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A geospatial approach for delineation of groundwater potential zones in a part of national capital region, India

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Abstract

Overexploitation of groundwater resources due to the expansion of industrial and agricultural sector pose a great threat to the availability of this precious resource in Sonipat District of Haryana. A total of seven thematic layers viz, landuse/ landcover (LU/LC), geology, geomorphology, drainage density, lineament density, slope (Digital Elevation Model) and water table depth were prepared by using an integrated approach of remote sensing (RS) and geographic information system (GIS) for the exploration of groundwater resources in the district. The thematic layers were integrated by using weighted overlay technique, to create the final groundwater potential zonation map. The ground water potential areas were demarcated into five zones 1-very poor, 2-poor, 3-moderate, 4-good and 5-very good. The very good groundwater potential zones (GWPZs) were found in the Western and Central parts of the district whereas; the moderate and poor categories were found in the Eastern part. The water table depth in the Western part was found to be shallower as compared to the Eastern part of the district. The good and very good groundwater potential zones were pre-eminent in the areas with higher lineament density, lower drainage density with low slope. The GWPZ map was validated by using water table depth and well discharge data of 2013. The groundwater potential zonation map developed in the present study will be useful for researchers, scientists, planners and policy makers to search out the suitable locations for water exploration and to implement the resource exploitation.

Keywords: Weighted overlay analysis, GIS, Digital Elevation Model, lineaments, GWPZ.

Introduction

Unplanned abstraction of groundwater leads to water scarcity, the most important environmental challenge facing the world. The continuous pollution and overexploitation of this vital resource are threatening both our ecosystems and future generations[1]. Out of the total fresh water supply, groundwater contributes about 60%, which is about 0.6% of the entire world's water[2]. Approximately, 1.5 billion people depend on groundwater resources. The total groundwater withdrawals are approximately 600-700*103 million m^3/year (20%) of total global water withdrawals[3]. In India, more than 90% of rural and nearly 30% of urban population use this resource for drinking purposes[4]. However, due to the population explosion, agriculture, industrialization[5] and urbanization[6] and several landuse/landcover changes, has led to water scarcity in many parts of the world especially in semi-arid and arid regions.

India accounts for only 4% of the world's freshwater resources while as it support more than 16% of the world's population[7]. India is leading towards freshwater crisis due to environmental degradation and improper management of groundwater resources. In rural areas, more than 85% and in the urban area, nearly 55% of the population directly use groundwater for drinking purposes. Moreover, 60% of the total irrigation in the country comes from groundwater resources[8]. According to Central Ground Water Board[9] report, 5723 blocks/watersheds were assessed for quality analysis and resource exploitation. Out of the total blocks, 839 are categorized as overexploited, 226 as critical and 30 with saline groundwater. World Bank reported (Anonymous 2002) that by the year 2025, India will be in water stress zone and by 2050 as water scarce zone.

Along with quality, the quantity of water is also important, because of its wide usability and hence need the mapping. With the emergence of technologies like remote sensing (RS) and geographic information system (GIS), delineation of potential groundwater zones has become an easy procedure. Remote sensing and GIS has wide range of applications particularly in remote and data-scare areas[10]. Moreover, it provides time-effective, cost-effective and informative means of assessing, exploring and managing groundwater resources without any physical contact[10-12]. Assessment of groundwater aquifers and their changes is identified by using the temporal remote sensing data, whereas GIS helps users in managing and integrating multi-thematic data[13]. Remote sensing satellite data provides useful information about the geographic features which directly or indirectly are responsible for the availability and movement of groundwater in an area[14]. Several researchers and scientists have explored Remote Sensing and GIS tools for the delineation of groundwater potential zones (GWPZs)[12,15-19] with effective and good results. Although, groundwater is not detected directly from satellite imagery, but the surface features (e.g. fractures, land use, landforms, drainage) derived from such imagery act as indicators of groundwater existence in an area[14].

In the above background, the aim of the present study would demarcate the Groundwater Potential Zones (GWPZ) in Sonipat district of Haryana. The geophysical studies of central groundwater board (CGWB) indicate that groundwater is saline. Moreover, about 28% area of the district is adversely affected with shallow groundwater, water salinity and is moderate to highly mineralized with EC (597 to 6710)µS/cm[20] and fluoride (>2mg/l)[21]. Also, groundwater is the only source of irrigation in around 42% area of the district which is having tremendous stress on groundwater aquifers due to increase in demand in the agricultural and industrial sector.

Study area: Sonipat district (2260.53 sq.km) is geographically situated between 28^{o} 48' 15" to 29^{o} 17' 10"N latitude and 76^{o}28'40" to 77^{o}12'45" longitude. The climate of the study area is semi-arid, with three well distinct seasons. The extreme summer heat touches 48°C in the month of June, alternating with cold winter in December (3°C). The normal annual rainfall of the district is 567 mm. It is mainly influenced by the southwest monsoon, normally sets in the last week of the June and continues until the end of the September, contributing about 76% of the annual rainfall[20]. The geological set of the district consists of The Quaternary Sediments which can be divided into The Newer Alluvium, The Older Alluvium, and The Aeolian Sediments as shown in Figure-3(b)[21]. Mineral resources present in the district include Kankar (granules of calcium carbonate) and calcium carbonate nodules, locally known as "Kallar" or "Reh" (These salts are rich in carbonates, sulfates, and chlorides of sodium, calcium, and magnesium). The study area is shown in Figure-1.

