Chapter

Analysis of Rainwater Harvesting Method for Supply of Potable Water: A Case Study of Gosaba, South 24 Pargana, India

Subhashis Chowdhury, Souvik Chakraborty and Rajashree Lodh

Abstract

In Gosaba, a village on the outskirts of South 24 Parganas, West Bengal, India, people experience a lot of problems related to shortage of potable water due to salinity and arsenic contamination in the supplied water. Rapid growth of industrialization, increased population, saline water intrusion etc. is causing a decrease in fresh water. Due to overuse of groundwater, GWT is declining rapidly in the Gosaba region. Moreover, seawater is intruding into the groundwater, causing pollution of surface water and a rise in Fe content, Cl content, arsenic content and salinity content in groundwater of that location. The runoff available from that amount of received precipitation is estimated using two empirical equations derived by Sir Aiexander Binnie; Ingels-De Souza and T.G. Barlow and the calculation confirms a good amount of runoff that can be utilized for harvesting in order to decrease the water scarcity of the location. The scarcity of fresh water in the Gosaba location can be minimized by adopting the rainwater harvesting (RWH) method, a sustainable process to obtain disinfected water at a very low cost. The technical part of the present study is to adopt RWH where rainwater is collected from rooftop of an institute building and to design tank where water can be stored and utilized further at minimum costs.

Keywords: salinity, groundwater, arsenic content, water harvesting, runoff calculation Gosaba block

1. Introduction

Various regions of West Bengal as well as India are facing the problem of water shortage due to depletion of groundwater table (GWT) at an alarming rate. South 24 Pargana located in the coastal area of West Bengal, India is one of them. Gosaba is one of the blocks in South 24 Pargana. The latitude and longitude of Gosaba are 22.16°N and 88.80°E respectively. The population density of South 24 Pargana is larger than that of West Bengal. Due to excessive use of groundwater, saline water intrusion is taking place rapidly in South 24 Pargana. The groundwater of Gosaba is contaminated by arsenic and also affected by saline water intrusion from the Bay of Bengal. Thus, there is scarcity of freshwater required for domestic and drinking purposes in the Gosaba region. It is very much needed to provide fresh water to different sectors and most importantly for household purposes. Since during monsoon tropical regions receives heavy rainfall, rainwater can be stored for future. Therefore, as an alternative rainwater harvesting (RWH) can be adopted to provide fresh water to the household during dry seasons at a reasonable cost of installation or for recharging groundwater. There are three processes involved in RWH technique: collection of rainwater in a waterproof surface such as impervious ground surface or roof, conveying the water through pipes and conduits from catchment to suitable storage tanks and storing the water properly at some location, may be rooftop or underground tank for future use. It includes primary screening of unwanted materials, first flush diverters and a water treatment plant. The harvested rainwater can decrease the dependency on groundwater caused by increased rate of population. RWH techniques can also prevent soil erosion and flood in coastal areas during rainy season as the excess water is collected in huge tanks. Storage tanks made up of concrete are most widely used in India to store rainwater and can be built below and above the ground surface. Although it is advisable to provide tanks above the ground surface as it is cost- effective and any damage, leaks, cracks etc. can be easily identified and tanks could be cleaned at regular intervals. Moreover, there remains a risk of contamination of water in underground tanks.

