Journal of Science and Technology
ISSN: 2456-5660 Volume 06, Issue 05, SEP-OCT 2021

www.jst.org.in DOI: https://doi.org/10.46243/jst.2021.v6.i05.pp122-131

Assessment of Groundwater Potential Zones Using Geographic Information System and Analytic Hierarchy Process (AHP) Techniques in Chhoti Kali Sindh Watershed in Ujjain district, Madhya Pradesh, India

Kishore Sonwane*[1], Habib Ullah Usmani[2]

[1]*(Department, of Geology, Govt. Motilal Vigyaan Mahavidyalay, Bhopal, M.P. India)*
[2]*(Department, of Geology, Govt. Motilal Vigyaan Mahavidyalay, Bhopal, M.P. India)*
**Corresponding Author: k.r.s.sonwane@gmail.com*

To Cite this Article
Kishore Sonwane, Habib Ullah Usmani, "**Assessment of Groundwater Potential Zones Using Geographic Information System and Analytic Hierarchy Process (AHP) Techniques in Chhoti Kali Sindh Watershed in Ujjain district, Madhya Pradesh, India**", *Journal of Science and Technology, Vol. 06, Issue 05, Sep-Oct 2021, pp.:122-131.*

Article Info
Received: 19-10-2021 Revised: 24-10-2021 Accepted: 25-10-2021 Published: 30-10-2021

Abstract: *Geographic information system (GIS) and Analytic Hierarchy Process (AHP) techniques combinedly employed for delineation of groundwater potential zones in the Chhoti Koli Sindh watershed, in the present study thematic layers of geology, geomorphology, lineament, drainage density, landuse have been prepared .DEM generated from the 20 m contour map and a slope maps has been prepared using DEM. These maps integrated is GIS environment and a multi criteria decision making (MCDM) approach in the form of analytical hierarchy process were employed in which the rating and weights for every theme were assigned according to their influence on these themes and groundwater potential zones were obtained using weightages as very high, high, moderate and poor potential zone. The potential zone map also reveals that about 62% of total area comes under high groundwater potential zone category.*

Key Word*: Analytic Hierarchy Process (AHP); Groundwater potential zone; Chhoti Kali Sindh watershed; GIS*

I. Introduction

Groundwater as one of the natural resources supports human health and ecological balance. According to an estimate approximately one third population of the world depends upon the groundwater for drinking. It is also the source for irrigation and industrial purposes. About 80% population of the rural area and approximately 50% of the urban area uses the groundwater for domestic purposes. Owing to more dependency on groundwater resources for domestic, irrigation and for other uses the rate of exploitation of groundwater resources has also increased. But the uniqueness of groundwater is its dynamic and replenishable nature. The exploration and exploitation of groundwater resources need the understanding of geology, geomorphology, linement and drainage of that area.

In the Chhoti Koli Sindh watershed groundwater is a critical natural resource for reliable water supply. Despite the fact that the district receives normal rainfall during the rainy season, individuals frequently confront water scarcity during the dry season. Water shortage in the Chhoti Koli Sindh watershed is caused by a number of issues, including rapid rate of population expansion and urbanization, over exploitation of groundwater, a lack of awareness, and a lack of efficient system for groundwater management. Though, whole of the Chhoti Kali Sindh watershed contains basaltic rocks known as Deccan trap which is favourable for groundwater occurrence.

Therefore, it seems more appropriate to investigate the suitable areas for groundwater extraction to increase the availability of water in the present watershed. Several conventional methods such as geological, hydrogeological, geophysical, and photogeological techniques are 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/remote sensing (RS) techniques and geographical information system (GIS) technology. The GIS and RS tools are widely used for the assessment of various natural resources [1]. This technique also effectively used as a tool for delineating the groundwater potential zones in area. The accuracy of results in delineation of groundwater potential zones without bias on any single theme has increased by and large due application of RS and GIS.

