Centre for Research on Settlements and Urbanism

Journal of Settlements and Spatial Planning

Journal homepage: http://jssp.reviste.ubbcluj.ro/eng/index.html

Assessment of Domestic Water Resources for Sustainable Utilization Using Geospatial Techniques. The Case of Pune City, India

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DOI: 10.24193/JSSP.2023.2.01 https://doi.org/10.24193/JSSP.2023.2.01

K e y w o r d s: *sustainable, urban development, water resources, water supply, water demand, water scarcity*

A B S T R A C T

Water resources have played a crucial role in the growth and development of human civilisation. Increasing demands of water resources to meet the needs of growing population have led to tremendous pressure on water resources. Water resources conservation and management need relevant information regarding the quality and quantity of water bodies, as well as the related driving factors responsible for the deterioration and depletion of water resources. In literature, conventional methods are limited to point locations that have sparse datasets. However, with the advent of geospatial techniques, it has become very easy to explore digital information that can quickly support extensive data analysis and interpretation on a larger scale. The aim of this study is to assess water resources such as water supply, distribution and coverage using geospatial techniques, and also to identify the water stress zones whilst forecasting the water demand in the future, which is indispensable for sustainable urban planning. The results show that water supply and duration per capita are unequal in the study area. The water demand of Pune city has continuously increased from 508 MLD in 2001 to 857 MLD in 2022, and will maintain this trend up to 1421 MLD by 2031. The composite water stress map indicates that Ghole Road, Nagar Road, Dhankawadi and Hadapsar wards have a high level of water stress, whereas Sangamwadi, Kothrud, Dhole Patil Road, Bhawani Peth, Kasba Vishrambagh and Sahakranagar experience low water stress. The values of water scarcity index in the study area have significantly changed, *i.e.*, from 0.68 in 2001, to 0.54 in 2011 and to 0.64 in 2022, which indicates that Pune city falls into the serious water shortage category. This index is expected to be around 1.05 in 2031, demonstrating that Pune will be subjected to major water deficiency, a condition which is clearly reflected in the composite water stress map.

1. INTRODUCTION

Water is the most essential renewable natural resource on the planet and plays a major role in a country's socio-economic development. Primarily, water is used for drinking and domestic purposes as well as for irrigation (PMC, 2012). Thus, the development of any nation depends on water availability and access. Water resources are available from three primary sources, namely precipitation, surface water and groundwater, which in turn play an essential role in water supply (Bhat, 2014).

The United Nations proposed 17 Sustainable Development Goals (SDGs) for 2030. As such, the sixth

SDG focuses on achieving universal and equitable access to safe and affordable drinking water for all (Tholiya et al., 2022). Adequate supplies of safe drinking water have been universally accepted as essential for human life. However, millions of people in developing countries do not have ready access to adequate and safe water resources (Abebe and Singh, 2012). Although 71% of the earth's surface is covered by water, only 2.5 % of the total available water is fresh and suitable for human consumption (Postel et al., 1996).

In India, the agricultural sector's water resource usage nearly accounts for 428 km^3 (about 69% of total water use), with 300 km^3 from surface resources and 128 km^3 from groundwater resources. Domestic water requirements are of about 25 km^3, whereas industrial usage is of approximately 15 km^3. These values are expected to increase up to 90 km^3 and, correspondingly, up to 103 km^3 by 2050 (Kumar et al., 2005).

Countries have an average utilization of water resources of 1700 m^3/ capita/ year and more have a low risk of scarcity as per the standard norms. If per capita water availability is less than 1700 m^3/year, then the country can be categorised as a water-stressed territory. If it is less than 1000 m^3/capita/year, the country can be classified as water-scarce territory; those with less than 500 m^3 are considered primary water constraints (Damkjaer and Taylor, 2017). The average annual per capita water availability in India was of 1545 m^3 in 2011 and of 1486 m^3 in 2021 (Chaudhari et al., 2022). These values are estimated to be further reduced to 1367 m^3 and 1191 m^3 in 2031 and, respectively, 2050. As a result, India falls in the water-stressed category of areas. India receives nearly 4% of the global precipitation and ranks 133rd globally in water availability *per* person *per annum* (Jaiswal, 2017).

Rapid population growth and urbanisation have increased water demands for domestic, industrial and agricultural needs (Kumar, 2018). Thus, we are facing numerous challenges in the water sector, including reduced water availability per capita and declining groundwater table in many areas (Singh and Singh, 2002). According to the report on groundwater levels elaborated by NITI (2019), some 21 Indian cities will run out of groundwater by 2020. These include Delhi, Bengaluru, Chennai, Hyderabad and others, affecting around 100 million people. It is estimated that approximately one-third of our population will suffer from chronic water shortages twenty years from now. According to previous research, only a few countries faced water scarcity in the 1950s. However, by the end of the twenty-first century, more than 300 million people will face water scarcity worldwide (Seckler et al., 1999), thus a stringent matter in the country. Pune, the cultural capital of Maharashtra State, is experiencing the same problems (Tholiya et al., 2022). The available water resources in the city are low and further aggravated because of its high population growth (Zhou et al., 2000). Therefore, the present research work focuses on the water resources assessment of various dimensions, the main items to be considered referring to water supply, distribution and coverage in the city. In addition, another important aim is to identify water stress zones as well as to predict future water consumption, which is an essential part of sustainable urban environment planning.

2. STUDY AREA

Pune is located in Bhima River basin along the banks of Mula - Mutha River (Mundhe and Jaybhaye, 2017). It is above 560m mean sea level (MSL) on the eastern flanks of Sahyadri hills (Fig. 1).

