Indian Journal of Geo Marine Sciences
Vol. 49 (12), December 2020, pp. 1856-1865

Assessment of groundwater potential using geospatial techniques for urbanized Mambakkam mini-watershed, Kancheepuram district, India

S Packialakshmi*[,a], K Nagamani[b] & N K Ambujam[c]
[a]Department of Civil Engineering, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu – 600 119, India
[b]Centre for Remote Sensing and Geoinformatics, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu – 600 119, India
[c]Centre for Water Resources, Anna University, Chennai, Tamil Nadu - 600 025, India
*[E-mail: bagyaram@gmail.com]

Received 27 November 2019; revised 02 February 2020

Evaluation of groundwater potential and mapping using geospatial platform is crucial especially for semi-arid hard rock and coastal adjoining terrain to identify the zones of very good, good, moderate and poor groundwater potential. The Mambakkam mini watershed, Tamil Nadu (India) is situated towards the southern part of Chennai city. It is experiencing commercial development of groundwater in addition with escalating domestic and industrial demands. The present study is aimed to develop the mapping of groundwater potential zones for the selected urbanized watershed by using the remote sensing and geospatial techniques. Data like water level, water quality, rainfall, climatology and geophysical resistivity from various sources and satellite imageries have been used for this study to observe the changes on the sources of water resource system. The Inverse Distance Weighted (IDW) method was used for generating the thematic layers of rainfall, depth to bed rock, weathered rock, jointed rock and water levels. The generated village wise groundwater potential map has shown a vast spatial variability of ground water potential and the area that belongs to the "very good" potential category is quite less in the entire study area (12 %) which alarms the development of existing groundwater resource. The study concluded that considerable falling trend of groundwater level during pre-monsoon showing the alarming threat for further development. Thus the presented study identified the risk of groundwater development and provides guidelines to water resource mangers and village officials to recommend conservation and protection strategies against the uncontrolled commercial development especially on the identified poor groundwater potential zones.

[**Keywords**: Groundwater potential, Remote sensing and GIS, Thematic maps, Water level fluctuations, Weighted overlay]

Introduction

The dependency on groundwater has increased drastically due to population growth and induced urbanization and associated economic developmental activities. In most parts of the developing countries, especially in semi-arid regions, reliance on groundwater resource has increased tremendously in recent years due to the erratic monsoons and scarcity of surface water sources[1]. Chennai is one of the highly urbanized coastal cities in India with rapid industrial, commercial and residential growth which needs huge quantity of portable water to meet out the domestic needs and other requirements. The Mambakkam mini watershed is located in the southern part of Chennai metropolitan area. Surface water is the most important contributing source to the urban water requirements which is insufficient and the deficit is met by transferring the groundwater particularly from the peri-urban villages. The recent developments in the area have also exerted tremendous imbalances on the water supply requirements of the city and its peripherals. Thus urbanization and unplanned development of land and water resources causes adverse impacts on the peri-urban areas.

For the categorization of the ground water potential regions in the Mambakkam mini watershed, the conventional methods of identification of groundwater potential zones are very difficult and time consuming, whereas mapping and classifying the ground water potential zone through geospatial technologies are very fast and nearly accurate[2-5]. However, ground verification was performed to calibrate and rectify the image interpretation[6-9]. The successful development of groundwater necessitates proper understanding of hydro geological characteristics of aquifers[10]. The fluctuation behaviour of groundwater level in response to rainfall varied much with respect to thickness of unsaturated zone, geological properties, to the location of monitoring well etc. The generation of thematic layers such as terrain slope, lineament, geology and geomorphology and overlay analysis are used for deciphering groundwater potential zones[11-14]. It has an added advantage over conservative techniques and can be applied on a wider prospect to categorize potential regions for development of groundwater and its sustainable uses[15-18] . Due to increased dependency on groundwater, the groundwater pumping is exceeding the natural recharge rate. Hence the assessment of groundwater potential and scope for artificial recharge in the over developed watersheds is very crucial[19]. Development of potential mapping based on geospatial techniques has a wider acceptability in locating artificial recharge for the over developed mini watershed. The site specific recharge studies by developing different thematic layers and conducting overlay analysis after assessing individual weightages are effectively utilized to assess the groundwater availability[20]. The issues of over exploitation in certain regions are alarming the necessity of cautious and recoverable developments[21,22]. There is a crucial need to evaluate the aquifer potential to undersatnd the status of ground water resources in the regional level. The presented study extensively used the application of geospatial methodologies to create various thematic layers and weighted overlay analysis is used for mapping groundwater potential zonation.

Materials and Methods

Study area

The Mambakkam mini watershed, Kancheepuram District of Tamil Nadu, India, is situated in the southern direction of Chennai, and is bounded by coastal line in the eastern direction. The selected study area is having an area l coverage of 224 km^2.

Figure 1 shows the index map of the study area. It consists of three administrative blocks, namely Thiruporur, St.Thomas Mount and Kattankulathur covering 66 panchayat villages. It lies on slightly high land and hard rock terrain areas on the west and coastal plains on the east[23].

Hydrogeology of the study area

Major water bearing stratum is located in the consolidated (weathered and fractured granites, gneisses and charnockites) and semi consolidated (sandstones and shales) formations (Fig. 2). Archean rocks of charnockite formations occupied the western part and coastal alluvium with coramandal and sandstones occupied the easten part dictating the hydrogeology of the area. Geomorphological landforms of buried pediment (shallow, moderate and deep) and beach ridges indicated the occurrence of shallow aquifer in the areas of crystalline and coastal regions. Major portions of central regions is well connected with marshy land terrains in the direction of eastern coastal alluvium which causes ample