Various researchers worked on the RWH techniques to reduce the scarcity of fresh water and save the groundwater. Awawdeh et al. [1] studied that the chronic water shortage in Jordan can be reduced by increasing the amount of rainfall harvesting from rooftops, roads, and parking lots. They conducted a study at Yarmouk University and evaluated the potentiality for potable and non-potable water savings by using rainwater [1]. Tobin et al. [2] studied the practice of rainwater harvesting (RWH) in a rural community in Edo State, Nigeria. A cross-sectional study design and a structured observational checklist were used for the assessment of the household rainwater harvesting system. Data were analyzed using statistical package for social sciences (SPSS) version 16 and results were presented as frequencies. It has been found that RWH was practiced by over 80% of households, with the rooftop as the catchment area. Stored water was most commonly used for personal hygiene purposes [2]. Roy [3] conducted an empirical study on the Bandu river basin in Puruliya district to explain the importance of rainwater harvesting in drought-prone areas of West Bengal. Puruliya district ranks first in vulnerability to drought hazards within the state of West Bengal. The Bandu river basin receives 1150 mm of rainfall even in the driest years but the distribution is uneven, as a resulting scarcity of water occurs. There are 31 villages in the Bandu river basin and the population density of the area is 375 persons/sq.k.m. The objective of the work was to adopt rainwater harvesting and estimate the runoff from the amount of rainfall received. The runoff was estimated through four empirical formulae and the results indicate the amount is a healthy one [3]. Khan [4] made a detailed review of the contribution of rainwater harvesting in the field of agriculture in the Ahmadabad region of Gujarat. Because of the little supply of water in villages by the government, the rural population is fully dependent on water for agricultural as well as domestic purposes. Both primary and secondary data from water samples and community surveys were used to analyze the costs and benefits of RH in the district. The major costs include the initial construction cost of the rainwater harvesting system and the maintenance costs. The major benefits include an increase in household dispensable income, time and energy saved from collecting water, and relief from epidemic droughts [4]. Said [5] carried out a case study in South Delhi to assess the potential of roof-top rainwater harvesting procedure. The study aims to explain rooftop rainwater harvesting that can be easily used by each individual with ease. Data were collected and analyzed in relevance to the actual average annual water consumption of each household and the volume of rainwater collected annually from an individual respective rooftop. The study advised the reduction of 20% in the per capita demand of each individual. The present study finds its usefulness in developing awareness towards the proper use of rainwater for sustainable management of water resources at an individual level [5]. Shittu et al. [6] used a rainwater harvest system to combat perennial water scarcity at the household level in Ibadan city. They collected rainfall data for a period of 10 years. The RWH System used comprised of six basic components: Roof Catchment; Gutters and Downspout; Conveying and Water Treatment, Leaf Screen and Roof-washers; Storage Tanks [6]. Kulkarni [7] summarized studies, research and surveys carried out to study, analyze and implement RWH. It has been observed that the use of the RWH method can fulfill more than 50 percent of water demand in domestic households. The commercial hubs, school complexes, and office premises have more potential for rainwater harvesting [7]. Khan et al. [8] adopted a rainwater harvesting system for the design of optimum rainwater storage tank size and efficiency assessment. The software developed by them proved to be satisfactory for any combination of location, catchment area, material, and water demand and can also estimate the reliability of the corresponding water supply system. The rainfall data for a 24-year period for different areas of Bangladesh was collected from Bangladesh Meteorological Department (BMD) and used in the model. The software was employed to evaluate RWHS in an arsenic affected region (Comilla), coastal location (Khulna), and a low-rainfall area (Rajshahi) [8]. Jagtap and Bhosale [9] developed a working system at a construction site named Daulat Heights in Pune, Maharashtra. The main objective of this paper was to make efficient use of rainwater and adoption of the newly launched concept of nature conversion. The project has to store a capacity of 129,600 liters of water with just Rs 48,060 [9]. Pauline et al. [10] primarily focused on the adoption of water harvesting structures by farmers in dryland areas of Tamil Nadu. A thorough study was conducted and designed by combining a descriptive survey of the study area and a population analysis approach of a participatory study. Different water conservation methods/structures found in the dry areas of Tamil Nadu are farm ponds, tank irrigation systems; compartmental bunding and recharge pit, etc. have been described [10]. Chakraborty et al. [11] have simulated the GWT in various locations of Purba Medinipur with the help of Visual MODFLOW. The lowered GWT is one of the major reasons for salinity in groundwater in Purba Medinipur. From the review of literature, it is evident that RWH technique is advantageous and can be developed for both quantitative and qualitative approaches for the present study area [11]. Chowdhury et al. [12] conducted a comprehensive study in West Bengal and Assam that revealed that there is substantial amount of arsenic affected areas in these two states that is affecting the quality of groundwater and causing various diseases in human being. They also provided few suggestions to treat the arsenic sludge [12].

The present study aims at calculation of runoff available for storing during rainy season using two empirical equations derived by Aiexander Binnie; Ingels-De Souza and T.G. Barlow; determination of Ar content, Cl content, Fe content and salinity in groundwater of South 24 Pargana, designing and installation of RWH plants and explaining the economic benefits of RWH methods.

2. Study area

The study area taken is in Gosaba location that is a block at Jayanagar in South 24 Parganas of West Bengal, India with an area of 297.6 Km^2. It is located in the proximity of the Bay of Bengal. The lithological character of South 24 Parganas is such that it is made up of Entisols, Alfisols, and Aridisols. Horizontal hydraulic conductivity

