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Delineation of groundwater potential zones using remote sensing and geographic information system techniques: A case study of Udaipur district, Rajasthan, India

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Abstract
Groundwater is a vital natural capital for the consistent and economic provision of potable water supply for both rural and urban environments. The surface water resources are inadequate to fulfill the water demand. Productivity through groundwater is quite high as compared to surface water, but groundwater resources have not yet been properly exploited. Keeping this view, the present study attempts to select and delineate various groundwater potential zones for the assessment of groundwater availability in the Udaipur district, Rajasthan, India using remote sensing and GIS technique. This study utilized RS and GIS techniques for generating thematic layers of different factors influencing groundwater occurrence. The multi-criteria decision-making technique coupled with GIS have been used to identify groundwater potential zones in the study area. Groundwater potential in the study area was identified by considering eight thematic maps, viz., geomorphology, soil, slope, topographic elevation, land use/land cover, recharge, post-monsoon groundwater depth and transmissivity. These maps were prepared using conventional and remote sensing data with the help of Arc GIS software. These themes and their features were assigned suitable weights as suggested by Saaty (1980) according to the relative importance of theme/feature in groundwater occurrence. The weights of the thematic maps and their individual features were then normalized by using Saaty's analytical hierarchy process. The selected thematic maps after assigning weights were integrated in a GIS environment to generate a groundwater potential index (GWPI) map, based on which groundwater potential zones were identified in the study area. On the basis of study, the study area were divided into four groundwater potential zones, viz., 'good', 'moderate', 'poor', and 'very poor', which cover 20 per cent good groundwater potential, 31.17 per cent moderate, 34.19 per cent poor and 14.64 per cent very poor groundwater potential zone. About 48.83 per cent of the basin falls under poor potential zone. Therefore, immediate attention is required for ensuring sustainable groundwater management in the basin.

Keywords: Groundwater, remote sensing and GIS technique, groundwater potential index (GWPI) map

Introduction
Groundwater is the most important natural resource of our planet. It is an important resource for human existence and economic development. Groundwater plays a lead role in maintaining ecological balance, human well-being and economic development (IPCC, 2001) [1]. Amazing growth of population, agriculture and industry has compelled an indiscriminate exploitation of this resource mounted huge stress on its cautious utilization (Mondal and Dalai, 2017) [16]. The depletion of groundwater resource is a matter of great concern for human society. Unfortunately, scarcity and rampant use of groundwater resources without appropriate scientific planning is very familiar scenario in India (Rodell *et al*., 2009) [21]. During the past twenty years, many parts of India experienced rapidly declining groundwater level due to increase in its extraction. Unplanned and unmanaged groundwater extraction in the area has resulted in aquifer-stress syndrome like falling groundwater depth and deterioration of quality (World Bank, 2011) [25]. Hence, identification of the critical parameters and their assessment are necessary for predicting groundwater potential and planning for this resource accordingly. Groundwater is a hidden and precious natural resource and hence cannot be directly detected.

Although a set of methods is used to explore groundwater resources, mapping of the same is a challenging task. Drilling test and stratigraphy investigation are the most widely used methods for determining the location of borehole and the thickness of the aquifereous materials to explore the groundwater resources (Jha *et al*., 2010) [11]. However, these methods are very cost effective and time consuming to find out availability of groundwater resources in a region (Fetter, 1994) [4]. Furthermore, various techniques have been adopted by various researchers such as, decision-tree model (Lee and Lee, 2015) [12], frequency ratio (Guru *et al*., 2017) [7], weights-of-evidence (Ghorbani Nejad *et al*., 2017) [6], artificial neural network (Lee *et al*., 2017) [13], randomforest model (Naghibi *et al*., 2016) [17], logistic regression model (Pourtaghi and Pourghasemi, 2014) [19], and evidential belief function (Nampak *et al*., 2014) [18] etc. Most of these approaches are based on bivariate and multivariate statistical techniques with limitations in making assumptions prior to investigation and sensitivity of findings (Thapa *et al*., 2017) [23]. In this context, analytic hierarchy process (AHP) is considered as a simple, transparent, effective, and reliable technique (Machiwal *et al*., 2011) [14], and hence can be used for delineating groundwater potential zones. As groundwater is dynamic in nature, integration of remote sensing (RS) data in the geographical information system (GIS) is very convenient to identify the groundwater potential zones (GWPZ) (Agarwal and Garg, 2016) [1]. Many of the existing studies (Jasrotia *et al*., 2016; Mallick *et al*., 2015; Chenini *et al*., 2010) [9, 15, 2] have widely applied RS and GIS techniques for the assessment of GWPZ. In the present study a part of the wakal river basin of the Udaipur district, Rajasthan has been selected for evaluation of ground water potential zones using remotely sensed data.