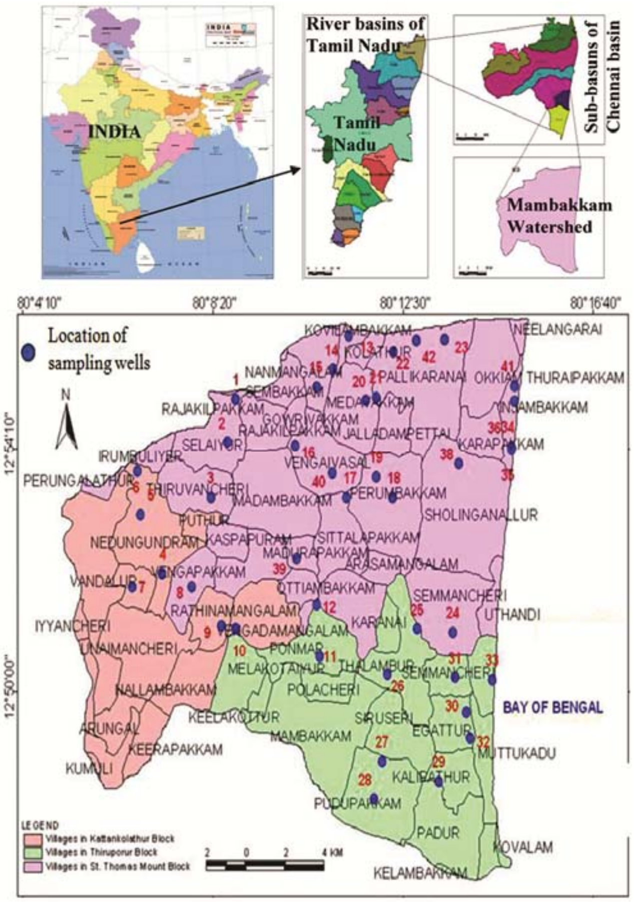

Fig. 1 — Study area map showing location of sampling wells

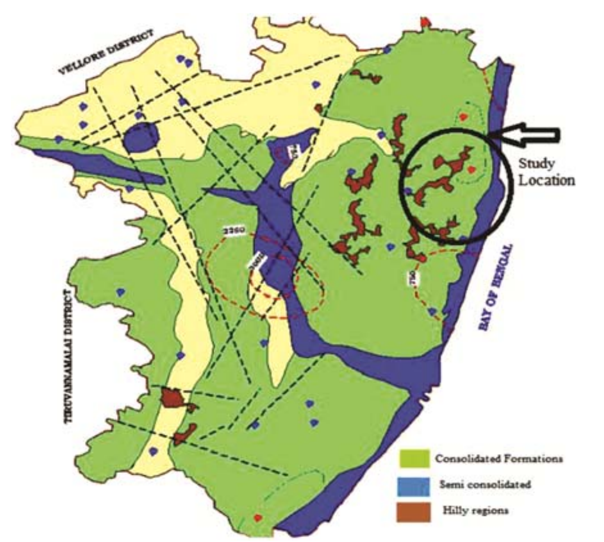

Fig. 2 — Hydrogeology map of the Kancheepuram disrict (Source: Groundwater brochure, Kancheepuram district, CGWB-Chennai, 2007)

groundwater potential than rocky western region. In the eastern coastal alluvium, the groundwater level fluctuated from 0.5 to 2.5 m during post monsoon (January) and 4.2 to 7 m during the pre monsoon (June) seasons, whereas in the western and central part of hard rock formation, the water level fluctuated between 0.5 to 3 m in the post monsoon and 5.6 to 10 m in the pre monsoon season[24,25].

Methodology

The general methodology employed for the present study includes data collection like satellite data, water level, water quality, rainfall, climatology, lithologs and geophysics resistivity data from various sources including the Tamil Nadu PWD, SG&SWRDC, TWAD Board, etc. The satellite imageries such as IRS-P6 LISS IV MX March 2008 and 2015 have been used for this study. The appropriate permission to use these imageries has been given by the Institute of Water Studies (IWS), Tamil Nadu. The hydro-meterological and hydro-geological data (2011-2016) have been collected from the State Surface and Groundwater Data Base Centre, Institute of Water Studies, Tamil Nadu and from Central Groundwater Board. In order to interpret and transform the information represented in the IRS satellite data, the various drawings and measuring instruments like light table, enlargement/ reduction machine and software such as Arc GIS 9.1, Arc View 3.2a and ERDAS 8.7 have been used during the research work for the preparation of thematic maps (Fig. 3).

The identification of objects and their classification from the hard copy is visually interpreted (Satellite Imagery on 1:50000 scale) based on image characteristics namely shape, tone, size, pattern, location, association, shade and texture. Using visual interpretation techniques, maps on different themes like geology, geomorphology, soil and lineament were prepared. Apart from this, base map, administrative map, drainage map, etc. were generated using topographical data. The digital satellite data was geo-rectified with sufficient control points on the ground obtained from the processed toposheets.

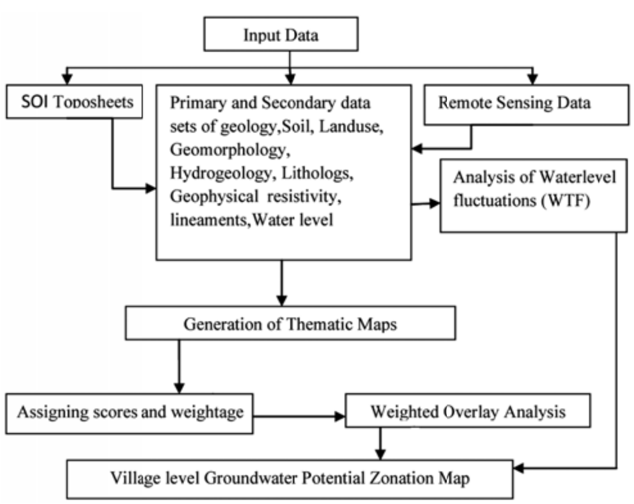

Fig. 3 — Methodolgy adopted to develop groundwater potential zonation map

Different themes interpreted on the film sheets from satellite and topographical data on a 1:50,000 scale were converted into raster format and these raster maps were processed geometrically using control points. The raster format was again converted into the vector format using Arc GIS software. Under the GIS environ, these vectorised themes with common projection coordinates were undergone overlay analysis so as to obtain integrated outputs. The Inverse Distance Weighted (IDW) method was adopted for generating the water level, depth to bed rock, weathered rock, jointed rock and rainfall map layers. In this method, the four neighbourhood locations were selected to identify the unknown point and elevation of interpolated location is related to these adjacent locations[26]. This relationship is represented as weighted input data points surrounding a raster position having inverse proportion to the specified power of their distance that is generally square or cubic from the pixel (Eq. 1).

$$H_P = \frac{\sum_{i=1}^{n} \frac{h_i}{{d_i}^2}}{\sum_{i=1}^{n}\left(\frac{1}{{d_i}^2}\right)} \quad \ldots (1)$$

Where, Hp is the interpolated elevational point of P and hi is the height of elevation of neighhood points; di is the distances of the points from point P; and n is the number of surrounding points selected for the interpolation process to estmate Hp[26].