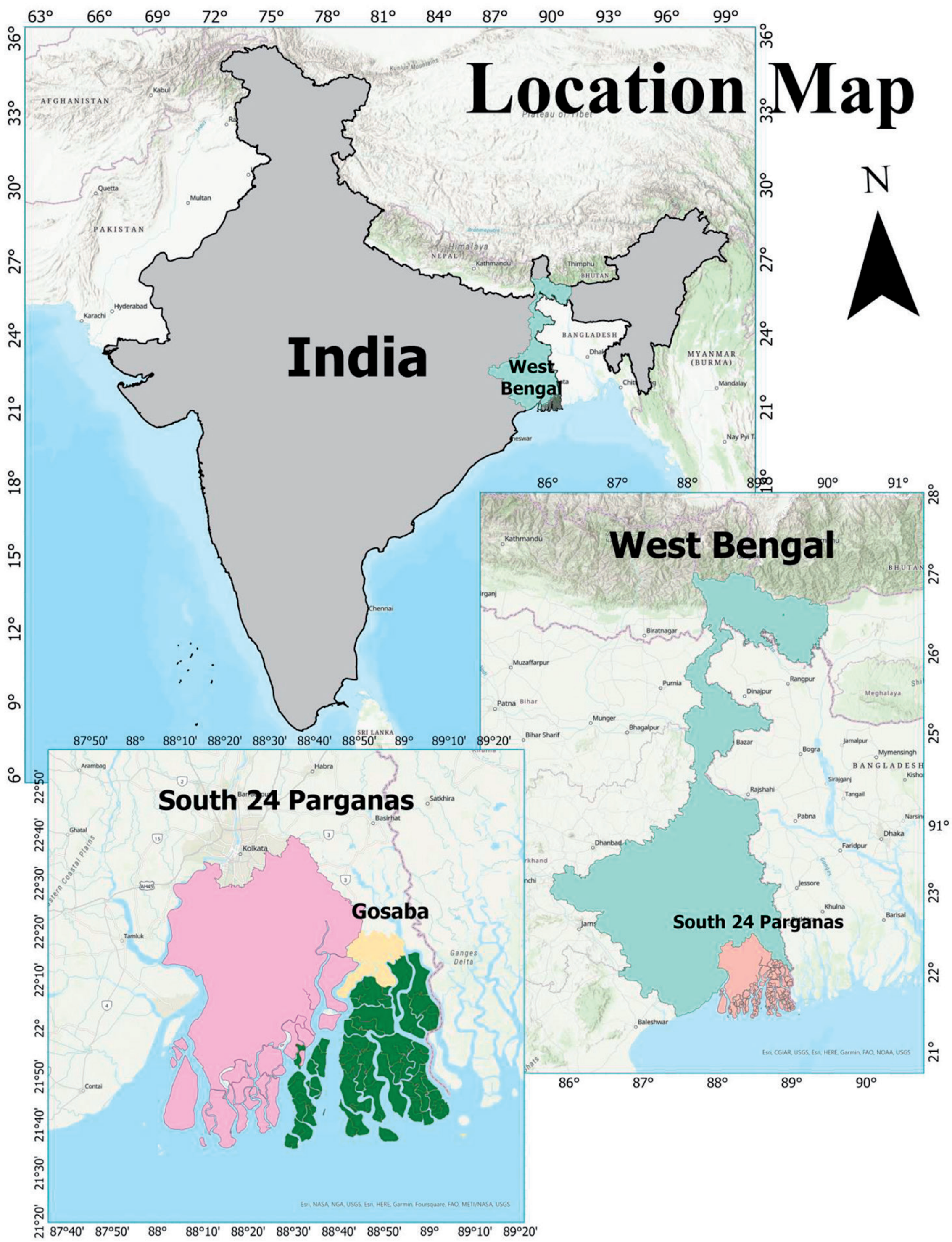
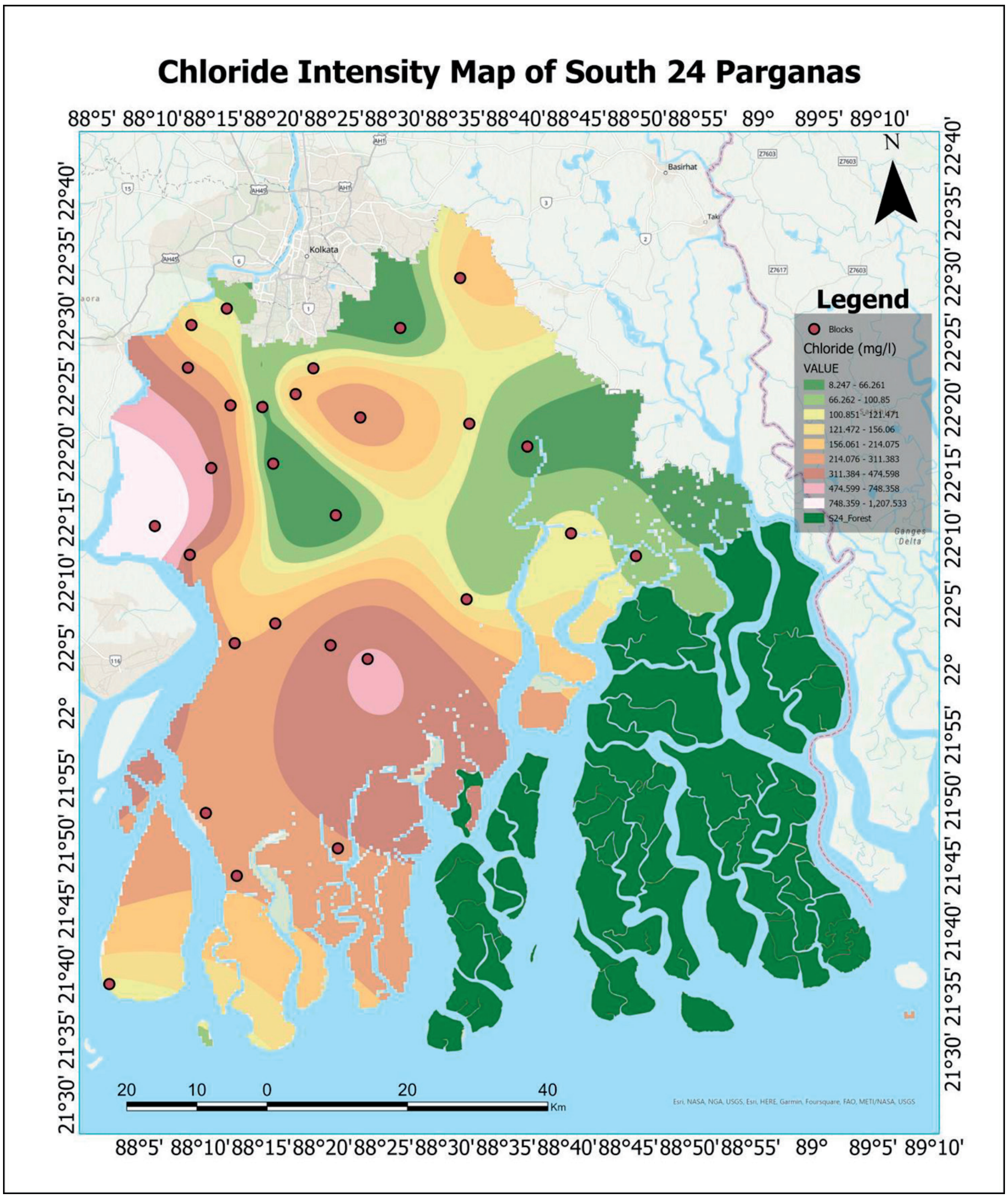