The area forms a part of The Indo-Gangetic Plains which belongs to Pleistocene Epoch of The Quaternary Period. The Geomorphologic features of the area comprise The Ambala Plains, The Aeolian Surfaces, The Active Flood Plains and The Older Flood Plains as shown in Figure-3(a). Soils vary from Sandy to Clay Loam. On an average, Sandy Loam soil comprises 67%, Sand 25.5% and 7.5% by Clay. The maximum of Sandy Loam soil is present in Gohana block which forms about 79% of the total soil texture of the district. The soils of the district are deficient in organic matter. The sub-soil water in the north block is quite fit for irrigation, while as the subsurface water is mostly brackish, which is unfit for irrigation. In the study area, groundwater occurs mostly in alluvial sand, silt, kankar, and gravel. During pre-monsoon, water level depth varies from 1.41–23.22m, and 0.99–24.46m during post-monsoon[20].

Materials and methods

Processing of satellite data: The satellite imagery data like Landsat-8 of the year 2014 was downloaded from the Landsat official website. Landsat-8 has 11 bands, in which the band 8 is Panchromatic band with a fine resolution of 15m. The bands like 2,3,4,5 were stacked together by layer stacking process in Erdas Imagine 9.3 to get a multispectral image (MSS), this MSS image was merged with the PAN band of the same image to get a 15m resolution image by band fusion process. From this image, the area of interest was extracted by the subsetting process in the Erdas imagine 9.3. The study area extracted was geo-rectified and reprojected with Universal Transverse Mercator projection, before the image was brought into the GIS environment.

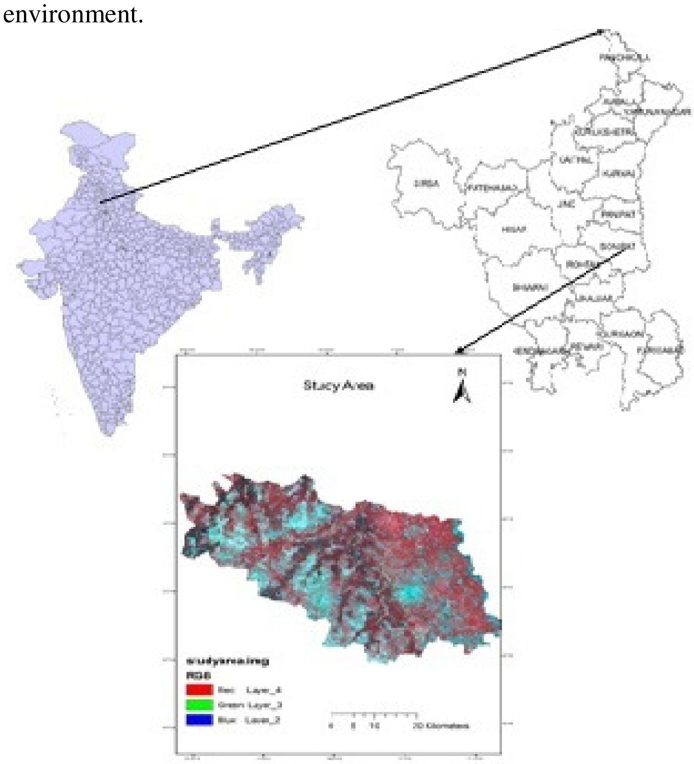


Figure-1: False colour composite (FCC) image of the study area.

Ancillary data and software used: Survey of India toposheet maps were used for the present work, all the toposheets were in 1:50,000 scale. The toposheets were first scanned and then georeferenced in Erdas Imagine 9.3. The different toposheet numbers 53C, 53D, 53G & 53H were used in the present study, which covers the whole study area.

The District Resource Map (DRM) of Sonipat district was collected from Geological Survey of India (GSI), Delhi. Water table depth data of the year 2007 and 2013 was downloaded from CGWB website (www.cgwb.gov.in/). ERDAS Imagine version 9.3 and ArcGIS 10.0 were used for image analysis and overlay analysis, respectively.

GIS Interpolation: Inverse distance weighting (IDW) interpolation is a technique that uses the attributes of known sampling locations to estimate the magnitude of that attribute at the unknown sampling locations. The interpolation is based on assumption, that there is an influence value of known location which decreases with the distance and hence the name inverse distance weighting. The value at unknown sampling location is calculated as the weighted average values of closest points (*m, typically 10 to 30*). The mathematical calculation is given below.

$$Z_j = \frac{\sum_i \frac{Z_i}{d_{ij}^n}}{\sum_i \frac{1}{d_{ij}^n}}$$

Where, Zj is the estimated value for unknown sampling point at location j, dij is the distance between i (known point) and j (unknown point), Zi is the value at point i, n is a user-defined exponent for weighting, fixed number of points normally.

This interpolation method is basic and is user-friendly which is available in almost any GIS. The IDW interpolation of different water quality parameters was carried out in ArcGIS 10.0.