Results and Discussion

This section discusses the components of soil, geology, geomorphology, lineaments, water level and aquifer characterization which are imperative for aquifer potential zonation and thematic maps were also generated for the study area. The generated thematic maps were analyzed in the geospatial environment to identify the favorable potential zones. The predominant soil types identified in this study area are Inceptisols, Entisols and Alfisols as shown in Figure 4a. Due to various stages of the fragmentation and weathering of the parent rock, the above soil types are seen in combination. The geology of the study area is derived from the geology resource map of Kancheepuram district developed by the Geological Survey of India as shown in Figure 4b. The western portion of the watershed is predominated by charnockite (orthopyroxene granite) and pyroxene granulite whereas coastal alluvium predominate the eastern portion of the study area. The exposures of charnockite are found along the western and south western periphery of the watershed in the form of low hills and hillocks. Isolated outcrops of charnockite are also noted in eastern and western parts of the study area. Pyroxene granulite occurs in and around the central regions. It is dark coloured, coarse grained and are composed of mainly pyroxene and highly weathered. Coastal alluvium includes beach ridges, sand dunes and beach sands and are found along the eastern coastal boundary of the study area.

Geomorphology

The investigation on geological and geomorphological characteristics is necessary in order to understand the rock and water-bearing characteristics as it has significant control over the groundwater potential[27-29]. There are 9 geomorphologic units derived from the satellite imageries, which were confirmed during the field check. Pediment covered the central region of the study area (Fig. 4c). The western portion was covered by denudational landforms, whereas coastal landforms occupied the eastern portion of the study area.

Lineament

A Lineament is a representation of linear feature in a landscape associated with faults, joints, depressions and fractures. Anthropogenic linearities such as roads,

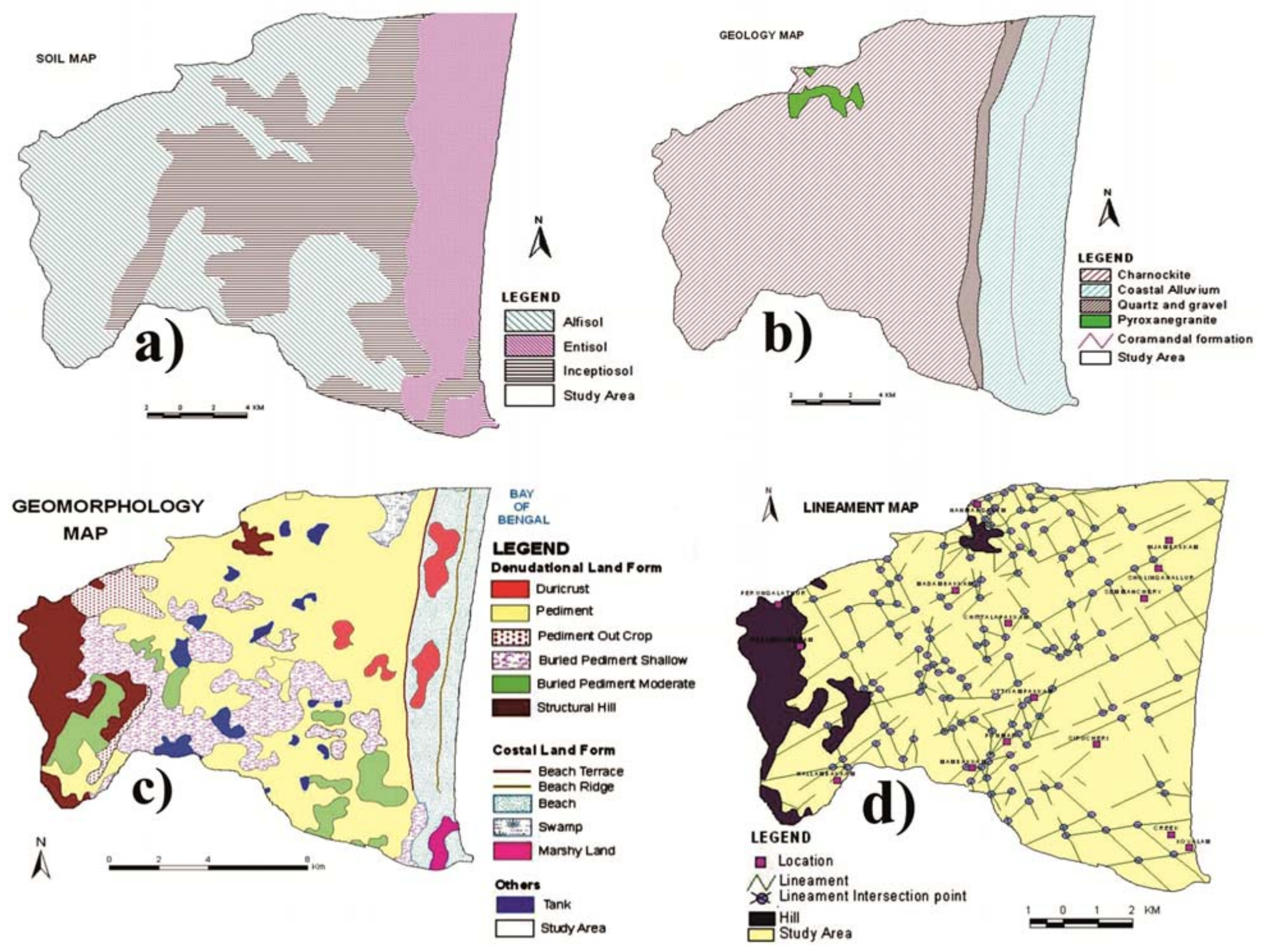

Fig. 4 — a) Soil map of the study area; b) Geology map of the study area; c) Geomorphology map of the study area; and d) Lineaments in the study area

