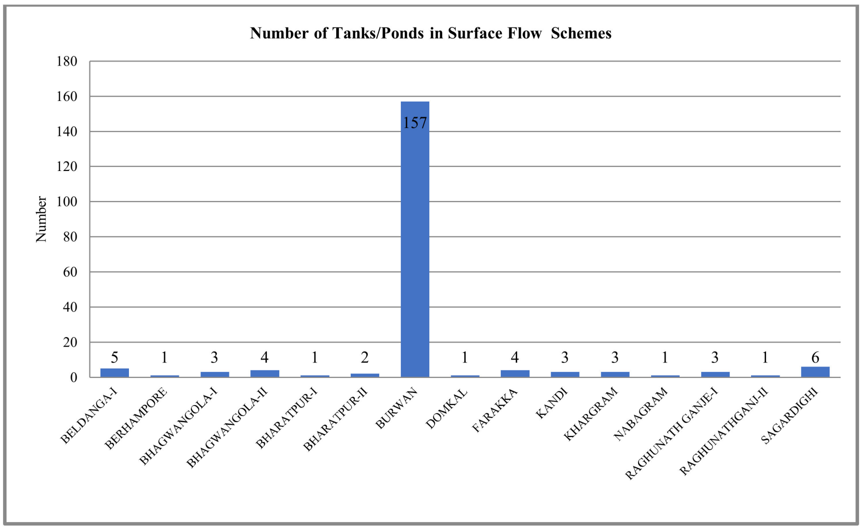


Figure 30. Number of tanks for storage.

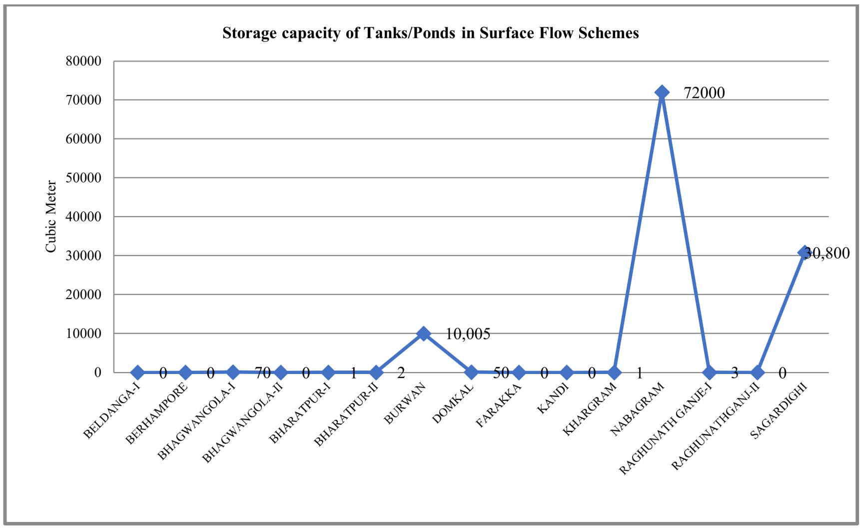


Figure 31. Groundwater storage capacity.

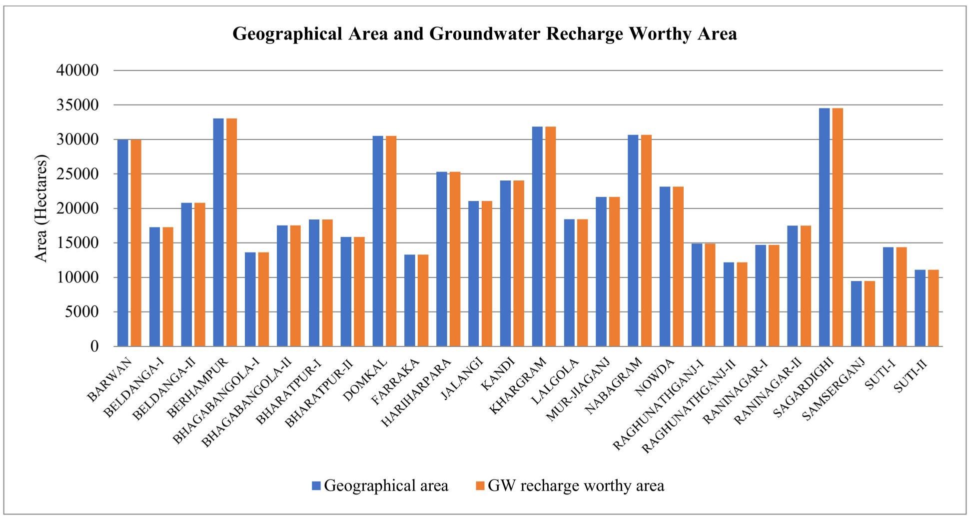


Figure 32. Geographical area and groundwater recharge worthy area.