Saaty (1977) evolved an Analytic Hierarchy Process (AHP) which is being used widely as a Multi Criteria Decision Making (MCDM) technique in the field of water resources engineering [3]. The method was first developed by Professor Thomas L. Saaty in the 1977. Furthermore, the Analytic Hierarchy Process (AHP) [4,5,6] has become an internationally acceptable quantitative technique, which is also adopted in the present study as flexible decision making tool for the assessment of the potential zones of groundwater resources in the study area. In recent years, numerous studies reported that multi-criteria decision making (MCDM) offers an effective tool for water resource management by adding structure, auditability, transparency,and accuracy to decisions[7,8,9,10,11,12]. The AHP has been successfully applied in several studies of water resource management by integrating MCDA [4,5,6] with RS and GIS techniques. Therefore, in the present study AHP coupled with MCDA, GIS and RS techniques employed to integrate hydrogeological, geomorphologic as well as climatic data to evaluate groundwater resources of the Chhoti Koli Sindh watershed, Ujjain District M.P. The purpose of study is delineation of the groundwater potential zones of study area

II. Study Area

Present study area Chhoti Koli Sindh (CKS) watershed situated between latitude $22^{o}55'$ to $23^{o}40'$ N and longitude $75^{o}43'$ to $76^{o}18'$ E; extends over 1767 sq. km and spread over three districts viz. Ujjain, Dewas and Shajapur of Madhya Pradesh. The location of the study area is given in Fig.1. Geologically, the area is composed of Deccan trap basalts of Cretaceous to paleogene age. These basalts are the only rock formations found in the watershed and are overlained the black soils, as weathering products of these basalts. These basaltic rocks where ever exposed at the surface characterized by primary volcanic igneous features as coloumnar joints, vesicular and amygdaloidal structure and spheroidal weathering.

