Vol. 45, No. 3, pp 244-254, 2017
Indian Journal of Soil Conservation
Online URL : http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home

Identification of groundwater potential zones and artificial recharge sites in Jaisamand catchment using remote sensing and geographical information system

Pravin Dahiphale[1] and P.K. Singh

College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur-313001, Rajasthan.

[1]E-mail: pravin.dahiphale59@gmail.com

ARTICLE INFO

Article history :
Received : August, 2016
Revised : June, 2017
Accepted : June, 2017

Key words:
Remote Sensing,
GIS,
Groundwater potential,
Recharge

ABSTRACT

The aim of this study was to delineate groundwater potential zones in the Jaisamand catchment of Udaipur district, Rajasthan. To meet growing demand for groundwater, it is essential to identify the groundwater potential areas through scientific approach. It is in this context the remote sensing (RS) and geographical information system (GIS) technique was applied to demarcate the ground water potential zones in the study area. In the present study, thematic layers such as slope, relief, soil, geology, geomorphology, drainage, land use, recharge, post monsoon groundwater depth and transmissivity were prepared and integrated using the Spatial Analyst Tool in Arc GIS 10 software implying weighted overlay methods to delineate the groundwater potential zones and artificial recharge sites. In weighted overlay analysis rank value assigned for each class of all thematic data layers according to their influence on groundwater hydrology and factor weighted values was assigned according to analytical hierarchy process (AHP). The maximum area shows moderate groundwater potential and it covers 49.65% area. The 33.21% area shows poor groundwater potential whereas 4.32% area shows very poor groundwater potential. The area, which is favorable for artificial recharge is 279 km^2, which contributes only 15.02% of the total study area.

1. INTRODUCTION

Groundwater refers to all waters stored beneath the surface of the Earth in aquifers. In order to use the water stored in an aquifer, it is necessary first to locate the aquifer, map its size, extent and depth, and then estimate recharge and discharge rates of water. The effects of additional extraction wells on the aquifer and its structural integrity must also be assessed (Dasgupta and Sikdar, 1992). Much of the information can only be confirmed by the use of well records, bore hole and other *in-situ* sampling methods. However, the RS and GIS are playing a rapidly increasing role in the field of hydrology and water resources development. RS provides multi-spectral, multi-temporal and multi-sensor data of the earth's surface (Choudhary *et al.,* 2003). One of the greatest advantages of using RS data for hydrological investigations and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful analysis, prediction and validation (Sharma and Saraf, 2002). The GIS technology provides suitable alternatives for efficient management of large and complex databases. The study focuses on development of RS and GIS based analysis and methodology in groundwater recharge studies in watershed (Gustafsson, 1993). For delineating the groundwater potential/prospective zones, GIS has been found to be an effective tool. Several conventional methods such as geological, hydrogeological, geophysical, and photogeological techniques were employed to delineate groundwater potential zones. However, recently, with the advent of powerful and high-speed computers, digital technique is used to integrate various conventional methods with satellite image/RS techniques and GIS technology. The GIS and RS tools are widely used for the assessment of various natural resources (Gitas *et al.,* 2014 and Salari *et al.,* 2014).

The situation of groundwater availability in the study area is very crucial due to over exploitation of groundwater resources. The water table is depleting at an alarming rate and deteriorating the quality of groundwater in several areas. Large number of wells, hand pumps and tube wells are becoming drying in many areas causing acute shortage of irrigation and drinking water supply in the catchment. So study was carried out in Jaisamand catchment area of Udaipur district. In this study IRS-1D LISS-III satellite data and Survey of India (SoI) toposheets used as the data source. Satellite images are increasingly used in ground water exploration because of their utility in identifying various geomorphic features.

2. MATERIALS AND METHODS

Study Area

The Jaisamand lake catchment is located in the Udaipur district which falls under semi-arid region of Rajasthan bounded by Longitude 73^{0}45' E to 74^{0}25'E and Latitude 24^{0}10' N to 24^{0}35' N. The lake is a prime source of drinking water supply for the city of Udaipur located at a distance of about 52 km from the lake. The Jaisamand Lake with a gross capacity of 414.6 mm^3 and live storage of 296.14 mm^3, is Asia's second largest artificial water storage reservoir built across the Gomati river. In Jaisamand catchment Gomati, Thavaria, Siroli, Vagurwa, Jhamri, Sukhali, Godi, Makradi and Bhangar are the major rivers. The total catchment of Jaisamand lake is 1857.87 km^2 with highest elevation is 693 m above mean sea level (msl).

Groundwater Potential Zoning

The thematic layers of 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 (Kumar *et al.*, 2011; Nishtha, 2009; Jha and Peiffer, 2009 and Machiwal *et al.*, 2011). 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 AHP to calculate normalized weights for individual themes and their features. To demarcate groundwater potential zones, all the eight thematic layers after assigning weights were added (overlaid) using Arc GIS software (Paul *et al.*, 2016). 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).

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

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 w_i = 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.

Saaty's Analytical Hierarchy Process (AHP)

The AHP, introduced by Saaty (1980), is an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pair wise

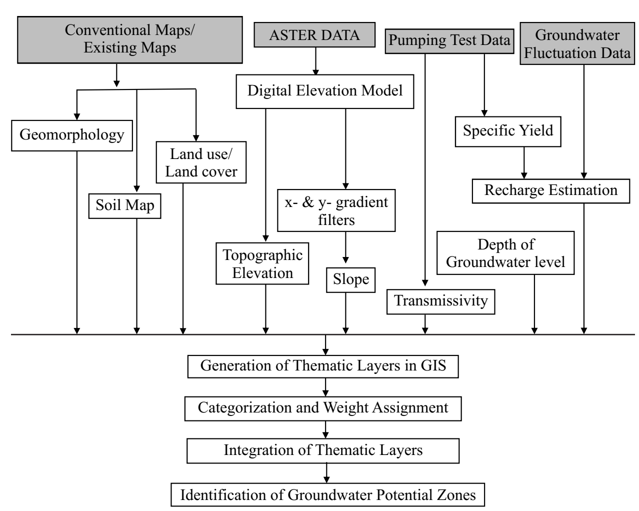

Fig.1. Flowchart for groundwater potential zoning using GIS

comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process.

