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Assessment of water demand and potential water sources to face future water scarcity of hilly regions

Kannan V.[a,*], Raja Priya P.[b], Tharkeshwari K.[c], Bineta Mazumder[c], Gayatri P.[c] and Jackline Neha[c]

[a] Department of Civil Engineering, National Engineering College, K.R. Nagar, Kovilpatti, Tamilnadu State 628503, India
[b] Department of Civil Engineering, Francis Xavier Engineering College, Tirunelveli, Tamilnadu State 627003, India
[c] Dr B.R. Ambedkar Institute of Technology, Port Blair, Andaman and Nicobar Islands 744103, India
*Corresponding author. E-mail: kannanvpandian@gmail.com

KV, 0000-0002-4104-1269

ABSTRACT

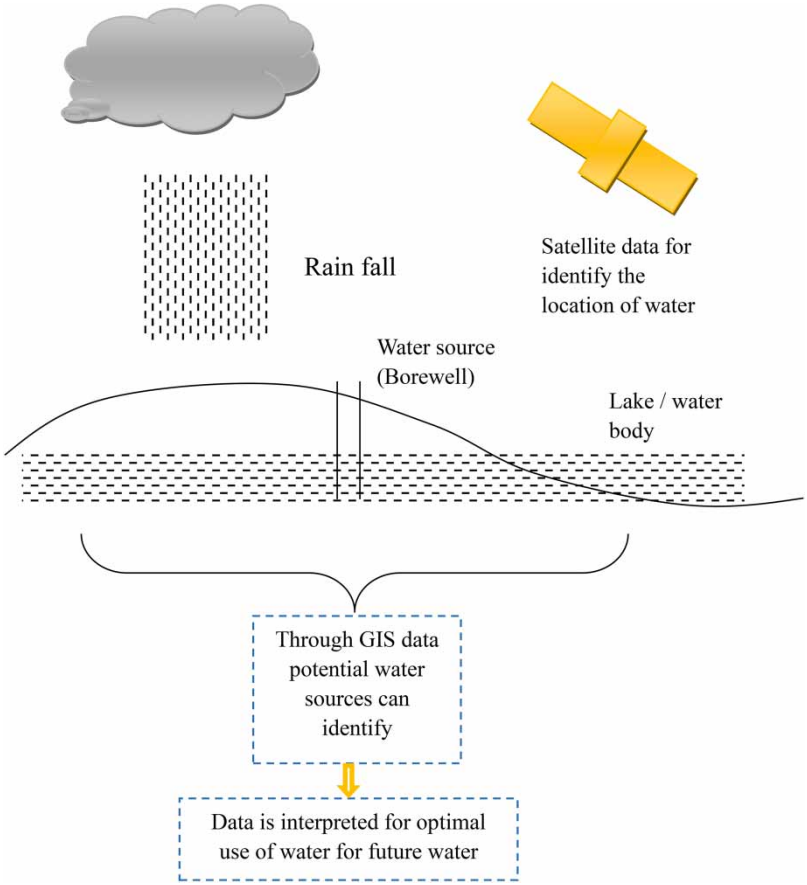
In this work, an attempt is made to predict the future water demand of a hilly region. The study area is selected based on the population and the water demand. For this work, Namunaghar and Wandoor Panchayats of Andaman and Nicobar Islands are selected. Initially, preliminary studies such as the current population and future growth and their water demand were analyzed. Also, using a geographical information system (GIS), the study area is located to identify the surface and groundwater sources. From the GIS data, a detailed map is prepared to conduct the physical verification and collect the water quality measurement. From the population forecast, it was identified that 435,000 and 480,300 l of water are required to meet the water demand in the year 2031 in Namunaghar and Wander Panchayat, respectively. It also assessed the GIS data and found out potential water sources of 157 (67 wells, 58 ponds, and other minor sources) and 485 (215 wells, 229 ponds, and other minor sources) at Namunaghar and Wandoor Panchayats, respectively. Finally, all the potential water sources were checked for quality for drinking purposes.

Key words: climate change, GIS, groundwater, remote sensing, water demand, water scarcity

HIGHLIGHTS

- Surface water and groundwater sources can be identified.
- A geographical information system (GIS) can be adapted to locate the water sources in the study area.
- Identifying probable and potential water sources and suggesting strategic water harvesting methods as per hydro-geological data.
- The potential water sources are identified.
- The data are interpreted for optimal use of water for future water demand.

GRAPHICAL ABSTRACT



INTRODUCTION

The prediction of water demand for household consumption is very much required to tackle water scarcity. Especially this kind of prediction is essential in the case of hilly regions and islands where rain is a primary source and is retained for public purposes. Even though the annual precipitation is high in Andaman and Nicobar Islands, nearly 75–80% of the water is lost due to runoff and mixed with seawater. This may lead to water scarcity in the future. For that reason, in this work, a detailed study is planned to predict the future population and the requirements for water to meet the public demand. The whole study is conducted on Namunaghar and Wandoor gram panchayats of Andaman and Nicobar Islands. The islands have a width of 15–40 km from east to west, and the slopes are from center to either east or west due to which the length of the drainage line to the sea is short. Because of this, there is only one perennial river Kalpong on North Andaman Island. Thus, the actual water availability is much less and islands face a severe problem of water scarcity even for drinking water. To make both the panchayats (Namunaghar and Wandoor Panchayats) independent of their water requirements by developing their own potential water sources is the main objective of this work, for which the study of both areas is necessary.