The amount of rainfall variations was depicted (Figure 33) and it discloses that 1000 mm rainfall was only available in Khargram, while most of the assessment units have more than 940 mm rainfall. A smaller amount of rainfall (<940 mm) was only noticeable in Domkal, Karakka, Raninagar-I & II, Samserganj and Suti-I. The groundwater recharge during the monsoons by different methods was studied (Figure 34) and it reveals that the recharge corresponding to monsoonal rainfall by the water table fluctuation method was higher than the recharge measured by the infiltration factor method and rainfall recharge. The trend of these three methods has a similar pattern, but the block-wise huge variations were observed in spite of their close location. Raghunathganj-I has the highest amount of recharge and the Sanserganj has the lowest amount in terms of all these three. In the case of the water table fluctuation method, more than 20,000 ham groundwater recharge was noticed in Barwan, Berhampur, Hariharpara, Kandi and Raghunathganj-I, while more than 10,000 ham groundwater recharge was observed only in Raghunathganj-I and Berhampur.

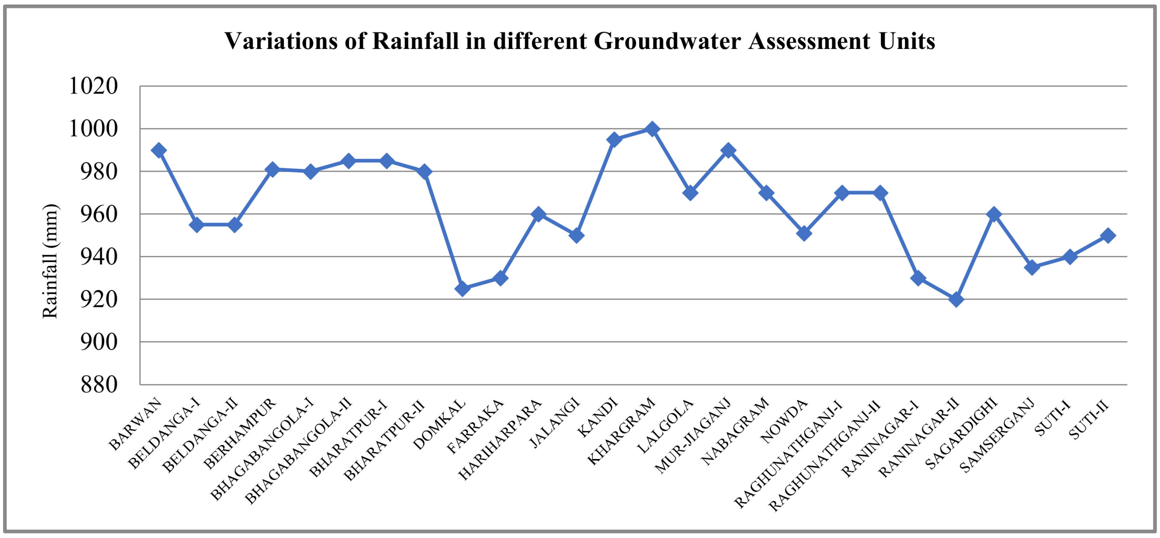


Figure 33. Block-wise variation of rainfall amount.

