Site selection and Storage System Design for RWH with artificial recharge based on hydro-geological and socio-economic consideration in qualitative and quantitative water-stressed areas of North 24 Parganas, India

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Abstract

Rural households of North 24 Parganasare adversely affected by combined qualitative and quantitative water stress. An attempt is made to establish a relationship between RWH potential based on hydro-geological and socio-economic characteristics. Total 924 rural household data were collected through a rigorous socio-economic survey in four study blocks viz. Barasat II, Amdanga, Barrackpore II, and Basirhat I to assess the water insufficiency. Land-use and Land-cover study showed a rapid increase in the built-up area to the extent of 21.69%, 10.44%, and 4.08% for Barasat II, Amdanga, and Basirhat I blocks, respectively during (2010–2020). Over this period, water bodies were reduced by nearly 19% and 6% in Barasat II and Basirhat I, respectively. The upper aquifer within 40 to 60 m depth was suitable for artificial recharge from the fence diagram. Artificial recharge structures like percolation tank with recharge shaft were suggested (within 40 m depth) for Amdanga block, re-excavation (up to a depth of 3 mbgl) for Basirhat I block and recharge well or pit to be excavated up to(30, 10, and 10 to 20 m) for highly built-up areas of Amdanga, Barasat II and Barrckpore II, respectively. Water quality parameters viz. TDS, ammonia-N, and chloride were found reasonably safe for drinking purposes in the rain water samples. The storage tank's capacity was calculated as 6,000 litres for individual rural households, with 60 gm of bleaching powder estimated for a full tank. The suggested methods would help local authorities successfully execute the RWH schemes inwater-stressed areas.

Introduction

A steep decrease in water availability affects social wellbeing or quality of life. Globally, 3.2 billion people live in high to very high agricultural water scarcity areas (FAO 2020). Globally, populations still do not have access to safe water, while the water requirement for domestic purposes is less than 10% (Cosgrove et al. 2018). Water has traditionally been treated as public goods and has been exploited most of the time. It is estimated that groundwater withdrawal would be 87% by 2050 (World Bank Group or WBG 2015). India was marked as the country with the largest freshwater withdrawals (more than 760 bcm per year) for 2014 (https://ourworldindata.org/water-use-stress#global-freshwater-use). More than 80% of rural India depends on groundwater. The magnitude of the water problem is aggravated in India by the complex use of a single source, i.e., groundwater. The groundwater exploitation took place through the introduction of the high-yielding 'Boro paddy' cultivation with shallow tubewell (STW) since 1970, especially in the southern part of West Bengal (International Water Management Institute 2017).

While drafting the groundwater, many contaminants like arsenic iron come out from the subsurface to the surface. Since 2004, villages of West Bengal had been experiencing a huge growth of STWs with the coming up of the National Policy of Arsenic Mitigation (NPAM). Individual households installed large numbers of private shallow hand-pump tube wells as sole drinking water sources in rural areas. Thus, human interactions create qualitative and quantitative water stress. As arsenic is an extremely toxic and carcinogenic metalloid. This geochemical arsenic threat is aggravated into the worst one due to poor socio-economic status, malnutrition, illiteracy, regular exposure of contaminated groundwater as drinking and cooking water through the food chain, irrigation water, and use of packaged drinking water not complying with the permissible limit set by Bureau of Indian Standards (BIS) (Bhattacharya et al. 2019; Ghosh et al. 2020; Mishra et al., 2021). Apart from health-related disorders, complex and multiple challenges, either direct or indirect, are also associated with loss of income earning capacity, labour productivity, job loss, increasing poverty, break up of a marital relationship, cases of suicide, cases of high dowry and ultimately exclusion from society or family due to arsenicosis. Such cases are prevalent in North 24 Parganas, Nadia, Purba Burdwan, and South 24 Parganas districts (Ahmed et al., 2011; Das and Roy 2013; Roy, 2019; Mishra et al., 2021). Almost very block of North 24 Parganas district was arsenic-affected as 42.4% of the district population (2,196,158 out of 5,184,365) had already been affected by arsenic contamination (Asian Development Bank or ADB, 2011). Thus, arsenic contamination became vulnerable and put millions of lives in danger even after four decades of extensive arsenic research (Chakraborti et al., 2018; Roy, 2019; Biswas et al., 2020).

Different available remedial measures for arsenic viz. arsenic removal filters, nano-filters, treatment of the aquifer by dilution method, artificial recharge, exploring deeper aquifer and arsenic removal plants etc. were unsuccessful because of cost implication, nonuser-friendliness, unpopular Government programs, lack of participation of the highly affected and marginal community in the decision-making platform (ADB, 2011; Mishra et al., 2021). Presently available and widely used arsenic mitigation filter systems further damage soil, surface water, and the local environment due to unplanned open disposal. Till 2019, in West Bengal, two important community-based, multi-village water supply schemes, viz., modified Sujapur-Sadipur model and Gobordanga model, were introduced to mitigate the arsenic contamination. These models successfully reduced the concentration of arsenic and iron from 200 ppb to 30 ppb and 1700 ppb to 250 ppb, respectively, but not cost-effective. An artificial recharge with RWH was done through a recharge pit which went through a shallow high-arsenic tube well (16 meters deep) in Ashoknagar, Habra I block, North 24 Parganas. This scheme successfully reduced the concentrations of arsenic from 128 μg/L to 80 μg/L after 1 month and to < 1 μg/L after 3 three months during thepost-monsoon season in the year of 2009 (ADB, 2011). Another pilot-scale arsenic removal plant was set up in Kasimpore, North 24 Parganas, in 2004. Apart from that, many areas of the district had a declining groundwater rate and arsenic contamination (ADB, 2011). However, the government of West Bengal initiated a supply of safe drinking water (@ 70 lpcd) for rural households through piped water-supply schemes under the Vision 2020 programme. Simultaneously, it was decided to phase out the hand-pumped tube wells water supply by 2020 (ADB, 2011), which is not yet materialized. However, it was also reported that no serious attempt was made to revive the traditional water harvesting system. A wide gap exists between the legislation of the rule and its implementation. Unfortunately, even after 75 years of independence, the Indian water bureaucracy still struggles for a firm water vision plan. The Government of India initiated several projects to conserve water and suggested adopting RWH though it remained in paperwork only, particularly in the arsenic-affected areas of South Bengal.RWH is the most viable option to address the combined qualitative and quantitative problems. The possibility of implementing RWH at the household level depends mainly on the socio-economic and environmental conditions (Das and Roy 2013; John et al., 2018; Banerji and Mitra 2017).

Most of the researchers concentrated their work either on the site-specific artificial recharge structure of RWH involving RS and GIS mapping or groundwater recharge modeling coupled with the design of different types of RWH structures with artificial recharge or estimation of tank size and self-prepared low-cost carbon-sand filter for treatment (Jha et al. 2014; Oke et al. 2014; Shaheed et al. 2017; Singh et al. 2017; Ibrahim et al. 2019; Ghosh et al. 2020). Few studies were associated with analyzing spatio-temporal trend of declining groundwater with statistical approach and using RS and GIS tool (Mann–Kendall test)

(Halder et al., 2020).Only a handful of researchers dealt with the arsenic awareness index or estimated the arsenic related health hazards with economic cost and welfare loss based on questionnaire-based perception study (Roy, 2007; Mishra et al., 2021) in the North 24 Parganas. However, none of the researchers have dealt with the 'water security' issue as a whole from a geo-physical vis-à-vis socio-economic viewpoint to ensure proper utilization of excess rainwater.

The present study attempts to provide an alternative approach covering the socio-economic to hydro-geological aspect to assess the extent of water scarcity and the feasibility of RRWH and overcome the adverse effects on groundwater quality and quantity. The groundwater recharge potentiality is identified by fence diagram while the artificial recharge sites and suitable structures are determined using RS and GIS platform. The storage tank's capacity with the prescribed dosage of disinfectants is also determined, and finally, the extent of water scarcity is judged by rural households, which remained so far unnoticed, especially in the four study blocks of North 24 Parganas, West Bengal. The present researchers also tried to reduce the vulnerability of increasing arsenic-iron contamination with groundwater level declining by proposing some remedial recommendations. The present study helps formulate a potential action plan for augmenting sustainable groundwater management by the local authority to extract the maximum benefit of RWH. Thus, the objectives of this study can be summarized as to assess alternative water sources with artificial recharge, identify the socio-economic feasibility of RRWH and delineate the strategies of rainwater harvesting (RWH) to combat the combined water stress.

Methodology

The study's methodology consists of four parts viz., identification of study area, data collection, data analysis, and implementation of RWH with recharge represented in Fig. 1.

2.1. Identification of the study area

In West Bengal, among the arsenic-contaminated districts, North 24 Parganas has the highest concentration of arsenic in groundwater (Public Health Engineering Department or PHED 2018). Identification of the study blocks was based on four categories of the stages of groundwater development[1] made by the Central Ground Water Board (CGWB 2013) (Table-1).

Table1: Identification of study area

Category	Characteristics	Selected Block	Justification of Selecting Study Block
Category-I	Safe[2] and arsenic affected	**Barasat II**	Proximity to district administrative headquarters
Category-II	Safe and water table declining with arsenic contamination	**Basirhat I**	>75% habitations having 'As' more than 10ppb, upper aquifer is slightly saline
Category-III	Safe with water table declining	**Amdanga**	Proximity to district administrative headquarters
Category-IV	Semi-critical	**Barrackpore II**	Proximity to district administrative headquarters

Source: CGWB (2013)

Category-I: Safe and arsenic affected - Barasat II block, Category-II: Safe and water table declining with arsenic contamination - Basirhat I block, Category-III: Safe with water table declining - Amdanga and Category-IV: Semi-critical – Barrackpore II block. Except for Basirhat I, the remaining blocks are selected near district administrative headquarters. However, >75% habitations having 'As' more than 10ppb, the upper aquifer is slightly saline in Basirhat I block that is why Basirhat I was selected (PHED 2018). Villages were selected from habitats with reported high arsenic-iron contamination (exceeding the permissible limits of 10 ppb and 0.3 ppm, respectively) based on the good data, State Water Investigation Directorate (SWID), Kolkata (Fig.2).

