Identification of Potential Groundwater Recharge Zones Using GIS Based Multi-Criteria and AHP Technique: A Case Study of Pune City, Western Maharashtra

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ARTICLE INFO

Received: 1 Dec 2022
Received in revised: 23 Jan 2023
Accepted: 5 Feb 2023
Published online: 13 Mar 2023
DOI: 10.32526/ennrj/21/202200257

Keywords:
Groundwater Recharge Potential/ Rainwater Harvesting/ Multi Criteria Analysis/ Analytic Hierarchy Process/ Weighted Overlay Analysis/ Pune City

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ABSTRACT

With dwindling supply of surface water, Ground water is increasingly being used as a source of fresh water in many cities across the world. Consequently, there is an increasing need to evaluate groundwater potential of an area. Over the past few decades, Remote Sensing and GIS have been used for systematic investigations on potential recharge of aquifers. As in major cities of the world, the demand for water in Pune City is also increasing every year and demand outstrips the supply of surface water. This study delineated potential zones for artificial recharge across Pune City by using Multi-criteria analysis and the Analytical Hierarchy Process (AHP) techniques.

Artificial recharge techniques especially the use of rainwater harvesting (RWH) are being deployed globally to augment supply of fresh water. Ground-water recharge is directly influenced by surface characteristics such as rainfall, geology, soil types, Land Use/Land Cover (LULC), drainage, lineaments/fractures, etc. Hence, six such parameters, namely, LULC, Slope, Soil texture, Rainfall, Drainage density, and Geology were considered to generate a groundwater recharge potential map. Based on the analysis, the study area was zoned into five classes, namely, low, moderate, good, very good and high groundwater potentials. About 45% of the city shows good to high potential for recharge. The results reveal that the high and good potential recharge zones lie to the western part of the city, whereas the central part (inner city) and the eastern part show medium to low potential for recharge. The results can help to identify areas for recharge and formulate a framework for systematic recharge of the existing aquifers in the area under study.

1. INTRODUCTION

Water scarcity is increasingly becoming a global phenomenon in urban growth centers, even in developed countries. Population growth and rapid urbanization have led to increased demand of water and over exploitation of groundwater and consequently water stress. In this scenario, maintaining the groundwater balance assumes immense importance. Artificial recharge of groundwater using different techniques such as roof-top rainwater harvesting, recharge pits, check dams, percolation tanks, and injection wells is therefore crucial for the restoration of the hydrological balance (Rao et al., 2022).

Research carried out by several workers (Senanayake et al., 2016; Adham et al., 2016; Paul et al., 2020) on rainwater harvesting (RWH) have focused on identifying potential sites for surface recharge to the aquifers in non-urban areas. Recharge of groundwater from rainfall has been studied extensively and numerous methods like Thiessen polygon (Kim et al., 2003), Agricultural non-point source (Mohammed et al., 2004), water balance approach (Jasrotia et al., 2009) and Soil Conservation Service Curve Number (SCS-CN) (Kadam et al., 2012) have been suggested to identify potential sites for groundwater recharge.

Citation: Vaddadi N, Vansarochana C, Raghavan V. Identification of potential groundwater recharge zones using GIS based multi-criteria and AHP technique: A case study of Pune City, Western Maharashtra. Environ. Nat. Resour. J. 2023;21(3):198-210. (https://doi.org/10.32526/ennrj/21/202200257)

Besides these conventional techniques, integrated application of Remote Sensing (RS), Geographic Information Systems (GIS) and Multi Criteria Decision Analysis (MCDA) techniques for the delineation of recharge zones/sites have drawn attention in recent times. The use of thematic layers and techniques like Weighted Overlay Method (WOA) based on Analytic Hierarchy Process (AHP) are increasingly being used for identification of ground water potential recharge zones, exploitation, and management of ground water resources.

The MCDA and WOA workflow incorporating different parameters, such as geology, geomorphology, soil type, land use/land cover, and slope was applied by Kadhem and Zubari (2020) to identify optimal locations for managed aquifer recharge in Bahrain. The use of MCDA was found useful in assessing potential groundwater zones in Sidhi area of India (Tiwari et al., 2020) and to identify suitable sites for potential recharge in West Medinipur district of West Bengal by Chowdhury et al. (2010). Paul et al. (2020) used multi-criteria evaluation technique for assessment of groundwater potential zones in the Paisuni River Basin, India. They suggested that proper technical design and identification of suitable sites are crucial to efficient RWH.

The AHP method applied using thematic layers like slope, drainage, lithology, LULC, and soil type has been used by several other researchers like Nasiri et al. (2013), Jamali et al. (2014), Akter and Ahmed (2015), Singh et al. (2017), Çelik (2019), and Benjmel et al. (2020). Akter and Ahmed (2015) evaluated potentiality of RWH systems in Chittagong city (urban catchment) of Bangladesh applying the AHP approach and using roof area, slope, drainage density and runoff coefficient as themes. Das and Pal (2019) used AHP and WOA to delineate potential groundwater zones in Puruliya District of West Bengal in India. Kumar et al. (2020) used RS, GIS and AHP techniques to identify potential groundwater zones in parts of the Deccan Volcanic Province. Venkatarao et al. (2019) calculated the groundwater recharge potential zones using a cross-correlation technique between groundwater levels in wells and rainfall events. Vaddadi et al. (2022) estimated the potential for ground water recharge available from roof-top rainwater harvesting for Pune city to be 49.05 million cubic meters (MCM) and that effective recharge using RWH techniques could supplement the groundwater annually by about 22-25 MCM.

The demand for Pune City in 2020 was 424 MCM and the budget for the year 2021-2022 was 568.31 MCM. With growth in population, the annual water demand will increase to 23.34 TMC (660.91 MCM) by 2031-2032. (Pune Municipal Corporation, 2021). The gap between demand and supply necessitates looking for alternative sources of potable water to cater to the shortfall. The objective of this study, therefore, was to delineate potential zones for artificial recharge across Pune city considering urban factors like land-use by using GIS, Multi-criteria analysis, and the Analytical Hierarchy process (AHP) techniques. Six parameters, namely, LULC, Slope, Soil texture, Rainfall, Drainage density, and Geology were considered to generate a groundwater recharge potential map.