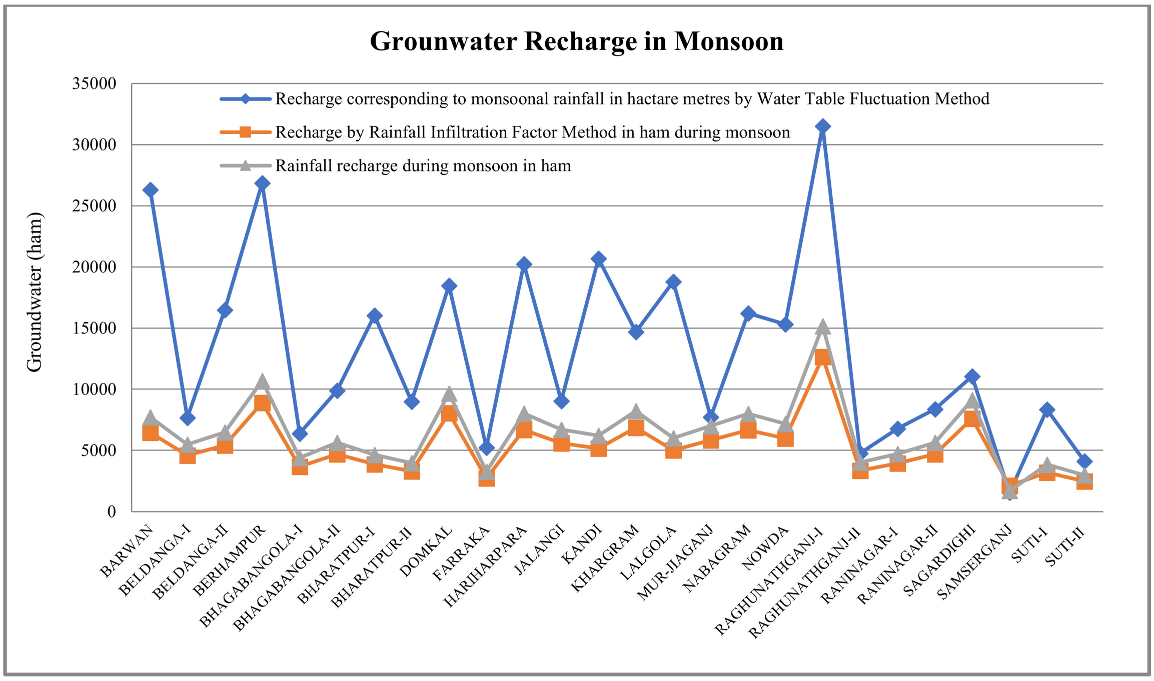


Figure 34. Groundwater recharge in monsoon season.

3.6. Utilization of Groundwater

The groundwater of Murshidabad district was used massively for agricultural purposes, which appears in the status of irrigation by different modes of the blocks. It reveals from a study that the irrigation area increased to 209,696 hectares in 2011–2012 from 113,032 hectares in 2001–2002. Therefore, the irrigational intensity increased to 25.06 from 16.73% in the same time period. The highest intensity in 2001–2002 was noticed in Farakka, Samsherganj, Raghunathgunj- II, Kandi, Berhampur, Barwan blocks, which was intensified in 2011–2012 in the Raninagar-II, Jalangi, Domkal, Bhogobangola-I & II, Bharatpur-I & II, Khargram, Nabagram, Barwan, Sagardihi blocks [77]. Here, the shallow and deep tube wells are predominantly used for irrigation, which is graphed (Figures 35 and 36), and the figures depict that the quantity of shallow tube wells are huge in number compared to deep tube wells. The maximum numbers of shallow tube wells (>11,000) are located in the Bharatpur-I block, while the minimum number is eccentrically observed in the Bharatpur-II block. About 50% of blocks have about 4000 shallow tube wells that were used for irrigation. However, only 35% of blocks have more than 30 deep tube wells that are used for irrigation. The highest numbers of 69 deep tube wells were noticed in Berhampur, followed by Domkal and Jalangi. Most of the blocks either do not have any deep tube wells or have only few in terms of their utilization in irrigation.

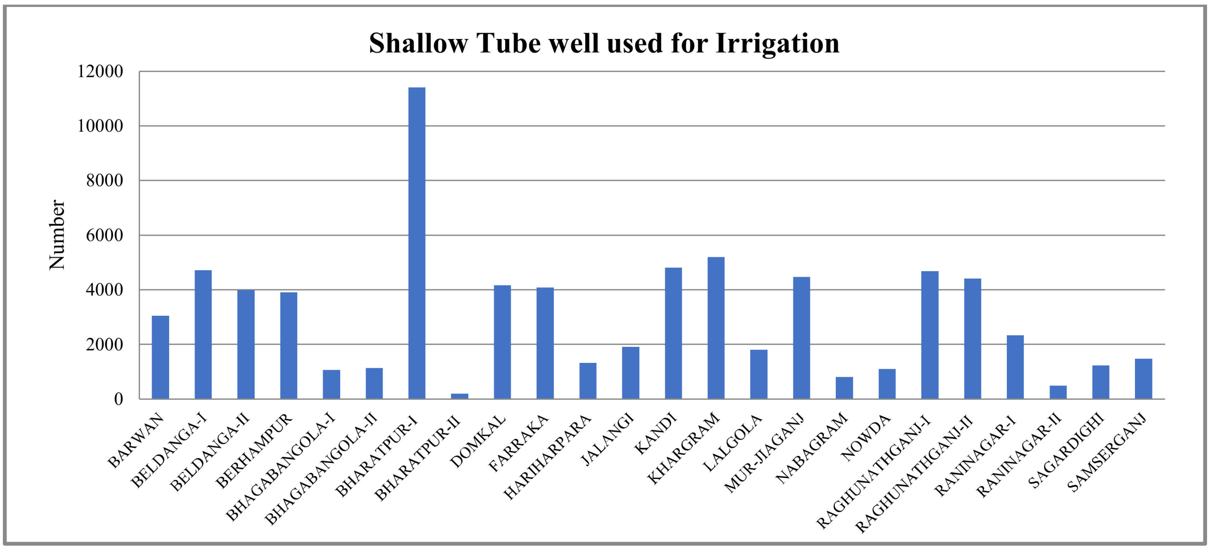


Figure 35. Shallow tube well used for irrigation.