The AHP considers a set of evaluation criteria, and a set of alternative options among which the best decision is to be made. It is important to note that, since some of the criteria could be contrasting, it is not true in general that the best option is the one which optimizes each single criterion, rather the one which achieves the most suitable trade-off among the different criteria. The AHP generates a weight for each evaluation criterion according to the decision maker's pairwise comparisons of the criteria. The higher the weight, the more important the corresponding criterion. Next, for a fixed criterion, the AHP assigns a score to each option according to the decision maker's pairwise comparisons of the options based on that criterion. The higher the score, the better the performance of the option with respect to the considered criterion. Finally, the AHP combines the criteria weights and the options scores, thus determining a global score for each option, and a consequent ranking. The global score for a given option is a weighted sum of the scores it obtained with respect to all the criteria.

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 individual features of these themes were assigned suitable weights (Machiwal *et al.,* 2011 and Waikar and Nilawar, 2014). The weights assigned to all the thematic layers are presented in Table 1.

The derivation of the normalized weights for individual themes using Saaty's AHP and eigenvalue technique is shown in Table 1 as an example. Similarly, the assigned weights of different features of individual themes were normalized by AHP and eigen value technique and are presented in Table 1 to Table 9.

Table: 2
Normalized weights of the geomorphology classes for ground water potential zoning

Geomorphology Classes	Groundwater Prospect	Weight Assigned	Normalized Weight
Water Body	Very good	8	0.381
Valley Fill	Good	7	0.333
Phyllite and schist	Moderate	3	0.143
Granite and gneisis	Poor	2	0.095
Structural Hill	Very Poor	1	0.048

Table: 3
Normalized weights of the land use/land cover classes for ground water potential zoning

Land Use/Land Cover Classes	Groundwater Prospect	Weight Assigned	Normalized Weight
kharif	Good	6	0.158
rabi	Good	5.5	0.145
Double/triple	Moderate	5.5	0.145
Current fallow	Poor	5	0.132
Deciduous forest	very poor	3	0.079
Scrub/deg. Forest	very poor	3	0.079
Scrub land	Poor	4	0.105
Water Body	Good	6	0.158

Table: 4
Normalized weights of the soil classes for groundwater potential zoning

Soil Classes	Groundwater Prospect	Weight Assigned	Normalized Weight
Clayey soils	Very good	8	0.320
Fine loamy	Good	5	0.200
loamy skeletal	Moderate	6	0.240
Coarse loamy	Moderate	5	0.200
Rock outcrops	Poor	1	0.040

Table: 1
Pair wise comparison matrix and normalized weights of the themes

Themes	Themes								Weight	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	5	0.173
LU	4/5	4/4	4/3.5	4/3.5	4/3	4/4.5	4/4	4/1	4	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	3.5	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	3.5	0.121
TE	3/5	3/4	3/3.5	3/3.5	3/3	3/4.5	3/4	3/1	3	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	4.5	0.156
WD	4/5	4/4	4/3.5	4/3.5	4/3	4/4.5	4/4	4/1	4	0.145
TR	1/5	1/4	1/3.5	1/3.5	1/3	1/4.5	1/4	1/1	1	0.034
								Column Total		1.000

Table: 5
Normalized weights of the slope classes for groundwater potential zoning

Slope Classes (%)	Groundwater Prospect	Weight Assigned	Normalized Weight
1-3	Very good	8	0.40
3-8	Good	6	0.30
8-15	Moderate	4	0.20
>50	Poor	1	0.05
Rock outcrops	Poor	1	0.05

Table: 6
Normalized weights of topographic elevation for groundwater potential zoning

Topographic Elevation Classes	Groundwater Prospect	Weight Assigned	Normalized Weight
<300 m	Very good	8	0.242
300-350 m	Good	7	0.212
350-450 m	moderate	6	0.182
450-550 m	Poor	5	0.152
550-650 m	Very poor	4	0.121
>650 m	very poor	3	0.091

Table: 7
Normalized weights for the recharge classes for groundwater potential zoning

Recharge Classes	Groundwater Prospect	Weight Assigned	Normalized Weight
<2 cm yr^{-1}	Very Poor	2	0.105
2-5 cm yr^{-1}	Poor	3	0.158
5-10 cm yr^{-1}	Moderate	6	0.316
>10 cm yr^{-1}	Good	8	0.421

Table: 8
Normalized weights of Post monsoon groundwater depth classes for groundwater potential zoning

Post monsoon groundwater depth classes	Groundwater Prospect	Weight Assigned	Normalized Weight
<5	Very good	6	0.30
5-10	Good	5	0.25
10-15	Moderate	3	0.15
15-20	Poor	2	0.10
>20	very poor	1	0.05

Suitable Strategies for Sustainable Groundwater Resources Management

For the management of groundwater resources, artificial recharge is a very important factor. Artificial recharge is the process of augmenting the natural movement of surface water into underground formations by some artificial means. This is accomplished by constructing infiltration facilities or by inducing recharge from surface water bodies. In hard rock areas, the underlying lithological units do not have sufficient porosity and permeability. In these areas, groundwater recharge falls short of the water that is being taken out of the aquifers. Hence, groundwater cannot suffice the requirement for agriculture or drinking water. Thus additional recharge by artificial methods becomes necessary to meet the water deficit. The performance of artificial recharge efforts can be immensely increased if they are performed through proper scientific planning. A RS and GIS based method is found to be very useful in suitability analysis for artificial recharge sites in the hard rock terrain (Saraf and Choudhary, 1998). For such analysis, the first task is to identify the factors facilitating recharge to take place. In this study, the thematic layers used for determining recharge zones are: (a) Transmissivity, (b) Recharge, (c) Groundwater Level (post-monsoon), (d) Topographic Elevation, (e) Soil, and (f) Slope. All the six thematic layers were combined using Boolean Logic Analysis to delineate to zones of suitability for artificial recharge structures. The prime task in this method is to identify the criterion and to formulate the set of logical conditions to extract the suitable zones. With this criterion, the output has only two classes: suitable or unsuitable. The areas in which the defined conditions of the information layers are fulfilled together, a value of 1 is given whereas the remaining part will have a zero value. The criteria considered in this study for demarcating suitable zones for artificial recharge are mentioned in Table 10. A flowchart showing steps for delineating artificial recharge zones is presented in Fig. 2.