2. About the study area

The study blocks have twofold crisis, i.e., qualitative and quantitative water stress coexisting with waterlogging in the rainy season. The study areas have alternative layers of sands, silts, and dark grey type clay bed of middle to upper Holocene age. Older alluvium of Pleistocene sediments occurs under the recent alluvium and comprise of fine to coarse-grained sand grey to brown in colour, gravel, clay with kankar, and ferruginous concretions. The soil of the study area is alluvial, sandy, and silty type (PHED 2018a). Apart from the top piezometric aquifer ranging (20to 30 mbgl), there are two more aquifers with depths ranging from 35 to 46 mbgl and 70 to 150 mbgl in the North 24-Parganas district. The intermediate aquifer is constituted of sub-angular to sub-rounded medium sand, sandy clay, and clay with fine sands and has heavy mineral assemblage (biotite, garnet, kyanite, and opaques), which has the source of excessive iron and arsenic contamination of the Quaternary age, thus, limiting the drinking-water to deeper levels (Kumar 2013; Asian Development Bank or ADB 2018). Deeper aquifers having a depth of 350 mbgl are relatively arsenic-safe (ADB 2020). The study blocks had a relatively thin clay barrier in consecutive aquifers, and thus, sometimes heavy use of the deep Pleistocene aquifer in these districts could be unsustainable (PHED 2018).

However, the study area covered 405.82 km^2 with a population density of 2,502.22 person/km^2 compared to the district figure of 4,094 km^2 and 2,445 person/km^{2}respectively. The number of households residing in Amdanga, Barasat II, Barrackpore II, and Basirhat I were 191673, 200918, 217171, and 171613, respectively, as per the 2011 census. The number of rural literate people was 2,929,366 out of a district total of 7,608,693. The sex ratio was 955, the average size of households was 4.5 whereas the percentage share of SC and ST population was 21.67% and 2.64%, respectively. Nearly 24.84% of households were engaged in agricultural activities. Water requirement for rice, potato, mustard, and wheat was 104.5, 30.0, 25.2, 37.0 cm for growing days of 93,88,88,88, respectively, and the daily water requirement was 1.075, 0.750, 0.300, and 0.425 cm (Marwah, 2018). The study area had two types of water distribution systems, i.e., the majority as ground water-based and a few surface water-based piped water supply schemes (PWSS) introduced recently for arsenic contaminated areas. There is a continuous water extraction from groundwater reserves for multi-dimensional developmental needs, leading to aquifer depletion while demand keeps increasing. More than 95% of the Amdanga and Barasat II population relied on STW for drinking purposes (Banerjee, 2016). Habitations affected by arsenic contamination in Barrackpore II, Barasat II, and Basirhat I were up to 50%, 50 - 75%, and more than 75%, respectively (ADB, 2011). Under the circumstances, the scenario of safe water supply is precarious in the 21st century. It was often the case that the Governmental department (PHED) monitored the tube wells and put a red cross to make the people aware of arsenic contamination, acknowledging that the rural households had been consuming contaminated water for the last 40 years without having any alternative.

2.3. Data collection

In the present study, four approaches were followed. i) different bore wells data were collected from the office of PHED, Barasat, in 2019. Hydro-geological data were collected from SWID and CGWB, Kolkata, 2020. ii) Historical rainfall data of 44 years (1972 to 2015) were collected from IMD, Pune, to analyze the potentiality and reliability of rainwater for RRWH. iii) Rainwater samples were collected from the study blocks and tested for quality and suitability for drinking purposes. iv) A socio-economic household survey was undertaken to identify qualitative and quantitative water stress, feasibility, and willingness of RRWH in the selected four study blocks. The survey was conducted in 2019, with a sample size of 924 households.

2.4. Data analysis

a. Feasibility of recharge aquifer by Fence diagram

A fence diagram was drawn by RockWorks Software (version 15) to assess the feasibility of recharge of the shallow aquifer.

b. Land-use and Land-cover (LULC) and Status of surface waterbodies by RS and GIS mapping

Recent changes of 10 years (2010 to 2020) LULC characteristics were identified from Landsat 7 ETM+ and American earth observation satellite Landsat 8 OLI/TIRS images amalgamating RS with GIS (table 2). Google Earth Images were used for selecting and validating the LULC classes. RS and GIS were used for the LULC changes and present status of surface waterbodies analyzed by the K-means clustering unsupervised classification. The key categories of the LULC were agricultural land, built-up area, fallow land, vegetation, and water bodies. Google map and GIS platform were used to identify water bodies map suitable artificial recharge sites for the study blocks.

c. Physico-chemical quality of rainwater

Rain water samples were collected in 1.0 litre sterilized glass bottles and placed with a broad mouth polyethylene funnel (diameter 22.3cm) on the mouth of the bottle. After10 minutes of heavy rain, the bottle was placed and filled with water. After the collection of rain water, the cap was locked tight, and the bottle was kept in the dark place so that no air space could be retained inside to minimize the chances of chemical changes. The parameters viz. Ammonia-N, Chloride, pH, and TDS were tested in the “Environmental Engineering Laboratory” of Department of Civil Engineering, Jadavpur University by Distillation method, Argentometric method, Electrometric method, and Gravimetric method, respectively (APHA et al. 1999).

d. Calculation of the storage tank: The design of the storage tank can be made following two approaches:

- Comparing the tank capacity with the area of the roof.
- Comparing the tank capacity with the quantity of water demanded by its users
- **Comparing the tank capacity with the Area of the Roof**

In this method, the tank's storage capacity is determined based on the actual catchment area and the potential of rainwater harvesting. The entire volume of the rainwater collected from the rooftop is assumed to be stored in the storage tank, and its storage capacity is determined based on the consumption and rainfall pattern.

Let us assume that the storage tank is to be designed for an average 70 sq. m roof area in the study area where the annual average rainfall is 1761 mm (based on 44 years {1971-2015} average historical rainfall data for North 24 Parganas)

Table 2: Runoff coefficients for various catchment surfaces

Type of Catchment	Coefficients
Roof Catchments	
Tiles	0.8 to 0.9
Concrete roof	0.85
Corrugated Metals Sheets	0.7 to 0.9
Ground Surface Coverings	
Concrete	0.6 to 0.8
Brick Pavement	0.5 to 0.6
Untreated Ground Catchments	
Soil on Slopes less than 10%	0.0 to 0.3
Rocky Natural Catchments	0.02 to 0.06

Source: (IRICE, 2006)(Sivanappan, 2006)

As given in Table2, the runoff coefficient for concrete rooftop is considered as 0.85. Thus, for every 1.0 mm rainfall, the quantity of harvestable water = ***70 x 0.001 x 0.85 = 0.0595 m^3*** *or* ***59.5 liters.***

The consumption of drinking and cooking water for a ***5-member family (@ 5 lpcd) = 5 x 30 x 5 = 750 litres per month (for 30 days) = 775 litres per month (for 31 days).*** Table 3. Illustrates the method of determination of the storage capacity of the tank.

Table 3: Calculation for capacity of storage tank

Sl. No.	Month	Monthly Rainfall in mm	Rainfall Harvested in litres	Cumulative rainfall harvested (5) in litres	Monthly Demand in litres	Cumulative Demand (7) in litres	Difference between (5) & (7) in litres
1	**July**	316.4	18826	18826	775	775	18051
2	**August**	384.2	22860	41686	775	1550	40136
3	**September**	329.2	19587	61273	750	2300	58973
4	**October**	172	10234	71507	775	3075	68432
5	**November**	27.1	1612.5	73119.5	750	3825	69294.5
6	**December**	3.4	202.3	73321.8	775	4600	68721.8
7	**January**	14.3	850.9	74172.7	775	5375	68797.7
8	**February**	24.8	1475.6	75648.3	700	6075	69573.3
9	**March**	32.6	1939.7	77588	775	6850	70738
10	**April**	62.3	3706.9	81294.9	750	7600	73694.9
11	**May**	117.8	7009	88303.9	775	8375	79928.9
12	**June**	277.3	16499.4	104803.3	750	9125	**95678.3**
	Total	1761					

From Table 3, it is obvious that the difference between cumulative harvested rainwater and cumulative demand is maximum in **June** at 95,678.3 litres. Hence, the storage tank's capacity should be 95,679 litres, say **96,000 litres,** which is not practically feasible.

- **Comparing the tank capacity with the quantity of the water demanded by its Users**

Let us assume that the proposed RRWH system is to be designed for meeting the drinking and cooking water requirement of a 5-member family dwelling in a building having a rooftop area of 70 sq.m.

The annual average rainfall in the study area (i.e., North 24 Parganas district) is 1761mm. The domestic water requirement is 5 lpcd.

Let us consider,

- The average area of the catchment for a typical single-storied residential unit **(A) =** 70 sq.m.

- Annual average rainfall (R) = 1761 mm (i.e.1.761 m)
- Runoff coefficient for flat terrace (C) = 0.85
- Assuming 80% of the rainfall occurring during monsoon season

Annual rainwater harvesting potential = 70 x 1.761 x 0.8 x 0.85 = 83.82 cum or 83,820 litres**.** The tank capacity is determined based on the dry period's tentative length, i.e., the period between the two consecutive rainy seasons. For monsoon extending over four months (7^{th} June- 15^{th} October, approximately, i.e., 131 days) the dry season is generally assumed to be spanning over approximately 200 days (excluding pre-monsoon and post-monsoon sporadic rainy days).

Water requirement for drinking and cooking purposes of the 5-member family during dry season (@ 5.0 lpcd) = 200 x 5 x 5 = 5,000 litres << 83,820 litres

Considering a suitable safety factor, the tank should have 20%excess capacity than calculated above, i.e.,6,000 litres.

e. Socio-economic data analysis

Two indices were calculated on the basis of responses of the households towards 4 and 7 perception-based questions, respectively. As an example, 'Is any member of your family suffering from water-borne disease (Dysentery, Jaundice, Diarrhoea and Typhoid)?' The response to each question asked was transformed into binary values – '1' and '0'; with '1' implying positive contribution towards the index while it was taken '0' otherwise. The indices were calculated by adding the indicators (i.e. binary values) to the questions related to the specific indices, viz. 'water related health issue index (WRHII)'and 'inclination to adopt RRWH index (IARRWHI)'. These indices thus considered only non-negative integer values varying from 0; the maximum was the number of questions corresponding to the index. For example, in the case of WRHI, we combined responses to seven questions. Suppose the responses to these questions for a particular household were 1, 0, 0, 1, 1, 1, and 0. Thus, the sum of these binary values came out as 5, which was in between 0 and 7 for each household. A cut-off value, equal 3, was then considered, and each household having the sum of the answers to all the 7 questions less than or equal to 3 was ascribed a value of 0, while the households have the sum greater than 3 were given the value 1. The cut-off value was considered in the way to have an almost equal number of households in each group. Similarly, we have considered large roof and small roof areas above 37 sqm and below 37 sqm, respectively. In the case of 'land availability' the same was considered as up to 100sqm for 'large land availability' and above 100sqm as 'small land availability'. The interrelation between these indices was subsequently explored through bivariate analysis and chi-square test (χ^2). A significant dependency was observed between these two indices. All variables like 'concrete roof area', WRHI, IARRWH and 'land availability' were considered as binary.

Bivariate contingency tables were developed among 'concrete roof area' and 'land availability' and two indices i.e. WRHII and IARRWHI. The variables were analysed with SPSS software version 16.