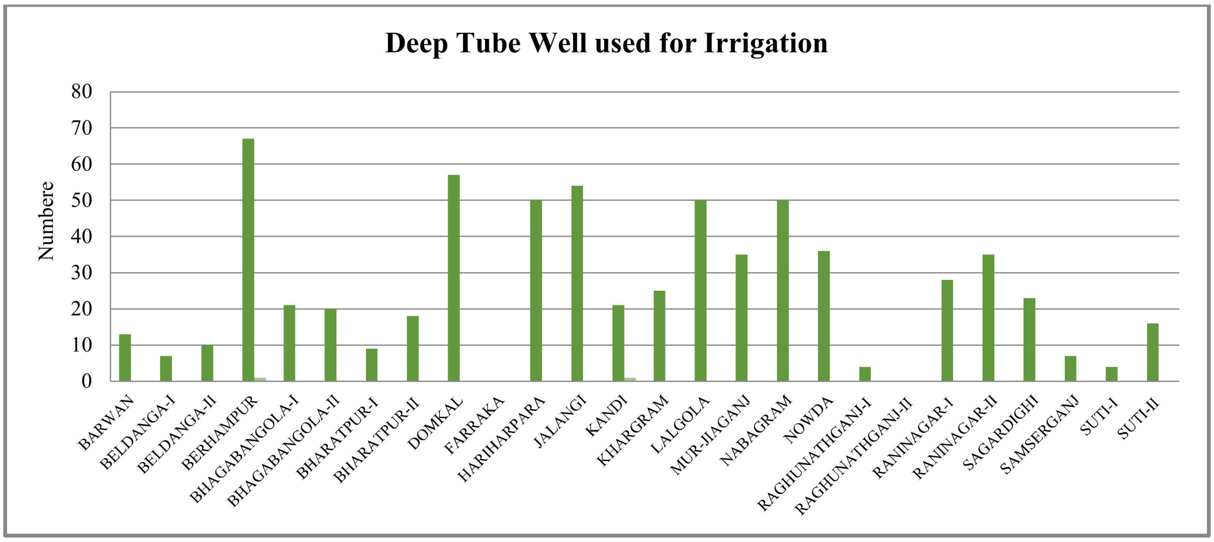


Figure 36. Deep tube well used for irrigation.

A comparative study of the net annual groundwater available and breathing gross groundwater draft uses in irrigation, household and industrial sectors was studied (Figure 37). It revealed that in most of the blocks, the net annual groundwater is more than its gross use. However, in some blocks, such as Domkal, Bhagobangola-I, Lalgola, Raghunathganh-I, and Raninagar-I & II, they have more gross draft uses than the net availability. Outlandishly, the situation of Domkal block is very alarming as the gross uses is about 27,000 ham while it has only 18,000 ham available of net annual groundwater. Probably thus, the groundwater storage of the Domkal block has been declining gradually since the year 2000 and these discrepancies was also observed in its pre- and post-monsoon groundwater storage. The net annual groundwater availability ranges from 2400 to 18,000 ham, while the existing gross graft uses ranges from about 1700 to 27,000 ham. Most of the blocks (about 70%) have 5000 ham or more net annual availability and gross draft uses of groundwater. Therefore, significant changes in the water intensity trend in the pre- and post-monsoon conditions of the blocks were examined (Figure 38) and it was found that block-wise, huge fluctuations exist. In most of the blocks, the post-monsoonal water level is more than in pre-monsoon condition, but it was found to be the opposite in the case of Suti-I & II and Beldanga blocks. Moreover, the rising trend is only observed in the Raghunathganj-I and Farakka blocks. All the other blocks have a falling trend in their water level and the highest falling trend (>65 cm/year) was found in the Bharatpur-I block, followed by the Bharatpur-II, Barwan, Khargram, Nabagram, and Sagardighi blocks, and they have about more than a 35 cm/year rate. This situation informs us this about the future uses of groundwater for various purposes in most of the blocks, and the formulation of micro-specific plans and enhancing awareness must be ensured.