Study Area

Study area is a part of Wakal river basin of the Udaipur district. It is a rainfed river basin lies on the west coast of India between 24° 46' 34.65" N to 24° 8' 49.41" N latitudes and 73° 6' 23.41" E to 73° 35' 54.18" E longitudes and spread across the states of Rajasthan and Gujarat. The study area falls in Survey of India (SOI) toposheets of 45H/2, 45H/3, 45H/4, 45H/5, 45H/6, 45H/7, 45H/8, 45H/10 and 45H/11. Total geographical area of Wakal basin is 1914.322 Km^2, of which 1867.478 Km^2 lies in the state of Rajasthan and 46.844 Km^2 in Gujarat. In Rajasthan state, the basin completely falls under Udaipur district though it occupies only 13.1 per cent of total area of the district. The geographical spread of Wakal basin is mainly in Udaipur district of Rajasthan. The 98 per cent area of the basin is coming under Udaipur district of Rajasthan, where as the remaining 2 per cent area is in Sabarkanta district of Gujarat state. Major part of the Wakal basin (81 %) falls under Kotra and Jhadol tehsil of Udaipur district. The General topography of the area is hilly and undulating. Most of the cultivated lands are located in the valleys. Surface drainage of the area is generally good due to slight undulations in the topography. Water flows through seasonal nala with high velocity, which is a main cause of erosion in the area.

Material and Methods

Present study deals with use of GIS for preparation, handling, and processing of different thematic layers. All the GIS related works were carried out by using Arc GIS 9.3.1 software. Arc GIS software is a PC-based GIS and Remote Sensing software, developed by the ESRI. ArcGIS desktop software products allow users to other, analyze, map, manage, share, and publish geographic information. At all levels of licensing, ArcMap, ArcCatalog and ArcToolbox are the names of the applications comprising the desktop package. ArcGIS Explorer, ArcReader, and ArcExplorer are basic freeware applications for viewing GIS data.

This study utilized RS and GIS techniques for generating thematic layers of different factors influencing groundwater occurrence. The multi-criteria decision-making technique coupled with GIS have been used to identify groundwater potential zones in the study area. The procedures adopted to identify and delineate groundwater potential zones using RS, GIS and MCDM techniques are illustrated in Fig.1.

Selection of thematic layers

In past groundwater studies concerning combined use of RS and GIS techniques, various thematic maps for delineating groundwater favorability zones were selected believing that all the thematic parameters have some influence on the occurrence of groundwater (e.g., Ettazarini, 2007; Ganapuram *et al*., 2009) [3, 5]. The number of thematic layers used depends on the availability of data in an area. In the present study, eight thematic layers (viz., geomorphology, soil, slope, topographic elevation, land use/land cover, post monsoon groundwater depth, recharge and transmissivity) have been consider for the delineation of groundwater potential zones.

Generation of thematic layers

In order to assess groundwater potential in the study area, eight thematic maps, viz., geomorphology, soil, slope, topographic elevation, land use/land cover, post monsoon groundwater depth, recharge and transmissivity were generated using remote sensing and conventional data. Out of these thematic maps, topographic elevation and slope maps were generated from ASTER data, whereas the remaining maps were generated using conventional data. These thematic maps were developed using Arc GIS software.

Geomorphology map

Geomorphology is the science of landforms and has a direct relation with the occurrence and movement of groundwater. In the present study, earlier-mentioned SOI toposheets were scanned, rectified, and then digitized in the Arc GIS software to prepare a thematic layer on geomorphology. Thereafter, different geomorphology classes were identified, which were then assigned weights according to their relative importance in groundwater occurrence or recharge in the study area following the Saaty's analytical hierarchy approach.

Soil map

Soil is defined as the residual material, which has been modified and acted upon by physical, chemical and biological agents. The influence of soil on groundwater occurrence mainly depends on its retention capacity or texture. The texture of a soil can be defined as the relative proportion of silt, sand and clay present in it. The clay soil having smaller pores induces more runoff and less infiltration, whereas the sandy soil induces more infiltration and thereby recharge the groundwater reserve (Fetter, 1994) [4].

As mentioned earlier, the soil map of the study area was obtained from the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Udaipur at 1:250,000 scale. The map was scanned, rectified and then digitized using Arc GIS software. Thereafter, different soil categories were identified and assigned weights according to their contribution to groundwater.

Slope map

The slope of a particular terrain is an important factor in groundwater studies, because it determines the time required for the water to accumulate at a given location. The slope gradient directly influences the infiltration of rainfall. The lesser the slope, the lesser will be the runoff, and hence infiltration and recharge will be more thereby making a flat terrain more promising for groundwater availability.

The slope map for the study area was prepared from the Digital Elevation Model (DEM). The DEM was subjected to two directional gradient filters (one in x-direction and another in y-direction). The filtering was done by using in-built linear filters (dfdx and dfdy) available in the Arc GIS software. Then, the resultant maps were used to generate a slope map of the study area by computing slope using following equation:

$$\text{Slope} = 100 \times \sqrt{DX^2 + DY^2} \Big/ \text{Pixel Size (DEM)}$$

Where,

DX = filtered DEM with x-gradient filter, DY = filtered DEM with y-gradient filter, and Pixel Size (DEM) = pixel size of the DEM.