rail networks and power lines etc. are not considered in the analysis (Fig. 4d). High density lineaments contribute to more groundwater recharge of the area[30-33]. Three sets of lineaments are recorded in the area, *viz*. NNE-SSW to NS, NW–SE and NE–SW. The north south lineaments that occur west to the Buckingham canal are indicative of the contact between charnockite and gritty sandstone. The remaining lineaments correspond to the foliation trend and fracture zones. Most of the drainages in this watershed are controlled by lineaments. The northwest – southeast lineaments mainly and the southeast – northwest lineaments to some extent control the twists and turns of the drainages. The elevational aspect information was directly obtained from the Digital Elevation Model (DEM) as shown in the Figure 5. These thematic layers were processed under the Arc View GIS environment and were prepared for the final generation of the output layer.

Aquifer characterization

The data on the geophysical resistivity survey collected from the study conducted by Nachimuthu[27] for the Mambakkam mini watershed were used in the present study in order to characterize the aquifer underlying the watershed. By analyzing the resistivity values and the lithology data collected from the State Groundwater Board, the point values of the depth to bedrock, fractured rock, and weathered rock have been assessed in selected locations of the study area. These values are used to generate the thematic layers of depth to bedrock, weathered rock and fractured rock as one of the important indicators to understand the nature of the aquifer. Further, the final output of these maps were verified with field check and simillar studies conducted in the study area. In the western portion of the study area which is a rocky terrain, the depth to bed rock is very less when compared to other regions. The central region has a greater depth to bed rock, and increased weathered and fractured layer thickness, that increases the groundwater potentiality in the particular zone.

The groundwater levels were periodically monitored from May 2015 to May 2016 for assessing the monsoon (May-January) and non-monsoon fluctuations (January-May). Forty two representative shallow wells were selected to analyse temporal (monsoon and Non-monsoon fluctuations) and spatial variations in groundwater levels (Table 1). These wells were selected and numbered in the order of proximity from the urban developments. Well No. 1 to 27 are located near to urban or peri-urban fringe and the others were located near to coastal stretch. Wells which are experiencing commercial explotation showed significant non-monsoon fluctuations (NMF) than monsoon fluctuations (MF). In the pre-monsoon, some of the wells located in the central region of the study area show a steep fall in the water level of more than 10 m, but in the post-monsoon, they showed a water level of around 3 m depth. For developing groundwater potential zonation, only pre-monsoon water levels are considered as these levels are showing significant fluctuations than post monsoon. This is one of the fast developing regions, and the prevailing groundwater market also causes the deepest water level during the pre-monsoon. By