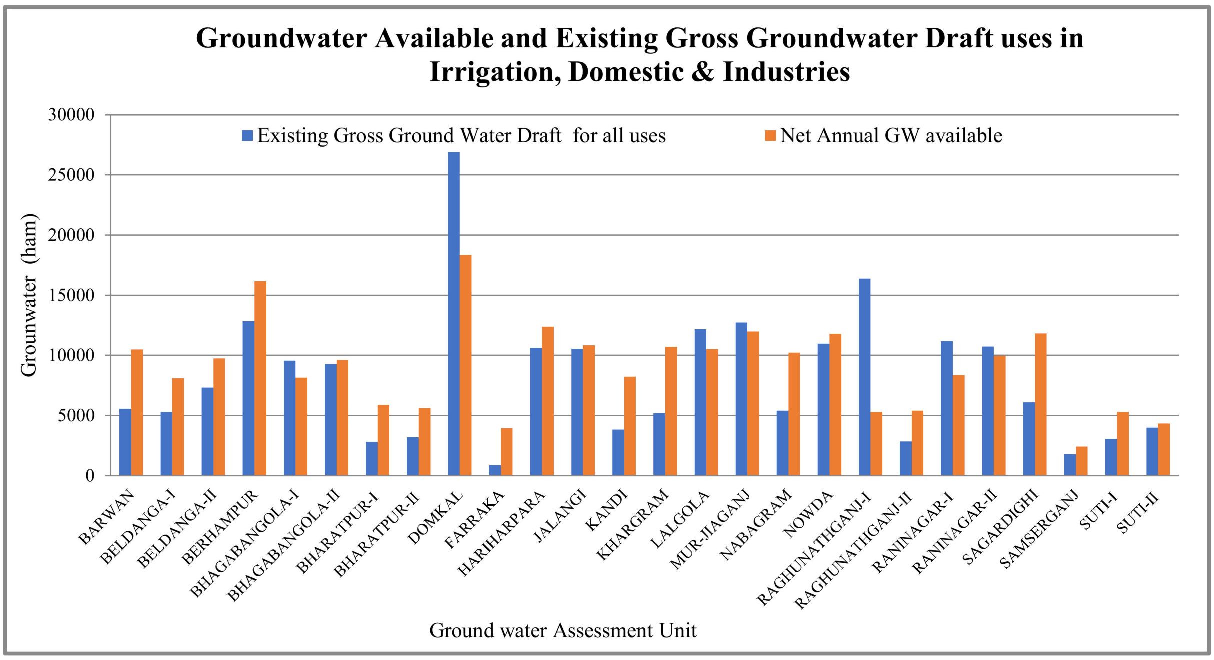


Figure 37. Groundwater available and existing gross groundwater draft uses.