Generation of thematic maps: For the exploration of potential groundwater resources, seven thematic maps, namely, geomorphology, geology, LULC, drainage density, lineament density, slope and water table depth were generated using remote sensing, GIS, and ancillary data with the help of ArcGIS 10.0. The slope map was generated from the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM). The geology and geomorphology maps were generated using the Landsat-8 dataset of 2015 with the help of District Resource Maps. The water level data of 2007 and 2013 was downloaded from Central Groundwater Control Board (CGWB). This data was imported into GIS environment in order to make the interpolation map by IDW technique in ArcGIS 10.0. The Landsat-8 dataset was also used for the generation of LULC map. In Landsat data, panchromatic band (15 m resolution) was merged with multispectral bands (30m) in order to enhance the resolution from 30m to 15m using band fusion technique. The Supervised and unsupervised classification was carried out using a maximum likelihood classifier to classify images[22]. Lineaments are the faults/fractures through which the surface water infiltrates into the groundwater and are regarded as suitable sites for groundwater recharge.

The lineaments were extracted using satellite data and other ancillary data like district resource maps (DRM), Bhuvan thematic maps, and geological map. Drainages are the features which provide the information of hydrogeological setup of an area because the pattern and drainage density are controlled by underlying lithology[23]. Drainage density has the direct impact on the availability of groundwater in an area and has an inverse relationship with the recharge i.e., less the drainage density network, more the recharge rate and vice versa[24]. Drainage density map was generated from DEM.

Groundwater potential zonation approach: For demarcating groundwater resources, each thematic map was assigned weight based on its direct or indirect influence on the movement and storage of groundwater[25]. The weight assigned to the theme is multiplied by the rate of the respective thematic unit to get the relative score of each thematic unit in a particular theme. The maps were then overlayed using a GIS based weighted overlay analysis approach for aggregating all the themes into a single output. There are two types of overlay analysis tools, namely, Weighted Overlay and Weighted Sum. In the present study, The Weighted Overlay Analysis tool was used due to its simplicity and quick processing. This technique of GIS was used for demarcation of potential groundwater zones by analyzing several input raster layers like geomorphology, geology, drainage density, lineament density, slope, landuse and landcover, and water table depth. The GWPZ map was classified into very poor, poor, moderate, good and very good, categories. The flowchart of the overall methodology is given in Figure-2.

Results and discussion

Thematic layers of the study area: Geomorphology: Geomorphology, the most important theme for evaluating the groundwater prospects has a dominant role in movement and storage of groundwater. Geomorphology theme was assigned the highest weight. Geomorphologically, the study area is divided into five classes i.e. The Abandoned Channel, The Active Flood Plains, The Aeolian surfaces, The Ambala Plains, and The Older Flood Plains. The flood plains are constructed when the water overflows its banks during heavy rainfall. The surface of these plains is relatively smooth and is adjacent to the river channel. Geomorphological Map of the study area is given in Figure-3(a). The Abandoned channels act as good sites for groundwater recharge. The rainwater gets stored in the channel which finally infiltrates into the aquifers. A single Abandoned channel was found in Sonipat Block of the district. Moreover, the Active Flood Plains along the River Yamuna in the Eastern part of the district acts as good recharge sites. The Active Flood Plains are associated with gravel and sand, which acts as a good passage of surface water into the groundwater aquifers. During heavy rains and floods, the water flows over the river banks and the area gets easily inundated. Thus, the water finally gets infiltrated into the aquifers.

Geology: The Sonipat district comes under the Indo-Gangetic Plains. Its most part is Alluvial Plain. Geologically, the study area is divided into five classes, i.e. Aeolian deposits, Channel Alluvium, Kankar Deposits, Newer Alluvium and Older Alluvium, which comprises the most part of the district[21]. The Alluvial Plains are favourable zones for the groundwater recharge, and hence, the area is easily recharged due to the rainfall and other surface water bodies.

The study area has a flat terrain with the major portion comprised of Older Alluvium and Newer Alluvium. In these areas, the runoff is less; hence, the surface water gets easily infiltrated into the aquifers. Geological Map of the study area is given in Figure-3(b).