The slope map was divided into different classes and suitable weights were assigned to each class based on its contribution to groundwater occurrence.

Topographic elevation map

As topography (land surface elevation) is one of the factors, which influence groundwater potential, topographical elevation map was considered as one of the themes for the present study. The higher the elevation, the lesser will be the groundwater availability. Sener *et al*. (2005) [22] reported relation of topographic elevations with groundwater occurrence. In present study, topographic elevation layer is generated from the topographic data downloaded from USGS (2004) [24]. The ASTER obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. ASTER consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. The topographic data are available in Geo TIFF raster file format at 30 m pixel resolution. The obtained topography file was imported to Arc GIS software and DEM was generated for the study area. Suitable weights to different elevations were given based on their contribution to groundwater occurrence/recharge.

Land use/Land cover map

The land-use/land cover thematic map of the study area was prepared using satellite imagery. IRS-1D LISS-III data at 23.5 m spatial resolution were used for preparation of the land use/land cover thematic map. The raw satellite images were digitally processed in a series of image processing operations: geometric rectification, image enhancement, image interpretation and multispectral classification. Further, supervised image classification was carried out to classify land use classes. Different land use/land cover classes define the rate of infiltration of rainfall and water to the ground.

Post monsoon groundwater depth map

The post-monsoon groundwater depth map for the study area was prepared based on 60 monitoring sites data using Arc GIS software. The developed map was divided into suitable classes and weights were assigned according to their relative importance from groundwater viewpoint.

Groundwater recharge map

Recharge is broadly defined as water that reaches an aquifer from any direction. It can be classified as direct, localized and indirect. The term direct recharge refers to the recharge derived from precipitation or irrigation that occurs fairly uniformly over large areas, whereas the term localized recharge refers to the concentrated recharge from depressions in surface topography such as streams and lakes. Point estimates of the net recharge at 60 sites for the study area was estimated using Water Table Fluctuation method. Using this point recharge values, a recharge map of the study area was prepared.

Transmissivity map

Aquifer transmissivity is very important factor as it governs groundwater movement and recharge process. The higher value of transmissivity increases the suitability of an area for artificial recharge. In this study, transmissivity values obtained in pumping test were used to prepare a thematic layer on transmissivity using Arc GIS software. Different transmissivity classes in the study area were identified and then assigned weights according to their transmissivity values using the Saaty's analytical hierarchy approach.

Delineation of Groundwater Potential Zones

The thematic layers on geomorphology, soil, slope, topographic elevation, land use/land cover, post monsoon groundwater depth, recharge and transmissivity were used for the delineation of groundwater potential zones in the study area. To demarcate the potential zones, all these thematic layers were assigned weights and then were integrated using Arc GIS software. The weights of thematic map and their individual features were decided based on the experts' opinions and local field experience (Jha *et al*. 2009; Machiwal *et al* 2011) [10, 14]. The weights of the different themes were assigned on a scale of 1 to 5 based on their influence on the groundwater potential. Different features of each theme were assigned weights on a scale of 1 to 9 according to their relative influence on groundwater potential. Based on this scale, the qualitative evaluation of different features of a given theme was performed as poor, moderate, good, very good and excellent. The relative influence of the individual themes and features on groundwater potential was decided based on the experts' opinion, information and local knowledge. Thereafter, a pair-wise comparison matrix was constructed using the Saaty's analytical hierarchy process to calculate normalized weights for individual themes and their features. To demarcate groundwater potential zones, all the eight thematic layers after assigning weights were vb added (overlaid) using Arc GIS software. The total weights of different polygons in the integrated layer were derived from the following equation to obtain groundwater potential index (Rao and Briz-Kishore, 1991) [91].

$$GWPI = (GM_w GM_{wi} + SO_w SO_{wi} + SL_w SL_{wi} + TE_w TE_{wi} + LU_w LU_{wi} + WD_w WD_{wi} + RE_w RE_{wi} + TR_w TR_{wi})$$

Where,

GWPI = groundwater potential index

GM = geomorphology

SO = soil type

SL = slope

TE = topographic elevation

LU = land use/land cover

WD = post monsoon groundwater depth

RE = groundwater recharge
TR = transmissivity
w = normalized weight of a theme and
wi = normalized weight of the individual features of a theme.
GWPI is a dimensionless quantity that helps in indexing probable groundwater potential zones in the area. The range of GWPI values was divided into four equal classes (called zones) and the GWPI of different polygons falling under different range were grouped into one class. Thus, the entire study area was qualitatively divided into four groundwater potential zones and a map showing these zones was prepared using Arc GIS software. The entire process of groundwater potential zoning is shown in Fig.1.