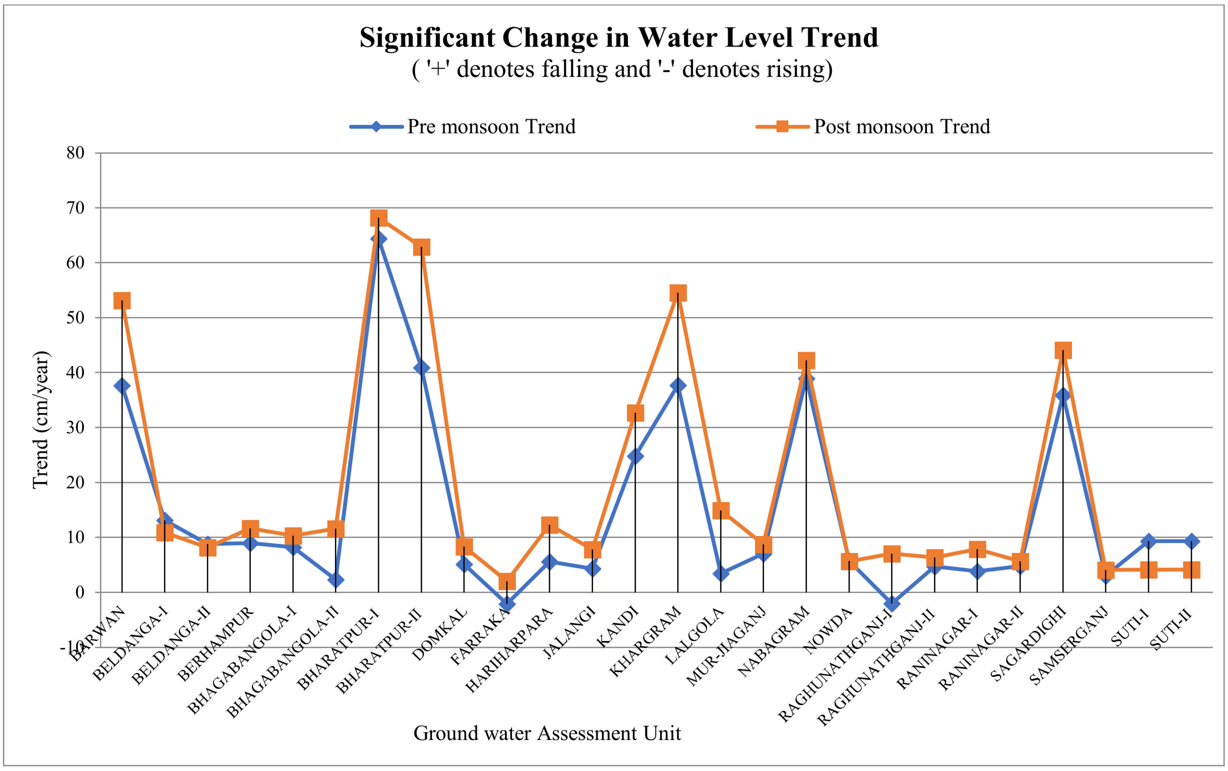


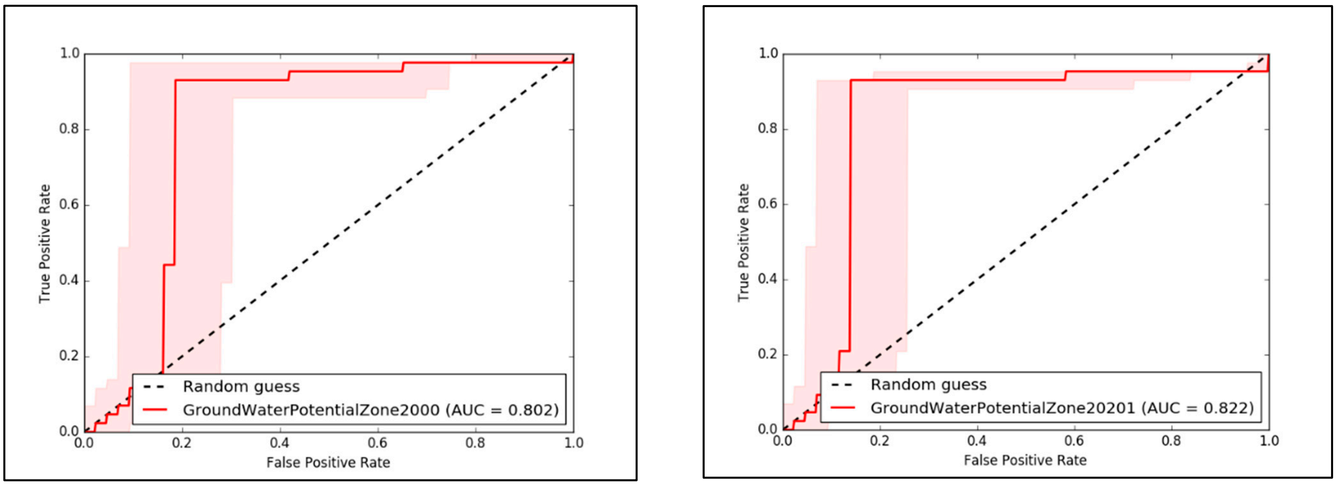
Figure 38. Significant change in water level trend.

4. Discussion

The spatiotemporal variations of the GWS, constant fluctuations, mostly reducing vistas, and alterations in the pre- and post-monsoon seasons of 2000 to 2020 in Murshidabad district were clearly analyzed in the current study. The middle to lower segments of the entire district were roofed by a moderate to very low amount of GWS in the year 2000, but afterwards a deficiency of the storage amount was detected in 2010, which was loosely recuperated in 2020, mostly during the post-monsoon season. Besides, the storage amount in the post-monsoon season was initially higher than the pre-monsoon condition over the years. Furthermore, assorted noteworthy alterations of GWS were also incidentally observed in nearly every block in the pre- and post-monsoon seasons. The seasonal oscillation of the GWS level was notably very high and gradually amplified in the years 2016 and 2017. In order to examine the circumstances and to reflect the storage disparity att he block level, several influencing criteria were scrutinized, in which, the LULC change was also considered and it was found that the entire district has undergone a hurried transformations in LULC, predominantly in the built-up areas and, therefore, it has acted as the biggest causative factor to the declining water level. In addition to that, rapidly mounting population growth, especially in the western part (north to south direction) of the district generates remarkable stress on water in diverse ways, such as its over-exploitation for agricultural, industrial, and domestic intentions, and the lessening recharge of water storage due to lower penetration rates. If this continued, the district will undergo water scarcity, for which a timely assessment is an incredibly crucial dictate. Henceforth, the current study was recognized as being incredibly noteworthy for planning, policy formulation, strategy construction, especially at the micro-level in the district.