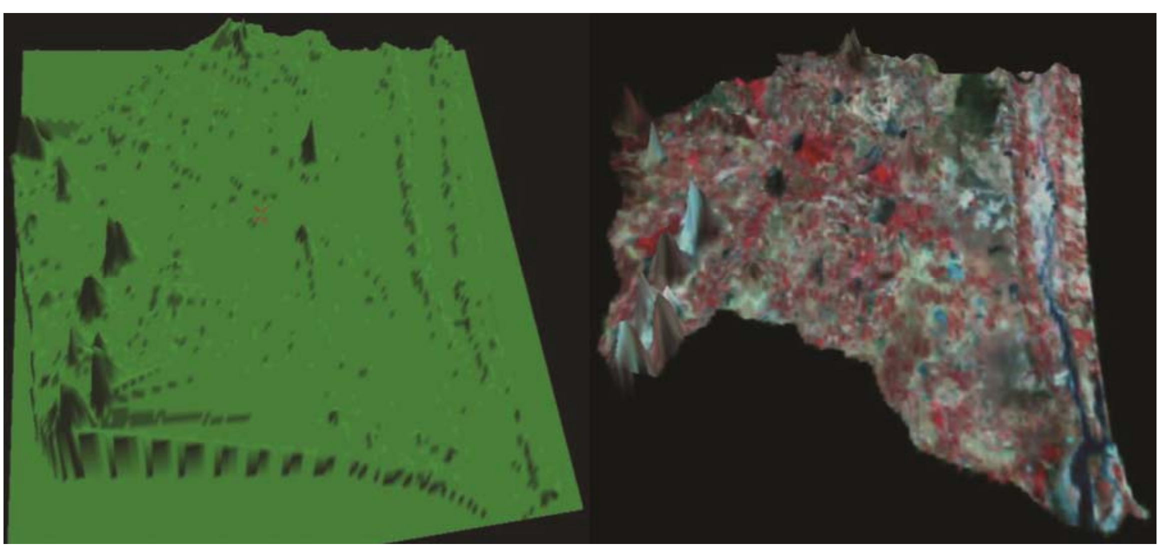

Fig. 5 — Digital elevation model of study area

Table 1 — Monsoon and non-monsoon fluctuations in the sampling wells

Sl. No	Lat (N)	Long (E)	Formations	M.S.L	May-15	Jan-16	May-16	MF	NMF
1	12.919	80.146	Hardrock terrain	26.00	18.9	24	20.43	5.1	3.57
2	12.902	80.144	Hardrock terrain	23.00	18.7	22.1	18.7	3.4	3.4
3	12.886	80.138	Hardrock terrain	16.00	10.6	15.01	11.8	4.41	3.21
4	12.864	80.120	Hardrock terrain	21.00	18.1	20.1	16.9	2	3.2
5	12.881	80.112	Hardrock terrain	25.00	18.2	23.3	17.9	5.1	5.4
6	12.898	80.108	Hardrock terrain	31.00	26.4	28.4	23.6	2	4.8
7	12.860	80.109	Hardrock terrain	30.00	26.4	29.32	24.4	2.92	4.92
8	12.860	80.131	Hardrock terrain	25.00	19.65	24.2	20.5	4.55	3.7
9	12.849	80.142	Hardrock terrain	28.00	24	26.9	24.1	2.9	2.8
10	12.848	80.145	Hardrock terrain	26.00	21.55	25.55	22.65	4	2.9
11	12.840	80.178	Hardrock terrain	8.00	3.1	7.7	3.4	4.6	4.3
12	12.855	80.177	Hardrock terrain	7.00	3.5	6.7	3	3.2	3.7
13	12.934	80.188	Hardrock terrain	12.00	-1.25	9.1	-3	10.35	12.1
14	12.923	80.183	Hardrock terrain	16.00	9.65	12.8	8.9	3.15	3.9
15	12.918	80.177	Hardrock terrain	20.00	14.9	15.95	14.5	1.05	1.45
16	12.901	80.169	Hardrock terrain	17.00	13.4	16.32	12.95	2.92	3.37
17	12.886	80.188	Hardrock terrain	10.00	5.75	8.35	5.7	2.6	2.65
18	12.886	80.205	Hardrock terrain	5.00	1.5	2.4	0.9	0.9	1.5
19	12.892	80.199	Hardrock terrain	3.00	-3.55	-0.1	-4.3	3.45	4.2
20	12.914	80.195	Hardrock terrain	16.00	9.55	13.1	8.3	3.55	4.8
21	12.915	80.199	Hardrock terrain	7.00	0.4	5.3	-0.8	4.9	6.1
22	12.933	80.204	Hardrock terrain	10.00	5.05	9.14	4.3	4.09	4.84
23	12.937	80.212	Hardrock terrain	3.00	-2.25	2.4	-2.45	4.65	4.85
24	12.847	80.227	Coastal Alluvium	9.00	3.7	7	4.6	3.3	2.4
25	12.848	80.214	Coastal Alluvium	6.00	-0.6	2.4	-0.5	3	2.9
26	12.835	80.203	Coastal Alluvium	9.00	-0.15	1.2	0.5	1.35	0.7
27	12.811	80.202	Coastal Alluvium	11.00	3.6	10.1	5.2	6.5	4.9
28	12.799	80.198	Coastal Alluvium	13.00	8.75	12.05	8.7	3.3	3.35
29	12.804	80.222	Coastal Alluvium	7.00	2.75	5	3.5	2.25	1.5
30	12.824	80.232	Coastal Alluvium	4.00	0.2	2.4	1.2	2.2	1.2
31	12.834	80.228	Coastal Alluvium	10.00	5.7	8.1	6.7	2.4	1.4
32	12.81667	80.23333	Coastal Alluvium	7.54	4.42	5.85	5.5	1.43	0.35
33	12.83333	80.24167	Coastal Alluvium	9.83	7.99	9.96	8.25	1.97	1.71
34	12.91667	80.25278	Coastal Alluvium	8.08	6.87	8.17	7.05	1.3	1.12
35	12.9	80.25	Coastal Alluvium	9.13	6.04	7.59	6.39	1.55	1.2
36	12.9	80.24917	Coastal Alluvium	9.71	6.67	8.25	5.91	1.58	2.34
37	12.91667	80.2528	Coastal Alluvium	7.76	2.44	5.33	2.99	2.89	2.34
38	12.89583	80.22917	Coastal Alluvium	6.30	4.69	6	4.55	1.31	1.45
39	12.52	80.17167	Hardrock terrain	12.52	9.55	11.79	10.21	2.24	1.58
40	12.85	80.17028	Hardrock terrain	17.27	15.37	16.89	14.7	1.52	2.19
41	12.91833	80.25111	Coastal Alluvium	8.71	5.27	6.33	5.4	1.06	0.93
42	12.935	80.20694	Hardrock terrain	10.50	8.07	12.02	8.18	3.95	3.84

observing trend lines of both Figures 6 (a) and (b), the representative wells which are locating near to the urban developments and the places of commercial exploitations were experiencing higher fluctuations than the wells which are located far away from the peri-urban fringe.

Groundwater potential evaluation under GIS environ

The ground water potential map has been prepared by integrating the thematic information on geomorphology, geology, lineament, rainfall, pre-monsoon water level, depth to bed rock, soil, land use and slope, by giving appropriate weightages. The layers of geology, geomorphology, lineament and landuse themes were interpreted from the satellite data and were digitized in the vector format. For the lineaments, buffer zones were created with a 10 m width, which is optimum for the influence and occurrence of groundwater. The point data such as, water level, rainfall and bed rock characteristics were obtained by interpolation and the processed thematic layers were structured into a GIS environ. The scores for different classes of identified map layers were considered for calculating the weightages. In the layer of geology, the classes of pyroxene granulite and quartz and gravel are considered as low potential structures to groundwater due their physical properties of being primarily hard, compact in nature and lack of primary porosity when compared to weathered charnockite and coastal alluvium. Likewise, all the thematic layers were given a relative weightage by considering the classes of relavent hydrogeological formations that represented its range of potential and storage of groundwater (Table 2). The Nominal Group Technique was employed to allocate the weightages and scores for the related thematic layers and the sub-classes were selected accordingly. In that technique, ranking of targeted themes were performed as per the expert opinion and the outputs of simillar studies. Each grid cell attained a value through an additive overlay technique which generated the raster formatted output layer. Greater value of the grid cell, is considered as the most preferred cell, which is located in the favorable groundwater potential zone. This has been assessed by considering possible maximum and minimum grid values calculated and are given in Table 1.