Table: 9
Normalized weights of transmissivity classes for groundwater potential zoning

Transmissivity classes	Groundwater Prospect	Weight Assigned	Normalized Weight
100-150 m^2 day^{-1}	Very poor	1	0.061
150-200 m^2 day^{-1}	Poor	1.5	0.091
200-250 m^2 day^{-1}	Poor	2	0.121
250-300 m^2 day^{-1}	Moderate	3	0.182
300-350 m^2 day^{-1}	Moderate	4	0.242
350-400 m^2 day^{-1}	Good	5	0.303

Boolean Logic Analysis

Once all the needed data sets (the thematic layers) have been created such a query would be to find all the suitable locations. Probably the simplest and best-known type of GIS model is based on Boolean operations. In effect, Boolean modelling involves the logical combination of binary maps resulting from the application of conditional operators. Only one or zero values are assigned to each unit area, specifying

Table: 10
Criteria for demarcating suitable artificial recharge zones

Thematic Layer	Suitability Criteria
Slope	<5%
Groundwater level (post monsoon)	>4 m below ground surface
Transmissivity	200-300 m^2 day^{-1}
Recharge	2-4 cm $year^{-1}$
Topographic elevation	<600 m
Soil	Coarse loamy and rock outcrop to loamy skeleton

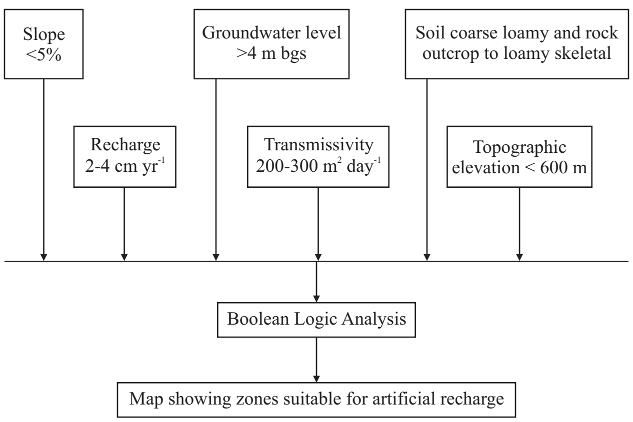

Fig. 2. Flowchart showing steps for delineating artificial recharge zones

whether it is satisfactory or unsatisfactory, respectively. The Boolean model consists of AND and OR operators. Based on set theory, the AND operator yields the logical intersection of the two data sets, and the OR operator obtains the logical union of the two data sets. The query data is analyzed based on Boolean logic and entered in the Raster Calculator (from spatial analyst) according to the existing thematic layers.

3. RESULTS AND DISCUSSION

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 Jaisamand catchment. The areal extent of different features of these thematic layers is given in Table 11 and Fig. 3 to Fig.10.

Geomorphology

Based on the physiographic characteristics, the landforms of the study area have been classified into five different units namely: (i) Structural hills (ii) granite and gneiss (iii) phyllite and schist (iv) valley fills and (v) water bodies as shown in Fig. 3. The characteristic features of these geomorphic units are described below:

Table: 11
Areal extent of different features of the thematic layers

Features of thematic layers	Area (km^2)	% Area
1. Geomorphology classes		
(i) Structural hills	623.1	33.54
(ii) Granite and Gneiss	1116.75	60.11
(iii) Phyllite and Schist	70.85	3.81
(iv) Valley fills	6.83	0.37
(v) Water bodies	40.34	2.17
2. Land use/Land cover classes		
(i) *kharif* only	297.15	15.99
(ii) *rabi* only	122.27	6.58
(iii) Double/tripple	131.60	7.08
(iv) Current fallow	539.36	29.03
(v) Deciduous forest	151.37	8.15
(vi) Scrub/Deg.forest	117.30	6.31
(vii) Other wasteland	451.14	24.28
(viii) Scrub land	7.36	0.40
(ix) Water bodies	40.34	2.17
3. Soil classes		
(i) Fine loamy soil	886.72	47.73
(ii) Coarse loamy	228.13	12.28
(iii) Loamy skeletal soil	61.93	3.33
(iv) Clayey soil	2.83	0.15
(v) Rock outcrops	678.26	36.51
4. Slope classes (%)		
(i) 1-3	179.37	9.65
(ii) 3-8	938.31	50.50
(iii) 8-15	44.12	2.37
(iv) 30-50	1.04	0.06
(v) >50	16.77	0.90
(vi) Rock outcrop	678.26	36.51
5. Topographic elevation classes		
(i) <300	27.74	1.49
(ii) 300-350	667.80	35.94
(iii) 350-450	955.26	51.42
(iv) 450-550	183.00	9.85
(v) 550-693	24.08	1.30
6. Recharge classes		
(i) <2	586.08	31.55
(ii) 2-5	1148.55	61.82
(iii) 5-10	113.79	6.12
(iv) >10	9.45	0.51
7. Post monsoon groundwater level classes		
(i) <5	239.32	12.88
(ii) 5-10	1123.37	60.47
(iii) 10-15	437.94	23.57
(iv) 15-20	52.12	2.81
(v) >20	5.12	0.28
8. Transmissivity classes		
(i) 100-150	4.82	0.26
(ii) 150-200	115.25	6.20
(iii) 200-250	195.44	10.52
(iv) 250-300	547.66	29.48
(v) 300-350	893.34	48.08
(vi) 350-400	101.35	5.46