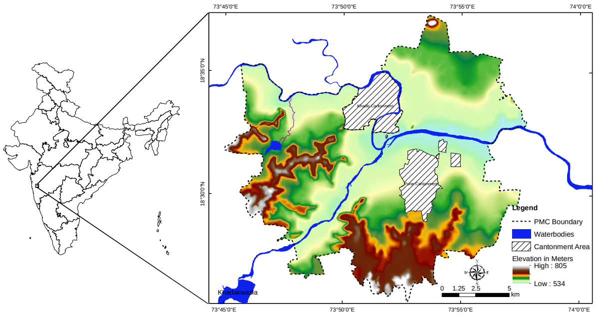
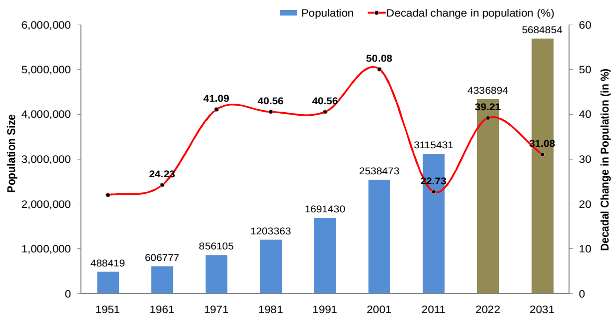


Fig. 1. Location of the study area *(source: U.S. Geological Survey 2020).*

Geographically, it extents between 18°25'N and 18°37'N latitude to 73°44'E and 73°75'E longitudes (Mundhe and Jaybhaye, 2015). The total geographical area of Pune city is of 250.56 km^2, with a population size of over 3.1 million (PMC, 2021).

In the last sixty years, the population of the city has increased more than six times, from 0.48 million in 1951 to 3.11 million in 2011 (Census of India, 2011). As per exponential population growth projection, this will be enhanced to 4.3 million in 2022 (Fig. 2).



Note: Estimated change in the years 2022 and 2031 considering exponential population method.

Fig. 2. Population increase and decadal change of Pune city *(source: Census of India 2011 and PMC 2021).*

Due to rapid expansion of IT companies, the population density of Pune city has increased from 10,410 persons/km^2 in 2001 to 17,309 persons/km^2 in 2022 due to high migrant population growth.

Population density is expected to reach the value of 22,689 persons/km² by 2031 (Fig. 3) (TERI, 2021).

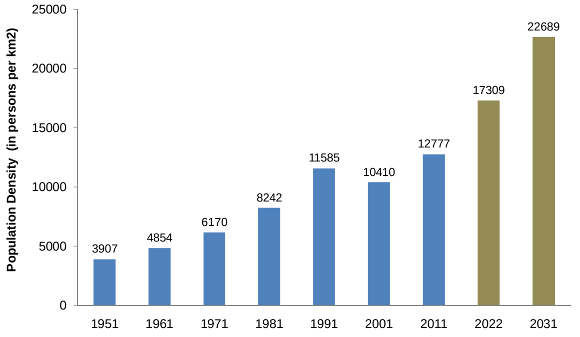


Fig. 3. Population density change in Pune city (1951–2031) *(source: Census of India 2011 and PMC 2021).*

The rapidly increasing population trend and geographical expansion of the city will require more domestic water. Water supply is a basic need of the city. Pune city draws water from various surface water sources such as Khadakwasla, Temghar, Panshet, Warasgaon and Bhama Askhed reservoirs. The Khadakwasla dam supplies around 1350 MLD of water to the city. The city's per capita average water supply is as high as 250 LPCD (litres/capita/day) compared to the standard of 150 LPCD (PMC, 2021). However, the north-eastern and central parts of the city are experiencing severe water scarcity. Major issues such as the loss of water and low coverage of metered connections have been observed in the study area. Given this situation, assessing the water resources for their sustainable usage in Pune city has become imperative. Thus, the main objective of this study is to evaluate the existing domestic water resources in the study area, identify water-stress zones, and forecast the demand of water resources in near future.

3. MATERIALS AND METHODS

The data for the present study are used from both secondary and primary sources. The secondary data has been collected from various sources, *i.e.*, governmental institutions, published reports, books, research journals, and library resources. The ASTER-GDEM data with a spatial resolution of 30 metres was used to generate the 3D map of the study area (Maskooni et al., 2020). Subsequently, topographic maps of the Survey of India (SOI) at a scale of 1: 50,000 were used to extract thematic layers including drainage networks, water bodies, roads, rail networks and others. Data relating to water distribution, water supply areas, and current and proposed reservoir locations were digitized into the QGIS platform using data from the Pune Municipal Corporation (PMC) and Google Earth (Mundhe and Jaybhaye, 2023). Presently, there are about 102 water supply zones that could be increased to 141 by the year 2031. For analysis purposes, this zone is further divided into 14 administrative wards. Demographic indicators such as the total population, number of households and others were collected from the Census report, primary census abstract and various reports of the Pune city. This proved to be useful for the description of the demographic aspects.

For assessment accuracy purposes, around 50 samples were collected with the help of Google earth image and GPS. Moreover, the ground truth data were compiled by applying a purposive sampling method in order to correctly render the accuracy assessment of the water related attributes. The data were thus collected, processed, analyzed and interpreted in the laboratory using ArcGIS, QGIS and Microsoft Office software.

The general methodological steps that were involved are as follows: (i) Procurement of satellite images, topographical maps, and related attribute data. (ii) Pre-processing techniques such as image rectification, enhancement, band extraction and subset employed on satellite imageries and topographical maps. (iii) With the help of satellite image and topographical maps, a 3D map of the study area was determined. (iv) Creation of various thematic layers such as drainage networks, road and railway line, water bodies, forest areas and administrative boundaries were digitized in a GIS platform. (v) Water resources related base maps were elaborated using these layers.

The following quantitative and qualitative techniques have been used for the study.

3.1. Composite water stress map

The composite water stress map was prepared using overlay analysis technique (Xiugang et al., 1999; Tiede, 2014). The overlay is a GIS operation that superimposes multiple data sets (representing different themes) as to identify their relationships (Clarke, 2010). Various parameters were used and mainly consisted of water supply and demand gap, duration of water supply and dependence of groundwater etc. (Fig. 4). Each parameter was assigned a rank according to its importance and then converted to a corresponding ranking scale (Ruess, 2015). The outcome of this exercise was a composite water stress map, which has helped in delineating water stress zonation.

