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Groundwater Assessment Using MIF Technique in a Small Basin of Malwa Region, Madhya Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Water, a vital natural resource and essential component for all living organisms, exists in two primary forms: surface water and groundwater. Groundwater, a significant global resource, is unevenly distributed worldwide. Enhancing groundwater recharge is a fundamental hydrological parameter for assessing, managing, and modelling groundwater resources. However, determining recharge rates is a complex and challenging task, despite its crucial role in recharge assessments. The current study has been conducted in northwest part of Madhya Pradesh. The Neemuch and Mandsaur district comes under semi-arid zones and faces the problem of scarcity of water annually. The primary objective of this study is to evaluate groundwater potential zones using an integrated approach using geospatial tools. Various thematic parameters i.e., slope, rainfall, geology, drainage

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density lineaments, geomorphology and soil were considered for identifying evaluate potential zones. Thematic maps were generated using SRTM DEM, Sentinel-2 Imagery, and Survey of India (SOI) toposheets at a scale of 1:50000. The selected thematic factors were integrated for the determination of the groundwater potential of the study area, with appropriate weightage factors given to different themes by means of the multi-influencing factor (MIF) approach. This process was repeated for other layers, resulting in reclassified layers. These layers were then combined to delineate zones classified as "very good", "good", "moderate", "poor", and "very poor" for groundwater potential. The assessment of groundwater potential information using geospatial techniques can aid in identifying suitable locations for providing safe drinking water to rural populations. This comprehensive integrated approach of RS and GIS in assessing groundwater potentiality offers valuable insights for effective identification of suitable areas to meet the potable water needs of rural communities.

Keywords: Geospatial techniques; remote sensing; GIS; multi-influencing factor (MIF); groundwater recharge; groundwater potential zones.

1. INTRODUCTION

Water is the main basic and essential component of the Earth's hydrosphere. It is a very important ingredient to form life, despite providing neither food, energy nor organic micronutrients. All living organisms are dependent on water. One of the most vital resources in the world is potable water. Potable water is available in different forms like surface water, groundwater, river, lakes etc. in all areas. Although there is plenty of water on Earth, but unavailable when and where it is in need. India is gradually moving out from the occupation of agriculture and moving towards the urban sector, which is silently expanding. The exploitation of groundwater has witnessed a significant increase in the last two to three decades in India [1]. Due to the disparity between recharge and groundwater extraction, the groundwater situation in India, which receives a substantial quantity of precipitation, is quite dismal. Although transportation of fresh water may be expensive and the supply may not always be sustainable. The rainfall occurrence is highly seasonal in many parts of India. In arid and semi-arid regions of India, the only source of freshwater is rainfall. Therefore, due to the lack of water accessibility prior to the monsoon season, these regions experience drought conditions. In such conditions, groundwater assumes a prominent and dominant role in meeting the water needs for cultivation, drinking, and other socio-economic actions. The development of economic agriculture highly depends on groundwater in many semi-arid climatic regions [2]. Consequently, recent research on groundwater recharge zones in various countries such as China, Iran, Saudi Arabia, Taiwan, etc. has revealed that the groundwater resource is diminishing [3-13]. Geophysical data with geospatial data have been integrated by many researchers [14,15]. The surface hydrological characteristics, such as soil, slope, drainage, geology, etc., play an essential role in groundwater recharge. Groundwater recharge is one practice option to utilize unused water in the replenishment of aquifers. Surface water bodies, such as rivers, lakes, and reservoirs, can function as recharge zones to increase groundwater potential. Therefore to enhance groundwater aquifers, the identification and delineation of zones with groundwater potential is quite essential. Geospatial techniques play an essential role in search of groundwater. To establish a good harmony between groundwater and runoff, rainfall conservation strategies for semi-arid region [16], groundwater potential mapping is required [17], (Sunitha et al. 2016). Easy understanding, data handling and processing made researchers comfortable to use Remote sensing and GIS tools. Remote Sensing data are processed in GIS software [18].

There are unequal distributions of renewable groundwater recharge zones between regions globally, but some regions which are at less rainfall area are more at threat [19,20]. The study area is situated in the semi-arid zones of Madhya Pradesh which lies in North West part of the state. The study area includes Neemuch and Mandsaur districts. The average annual intensity of groundwater withdrawals of the districts ranges from 0.10-0.15 m/area. Thus, there is a need of proper evaluation of the groundwater. This study deals with the multi-Influencing factor used to generate groundwater potential map in semi-arid regions of Malwa region in Madhya Pradesh. From these results a soil and water conservation techniques are suggested from the future point of view.

2. MATERIALS AND METHODS

2.1 Study Area

Madhya Pradesh is an agricultural state. It is situated in the central part of India. It has almost all the climatic conditions. About 70.31% of the population lives in rural area while 29.69% lives in urban area. The key livelihood of the people in malwa region is agriculture. The geographic area is about 4516.40 Km^2 and lies between north latitude 24^{o}44’59”- 23^{0}51’27” and east longitude 75^{0}00’31”-74^{0}46’40” (Fig. 1). The topographic elevation ranges from 90 - 239 meters. Geographically, the study region is predominantly lies in Deccan Trap basalts, with only a narrow patch of alluvium and isolated patches of sedimentary rocks from the Vindhyans supergroup. The district primarily exhibits gentle slopes, ranging from 317 m to 579 m above the mean sea level. The normal maximum temperature in May reaches approximately 40°C, while the minimum temperature in January is around 9.5°C. The monthly maximum temperature on an average stand at 31.6°C, with the daily mean minimum temperature exceeding 19°C. The summer season is characterized as the driest period of the year. The study area experiences dry streams for the majority of the year, except from June to September during the monsoon season. The air remains dey and hot throughout the year. The physiography is primarily dominated by Deccan Trap, resulting in loamy and clayey soils. The depth of the water level varies, with a pre-monsoon measurement of 13.82 and a post-monsoon measurement of 3.23. Consequently, a substantial percentage of the population is engaged in agricultural activities. The main crops grown in this area include wheat, gram, mustard during the rabi season, and jowar, rice, urad, and moong during the kharif season. The drainage streams in the study area converge at the Gandhi Sagar dam, located in the eastern part of the selected area.