2. THE STUDY AREA

Pune City, a part of the Pune urban area is a plateau region set on the western margin of the Deccan Volcanic Province. The Pune Municipal Corporation (PMC, Pune City) covers about 331.26 km^2. Pune City is the second largest city in Maharashtra state and ninth largest in India with a population of 3,124,458. (Census India - Population Census, 2011). The study area lies between 18°27’ and 18°40’ N - 74°39’ and 74°00’ E (Figure 1) and is within the Deccan Volcanic Province. Of the total area of the city, the study area covers about 250 km^2. The average annual precipitation is 780 mm with maximum rainfall occurring in the month of July. The area experiences three seasons - summer, monsoon and winter and usually faces a shortage of water if the monsoon has failed in the previous year.

2.1 Geology and hydrogeology

The area falls in the Western part of the Deccan Volcanic Province and is underlain by basalts of upper Cretaceous to Eocene age. The city is bounded by hills on the West and in the South. Mula and Mutha Rivers are the main rivers in the study area. Two more rivers, Pavana and Indrayani flow from North-western direction. The drainage is dendritic, sub-dendritic and sub-parallel. Structural control in the drainage is evident at many places.

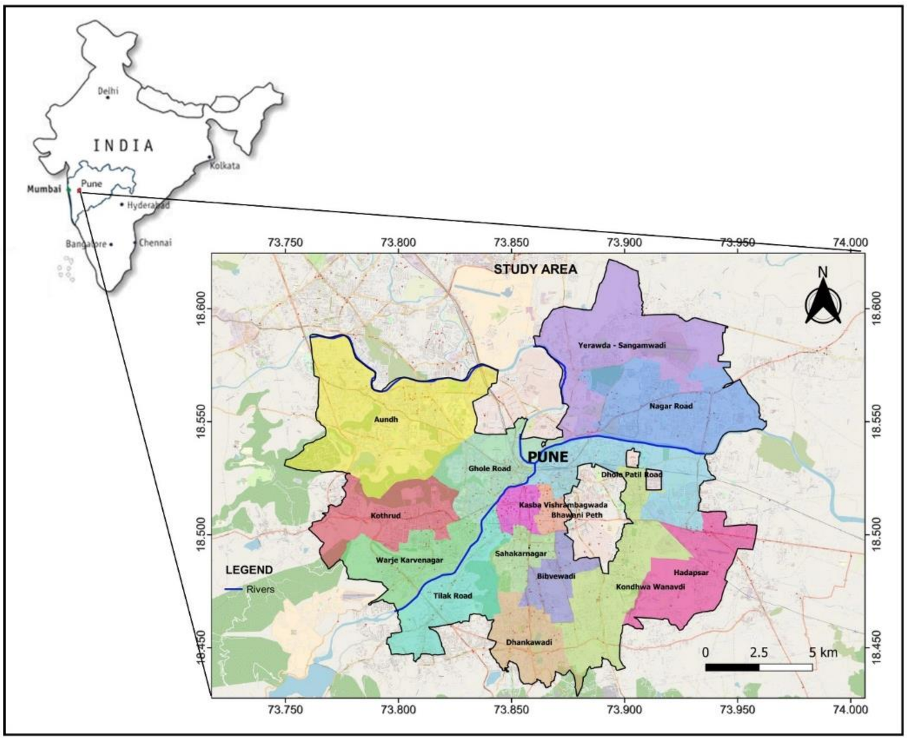

Figure 1. Location map of study area

Based on lithostratigraphy, the lava flow sequence seen in the area have been divided into four Formations - Indrayani, Karla, Diveghat and Purandargarh Formations. The flows belonging to Indrayani, Diveghat and Purandargarh Formations are dominantly of simple nature, while those of Karla Formation show a compound nature.

Based on field characteristics, the lava flows are broadly classified into two types, namely, simple and compound flows. The simple flows are characterized by a fragmented top, a thin brecciated base (basal clinker) and a compact, jointed massive core. The compound flows are vesicular and amygdaloidal at the top and show a certain amount of weathering at places. The middle portion is hard, compact, fractured, and jointed. The basal sections of these flows are characterized by pipe amygdales. The thickness of the flows varies on an average from 10 to 20 meters.

The water bearing capacity of the rock formations is mainly governed by the porosity which determines the volume available for storage of water. Due to their compact nature the basalt flows show very low primary porosity and permeability. Secondary porosity developed due the presence of openings and cavities, vertical joints and horizontal sheet joints, weathering, and flow contacts impart the water holding and transmission capacity to these flows.

The weathered parts of the flows exhibit higher porosity and permeability when compared to the fresh units. The secondary porosity is also higher in the flows exhibiting columnar joints, sheet joints, brecciated and vesicular flow tops.

In terms of hydro-geological properties, the flows are usually classified as vesicular/amygdular basalt (which also includes the Flow Top Breccia (FTB)), jointed basalt, and massive, compact basalt. The vesicular/amygdular basalt, jointed basalt, and weathered basalt act as aquifers as they have better porosity while the massive compact basalts act as aquifuges or aquitards. The clayey tuffaceous layers occurring between the flows act as an aquiclude.

Groundwater circulation happens through the fractured portions in the massive basalt, the vesicular upper sections and through the weathered portion of the flows. Recharge to deeper horizons occurs mainly through deep fractures and fractured dykes.