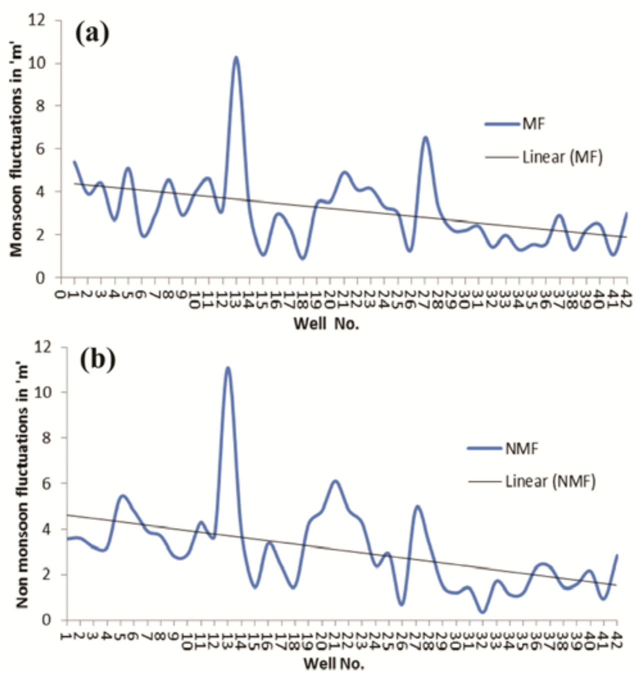

Fig. 6 — Groundwater level fluctuations a) between May 2015 – January 2016; and b) between January 2016 – May 2016

Pyroxene granulite, gravel and quartz are considered as low aquifer potential due to lack of primary porosity. These terrains are primarily hard and highly compact in nature. Therefore groundwater flow is complicated in these rocky structures. The areas of low drainage density lead to high permeation resulting in good groundwater potential regions when compared to denser drainage areas[34,35]. High drainage density is favourable zone for runoff generation rather than infiltration potential. Pediment outcrop and structural hills are having low potential prospects due to higher rate of runoff and related low ranges of infiltration. Urbanized pockets are classified as less permeable and low hydraulic conductivity zones. The major groundwater storing and controlling features such as lithology, intersection of lineament, slope, geomorphology, land use, and drainage are significant

Table 2 — Calculated minimum and maximum grid cell values for assessing favourable potential zonation

Map layer	Min. grid cell score	Max. grid cell score	Weightaige of the layer	Min. grid cell value	Max. grid cell value
Geomorphology	1	9	18.38	18.38	165.42
Geology	1	7	8.76	8.76	61.32
Lineament	1	8	15.72	15.72	125.76
Rainfall	4	6	16.63	16.63	99.78
Pre-monsoon water level	1	7	4.23	4.23	29.61
Depth to bed rock	1	9	12.34	12.34	111.06
Weathered rock	1	6	6.58	6.58	39.48
Fractured rock	1	5	6.10	6.10	30.5
Soil	1	7	7.19	7.19	50.33
Landuse	1	9	5.13	5.13	41.04
Slope	1	7	6.21	6.21	43.47

to groundwater occurrences and movement in the study area. By comparing geology map and water level map, it is inferred that central region of marshland terrain, fractured charnockite and eastern coastal alluvium exhibit appreciable groundwater potential than rocky western regions which is well correlated with water level map. The process of interpretation under GIS environ, helps in developing the groundwater potential zonation map (Fig. 7). The potential zonation map clearly confirms the groundwater potential areas of the Mambakkam mini watershed. The village wise groundwater potential is obtained by overlaying the village theme on the output of potential mapping.

This study has shown the large spatial variability in groundwater potential zonation. This variability closely followed the variability in the structure, geology, geomorphology, lineaments density, land use and aquifer thickness in the investigated area. The central region of the study area comes under the good and favourable potential zones, where most of the shallow agricultural wells act as a source for commercial extraction. The intersection of northwest – southeast lineaments and the southeast – northwest lineaments located in the central region results in improved permeability and secondary porosity. The major portion of the moderate to poor potential zonation occupies the western and southern part of the study area. The majority of poor groundwater potential zones are located in the western part related to the higher elevated area and rocky terrain, than the central region of the study area. The packaged water

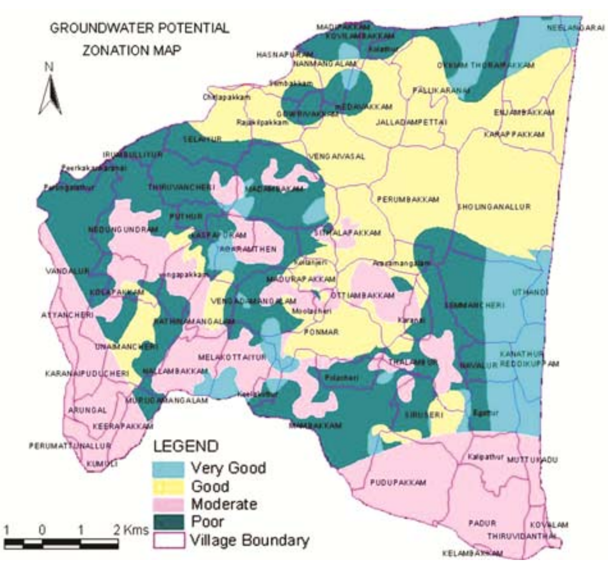

Fig. 7 — Mapping of groundwater potential zonation

industries, which are located in the western part of the study area, augment the groundwater directly from the very deep aquifer which is affecting the static reserve of the aquifers. The villages located in the northern direction of the study area are having appreciable potential in some pockets, but their quality is not substantial due to geogenic and anthropogenic reasons. In the southeast portion of the study area, which is involved in the commercial development of the groundwater particularly during summer periods and also in the less rainfall period, should be protected against uncontrolled commercial extraction and this should be minimized to a greater extent. Several researchers have reported the similar findings in their studies[36-40].

The area that belongs to the very good groundwater potential zone is quite less in the entire study area (very good – 12 %; good – 23 %; moderate – 27 % and poor – 38 %) which alarms the existing as well as the future development of the groundwater potential zones. By observing the trend of groundwater development especially for the commercial purposes and prevailing water level fluctuations, the scanty proportion of good potential zones will also be stressed further. This shows that land and water resources located in the peri urban fringes are highly occupied for urban related activities. The developed groundwater potential zonation mapping may be helpful for providing strategic measures to improve the prevailing scenario for optimal development of aquifers. Hence the study argued the importance of conservation and recharging strategies in the identified hot spots in order to sustain the resource base for future.