2.2 Data Collected and Software Used

The study involved the utilization of GIS for the preparation, handling, and processing of different thematic layers. Using SRTM-DEM (30-m resolution) data, the flow direction map was created initially, followed by the generation of streams using spatial analysis tools in ArcGIS 10.5. To demarcate the study area in the Malwa region, the Arc SWAT 2012.10. software was utilized. The lineament map was digitized from the open software Bhuvan at a scale of 1:50,000. The soil map was prepared from a scanned map provided by the National Bureau of Soil Survey & Land Use Planning (NBSS&LUP) in Nagpur. The Land Use Land Cover (LULC) image was collected from sources such as Sentinel-2B, Google Earth, and Bhuvan (LISS_IV and Resource SAT-II). Stacking of layers (2-, 3-, 4-, and 8-layer) was processed in ERDAS IMAGINE 9.3 software, and supervised classification was conducted to generate the Land Use Land Cover map. The geology and geomorphology maps were also digitized from Bhukhosh.

For the validation of groundwater recharge sites, net groundwater availability data was collected from the Water Resource Department in Madhya Pradesh. Groundwater data and rainfall data

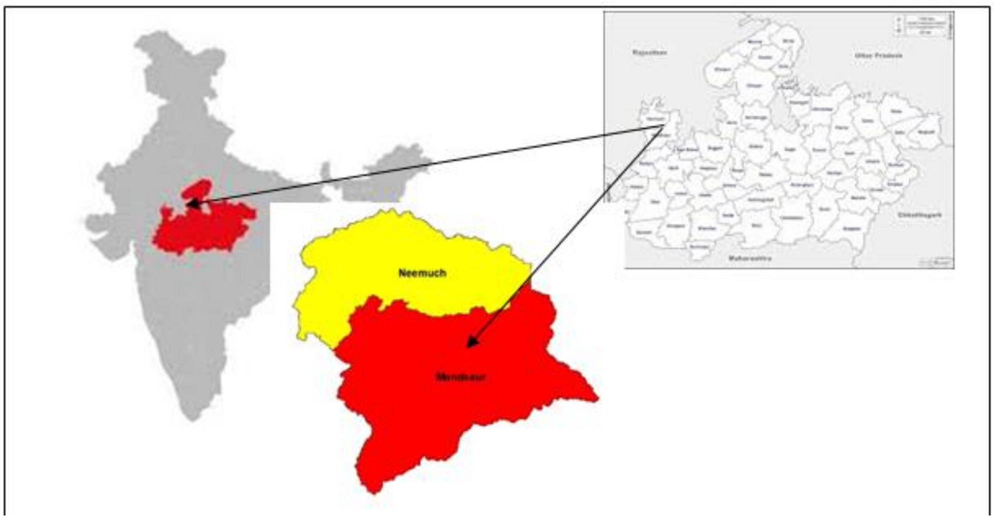

Fig 1. Location map of the study area

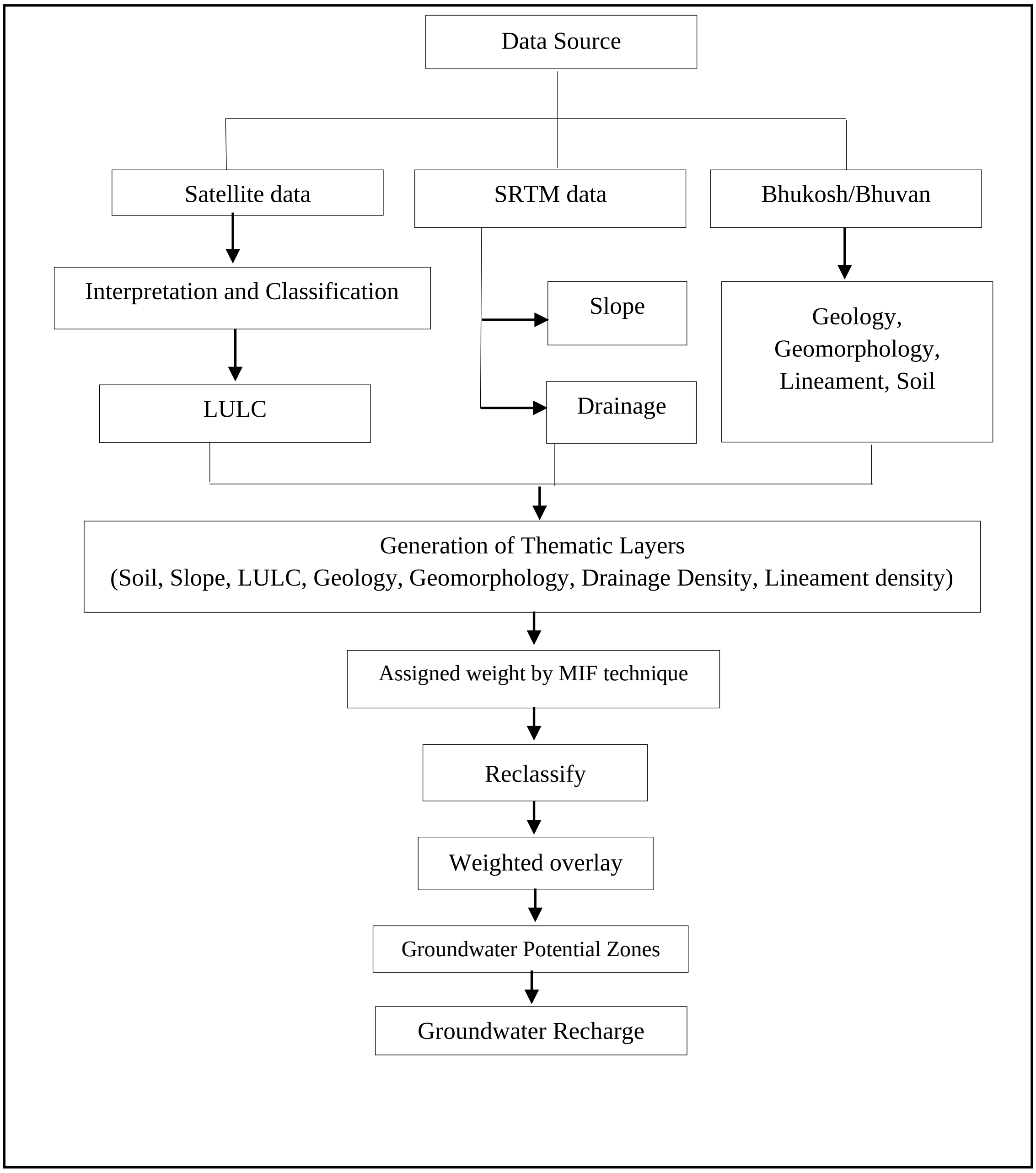

Fig. 2. Procedure for identification of groundwater recharge sites

were gathered from various sources, including the Madhya Pradesh Water Resource Department (MPWRD), Central Ground Water Board (CGWB), and the Indian Meteorological Department (IMD) in Pune. The maps were georeferenced using the (World Geodetic System) WGS 84 datum and (Universal Transverse Mercator) UTM zone 43N, WGS_1984_UTM_43N projection.

Thematic Layer: The information collected was used to create the thematic layers of the slope, drainage density, soil texture, geology, lineament density, rainfall, geomorphology, and land use/land cover. Fig. 2. depicts the comprehensive procedure flowchart for identifying groundwater recharge sites. The thematic layers that are affecting the groundwater recharge are physiographical parameters and meteorological parameters. These agents were measured to assess the groundwater potential zone and then the groundwater recharge sites. The SRTM-DEM data was used to generate the slope and elevation maps. Additionally, the DEM data have been used to extract the drainage layer which is consequently used for the determination of drainage density. The lineament density was calculated using the lineament layer, which has been developed by digitizing it manually using the satellite image. 