[1]The stage of Ground water Development of the research area is based on (CGWB 2013) is to be computed as (Stage of development= (Existing gross draft for all uses/Net annual groundwater availability) X 100 by CGWB. Stage of groundwater is a ratio between ground water drafts to total replenishable resource. If ground water development was exceeding 100 % of the natural replenishment, then categorized as 'Over-exploited', if the development was found to the extent of 90 to 100 %, categorized as 'Critical', if the stage of ground water development is the range of 70 to 100 % with long-term decline of water levels either during pre- or post-monsoon categorized as 'Semi-Critical' and stage of ground water development below 70% categorized as 'Safe' (CGWB).
[2]According to the report less than equal to 70% of groundwater withdrawal is safe, more than 70% to 90% drafting with the declining post-monsoon trend is semi-critical where water drafting is not permitted.

Results And Discussion

3.1Quantitative status of water in the study area

3.1.1 Status of PWSS

As f 2018, in North 24-Parganas, nearly 5% of the habitations were brought under the surface water supply scheme with the major portion of habitations still depend on groundwater. Out of groundwater-based PWSS, 64% are covered by different small PWSS, each covering nearly ten habitations. However, these groundwater-based scheme is typically fitted with a bore well and pumps, supplying water to households after disinfection through chlorination (ADB 2020). Presently, only one major surface water-based PWSS is running to provide arsenic-safe water in five blocks, part of Amdanga, Barrackpore II, a small part of Basirhat I, and other two blocks of North 24 Parganas. Groundwater is the only source for the PWSS in Barasat II (PHED 2018) (Table-4).

Table4: Status of drinking TWs and DTWs

Block	Spot sources (TW)		Spot sources DTW		DTW Declining trend of GW level (mbgl)
	Running	Need to repair	Running	Need to repair	
Amdanga	211	35	519	0	42
Barasat II	272	75	252	30	22
Basirhat I	126	28	457	52	22
Barrackpore II	143	52	445	8	0

Source: PHED, Barasat office, 2019

3.1.2 Status of irrigation

All types of TWs like STW, middle capacity DTW (MDTW), and DTW are used to tap groundwater from porous sediment zones for agriculture, industry, and drinking purposes. Over 90% of groundwater is drafted by STWs particularly for winter cultivation. Traditionally, all study blocks practice boro, wheat, jute, sugarcane, musur, mustard, til, potato and sugarcane cultivation, which require intensive irrigation. For wheat farming, use of STWs was found to be exceptionally high in Basirhat I. Overall, the maximum share of land, i.e. nearly46,000 hectares, was used to cultivate Boro paddy (Table-5).

Table 5: Crop-wise share of land and production for the study blocks

Block	Aus	Aman	Boro	Wheat	Jute	Mustard	Til	Potato	Sugarcane
	Land (production)	Land (production)	Land (production)	Land (production)	Land (production)	Land (production)	Land (production)	Land (production)	Land (production)
Amdanga	273 (648)	7065 (17291)	41118 (10469)	51 (125)	4320 (70632)	2391 (3059)	153 (167)	402 (11336)	33 (3344)
Barasat II	–	5579 (13819)	2506 (7404)	52 (114)	3016 (46386)	2195 (2937)	79 (78)	249 (8536)	–
Barrackpore II	–	415 (1145)	85 (286)	–	–	103 (122)	–	29 (573)	–
Basirhat I	99 (256)	5604 (13771)	2173 (7744)	524 (1411)	2165 (38818)	1429 (2267)	44 (43)	545 (16697)	–

Source: District Statistical Hand Book, 2013. Note: Land area in hectare, Production in MT

In the study blocks, 10,413.4 ha.m groundwater as drafted, nearly 86% of the district total of 54,095 ha.m. The cultivable command area (CCA) has been increased significantly due to intensive agriculture facilitated by numerous DTWs and STWs (CGWB 2017a). However, the CCA is generally up to 10 hectares for STW, 10 to 15 hectares, and 15 to 50 hectares for MDTW and DTW, respectively (CGWB 2017a). STW, MDTW, and LDTW were supposed to run 6-8 hours per day, but in actuality, they ran more than that, and simultaneously, illegal rented drafting also happened. Barrackpore II block falls under the semi-critical stage though DTW and high capacity DTW (HDTW) were run at 120 and 130 m^3/hour, respectively (Table-6). Barasat II block had the highest number of users of STW and DTWs (at 126 m^3/hr) used for irrigation and pisciculture (Ministry of Water Resources (MoWR), 2017).

Table 6: Drafting and recharge scenario of groundwater

Blocks	No. STW	Drafting (m^3/day)	No. of DTW	Drafting (m^3/day)	Stage of GW development in %	Recharge from rainfall (ha.m)	
						Monsoon	Non-monsoon
Amdanga	1964	1178400 -3142400	30	72000 - 144000	57.46	4595.9	1288.3
Barasat II	2318	1390800 - 3708800	27	64800 - 129600	71.19	4043.8	1054.9
Barrackpore II	24	14400 - 38400	15	36000 - 72000	**97.99**	4016.5	1020.7
Basirhat I	1991	1194600 - 3185600	4	9600 - 19200	52.39	4617.8	1372.0

Source: District Statistical Hand-Book 2012-13, SWID, PHED, CGWB (2006-2017) Kolkata

3.1.3. Status of pre-monsoon and post-monsoon piezometric water level

Well-wise yearly CGWB data (2011 to 2017) is used for quantitative analysis of groundwater in the study area. Well numbers W1 to W5 are located in Amdanga Block, W6 to W10 in Barasat II, W11 to W14 in Basirhat I block andW15 are situated in Barrackpore II (Fig. 3). The overall 11 years (2006 to 2017) average post-monsoon falling trend was observed to be 2.98 mbgl/year i.e. 32.78 mbgl in Barrackpore II. The second-highest post-monsoonal long-time piezometric water level falling trend was observed to be 2.19 mbgl in Barasat II for the same 11 years. All wells had a sharp decline during the post-monsoon season, which happened after recharge during the monsoon. However, W4, W8, W11 and W13 got choked throughout 2011-2013 and incidentally were revived again, indicating an increase in the over-drafting of groundwater with time. During the last seven years, there had been a large-scale decline of nearly 10 mbgl found in Barrackpore II, Barasat II and Amdanga block.

In both Basirhat I and Amdanga blocks, more than 4500 ha.m potential recharge happened during monsoon whereas, in Barrackpore II and Barasat II, the same was more than 4000 ha.m. It implied that the drafting of groundwater exceeded the natural recharge of the monsoon season. The net available groundwater for future usage is estimated at 27.14%. Thus, Barasat II has been gradually converted into a 'semi-critical block'. Except for Barrackpore II, the other three blocks were categorized as 'safe' for future drafting in terms of quantity but not quality.

Halder et al. (2020) reported that an extensive abstraction of groundwater by submersible pump took place due to drying the river beds. Thus, 25%, 45%, and 60% of the wells located near the agricultural land of a river basin of West Bengalshowed a declining trend of ground water level in monsoon, pre-monsoon, and post-monsoon season (1996 to 2018). The agglomerated hierarchical cluster analysis results showed that most of the well water level fluctuationstook place between 1.8 and 4.33 mbgl. The Standard Groundwater Level Index showed that the well of Simlapal, Bheduasol and Neradeul had a higher frequency of drought years.

3.1.4 Qualitative status of the water

According to CGWB data,1st shallow aquifers had a higher concentration of arsenic (>10 ppb) and iron (0.3 mg/l) as specified in IS:10500, 2012. The 2ndaquifers of Barrackpore II and Basirhat I were found to have an arsenic concentration of 17 and 8 ppb, respectively (Table-5). The highest arsenic contamination occurred to the extent of 125 ppb in Barasat II. Most of the contaminated tube wells (65.93%) were found in Barrackpore II followed by Barasat II, Basirhat I, and Amdanga block with nearly 43%, 37%, and 20% contamination, respectively. However, more than 96 habitations were found to be affected by high arsenic contamination in the Amdanga block. Four villages from Barrackpore II and Basirhat I and 16 villages from Barasat II block have been under the serious threat of arsenic contamination. Iron concentration was reported as 10.60, 1.01, 1.52, and 6.77ppm in Barasat II, Barrackpore II, Basirhat I, and Amdanga, respectively.

However, in North 24 Parganas, a total of 33 groundwater-based PWSS were considered for the provision of ARPs (PHED 2018). Hossain et al. (2006)conducted a comparative study on ARPs in two different blocks (Domkol in Murshidabad district, Swarupnagar, and Deganga in North 24 Parganas), which showed that 39 (80%), 38 (95%), and 14 (87.5%) ARPs were not functional at all. The results showed that 95% and 80% of the tube wells connected with ARPs in Swarupnagar and Domkol were found to have arsenic concentrations above 50 ppb. Thus, ADB (2011) recommended Piped Supply Schemes based on groundwater or surface water supply for arsenic affected areas like Barrackpore II where 15 villages with 61,814 population would be covered by this scheme with ponds as the source of water. Habra I, Habra II, Gaighata, part of Amdanga, part of Deganga, and part of Barrackpore II would cover 335 villages with 11,854 population benefited and water source as the River Hooghly.

Another scheme was suggested for the same water sources, which would cover part of Barrackpore I, Barasat I, Amdanga, and Degangaextending benefits towards 234 villages having 719,555 population to overcome the arsenic situation. In North 24 Parganas, arsenic-contaminated groundwater is the main source of drinking water supply(PHED 2018). CAWST (2011) reported that the concentration of arsenic contamination in the shallow aquifer has been traced in the eastern part of the river Hooghly, especially the eastern part of Barasat I, the western part of Deganga, the north-western region of Barrackpur I, arable and urban land of Barasat II, the southern region of Habra I and north-eastern part of Amdanga, where the intake of arsenic had been more than 50 ppb through drinking water. The top aquifer is contaminated by arsenic and iron. Therefore, tapping the arsenic-free aquifer for drinking purposes should be recommended with proper cement sealing in the clay zone where no potable water supply scheme exists (PHED 2018). Bera & Das Chatterjee (2019) reported high arsenic concentration in 15 m depth and considered high risk for drinking water in Barasat II and Amdanga blocks.

3.2 LULC change due to urbanization over (2010-2020)

In our study, rural settlement and impermeable surfaces, including roads, are categorized as ‘built-up area’, while bare land, seasonal bare land, and brick kiln came under ‘fallow land’. Under ‘vegetation’, we considered an open field, grass, forest patch, roadside trees, shrub, scattered trees, and kitchen garden. River, pond, big water bodies (locally known as bills and jheels), wetland, and other surface water bodies are classified as ‘water-bodies, while ‘agricultural land’ is another category. Thus, the key categories of the LULC were agricultural land, built-up area, fallow land, vegetation, and water bodies.