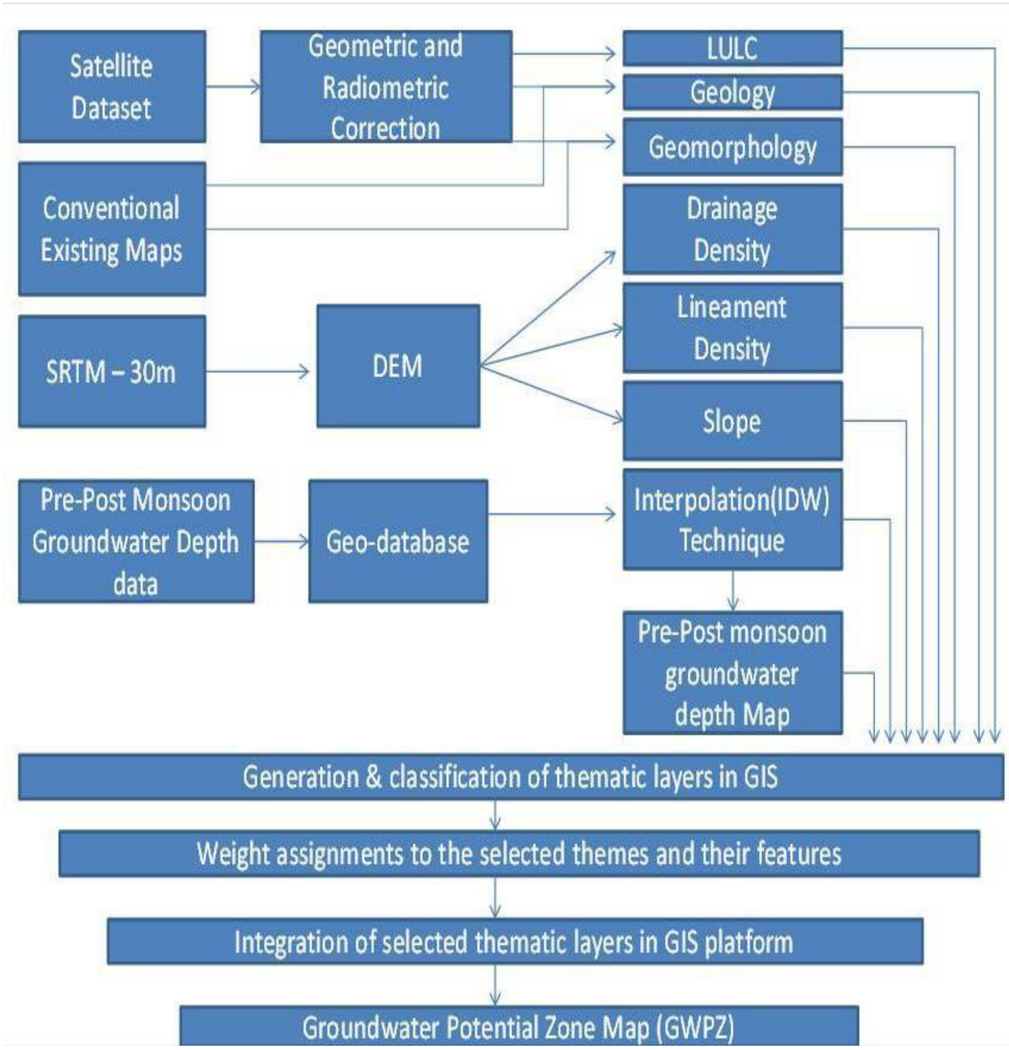
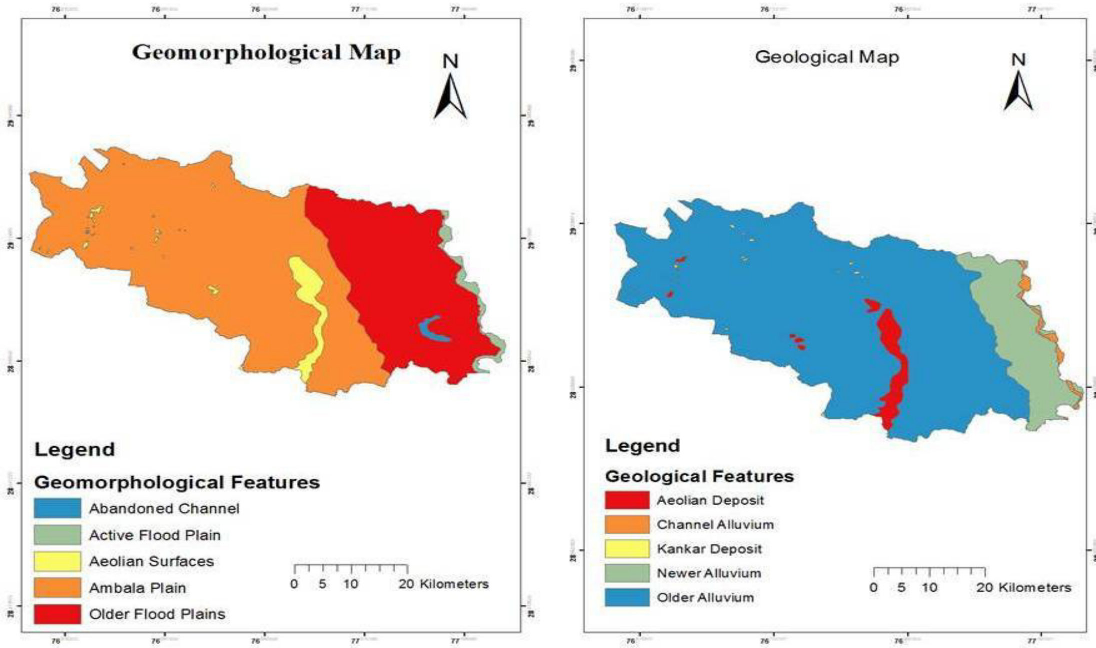


Figure-2: Flowchart of overall methodology.

Drainage Density: Drainage density is defined as the ratio of the total length of the drainage network of the area to the total area of the drainage basin. The drainage network was created from SRTM DEM as shown in the Figure-4(a). The drainage pattern is dendritic in the study area and the drainage density has been grouped into six classes, i.e., 0-0.5, 0.51-1, 1.01-1.51, 1.51-2, 2.01-2.51, and 2.52-3.01. The light brown to dark brown colour on the map shows higher drainage density and the blue colour shows the lower drainage density. The river Yamuna flows down from Northeast to Southeast all along the border of the district on the Eastern side. The higher drainage density was found in the Western part of the district, whereas, the Central part has medium drainage density.