30 years (1991-o2021) rainfall data were taken to generate thematic maps for the study area. The reclassification of the thematic maps was followed by assigning weightage to each layer using the multi-influencing factors (MIF) technique. This procedure estimates individual weight that has been given to each thematic layer which is considered like soil, geology, drainage density etc. [21]. The effects can be closely observed from the inter-relationship between the layers. After observing the strong and sturdy correlation between the factors, score 1 is assigned. If the impact is minimum and showing the poor relationship between the factors, the score assigned is 0.5. Summation of all the weights will give the independent weights of each impacting agent [22]. All the relations are weighted according to the direct and indirect impact on groundwater recharge. The sub-classes are classified based on relative relationships [21,22]. Utilizing this relation, the proposed score or the individual weightage is calculated by the following equation

$$\text{Proposed score} = \frac{(X+X')}{\Sigma(X+X')} \times 100 \quad \text{........(eq 1.)}$$

Where, *X* is a major impact and *X′* is a minor impact. Inter-relationship between the layers impacting on groundwater recharge zones.

3. RESULTS AND DISCUSSION

The delineation the groundwater potential zones were done by using various thematic layers in the semi-arid region of Malwa. The process involved creating and weighting thematic maps, followed by the application of the multi-influencing factor technique. The resulting groundwater potential zones were determined based on the different thematic maps of rainfall, elevation, drainage, slope, soil, geology, geomorphology and land use and land cover.

3.1 Preparation of Thematic Maps

3.1.1 Geology

Groundwater depends on the occurrence of rock and movement of water. Hence geology is key feature to understand. Neemuch and Ratlam, the geologic formation of Alluvium, Basalt, Laterite, sandstone and shale was found. Basalt is dominating geology in this Malwa region, occupies 83% of the total area. Geology map is shown in the Fig. 3.

3.1.2 Geomorphology

The underground water moves according to the geomorphic units which is under the surface [21]. Thus, geomorphology map plays a dynamic role in finding out the groundwater potential zones. The geomorphology landform was detected and generated from the satellite data using visual interpretations and the survey of India toposheet maps. It was found that 92% (4246.81 Sq Km) is covered with Pediment pediplain complex followed by moderately desiccated plateau (2%) and other formations which is shown in Fig. 4.