Water is feasibly the most valuable natural resource after the air. Though the surface of the earth consists mainly of water, only a small part of it is usable, which makes this resource limited (Gain & Wada 2014). This precious and limited resource, therefore, must be used with care. As water is required for different purposes, its suitability must be checked before use. Also, sources of water must be monitored regularly to determine whether they are in sound health or not. The poor condition of water bodies is not only an indicator of environmental degradation, but also a threat to the ecosystem (Hoglund 1999; Homer 2012). In industries, improper quality of water may cause hazards and severe economic loss. Thus, the quality of water is very important from both environmental and economic aspects (Leigh & Lee 2019). Water quality analysis is therefore essential for any type of use (Lindqvist *et al.* 2021). After years of research, water quality analysis is now carried out using some standard protocols. There are guidelines for sampling, preservation, and analysis of the samples.

Namunaghar is a small village of 263.24 ha in Ferrargunj Tehsil in the South Andaman district in the Union territory of Andaman and Nicobar Islands, India. The village is administrated by a sarpanch, a locally elected representative of the village. Namunaghar depends on Port Blair, the nearest town for all major economic activities. The village has government-provided water facilities that include one tap, one well supply, one tank, two tube wells, and two handpumps (Fabre et al. 2015). The villagers also acquire water from some of the natural water sources – two rivers, two canals, and two springs. Namunaghar is also surrounded by two lakes. The population of the village depends on the source of drinking water during summer on tap. They depend on the agricultural markets (Mandi) of the nearby towns of Port Blair and South Andaman to sell, and make their living.

Wandoor is a village with an area of 1,315.79 ha also coming under Ferrargunj Tehsil in the South Andaman district in the union territory of Andaman and Nicobar Islands. This place is famous for its beautiful beach and scenic beauty and is very popular among tourists. The management and use of existing and potential water sources is a topic of critical importance. As the demand for available supplies increases, the problems of water allocation and distribution will increase, and hard decisions with regard to societal utilization will be needed (Gain & Wada 2014). Also, the population is increasing which means the need for water is also increasing, so it is necessary to identify the probable sources and their augmentation so that the people of the area can use the water and water scarcity can be reduced.

Population forecasting is used to determine the expected population for a particular design period of a water supply system with the help of the study and analysis of future events and available records (Darvini & Memmola 2020). The population is an important parameter that is determined for the design of the water system of a particular area. The design population is estimated due to all factors governing the future growth and development of the work area in the industrial, commercial, educational, social, and administrative spheres. The growth of the population in the study area for the future and the design for water storage will be based on the population at the end of the design periods (Di Baldassarre *et al.* 2019).

Factors affecting changes in population are increase due to births, decrease due to deaths, increase/decrease due to migration, increase due to annexation, change (in education, politics, recreation, and economic), increase in facilities of the transport system, and sudden increase in religious importance of the villages (Yang 2013). The current and previous years' population records for the study area can be retrieved from the CENSUS (a usually complete enumeration of a population) population data of the local government. The future population growth and water demand can be obtained from the suitable numerical method for the selected study area.

Population forecasting is important since it helps people, i.e., government, and researchers to make decisions about the future (Dimkić 2020; Rusli *et al.* 2021). It helps in estimating the basic needs of humans, such as the demand for food, water, power, and transportation (Gohari *et al.* 2013). Precise calculation of population contributes to various aspects of providing facilities to the public. In civil engineering, many structures like sewage treatment plants, water treatment plants, sizes of reservoirs, and storage tanks are dependent upon the future population of the area for a specific design period (Walmsly & Pearce 2010; Garg 2016). Therefore, one needs to figure out accurately the population of the desired span of years. The report has been prepared to compare the various population forecasting methods.

Since very early times man has obtained water from surface sources such as rivers, lakes, etc., as well as from subsurface or groundwater sources such as springs, wells, etc. Due to the relatively lower requirement for water in the early times, this was mainly for domestic purposes; these sources were deemed to be sufficient to meet the requirements of the persons residing in the nearby areas (Ahopelto *et al.* 2019). Further water was directly procured from these sources as per requirements, and there was no public water supply system (Brown et al. 2011). However, with the growth of the population, the demand for water also increased which led to the development of new sources of water, construction of conduits and aqueducts for the conveyance of water from a distance and subsequent storage to be ultimately distributed to the inhabitants through a pipe system (Bessah *et al.* 2020). Where the source of water happened to be situated at a level lower than that of the areas to be served, it became necessary to lift water by the installation of pumps, which was therefore the next step in the development of the public water supply system, for which water demand analysis needed to be done (Daigger & Crawford 2007).