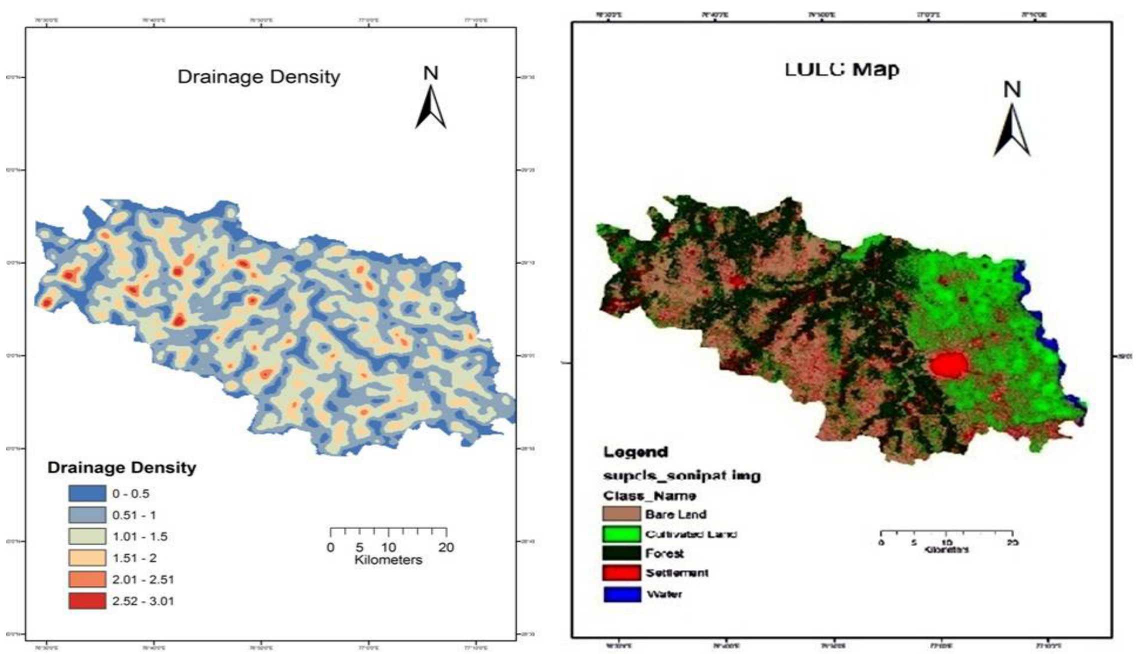
Some parts of the Eastern and South-eastern area show lower drainage density, due to the presence of vegetation cover and soils with higher permeability as shown in Figure-4(a) and 4(b). The same results were proposed by Avtar et al., 2010[25]. The higher drainage density areas have higher surface flow and lower infiltration rate[26].

Landuse/Landcover (LULC): LULC is one of the important parameters that influence the movement and occurrence of groundwater in an area. The LU pattern has a greater impact on groundwater recharge. It either reduces runoff and increases the residence time of water to infiltrate or by plants which trap the surface water, the water droplets thus trapped infiltrate easily into the aquifers[19]. The LULC map of the area was classified into five broad classes, Bare land, Cultivated land, Forests, Settlement and Water bodies. The Bare land was the dominant class found in the study area followed by forest, cultivated land, and the settlement. The barren lands were mostly found in South-western and Central part of the district. LULC effects evapotranspiration, groundwater recharge, and surface runoff, which indirectly affects groundwater recharge. The waterlogged areas, agricultural areas and forest areas are good sites for groundwater recharge whereas densely built-up areas have poor groundwater potential due to excess runoff. The district has abundant cultivated land, and hence the rain water and irrigation water gets easily infiltrated down into aquifers. LULC map is given in Figure-4(b).



a b

Figure-3: (a) Geomorphology map of the study area, (b) Geology map of the study area[21].



a b

Figure-4: (a) Drainage density map of the study area, (b) LULC map of the study area.

Slope: Slope plays an important role in groundwater recharge, higher the slope lower the groundwater potentiality and vice-versa[27]. A higher slope causes more runoff and less infiltration as compared to the lesser slope, whereas in lower slope rainwater has the higher residence time to percolate into the aquifers. The whole district is flat which constitute the Alluvial Plain. The slope of the study area has been divided into five classes, very low (0 - 0.35), low (0.36 - 0.84), moderate (0.85 - 1.5), high (1.51 - 4.2) and very high (4.21 - 11.26). The terrain with higher infiltration rate with 0 - 1% slope was considered under ''very good'' category for the availability of groundwater. Most of the study area shows 0 - 0.8% slope, which indicates that the whole area of the district comes under the flat terrain. The Western part of the district was found flatter than the Eastern part. The slope of the study area is given in Figure-5(a).

Lineament Density: Lineaments are hydrologically very important for groundwater recharge. They are like faults, fractures, and joints and thus provide the pathways for the movement of groundwater[19]. Lineament density (Ld) is defined as the total length of all the lineaments demarcated divided by the total area under consideration[28] as shown below.

$$\mathrm{Ld} = \sum_{i=1}^{i=n} \mathrm{L_i}\ \mathrm{A}\,(\mathrm{m}^{-1})$$

Where: $\sum_{i=1}^{i=n} L_i$ = total length of all the lineaments (m^2) and A = area (m^2).