A few studies have been conducted on the assorted blueprint of groundwater storage, disparity depletion and shortage in India mainly using satellite data [21,22,43,51]. However, using the current RS data by employing the MCDM method at the block or district level, especially on Murshidabad district, considering the significant neighborhood criteria to inspect GWS dynamics covering pre- and post-monsoon seasons over a long episode of 20 years (2000–2020), was our unsullied and remarkable endeavor. It was noted that most of the previous water-related research had been completed on arsenic concentration in different blocks of the district [77–79], as well as quantification of groundwater resources of the Kandi subdivision of the district [76], spatio-temporal analysis of groundwater resources using GIS [76,80], the changing cropping pattern and irrigation intensity [78], the effect of population growth on the environment, including drinking water [81,82], cropping intensity, and productivity, agricultural development influenced by integrated water [83], quality of groundwater and impact on human helath [84], assessment of wetland ecosystem health of the district [85], and the delineation of the aquifer of the Raghunathganj-I block of Murshidabad district [86,87]. It was revealed from those works that the amount of groundwater has been declining, the quality of drinking water has lowered, and some areas were arsenic-affected.

The groundwater is accumulated in the water table and confined to semi-confined aquifers were noticed in the entire Murshidabad district; block-wise, huge variations of its recharge were observed. The increasing demand of groundwater of a moderately dense population (1334/km^2) in the region was predominantly for domestic and farming intention. Thus, the shallow and deeper aquifers are plugged by dug wells and average to heavy duty tube wells (depth 4–20 mbgl) in the pre-monsoon season. Moreover, as huge parts of the district are arsenic contaminated (0.05 to 1.12 mg/L) and the open wells are desiccated in dry seasons due to their restricted positions in clay, on the upper aquifer section. The highest arsenic level (1.12 mg/L) was found in Raninagar-II block, followed by the Domkal, Berhampur, Jalagi, and Mushidabad-Jiaganj blocks (ranges up to 0.5 mg/L), while the moderate ranges (0.05 to 0.3 mg/L) were found in the rest of the blocks. Therefore, the intact district is facing a declining tendency of GWS with a fluctuating drift in pre-monsoon and post-monsoon seasons during 2000 to 2020. The urban divisions are principally suffering from smaller water storage amounts owing to hazardous and impromptu urban expansion, LULC transformations and therefore, the district has started to face the solemn challenges of a water crisis, which may become catastrophic in the future. The study reveals that the formulation and implementation of any water-saving diplomacy must include a periodical assessment of GWS in the district. It has to analyze the block-level spatio-temporal groundwater storage discrepancy and potentiality in the entire Murshidabad district along with the chief influencing criteria, using advanced RS data and geospatial techniques and the MCDM method. The entire district is covered by three groundwater potential zones, namely fair, good and excellent. The middle to eastern part of the district is covered by an excellent potentiality, with good potentiality observed in the middle to western parts and rest of the parts showing fair potential in respect to groundwater storage. In order to validate the classified groundwater potential zones, a total of 45 grid points have been selected for extracting the receiver operating characteristic (ROC) curve with the area under the curve (AUC) (Mohammady et al. 2012; Pradhan, 2013) [88,89]. Out of the total 100 generated grid points, 45% are under the consideration of collection of bore-hole yield data. Figure 39a,b show the ROC curves of groundwater potential zones for the years 2000 and 2020 respectively. The value of AUC is 0.802 in 2000 and 0.822 in 2020, which corresponds to 80.20% and 82.20% respectively. The correspondence AUC values are >70%, which signifies that the AHP method is acceptable based on its overall accuracy to generate the groundwater potentiality zones in 2000 and 2020 in Murshidabad district.



(**a**) (**b**)

Figure 39. (**a**) RUC Curve (2000), (**b**) RUC Curve (2020).