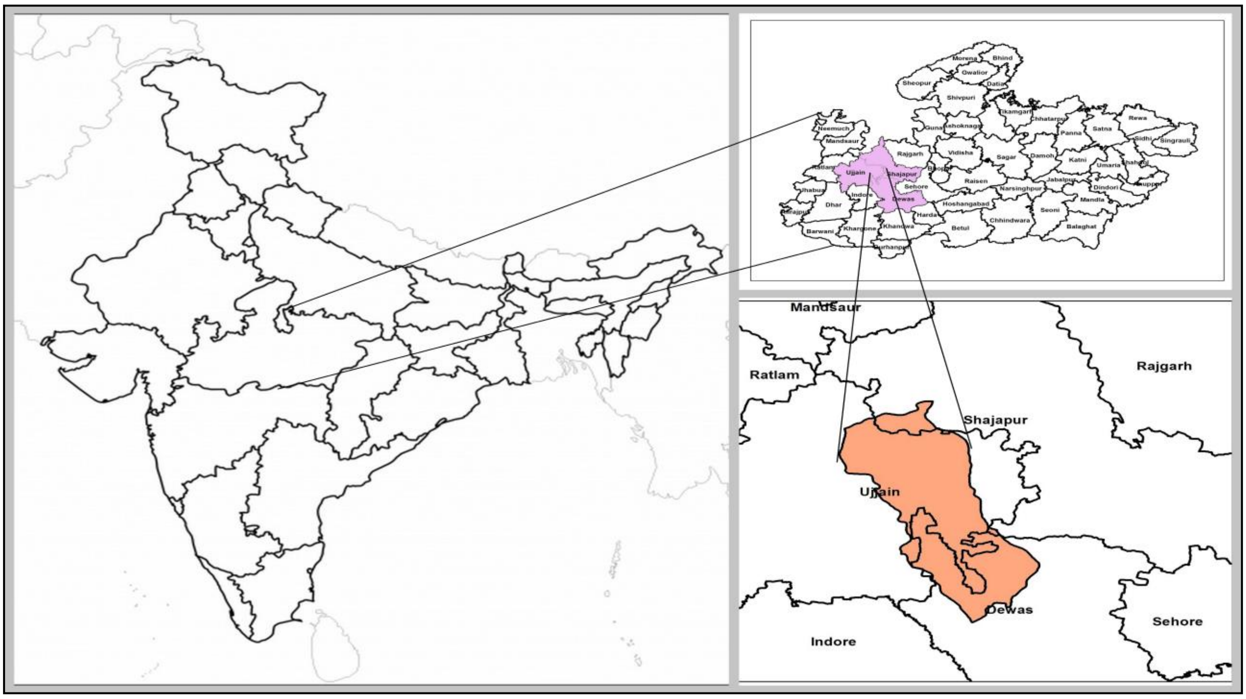

Fig.1. Showing location map of the study area

III. Methodology

The methodology involves collecting and preparing all the nine thematic layers using Arc GIS software. The study was attempted by considering different layers obtained from different sources on geology, geomorphology, drainage density, lineament density, slope land use and land cover, soil, and rainfall. These data were processed in the GIS environment to create the database. Geology and geomorphology maps were prepared using SOI Topo maps 1:50,000 scale and LISS-III satellite image. Digital Elevation Model (DEM) extracted from SRTM-30 m resolution which was used to prepare slope and drainage density layers. The soil map is obtained from National Bureau of Soil Survey (NBSS) on a scale of 1:50,000. Rainfall data for the period of 5 years were collected from the Indian Meteorological Department and to obtain a rainfall map the interpolation of rainfall values was done. Once the database was created for all the eight layers, the weight assigned to each layer was determined using the analytical hierarchy process (AHP).

The geo-referenced maps were assigned weights computed by the analytical hierarchy process. The normalized weights for the layers were obtained by satisfying the consistency index and consistency ratio (CR) values of the constructed pairwise matrix. The matrix thus created is said to be consistent if its CR value falls below 0.1. The layers were subjected to weighted overlay analysis after assigning the determined weights. The Groundwater Potential Index (GWPI) values were calculated using the equitation:-

$$GWPI = GrGw + DrDw + LrLw + SlrSlw + GerGew + SrSw + LurLuw + RrRw + ErEw \qquad (1)$$

Where GWPI is groundwater potential Index, G is geomorphology, D is drainage density, L is lineament density, Sl is slope, Ge is geology, Lu is land use and land cover, S is soil, R is rainfall, and E is elevation. The suffix r and w represents the rank and weight of each layer. On the basis of calculated value of this Index the groundwater potential zones classified into five classes and the result were verified using well yield and groundwater levels fluctuation data of pre and post monsoon seasons.

(AHP) Analytical hierarchy process as an architecture decision making approach for rank and weight determination that involves expert knowledge by constructing an eigen value pairwise comparison matrix. This method is considered the best-method for decision-making in a problem in which several parameters are involved influence the result. This process involves the designing of a pairwise matrix where the weights of each parameter is determined by considering their relative importance [13]. The factors influencing the result were developed as a structured hierarchy, and a pairwise matrix was constructed by arranging criteria in rows and columns. The rows considered as criteria A and the criteria B was taken as column. A scale from 1 to 9 was developed as a relative scale of importance which was constructed using the matrix developed by Saaty. The matrix is completed by comparing both the criteria and by assigning ranks based on relative importance. The diagonal of this matrix was assigned 1 as criteria A and B have equal importance over the other. The rank of 9 was assigned to criteria which effects extremely high over the others. Saaty scale of relative importance is shown in Table 1 and Table 2 displays the constructed pairwise matrix for this study. If consistency ratio < 0.1, and then the criteria weights thus obtained were used for analysis. This method provides the decision-maker, with a wide range of choices. This method also allows checking for the subjectivity of the determined weights by examining its consistency ratio [14]. Reconstruction of the matrix with different choices can be made if the conditions are not satisfied [15]. The matrix thus created was checked for consistency which is determined by computing the consistency index (CI) and consistency ratio (CR) equations given:-

$$CI = \lambda_{max} - n/n-1 \qquad (2)$$

$$CR = CI/RI \qquad (3)$$

Table 1: Satty's scale of relative importance

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favour one activity over another