3.1.1. Water demand

We used population density and per capita water consumption to determine the index for assessing water demand (Xinchuang et al., 2020). The water demand (D) for the city was mainly determined by the consumption of water by residents, agriculture, industry, and others. The water demand is calculated as follows (Chen et al., 2020):

$$D = D_{urb} + D_{agr} + D_{ind} + D_{env} \quad (1)$$

where:
D – demand;
D_{urb} – urban residents living water;
D_{agr} – agriculture irrigation water;
D_{ind} – urban industrial production water;
D_{env} – urban public environment water.

3.1.2. Water demand - supply gap

This study considered the city as a self-maintained and relatively closed system, in order to assess the relationship between the supply and demand for water resources and to further explore urban planning construction (Deng et al., 2020). The ratio of water resource supply to water resource demand was used as an assessment criterion. For determining the water supply demand gap, we used the following formula based on incoming water and consumption (Chen et al., 2020):

$$GWR = D – S/D \text{ X } 100 \qquad (2)$$

where:
GWR – the gap of water resource in %;
D – the amount of water required/demand;
S – the water supply.

3.1.3. Duration of water supply

The PCWS indicator (per capita water supply) establishes the amount of water supplied to each resident for a month (Bandari and Sadhukhan, 2021). It should be 150 litres/ capita/day (lpcd) in urban areas (MoUD, 2009). The per capita water supply is estimated using the following equation:

$$PCWS = Q/N \text{ X } P \qquad (3)$$

where:
PCWS – per capita water supply;
Q – the total water input into the distribution system every month (in litres);
N – the number of days in the given month;
P – the total number of residents.

3.1.4. Accuracy assessment

Accuracy is defined as the degree of closeness of results to the true values. It settles the quality of the information derived from various sources. For the accuracy of assessment, around 50 samples were collected with the help of Google earth image and GPS instruments. For this study, the ground truth data were collected through a purposive sampling method for the accuracy assessment of the composite water stress map. This is relevant for determining how accurate and useful the resulting classification is. It is also helpful to conduct an accuracy assessment, even more so since the resulting maps will to be used in the decision-making process. The overall accuracy is calculated by the sum of all samples on the diagonal (total correct pixels) divided by the total number of samples (Jensen, 2017).

3.2. Exponential population projection method

Population growth is the positive change in a particular population as a function of time (Kaaviya and Devadas, 2021). This growth is not linear but exponential, so the formula for population growth can be found by starting from the premise that P (population) multiplies by a rate of r over time. The equation is (Al-Eideh and Al-Omar, 2019):

$$P_{(t)} = P_o e^{rt} \qquad (4)$$

where:
$P_{(t)}$ – the population at any time *t*;
P_o – initial size of the population;
r – the constant of proportionality;
t – the period in years elapsed from year 0 to t;
e – unit less constant ≈≈ 2.71828 (Biswas, 1989).

Where linear growth increases by some constant factor, exponential growth increases by a multiple of some number, so the exponential growth will always outpace the linear growth over a long enough period of time. Exponential population projection has been considered for all future development plans.

3.3. Water scarcity index

Water scarcity is defined as a situation when insufficient water resources are available to satisfy long-term average requirements (Wang et al., 2022). Several methods have been developed to assess water scarcity according to water quantity and water quality, such as the Falkenmark index, Criticality ratio, International Water Management Institute (IWMI) indicator, water poverty index, blue water availability, and green water availability (Falkenmark et al., 1989; Seckler et al., 1998; Alcamo et al., 2000; Sullivan et al., 2003; Oki and Kanae, 2006; Savenije, 2000; Zeng et al., 2013; Pedro-Monzonís et al., 2015; Ma et al., 2020).

In general terms, water scarcity represents the overexploitation of water resources when water demand is higher than water availability (Brown and Matlock, 2011). Therefore, the water scarcity index (WSI), which means the ratio of water supply to water demand, has been widely used (Sun et al., 2008; Li et al., 2019; Chen et al., 2020). It has been also employed in the current research work to calculate the dynamic relationship between water supply and water demand:

$$WSI = Wd/Ws \quad (5)$$

where:
WSI – water scarcity index;
Wd – water demand (m^3);
Ws – water supply (m^3).

The value of WSI must be greater than zero. When the value of WSI is less than 0.1, there is surplus, when it is between 0.1 and 0.2, there is a slight shortage, when values range from 0.2 to 0.4, there is a moderate shortage, from 0.4 to 1, a serious shortage, and value 1 means a major water shortage (Guo and Shen, 2016).

3.4. SWOC analysis

The SWOC analysis determines a research work's strengths, weaknesses, opportunities, and challenges (Gurel and Tat, 2017). The SWOC analysis is a simple but effective tool for sizing up an organization's resource capabilities and deficiencies, market opportunities, and the external threats to its future (Thompson et al., 2007). The SWOC analysis is a strategic planning technique used to investigate internal (strengths and weaknesses) and external (opportunities and challenges) factors that affect performance and growth.