The presence of lineament in an area acts as a conduit for groundwater potential zone. The large lineaments, presence of intersections, faults acts as good groundwater potential zones. Therefore, an area with higher lineament density have the greater impact on GWPZ's[19]. The trend of lineaments in the district is along the North North-East (NNE) - South South-West (SSW) and NW - SW directions. The highest density of lineaments was found in the Central part (Sonipat block) followed by Gohana in the Western part of the district. The district possesses a good number of lineaments and hence is the indication of potential groundwater zones in the area. The lineament density map is given in Figure-5(b).

Pre-monsoon and Post-monsoon Groundwater Depth: The groundwater table depth data (pre-monsoon and post-monsoon) of the year 2007 and 2013 was collected from CGWB. The groundwater depth maps were generated using the IDW technique in ArcGIS 10.0 and were divided into six classes as shown in Figure-6. Considering the pre-monsoon water table depth of 2007 and 2013, the depth in Western areas (Kathura, Gohana) has increased drastically, while as in Eastern areas, the deepest aquifers were found at a depth 21.8 - 25.21 mbgl in 2007 and the same aquifers in the same region were found at 25.01 - 31.86 mbgl. The same results were found in post-monsoon depths of 2007 and 2013. This drastic increase in the depth may be due to overexploitation of groundwater resources for agricultural and industrial purposes. Due to improvement in these two sectors, more and more water is exploited and hence, lead to deep aquifers in the study area. The monsoon rain is the major contributor of groundwater recharge in the area; hence, during monsoon and post-monsoon period, the groundwater aquifers have a shallow depth. However, during pre-monsoon time, there is very less rainfall and due to overexploitation of this resource lead to deep aquifers in the area. The discharge rate of the groundwater is greater than the recharge rate during pre-monsoon period, hence, lead to deep groundwater aquifers in the area. According to CGWB (2013)[29] report of the district, the groundwater resources are overexploited in Ganuar, Rai, and Sonipat blocks. However, the Gohana and Kharkhauda blocks were found to be in critical condition. Among the seven blocks, only two blocks (Kathura and Mundlana) were found to be in the safe category. The overexploitation of the groundwater in the district is due to urbanization and excess use in agricultural activities. The lower water table has given higher rank, and higher water table has given a lower rank in this study.

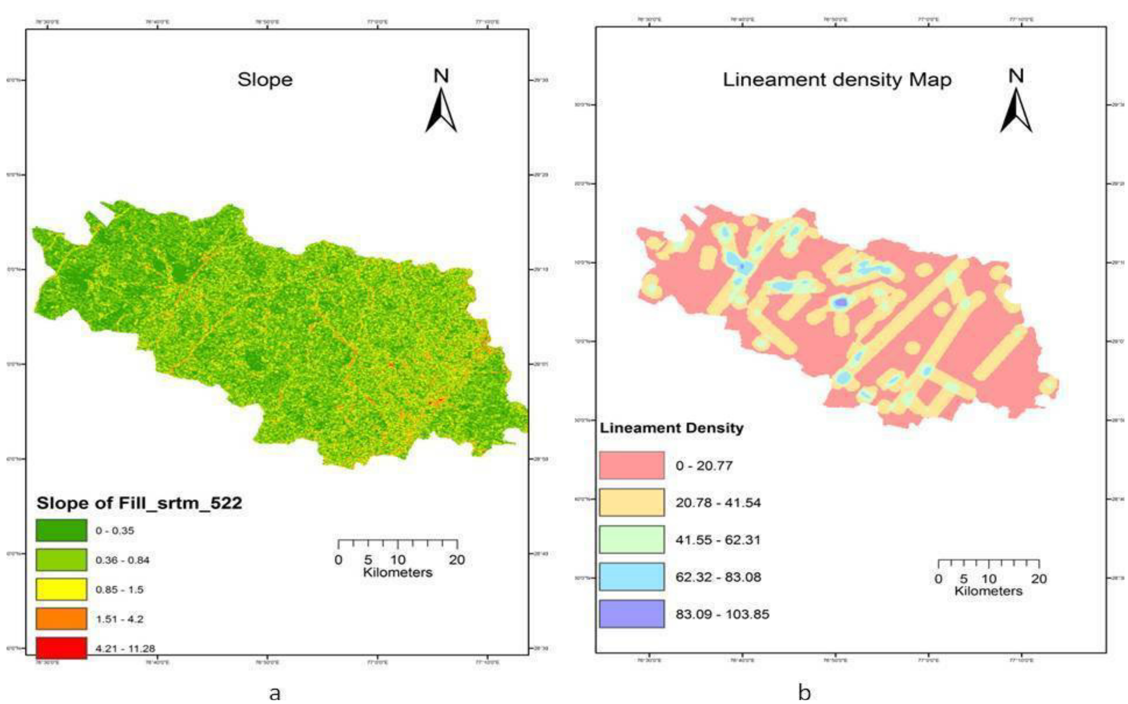


Figure-5: (a) Slope map of the study area, (b) Lineament density map of the study area.