Locating point using NOTECAM

NOTECAM is a camera app combined with GPS information (including latitude, longitude, altitude, and accuracy). It can leave a message and put all information together into a photograph. This application has been used to collect spatial data about water resources available in Panchayat.

Creating a GIS map of water resources

The Geographical Information System (GIS) is a computer system for capturing, storing, checking, and displaying data related to the position of the earth's surface. Due to the rapid population growth and the associated water demand, the value of the GIS as an environmental analysis tool is ever-increasing (Elias 2012). The capability of the GIS to display geo-referenced data layers quickly and accurately makes it an essential tool for water resource planning and management. The relative spatial data (latitude, longitude) and non-spatial data (type of source, location details, purpose, perennial, and non-perennial) of surface and groundwater sources from Namunaghar and Wandoor Panchayats were collected, and then these data are attached to the spatial data in the base map using the GIS. Then, the base map of the given area is geo-referenced with respect to the latitude and longitude (Fabre *et al.* 2015).

Groundwater is a precious resource around the globe and is reducing in quantity day by day. For that reason, there is a requirement for the differentiation of the potential groundwater zone (Fernald *et al.* 2012). The GIS and remote sensing technology have become important strategies to locate groundwater latent zones (Clarke 1986; Fu and Sun 2010).

Contouring in the GIS

Contours are the lines that connect the location of equal value in a raster data set that represents continuous phenomena such as elevation temperature, etc. The line features connect cells of a constant value in the input. The contour line distribution shows how values change on a surface. When there is a little space in a value, the rows are spaced more apart. When values increase or decrease quickly, rows are closer together. By following a polyline of a specific outline, we can identify which location has the same value. Contours are also a useful surface representation because they allow us to simultaneously visualize the surface topology, i.e., flat and steep areas (distance between contours) and ridges and valleys (converging and diverging polylines). Digital elevation models (DEMs) are geospatial datasets that contain elevation values that are used in the GIS to create contour maps.

From the above study, it is planned to assess the population growth in 2031, 2041, and 2051, and the water requirements to meet the demand. In this work, a GIS image is used to crop the potential sources of water which is identified and segregated as groundwater source, pond, stream, pit, well, etc.; it is also planned to take a site visit to know the exact condition of GIS-based water sources and availability of the water at different seasons. And finally, all the potential sources are examined for discharge level and the quality of the water to assess water requirements to meet future demand.

RESULTS AND DISCUSSION

The population details of people residing in Namunaghar and Wandoor Panchayats were collected from the CENSUS department in Port Blair. Also, the population data as of 2020 were collected from the panchayat. The details of the population according to the census department (from 1961 to 2011) and respective panchayat are represented in Figure 1. The current population for the study area is reported in Table 1. In this work, three methods, the Arithmetical Increase Method, Geometrical Increase Method, and Incremental Increase Method (Ahlburg 1992) were used for effective calculation of the population in the future (see Table 1).

Water demand calculation

Water is a scarce and limited resource. Water scarcity is a growing problem in the study areas of Namunaghar, and Wandoor, and is likely to only get worse because of climate change. With the growing population and growing wealth in the area, increasing pressures are placed on water reserves. In such rural areas, population pressure, agriculture, and emerging tourism activities all combine to increase the stress on the water supply.

The main reason for the growth in demand for water is population growth. Unfortunately, these regions are also the regions with the greatest water shortage. With a growing population comes a growing demand for water from the three main sectors of agriculture and industry.

Plotting the water sources

To know the details and location of available water resources in the study area, mapping of different types of water resources such as wells, bore water sources, streams, rivers, etc., has been done using GIS software.

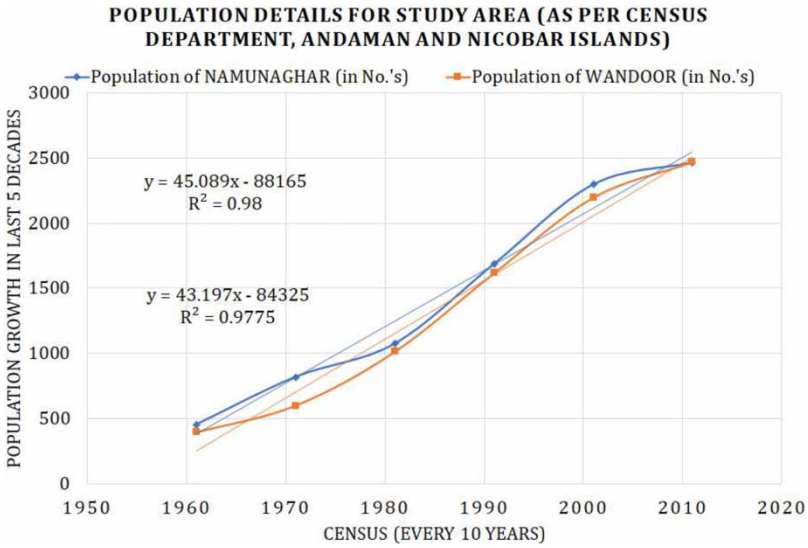


Figure 1 | Population details.