In Amdanga block, built-up area and water bodies were increased by 10.44% and 1.92%, respectively, from 2010 to 2020 (Fig. 4). While agricultural land, fallow land, and vegetation cover were reduced by 11.46%, 0.29%, and 0.61%, respectively. A nominal increase in the share of water bodies may be attributed to the expansion of pisciculture as a profitable occupation. In the case of Barasat II, 1.16%, 21.69%, and 1.33% increase were observed for agricultural land, built-up area, and fallow land, respectively, over the year last decade. The increase in percentage share of fallow land can be attributed to the mushroom growth of brick kilns in the Barasat II block, which became inevitable to keep pace with the rapid urbanization rate in the adjacent municipalities like Madhyamgram and Rajarhat-Gopalpur. In Basirhat I, the built-up area, fallow land, and agricultural land were increased by 4.08%, 3.12%, and 0.38%, respectively over the decade. As a whole, urbanization has been continuing in Amdanga, Barasat-II, and Basirhat I blocks, in the form of an increase of percentage share of the built-up area, which has rapidly been converted from agricultural land, vegetation, and water bodies to built-up areas. This implied a serious threat for surface watercourses and a decrease in the natural recharge of groundwater despite the occurrence of heavy rain over the study area.

However, the western and north-western parts of this district, such as Rajarhat Newtown, Gopalpur, Barrackpore, Barasat, Bidhannagar, Dum Dum, and Habra, had experienced the highest growth of urbanization compared to the remaining part of the district (Basu et al. 2003; Bera & Das Chatterjee 2019). Well water level at Chandrakona showed a relatively higher level of fluctuation (6.305 m) due to the increase in the built-up area i.e., a huge change in LULC over (1996 - 2018) and alteration of precipitation dynamics (Halder et al. 2020). They further stated that all arable land with STWs had water levels falling in danger zone. Agriculture, infrastructure, and other anthropogenic expansions are primarily responsible for the negative changes in LULC (Dibaba et al. 2020).

3.3 Historical rainwater availability for the study area

The study area belongs to humid and subtropical climatic conditions with a hot and dry summer spanning from March to May, monsoon season from June to September, post-monsoon season from October to November, and a pleasant winter from December to February. The forty-four years (1971 to 2015) average rainfall for North 24 Parganas was 1762 mm. The rainfall distribution pattern indicates the occurrence of huge rain over a shorter time, signifying the high potential for RWH in the study area. However, the major portion of the rainwater flows down as runoff due to a lack of awareness of the population inhabiting the study area. This excess safe water needs to be appropriately managed. The rainfall pattern of six years, i.e., 1971, 1978, 1985, 1994, and 1999 showed the occurrence of greater rainfall in the monsoon period indicating favourable recharge conditions (Appendix 1). Throughout 2010 to 2013, the monsoonal rainfall trend decreased from 1293 mm to 862 mm with an average value of 1053mm. In the last six years (2010 to 2015), rainfall patterns showed high rainfall values in the post-monsoon season. The rainfall distribution pattern implies a massive potential for RWH in the study area.

3.4 Aquifer framework of the study blocks

The isolated patches of semi-confined piezometric water level were found in Barrackpore II, Barasat II, and Amdanga Blocks, whereas confined water level is found in Basirhat I block. The transmissivity for 1st and 2nd aquifer was reported to be1628.6 m^2/day and 1618 m^2/day for Barrackpore II, 2021 m^2/day, and 3891 m^2/day for Barasat II, 44.94 m^2/day, and 3962 m^2/day for Basirhat I and 1473.67m^2/day and 1956.5 m^2/day for Amdanga block respectively. The storativity was reported to be 0.029 and 6.5x10^{-4} in Barrackpore II, 0.029 and 3.8x10^{-1} for Barasat II, 0.029 and 4.86x10^{-6} for Basirhat I, respectively.

Table 7: Aquifer status of the study blocks (2006 to 2017)

Blocks	Aquifer with depth (mbgl)	Pre monsoon trend		Post monsoon trend		Thickness of the Granular zone (m)	Discharge (m^3/hr)	As (ppb)	Fe (ppm)	pH
		Water level range (mbgl)	Fall (mbgl)	Water level range (mbgl)	Fall (mbgl)					
Amdanga	1st 38-109.29	7.77-14.25	1.6	8.49-10.78	2.61	71.29	27.68	13	0.2 – 6.77	7.29 -7.78
	2nd 109.29-157.30					48.01				
	3rd A 163.30-191.53					28.23				
Barasat-II	1st IA 0-60, 1st IB 61-225	3.21-4.95	1.41	2.00-15.91	2.19	60 164	91.72	125 51.7	0.3 – 2.0	7.38 – 7.81
	2nd A 220-245					25	27			
Barrackpore II	1st IA 10-67, 1st IB 60-174.	0.75-25.2	24.86	6.15-24.7	32.78	57 114	40.44	1.0	1.0	8.32-8.43
	2nd IIA 146-225, IIB 237-254	13.11-22.65		6.1-15.2		79 17	41.22	17		
	3rd 325-360					35				
Basirhat-I	1st IA 3-38, IB 32-85	1.75-7.66	1.03	7.14-8.1	7.82	35 53	44.94	69.5	0.13 – 0.71	7.25-8.51
	2nd 119-175	4.0-6.47		3.9-6.1		56	39.61	8.0		

A = aquifer, Source: CGWB, Kolkata office (2017)

3.5 Assessment of the feasibility of artificial recharge for depleting aquifer

In all the study blocks, unethical groundwater drafting had so far taken place up to 2nd aquifer in the case of Barrackpore II, Barasat II, and Basirhat I (Table:7). In Barasat II, the drafting limit (45 m^3 /hr) was exceeded by more than twofold (91.72 m^3/hr) in the case of 1st aquifer. It was worth mentioning that there was a wide difference between the data catered by the Government and non-governmental agencies regarding water quality, the number of arsenicosis patients, the number of private STWs and multiple uses of STWs. The potential arsenic safe aquifer for drinking purposes was found at a depth of more than 300 (3rd aquifer) in Barrackpore II, more than 220 ('2nd aquifer') for Barasat II, more than 119 ('2nd aquifer') for Basirhat I and beyond 109 in case of Amdanga. During the field survey, it was observed that STWs were installed at a very close interval (standard 15 m) in most of the cases, which could be one of the probable reasons for the decline of the draw-down cone in the study blocks. Artificial recharge is usually recommended when the minimum difference between the pre and post-monsoon piezometric water level head is 6.0 m (PHED, 2013). However, the huge storage of groundwater is located very near to the surface ranging from the depth of 10 to 67mbgl(Centre for Affordable Water and Sanitation Technology or CAWST 2011; PHED 2018a). Various kinds of structures can recharge the groundwater of aquifers to ensure the percolation of safe rainwater into the aquifer instead of draining away from the surface. Submersible or turbine pumps are fitted to the high-capacity DTWs. The output of DTW is roughly 15 times the output of an average STW (MoWR 2017). DTW is most vulnerable to groundwater depletion as it is run around the clock during the irrigation season. All TWs are drilled from porous zones of sedimentary formations resulting in the gradual decline of the drawdown cone.

Barrackpore II and Barasat II are highly vulnerable from a groundwater availability point of view due to rampant urbanization taking place over the last couple of decades and may cause further decline of groundwater in the future. Thus, serious attention is also required to introduce artificial recharge in this area.

3.5.1 Fence diagram based on the litholog well data (PHED 2017)

A generalized fence diagram was developed based on bore wells drilled at different study areas (Fig. 5). The entire study area has an underlying thick layer of unconsolidated alluvial sediments with thickness ranging from 400 to 500 m. However, it is generally composed of argillaceous material i.e., clayey materials with stratified sand zones at different depth levels of varying thickness.

The fence diagram indicates that a (20 to 30) m thick sand layer occurs within the depth of (30 to 60) mbgl. Another sand zone greyish in nature occurs below the depth of (125 to 130) m, indicating both the aquifers are fresh water-bearing. All the wells penetrating through sand and clay beds were interconnected. However, the upper one consists of a high proportion of arsenic i.e., more than 10 ppb and the upper sand zone is exploited by a large number of STWs, causing a lowering of water level in the aquifer as a consequence of large-scale groundwater withdrawal. However, the middle aquifer zone that occurs below 125 m does not contain high arsenic at all places. However, this aquifer is eventually also arsenic-contaminated due to vertical leaching from the overlying aquifer. There are small grey sand layers in all the study blocks in patches up to 60 mbgl. This upper aquifer occurring within (40 to 60) m depth and having a declining water level should be given due priority to manage artificial recharging.

Water Aid (2011) reported that hand tube wells were installed at relatively low cost (<50 USD) by a large number of households with three pipes and one filter (about 20 m). The decline of the well water table implies over-drafting, jeopardizing the rural water supply. It is apprehended that in the near future the aquifers in North 24 Parganas will run completely dry (Banerji and Mitra 2017).

3.5.2 Surface water bodies

The study area is also characterized by the presence of plenty of surface water bodies in the form of rivers, streams, ponds, lakes, bheris, canals, roadside burrows and beels etc. Major rivers flowing through Barrackpore II, Bashirhat-I, Barasat II, and Amdanga are the Hooghly (the Ganges), Ichhamati, Sunti, and Jamuna. The study area, especially the rural hinterland, is dotted with a large number of small water bodies (ponds), and these are mainly used for fisheries (Appendix. 2). The district has a number of water bodies/tanks that should be put to good use to withdraw potable water without affecting the water bodies. It may be necessary to treat water from ponds/pools (not used for pisciculture) to minimize the level of contamination and supply it as piped water wherever feasible (Government of India Planning Commission, 2007).

3.6 Identification of artificial recharge sites with suitable structures

A huge potentiality of RRWH is left out untouched. It is necessary to reform effective regulations at national and international levels to prevent the outbreak of arsenic-based health hazards in the future (Sinha and Prasad 2020). The shallow aquifers of all four study blocks have grey to yellow sand layers with fine to coarse grain-sized sand, silt and gravel beds which implied significantly high water holding capacity (PHED 2018a). Grey yellow sand is dominated throughout the study area and indicates a very high potential for groundwater recharge. The water can be recharged naturally by excavating the topmost thin clay layer.

In the north-eastern part of Amdanga block, there are paleo-channels of river Jamuna, and those still exist in the form of different water bodies. These existing ponds and water bodies need to be re-excavated up to the depth of (6 to 8) m till the underlying brownish-yellow sand layer is reached. A percolation tank with a recharge shaft is suggested for the north-western portion of the Amdanga block (Fig. 6.1). Recharge shafts are artificially created into surface water bodies, submerging a land area with adequate permeability to facilitate sufficient percolation to recharge the groundwater. Surface runoff and rooftop water can be diverted into this percolation pond. Water accumulates in the pond then percolates in the recharge shaft to augment the groundwater. The shaft should be packed with coarse sand and precise gravel. Consequently, impounded water in the pond would have hydraulic continuity of the first aquifer, which would be recharged directly through this filter media. The recharge shaft should be driven up to the level of 1st aquifer (within 40 m depth) of the Amdanga block. In Basirhat I block, the natural recharge will be very easily accomplished by re-excavating the water bodies up to a depth of 3 mbgl.