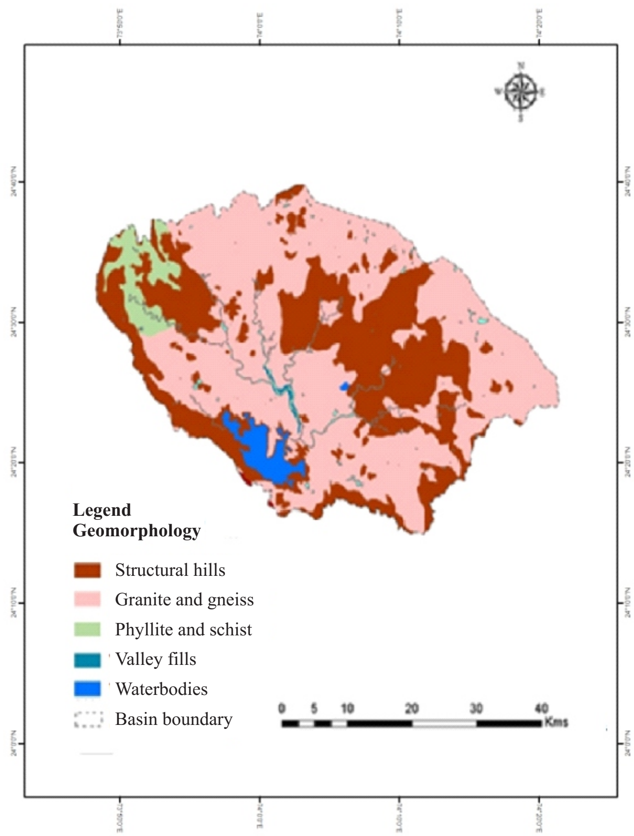

Fig. 3. Thematic layer of geomorphology

Structural Hill

About 623.10 km^2 area, which is 33.54% of the total study area is falling under this geomorphologic feature. Structural hills are linear to arcuate hills showing definite trend lines with varying lithology associated with folding, faulting, etc. This type of geomorphology mainly occurs in east portion and boundary of the study area. This feature categorized as very poor because it is not influence for groundwater occurrence.

Granite and Gneiss

The litho units of granite and gneiss are hard and compact, fine to medium grained and characterized by alternating bands of light and dark color ferromagnesian minerals. Gneiss is coarsely foliated in bands. The bands can be straight, pancake-like, or wavy. The bands differ in composition and are coarse grained making them easy to identify. Many of the light colored bands are composed of either quartz or feldspar. Gneiss has about the same mineral composition as granite, but the pressure of metamorphism causes the minerals to line up, giving gneiss a distinct banded appearance. The granite and gneiss categorized as poor for groundwater occurrence. The study area has granite and gneiss, encompassing area about 1116.70 km^2 which is 60.11% of total study area.

Phyllite and Schist

Phyllite is a foliate metamorphic rock that is made up mainly of very fine-grained mica. The surface of phyllite is typically lustrous and sometimes wrinkled. It is intermediate in grade between slate and schist. If not enough heat and temperature were applied then metamorphic rock could have been formed called phyllite**,** which is not as hard as slate. However, if the shale was in an area that was exposed to higher pressures and moderate temperatures, it might have been transformed into schist. About 3.81% study area falling under this geomorphologic feature.

Valley Fills

The study area has valley fills, encompassing an area about 6.83 km^2, which is 0.37% of the total study area. The valley fills are formed by fluvial activity usually at lower topographic locations and comprised of boulders, cobbles, pebbles gravels, sand slit, and clay. The unit has consolidated sediment deposits and is usually good for groundwater occurrence. It is directly influenced for groundwater occurrence so categorized as good.

Water Bodies

About 40.34 km^2, which is 0.37% of the total study area occupy by water bodies. This feature greatly influenced for groundwater occurrence so categorized as very good.

Slope Map

The slope percentage in the area varies from 0 to 50%. Based on the slope, the study area was divided into six slope classes: (i) 1-3, (ii) 3-8, (iii) 8-15, (iv) 30-50, (v) > 50% and (vi) Rock outcrop. The area having 1 to 3% slope falls in the 'very good' category due to the nearly flat terrain and relatively high infiltration rate. It covers 179.37 km^2 areas, which is about 9.65% of the total study area. The area with 3 to 8% slope is considered as 'good' for groundwater storage due to slightly undulating topography with some runoff, which is about 50.50% area of the total study area. The area having a slope of 8 to 15% causes relatively high runoff and low infiltration, and hence categorized as 'moderate', which is about 2.37% area of the total study area. The fourth (30-50%), fifth (> 50%) and rock outcrop category are considered as 'poor' due to higher slope and runoff, which is about 37.47% area of the total study area. A slope map prepared from Digital Elevation Model is shown in Fig. 4.