Table 1 | Population details collected from panchayat (2020)

Namunaghar Panchayat		Wandoor Panchayat	
No. of males	**No. of females**	**No. of males**	**No. of females**
1,546	1,494	1,684	1,547
Total population = 3,040		Total population = 3,231	

Collection of base map

A base map was collected from Andaman Public Work Department (APWD), Port Blair office from the town planning section (see Figure 2(a) and 2(b)) which gives an overall view of Namunaghar and Wandoor Panchayats. With these maps, a field survey was conducted. The field survey is all about the collection of information from the study area. To obtain sufficient information from the area, different data collection tools were used which are questionnaires and interviews conducted with local people residing in the study area with personal observation. Questionnaires were the major tools for the collection of available water resources and their respective details for the study. The field survey involves data such as type of water resource (natural/manmade), e.g., well, pond, stream, etc., owner of the water source, i.e., personal/public, latitude and longitude, and purpose of the water source.

Plotting the water sources

In order to know the exact location of water sources the mapping was done using GIS software (McCollum et al. 2020). Also, the details collected during the field survey were plotted in the GIS software to prepare a GIS map. The details of GIS mapping of water sources and potable water sources for the Namunaghar and Wandoor area are shown in Figure 3(a) and 3(b). From the GIS map, it can be noted that the potable water sources for the study area are smaller than the water sources. For the detailed study, the contouring details were prepared to understand the geographical undulation and its gradients, helping will help to connect the water sources from one point to another point for enhancing the yield of the water and to decrease future water demand. The contour for the study area is shown in Figure 4.

Discharge

Weirs are typically installed in open channels such as streams to determine discharge (flow rate). The basic principle of the discharge is directly related to the water depth above the crotch (bottom) of the V; this discharge is called head (h). The

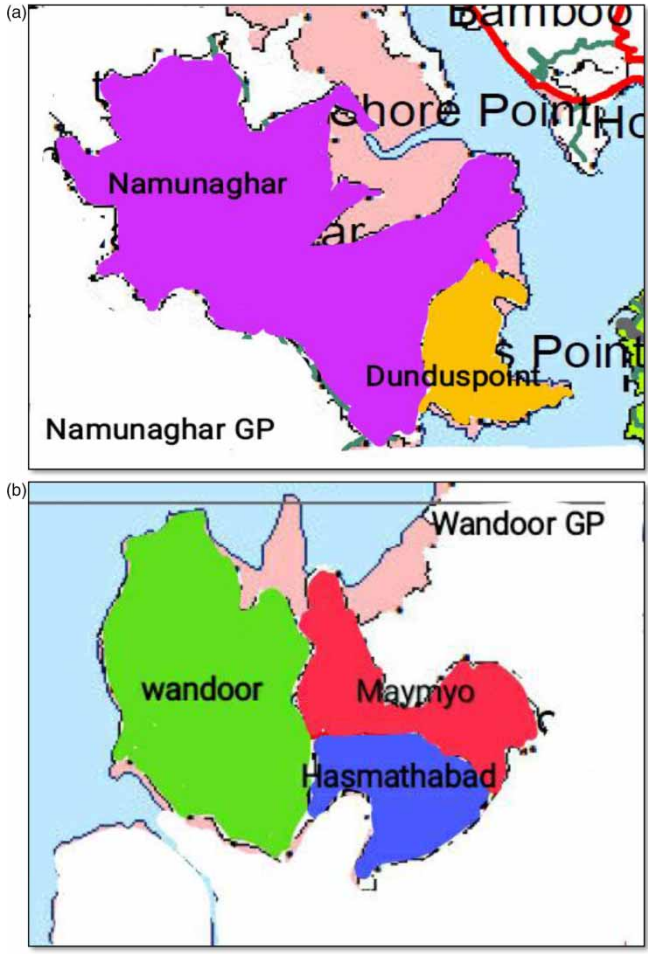


Figure 2 | GIS map for study area of (a) Namunaghar Panchayat and (b) Wandoor Panchayat.

V-notch design causes small changes in discharge to have a large change in depth allowing more accurate head measurement than with a rectangular weir (see Figure 5). In this work, we preferred a triangular notch or V-notch. The overflow is measured using a meter scale up to the bed.

A V-notch weir is a sharp-crested weir that has a V-shaped opening instead of a rectangular-shaped opening. These weirs, also called triangular weirs, are typically used instead of rectangular weirs under low–flow conditions, where rectangular weirs tend to be less accurate.

$$Q = \frac{8}{15}\, cd \sqrt{2g \tan\left(\frac{\boldsymbol{\theta}}{2}\right) H^{5/2}} \tag{1}$$

where **cd** is the coefficient of discharge, **g** is the gravitational acceleration (m/s^2), $\boldsymbol{\theta}$ is the angle of *V* shape (°), **H** is the water elevation over the crest of weir (m)

For performing the test in the laboratory, a water sample is collected on a gallon. Various physical and chemical parameters were tested.