3. METHODOLOGY

In the present study, a MCDA approach using AHP was used for delineation of potential ground water recharge zones. Physiographic elements have a close relationship with groundwater recharge (Doke et al., 2021). According to Choudhari et al. (2018) the level of groundwater varies according to elements such as geology, drainage density, lineament, rainfall, and land-use. Many researchers have used criteria like lithology, geomorphology, geology, drainage density, soils, lineament, rainfall, land-use, and distance from the river for delineation of groundwater zone (Das and Pal, 2019; Maity and Mandal, 2019). Rao (2006) computed a groundwater potential index (GPI) considering factors such as rainfall, slope, run-off, infiltration, soil cover, moisture content, lineaments, weathered and fractured rocks, drainage, groundwater levels, and vegetation with relation to geomorphological units.

3.1 Thematic layers

The present study uses multi-criteria, namely, LULC, slope, geology, soil, drainage density, and rainfall which are some factors known to affect the recharge of groundwater. Thematic maps were prepared using QGIS for these factors for further AHP and WOA studies.

Survey of India toposheets were used as the reference map by georeferencing and digitisation and for generating the drainage density. Geological data obtained from the District Resource Map of Geological Survey of India (GSI, 2001), was geo-referenced and digitized to obtain the geological map of the area. Landsat 8 was used for generating LULC layer (Vaddadi et al., 2022) and classified into four classes. The slopes for the area were calculated in degrees from Cartosat DEM image of 5 m resolution. Soil data was obtained from the soil map of the Indian National Bureau of Soil Survey and Land Use Planning (NBSS and LUP). The classification of soils given by NBSS and LUP is used in this study. High Spatial Resolution (0.25×0.25 degree) 'Gridded Rainfall Data Set Over India' data available from India Meteorological Department was used to create the rainfall map (Pai et al., 2014) (https://imdpune.gov.in/cmpg/Griddata/Rainfall_25_Bin.html). Drainage was digitized from toposheet, and the density was calculated using point density method in QGIS.

Geospatial data (Table 1) was processed using QGIS software, while weight generation and associated functions like Consistency Index and Consistency Ratio were calculated by the AHP method in Microsoft Excel. The input thematic layer data for the different layers was reclassified to obtain four or more discrete classes based on the available data and literature survey. The workflow used for the study is shown in Figure 2.

Table 1. Data sources

Data type	Resolution/Scale	Thematic layer	Data source
Landsat 8 OLI/TM	30 m	Land use/land cover	Earth Explorer - USGS
Cartosat DEM	5 m	Slope, drainage density	Bhuvan ISRO
District Resource Map - Geology	1:250,000	Geology (Lithology)	Geological Survey of India
Rainfall data	0.25×0.25 degree	Rainfall	India Meteorological Department
Soil map	1:250,000	Soil distribution	National Bureau of Soil Sciences and Land Use Planning

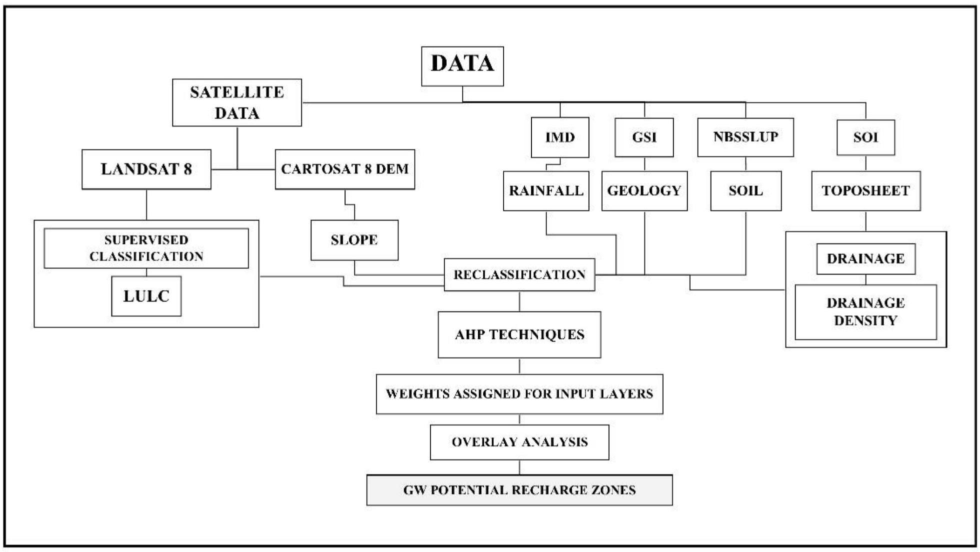

Figure 2. Workflow used in the analysis

3.2 AHP analysis

AHP is a decision-making procedure widely used in management for establishing priorities in multicriteria decision problems. It uses a structured mathematical process based on expert knowledge. AHP was first developed by Saaty (1987). Though introduced as a management tool, it has been used across disciplines as an effective tool for dealing with complex decision-making. AHP converts multi-dimensional complexity into a single dimension scale of priorities (Choosumrong et al., 2012).

The AHP process has also been widely used in GIS to normalize the assigned weights of different thematic layers. In this study, the weights of different thematic layers were assigned based on literature survey, published data and expert opinion for different environmental and geological conditions (Table 2).