Figure 1.
Study area.

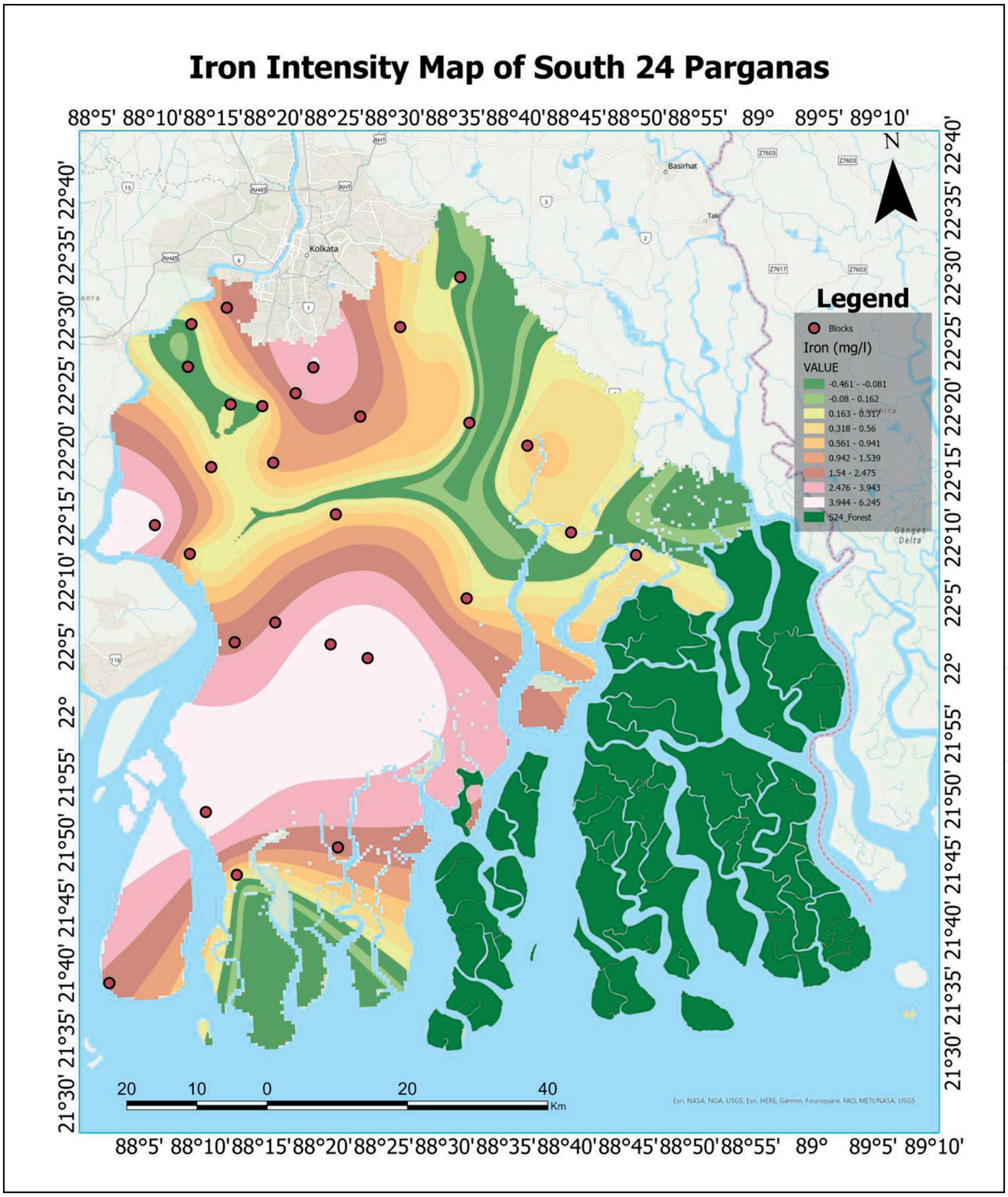
of this type of soil is more than vertical permeability and for that reason; it is more susceptible to seawater intrusion. The study area is represented by **Figure 1**.