The remedial measure that can be given to overcome the water scarcity in the area is a 'spring box'. The purpose of this work is to present a detailed briefing of a spring box with its structure plan and estimation. This structure is proposed upon a spring at Namunaghar; springs occur where the natural flow of groundwater emerges at the earth's surface, usually at hillsides or low-lying areas. The water that flows from springs is usually safe from contaminants, due to the fact that

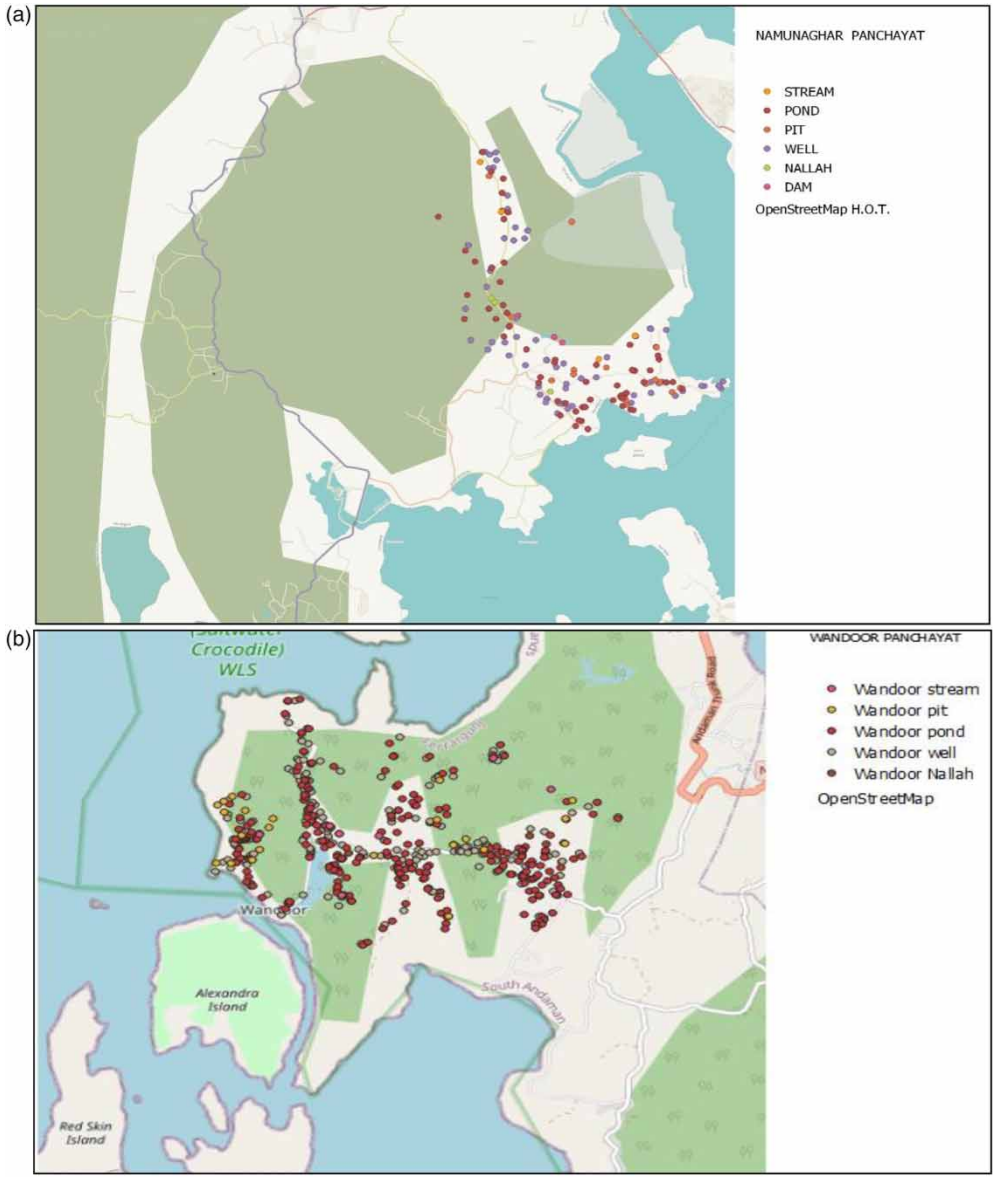


Figure 3 | GIS maps of (a) Namunaghar water source and (b) Wandoor water source.

groundwater is naturally filtered as it flows through the earth. Therefore, spring water is generally safe for human consumption, requiring little to no treatment. This makes springs a relatively inexpensive, yet safe water source. The source is at a hill shade so the spring box constructed at the source will be connected with another storage tank at a lower level to store the water. Figure 6 shows the potential water source for the Namunaghar area.