5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed

Table 2: Pairwise comparison matrix and normalized weight

	Geomorphology	Drainage density	Lineament density	Slope	Lithology	Landuse	Soil	Rainfall	Normalized weight
Geomorphology	1.00	2.00	3.00	5.00	7.00	9.00	8.00	2.00	0.30
Drainage density	0.50	1.00	2.00	3.00	4.00	8.00	5.00	0.50	0.17
Lineament density	0.33	0.50	1.00	3.00	4.00	5.00	4.00	0.33	0.12
Slope	0.20	0.33	0.33	1.00	3.00	4.00	3.00	0.33	0.08
Lithology	0.14	0.25	0.25	0.33	1.00	3.00	4.00	0.20	0.05
Landuse	0.11	0.13	0.20	0.25	0.33	1.00	3.00	0.20	0.03
Soil	0.13	0.20	0.25	0.33	0.25	0.33	1.00	0.25	0.03
Rainfall	0.50	2.00	3.00	3.00	5.00	5.00	4.00	1.00	0.21
Total	2.91	6.41	10.03	15.92	24.58	35.33	32.00	4.82	1.00

IV. Results and Discussion

The groundwater potential zones, directly or indirectly, depends upon the eight parametric layers considered for the study. The influence of each layer on the other and to itself was determined and the appropriate weights were assigned to them for the overlay process. The influence and the weight assigned for each layer are listed below in Table 3.

Table 3: Parameters and APH ratings and weights

S. No.	Parameter	Range	Rating	Weight
1	Geomorphology	Pediplain	0.37	0.30
		Plateau	0.26	
		Channel Bar	0.16	
		Pediment	0.16	
		Escarpment	0.05	
2	Drainage density	0-7.5	0.51	0.17
		7.5-15	0.25	
		16-23	0.14	
		24-30	0.06	
		31-38	0.04	

3	Lineament density	1.83-2.28	0.47	0.12
		1.37-1.83	0.19	
		0.92-1.37	0.16	
		0.46-0.92	0.12	
		0-0.46	0.07	
4	Slope	0-1%	0.83	0.08
		1-3%	0.17	
5	Geology	Aluvium	0.55	0.05
		Aa to compound pahoehoe basaltic lava flows (4 flows) with an intertrappean bed	0.27	
		Aa basaltic flows (6 flows)	0.12	
		Aa flows with some showing pahoehoe charaters	0.06	
6	Soil	Entisols	0.64	0.03
		Inceptisols	0.21	
		Vertisols	0.15	
7	Landuse	Agriculture Land	0.53	0.03
		Mining	0.23	
		Wastelands	0.11	
		Settlement	0.09	
		Waterbody	0.04	
8	Rainfall	930-1000	0.47	0.21
		860-930	0.21	
		790-860	0.12	
		720-790	0.14	
		650-720	0.06	

Geomorphology map

Many of these landform features are favorable for the occurrence of groundwater and are classified in terms of groundwater potentiality. The geomorphology for the present study area was digitized from Survey of India Toposheets (1:50,000 scale) and also by the visual interpretation using LISS-III satellite image and categorized into 6 landforms viz., plateau, scarp, pediment, pediplain, channel bar and waterbodies. About 96 % of the total area of the present watershed is occupied by the pediplain. This is the landform that is resulted by the coalescence of pediments and is relatively flat terrain. Padiment and plateau extended over about 3% of the total area. The highest rank of 0.37 has been assigned to padiplain and the lowest rating 0.05 was assigned to escarpment which was found to have less than 1% spread among the total area. The overall weight for this layer was given as 0.30 (Table.3).

Drainage density

The digital elevation model obtained from SRTM with 30×30 m resolution was used to derive the drainage density map. By determining the flow direction and flow accumulation of the region using Arc GIS software, the line density or the drainage density was obtained and was grouped into five classes. The drainage density of the study area varies between 0 and 4.5 km/ km^2. About 58% of the total area constitutes low and very low drainage density as the entire region has a flat terrain. Only 0.54 % of the total area constitutes a very high drainage density zone where the drainage density value is between 2.5 and 4.5 km/km^2. An area with high drainage density shows increases in surface runoff and less percolation compared to a low drainage density area. Factors such as geology, land use and geomorphology affect the drainage density of a region [16]. Hence, the region with the highest drainage density 31–38 km/km^2, is assigned with the lowest value of AHP rating of 0.04, and for regions with the lowest drainage density say 0–7.5 km/km^2, is assigned the rating of 0.51. The drainage density map of the present area is shown in Fig. 2 B.