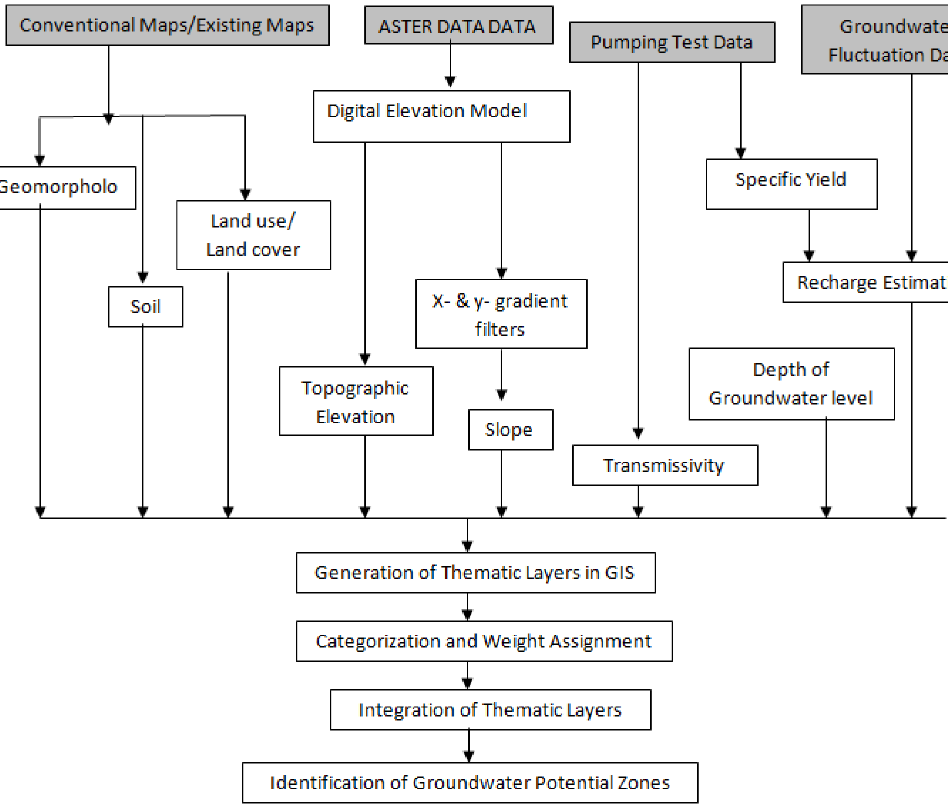


Fig 1: Flowchart for groundwater potential zoning using GIS

Results and Discussions

Features of Different Thematic Maps

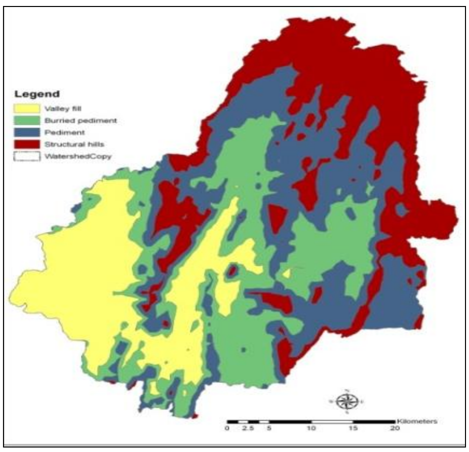
The eight thematic layers i.e. geomorphology, soil, slope, topographic elevation, land use/land cover, post monsoon groundwater depth, recharge and transmissivity were generated for the Wakal river basin. The areal extent of different features of these thematic layers is given in Table 1.

Geomorphology

Based on the physiographic characteristics, the landforms of the study area have been classified into four different units namely: (i) pediment, (ii) buried pediment, (iii) valley fills, and (iv) structural hills as shown in Fig. 2.

Soil map

The thematic layer of soil for the study area reveals six main soil classes viz., Loamy to Coarse loam, Loamy skelton to Fine loam, Fine to Loamy skelton, Loamy skelton to Coarse loam, Rock outcrop to Loamy, Rock Outcrop to Fine loam. It is apparent from Fig.3 that the majority of the study area is dominated by loamy to coarse loam and rock outcrop to loamy soil, which is about 86 per cent of the total study area. These six soil classes can be categorized into five classes namely 'very good', 'good', 'moderate', 'poor' and 'very poor' according to their influence on groundwater occurrence.