Conclusion

The knowledge and awareness on the occurrence, movement and stage of development of groundwater is imperative especially in the regions like semi-arid and hard rock terrains. In the national as well as in the international context, the areas which are located in the urban fringe have undergone severe stresses related to land and water resources as these are in high demand for urban activities. The extraction of groundwater for commercial purposes, decline of agricultural activities and lack of awareness on recharge mechanisms are threatening the static reserve of the aquifers. It results in the alarming depletion of the groundwater level especially in the 'below normal' rainfall years. This situation urges the periodical evaluation of the groundwater potential to preserve the aquifer system, to balance the ground water recharge and discharge conditions, and plan for a sustainable development of this mini watershed. The generated potential map would provide the basic outline for locating recharge structures for further augmentation and protecting vulnerable zones. From groundwater potential mapping, it is indicated that area belonging to very good categorization is quite less in the entire study area (12 %) which threatens the future developments of groundwater. The eastern coastal boundary of the study area also urges the rigid monitoring mechanism for safeguarding the freshwater aquifers from the ingression of saline water. Further, the study explored that most of the commercial extraction wells are targeting the meager portions of very good and good potential areas of the study area which causes the severe damages and irreversible effects on the freshwater aquifers. In view of these, the study suggested the intensive monitoring and stringent regulatory measures for further development.

Supplementary Data

Supplementary data associated with this article is available in the electronic form at http://nopr.niscair.res.in/jinfo/ijms/IJMS_49 (12) 1856-1865_SupplData. pdf

Acknowledgements

The baseline study of the present work was conducted under the Interdisciplinary Water Resources Project in association with Saci WATERs, Hyderabad (India) and the Government of Netherlands. The authors are thankful to State and Central Water Resources Department for providing the data sources to conduct the present research. They are grateful to the anonymous peer reviewers for their valuable suggestions.

Conflict of Interest

There is no conflict of interest.

Author Contributions

SP: Collection of data, analysis and interpretation; KN: Mapping of thematic layers; SP & KN: Analysis of field data with GIS outputs; and NKA: Critical analysis and concluding remarks.

References

1 Abdalla F, Mapping of groundwater prospective zones using remote sensing and GIS techniques: A case study from the Central Eastern Desert, Egypt, *J African Earth Sci*, 70 (27) (2012) 8-17.

2 Jha Madan K, Chowdary V M & Chowdhury A, Groundwater assessment in Salboni Block, West Bengal (India) using remote sensing, geographical information system and multi-criteria decision analysis techniques, *Hydrogeol J*, 18 (2010) 1713-1728.

3 Pandey V P, Shrestha S & Kazama F, A GIS-based methodology to delineate potential areas for groundwater development: a case study from Kathmandu Valley, Nepal, *Appl Water Sci*, 3 (2013) 453–465. doi: 10.1007/s13201-013-0094-1

4 Arkoprovo B, Adarsa J & Prakash S S, Delineation of groundwater potential zones using satellite remote sensing and geographic information system techniques: A Case study from Ganjam district, Orissa, India, *Res J Recent Sci*, 1 (9) (2012) 59-66.

5 Bagyaraj M, Ramkumar T, Venkatramanan S & Gurugnanam B, Application of remote sensing and GIS analysis for identifying groundwater potential zone in parts of KodaikanalTaluk, South India, *Fron. Earth Sci*, 7 (2013) 65-75. doi: 10.1007/s11707-012-0347-6

6 Saravanan S, Identification of Artifical Recharge sites in a hard rock terrain using remote sensing and GIS, *Int J Earth Sci Eng*, 5 (6) (2012) 1590-1598.

7 Pinto D, Shrestha S, Babel M S & Ninsawat S, Delineation of groundwater potential zones in the Comoro watershed, Timor Leste using GIS, remote sensing and analytic hierarchy process (AHP) technique, *Appl Water Sci*, 7 (2017) 503-519. DOI 10.1007/s13201-015-0270-6)

8 Kumar P, Herath S, Avtar R & Takeuchi K, Mapping of groundwater potential zones in Killinochi area, Sri Lanka, using GIS and remote sensing techniques, Sustain, *Water Resour Manag*, 2 (2016) 419-430. DOI 10.1007/s40899-016-0072-5

9 Hussein A A, Govindu V & Nigusse A G M, Evaluation of groundwater potential using geospatial techniques, *Appl Water Sci*, 7 (2016) 2447-2461. DOI 10.1007/s13201-016-0433-0

10 Jin-Yong L, Myeong-Jae Y & Daekyoo H, Dependancy of hydrologic responses and recharge estimates on water level monitoring locations within a small catchment, *Geosci J*, 9 (3) (2005) 277-286.

11 Sreedhar G, Vijaya Kumar G T, Murali Krishna, Ercan K & Cuneyd D, Mapping of groundwater potential zones in the Musi basin using remote sensing data and GIS, *Adv Eng Softw*, 40 (7) (2009) 506-518.

12 Jasmin I & Mallikarjuna J, Review: Satellite-based remote sensing and geographic information systems and their application in the assessment of groundwater potential, with particular reference to India, *Hydrogeol J*, 19 (4) (2011) 729-740.

13 Suja Rose R S & Krishana N, Spatial analysis of groundwater potential using remote sensing and GIS in the Kanyakumari and Nambiyar basins, *J Indian Soci Remote Sens*, India, 37 (4) (2009) 81-692.

14 Adji T N & Sejati S P, Identification of groundwater potential zones within an area with various geomorphological units by using several field parameters and a GIS approach in Kulon Progo Regency, Java, Indonesia. Arabian J Geosci, 7 (1) (2014). doi:10.1007/s12517-012-0779-z

15 Chusanatus S, Siriral U, Sitisak M, Teerawash I, Kewaree P, *et al*., Application of GIS techniques for determining suitable

areas for Managed Aquifer Recharge in the lower Ping-Yom river basin Thailand, *XXXVIII IAH Congress, Groundwater Quality Sustainability, Krakow, University of Silesia*, 2 (2010) 1961-1972.