Lineament map

Lineaments represent the presence of linear features like joints, faults, and fractures which provide a route for percolated water and also an indirect indicator of a potential zone [17]. Lineaments are structurally controlled linear or curvilinear features, identified over the satellite image by their relatively linear alignments. Lineament density was also digitized from the digital elevation model from SRTM 30 × 30m using Arc GIS software. Lineament density of an area can directly reveal the groundwater potential since the presence of lineaments usually denotes a permeable zone [18]. Lineament density for the study area varies from 0 to 2.28 km/km^2 and was categorized into five classes for the convenient of assigning weights. The higher value of lineament density indicates the higher potential for groundwater recharge hence assigned the highest rating of 0.47 to regions with 1.83–2.28 km/km^2 of lineament density. This class has covered 0.67% of the total area. The moderate value of lineament density ranges between 0.92 and 1.37 km/km^2 about 6.98% of the study area is covered by this category and for which class; a rating of 0.16 and 0.12 was assigned. The regions with the lowest lineament density say 0–0.46 km/km^2 with aerial coverage of about 73.83% of the total area, a rating value of 0.07 has been assigned to this lineament density the overall a weight assigned for this layer is 0.12.the lineament density map generated for the study area is shown in Fig. 2 C.

Slope map

Slope is the factor that directly affects the runoff and infiltration of an area. Steeper the slope higher the runoff and gentle slope leads to less runoff. Slope calculated for the CKS watershed in percentage rise varies from 0 to 3% which suggests gentle slope. The slope map of the study area was classified into two classes depending on the slope value (Fig. 2 D). About 96% of the total region were flat terrain having a slope value ranging between 0 and 1% and was assigned highest value of rating of 0.83 as it is considered to be best-suited region for infiltration, where as the classes having slope value between 1 and 3 % extended to very limited, area of 3%, may considered to be moderately suitable for infiltration and assigned a rank of 0.17.

Geology map

The properties of different water-bearing geological formations play an important role in the occurrence and movement of groundwater. The geology of the study area was digitized from the district resource map (DRM) and remotely sensed image and was categorized into four main groups say Alluvium , Aa to compound pahoehoe basaltic lava flows (4 flows), Aa basaltic flows (6 flows) and Aa flows with some showing pahoehoe charaters with an intertrappean bed consolidated red bole. As the present study area covered by basaltic lava flows which is underlained by weathered the rock material. The hard and compact rocks present were assigned a less weight as these hard, compact regions that do not favour the groundwater recharge but highly weathered and columnar structured support to water recharge. 10% of the total area contains alluvium and assigned a rating of 0.55 as this formation favours the recharge and is well known for effective groundwater recharge. The geological map of the study area interpreted from remotely sensed data is shown as Fig. 2 E.

Soil map

The topmost layer above the earth which serves as the medium for water percolation is soil. The rate of infiltration depends on the permeability and water holding capacity of the soil [20]. The soil map of the present area was obtained from National Beauro of Soil Survey on 1:50,000 scale, which reveals three major classes of soil. Thus hydrogeological soil groups in the study area are shown in Fig.2 F. It has been computed that 21.36 % of the area contained inceptisol, 4.94 % of the region has entisols, vertisols were found to cover 72.17 % of the study area. Among these groups vertisol and inceptisols were given lower rating compared to entisole as these two groups contain clay and expansive clay in large volume dose not favour condition for groundwater recharge. The highest rating of 0.64 was assigned to soil group of entisole and the lower rating of 0.15 was assigned to soil group of vertisols. The overall weight for this layer is assigned 0.03.