3.1.3 Soil map

Soil type has a major impact on the water percolation and infiltration process for the aquifer recharge [23]. Soil having high infiltration rate will be best suited to find the artificial recharge sites. It has been found that the study area has primarily three soil texture classes i.e., fine clay, loamy and calcareous loamy. It was found that the most dominating soil texture is fine clay (57%) covers area of 2582.16 Sq Km followed by Calcareous loamy (39%) covers area of about 1792.1 Sq. Km. and loamy (4%) covers area of 181.2 Sq. Km. The thematic layer of soil map is given in the Fig. 5.

3.1.4 Slope Map

To get the groundwater potential zones, slope is all-important key parameter. Surface water is directly influenced by the process of infiltration in the study area [24]. Using SMRT-30 m DEM data in ArcGIS, the slope map was generated, depicting slopes ranging from 341 to 651 meters above mean sea level. The study classified the slope into five classes: very low, low, moderate, high, and very high. It was observed that the largest portion of the area falls under the very low slope category. Specifically, approximately 63% (2865.29 Sq Km) of the total study area is classified as very low slope. Fig. 6, provides details of the slope map.

3.1.5 Land use / land cover

Land use changes depends upon the manmade growth with respect to industrialization. In this malwa region it is discovered that the main occupation of the people is agriculture. Therefore, maximum land is under the agricultural land. Agricultural land includes fallow land and crop land. The classes are mentioned in Fig. 7. In the total study area, 29% is covered with agriculture land, while 34% is covered with fallow land. Crop land accounts for a total of 63% of the study area.