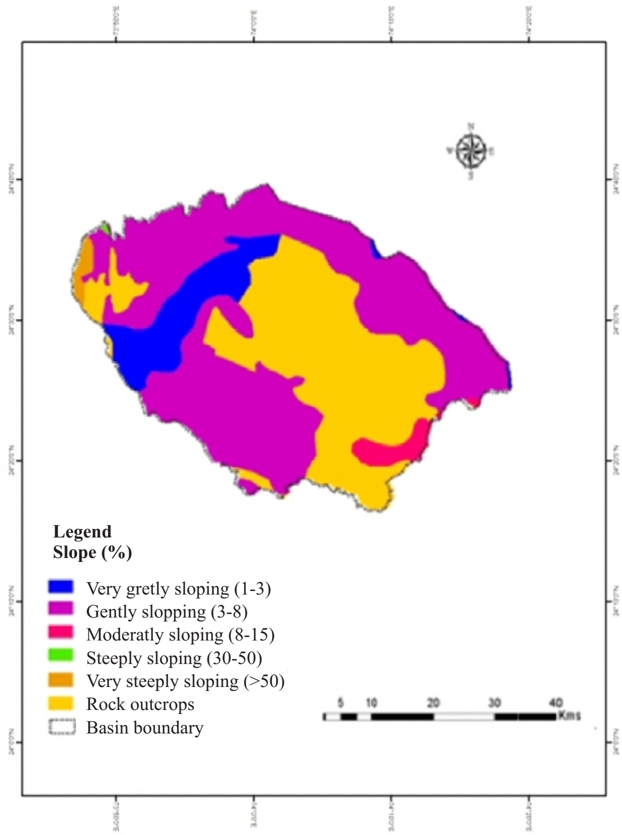

Fig. 4. Thematic layer of slope

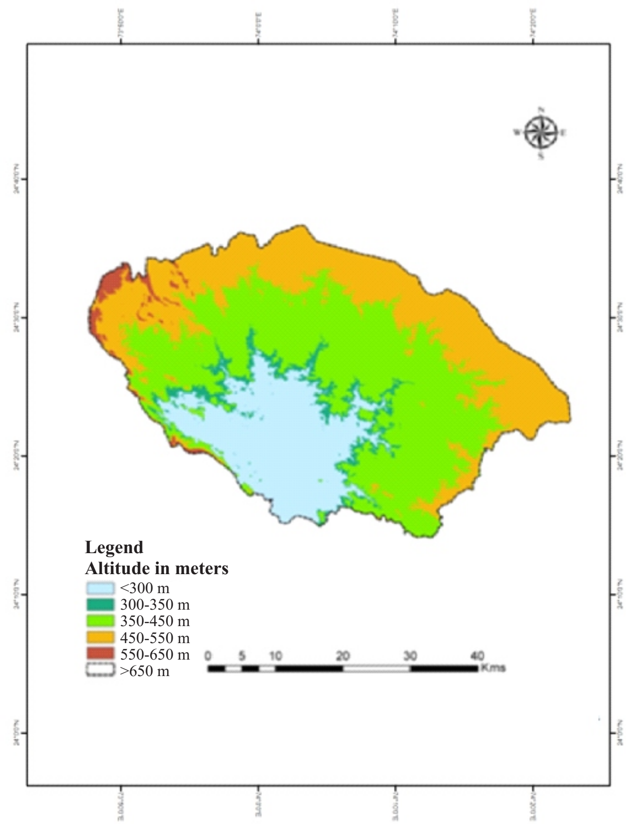

Fig. 5. Thematic layer of topographic elevation

Topographic Elevation Map

The topographic elevation map has been divided into five classes: (i) <300, (ii) 300-350, (iii) 350-450, (iv) 450-550 and (v) 550-693 m. The highest topographic elevations 550-693 exist in western portions of the study area and it covers 24.08 km^2 areas. 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 350-450 m in 703 km^2 areas, which is about 51.42% of the study area. The topographic elevation map is shown in Fig. 5.

Post Monsoon Groundwater Depth Map

The post-monsoon groundwater depth in the study area ranges from 0.28 to 14.45 m below the ground level. Post-monsoon groundwater depth map for the study area is shown in Fig. 6, which reveals that the groundwater depth ranges from 0 to 4 m in 34% of the total study area and from 10 to 15 m in 23.57% of the total study area. The deeper groundwater levels in the north and east portion of the study area along with small and scattered patches are due to excessive pumping of groundwater for irrigation.

Recharge Map

The annual net groundwater recharge in the study area

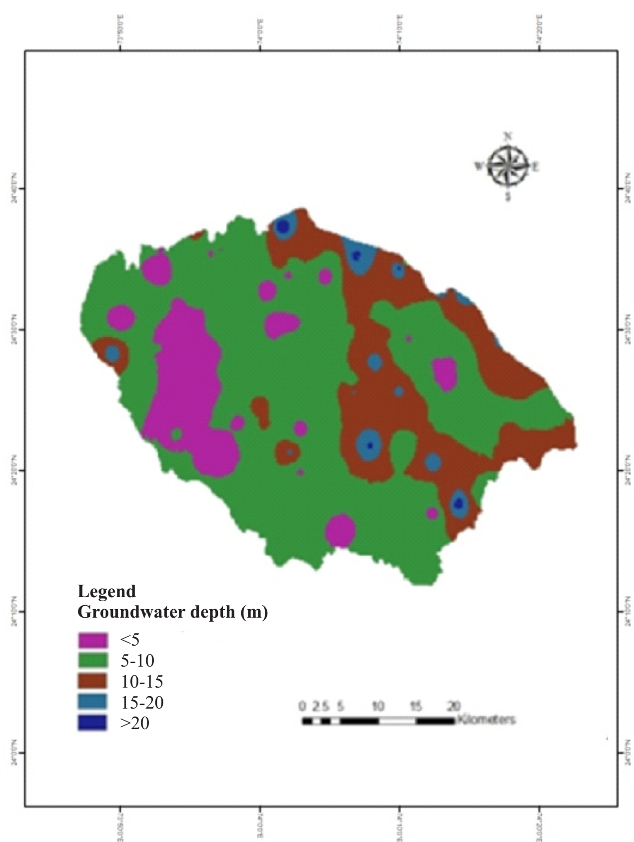

Fig. 6. Thematic map of post-monsoon groundwater depth

varies from 0.19 to 14.59 cm. Based on these recharge estimates, the area has been divided into 4 recharge zones: (i) < 2, (ii) 2-5, (iii) 5-10 and (iv) >10 cm yr^{-1} as shown in Fig. 7. It is apparent from the figure that a net recharge of 2-5 cm yr^{-1} is dominant in the study area, which is about 61.82% of the total study area. Some patches in the north and middle portions of the study area have very low recharge rate (< 2 cm yr^{-1}). A high recharge rate (>10 cm yr^{-1}) is confined to one patch in the southwest portions of the study area.