Land use/land cover map

Information on soil moisture, permeability, amount of runoff, and percolation are decided based on land use type of the study region [19]. The land use map of study area was digitized from the LISS-III satellite data and found to have five major land use classes. The land use pattern in the study area categorized into agriculture, mining, wasteland, built-up and waterbodies (Fig.2 G). About 89.9% of the total land use area includes agricultural land, 7% of wasteland, 1.1% of water body mask, and the remaining 2% as settlement and mining together. The AHP ratings were assigned based on the quantity of water available for recharge according to the landform characteristics. The highest rating of 0.53 is given to agricultural land and the lowest rating of 0.09 is given to the paved built-up regions and 0.04 was assigned for water body mask. The overall weight assigned to this layer was 0.03.

Rainfall map

Rainfall is the major source of recharge to the groundwater. The area mainly depends on the monsoon rains, received from the southwest monsoon. Intensity and duration of rainfall have significance on infiltration and runoff volume [21]. The annual average rainfall in the study area for 5 years ranges between 650 and 1000 mm. The rainfall map has been created by interpolating the rainfall data for the 30 rain gauge stations, and the map so obtained was categorized into five groups (Fig.2 H). Higher the rainfall, more the volume available for percolating through soil layers. Hence, for regions receiving more rainfall say 930–1000 mm of rain has been rated as 0.47 and for the region with lower rainfall say 650–720 mm of rain, a rating of 0.06 was assigned. As the rainfall has more influence on the potential zone, it has been assigned an overall weightage of 0.21.

Development of groundwater potential zones

The eight thematic layers created in GIS background, and the appropriate ranks and weights determined by the AHP method were assigned for the overlay process. The results obtained were categorized into five classes from very low potential zone to very high potential zone based on index value calculated using Eq. 1. The study area being a flat terrain provides the most favorable conditions for recharge of groundwater. Using the rating and weightages about 7.11% (119763.86 ha) has been demarcated as very high potential zone (Fig. 2 I) which is more likely to be found in the vicinity of the river and where alluvial deposits found predominantly. Though the rainfall is moderate in this region, due to higher lineament density and lowest drainage density, this region falls under the very high potential zone. Similarly, the northwest region having very high rainfall intensity, but because of higher drainage density, all the water becomes runoff leaving no volume for the recharge. Hence, this region grouped to be of very low potential zone with aerial coverage of 0.20% (349 ha). High potential zone spreads over 67.80% (119763.85 ha) of the total area and 24.90% (43978.91 ha) area is demarcated as moderate potential zone, better geology and geomorphology favours the rain water to recharge and to become high and moderate zone to occur in western and southern region (Table 4).