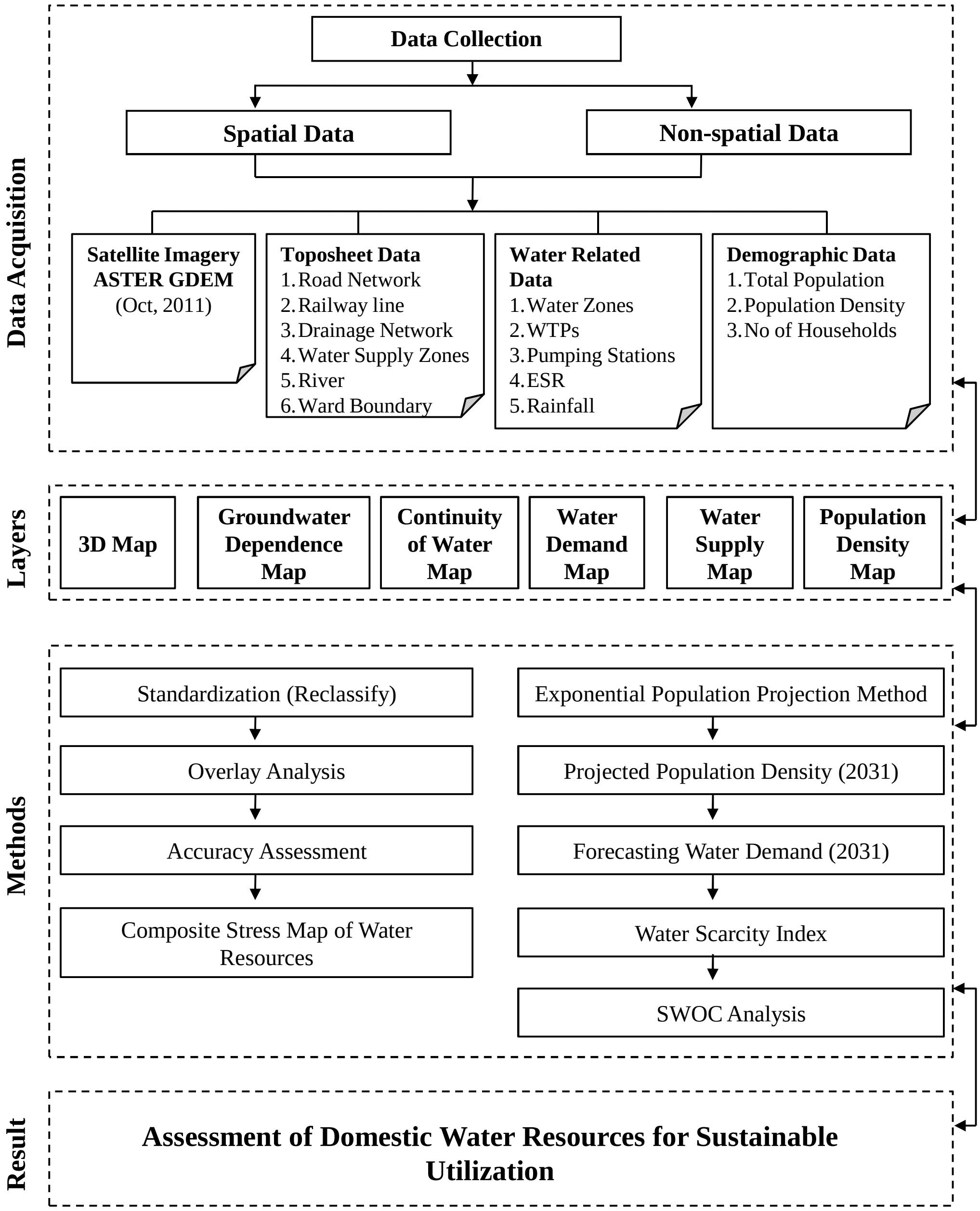


Fig. 4. Methodology flowchart.

This technique enables groups and individuals to move away from everyday problems and prepare strategies to solve them (David, 2011). The SWOC analysis framework is a vital and helpful tool for managing and upgrading datasets. It is performed while exploring new initiatives, revamping internal policies, considering pivot opportunities or changing a plan midway through its execution.

4. RESULTS AND DISCUSSION

Water is one of the essential commodities without which no development of any city is possible. Therefore, the present research work intends to emphasize the assessment of water resources.

4.1. Assessment of domestic water resources

The present research considers various indicators for the assessment of domestic water resources such as population density, water demand, water supply, water demand and supply gap, continuity of water and groundwater dependence.

4.1.1. Population density

For the ward-level analysis, we considered population density as an indicator, which measures the pressure on the environment, including the exploitation of natural resources such as water and land contamination of a city and its surroundings. Increased or decreased pressure on an urban environment is illustrated by the growth of population density over time. In Pune city, population density continued to increase from 10,410 persons/km² in 2001 to 17,309 persons/km² in 2022. This was mainly because of the rapid expansion of industrial areas and job opportunities available in the city. Most of the population densities across Pune city wards seem to be almost uniform (Fig. 5).

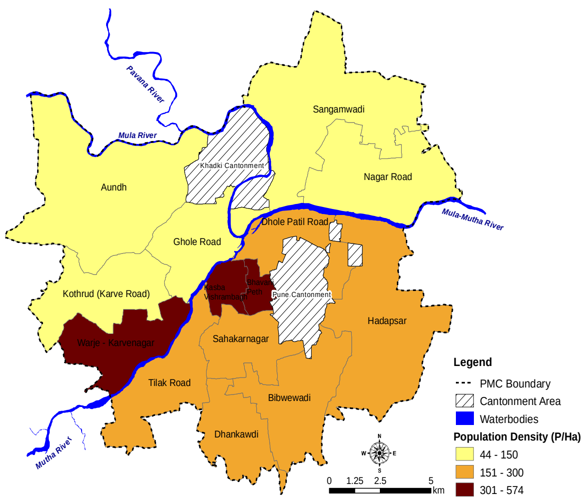


Fig. 5. Population density (person/ha) *(source: based on data from Census of India 2011 and PMC 2021).*

However, compared to the overall average value of the city, in the case of the Bhawani Peth, Kasba-Vishrambhaugwada and Warje-Karvenagar wards, population density is extremely high in 2022, *i.e.*, 574 p/ha, 411 p/ha and, respectively, 326 p/ha. This analysis helps to identify the vulnerable areas and suggests immediate attention to be given to their corresponding management.

4.1.2. Water demand

Another aspect dealt with in this study was the domestic water demand, which was calculated by using the areas' per capita requirement and population number. In the present study, the projection of the population for the years 2022 and 2031 is based on the exponential population projection, whereas, the calculation of water demand is based on the National Building Code standard of 200 liters/capita/day (lpcd). According to the agreement between PMC and the state irrigation department, the city has allotted 900 MLD of water while the city consumption is around 1350 MLD in 2022 (Table 1).