Spring boxes the spring water from contamination by surface runoff and contact with humans and animals. They also provide a permanent point of collection. But their most main advantage is their storage of water. If a spring has a low flow, it might still be sufficient for the needs of a community if allowed to accumulate over the course of a night and other time periods when not in use. This allows a spring to serve many more people than it otherwise could. Yet another advantage is that spring boxes may also act as settling basins, to assist in the removal of suspended sediment from the water. This is a distinct health advantage because bacteria and other organisms that cause harmful effects are generally attached to soil particles in the water.

For this work, there are some observations that are drawn at different time intervals in the process of completion of the work. Population forecasting is being done using the data that were available from the respective

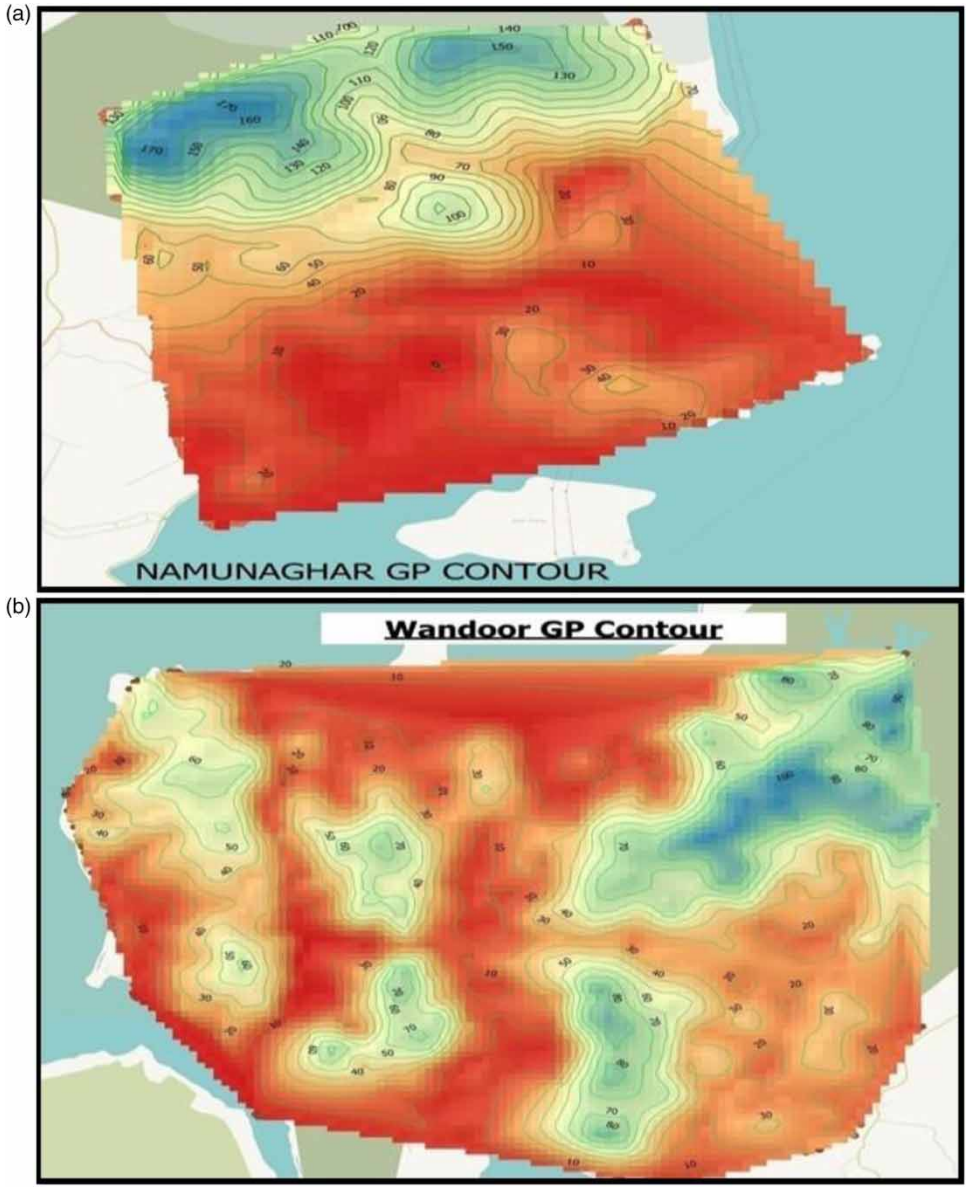


Figure 4 | Contour maps of (a) Namunaghar and (b) Wandoor.

departments, and the future water demand is also worked on the basis of population forecasting. From the field survey, the details required for mapping the sources have been done. The quantitative and qualitative analysis of probable water sources was carried out. Estimation of the suggested structure was done for the augmentation of probable water.

Using the CENSUS data, the worked population obtained using different methods is given in Figures 7–10.