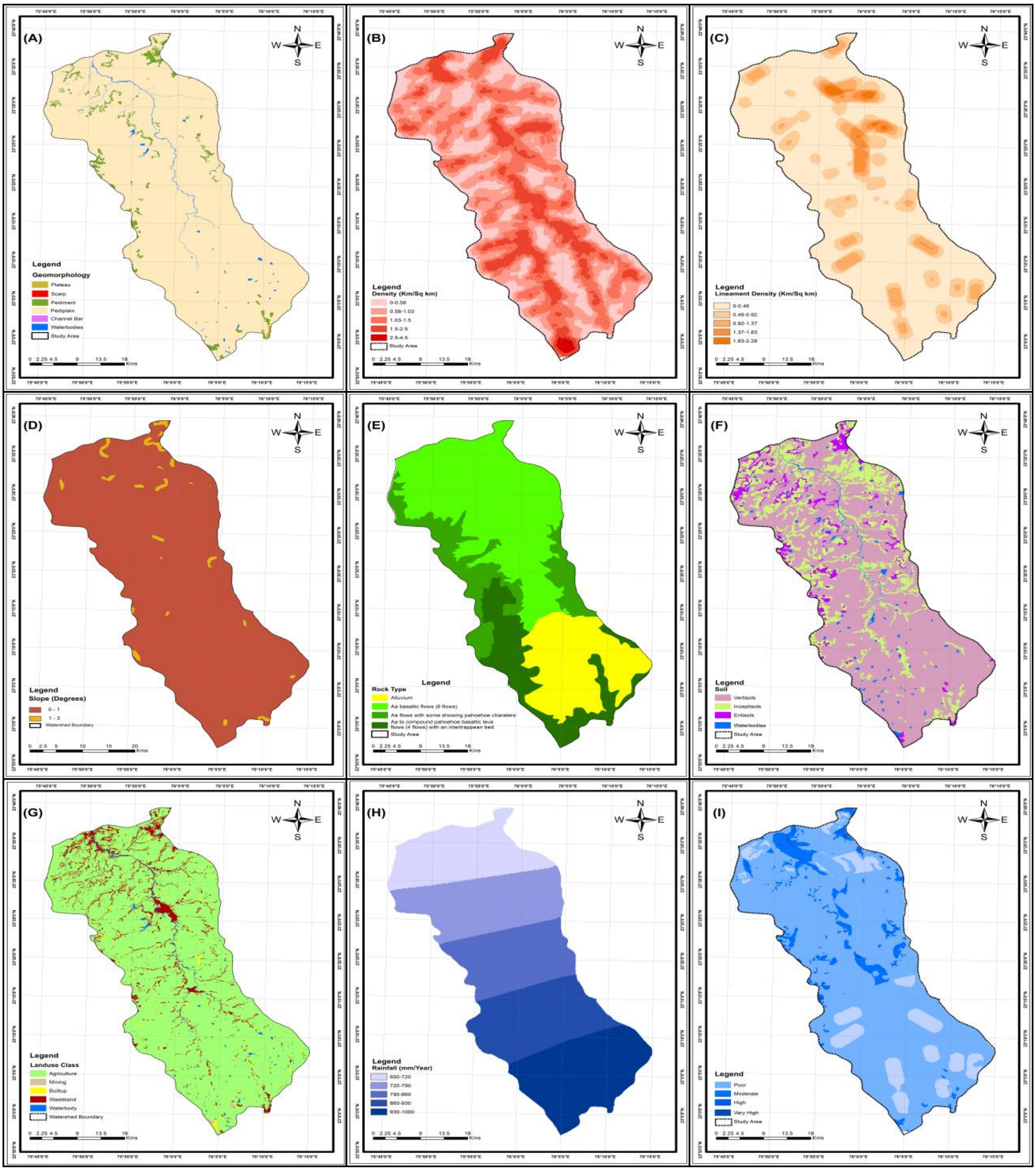

Fig.2. Thematic maps prepared (A) geomorphological map (B) drainage density (C) lineament density (D) slope (E) geology (F) soil (G) landuse/landcover (H) annual rainfall (I) potential zone map

Table 4: Classes of groundwater potential zones in the study area

S.No.	Groundwater potential Zone	Area	%
1	Poor	349.35	0.20
2	Moderate	43978.91	24.90
3	High	119763.85	67.80
4	Very High	12555.89	7.11

V. Conclusion

The geographic information system is a useful tool for obtaining results through spatial and visual interpretation. To obtain the ranks and weights for the parametric layers, the tool is connected with the analytical hierarchy process. As a result, the groundwater potential zones for Chhoti koli Sindh watershed was delineated using this integrated technology. The results obtained were grouped into five classes. Locations, such as Bordadhakad, Chidawad, Bhatuni, Nipaniya and few portions along the river course, were found to fall in very high potential category covering about 7.11 % of the total area. About 67.80% part of the study area have a high potential for groundwater. The moderate zone was about 24.9% of the total area covering Kallapipalya, Kadhai, Gundi Kalan, Barothiya and in some parts of study area. Jhumki and Jhalara regions fall on low and very low category of the potential zone with an area covering 0.20 % of the total area. The geomorphology, drainage density, Lineament density and rainfall were found to the predominant factors affecting the recharge in the study area. Artificial recharge techniques and a participative approach can be used in these areas with a moderate or low potential for increasing the groundwater table and preventing over exploitation.