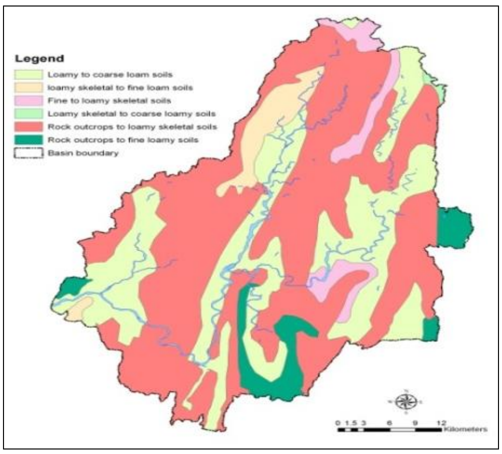


Fig 2: Thematic layer of Geomorphology **Fig 3:** Thematic layer of So Slope map

The slope percentage in the area varies from 0 to 50 per cent. Based on the slope, the study area were divided into six slope classes: (i) 0-3%, (ii) 3-5%, (iii) 5-8%, (iv) 8-15%, (v) 15-30% and (vi) >30%. The area having 0 to 3% slope falls in the 'very good' category due to the nearly flat terrain and relatively high infiltration rate. It covers 398.76 km^2 areas, which is about 21 per cent of the total study area. The area with 3 to 5% slope is considered as 'good' for groundwater storage due to slightly undulating topography with some runoff, which is about 14 per cent area of the total study area. The area having a slope of 5 to 8% causes relatively high runoff and low infiltration, and hence categorized as 'moderate', which is about 27 per cent area of the total study area. The fourth (8-15%), fifth (15-30%) and sixth (>30%) category are considered as 'poor' and 'very poor' due to higher slope and runoff, which is about 39 per cent area of the total study area. A slope map prepared from Digital Elevation Model is shown in Fig. 4.

Topographic elevation map

The topographic elevation map has been divided into five classes: (i) <400 m, (ii) 400-600 m, (iii) 600-800 m, (iv) 800-1000 m and (v) >1000 m. The highest topographic elevations (about >1000 m MSL) exist in small scattered patches in the north and northeastern portions of the study area. The topographic elevation is usually low in the southwest and south portions of the study area. The study area is dominated by topographic elevations of 400-600 m in 703 km^2 areas, which is about 37 per cent of the study area and 600-800 m in 557 km^2 areas, which contributes 29 per cent of the study area, located in middle, south, southwest and southeast portions of the study area. The topographic elevation map is shown in Fig. 5.

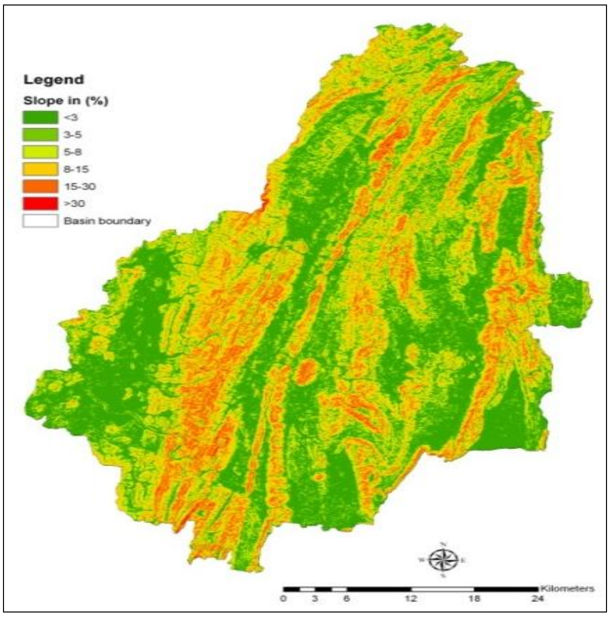


Fig 4: Thematic layer of Slope

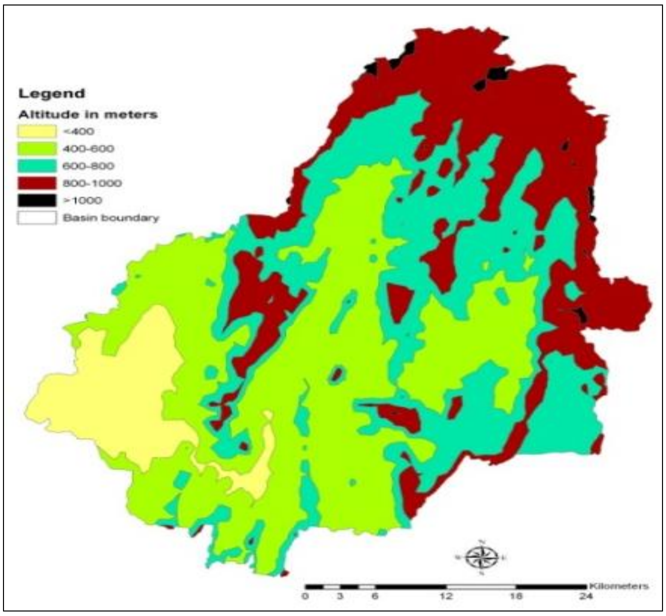


Fig 5: Thematic layer of Topographic Elevation

Land use/ Land cover map

A land use/land cover thematic map was distinguished into four different classes: (i) agricultural land, (ii) fairly dense forest, (iii) degraded forest and (iv) open scrub, as shown in Fig. 6. Different land use/land cover classes were ranked according to their water requirement. Agricultural lands were given the highest rating over other land use features because it requires more water for irrigation, resulting in groundwater recharge. Dense forest was assigned a higher rating than degraded forest, because vegetation prevents direct evaporation of water from the soil, and the roots of a plant also absorb water, thus preventing water loss. Open scrub was assigned the lowest rating, because it allow less time for the infiltration of wat