Table 1. Detailed water demand and supply statistics for the years 2011 and 2022.

Aspect	2011	2022
City population	3.1 million	4.3 million*
Per capita average water supply/demand	194 lpcd***	200 lpcd**
Total water demand of the city	604 MLD*	867 MLD*
Total water supply (MLD)	1123 MLD***	1350 MLD****
Losses 25% + 5 % NRW	337 MLD ***	405 MLD ****
Net water supply to the city	786 MLD***	945 MLD****
WTP installed capacity	908 MLD***	1768 MLD****

Source: National Building Code (2016) and TERI (2021).
Notes: *Computed based on exponential population growth method; ** Computed based on National Building Code (2016) and TERI (2021). *** Computed based on PMC (2012);.**** Computed based on PMC (2021).

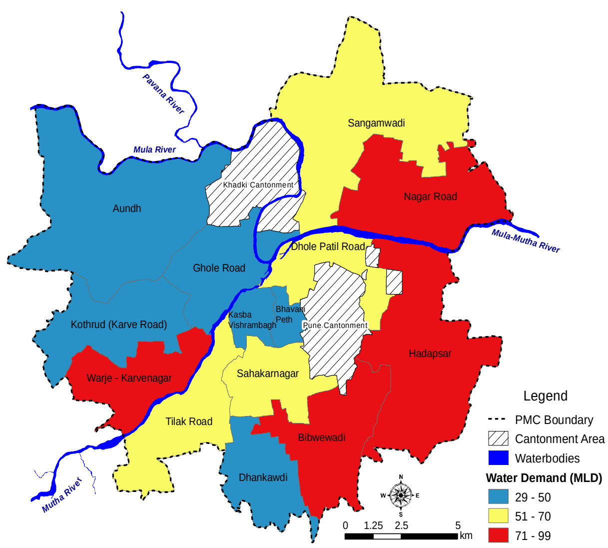


Fig. 6. Water demand *(source: based on data from PMC 2021).*

This reflects the fact that the city's population is growing rapidly and the allotted water can't meet the growing water demand (TERI, 2021). The ward-wise average water demand of Pune city is of 56 million liters/day (MLD). Figure 6 shows the ward-wise water demand of the study area for the year 2022.

The wards of Warje-Karvenagar, Hadapsar, Nagar Road, and Bibwewadi have more water demand, *i.e.*, 99 MLD, 79 MLD, 77 MLD and, respectively, 75 MLD, due to rapid population growth, whereas the Ghole Road, Bhawani Peth, Aundh, Kasba-Vishrambagh, Kothrud, and Dhankawadi wards have less water demand, *i.e.*, 29 MLD, 33 MLD, 36 MLD, 41 MLD, 43 MLD and, respectively, 44 MLD.

4.1.3. Water supply

Per capita water supply is an indicator of the water supply situation in an area and gives an idea of the amount of water available at an individual level. This can be computed by dividing the total water supply by the total population. The average per capita water supply in the city of Pune is 194 liters/capita/day (lpcd), which is higher than the standard of 150 lpcd (Tholiya et al., 2022). The Central Public Health and Environmental Engineering Organization (CPHEEO) set these norms for the Indian cities and towns while designing water supply schemes. However, in the case of the Pune city ward-wise, per capita water supply varies from 138 lpcd to 358 lpcd based on the geographical settings. Figure 7 shows unequal patterns of water supply across the city.

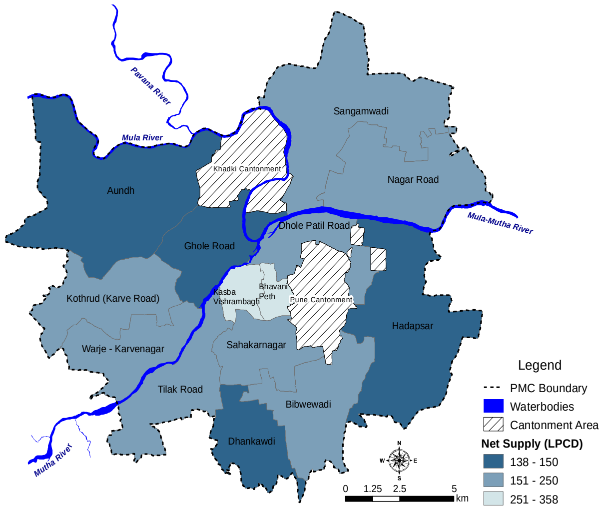


Fig. 7. Water supply *(source: based on data from PMC 2021).*

The maximum per capita water supply is utilized by the Bhawani Peth (358 lpcd) and Kasba Vishrambhaug (260 lpcd) areas because of the flat terrain and superior water supply network, while, the Dhankwadi (138 lpcd), Ghole Road (139 lpcd), Hadapsar (140 lpcd) and Aundh (149 lpcd) wards receive less water supply, which is below 150 liters/capita/day (lpcd) because of the rapid population growth, climatic conditions, lack of proper water meters, low pressure of water supply and the old water distribution network.

4.1.4. Water demand and supply gap

The water demand and supply gap is the difference between the amount of water demand and the amount of water supply (An et al., 2021). In Pune city, the Dhankawadi and Ghole Road wards have the highest water requirement and supply gap (deficit), which is more than 31% because of the unplanned growth of the city. The scheme for strengthening the water supply system should focus more on the wards of Dhankawadi and Ghole Road to provide additional water. Figure 8 shows that surplus water demand and supply gap is high in the wards of Bhawani Peth (79%), Kasba-Vishrambagh (30%), Sahakarnagar (11%), Sangamwadi (9.5%) and Dhole Patil Road (9.5%). This implies that the excess water may be transferred to the shortfall areas.