Table 2. Input parameters

Rank	Thematic layer	Class	Class description	Weight/Sub rank	Area (km²)	Area (%)	Normalized weight
1	LULC	4	Vegetation	4	36.42	15.00	0.41
		3	Water	3	2.08	1.00	
		2	Barren land	2	86.37	34.00	
		1	Construction	1	125.65	50.00	
2	Slope	0-5°	Flat surface	6	189.52	75.28	0.23
		5-10°	V. gentle slope	5	44.39	17.63	
		10-15°	Gentle slope	4	12.06	4.79	
		15-20°	Moderate slope	3	4.37	1.73	
		20-25°	Steep slope	2	1.07	0.42	
		<25°	Very steep slope	1	0.36	0.14	
3	Drainage density	<80	Very low drainage	4	9.83	4	0.14
		80-160	Low drainage	3	78.89	32	
		160-240	Moderate drainage	2	115.06	46	
		>240	High drainage	1	46.62	19	
4	Rainfall	>4.8 mm/day	High rainfall	4	29.62	11.83	0.11
		4.1-4.5 mm/day	Moderate rainfall	3	142.63	56.95	
		3.8-4.13 mm/day	Low rainfall	2	55.28	22.07	
		<3.8 mm/day	Very low rainfall	1	22.93	9.16	
5	Soil	Type 1 (118*)	Loamy, mixed and iso-hyperthermic, moderate stoniness	5	104.44	42	0.07
		Type 2 (76*)	Clayey skeletal, strongly calcareous, strong stoniness	4	0.36	0	
		Type 3 (216*)	Fine, clayey, moderately calcareous, moderate stoniness	3	4.96	2	
		Type 4 (266*)	Fine, strongly Calcareous, clayey, montmorillonitic	2	4.89	2	
		Type 5 (244*)	Clayey, calcareous, moderate salinity, fine	1	135.86	54	
6	Geology	Karla formation	Dominantly compound pahoehoe flows	4	128.59	51	0.04
		Diveghat formation	Dominantly Aa’ and simple flows with thick FTB (Fragmented tops)	3	61.67	25	
		Indrayani formation	Aa’ flows with thick FTB (Fragmented tops)	2	58.91	24	
		Purandargarh formation	Aa’ and simple flows with thin FTB (Fragmented tops)	1	1.35	1	

*Soil types - Figures in parentheses indicate Index number as per NBSS and LUP map.

After the ranking of the criteria, the weight for each criterion was determined by using AHP to get a Pairwise Comparison Matrix (PCM) for the main decision criteria being used (Table 3). In doing a pairwise comparison, the relative importance of a set of criteria is decided for determining the suitability for a given objective. The comparison and rating between criteria are conducted using a 9-point continuous scale. (Saaty, 2008).

The following steps were adapted to allocate and normalize weights of the thematic layers using the AHP technique - (1) Defining the criteria; (2) Defining scaled rank (weights) for each criterion based on expert opinion and literature survey; (3) Establishment of pairwise comparison metrics (P) based on scaled ranks; (4) Calculation of the geometric mean; (5) Calculation of normalized weights; and (6) Calculation of consistency ratio to verify the coherence of judgments.

AHP process involves a PCM of the various criteria which influence a particular process to derive priority weightages. The influencing factors or themes are based on expert judgement.

The PCM is calculated on basis of assigned weightages and, shows how a particular criterion is significant when compared to the others Saaty (1987), Saaty (1990), and Saaty (2008). Based on PCM, the relative weight matrix and the normalized principal eigenvalue were derived to determine the percentage of contribution of each criterion.

Table 3. Pair-wise comparison matrix for the six themes and calculation of normalized weights by the analytic hierarchy process

Matrix	LULC	Slope	Drainage density	Rainfall	Soil	Geology	Normalized principal eigenvector
LULC	1	3	5	3	5	5	0.41
Slope	1/3	1	3	3	3	5	0.23
Drainage density	1/5	1/3	1	2	3	5	0.14
Rainfall	1/3	1/3	1/2	1	3	3	0.11
Soil	1/5	1/3	1/3	1/3	1	3	0.07
Geology	1/5	1/5	1/5	1/3	1/3	1	0.04

Each of the six thematic layer has four or more sub-classes, thereby making the relationships between these interdependent classes complex. The relationship between the factors and their relative importance is derived using the AHP. The result of the AHP is assignment of normalized weights which are then used in the weighted overlay analysis.

3.3 Overlay analysis

The final weights are obtained from the computation of the principal Eigenvector of the PCM. To evaluate the consistency of the pair-wise comparison in AHP, the Consistency Index (CI) is determined based on the maximum Eigen value, λmax.

λmax is calculated by summing up the product of each element in the relative weights (the Eigen vector) by the respective column total of the original comparison matrix.

The CI is determined by the equation below.

$$CI = -(\lambda max - n)/n - 1 \quad (1)$$

Where; λmax is the largest Eigen value of the matrix and can easily be determined from the matrix mentioned, and n is the number of factors or criteria being considered. In this case, the λmax obtained is 6.539 and the CI is 0.108.

To verify whether the CI is appropriate, Saaty (1990) suggests the Consistency Ratio (CR) which is determined as the ratio between the CI and the Random Consistency Index (RCI). The value of RI for selected ‘n’ values are as per the Consistency Index suggested by Saaty (1990).

$$CR = CI / RCI \quad (2)$$

The comparison matrix is consistent if the resulting CR is less than 10% (Saaty, 1990). If the CR exceeds 10%, it is necessary to rework the comparison matrix and recalculate the weights to get a better weighting scheme.

The CR obtained was 0.87 (8.8%) which is less than the threshold limit (0.1). This indicates that the weight assignment for the parameters used in this study is consistent.

4. RESULTS AND DISCUSSION

Anthropogenic alterations, which are a result of increasing urbanization lead to a major impact on the natural resources like water especially in terms of recharge potential. The quantitative impacts of urbanization include a general decline in groundwater level, a reduction of the areal extent of the aquifer, and a change in groundwater flow direction (Khazaei et al., 2004).

4.1 Thematic layers

To implement effective artificial recharge methods, it is important to determine potential recharge zones especially in urban areas. Several spatial factors come into play when considering potential zones for recharge by RWH. Besides rainfall, other factors like slope of the land and soil texture also play a crucial role in the recharge. The ranking of the criteria used in the study are summarized in Table 2.

Land use/land cover impacts the rate of surface runoff, infiltration, and utilization of the groundwater (Senanayake et al., 2016). Urbanization, especially concretisation leads to increased run-off and surface flow thereby reducing the water available for recharge. The LULC of an area is thus a particularly important influencing factor in recharge in an urban context. The greater the concretisation, the less is the recharge and hence LULC was given the highest attribute rank. Within LULC, the built-up area was given the lowest weight. Vegetated areas, wetlands and water bodies are considered to have high infiltration rates.