References

[1]. Israil M, Al-hadithi M, Singhal DC, Bhishm K, Rao MS, Verma SK (2004) Groundwater resources evaluation in the piedmont zone of Himalaya, India, using isotope and GIS techniques. Roorkee, National Institute of Hydrology Roorkee.

[2]. Saaty TL (1977). A scaling method for priorities in hierarchical structures. J Math Psychol 15(3):234.

[3]. Aggarwal R, Kaur S, Juyal D (2009) Micro level assessment of water resources in bist doab tract of Indian Punjab. Agric Eng 46(2):33–39.

[4]. Saaty TL (1980) The analytic hierarchy process. McGraw-Hill, New York.

[5]. Saaty TL (1986) Axiomatic foundation of the analytic hierarchy process. Manage Sci 32:841–855.

[6]. Saaty TL (1992) The hierarch on: a dictionary of hierarchies. RWS Publications, Pittsburgh, p 496.

[7]. Dunning DJ, Ross QE, Merkhofer MW (2000) Multiattribute utility analysis for addressing Section 316(b) of the Clean Water Act. Environ Sci Policy 3:7–14.

[8]. Flug M, Seitz HLH, Scott JF (2000) Multicriteria decision analysis applied to Glen Canyon Dam. Water Resour Plan Manage ASCE 126(5):270–276.

[9]. Joubert A, Stewart TJ, Eberhard R (2003) Evaluation of water supply augmentation and water demand management options for the City of Cape Town. J Multi Criteria Decis Anal 12(1):17–25

[10]. Machiwal D, Jha MK, Mal BC (2011) Assessment of groundwater potential in a Semi-Arid region of India using remote sensing, GIS and MCDM techniques. Water Resour Manage 25:1359–1386.

[11]. Adiat KAN, Nawawi MNM, Abdullah (2012) Assessing the accuracy of GIS-based elementary multi criteria decision analysis as a spatial prediction tool—A case of predicting potential zone of sustainable groundwater resources. J Hydrol 440:75–89.

[12]. Mallick J, Singh CK, Al-Wadi H, Ahmed M, Rahman A, Shashtri S, Mukherjee S (2014) Geospatial and geostatistical approach for groundwater potential zone delineation. Hydrol Processes.

[13]. Saaty TL (2008) Decision making with the analytic hierarchy process. Int J Serv Sci 1(1):83

[14]. Shekhar S, Pandey AC (2015) Delineation of groundwater potential zone in hard rock terrain of India using remote sensing, geographical information system (GIS) and analytic hierarchy process (AHP) techniques. Geocarto Int 30:402–421.

[15]. Chandio IA, Matori ANB, WanYusof KB et al (2013) GIS-based analytic hierarchy process as a multicriteria decision analysis instrument: a review. Arab J Geosci 6:3059–3066.

[16]. Siva G, Nasir N, Selvakumar R (2017) Delineation of groundwater potential zone in Sengipatti for Thanjavur District using analytical hierarchy process. IOP Conf Ser Earth Environ Sci.

[17]. Pinto D, Shrestha S, Babel MS, Ninsawat S (2017) Delineation of groundwater potential zones in the Comoro watershed, Timor Leste using GIS, remote sensing and analytic hierarchy process (AHP) technique. Appl Water Sci 7:503–519.

[18]. Sitender R (2010) Delineation of groundwater potential zones in Mewat District, Haryana, India. Int J Geomatics Geosci 2(1):270–281.
[19]. Ibrahim-Bathis K, Ahmed SA (2016) Geospatial technology for delineating groundwater potential zones in Doddahalla watershed of Chitradurga district, India. Egypt J Remote Sens Sp Sci 19:223– 234.
[20]. Gupta D, Yadav S, Tyagi D, Tomar L (2018) Multi-criteria decision analysis for identifying of groundwater potential sites in Haridwar, vol 3, pp 9–15.
[21]. Abuzied SM, Yuan M, Ibrahim SK et al (2015) Delineation of groundwater potential zones in Nuweiba Area (Egypt) using remote sensing and GIS techniques. Int J Signal Process Syst 4:203–214.