Post-monsoon groundwater depth map

The post-monsoon groundwater depth in the study area ranges from 0.28 m to 14.45 m below the ground surface. Post-monsoon groundwater depth map for the study area is shown in Fig. 7, which reveals that the groundwater depth ranges from 0 to 4 m in 34 per cent of the total study area and from 4 to 6 m in 54.26 per cent of the total study area. The deeper groundwater levels in the east portion of the study area along with small scattered patches are due to excessive pumping of groundwater for irrigation.

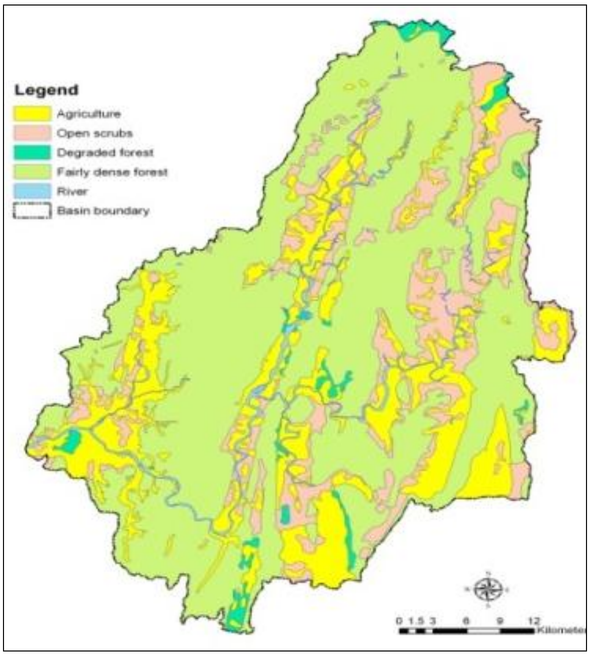


Fig 6: Thematic layer of Land use/Land

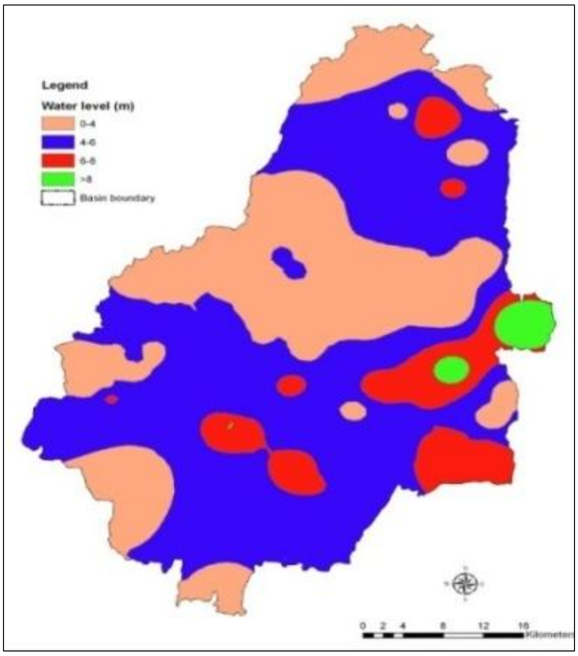


Fig 7: Thematic layer of Post monsoon Groundwater Depth

Recharge map

The annual net groundwater recharge in the study area varies from 0.15 to 12.02 cm. Based on these recharge estimates, the area has been divided into 5 recharge zones: (i) 0-1 cm/year, (ii) 1-2 cm/year, (iii) 2-3 cm/year, (iv) 3-4 cm/year, and (v) >4 cm/year as shown in Fig. 8. It is apparent from the figure that a net recharge of 1-4 cm/year is dominant in the study area, which is about 82 per cent of the total study area. Some patches in the north and middle portions of the study area have very low recharge rate (<1 cm/year). A high recharge rate (>4 cm/year) is confined to five patches in the east, southeast and southwest portions of the study area.

Transmissivity map

Transmissivity values obtained from the pumping tests have been used to prepare point map of transmissivity. Further, this point map was interpolated by using IDWMA method to generate a raster map of transmissivity. It is seen that the transmissivity in the study area varies from 132.82 m^2/day to 343.94 m^2/day. Based on these transmissivity values, the area was divided into five transmissivity classes namely 'extremely low' (<150 m^2/day), 'very low' (150-200 m^2/day), 'low' (200-250 m^2/day), 'moderate' (250-300 m^2/day) and 'high' (>300 m^2/day) as shown in Fig. 9. It is apparent from the map that a very low transmissivity (150-200 m^2/day) is confined to three patches in the west and southeast portions of the study area. The transmissivity ranges of 200-250 m^2/day is dominant in the study area, which is about 50 per cent of the total study area.