3. Status of water sources in the present study location

Groundwater used for domestic water consumption in South 24 Parganas is sixty-eight (68) Million cubic meters (MCM) which is very much significant, as a result, groundwater is depleting very fast. According to Census India 2011 report, the population of Gosaba block was five thousand three hundred and sixty-nine (5369) that has increased substantially in the current year 2021, the increment being around 7% p.a. The population in Gosaba is around 10,000 as of the year 2020. The density of population in South 24 Parganas is more than that of West Bengal as a consequence



of which groundwater is extracted more resulting in saline water intrusion as per Ghyben Herzberg Principle that states one scale decline of groundwater results in forty scale intrusion of seawater into the mainland. From the information provided by Public Health Engineering Department (PHED), South 24 Pargana, it has been confirmed that groundwater is contaminated with arsenic, arsenic contamination in Jayanagar was 0.05 mg/l, salinity in groundwater in the year 2011 was ranged from 0 ppm at Budge Budge to 4624 ppm in Mathurapur-II and in Jayanagar-I was 2195 ppm. Iron content in groundwater is also a big problem in South 24 Pargana. The concentration of iron in groundwater is ranged from 0 at few places to 6.15 ppm at Magrahat II and in Jayanagar is 3.96 ppm which is beyond the acceptable limit according to IS 10500:2012. The contour map of chloride, iron content and salinity in groundwater of that location is shown in **Figure 2**.



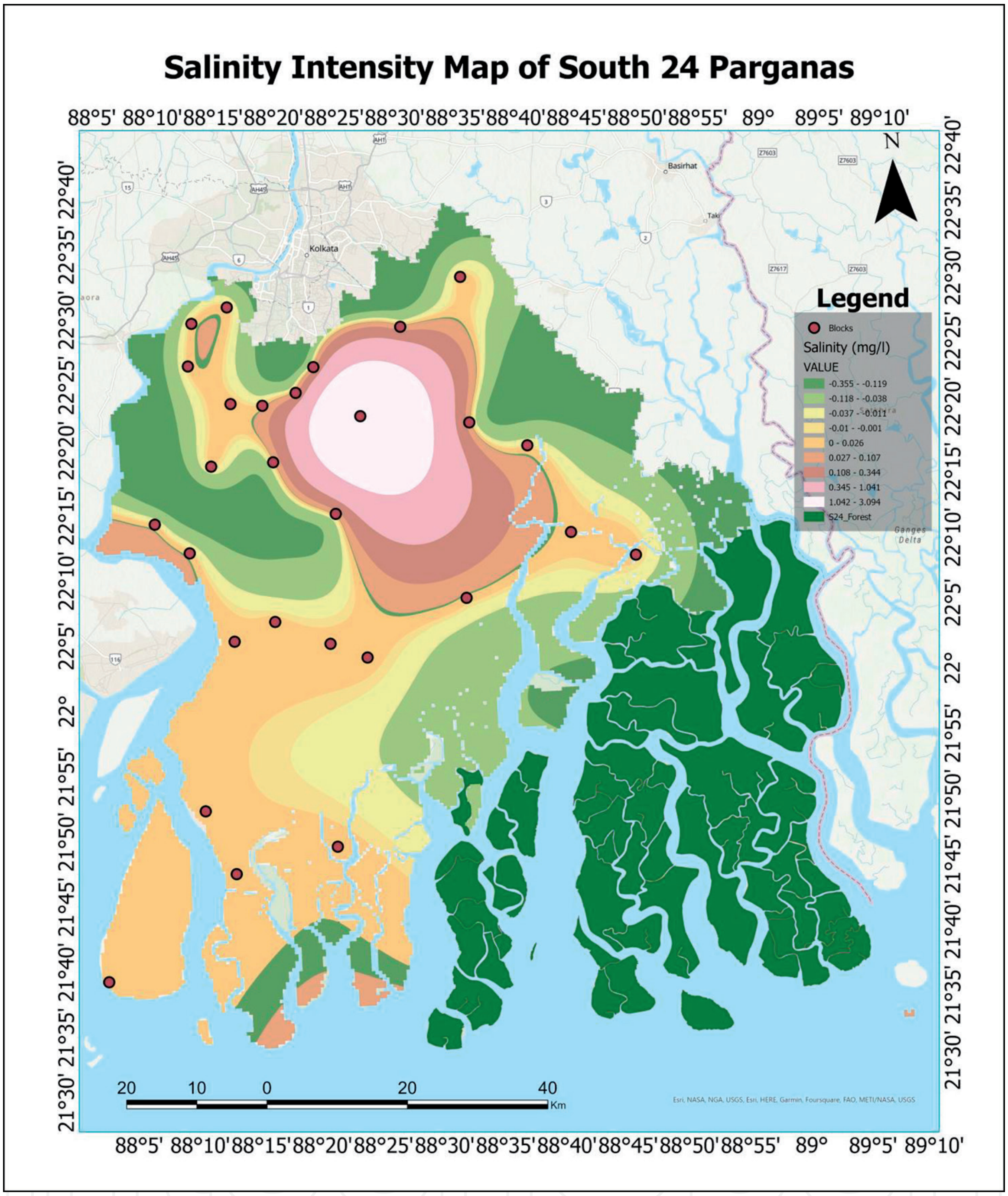


Figure 2.
Groundwater quality parameter's contour map in South 24 Parganas of West Bengal.