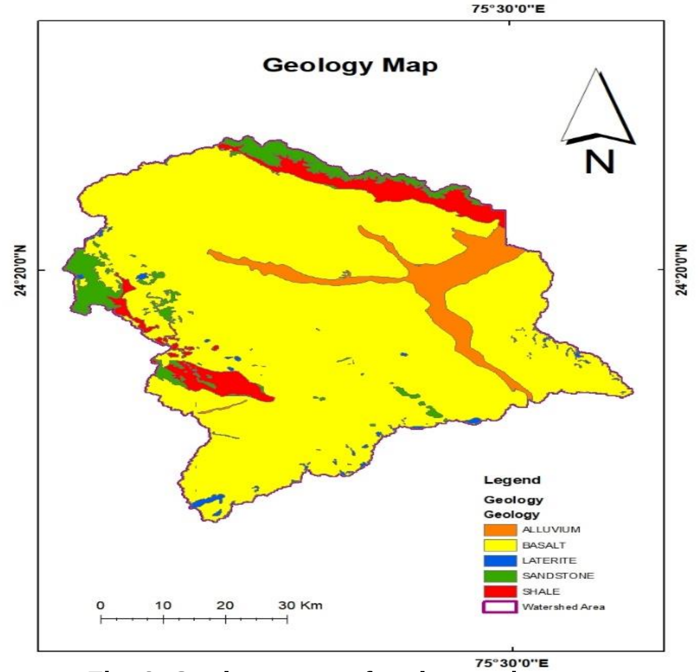

Fig. 3. Geology map of malwa region

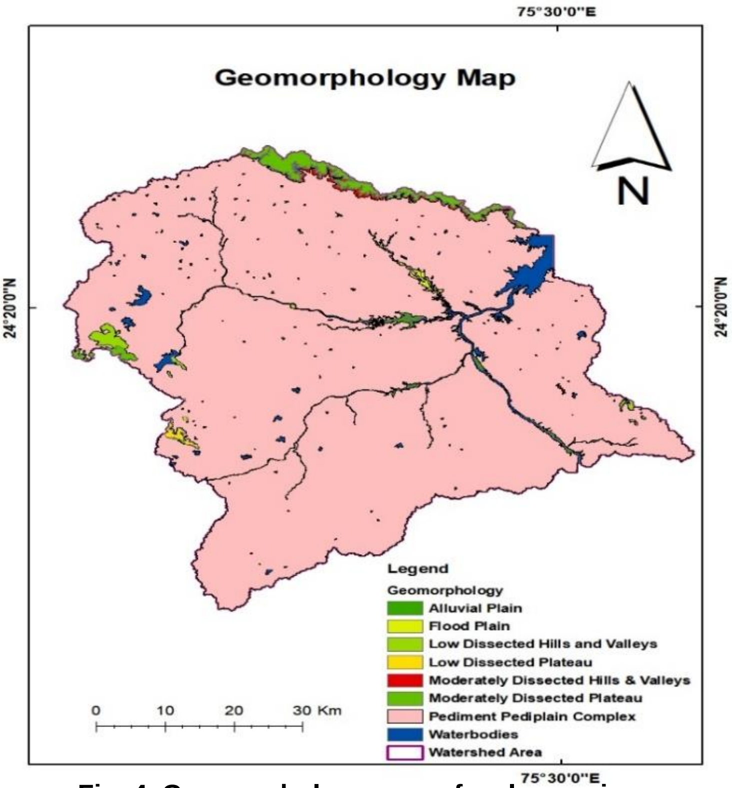

Fig. 4. Geomorphology map of malwa region

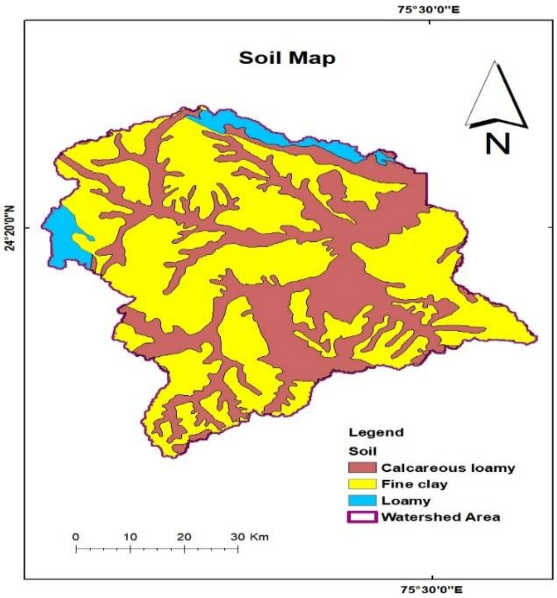

Fig. 5. Soil map of Malwa region

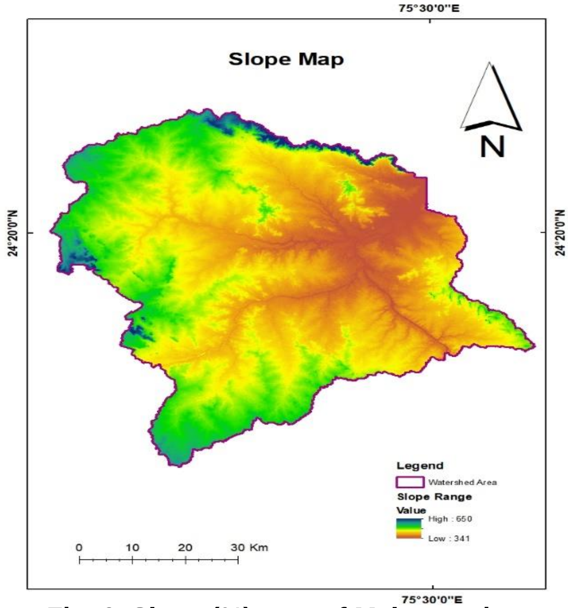

Fig. 6. Slope (%) map of Malwa region

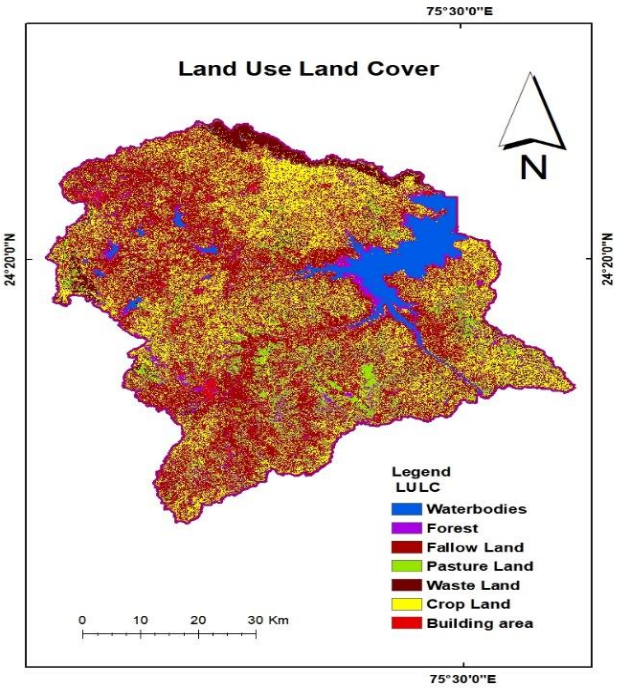

Fig. 7. Land Use/ Land Cover map of Malwa region

3.1.6 Lineament density

Linear feature like fracture and joints are present below the earth surface of any area. Water holding and water transmission capacity of these lineaments is very good as lineaments increase the permeability, a hydraulic conductivity, and also indicate the porosity in the soil. Thus the presence of lineaments in a particular area is considered helpful for groundwater recharge. The lineament density of the Malwa region is generated through a lineament map. The lineament map is shown in Fig 8.

3.1.7 Drainage density

It has a significant role in determining groundwater potential zones. Runoff and drainage density are intimately correlated, and this relationship has an impact on an area's capacity to recharge. The maximum stream order in the study area was found as 4. The detailed stream order and drainage density are shown in the map (Figs. 9 and 10 respectively).

3.1.8 Elevation

The topographic elevation is generated using SRTM DEM- 30m using spatial analysis tools. It was observed that the elevation lies between 371 to 579 meters (MSL) in the study area (Fig. 11).

3.1.9 Weightage calculation

Multi-influencing factor technique is used in this study. The major and the minor effect of the thematic maps are observed carefully and proposed score is calculated. Every thematic layer has weightage classification. Weighted value of each class is referred from different literature review (Masitoh et al, (2022); [19]; Maity and Mandal [2,25-28]. Weightage given to each major impact is 1 and that of minor impact is 0.5. The major and the minor effect is shown in the Table 1. From the equation 1 the proposed score is calculated and weightage is assign to every thematic map. Thus, forming the groundwater potential zone map [29-32].