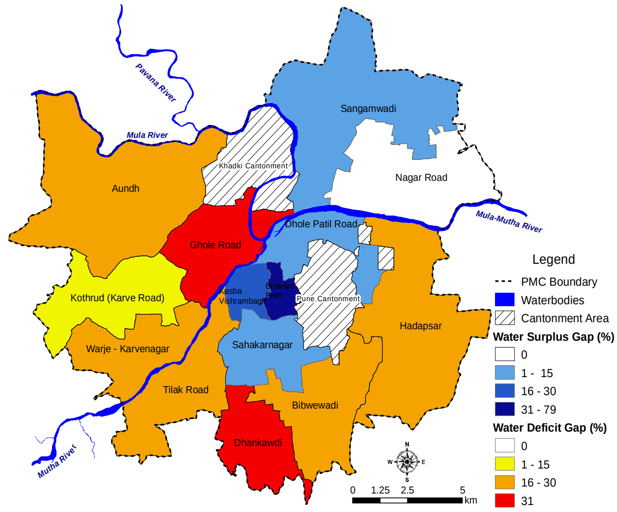


Fig. 8. Water demand and supply gap *(source: based on data from PMC 2021).*

4.1.5. Continuity of water supply

In Pune, the continuity of water supply is also unequal across wards. The city receives water six hours a day on average.

In Nagar Road, the continuity of water is 2 hours/day, whereas in the Dhankwadi, Tilak Road, Sahakarnagar, and Hadapsar wards, it is only 4 hours. These wards are located at higher elevations, on undulating terrain and hillocks, which gradually restricts the pressure up to the last consumer. However, the Dhole Patil Road ward has received the most of water supply in the city, with 20 hours of water/day because of lowest elevation and the location in the center of the city (Fig. 9).

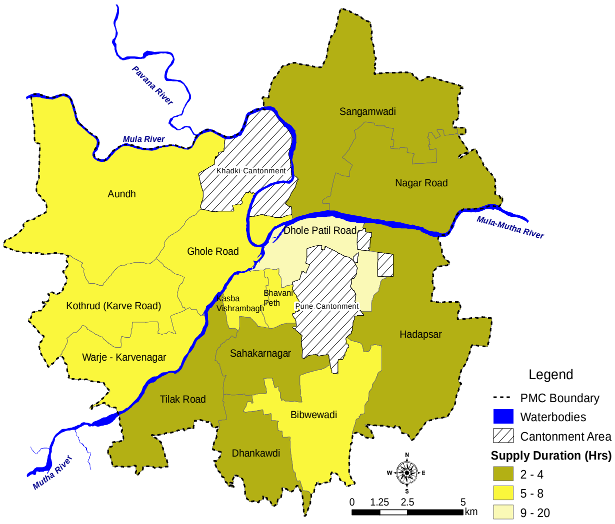


Fig. 9. Continuity of water (in hours) *(source: based on data from PMC 2012).*

4.1.6. Groundwater dependence

According to the report on water sustainability assessment in Pune, elaborated by TERI (2021), the majority of non-potable water used in this city comes from groundwater. However, there is no system to track groundwater extraction. It is unclear how much of the water consumption of the city is supplied by groundwater. The absence of data on groundwater recharge and extraction creates an information gap for policymakers. According to Pune's Aquifers report, the groundwater level in Pune city is rapidly declining because of its rapid growth (Fig. 10).

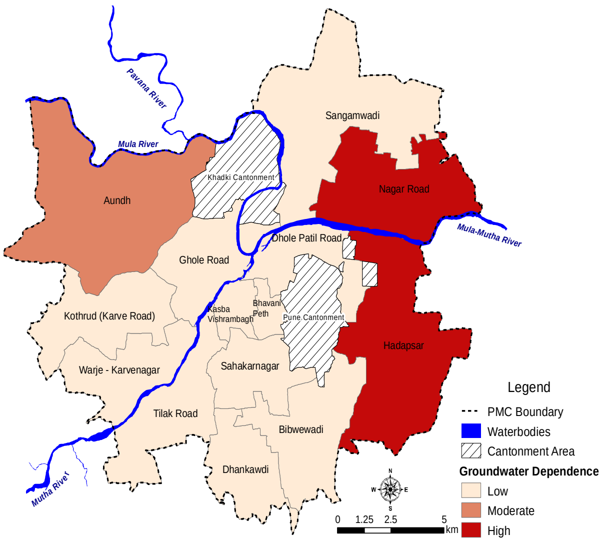


Fig. 10. Groundwater dependence *(source: based on data from PMC 2012).*

The groundwater extraction has increased from 56.6 million cubic meters (MCM) in 2011 to 113.2 million cubic meters in 2019 (TERI, 2021), thus doubling its value over the last decade. There are no quantities of groundwater abstraction to support the ward-level analysis. There are only qualitative data derived from various reports. A few privately conducted studies clearly show that the Hadapsar and Nagar Road wards, followed by the Aundh area, are heavily reliant on groundwater because of a shortfall in water supply.

4.1.7. Composite water stress map

Various parameters such as population density, water demand and supply gap, water continuity and groundwater dependence were used for creating the composite water stress map. Each parameter was ranked based on its importance, and the values were converted into a ranking scale. The composite stress map for water resources in Pune city is divided into three categories, *i.e.* low, medium and high. The Ghole Road, Nagar Road, Dhankawadi and Hadapsar wards have a high level of water stress. This is mainly generated by a deficit gap in water demand and supply, a low per capita water supply, a short duration of water supply, and a high reliance on groundwater. Conversely, Aundh, Warje, Tilak Road and Bibwewadi are categorised as intermediate when compared to wards that experience a low level of water stress, such as Sangamwadi, Kothrud, Dhole Patil Road, Bhawani Peth, Kasba Vishrambagh and Sahakranagar (Fig. 11).