Therefore, the outcomes of this novelty effort should be amalgamated in the sustainable setting up and supervision of water, treating it as a finite and exclusive resource. The study suggests some key issues for planning and apposite supervision:

1. The information, maps, upshots gathered in the present endeavour ought to be included in strategy planning in an appropriate way. Thus, the efficient water uses in most of the blocks of the district can be ensured as the net annual groundwater is more than its gross uses.
2. The block level micro-planning, and sustainable groundwater scheduling should be accentuated by endorsing exterior water protection, an astute use of water, configuration of progressive tariffs on water, enhancing consciousness, promoting water-saving practices, apposite irrigation planning and systematic scheduling of water distribution.
3. The supervision and arrangement of GWS and integrated and restricted LULC must be encouraged and howsoever, upgrading the local governance, building of strategic control in excess of the infrastructural expansion by executing and implementing plans at the blocks, as it is painstaking as a momentous administrative unit.
4. The awareness regarding the enhanced reality of depletion, oscillations, scarcity, pollution of water and arsenic contamination, and its repercussions must be initiated and the sensible, efficient and effective exercise of water must be improved and continued.
5. The local governing bodies and NGOs should be encouraged to campaign on apposite capacity building and a vigilance curriculum should be instigated regarding the GWS and interrelated concern.
6. The availability of adequate water storage data from large observation wells, and a comprehensive study on the spatio-temporal disparity of water storage using the geospatial technology should be initiated in the district, followed by intensive spatial planning for the proficient management.
7. The planning must include a vigilant inspection to generate and store pertinent and updated data of water storage and related concerns, along with the maps generated through employing geospatial techniques andthe application of scientific methods, as well as the physical and demographic temperaments of each blocks and overall standing of groundwater of the district.

5. Conclusions

The present endeavor to assess the groundwater dynamics and its oscillation for the last 20 years and subsequently examined the changing nature, fluctuations and blueprint of the influencing criteria of GWS in the Murshidabad district in West Bengal. It is revealed from the study that an intermittent decline of GWS level of the pre- and post-monsoon seasons throughout the district occurred, and the changing quantity and declining trend for the period of 2000–2020 was also noticed. The spatial change and fluctuations in groundwater were found sturdily prejudiced by the inconsistency of rainfall and other influencing criteria, and all these promoted an abundant attenuation of water. The block-level inquiry indicates the existence of some pockets of unwarranted extraction in most blocks, ensuring the decline of GWS and its vacillations even below 10 mbgl. However, the present study discloses that groundwater depletion was established as a gigantic net loss of water in a slower tempo, and reflected its exploitation for irrigation, industrial, and other anthropogenic exercises, indicating a water stress situation in the near future. Here, the active water supply is inadequate to meet the inhabitants' agricultural, industrial, and municipal needs, and possibly it will worsen over the imminent decades. The study also demonstrates the well-harmonized and collective role of RS and GIS in addressing the concern of groundwater dynamics.

The study indicates that the extraction of groundwater for agricultural, industrial and domestic purpose needs to be supervised. As the Murshidabad district receives an adequate quantity of rainfall, groundwater recharge through numerous structural measures and recharging wells should be encouraged. It will help in assuring the regular supply of water and contribute largely in sustaining the water balance. Apart from the formulation of policy documents, explicit action plans and regulations the awareness campaign must be promoted to ensure peoples' contribution in supporting the minimal use of water. Furthermore, community-based participatory approach needs to be endorsed by shifting the meditation from the unending reductionist manufacturing approach into an economically realistic point of view.

The present attempt intended to evaluate the block-level changes and aid in the identification of potential zones of GWS in the Murshidabad district of West Bengal with the permutation of remotely sensed data and geospatial techniques, as well as the MCDM method. The execution of RS data in the study became very fruitful as it accessed a bona fide picture of GWS dynamics over the period of 2000 to 2020, enfolding the pre- and post-monsoon seasons. Moreover, the exploration of block-level additional secondary data thereafter showed the contribution of influencing criteria such as the slope, lithology, drainage, rainfall, soil, LULC, etc., in GWS diminution and oscillations. The study reveals that the entire Murshidabad district is roofed by good potentiality (mainly middle to western parts), followed by an excellent potentiality (primarily middle to eastern parts) of groundwater over the periods of 2000 to 2020, but this should be used cautiously, as a large section of the region belongs to arsenic contaminated areas. It is to be mentioned that the present investigation of GWS dynamics by using recent RS data and employing the MCDM method at the block level is the first of such kinds of studies in the Murshidabad district. Therefore, this effort demonstrated the intact excellent performance and fruitful outcomes of modern techniques for such a kind of assessment to replicate GWS anomalies at the block level, and therefore, we would like to advocate such more studies over other regions. Furthermore, this kind of study is becoming imperative to assess water storage, and block-level outcomes can effectively be exploited for integrated planning and supervision to save this unique resource.

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