3.1.10 Evaluation of groundwater Potential Zone map

A complete realistic database is delivered by remote sensing, although the GIS tool assists in storage and investigate the spatial database in a processer system. Therefore, the application of remote sensing and GIS tools and techniques carried out for the identification of groundwater potential zones and recharge zone. As per the results of the study, the groundwater potential zone map is generated in Arc GIS 10.5 and ERDAS. Multi-influencing factor techniques (MIF) are deliberately hired to assess the influence of all the thematic layers for the identification of different groundwater potential zones. Total nine thematic layers viz., soil, lineament, slope, geology, rainfall, geomorphology, drainage density, LULC and topographic elevation are observed for the study of groundwater potential zoning. The different weightages and ranks are provided to different thematic maps. The ground water potential zone map was created. The ground research disclosed five different classes, based on the result very high, high, moderate, poor, very poor. Moderate area was found dominating covering about 37.50% (1736.51Sq Km) of total area (Fig. 12). The groundwater trend was also studied from 2011-2020. The Fig. 13 shows the declining graph of fluctuation, denoting, there is over exploitation of water from year 2011 to year 2020 [33-35].

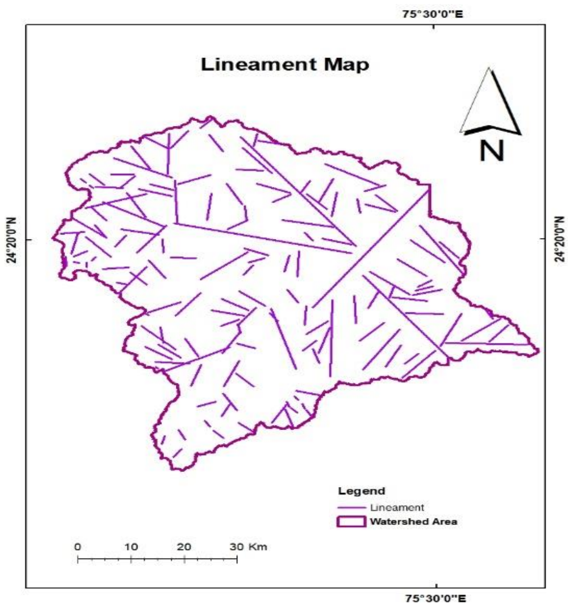

Fig. 8. Lineament map of Malwa region

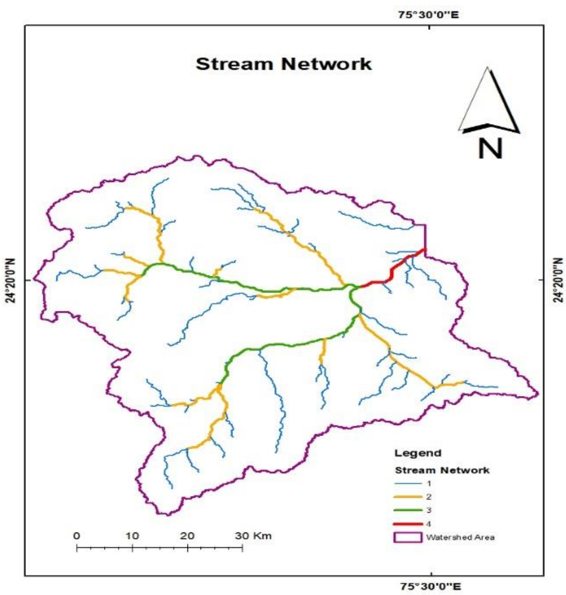

Fig. 9. Stream order map of Malwa region

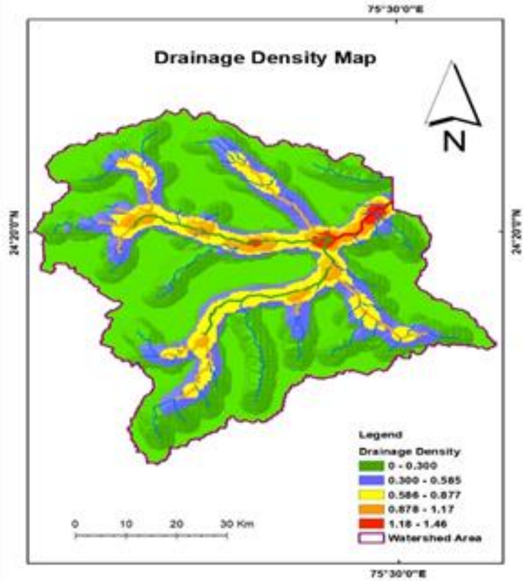

Fig 10. Drainage density map of Malwa region

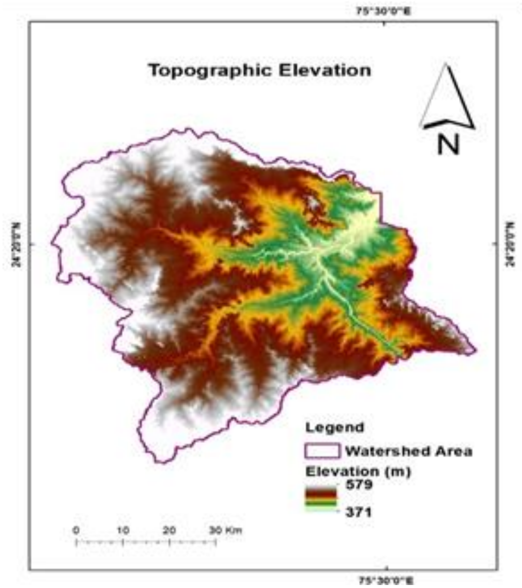

Fig. 11. Topographic elevation map of Malwa

Table 1. Major and minor effect of thematic layer and the proposed score

Factor	Major (X)	Minor (X')	($X + X'$)	Proposed score
Geomorphology	1+1+1	-	3	14
Land Use Land Cover	1	05	1.5	7
Rainfall	1	0.5	1.5	7
Drainage Density		0.5+0.5	1	5
Lineament Density	1+1	0.5	2.5	12
Soil	1+1+1	0.5	3.5	17
Slope	1	0.5+0.5+0.5	2.5	12
Elevation	1+1	-	2	9
Geology	1+1+1	0.5	3.5	17
Total		Σ (X+ X')	21	100