In the Barasat II and Barrackpore II block, ponds are also needed to be re-excavated to the extent of even less than 3 and 10 m. In urban-influenced areas like Barasat II, Barrackpore II, and Amdanga, artificial recharge can be performed using RRWH with recharge pit/well (Fig. 6.2). This recharge well should consist of a filter bed and is to be excavated up to the depth of 30, 10, and 10 to 20 m for Amdanga, Barasat II, and Barrckpore II, respectively.

Typical schematic diagrams of percolation pond with the provision of recharge shaft and RRWH with recharge wells are shown in appendix.3.

The Planning Commission (2007) report, Government of India suggested that flooded river basins, rainwater, dug wells, surface water, and village ponds are available in plenitude in the state and may be harnessed for drawing arsenic-free drinking water as long-term measures. Central Ground Water Board (CGWB) strongly prohibited arsenic contaminated water for drinking purposes. Treatment alternatives for arsenic remediation should be fool-proof with minimum environmental impact, and integrated management of arsenic bearing sludge needs to be investigated. On the contrary, the State is enjoying an average rainfall of about 1600 mm every year and that too is very precious. Thus, rain water harvesting should be a local solution wherever it is feasible. A detailed study is needed on cumulative effects of quantity and quality trend and pattern of groundwater for sustainably managing aquifer. In that case, aquifer yield testing with the adoption of RWH could be an important solution (Halder et al., 2020).

3.7 Physico-chemical Quality of rainwater for the study area

Rainwater samples were collected from all four study blocks during July 2021 (Table- 8). Those were tested in the laboratory and compared with the drinking water standards of BIS 10500 (2012).

Table 8: Rainwater Quality for the study area

Study Blocks/ Standards	Location of Rainwater Sample	Rainwater Quality and Standard			
		Ammonia-N (mg/l)	Chloride (mg/l)	pH	TDS (mg/l)
Basirhat I*	22° 48’26” N & 88° 30’39” E	< 0.1	9.0	6.59	22.0
Barasat II*	22° 39’32” N & 88° 29’07” E	0.15	4.0	6.01	<10.0
Barrackpore II*	22° 45’43” N & 88° 22’03” E	0.16	4.0	6.05	18.0
Amdanga*	22° 48’26” N & 88° 30’39” E	0.24	4.0	6.06	16.0
WHO (2008)	---	< 1.5 mg/l	> 0.2 – 0.5 and < 5 mg/l	6.5 – 8.5	-
BIS: 10500 (2012)	–	1.2	250	6.5 - 8.5	500

*Primary data collected during 25 to 28.07.2021

Rahman et al. (2014) reported the overall quality of harvested rainwater as quite satisfactory and encouraging for households to adopt RRWH to achieve the self-sufficiency of water supply.

In this study, rainwater samples collected from Basirhat I block had pH value in the range of 6.5 to 8.5, i.e. the range prescribed by WHO and BIS 10500. However, for the other three blocksviz. Barasat II, Barrackpore II and Amdanga, the pH ranged from 6.01 to 6.06, indicating the slightly acidic nature of the rainwater. Thus, the rainwater can be safely consumed for drinking purposes subject to the provision of a very nominal degree of pre-treatment in the form of i) soda ash injection ii) provision of calcite neutralizer filter and iii) backing soda addition etc. However, regarding the parameters viz., TDS, ammonia-N, and chloride all rainwater samples appeared to be reasonably safe from the point of view of drinking purposes.

3.8 Suitable design of the storage tank for RRWH system for a typical household

It has always been a great challenge to ensure the supply of safe water overnight, but it would be possible to supply harvested water gradually in the contaminated area for the well-being of the affected community. Rainwater is an essential source of fresh water, especially for the areas suffering from poor quality water. Pacific Scientific Consultancy Private Limited (PSCPvt) (2015) estimated that RWH could harvest 2780 m^3 of water annually, which had 20% potential storage capacity of a cement factory in Surjyapur, Barrackpore II. It is necessary to introduce RRWH for Barrackpore II, Barasat II, and Amadanga (Bera and Das Chatterjee 2019; Das and Angadi 2020). Whereas, Banerji and Mitra (2017) suggested that if RRWH were made mandatory for all buildings, it would be possible to restrict the over-extraction of groundwater. This can be made feasible by setting up PVC tanks on rooftops. Local communities would be able to utilize freely available rainwater and supplement the daily supply of surface water with it. Banerjee and Jatav (2017) argued and stated that re-cycling wastewater and RWH were hardly taken up in Barrackpore II. The percolation tank played a vital role in groundwater recharge with a relatively flat slope of less than 2% (WaterAid 2011; Rana and Suryanarayana 2020). Planning Commission (PC 2007) mentioned that the major technical disadvantage of RWH in rural Bengal was the roof materials (straw, asbestos, roof tiles other than concrete) which could not yield a sufficient quantity of harvested water.

The harvested rainwater can be used for drinking purposes after filtration or directly for gardening and non-potable different domestic uses and also used for recharging. In this study the design of the storage tank was estimated by using two approaches viz. i) Comparing the tank capacity with the area of the roof ii) Comparing the tank capacity with the quantity of water demanded by its users, described in detail under section 2.4.d.

However, considering the quantity of rainwater likely to be demanded by the users throughout the dry season, the method-ii seems to be more justified. Based on this understanding, the storage tank's capacity is estimated at 6,000 litres, i.e. 6 m^3, which can vary from (6-10) m^3.

In that case the dimensions of the storage tank are calculated as {1.5 m (depth) x 1.25 m (width) x 3.2 m (length)}.

After flushing out the initial rainwater, the rainwater available from the residential rooftop is to be conserved in the storage tank, which may consist of an in-built filtration unit, comprising three chambers successively for minimizing the turbulence of water, for desilting and finally for filtration of rainwater. A mesh should be provided at the rain pipe so that leaves or any other form of solid debris is ultimately prevented from entering the tank. In the desiltation chamber, the portion of suspended solids consisting of sand, silt and other coarser materials will settle at the bottom and then it will enter the filtration chamber flowing over the partition wall (1.10 m height). In the filtration unit, water passes through a filter media consisting of coarse sand (1 to 2 mm size and 30 cm thick), fine gravel (3 to 5 mm size and 20 cm thick) and coarse gravel (6 to 9 mm size and 20 cm thick) successively from the top placed over a perforated sheet (slot size- 3 mm) of mild steel kept at 20 cm above the base of the filtration chamber (Fig. 7).

3.9 Disinfecting the harvested rainwater

Understanding the severity of the problem, the PHED installed membrane-based desalination plants in Ashoknagar and Habra II under North 24 Parganas. The scheme was already artificially recharged by the RWH structure constructed and was capable of diluting arsenic level to 1 ppb. RRWH scheme was also installed in Hasnabad Panchayat Samiti Office, with the funding made by North 24 Parganas Zilla Parishad (Chatterjee et al., 2009). However, Roy (2019) recommended RWH with a purification system as a cost-effective measure for the supply of safe drinking water with increasing awareness and education.

T**able 9: Recommended dosage of bleaching powder (in gm) for disinfecting water (WBPCB, 2004)**

Storage capacity of tank (litre)	Full tank	Tank three fourth	Tank half full (1/2)	Tank one fourth (1/4)
5,000	50	37.5	25	12.5
6,000	**60**	**45.0**	**30**	**15.0**
7,000	70	52.5	35	17.5
8,000	80	60.0	40	20.0
9,000	90	67.5	45	22.5
10,000	100	75.0	50	25.0
12,000	110	82.5	55	27.5

In the present study, the proposed system has a storage tank capacity of **6,000 litres**. The required dosage of disinfectant (i.e. bleaching powder) can be estimated as **60 gm** for a full tank, which can be proportionately reduced with the reduction in the volume of stored water as given in Table 9.

3.10 Design of the recharge pit/well for artificial recharge

In urban-influenced rural areas, the excess rainwater available from rooftops (approximately 75% of harvested rainwater) can be utilized for recharging the aquifer through recharge pits/wells. This artificial system needs to be designed in a way that it does not occupy large space for collection and recharge system. Recharge Pits/wells may be of any shape and size. In the case of a typical rooftop with 100 m^2, they are generally constructed 1 to 2 m. wide and 2 to 3 m deep. The pits/wells are filled with boulders (5 to 20 cm), gravels (5 to 10 mm) and coarse sand (1.5 to 2mm) at the bottom to the top (Fig. 8). The silty materials will be deposited on the top of the coarse sand layer and can easily be removed. The top layer of sand should be cleaned periodically to maintain the recharge rate.

This aquifer recharge can enhance the water level in the aquifer of the subsurface storage and can dilute the arsenic-iron concentration in the shallow aquifer. It can also minimize the possibility of floods and associated damages every year.

Over the last four years, alarming depletion of piezometric level was observed at 11 to 16 m bgl in Dum Dum, Kestopur, and Paikpara. The groundwater withdrawal for drinking and other domestic purposes has immense effects on the fluctuation of water levels. The general flow of water in this region is towards the south-eastern part. Historically, this area had handsome annual rainfalls of 1362.2 mm, 1377.6 mm, 1279.3 mm and 2268.4 mm in 2010, 2011, 2012 and 2013, respectively. The chemical quality of water samples of the piezometers and dug wells was not safe for drinking due to high arsenic concentration (CGWB, 2017b).

3.11. Socio-economic study

The underground hydro-geological factor and above ground formal, informal and macro-micro level socio-economical practice define the status of groundwater. The linkages between all spheres viz. social, economic and environmental involving community participation, is highly significant in reducing arsenic in drinking water (Chakraborti et al., 2018).

In the present study, the contaminated water supply and its level of deprivation could be measured by socio-economic proxy indicators. Details of the questionnaire survey are shown in table 10.

Table 10: Details of a socio-economic study

Blocks	Population density (person/sq. km) (2011)	Water demand (lpd)	No of surveyed households	Arsenic affected population
Amdanga	1376.17	96,331.9	179	185014
Barrackpore II	5335.90	373513.0	211	37234
Barasat II	1761.82	123327.4	248	38827
Basirhat I	1535.00	107450.0	286	10365
Total			**924**	

Source: CGWB (2013), Census of India 2011, PHED 2017, Field data (2019)

Almost most of the surveyed households (79%) were in low-income groups (up to Rs. 10,000) mainly engaged in cultivators, daily labors, construction and domestic workers, etc. While the middle-income (above Rs. 10,001) households were mostly engaged in governmental service, private sector, business, and others (Table 11). In the low-income category, the majority of the respondent households belonged to the Non-Hindu category (51.9%), while the same belonged to the Hindu community for the middle-income group (10.7%).