The brief detail collected from the field survey of different panchayats with a total number of sources obtained is given in Tables 2 and 3.

Discharge of probable source

The discharge of the probable water source was found by a triangular notch (V-notch). The calculation of the discharge of the stream is given below:

Figure 5 | Discharge determination using V-notch.

Figure 6 | Potential source (Namunaghar Panchayat).

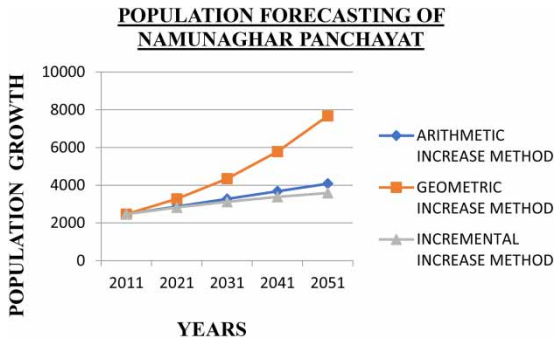


Figure 7 | Graphical representation of the worked population using different methods of the Namunaghar Panchayat.

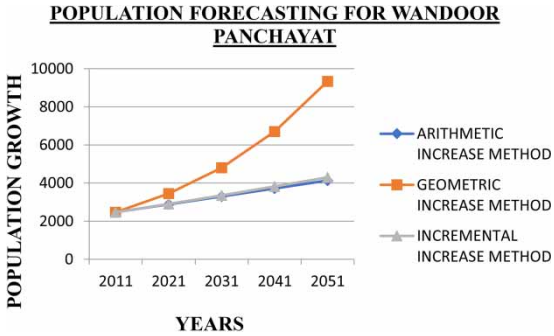


Figure 8 | Graphical representation of the worked population using different methods of the Wandoor Panchayat. Per day water supply in the Namunaghar Panchayat = 2 lakh l/day; per head = 100 lpcd.

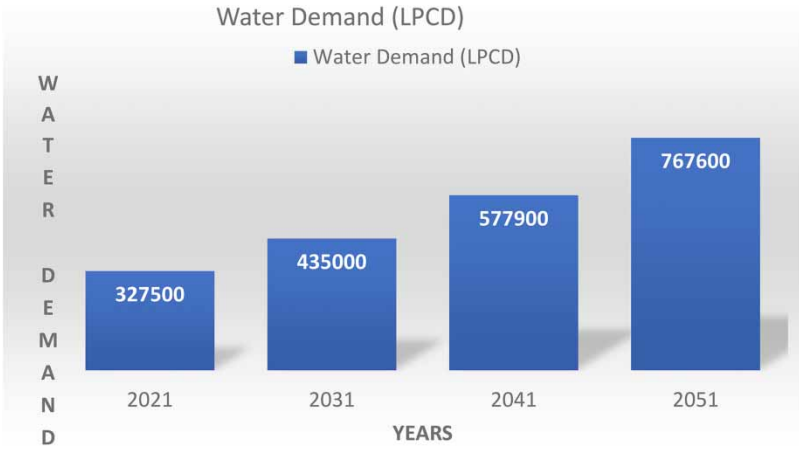


Figure 9 | Water demand in the Namunaghar Panchayat. Per day water supply in the Wandoor Panchayat = 1.3 lakhs l/day; per head = 100 lpcd.

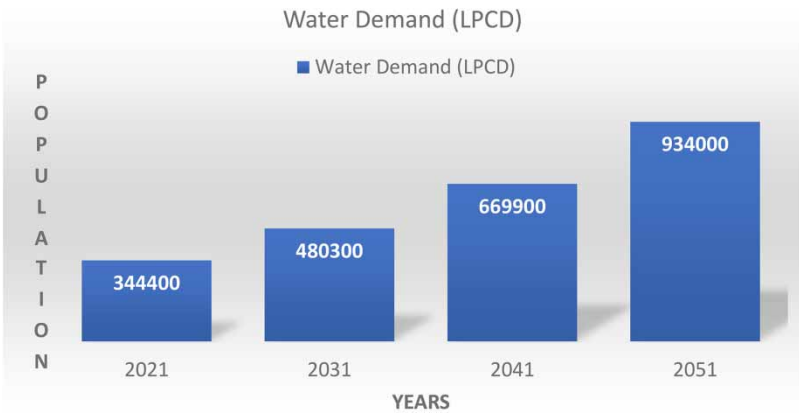


Figure 10 | Water demand in the Wandoor Panchayat.