Land use/ Land Cover Map

A land use/land cover thematic map was distinguished into nine different classes: (i) *kharif* only (ii) *rabi* only, (iii) double/tripple (iv) current fallow (v) deciduous forest (vi) scrub/degraded forest (vii) other waste land (viii) scrub land and (ix) water bodies as shown in Fig. 8. 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. Scrub land was assigned the lowest rating, because it allow less time for the infiltration of water.

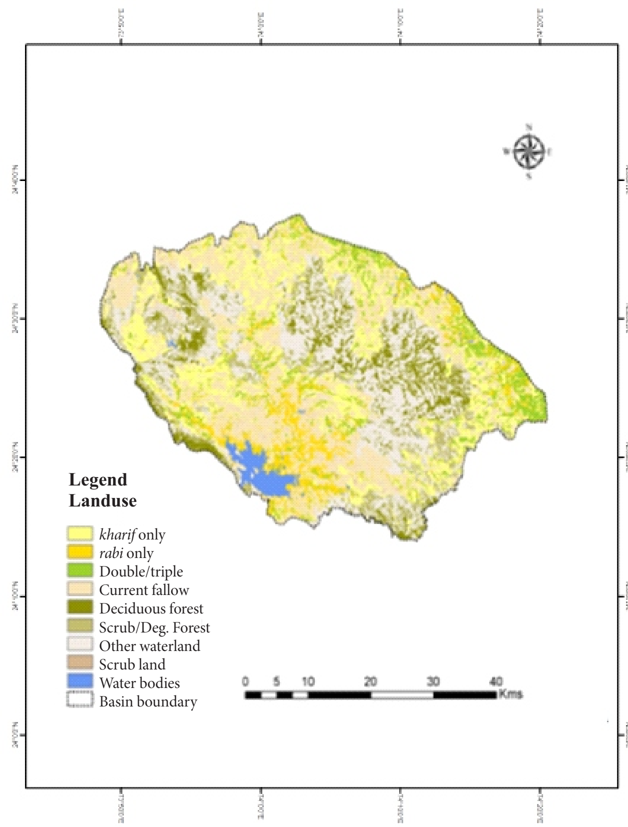

Fig. 8. Thematic layer of land use/land cover

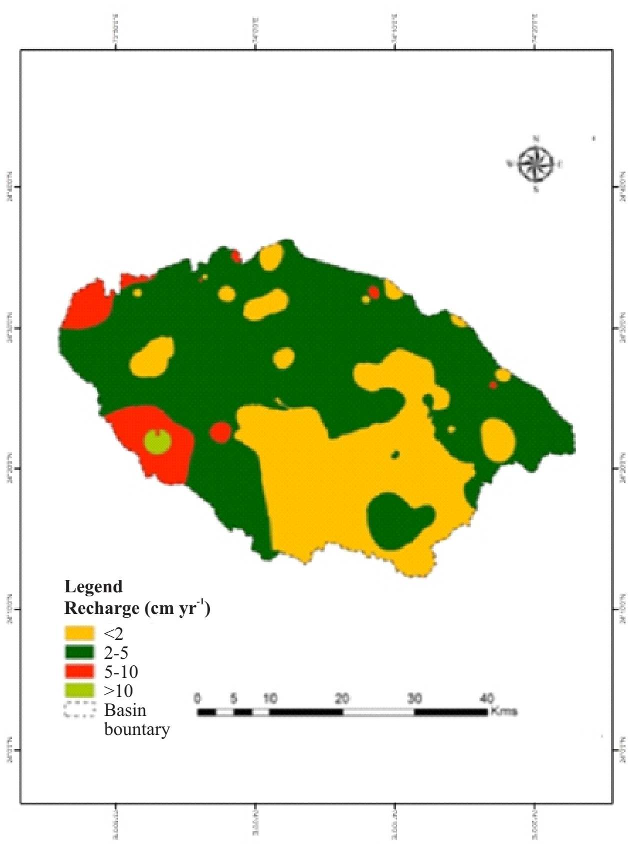

Fig. 7. Thematic layer of recharge

Soil Map

The thematic layer of soil for the study area reveals six main soil classes *viz.*, Fine loamy soil, coarse loamy, loamy skeletal soils, clayey soils and rock outcrops. It is apparent from Fig. 9 that the majority of the study area is dominated by fine loamy soil which is about 47.73% of the total study area. These five soil classes can be categorized into five classes namely 'very good', 'good', 'moderate' and 'poor' according to their influence on groundwater occurrence.

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 inferred that the transmissivity in the study area varies from 123.82 to 386.94 m^2 day^{-1}. Based on these transmissivity values, the area was divided into six transmissivity classes namely, very poor (100-150), poor (150-200), poor (200-250), moderate (250-300), moderate (300-350) and good (350-400 m^2 day^{-1}) as shown in Fig.10. It is apparent from the map that a very