LULC was derived from Landsat 8 Satellite of 30 m Resolution for year 2019 (Vaddadi et al., 2022). The study area was classified into four classes Barren Land, Settlement, Water Bodies and Vegetation based on a Supervised Classification study (Figure 3). The analysis shows that a major part of the study area is occupied by constructions or built-up area which occupies about 125 km^2 (50%). About 86 km^2 (34%) is occupied by barren land. Vegetated areas and water bodies which are very good for infiltration together constitute 39 km^2 (16%).

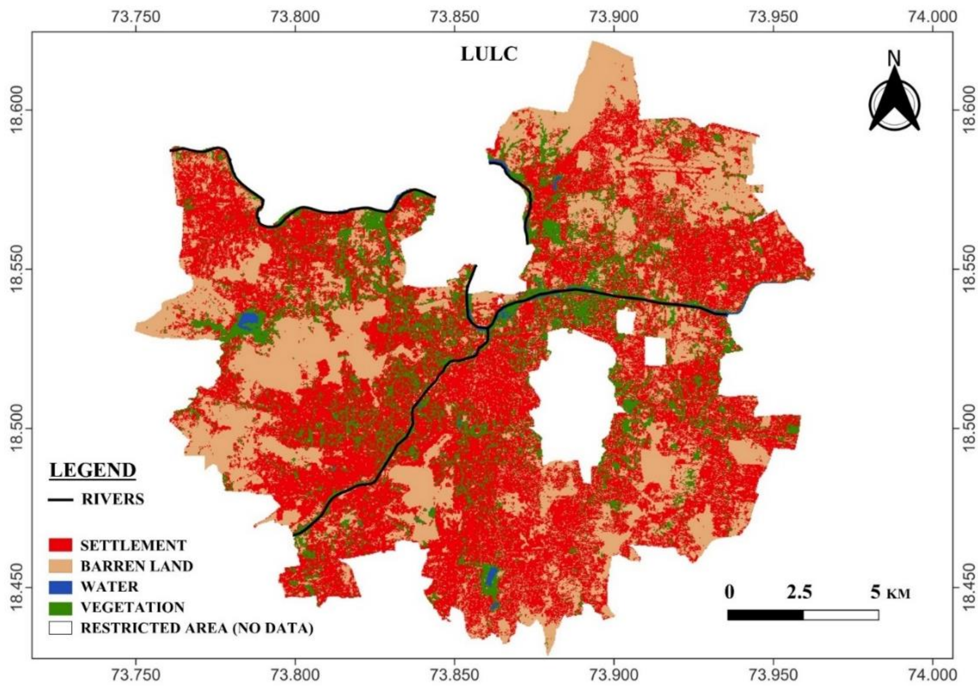

Figure 3. LULC map

The slope of an area influences rainfall infiltration and is an important parameter in recharge potential. Infiltration will be higher in low-slope areas where surface flow and run-off are less and where it takes more time to travel downstream, as compared to high slope areas where the run-off is higher and quicker (Rajaveni et al., 2015).

The slopes for the area were calculated in degrees from Cartosat DEM image of 5 m resolution. The slopes were classified into six classes with slope from 0-31°. The maximum areal extent in the study area was for range 1-5° (Flat surface). About 189 km^2 (75%) of the study area is flat and conducive to infiltration (Figure 4).

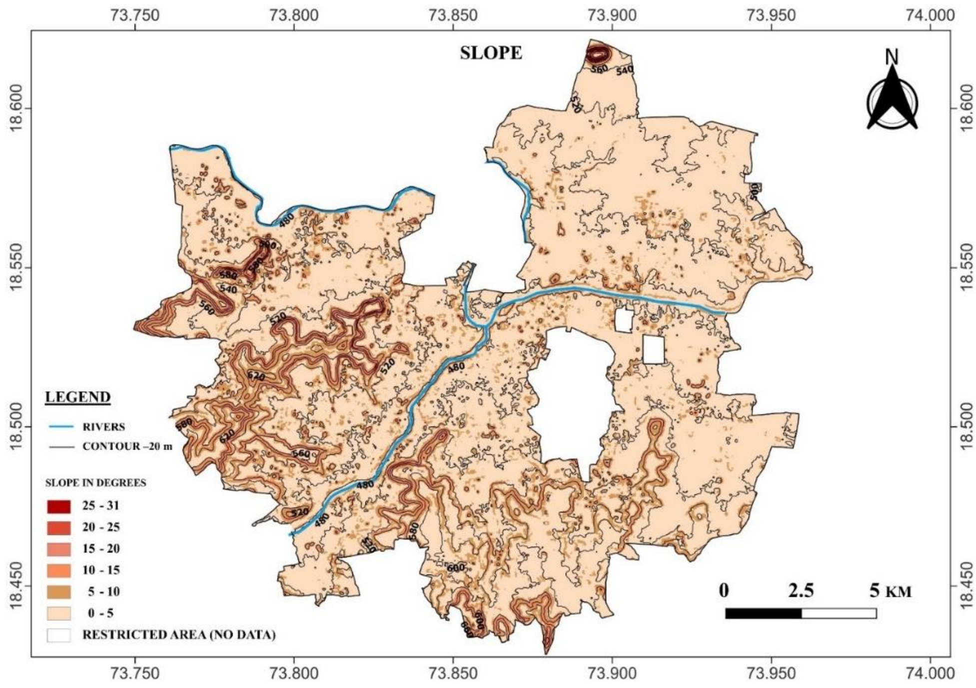

Figure 4. Slope map

Drainage density is a significant parameter which affects the groundwater recharge potential. A low drainage density region causes more infiltration and results in good groundwater potential zones as compared to a high drainage density region (Shekhar and Pandey, 2014). Drainage was digitized from toposheet, and the density was calculated using point density method in QGIS. The obtained densities were classified into four classes which ranged from 0.43-306.80. Of these classes, the areas occupying low and very low density which are good for ground water infiltration occupy about 162 km^2 (65%) of the area. Area with moderate density occupies an area of 79 km^2 (32%) and is also suitable for recharge. Drainage class with least density was assigned the highest weightage on account of the lower number of drainages per unit area (Figure 5).