Similarly, arsenic contamination in Jayanagar was 0.05 mg/l. Water samples were taken from twenty-nine locations of South 24 Pargana. According to IS 10500:2012, the permissible value of salinity in drinking water should be within 1000 ppm and similarly, the permissible value of arsenic in drinking water should be less than 0.01 mg/l. By inspection of the above value, it is found Gosaba block in Jayanagar was both saline and arsenic affected. Surface water is also saline due to the geographical location of South 24 Pargana. So, Gosaba block in Jayanagar is water scarce area. Water samples were taken from twenty-nine locations of South 24 Pargana. According to IS 10500:2012, the permissible value of salinity and arsenic in drinking water should be within 1000 ppm and less than 0.01 mg/l respectively. After thorough investigation, it has been found that the Gosaba block in Jayanagar is water scarce area as the groundwater is both saline and arsenic affected and surface water is also saline due to the geographical location of South 24 Parganas. Moreover, according to Central Water Management Index, 2018 by NITI AAYOG, South 24 Parganas have been found as water scarce area with the ratio of total water to total population available less than 1000 per cubic meter per capita per year.

4. Estimation of runoff

There are different methods used for determination of runoff in a catchment. In the present study some tables and empirical formulae are used depending on availability of data to estimate the quantity of rainwater available for runoff in Gosaba block.

Binnie's coefficient method: According to this method, runoff and rainfall are correlated as $R = KP$, where P is precipitation in cm, R is runoff in cm and K is the runoff coefficient that changes with the landcover type (Usual values of K are given in **Table 1**).

Ingles and De Souza's formulae: According to Ingels and De Souza, runoff calculation based on rainfall can be done in two separate equations one for plains and the other for hills. The equations are –

For plains, $R = (P\text{-}17.8)\ P/254$; for hilly areas, $R = 0.85P\text{-}30.5$. The calculations are shown in **Table 2**.

Barlow's Table: T.G. Barlow divided the catchment into 5 different types named as A-E after many studies to estimate the percentage of runoff generated by them. The present study area comes under category A (Flat, cultivated, absorbent soil) and the coefficient of this type is 25 percent of the total rainfall. Thus, the equation stands $R = 0.25P$, and the calculation of availability of runoff according to this equation is given in **Table 3**. The seasonal variation of rainfall in Gosaba block of South 24 Parganas is shown in **Figure 3** (Source: IMD Kolkata [15]), that depicts that the area

Type of area	Values of K	Runoff generated by			Calculated average runoff R (cm)
		Normal rainfall in district (196 cm)	Rainfall in 2020 (191.8 cm)	Rainfall in Gosaba block according to CGWB (175 cm)	
Industrial and Commercial Area	0.90	176.40	172.62	157.50	168.84
Concrete or Asphalt Pavement	0.85	166.60	163.03	148.75	159.46
Urban Residential	0.3–0.5	78.40	76.72	70.0	75.04
Parks, Pastures and Farms	0.05–0.3	34.30	33.57	30.63	32.83
Forests area	0.05-0.2	24.50	23.98	21.88	23.45

Table 1.
Average availability of rainwater for runoff (mm) according to Binnie Values of runoff coefficient K (source: Ministry of Water Resources, GoI [13]); Rainfall Data (source: Meteorological Department, GoI [14]).

Land type	Runoff generated by			Calculated average runoff *R* (cm)
	Normal rainfall in district (196 cm)	Rainfall in 2020 (191.8 cm)	Rainfall in Gosaba block according to CGWB (175 cm)	
Hills	136.10	132.53	118.25	128.96
Plains	137.51	131.39	108.31	125.74

Table 2.
Average availability of rainwater for runoff (mm) according to Ingels and De Souza.

Land type	Runoff generated by			Calculated average runoff *R* (cm)
	Normal rainfall in district (196 cm)	Rainfall in 2020 (191.8 cm)	Rainfall in Gosaba block according to CGWB (175 cm)	
Total area	49	47.95	43.75	46.90

Table 3.
Average availability of rainwater for runoff (mm) according to Barlow.