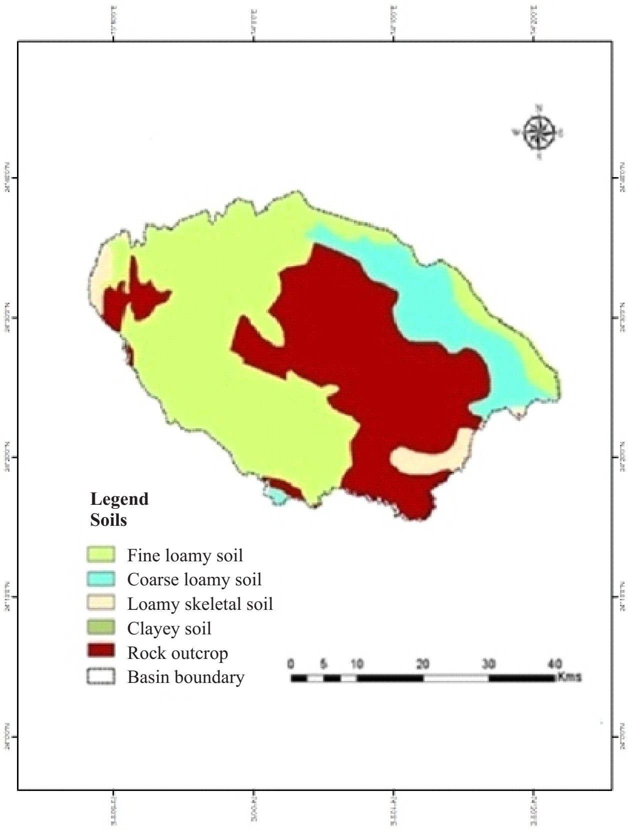

Fig. 9. Thematic layer of soil

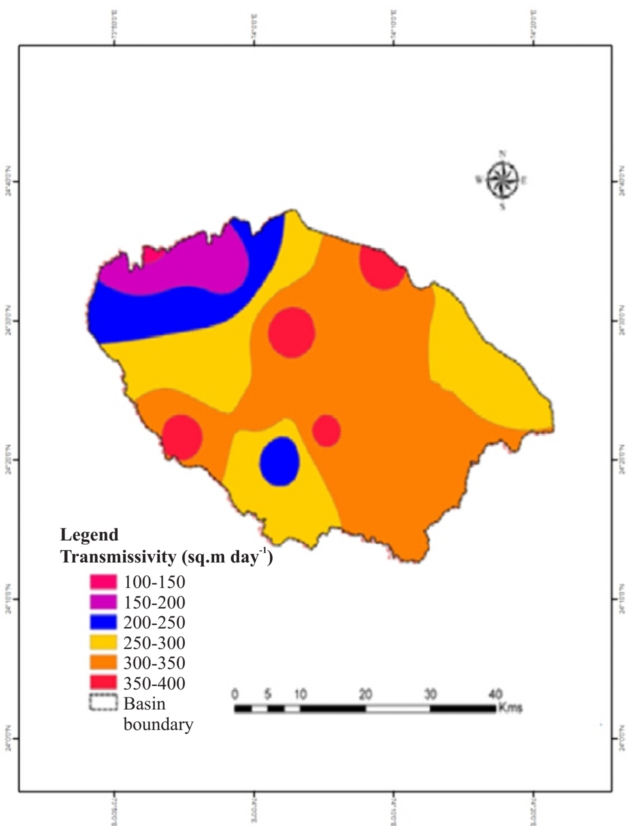

Fig. 10. Thematic layer of transmissivity

low transmissivity (100-150 m^2 day^{-1}) is confined to four patches in the northwest and southeast portions of the study area. The transmissivity ranges of 300-350 m^2 day^{-1} is dominant in the study area, which is about 48.08% of the total study area.

The eight thematic layers 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.

Groundwater Potential Zones

The groundwater potential map of the study area (Fig.11) 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 lake. 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 12.82% and contributed Kheroda, Neemri, Mnsingpura, Lakarwas, Adinda, Runeeja, Edana, Gingla, Wali, Bed etc. villages. The maximum area has moderate groundwater potential and it covers 49.65% area. This zone

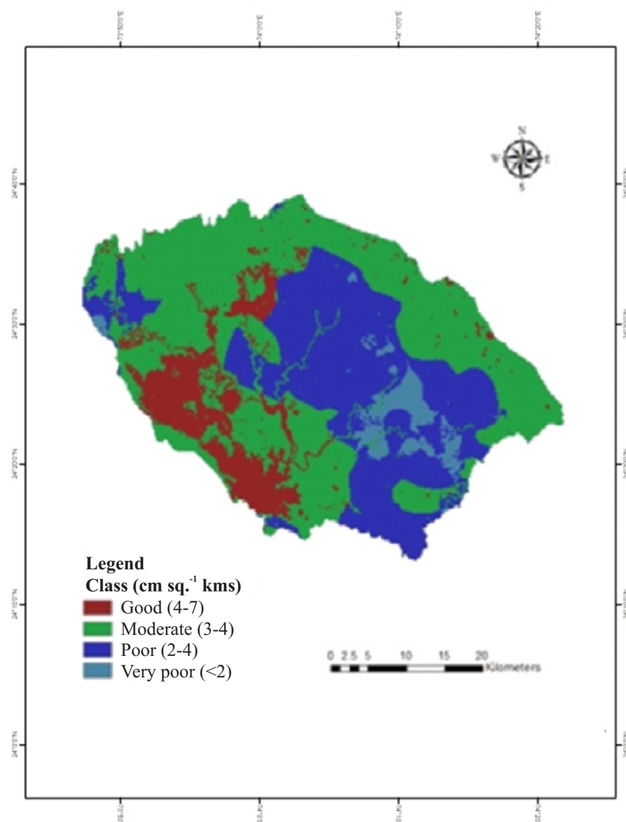

Fig. 11. Groundwater potential zones of Jaisamand catchment

includes Deopura, Karawali, Kharka, Ratanpura, Morpura, Talab, Jamboora, Buthel, Mamadeo, Karget, Pindoliya, Loda, Basa, Bemla, Rayala, Phoosariya etc. villages.

The 33.21% area shows poor groundwater potential zone and this zone includes Agar, Deoliya, Ajani, Ramina, Kund, Kelwa, Kaccher, Bhekra *etc.* villages. In study area 4.32% area shows very poor groundwater potential and which includes Dhawari, Patiya, Bobri, Arniya, Tekan, Kasotiya etc. villages. The various classes of groundwater potential zones along with corresponding area are shown in Table 12.

Artificial Groundwater Recharge Zones

The favourable artificial groundwater recharge zone for the study area is delineated using RS and GIS technique. In this map green colour indicates the favourable zone for artificial recharge. It was found in the southern part of the basin which includes villages of Karawali, Deopura, Talab, Kharka, Payari, Basa, Pheela, Okhariya, Loda, Gingla, Buthel, Edana *etc.* and some other scatter portion of catchment. For artificial recharge, suitable recharge structures such as percolation ponds, check dams and earthen dams are recommended for construction. The area, which is favorable for artificial recharge is 279 km^2, which contributes only 15.02% of the total study area. Map of the suitable zones for artificial recharge in the study area is shown in Fig.12.