Table 11: Key socio-economic variables considered

Variables	Category	Percentage
Education level of the respondent	Up to class V	57.0
	Up to class X	35.2
	Graduate	1.58
Family size	1to 4,	53.5
	5 to 10,	43.9
	11 and more	2.6
Occupation	Cultivator	38.3
	Service	22.4
	Daily Laboure	20.9
Monthly income	Up to 5000	38
	5001 to 10000	41
	10001 and more	21
Use of Arsenic-iron Contaminated Drinking Water	Yes	89.1
Known iron	Yes	25.2
Known arsenic	Yes	27.3.
Household expenses for water related diseases in last 5 years	Yes	55.4
Ownership of house	Yes	94.9
Homestead Land	Yes	83.7
House material concrete	Yes	43.6
Concrete roof	Yes	48.5
Ownership of tank	Yes	12.6
Ownership of Pond	Yes	14.0
Adequacy of supplied water in Summer	Yes	17.2
Previous experience of water harvesting	yes	31.1

Source: field data (2019).

In the course of the socio-economic survey, we observed that the households of the study blocks were solely dependent on STW for drinking purposes, thus putting enormous pressure in multiple ways. Some existing ponds had been turned into dumping grounds. The locations of monitoring well and surveyed households are shown in appendix.4.

According to PHED, no water-based surface PWSS existed in the affected villages. While some of the TWs were banned by the PHED, households continue to consume such contaminated water with no alternatives. Under such serious circumstances, households set submersible pumps with their STWs, driving the groundwater towards escalating stress.

Table 12: 'Water-related health issue index (WRHII)' and 'Inclination to adopt RRWH index (IARRWHI)'

	Less IARRWHI	More IARRWHI	Total	Less/total
Low WRHII	261 (40.40%)	385 (59.6%)	646 (100%)	261/385
Acute WRHII	94 (33.94%)	183 (66.06%)	277 (100%)	94/277
Total	355	568	923	

p value=0.065

The p-value of the chi-squared test is observed to be 0.065, which implies a significant relation between WRHII and IARRWHI at 10 percent level. The relation is positive as the product of the diagonal frequencies is greater than the product of the off-diagonal frequencies. In other words, higher WRHII signifies higher IARRWHI. During the survey, we also found some patients suffering from different types of arsenicosis but were forced to continue consuming contaminated water despite knowing the adverse consequences of the same. Under such serious circumstances, households had been still setting submersible pumps with their STWs. Irrespective of economic status, households used to consume arsenic-iron contaminated water in the form of bottled water (9.9%), tubes well fitted with submersible pump (4.4%), personal STWs (56.3%), PHED tube-wells (TWs) (53.8%) all sources of contaminated water. Among water-related diseases, the percentage of people suffering from arsenic-related skin problems was reported as 20.3%. However, the percentage of surveyed populations suffering from pigmentation and skin lesions were obtained as 11.8% and 2.8%, respectively. In the survey, it was found that respondents had been suffering from constipation (14.2%), dysentery (6.7%), jaundice (8.5%), typhoid (6%) and gastrointestinal diseases (49.2%), respectively and those facts raised the issue of quality of safe water. Almost 77.9% of the surveyed population complained that mosquito biting and water-logging were regular phenomena. For example, respondents reported there were cases of malaria (1.1%), dengue (5%) and chikungunya (0.5%).

Das and Roy (2013) found that the patients with arsenicosis were often excluded from society, even from their families, which were very common in Murshidabad, West Bengal. Mishra et al. (2021) developed a comprehensive arsenic awareness index (CAAI) and key awareness drivers (KADs) to evaluate farmers' perception of arsenic related health issues in arsenic-affected areas viz. North 24 Parganas, Nadia, Purba Burdwan and South 24 Parganas of West Bengal and Chandpur, Faridpur of Bangladesh. The results of CAAIs showed that the farmers of Bangladesh were generally more arsenic-aware (CAAI 7.7) than West Bengal (CAAI 6.8). Both farming communities agreed on policy changes on water testing and clean water supply, and they suggested for increasing awareness of risks related to the food chain. Joyashree Roy (2007) estimated the economic costs of arsenic-related health problems based on a questionnaire survey of 473 households in the districts of North 24 Parganas and Midnapore. They also assessed the magnitude of arsenic-contaminated water problem by estimating three equation systems such as averting actions, medical expenditures and loss due to sick days functions and found that by reducing arsenic concentration to the then safe limit of 50 µg/l, a representative household would benefit by Rs 297 ($7) per month. This investigation found that households were willing to pay the investments had they been made aware of.

Table 13: 'Concrete roof area' and 'Land availability'

	Land Availability		
	Large	Small	Total
Large roof area	22 (27.16%)	59 (72.84%)	81 (100%)
Small roof area	461 (54.75%)	381 (45.25%)	842 (100%)
Total	483	440	923

p= 0.000

Table 13 shows a significant negative relation between 'concrete roof area' and 'land availability' at 1 per cent level. Despite the prevalence of water contamination, rural people have not been adopting RRWH. It was found that irrespective of economic class and educational status, there had been a serious dearth of the technological know-how of RRWH. Nearly 31% of households used to collect rain crudely, and very few drink it very rarely. Nearly 45% of households had the infrastructural capability of RRWH, such as ownership of the house, water tank, concrete roof, pond and homestead land. However, the one-time individual expenditure for the installation of RRWH was $ 1049.41 (Rs.74,320) for approximately 37.0 sq. m of roof area as on. It was reasonably affordable for the APL section considering the one-time investment for the installation of RRWH and its associated long-time benefit, as this would minimize the chances of water risk and diseases, loss of school day due to heavy rain (28.6%), treatment expenses for waterborne and vector-borne diseases and water logging (63.8%). As the relation between 'concrete roof' and 'land availability' was negative, households with larger roof areas ought to be suggested to build their storage tank on their own rooftop. Rural people had been indiscriminately wasting rainwater across the study area. 11.2% of surveyed households of Amdanga and Basirhat I blocks reported that spot TWs and deep tube-wells (DTWs) of drinking water were not found in working condition over the years due to significant decline of piezometric water level or lack of proper maintenance. However, between the phases of collection and consumption, various associated factors add to further contamination. It was found that households having sufficient income might be willing to adopt and incur the expenditure of RRWH. Similarly, several cross tables were computed for other factors with the concrete roof, but they are not significant for the present study.

A study by Many parts of West Bengal faces a serious problem of water scarcity due to falling of groundwater level with arsenic contamination. Before it is too late, measures should be urgently adopted to control groundwater exploitation. Community participants should be encouraged with rainwater harvesting and artificial recharge schemes (John et al., 2018). Geographical information has opened new avenues for groundwater research and laid the platform for further research. Through community participation, people can understand the risk of groundwater depletion and work towards its development so that during the rainy season, the dependency on the resource is reduced. Artificial Recharge and water harvesting techniques are the only next alternatives (John et al., 2018). According to PHED (2011), the key strategy for sustainable drinking water supply is 'water security for all' with community participation and intersectional involvement. Getting people to participate in any social development programme is not easy. RRWH would make people aware of the necessity of water conservation through social knowledge followed by its real-life application (Biswas et al. 2020).

5. Recommendations

Following measures would be suggested for considering the magnitude and extent of the water situation.

- It is necessary to introduce appropriate land use and restrict and penalize illegal construction and landfilling. Region-wise micro-level aquifer maps, arsenic-iron-based vulnerability maps and LULC maps should be published in the public domain to make people aware of the quantity-quality status of the aquifer and any drastic change in land use and share a periodical update.
- The main focus would be to shift from the construction of a high-cost arsenic treatment plant to RWH.
- RRWH with recharge wells for all built-up areas, percolation pond with recharge shafts and re-excavation of the existing wells or ponds may be adopted to avoid valuable land acquisition.

- A sense of ownership is to be generated by giving ‘pond patta’ to the households in the rural areas, i.e. one kind of pond audit should be conducted every five years and reward households by giving some kinds of incentives.
- Water misuse should be restricted by installing a water meter. Tax may be levied on water consumption beyond 70 lcpd.
- Existing schemes have to be modified into a package coalescing the existing schemes like ‘Jal Dharo Jal Bharo’ (water conservation scheme) and ‘Pradhan Mantri AbasYojana’ or ‘Nijo griho nijo abas’ (pucca house scheme for BPL) and re-excavation and development of new ponds for RWH under the ‘NREGA’[3] scheme into a single scheme towards the development of RRWH for households. These four projects at present have been running side by side by the State and the Central Government, respectively. RRWH scheme should be implemented jointly involving the government, NGOs, and individuals. This single project would help the financial empowerment of rural people.
- A water safety plan of RWH should introduce simple technical know-how of rooftop RWH by organizing frequent meetings, training, workshops, increasing the social awareness program among the affected community for social acceptance of scheme and rescuing their aquifers for the future generation.
- There is a need to introduce incentives for the success of RRWH.
- RRWH should be made mandatory even for small rooftops of households in rural areas with low-cost water treatment technology like slow sand filters.
- Drinking tube wells should be constructed by tapping an arsenic-free aquifer with proper cement sealing in the clay zone above the aquifer to be tapped. Conjunctive use of different water sources, i.e. RWH, surface water, and safe groundwater supply, would be a suitable option.

[3] (NREGA) National Rural Employment Guarantee Act,2005. This is a social security scheme of Govt. of India and it provides employment of the rural people of India.

Conclusions

Our study found that, over time, the share of land of vegetation and water bodies turned into fallow lands or were turned into the other purposes mainly converted into built-up areas. This implied a serious threat to surface water and natural recharge. The gradual post-monsoonal decline was found in all study blocks. Unauthorized heavy-duty tube wells draft fresh groundwater-bearing aquifers for domestic and irrigation purposes. Without maintaining the minimum safe distance among the STWs or DTWs resulted in a sharp decline in drawdown cone; thus, the piezometric water level has been declining. The cumulative effects of unsafe water on households have so far been neglected continuously. Rural households are unwilling to adopt RWH due to mental taboo despite the serious threat of arsenic. It was challenging to popularize RRWH unless a person could understand the manifold adverse effects of unsafe water. Instead of this, water has been treated as a public good without any kind of imposition of water tax in West Bengal. The problem of arsenic has been yet to be addressed with due importance, especially for the rural areas with low-cost technology. Thus, people have been coping with water shortages both in terms of quality and quantity. Recently, the Government of West Bengal started supplying surface water. The supplied water had been sometimes more than its requirement. Most of the middle class, wealthy and low-income households are willing to adopt RRHW if the government would have provided it free of cost or offered some incentives or subsidies.