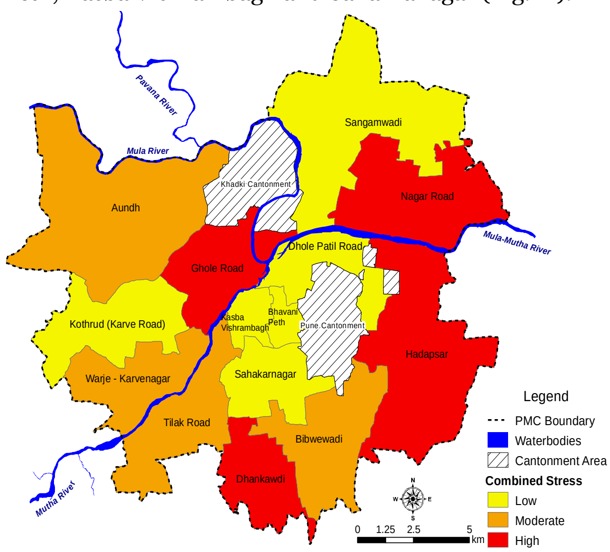


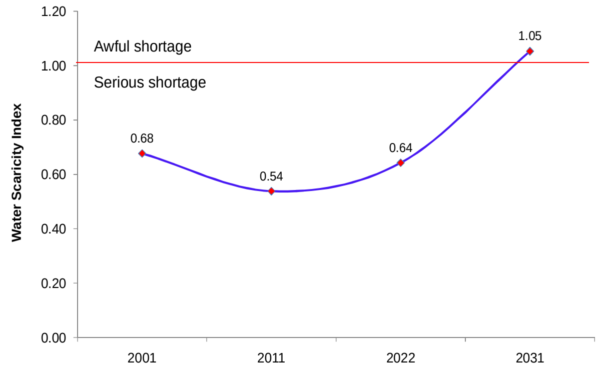
Fig. 11. Composite water stress map (*source: created by authors).*

After analysis, the next step is to check the quality of the results using the accuracy assessment. For this purpose, around 50 samples were collected with the help of Google earth image and the GPS instrument. The overall classification accuracy obtained was 83% for the composite water stress map. If the overall accuracy was above 50%, it indicated that the accuracy of the map was reasonably good to excellent.

4.2. Water scarcity index (WSI)

The water demand of Pune city has continuously increased from 508 MLD in 2001 to 857

MLD in 2022. While the WSI values in the study area have significantly changed over the decades, they were all in a state of serious water scarcity. Water Scarcity Index (WSI) values in the previous two decades were 0.68 in 2001, 0.54 in 2011 and 0.64 in 2022 (Fig. 12).



Note: WSI, values greater than 1 indicate major shortage of water resources, while values between 0.4 to 1 indicate serious shortage of water resources.

Fig. 12. Water Scarcity Index of Pune city during 2001 – 2031.

This value is expected to be around 1.05 in the year 2031, indicating that Pune has a major water deficiency. Thus, the water resources status of Pune city fell into the serious shortage category from 2001 to 2022.

4.3. Forecasting water demand and water zones

Pune city will experience a rapid increase in population by 2031, which will stand at around 5.6 million. In addition, the city's population density will continue to increase from 17,309 persons/ km² in 2022 to 22,689 persons/km² in 2031. Figure 13 shows the ward-wise population density for the year 2031.

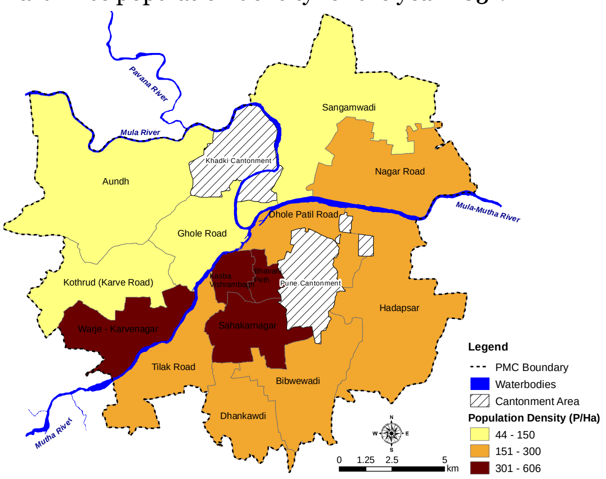


Fig. 13. Proposed population density of Pune (2031) *(source: based on data from PMC 2021 and TERI 2021).*

Wards such as Bhawani Peth, Kasba-Vishrambhaugwada, Warje-Karvenagar and Sahkarnagar will have a high population density, which will lead to increased water demand in these areas. Therefore, more attention should be given to this matter. The future water demand of Pune city was computed based on the CPHEEO manual. Pune Municipal Corporation claims the city provides 250 liters of water/capita/day (lpcd) (PMC, 2021). The city will increase the water demand to 1421 MLD by 2031 (Table 2).

Table 2. Estimation of water demand statistics for the years 2031 and 2041.

Aspect	2031	2041
City population	5.6 million*	7.6 million*
Per capita average water supply/demand	250 lpcd**	250 lpcd**
Total water demand of the city	1421 MLD*	1920 MLD*
WTP installed capacity	1768 MLD**	1768 MLD**

Source: PMC (2021) and TERI (2021).
* Computed based on exponential population growth method;
** Computed based on PMC (2021).

Given the limited water supply of the Pune Municipal Corporation by the State Department of Irrigation, the decision-maker and local authorities may consider other sources or practices for water management. The installed capacity of water treatment plants is 1768 MLD, which can meet the water demand of Pune until 2031 (TERI, 2021). However, in 2041, the city will require around 1920 MLD of total domestic water, which indicates a water supply shortfall.

In Pune, the maximum water requirement for 2031 will be in the eastern part of the city, which is more than 71 MLD (ward-wise). This includes the Warje-Karvenagar, Tilak Road, Sahakarnagar, Bibewadi, Hadapsar, Dhole Patil Road and Sangamwadi wards. This is mainly due to the plain topography and high population growth rates. Besides, demand in the areas of Aundh, Ghole Road, Kasba-Vishrambagh and Bhawani Peth will be relatively lower (Fig. 14).