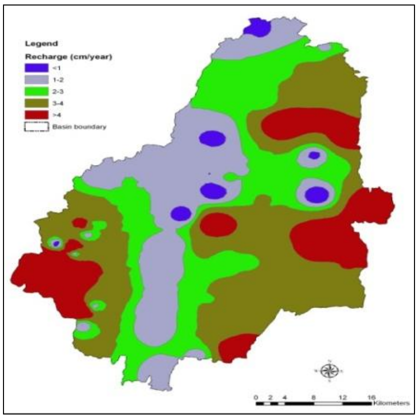


Fig 8: Thematic layer of Recharge

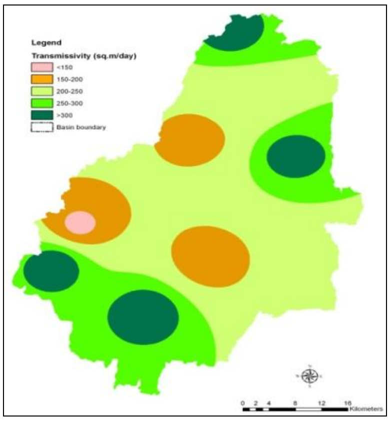


Fig 9: Thematic layer of Transmissivity

Table 1: Areal extent of different features of the eight thematic layers

Features of thematic layers	Area (km^2)	% Area
1. Geomorphology classes		
(i) Vally Fill	412.34	21.54
(ii) Buried Pediment	461.83	24.13
(iii) Pediment	554.14	28.95
(iv) Structural Hill	486.01	25.39
2. Land use/Land cover classes		
(i) Agriculture	434.70	22.71
(ii) Fairly Dense Forest	1146.27	59.88
(iii) Degraded Forest	37.25	1.95
(iv) Open Scrub	296.10	15.47
3. Soil classes		
(i) Loamy to Coarse loam	560.90	29.30
(ii) Loamy skelton to Fine loam	78.94	4.12
(iii) Fine to Loamy skelton	81.83	4.28
(iv) Loamy skelton to Coarse loam	4.99	0.26
(v) Rock outcrop to Loamy skelton	1083.88	56.62
(vi) Rock Outcrop to Fine loam	103.78	5.42
4. Slope classes (%)		
(i) <3	398.76	20.83
(ii) 3-5	267.04	13.95
(iii) 5-8	511.58	26.72
(iv) 8-15	251.53	13.15
(v) 15-30	284.70	14.87
(vi) >30	200.71	10.48
5. Topographic elevation classes		
(i) <400 m	168.77	8.82
(ii) 400-600 m	702.99	36.72
(iii) 600-800 m	556.63	29.08
(iv) 800-1000 m	473.82	24.75
(v) >1000 m	12.11	0.63
6. Recharge classes		
(i) <1 cm/year	40.78	2.13
(ii) 1-2 cm/year	440.15	22.99
(iii) 2-3 cm/year	480.58	25.11
(iv) 3-4 cm/year	641.15	33.49
(v) >4 cm/year	311.66	16.28
7. Post monsoon groundwater depth classes		
(i) 0-4 m	650.62	33.99
(ii) 4-6 m	1038.79	54.26
(iii) 6-8 m	190.18	9.93
(iv) >8 m	34.73	1.82
8. Transmissivity classes		
(i) <150 m^2/day	14.31	0.74
(ii) 150-200 m^2/day	261.08	13.64
(iii) 200-250 m^2/day	961.11	50.21
(iv) 250-300 m^2/day	466.28	24.36
(v) > 300 m^2/day	211.54	11.05

Groundwater Potential Zoning

The eight thematic maps namely geomorphology, soil, slope, topographic elevation, land use/land cover, post monsoon groundwater depth, recharge and transmissivity were considered for identifying groundwater potential zones in the study area. The assignment of weights to the themes and their features and the integration of different themes in a GIS environment are discussed in the following sections.

Weights for thematic maps

After understanding the behaviour of different thematic features with respect to groundwater control in the study area, the different themes and their individual features of these themes were assigned suitable weights. The weights assigned to all the thematic layers are presented in Table 2.

Table 2: Weights of eight themes for groundwater potential zoning

S. No.	Themes	Weight
1	Geomorphology	5
2	Land use/Land cover	4
3	Soil	3.5
4	Slope	3.5
5	Topographic Elevation	3
6	Recharge	4.5
7	Post-monsoon Groundwater Depth	4
8	Transmissivity	1

The derivation of the normalized weights for individual themes using Saaty's analytic hierarchy process (AHP) and eigenvalue technique is shown in Table 3 as an example. Similarly, the assigned weights of different features of individual themes were normalized by AHP and eigenvalue technique.