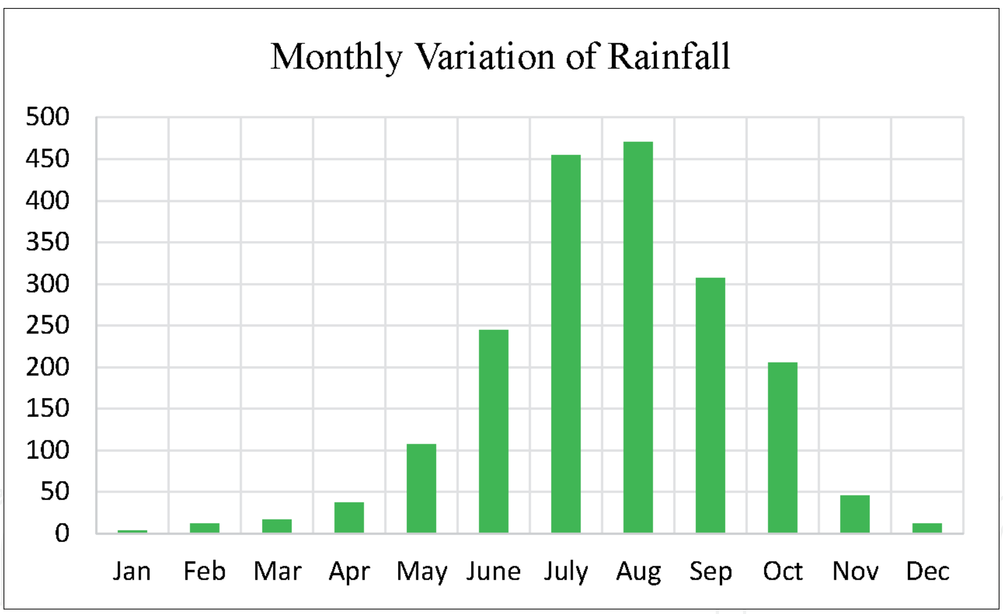


Figure 3.
Monthly variation of rainfall in Gosaba block of S 24 Parganas, WB.

receives maximum rainfall in the month of August and minimum rainfall in the month of January.

From the calculations, it is found that the area receives good quantity of runoff that can be harvested for future use. The runoff needs to be collected, stored and utilized to reduce water scarcity and reduce the overuse of groundwater. During the rainy season excess runoff should be stored for use in dry season. Different amount of runoff is generated by different types of terrain (hilly, plains) and different areas (forest, residential, farms etc.). So, design of RWH plant should be done based on the type of land. The present study area is in plain land, so the calculations and design are done with a normal rainfall of 196 cm.

5. Methodology

5.1 Design of RWH system

- RWH plant is provided at Gosaba R. R. Institute, Bharat Institute of Information Technology, PRITET computer training institute.
- According to IMD, Kolkata information, in 2020 the rainfall in South 24 Parganas was 196 cm. The roof area of Gosaba R.R. College is around 5000 m^2. The coefficient of runoff in this study is taken as 0.95.
- Water from the rooftop of the three institute buildings chosen is stored in the reservoir installed on the ground of dimension (16 m × 8 m × 3.95 m) with 15 cm thickness. The cost of each reservoir is Rs 10,925,400.
- From the rooftop, the water is conveyed through PVC pipe of diameter 75 cm and length 18 m. Specification of the main pipe is 8- inch diameter. The cost of the entire pipe is Rs 1,200,000. For enhancing pressure in low pressure region boost pumping station is also provided. 8-inch pipe is provided throughout the Gosaba block with two pipe branches on either side of the main pipe.
- Treatment units like 2 units of Rapid Sand Filter of length 12 m and width 6 m are provided. The size of gravel, sand used in the RSF are also calculated. The total cost of RSF is Rs 180,000.A rapid sand filter is installed before the reservoir to filter out solid particles in water.
- 3 centrifugal pump sets of 20 hp. with a delivery head of 8 km is provided. Cost of the pump is Rs 90,000 each resulting in a total cost of Rs 270,000.
- In the end, a sufficient chlorine dose is provided to keep the pH range between 6.5-8.5. Freshwater sources in the Gosaba location have been analyzed.
- Volume of rainwater collected in rooftop is calculated as ($V = A \times R \times C$), where R is the rainfall intensity, A is the roof area and C is the runoff coefficient. Considering three RWH plants are installed in the location, the total amount of water stored in a tank in the Gosaba location is calculated as 70 l/capita/day which is much more than the per capita demand of water.
- The total cost of the project serving fresh water to 10,000 people in Gosaba is Rs 35,057,000 which is justified.

The schematic representation of storing to the distribution of rainwater to the consumer has been given below in **Figure 4**.

5.2 Cost analysis of RWH system

The main objective of RWH is to decrease the usage of groundwater and provide both drinking water and non-potable water. The rain water usually contains various contaminants that has to be filtered and disinfected before being used for domestic purposes. Non potable usage of RWH includes gardening, washing and toilet purposes and so requires