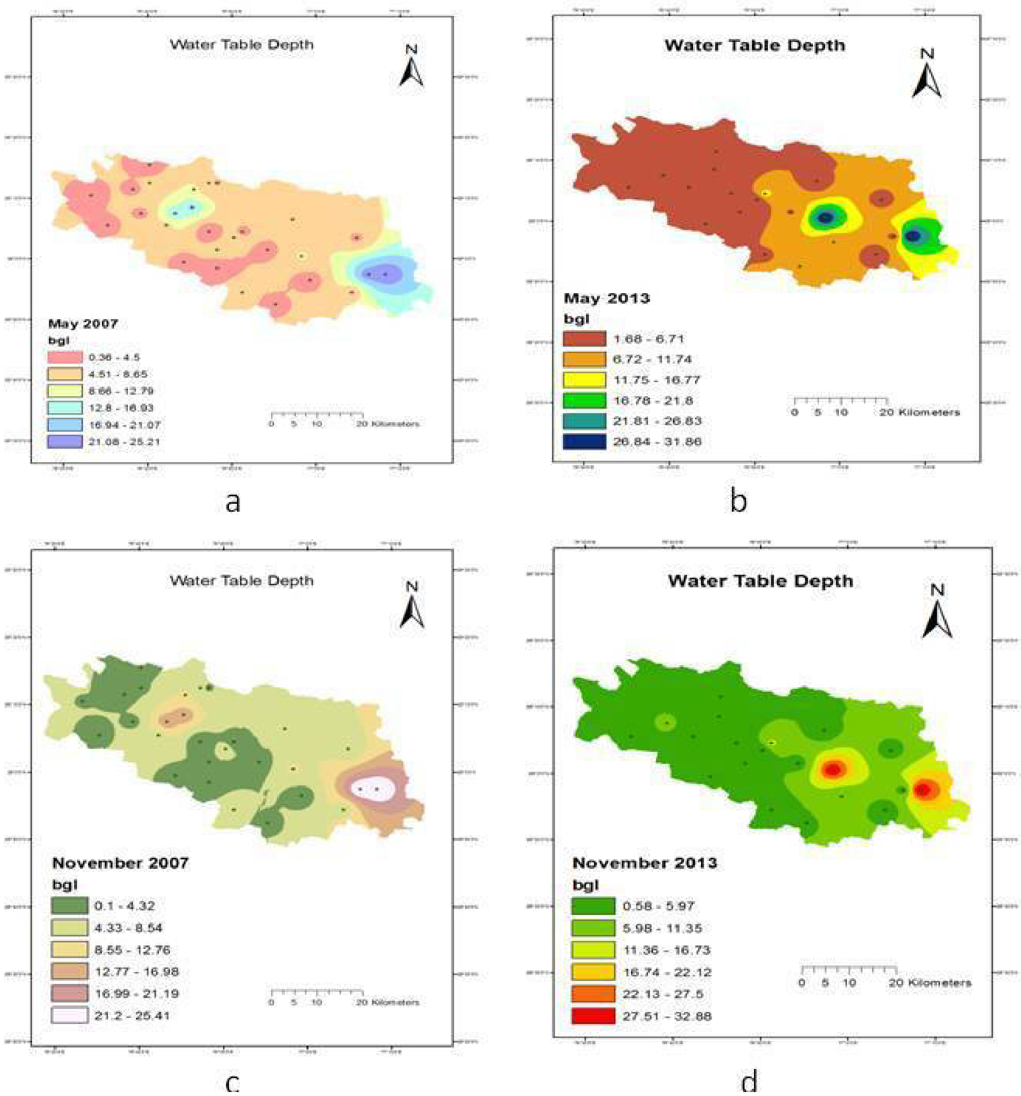


Figure-6: (a) Water table depth map of May 2007, (b) Water table depth map of May 2013, (c) Water table depth map of November 2007, (d) Water table depth map of November 2013.

Analysis of Groundwater Potential Zonation: The demarcation of different groundwater zones is based on the overlay analysis approach, carried out in GIS environment. The seven themes were evaluated, i.e. i. Geology (G), ii. Geomorphology (Gm), iii. Lineament density (Ld), iv. Slope (S), v. Drainage density (Dd), vi. Land Use Land Cover (LuLC), vii. Ground water depth (Gd). The themes were assigned a value based on their control on the occurrence of groundwater[11]. The thematic maps were assigned a suitable weight and rank and were integrated together in GIS environment as groundwater potential index (GWPI) as given in Table-1.

GWPI=GwGr+GmwGmr+LdwLdr+SwSr+ Ddw Ddr+ LuwLuC + GdwGdr

Where: w = weight of a theme and r = rank of thematic unit in the theme.

In the GWPZ map, the potential zones were classified into five classes, 1-very poor, 2-poor, 3-moderate, 4-good and 5-very good. The very good category zones were present mostly in flat terrain with high lineament density, the reason is that the slope is inversely proportional to groundwater recharge, and the presence of lineaments acts as a good passage of surface water into the aquifers.

The Central and Western part of the district has shown the abundance of potential zones of groundwater. The Eastern part of the district is more elevated than the Western part with fewer lineaments, and high settlement which leads to less availability of groundwater potential zones in this area. The areas like Alluvial Plains with lower drainage density, higher lineament density with low elevation are good in groundwater prospects. However, the areas with higher drainage density, lower lineament density, and with higher slope are poor in groundwater prospects[25].

Table-1: Weight and rank assigned to different thematic layers.