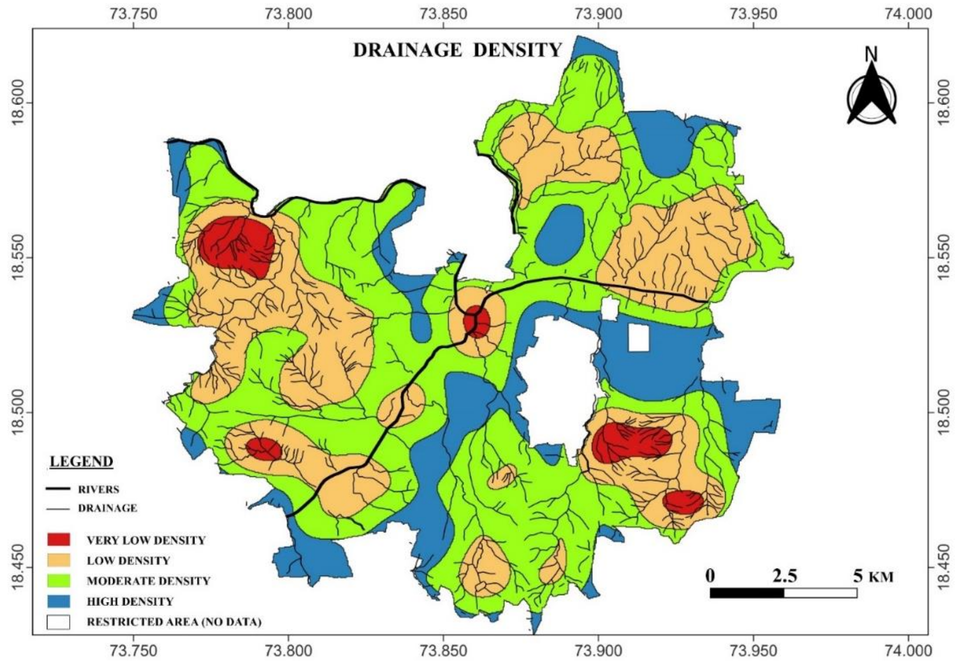

Figure 5. Drainage density map

Rainfall is essential to recharge. Groundwater is formed by rain infiltrating the ground. Using tritium injection studies, Rangarajan and Athavale (2000) estimated a linear relation between rainfall and natural recharge for major hydrogeological units like granites, basalt, sediments and alluvium. According to Mondal and Ajaykumar (2022), rainfall is the primary source of groundwater recharge, whereas irrigation areas, rivers, ponds, lakes, etc., are the secondary sources of groundwater recharge. Grid based rainfall data with a resolution 0.25×0.25 degrees was downloaded from India Metrological Department (IMD) site (https://imdpune.gov.in/cmpg/Griddata/Rainfall_25_Bin.html). This data was then converted to Rainfall point data by using the IMD data converter. This point data was then interpolated to create the Rainfall Map (Figure 6). Though rainfall is a key factor for assessing the suitability of a region for harvesting it was ranked much lower than LULC and slope since it was found that a major part of the city area is built up leading to run-off instead of infiltration.

The rainfall in the area ranged between a high of 4.79 and a low of 3.47 mm/day. Based on this, the study area was re-classified into four classes of high, moderate, low, and very low rainfall. These occupy 11.83%, 56.95%, 22.07%, and 9.16%, respectively.

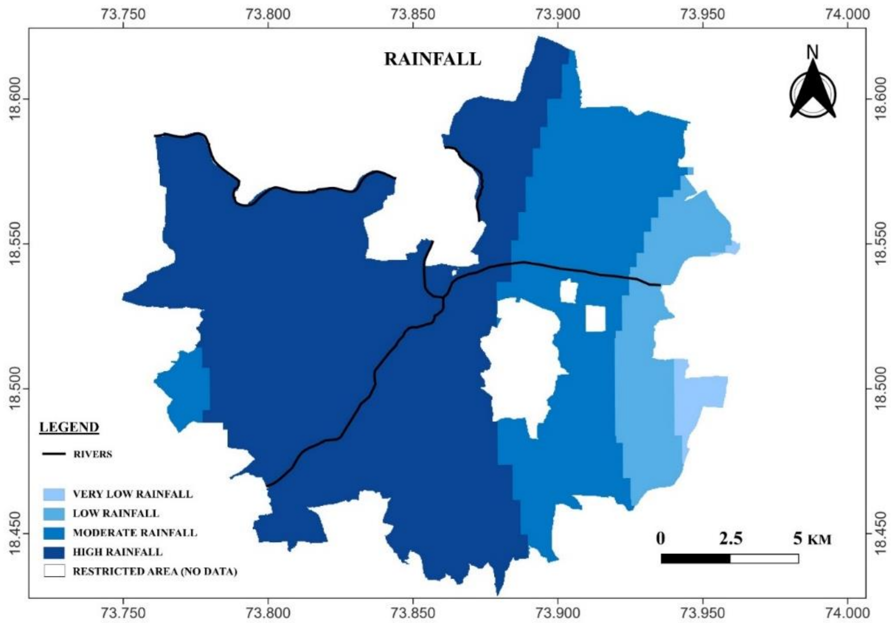

Figure 6. Rainfall map

Soil texture is another important parameter that influences rainfall infiltration into the ground. The rate and amount of infiltration depend on grain structure, size, and shape. Soil texture and hydraulic characteristics (permeability) influence rate of infiltration.