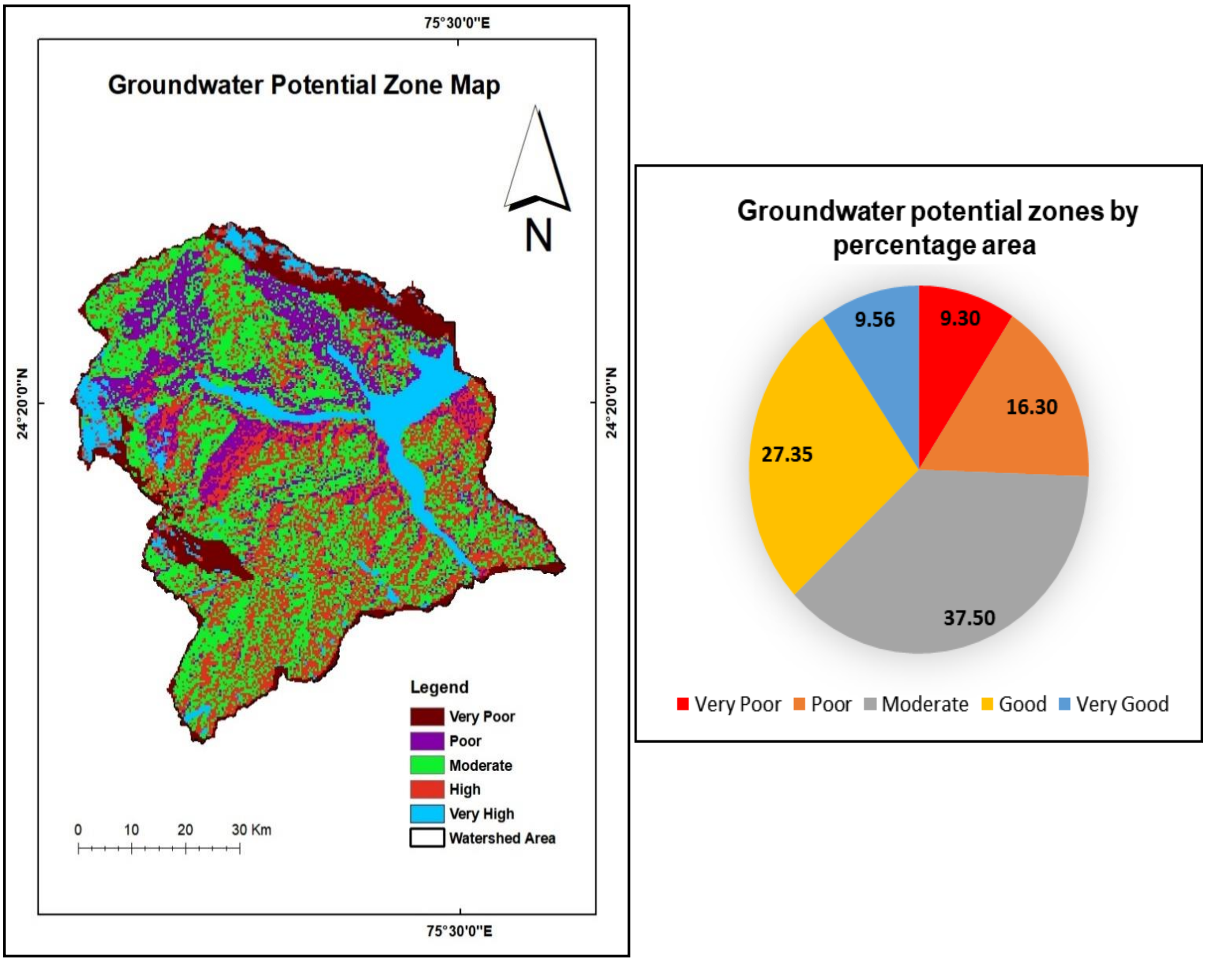

Fig. 12. Groundwater potential zone map with percentage covered of Malwa region

Table 2. Weightage and rating of the sub classes prompting the groundwater potential zones

Factors	Sub-classes	Rating	Weightage
Geology	Alluvium	17	17
	Basalt	10	
	Laterite	5	
	Sandstone	7	
	Shale	4	
Geomorphology	Alluvium Plan	5	14
	Flood Plan	14	
	Low Dissected Hill and Valley	1	
	Low Dissected Platue	2	
	Moderately Dissected Hill and Valley	2	
	Pedi plane complex	7	
Land Use Land Cover	Agriculture	2	7
	Built-up area	1	
	Forest	5	
	Pasture Land	2	
	Waste Land	1	
	Waterbodies	7	