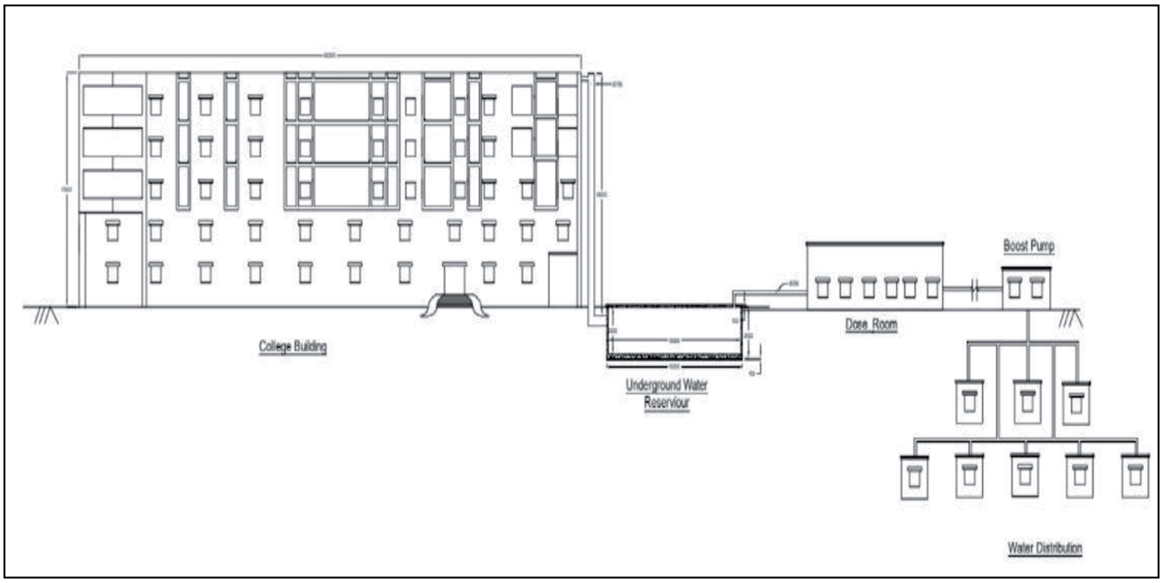


Figure 4.
Schematic diagram of rainwater harvesting scheme in Gosaba, South 24 Parganas.

no treatment. The physical, chemical and biological treatment of harvested rainwater is not required that makes the RWH system economical and cost effective [1]. The storage tank is the costly part of the entire RWH system, the cost analysis presented here consists of cost of materials and construction of storage tank at Gosaba R. R. Institute, Bharat Institute of Information Technology, PRITET computer training institute, South 24 Parganas.

The details of the quantity of materials used for construction of reservoir is given in **Tables 4** and 5.

Sl. No.	Particulars	No.	Length (m)	Breadth (m)	Height (m)	Quantity
1.	Excavations	1	16.30	8.30	3.50	473.51 m^3
2.	PCC (1:4:8)	1	16.30	8.30	0.15	20.29 m^3
3.	RCC (1:1:2)					
	(a) Top slab	1	16.6	8.6	0.15	21.41 m^3
	(b) Base slab		16.30	8.30	0.30	40.58 m^3
	(c) Vertical slab		48	0.30	3.50	50.4 m^3
	(d) Deduction for manhole		$\pi \times (0.25)^2$	–	0.15	$-0.0294 m^3$
						112.56 m^3
4.	20 mm thick plastering (1:2)	1				
	(a) Base	1	16	8	–	128 m^2
	(b) Sides	1	48	–	3	144 m^2
5.	% of steel	1	1/100 × 112.36	1.123 m^3	(1.123 × 7850)	8815.5 Kg

Considering pipe, pump and other ancillary costs total cost of the project is Rs 35,057,000 which is justified.

Table 4.
Details of quantity.

Sl. No.	Particulars	Quantity	Unit/Item rate	Amount (Rs)
1.	Cement	47.75 m^3	280 per bag	3,85,000
2.	Sand	57.3 m^3	58/m^3	3325
3.	Stone chips	105.2 m^3	68/cft	2,52,620
4.	Steel	8815.5	50/Kg	440,775
		Total amount		1,081,720
5.	Water charge	1% of total cost		108,172
	Total amount			1,092,538

Table 5.
Rate analysis of materials.

For concrete work,
Sand = (1/4 × 1.54 × 112.56) =43 m^3; Stone chips = 86 m^3.
For plastering,
Volume of wet mortar = (20/1000 × 272) = 5.44 m^3.
Dry volume of mortar = (5.44 × 1.3) = 7.07 m^3.
Cement = (7.07/3) = 2.35 m^3; Sand = 4.7 m^3.
For PCC work,
Cement = (20.29 × 1.54 × 1/13) = 2.40 m^3.
Sand = 9.6 m^3; Stone chips = 19.2 m^3.

6. Conclusion

The present study assessed the suitability of rainwater harvesting and its use in various domestic and irrigation sectors in a very remote area of West Bengal having scarcity of good quality of water. Gosaba block of West Bengal is a very much water scarce area, as the groundwater in the location is contaminated with saltwater and arsenic. Therefore, there is scarcity of freshwater required for domestic works, irrigation and drinking purposes. In order to get rid of the problem and to maintain the GWT, an alternative method of harvesting rainwater is adopted for the present study. Rainwater harvesting is defined as the method of supplying fresh water in salinity and arsenic affected coastal areas of West Bengal. The availability of rainfall as runoff is estimated based on different empirical equations. The area received maximum rainfall in July–August of 2020 with a normal rainfall of 196 cm. To augment the supply of water to the ten thousand people in the study area, three institutional buildings are chosen. Water is collected at the roof catchment area of those institutional buildings. Through pipe and valve surplus, rainwater is conveyed to the rapid sand filter which is composed of sand, gravel and further carried to the reservoir to store and supply water throughout the year. Before distributing the water, chlorination is applied. By proper grid system and arrangement of boost, station water is supplied to every consumer at an affordable cost of installation of rainwater harvesting system. The tank has storing capacity of 70 l/capita/day of water ad total cost of project is just Rs 35,057,000 which is reasonable. It was also found that the quantity of stored and harvested rainwater could be used throughout the year and not only in rainy season.

Abbreviation

- Ar: Arsenic
- CGWB: Central Ground Water Board
- Cl: Chloride
- Fe: Ferrite
- GWT: Ground Water Table
- IMD: Indian Meteorological Department
- PVC: Poly Vinyl Chloride
- RWH: Rainwater Harvesting

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