The soil map was obtained from NBSS and LUP. It was then clipped to the study area and used to create the soil type vector data. The classification of soils given by NBSS and LUP is used in this study. The study area exhibits five broad textural classes or types of soil (Figure 7). About 42% (104 km^2) of the area is occupied by loamy, mixed and iso-hyperthermic, moderate stoniness soil which is good for infiltration. Fine Clayey and calcareous soil occupies 136 km^2 (54%) of the area. The other layers together constitute only about 4% of the area. According to Cornell University (2010), Sandy loams, Loams, Clay loams or Clay soils have an infiltration capacity of 0.4 to 0.8, 0.2 to 0.4, and less than 0.2 inches per hour, respectively. Considering the texture and its sand content, Type 1 soil (loamy, mixed, and iso-hyperthermic soil) was given the highest rank and the Type 5 soil (clayey soil) the lowest rank.

The lithology of an area determines the infiltration capacity as different rocks exhibit different properties. Porosity differs from one type to another and has an essential effect on the recharging capacity (Senanayake et al., 2016). The lithology was derived from the District Resource Map of the Geological Survey of India (GSI, 2001). The resource map was georeferenced and digitized to obtain the geological map of the area. The area contains basaltic flows belonging to four different formations, namely, Karla,

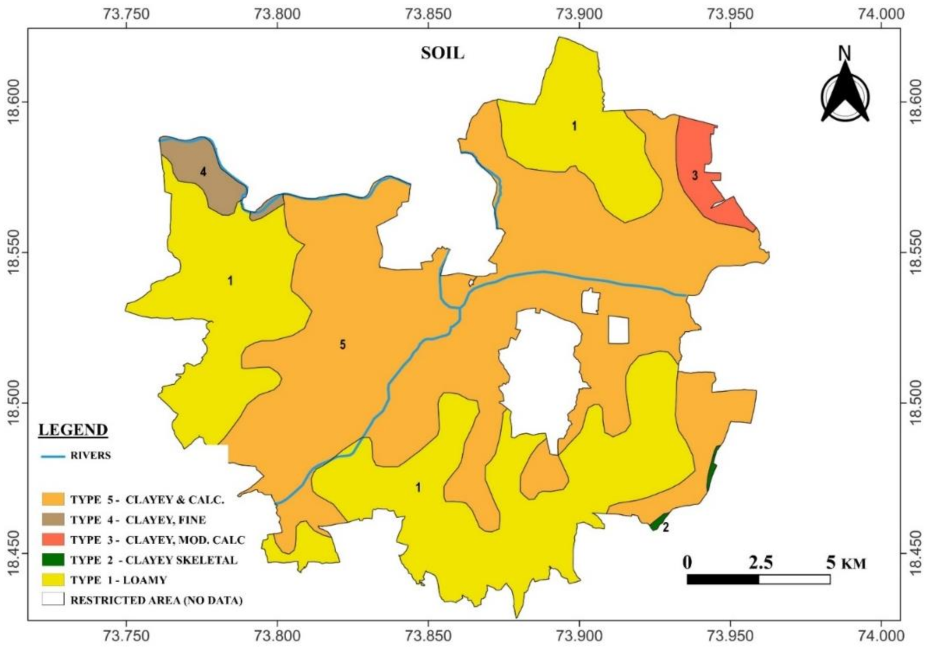

Figure 7. Soil map

Diveghat, Indrayani, and Purandargarh formations, each exhibiting distinctive characteristics (Figure 8) A major part, about 129 km^2 (51%) of the area is occupied by the Karla Formation constituted of dominantly compound pahoehoe flows. Other lithologies like aa' and simple flows with thick fragmented tops, known as Flow Top Breccia (FTB), predominantly aa' flows with thick FTB and aa' and simple flows with thin FTB constitute 25%, 24%, and 1% of the area, respectively. Being vesicular in nature, the compound pahoehoe flows show maximum recharge potential. According to Kulkarni et al. (2000), the weathering and jointing of the vesicular amygdaloidal basalt and the joints within the compact basalt create the aquifers. Aa' flows being compact and dense in nature do not exhibit much infiltration capacity.

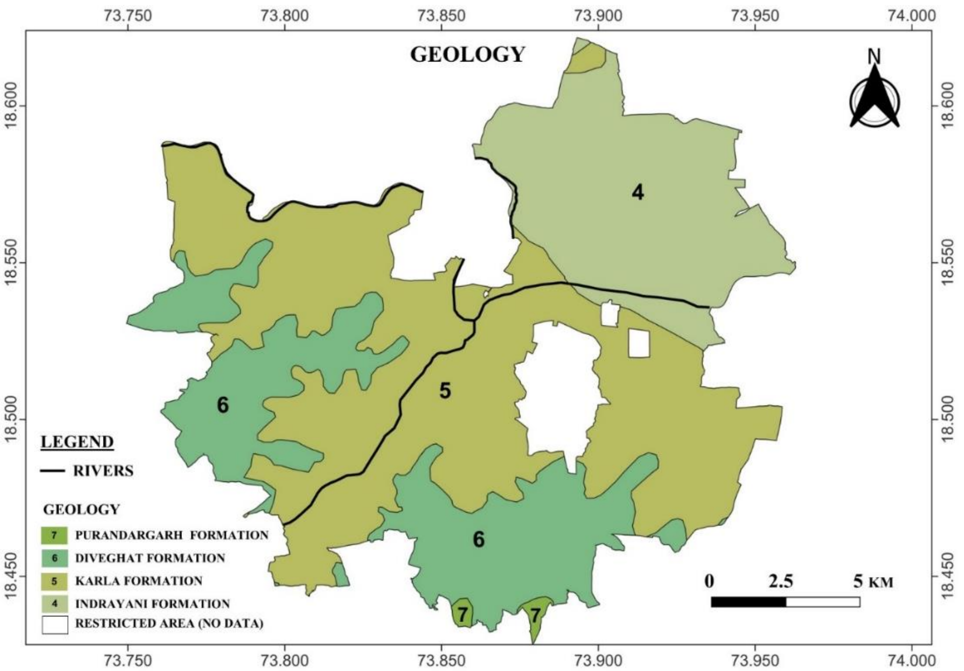

Figure 8. Geological map of the area

4.2 Groundwater recharge potential zones

After obtaining the weights from the AHP analysis, the six thematic layer maps were integrated using Weighted Overlay Analysis in the open source QGIS software to determine the Groundwater Recharge Potential (GRP). The following equation was used to estimate the groundwater potential.

$$\mathrm{GRP} = \sum_{i=1}^{6}(\mathrm{MC_i} \times \mathrm{w_i} \times \mathrm{r_i}) \quad (3)$$

Where; MC_1 and MC_6 are the 6 main criteria, w_1-w_6 are the normalized weights generated using AHP method and r_1-r_6 are the ranks given to the main criteria.