Table: 12
Groundwater potential zone classes and area

Class	Area (km^2)	% Area
Good	238.10	12.82
Moderate	922.38	49.65
Poor	617.07	33.21
Very poor	80.33	4.32

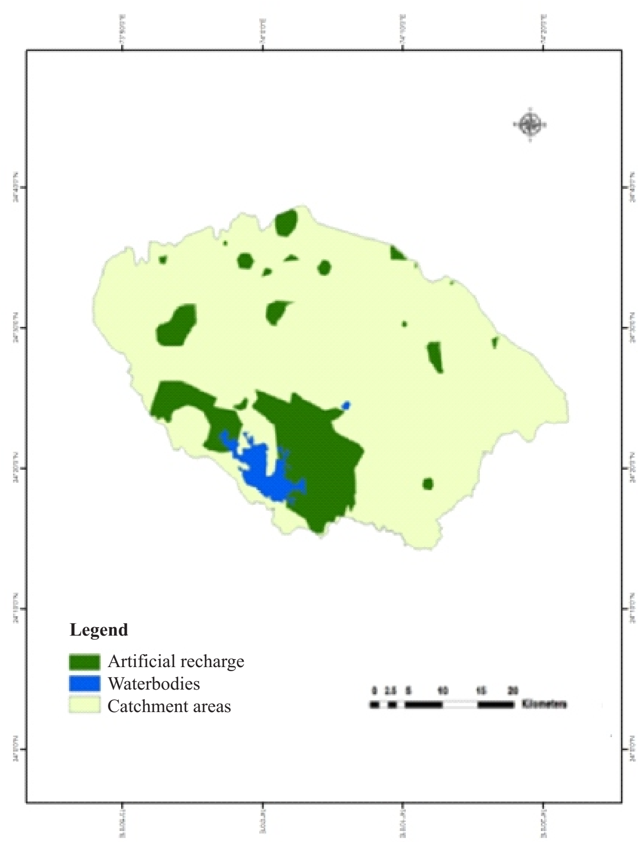

Fig. 12. Favourable artificial groundwater recharges zones of Jaisamand catchment

4. CONCLUSIONS

The transmissivity value in the study area varies from 123.82 to 386.94 m^2 day^{-1}. The annual net groundwater recharge in the study area varies from 0.19 to 14.59 cm. The deeper groundwater levels in the north and east portion of the study area along with small and scattered patches are due to excessive pumping of groundwater for irrigation. The maximum area has moderate groundwater potential and it covers 49.65% area. The 33.21% area shows poor groundwater potential whereas 4.32% area shows very poor groundwater potential. The area, which is favorable for artificial recharge is 279 km^2, contributes only 15.02% of the total study area. For artificial recharge, suitable recharge structures such as percolation ponds, checkdams and earthen dams are recommended for construction.

ACKNOWLEDGEMENTS

The first author is thankful to DST for providing financial support through INSPIRE Fellowship during research work.

REFERENCES

Choudhary, V.M., Roan, N.H. and Sharma, P.B.S. 2003. GIS based decision support system for groundwater assessment in large irrigation project areas. *Agr. Water Manage.*, 62: 229-252.

Dasgupta, S. and Sikdar, P.K. 1992. Groundwater potential in the upper catchment of the Silai river basin Bankura district, West Bengal. *Indian J. Earth Sci.*, 19(2-3):128-135.

Gitas, I.Z., Ayanz, J.S.M., Chuvieco, B.D.E. and Camia, A. 2014. Advances in remote sensing and GIS applications in support of forest fire management. *Int. J. Wild Land Fire*, 23:603-605.

Gustafsson, P. 1993. High resolution satellite data and GIS as a tool for assessment of groundwater potential of semi-arid area. In: IXth Thematic Conference on Geologic Remote Sensing. February 8-11, 1993 at Pasadena, California, USA.

Jha, M.K. and Peiffer, S. 2009. Applications of remote sensing and GIS technologies in groundwater hydrology: past, present and future. Bay CEER, Bayreuth, Germany, 201 p.

Kumar, A., Sharma, H.C. and Kumar, S. 2011. Planning for replenishing the depleted groundwater in upper Gangetic plains using RS and GIS. *Ind. J. Soil Cons.*, 39(3): 195-201.

Machiwal, D., Jha, M.K. and Mal, B.C. 2011. Assessment of Groundwater Potential in a Semi-Arid Region of India Using Remote Sensing, GIS and MCDM Techniques. *J.* Water Res. Manage., 25(5): 1359-1386.

Nishtha, 2009. Studies on groundwater resources management by using GIS. Unpublished M.E. thesis submitted to CTAE, MPUAT, Udaipur (Rajasthan).

Paul, J.C., Panigrahi, B., Padhi, G.C. and Mishra, P. 2016. Geo-informatics based groundwater plan preparation of Kichna nala watershed of Odisha. *J. Soil Water Cons.,* 15(4): 325-331.

Rao, B.V. and Briz-Kishore, B.H. 1991. A methodology for locating potential aquifers in a typical semi-arid region in India using resistivity and hydrogeologic parameters. *Geoexploration,* 27(1): 55-64.

Saaty, T.L. 1980. The analytic hierarchy process. McGraw-Hill, New York.

Salari, A., Zakaria, M., Nielsen, C.C. and Boyee, M.S. 2014. Quantifying tropical wetland using field survey, spatial statistic and remote sensing. *J. Wetlands,* 34:565-574.

Saraf, A.K. and Choudhury, P.R. 1998. Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. *Int. J. Remote Sens.*, 19(10): 1825-1841.

Sharma, B. and Saraf, A.K. 2002. Study of land use groundwater relationship using an integrated remote sensing and GIS approach, *http:/www.gisdevelopment.net*.

Waikar and Nilawar 2014. Identification of Groundwater Potential Zone using Remote Sensing and GIS Technique. *Int. J. Inno. Res. Sci. Engg. Tech.,* 3(5): 12163-12171.