Theme	Features	Weight	Rank
Geology	Aeolian deposits	20	4
	Channel Alluvium		6
	Kankar Deposit		1
	Newer Alluvium		3
	Older Alluvium		4
Geomorphology	Abandoned Channel	25	5
	Active Flood Plain		6
	Aeolian Surfaces		2
	Ambala Plain		4
	Older Flood Plains		3
Drainage Density	0-0.5	15	6
	0.51-1		5
	1.01-1.5		4
	1.51-2		3
	2.01-2.51		2
	2.52-3.01		1
Slope	0-0.35	10	5
	0.36-0.84		4
	0.85-1.5		3
	1.51-4.2		2
	4.21-11.28		1
LULC	water	20	5
	Cultivated Land		4
	Forest		3
	Bare Land		2
	Settlement		1
Lineament Density	0-20.77	20	1
	20.78-41.54		2
	41.55-62.31		3
	62.32-83.08		4
	83.09-103.85		6
Water table depth 2007	<5	10	6
	<10		5
	<15		4
	<20		3
	<25		2
	<30		1

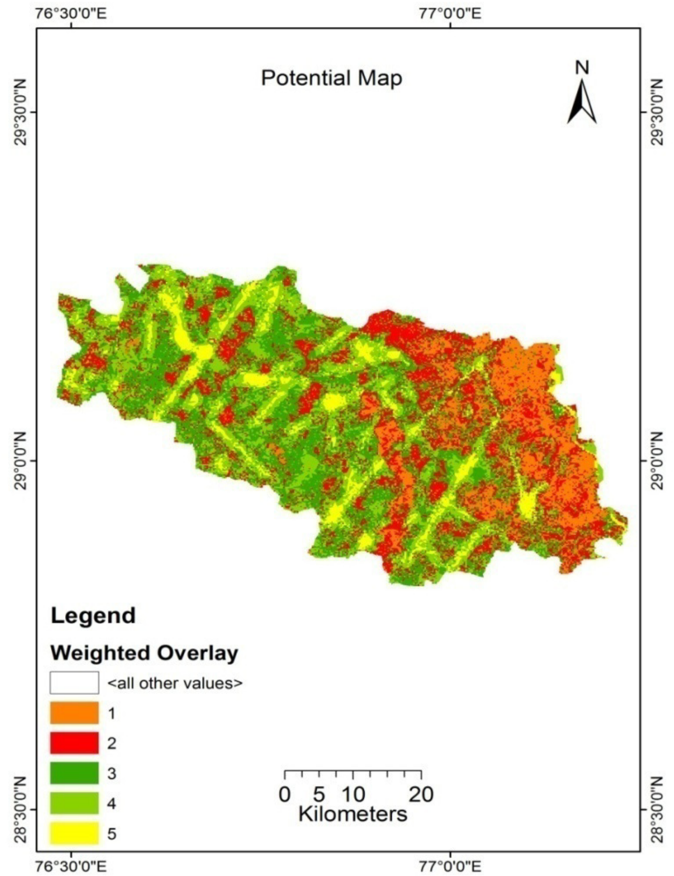


Figure-7: Groundwater potential zonation map of the study area.

Validation of Groundwater Potential Zonation Map: The groundwater potential zonation map was validated by using well discharge data of 53 wells collected from the field and water table depth data collected from CGWB. The water table depth data of 2013 (post-monsoon) shows that the depth is lowest in the Western part as compared to the Eastern part of the district. From the Figure 6 and 7, it is confirmed that the very good GWPZs are greater in the Western part as compared to the Eastern part of the district because of the presence of shallow aquifers in the area. According to CGWB (2013)[29] report, the discharge rate of groundwater from Kharkhuada and Mundlana block is generally up to 10 Ips which falls in the moderate category. However, in Ganuar and Sonipat blocks, it is 20 Ips which come under good category on the GWPZ map. The shallow tube wells (20-30 m) depth with discharge range of 8-10 Ips is dominant. However, in some parts of Sonipat and Ganuar block, the shallow tube wells (upto 45m) with discharge rate more than 12 Ips are prevalent[29].

Conclusion

The present study has focuses on the utility of remote sensing and GIS for identification and demarcation of groundwater potential zones in the semi-arid area of Sonipat district, Haryana. The groundwater potential zones were classified into five categories, 1-very poor, 2-poor, 3-moderate, 4-good and 5-very good. The very good groundwater potential zones were found in the areas where there was high lineament density. They were mostly found in the Central part (Sonipat, Ganuar) of the district, which belongs to the plain area. The Central and South-Eastern part (Rai) of the district were the areas that has shown a higher downfall in water level from the last two decades. Both, flood plain of the Yamuna River and the Alluvium are the areas belonging to the good class category in GWPZ map. The GWPZ's were validated using water table depth data and well discharge data. Although RS and GIS is showing good site for groundwater zones in South-western and Central part of the district, but the quality of the water needs to be checked for drinking and agricultural purposes. In the Sonipat and Gohana block of the district, the decline in water table depth was observed, that could be due to highest growth of urbanization. Thus, a proper management and strategies need to be adopted for exploration of this precious resource in this part of the district. The GWPZ map generated in this study will be very useful for policy makers, engineers, planners, researchers and the local groundwater governing body (CGWB) to find out the suitable locations for groundwater exploration. It can also be helpful in formulating effective groundwater exploitation strategies so as to ensure the long-term sustainability of this vital resource.

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