Table 3: Pair wise comparison matrix and normalized weights of the themes

Themes	Themes								Normalized Weight
	GM	LU	Soil	Slope	TE	RE	WD	TR	
GM	5/5	5/4	5/3.5	5/3.5	5/3	5/4.5	5/4	5/1	0.173
LU	4/5	4/4	4/3.5	4/3.5	4/3	4/4.5	4/4	4/1	0.145
Soil	3.5/5	3.5/4	3.5/3.5	3.5/3.5	3.5/3	3.5/4.5	3.5/4	3.5/1	0.121
Slope	3.5/5	3.5/4	3.5/3.5	3.5/3.5	3.5/3	3.5/4.5	3.5/4	3.5/1	0.121
TE	3/5	3/4	3/3.5	3/3.5	3/3	3/4.5	3/4	3/1	0.105
RE	4.5/5	4.5/4	4.5/3.5	4.5/3.5	4.5/3	4.5/4.5	4.5/4	4.5/1	0.156
WD	4/5	4/4	4/3.5	4/3.5	4/3	4/4.5	4/4	4/1	0.145
TR	1/5	1/4	1/3.5	1/3.5	1/3	1/4.5	1/4	1/1	0.034
Column Total =									1.000

Note: GM = Geomorphology, LU = Land use/Land cover, TE = Topographic Elevation, RE = Recharge, WD = Post-monsoon Groundwater Depth, TR = Transmissivity.

Groundwater potential zones

The groundwater potential map of the study area (Fig. 10) reveals four distinct zones representing 'good', 'moderate', 'poor' and 'very poor' groundwater potential in the area. The 'good' groundwater potential zone mainly encompasses valley fill and buried pediment areas around the river systems. It demarcates the areas where the terrain is most suitable for groundwater storage and also indicates the availability of water below the ground. The area covered by 'good' groundwater potential zone is about 382.94 km^2 (20 per cent). Parts of Khed Brahma, Kotra and Jhadol blocks of villages Jura, Dalmiya, Subri, Guran, Boti Kalar, Kotra, Thana, Ora etc. are mainly fall under this zone. The southeastern portion and some small patches in the south, central, northeastern and southwestern portions of the study area of villages Pipalimala, Adkaliya, Pipali Khadri, Khara, Richhavar, Bagpura, Virpura, Dhabra, Majawad etc. fall under 'moderate' groundwater potential zone. It encompasses an area of 596.61 km^2, which is about 31.17 per cent of the total study area. The 'poor' groundwater potential zone mainly dominant in the study area and encompassing an area of 654.48 km^2, which is 34.19 per cent of the total area. The groundwater potential in the north portion and some small patches in the central, northeastern and northwestern portions of the study area of villages Suroh, Meran, Thal, Inton Ka Khet, Sivdiya, Behda, Mokhi, Bhat, Kankal Ka Nal etc. are very poor covering an area of 280.29 km^2, which is 14.64 per cent of the total study area. The 'very poor' groundwater potential in the study area is most likely due to the presence of hillocks, rock outcrops and steep slopes.

The use of strategic documents, such as the map of groundwater potential zoning, allows the ability to predict sites favourable for well positioning and to optimize expenses of new water resources research (Ettazarini, 2007) [3]. The method can thus be used as a first estimate of the groundwater potentiality that goes parallel with probability of drilling success, but local studies in favorable zones should provide precisions for drilling location. Good groundwater potential zones are the most favourable for installing new production wells. It is most likely that well yields will be high in the good potential zones. Whereas, low well yields occur in poor groundwater potential zones.

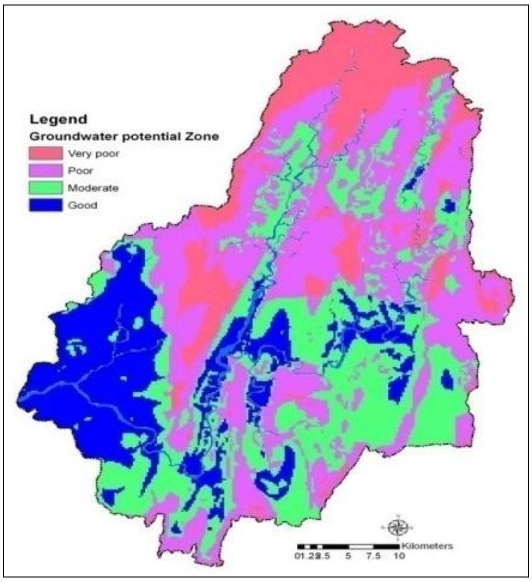


Fig 10: Groundwater potential zone map of Wakal river basin

Conclusion

On the basis of study, the study area were divided into four groundwater potential zones, viz., ‘good’, ‘moderate’, ‘poor’, and ‘very poor’, which cover 20 per cent good groundwater potential, 31.17 per cent moderate, 34.19 per cent poor and 14.64 per cent very poor groundwater potential zone. About 48.83 per cent of the basin falls under poor potential zone. Therefore, immediate attention is required for ensuring sustainable groundwater management in the basin.

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