So far, this mixed-mode approach combining physical, socio-economic, and aquifer characteristics have been unexplored. It would be useful for the policymakers and local authorities to delineate appropriate planning and management strategies regarding RWH. As a strategy, a part of the excess rainwater could be harvested and used for domestic purposes, including drinking after providing necessary treatment, while the rest could be directed for artificial recharge through appropriate structures in selected sites. This will reduce the chances of inundation through proper utilization of excess rain water and remediate the problems of groundwater scarcity and inorganic arsenic-iron contamination. It is, therefore, the need of the hour to make RRWH schemes mandatory in a true sense. At the same time as a long-term resolution, a region-specific strategy is to be formulated to eradicate the hazard of arsenic and water scarcity.

Declarations

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Consent for publication: Not applicable

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request

Conflicts of Interest: The authors declare no conflict of interest**.**

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Figures

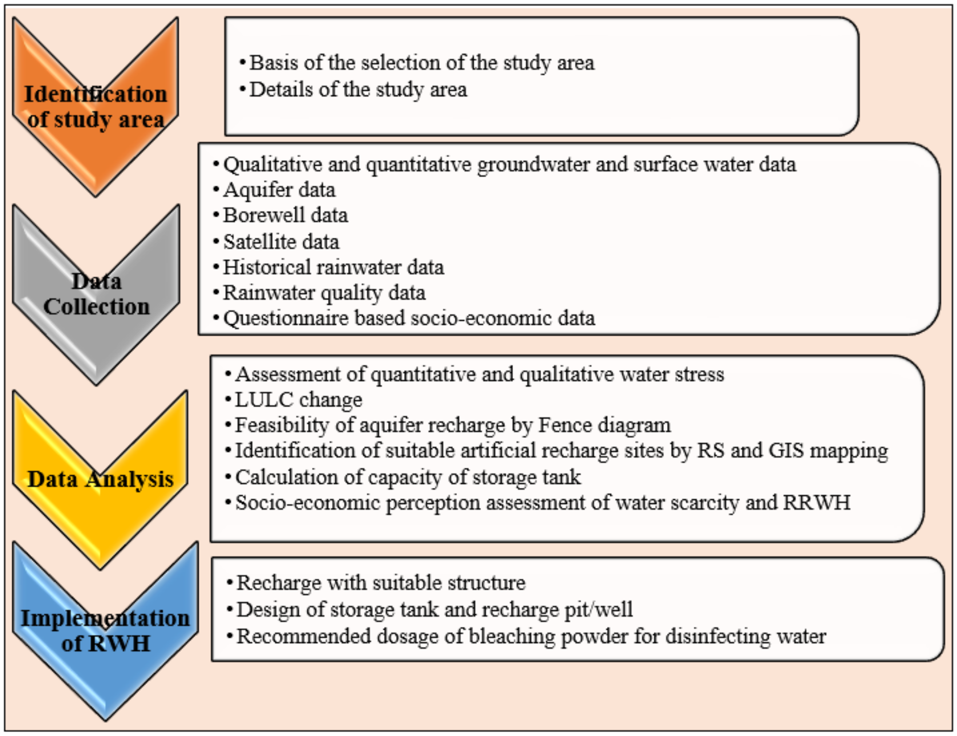


Figure 1

Graphical Representation of Methodology

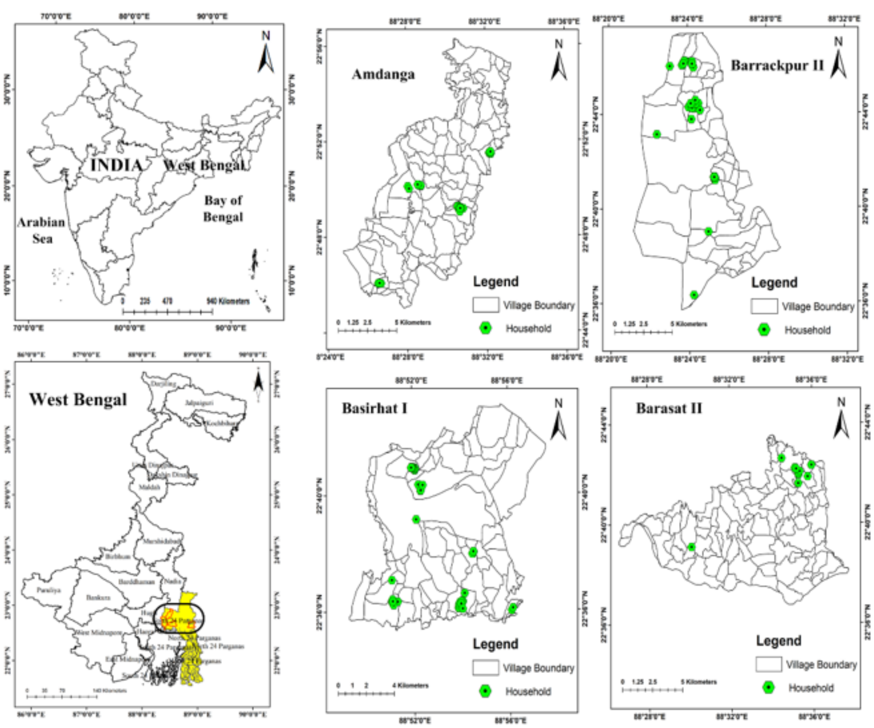


Figure 2

Study Area

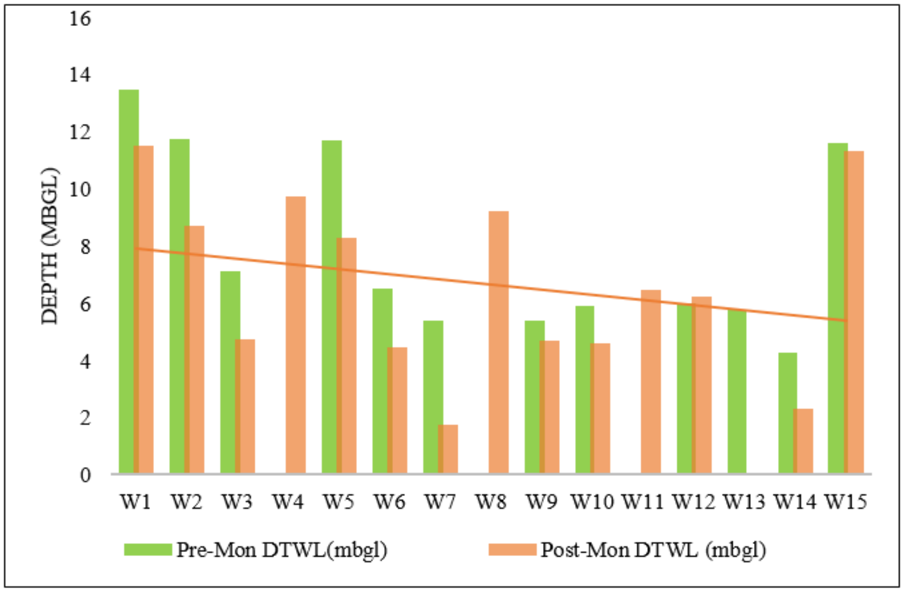


Figure 3

Pre and post-monsoon well water level

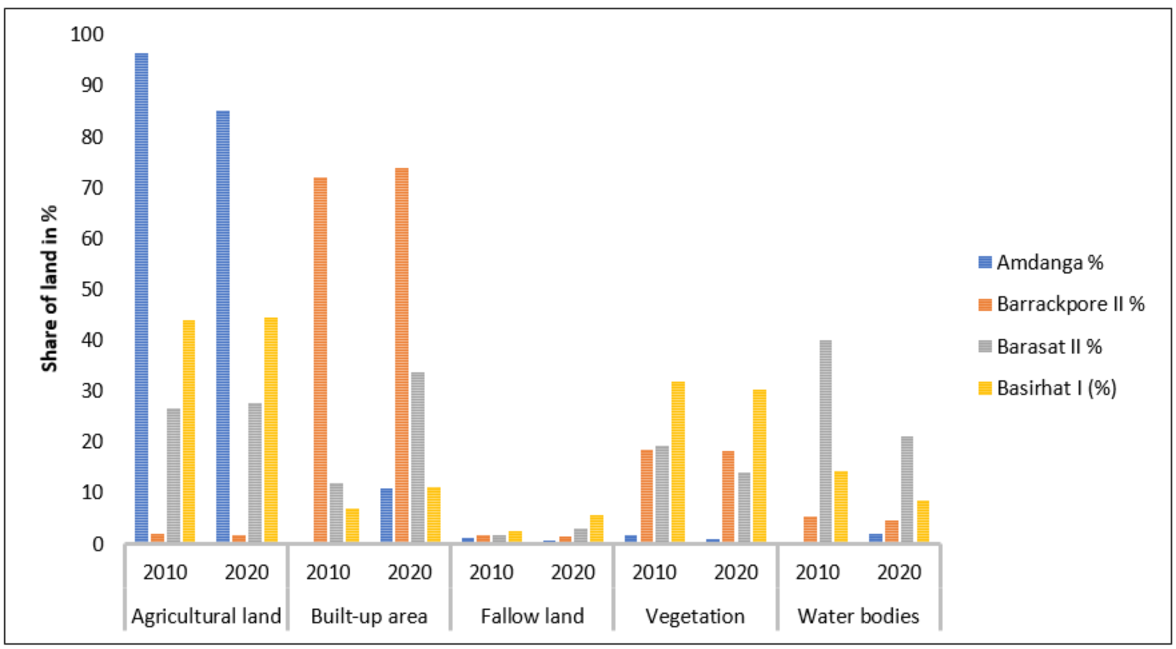


Figure 4

Percentage of share of land in LULC Amdanga, BarasatII and Basirhat I during 2010 to 2020