Factors	Sub-classes	Rating	Weightage
Elevation	0-1	9	9
	1-2	7	
	2-3	5	
	3-5	2	
	>5	1	
Drainage Density	Very High	5	5
	High	4	
	Medium	3	
	Low	1	
	Very Low	1	
Rainfall	Very Low	1	7
	Low	3	
	Medium	5	
	High	6	
	Very High	7	
Soil	Calcareous loamy	17	17
	Fine clay	5	
	Loamy	10	
Lineament Density	Very High	12	12
	High	10	
	Medium	9	
	Low	3	
	Very Low	1	
Slope	Very High	1	12
	High	2	
	Medium	9	
	Low	10	
	Very Low	12	

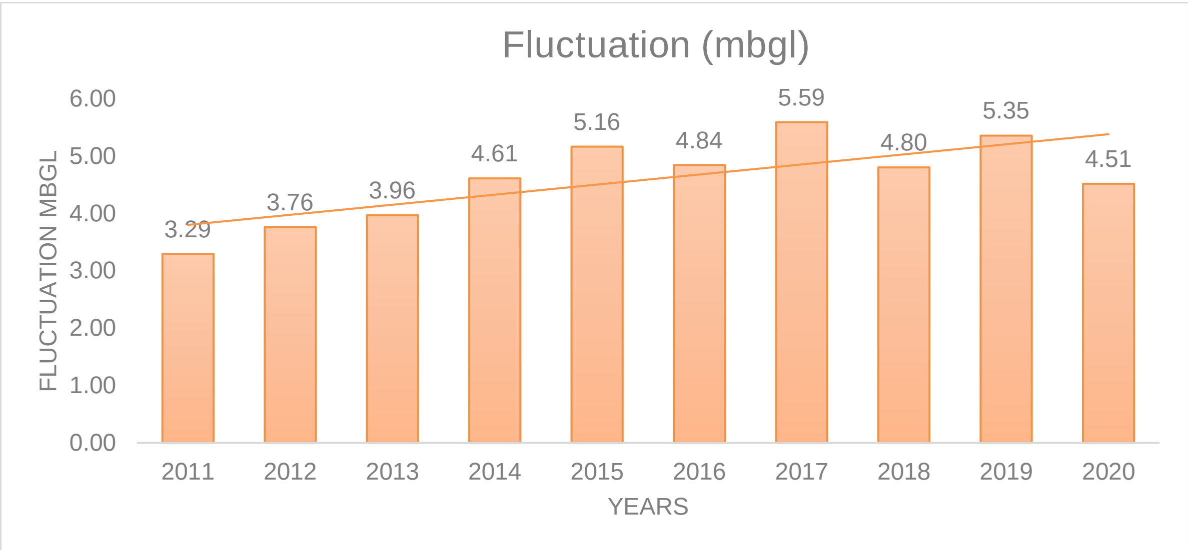

Fig. 13. Groundwater fluctuation trend from 2011-2020

4. CONCLUSION

Geospatial techniques have become an essential resource tool for the exploration of groundwater due to their efficiency and time-saving capabilities. This study conducted an assessment of Groundwater Potential Zones in the semi-arid region of Madhya Pradesh, using a combination of multi-influencing factors (MIF), remote sensing, and Geographic Information System (GIS). The study applied a modest method that yielded satisfactory results in identifying groundwater recharge zones. The findings indicate that various physiographical parameters such as geology, geomorphology, lineament, drainage density, soil, slope, land use land cover, as well as meteorological factors like rainfall and groundwater fluctuations, are inter-dependent for a successful analysis of groundwater potential zones. In summary, the paper highlights the importance of geospatial techniques and their application in conjunction with MIF, remote sensing, and GIS for assessing groundwater potential zones. The study emphasizes the significance of considering multiple influencing factors, both natural and human-induced, to effectively identify areas with high potential for groundwater recharge. The layers were generated and overlayed with the help of data collected from individual departments and organizations. Suitable ranking and weightages are provided to each factor depending upon the groundwater level fluctuations by using multi-influencing factors method. Based on the result, five classes were found very high, high, moderate, poor, very poor. Moderate area was identified leading, covering about 37.50% (1736.51Sq Km) of total area. Followed by Good (27.35%) Poor (16.30%), very good (9.56%) and very Poor (9.30%) zones of groundwater potential. The groundwater trends from the year 2011-2020 were also studied. The groundwater trends indicate the direction and magnitude of the change in water levels of the groundwater over the periods of year 2011-2020. The trend analysis of the observation well data indicates a slight consistent increase in the trend value of groundwater level during the specific period. Thus, to maintain the sustainability of groundwater in the region, efficient planning and management is quite essential. Therefore, suitable strategies need to be drawn for the study area to restrict the ground water decline and improve the ground water condition for efficient utilization. Water harvesting structures need to be planned to recharge more water for the tensed areas. Rainwater harvesting through conservation structures like farm ponds, Nadi, percolation tanks, surface check dams and primary and secondary surface reservoirs. Recharging groundwater, such as through methods like dead wells, nala bunding, and anicuts, is considered highly effective for replenishing underground water sources. However, the proper location of rain harvesting structures can be decided based on the number of parameters like slope, lineament, geology, geomorphology etc, which will be done in the future for the study area to propose the water harvesting structures. Efficient crop planning can also be done wheat crop can be replaced in the Rabi season with gram crops or with millets in the water-stressed area and cash crops like sugarcane, and soybean can be introduced in water-surplus areas. These results help in proper exploration and recharge planning for groundwater resources. This study overall helps in assessing the groundwater potential zones along with highlighting the critical areas for the development of natural and non-natural structures in view of sustainable groundwater usage in the semi-arid region of Madhya Pradesh, India.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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