- Actual discharge: $T_1 = 3.04_S$; $T_2 = 3.37_S$; $T_3 = 2.89_S$

$$\text{Average time} = \frac{T_1 + T_2 + T_3}{3}$$
$$= \frac{3.04 + 3.37 + 2.89}{3}$$
$$= 3.1\text{s}$$

Table 2 | Total water sources

Panchayat	Village	Types of sources						Total sources
		Pond	Well	Stream	Nallah	Check dam	PIT	
Namunaghar	Namunaghar	43	49	3	4	3	11	157
	Dunduspoint	15	18	1	1	1	8	
Wandoor	Wandoor ward 1	28	16	1	1	–	1	485
	Wandoor ward 2	22	39	3	–	–	2	
	Wandoor ward 3	32	39	1	1	–	12	
	Wandoor ward 4	15	22	–	–	–	–	
	Maymyo	55	39	1	4	–	7	
	Hasmathabad 1	20	15	–	–	–	–	
	Hasmathabad 2	47	34	–	3	–	1	
	Lohabarrick	10	11	1	–	–	2	

Table 3 | Details of probable sources

Village	Ward no.	Types of source	Nearest Landmark	Latitude	Longitude	Purpose	Remarks
Namunaghar	1	Stream 1	Near Adkal Raj (Laxmi Nagar)	11.700622	92.677319	Drinking and Domestic	Perennial
Dunduspoint	1	Well 1	Near harbor	11.671346	92.707574	No use	Perennial
Wandoor	2	Stream 3	Near Vijay Meshak House	11.599647	92.62808	No use	Perennial
Wandoor	Maymyo	Stream 1	Near Lorean Kerketta House	11.606587	92.649004	Drinking	Perennial

- Volume = 250 ml

$$Q_{actual} = V/T$$
$$= 2.50/3.1$$
$$Q_{actual} = 80.64\,\text{cm}^3/\text{s}$$

- Theoretical discharge

Head = 4.8 cm

$$Q = 8/15\ cd\sqrt{2}g\tan\left(\frac{\theta}{2}\right)5/H2$$
$$Q = 0.6 \times (4.8)^{5/2} \times \sqrt{2} \times 9.81 \times \tan\left(\frac{90}{2}\right)$$
$$Q = 71.54\,\text{cm}^3/\text{s}$$

Discharge obtained for a probable water source is found to be:

- Actual discharge = 80.64 cm^3/s = 6,967.296 l/day
- Theoretical discharge = 71.54 cm^3/s = 6,181 l/day

Qualitative analysis of probable source

To check the suitability, a qualitative analysis of the probable water source which is located in the Namunaghar Panchayat ward 1 was done. The parameters which were checked are physical and chemical. The sample from the probable source analyzed for drinking water quality parameters was found to be within Indian Standard Code and World Health Organization (WHO) guidelines, except turbidity and total suspended solids (see Table 4).

However, turbidity and total suspended solids values are nearer to the permissible limit. Similarly, all the samples from various spot are analyzed and found suitable for drinking purposes in the future.

Table 4 | Physical and chemical parameter test results of probable water source

SNO	Parameter	Results	Unit
1	PH	6.5	–
2	Turbidity	8.6	NTU
3	Chloride	20.99	mg/l
4	Hardness	40	mg/l
5	DO	6.69	mg/l
6	BOD	1.07	mg/l
7	COD	111.46	mg/l
8	TS	592	mg/l
9	TSS	402.4	mg/l
10	TDS	116	mg/l

CONCLUSIONS

From the detailed study in the study area, the following conclusions may be drawn:

- In the Namunaghar Panchayat, a total of 157 water sources were identified from which only two sources were found to be perennial, and 485 sources were identified in the Wandoor Panchayat from which two water sources were found to be perennial.
- The result of water testing will be helpful for further water distribution planning and advancement in the planning for effective water sources.
- The average ranges of water quality are considered as per the IS drinking water specification. All the quality parameters are found to be within the permissible limit in the sample. After qualitative analysis of the sample, it is found that the sample water is turbid and has some suspended solids in it. With some filtration treatment, it will be feasible for drinking and other purposes.
- This report can be useful in providing information related to the water sources of Namunaghar and Wandoor areas that can be helpful in managing the water requirement of the area.
- If the water sources are being properly utilized and maintained, then they can satisfy the water demand but the present available water cannot fulfil the water demand of the area.

FUTURE DIRECTION

- The suggested structure for the probable source located at the Namunaghar Panchayat is a ‘spring box’ which will be connected to a storage tank that will be placed at a lower level to store water. This structure is selected based on the study of quantitative analysis of water sources and qualitative analysis of sample water.
- Public wells located in the study area need to be maintained frequently, because of the formation of algae inside the wells, water gets contaminated which leads to a bad odor, even some wells are found to be in a damaged condition due to which people are not able to access the water.
- The areas we were allotted are interspersed with periods of intense rainfall. Therefore, to maximize the available water through rainwater harvesting and conservation, some techniques are being suggested keeping in observation the climate, agricultural need, and geography of the area.
- Some water harvesting techniques based on the contours of the study area are contour furrows, stone lines, and grass strips. The technique used depends on the steepness of the slope, soil type, conditions, and crops grown.

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AUTHORS CONTRIBUTIONS

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by T.K., B.M., P.G., and J.N. The first draft of the manuscript was written by K.V. and P.R.P., and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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