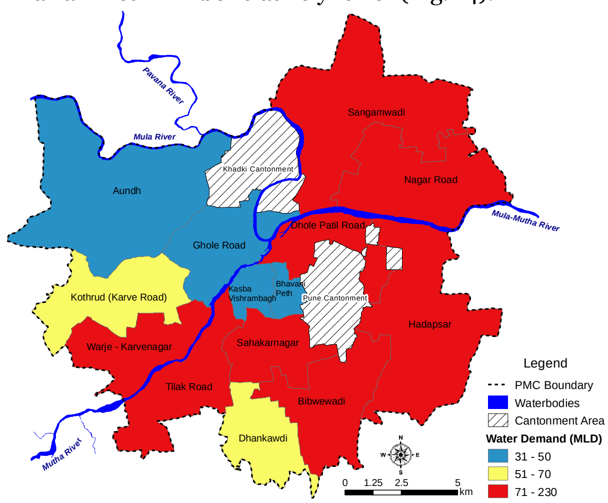


Fig. 14. Proposed water demand of Pune (2031) *(source: based on data from PMC 2021 and TERI 2021).*

In addition, the number of service reservoirs (SRs) in Pune will increase from 102 in 2022 to 141 in 2031. The proposed system will form 141 water supply zones within PMC jurisdiction, which include Warje (34), Vadgaon (32), Parvati (12), Cantonment (25), Bhama Askhed (37), and Holkar (1) among others (Fig. 15).

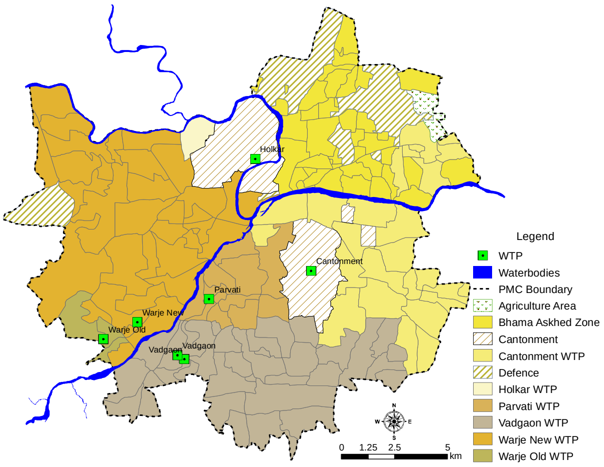


Fig. 15. Proposed water supply zone of Pune city – 2031 *(source: based on data from PMC 2014).*

This may be helpful for decision-making and sustainable planning.

4.4. SWOC analysis

The SWOC analysis aims to maximize strengths and opportunities while minimizing challenges and transforming weaknesses into strengths and opportunities. The SWOC analysis is used to develop strategies for efficient and sustainable water supply in the study area.

The strengths of the water supply system are as follows: i) in the western part of the city, there are existing dam sites in the heavy rainfall area. ii) most of the water flows into the city through gravity; iii) full treatment capacity; iv) 70% water distribution coverage; v) average per capita water supply that exceeds national standards.

The opportunities for water supply are as follows: i) 100% metering will result in a 100 % collection of tax on water; ii) private sector collaboration in service delivery; iii) a large number of drainage facilities can be used for decentralized wastewater treatment and the reuse of water.

The weaknesses associated with water supply in the study area include high water losses, low storage capacity, low metered connections, more households that are not connected to the water supply network and unequal water supply in marginal areas. Water supply system challenges include high groundwater dependence, lack of awareness regarding the willingness to pay, uneven topography, resulting in low water pressure and siltation threats in reservoirs (annual siltation rate is 0.46 million cubic meters).

Based on the research findings, a few recommendations for a sustainable water supply system can be made, namely: i) installing new water treatment plants and improving storage capacity in the Hadapsar, Dhankawadi, Nagar Road and Ghole Road wards. ii) promoting rainwater harvesting in all wards, particularly in the Hadapsar, Dhankawdi and Nagar Road areas. iii) promoting water efficiency: water sourcing, distribution, supply, and end-use. iv) constructing new water treatment plants and expanding the storage capacity in the Vitthalwadi, Kharadi and Mundhwa areas; v) PMC has laid a raw water line from Khadakwasla to Parvati waterworks to reduce canal seepage losses and avail the full sanctioned water supply; vi) water auditing, regular inspection and repair of leaky joints; vii) introducing the public-private partnership for the functioning and management of the water supply system; viii) PMC should encourage consumers to get a water meter connection. The present study highlights the necessity of joint use of water resources, which seems to be required in the near future. Such studies are highly applicable to the major cities in India.

5. CONCLUSIONS

Both the population density and water demand of the city have increased significantly from 2011 to 2022. The values of water scarcity index computed for the study area have drastically changed in the last two decades, from 0.68 in 2001 to 0.54 in 2011 and 0.64 in 2022, which indicates that the city falls in the serious water shortage category. This value is expected to be around 1.05 in the year 2031, indicating that Pune will have a major water deficiency, which will lead to increasing socio-economic and environmental problems in the city. Similarly, it also becomes a constraint for the sustainable utilization of water resources.

The geospatial technology has been proved to be an effective tool to find spatial solutions based on various sources of spatial as well as attribute data. The composite stress map clearly revealed that the Ghole Road, Nagar Road, Dhankawadi and Hadapsar wards have a higher level of water stress in comparison with other wards, indicating urgent needs of comprehensive city planning and effective management of municipal services. The present study will be helpful in assisting local administrators, decision-makers, researchers and other stakeholders in providing a ready reference for initiating immediate actions at a local level as well as to achieve sustainable goals and targets.

6. ACKNOWLEDGMENTS

We are grateful to the Principal of Sir Parashurambhau College, Pune for providing laboratory facilities. We thank the Pune Municipal Corporation for providing attribute data. We would like to thank the anonymous referees for their critical review, comments and suggestions which helped us improve the research work.

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