The groundwater recharge potential map of the study area generated through this weighted overlay analysis has been categorized into five zones, viz., low, moderate, good, high and very high potential. The Groundwater potential map (Figure 9) shows a coverage of 13.24 km^2 (5%), 124.71 km^2 (50%), 72.92 km^2 (29 %), 8.11 km^2 (3%), and 30.27 km^2 (12%) for the above zones, respectively.

Assessment of potential zones within the study area reveals that the high and good potential zones lie to the western part of the city. The central part or inner city, which is mainly built-up area, shows low potential for recharge. Earlier studies by Vaddadi et al. (2022) on roof top rainwater harvesting estimated the total water available for Rainwater harvesting in Pune city to be 49.05 Million Cubic Metres (MCM) and that effective recharge using RWH techniques could supplement the groundwater annually by about 22-25 MCM. The present study, when used in conjunction with the RWH studies, can provide effective strategies to manage systematic groundwater recharge of the shallow aquifers.

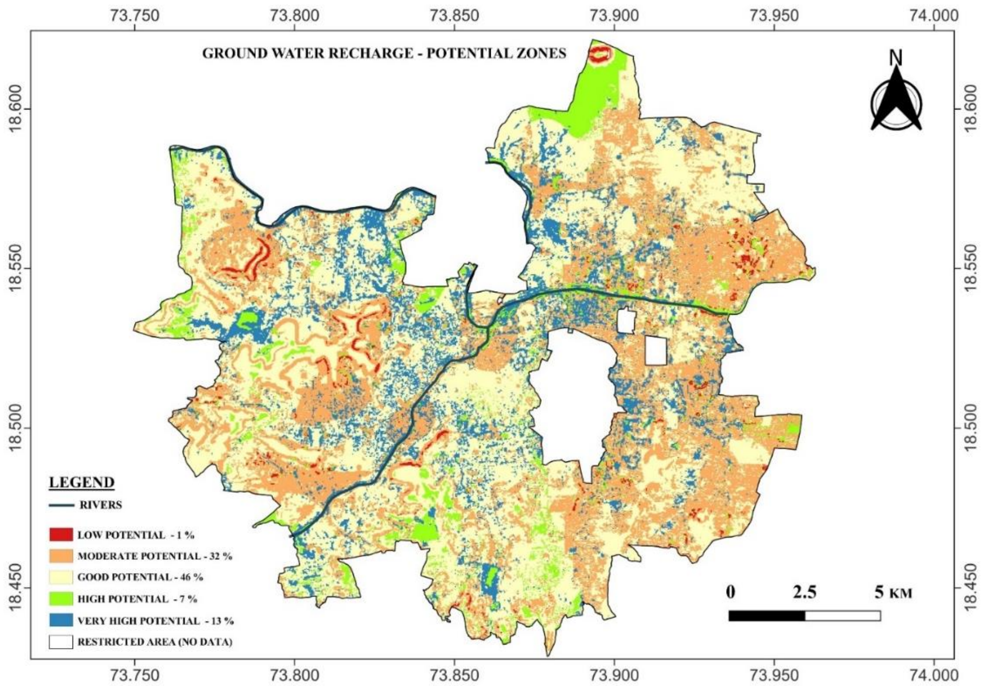

Figure 9. Map of ground water recharge potential zones

5. CONCLUSION

Use of rainwater harvesting for recharge of groundwater has become an effective method globally to maintain the water balance, overcome water crisis and to ensure sustainable water resources management, especially in urban growth areas. For effective recharge to happen, it is vital that the mapping and identification of groundwater potential zones in an area are done on a systematic and scientific basis.

The recharge potential for ground water zones was mapped using thematic layers, MCDA and AHP techniques. Groundwater in the study area is mainly controlled by the Land cover and use (LULC), Slope, Rainfall, Soil and Drainage Density, and lithological factors. Based on the study, the study area is classified into five classes, namely, low, moderate, good, very good and high groundwater potential. The results show a coverage of 5%, 50%, 29%, 3%, and 12% for the above zones, respectively. This indicates that nearly half (45%) of Pune city has good to high potential for recharge. Assessment of potential zones within the study area reveals that the high and good potential zones lie to the western part of the city. The central part or inner city which is mainly built-up area shows low potential for recharge. Though the city has seen rapid urbanisation in the last decade resulting in concretisation, major parts of the city show good potential for recharge. The prospective zones were also cross-checked with groundwater priority recharge maps published by the state's Groundwater Survey and Development Agency (GSDA, 2017). Comparison of the maps of representative areas show a good relationship between the two. The study is of immense importance, as the results when used in conjunction with the roof top RWH studies can help to identify effective sites/areas for recharge and to formulate a framework for systematic recharge of the existing aquifers in the area under study. Further, the workflow has been implemented using Open-Source Software and Open Data and is thereby applicable to other urban areas too.

ACKNOWLEDGEMENTS

We acknowledge with thanks Mr. Job Thomas for his help in the processing of data. The authors also thank Mr. Jeff McKenna, Gateway Geomatics, Canada for agreeing to review and suggest changes to the language and grammar for improving the manuscript. We also acknowledge with thanks the invaluable suggestions from the anonymous reviewers.

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