16 Singh C K, Shastri S, Singh A & Mukherjee S, Quantitative modeling of groundwater in Sutlej river basin, Rupnagar district, Punjab using remote sensing and GIS, *Environ Earth Sci*, 32 (2011) 871-881. doi 10.1007/s 12665-010-0574-7.

17 Satheesh Herbert Singh D, Manjubashini A, Meenu V J, Meribha Titus G S & Juliet S, Integrated Groundwater Quality Assessment Using GIS In Thirukalukundram Area, Kancheepuram District, Tamilnadu, *Int J Innovat Res Sci Engg Technol*, 3 (1) (2014) 8441-8446.

18 Thapa R, Gupta S, Guin S & Kaur H, Assessment of groundwater potential zones using multi-influencing factor (MIF) and GIS: a case study from Birbhum district, West Bengal, *J Appl Water Sci*, 7 (2017) 4117–4131. DOI 10.1007/s13201-017-0571-z

19 Maggirwar & Bhavana Umrikar N, Possibility of artificial recharge in over developed miniwatersheds: A RS-GIS approach, *e-Journal Earth Science India*, 2 (2) (2009) 101-110. http://www.earthscienceindia.info/

20 Nag S K & Ghosh P, Delineation of groundwater potential zone in Chhatna Block, Bankura District, West Bengal, India using remote sensing and GIS techniques, *Environ Earth Sci*, 70 (2013) 2115-2127. doi:10.1007/s12665-012-1713-0

21 Arya S, Vennila G & Subramani T, Spatial and seasonal variation of groundwater levels in Vattamalaikarai River basin, Tamil Nadu, India - A study using GIS and GPS, *Indian J Geo-Mar Sci*, 47 (09) (2018) 1749-1753.

22 Brkić Z, Kuhta M, Larva O & Gottstein S, Groundwater and connected ecosystems: an overview of groundwater body status assessment in Croatia, *Environ Sci*, Europe, 31 (75) (2019) pp. 20.

23 Packialakshmi S & Ambujam N K, A Hydrochemical and geological investigation on the Mambakkam Mini watershed, kancheepuram District, Tamil Nadu, *J Environ Monit Assess*, 184 (2012) 3293–3306. DOI 10.1007/s10661-011-2189-1

24 District Groundwater Brochure, Kancheepuram water Year, 2007

25 Packialakshmi S, Application of Groundwater Balance Equation for Estimating the Stage of Groundwater Development in the Urbanized Environment, *Int J Earth Sci Engg*, 08 (3) (2015), pp 256-258. ISSN 0974-5904

26 Achilleos G A, The Inverse Distance Weighted interpolation method and error propagation mechanism – creating a DEM from an analogue topographical map, *J Spat Sci*, 56 (2) (2011) 283–304.

27 Nachimuthu S, Recharge capacity and hydrogeochemistry of Mambakkam mini watershed, Kancheepuram District, Tamil nadu, India- A Geophysical and geochemical Approach, (Unpublished Ph.D Thesis, Madras University, Chennai, Tamil Nadu), 2008.

28 Vijith H & Satheesh R, Geographical Information System based assessment of spatiotemporal characteristics of groundwater quality of upland sub-watersheds of Meenachil River, parts of Western Ghats, Kottayam District, Kerala, India, *Environ Geol*, 53 (1) (2007) 1-9.

29 Ramkumar T, Venkatramanan S, Anitha Mary, Tamilselvi M & Ramesh G, Hydrogeochemical quality of groundwater in Vedaranniyam Town, Tamilnadu, India, *Res J Earth Sci*, 1 (1) (2009) 28-34.

30 Moore G K & Waltz F A, Objectives and procedures for lineament enchancement and extraction: *Photogramatery Engg Remote Sens*, 49 (1983) 641-647.

31 Todd D K & Mays L W, *Groundwater hydrology*, 3rd ed, (John Wiley & Sons, Hoboken), 2005, pp. 656.

32 Das S & Pardeshi S D, Integration of diferent infuencing factors in GIS to delineate groundwater potential areas using IF and FR techniques: a study of Pravara basin, Maharashtra, India, *Appl Water Sci*, 8 (197) (2018) pp. 16.

33 Ramasamy S M, Balaji S & Kumanan C J, Tectonic evaluation Precambrian South Indian shield (rocks) using remotely sensed data, 27 (2) (1999) 91-103.

34 Fashae O A, Moshood N T, Abel O, Talabi A O & Adedeji O I, Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria: an integrated GIS and remote sensing approach, *Appl Water Sci*, 4 (2014) 19-38. DOI 10.1007/s13201-013-0127-9

35 Nagarajan M & Singh S, Assessment of groundwater potential zones using GIS technique, *J Indian Soci Remote Sens*, 37 (2009) 69-77.

36 Narain V & Nischal S, The periurban interface in Shahpur Khurd and Karnera, India, *Environ Urban*, 19 (1) (2007) 261-273.

37 Aguilar A, Peri-urbanization, illegal settlements and environmental impact in Mexico City, *Cities*, 25 (2008) 3133-145.

38 Maina Thuo A D, Impacts of urbanization on land use planning, livelihood and environment in the nairobi rural-urban fringe, Kenya, *Int J Scientific Technol Res*, 2 (7) (2013) 70-79. ISSN 2277-8616.

39 Ramesh R, Effects of land-use change on groundwater quality in a coastal habitat of south India, Impact of Human Activity on Groundwater Dynamics, (Proceedings of a symposium held during the Sixth IAHS Scientific Assembly at Maastricht, The Netherlands, July 2001), IAHS Publ. no. 269, 2001, pp. 161.

40 Li F, Chen X, Zhang W, Tian C & Guan Q, Saline-fresh water interface variation during the past 34 years in Shouguang City, China, *Indian J Geo-Mar Sci*, 47 (10) (2018) 1986-1994.