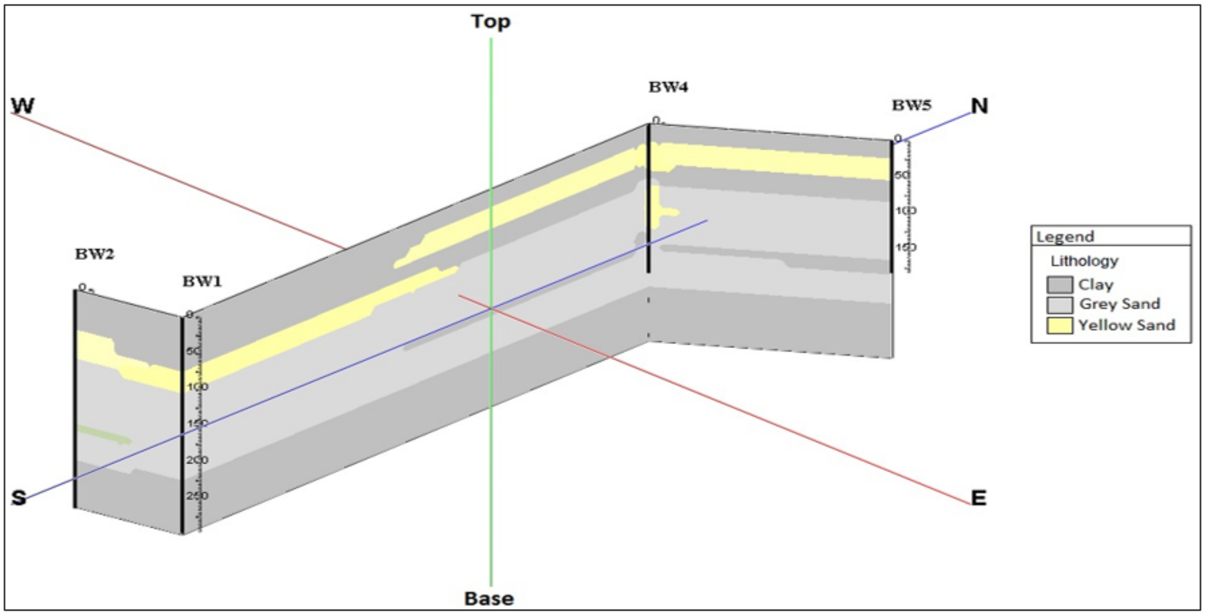


Figure 5

Fence diagram of bore wells of the research area

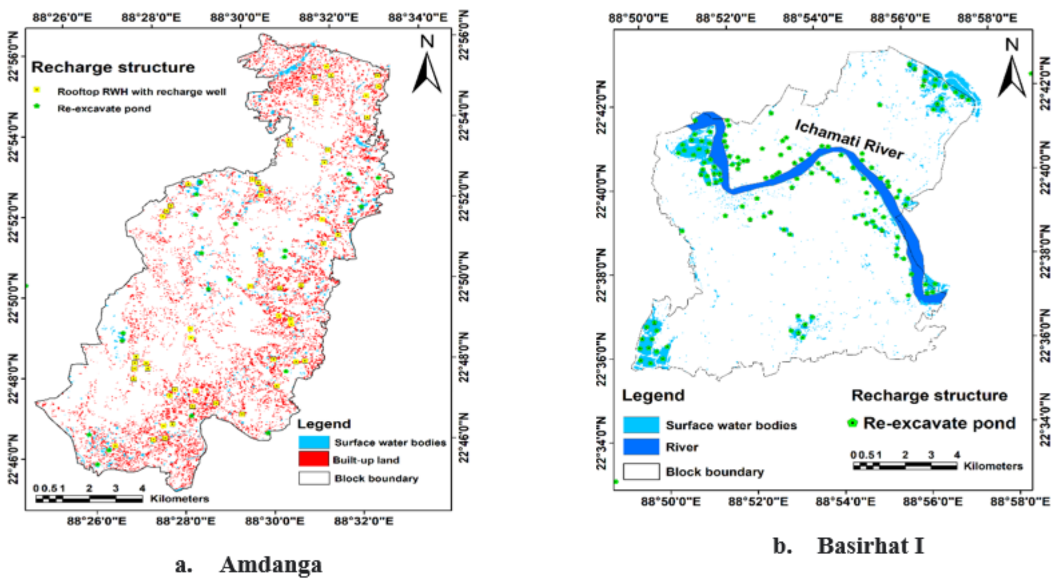
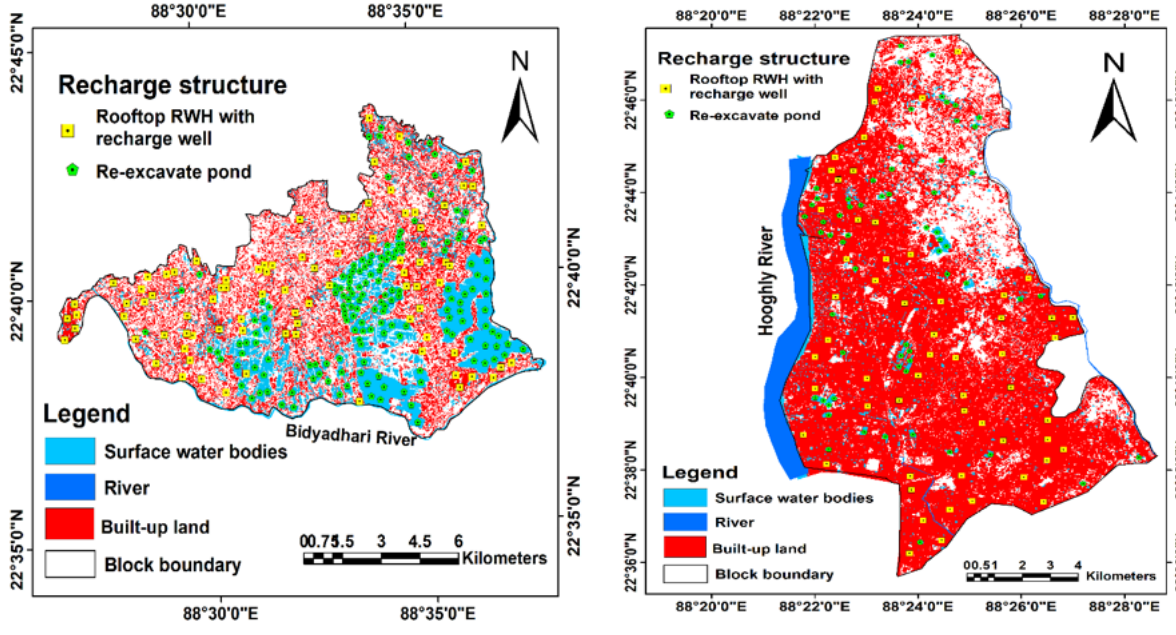


Figure 6

6.1 Identification of sites for suitable artificial recharge structure in Amdanga and Basirhat I



c. Barasat II

d. Barrackpore II

Figure 7

6.2 Identification of sites for suitable artificial recharge structure in Barasat II and Barrackpore II

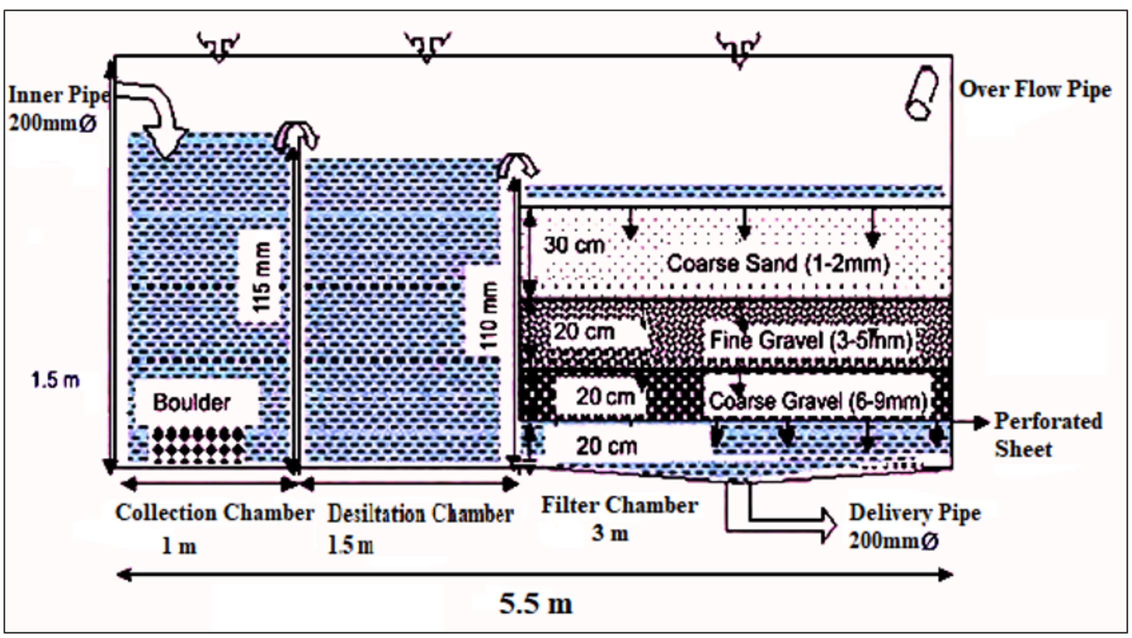


Figure 8

Fig. 7 A typical schematic diagram of underground rainwater storage tank

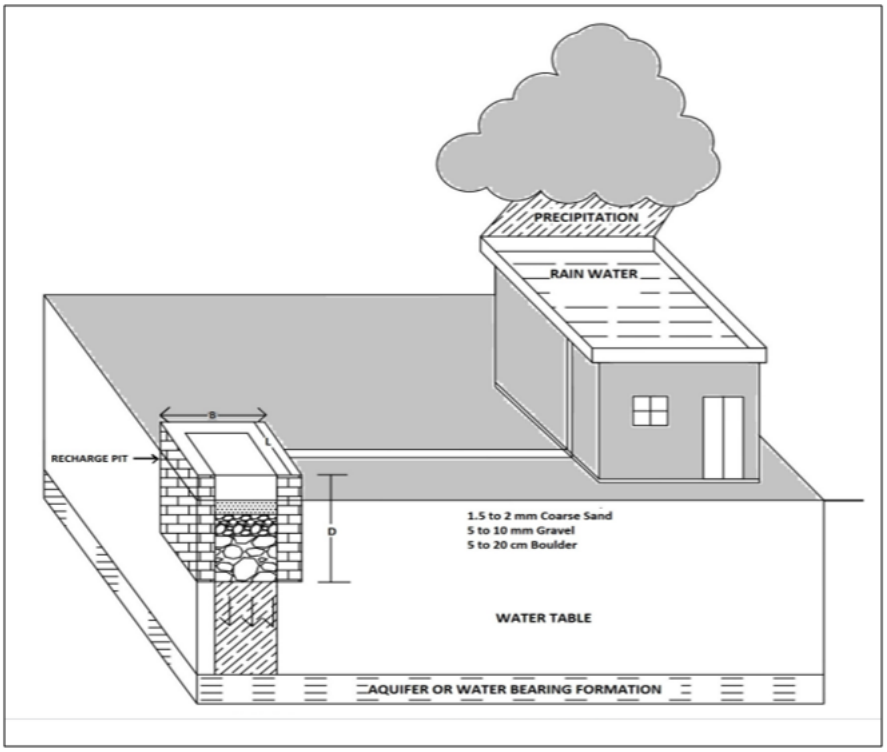


Figure 9

Fig. 8 A Typical schematic diagram of recharge pit/well

Supplementary Files

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- Appendixfigures.docx