Geospatial Assessment of Groundwater Potential Zones: A Review Focused on Groundwater Basins

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***Abstract*—Groundwater is an important resource for human growth to the planet's most plentiful freshwater supply. Its significance extends beyond drinking water supply to include vital roles in irrigation and economics activities, particularly in the region. However, population increase, and poor management pose a threat to the amount and quality of groundwater in many emerging nations. The paper develops an integrated remote access to the Analytic Hierarch y process, Analytic Hierarchy Process-Geographic Information Systems (AHP-GIS), and sensing to find out geoenvironmental parameters groundwater potential zones (GWPZs) in semi-arid regions. By serving many factors, including relief land use and hydrological data, we produced a groundwater potential map that facilitates sustainable water management. Our results highlight the vitality of systematic evaluation and evidence-based decision-making in groundwater resources, the papers provide valuable new information management, as well as the demand for prudent regulation to prevent over-exploitation. Water resources are limited within the region, the research provides valuable new information on groundwater evaluation, agricultural productivity can be increased.**

***Keywords*—groundwater, Analytic Hierarchy Process (AHP), remote sensing, geospatial analysis**

I. Introduction

Groundwater is the world's most abundant freshwater resource and is vital to human development [1]. This vital resource for life is buried in pores and fissures of the rocks and soil [2]. Due to its ability to be taken from wells and boreholes, groundwater is the most popular global supply of drinking water. It is also frequently seen as more dependable than surface water [3]. Additionally, the resource of groundwater is essential for irrigation [4], which helps reduce poverty by boosting food production, enhancing rural households' financial circumstances, raising farmers' incomes, and generating employment in the agricultural industry and other associated fields [4–6].

Both the quantity and quality of groundwater are impacted directly or indirectly in emerging nations by unchecked population growth and poor resource management. Therefore, inappropriate use of water policy and unscientific extraction are also potential culprits. For this reason, groundwater resource evaluation is essential to sustainable management [7]. Furthermore, various revenue-generating endeavors like microbusinesses and small industries may benefit from the availability of groundwater resources [8–10]. Communities can participate in a variety of economic activities when they have access to water for productive usage, which can improve income, create jobs, and promote general economic growth [11, 12]. Groundwater is a dependable and secure resource when it is handled and safeguarded appropriately.

Analysis offers an inexpensive and effective way to evaluate resources for water and monitor changes over time. [13–15]. Geospatial methods and remote sensing have become effective instruments for locating and evaluating groundwater zones. To precisely map regions with high groundwater potential, these methods employ hydrological models, satellite images, and topographical information [4, 16–19]. To facilitate evidence-based decision-making and sustainable water management, remote sensing and geospatial [19] Geographic Information Systems (GIS), remote sensing, and other methods have been utilized in several studies to evaluate groundwater potential. For example, In the upper Blue Nile Basin of Ethiopia, the Guna Tana landscape was investigated [20]. Similarly, Dumka District in Jharkhand, India, employed GIS, Analytical Hierarchy Process AHP approach combined with remote sensing [21], to identify possible areas of groundwater. Within the Tamil Nadu Chitter Basin, another research employed the geographical information systems based AHP approach, examine various geoenvironmental characteristics for the establishment of zones with groundwater potential [22]. A combination regarding GIS and remote sensing was utilized in one study to identify groundwater potential zones, along with AHP Approaches, have been taken in identifying the southwestern Ghats region of India [23]. Researchers manipulated and analyzed spatial control data layers in the Deccan, Maharashtra, volcanic province, application of defining groundwater potential zones with RS and GIS. Another study examined a range of geoenvironmental parameters groundwater potential zones (GWPZs) that are geographically spread, through the preparation and use of data layers: elements include slope, soil texturing, lines and stream density network, land use cover, lithology, and geomorphology [24, 25].

However, other research in other areas has also concentrated on mapping and evaluating Geospatial technology is weighted index overlay, which has considered remotely sensed and GIS techniques for determination of the potentiality in general, was carried out in different sites to date; for example, [7]. Weighted Index Overlay Analysis Dhungeta Ramis subbasin of Wabi Shebele Basin: A Case Application A MCDM based approach integrating delineating groundwater potential zones is another application of remote sensing and GIS techniques [26] as AHP-CT. Due to the annual decrease in the supply of potable water [27] targeted mapping of the groundwater potential zones and flood risk zones in the District of Visakhapatnam, India. Isnain [2] mapped groundwater potential zones in Kota

Belud, Sabah, and the neighboring areas utilizing remote sensing and GIS methods, accounting for 10 contributing factors: roughness, precipitation, slope, soil texture, and topographic moisture index, geomorphology, land use/cover, drainage density, along with the topographic position index. intended to produce an accurate groundwater potential map using a geospatial approach integrated with the Analytical Hierarchy Process in the Ashore District in Bangladesh [17, 28].

Furthermore, Shekar [29] Groundwater potential zones were assessed, and Integration of different GIS, Analytic Hierarchy Fuzzy and Process Analytic Hierarchy Process techniques worked out some ideal sites of artificial recharge. The value of GIS, distant sensing and making methods in locating and charting groundwater. This paper identifies the potential zones in various scenarios. They provide insightful information on how to manage water resources and make wise decisions; some noteworthy publications include [1, 4, 8, 11, 30–39].

Furthermore, geospatial and remote sensing methods offer reliable and affordable ways to monitor and evaluate water resources, which are necessary for targeted interventions and evidence-based decision-making [40–42]. Without enough water, in most cases, it is not possible to cultivate crops and sustain life throughout the arid season due to the region's high temperatures and sparse rainfall. Possible groundwater areas include determined to aid with the construction of irrigation systems that boost food output and employ people in the agricultural sector and related industries. This has the potential to reduce poverty and improve rural people' financial situation.

Nonetheless, it's critical to acknowledge the constraints and difficulties related to poverty alleviation and groundwater management. To avoid overexploitation, subsidence, and aquifer depletion, aquifer extraction needs to be strictly controlled [9, 43, 44]. In addition, it is important to take gender dynamics, social inclusion, and equality into account to make sure that the most vulnerable and disadvantaged groups have access to water resources[43, 45]. Although the only solution to reduce the water scarcity in the research area is to develop groundwater, several scientific methods must be considered to identify, demarcate, and develop potential groundwater resources. The results of the research work will be useful for a deeper understanding of the GWP zone in the study area [46].

II. Literature Review

The definition of GWP is a broad term that varies based on the goal of each study, according to literature studies. While some researchers [47–49], have examined the groundwater yield in a region, others [9, 50–52] have concentrated on groundwater storage. From the standpoint of storage, Total water volume in aquifers with long-term storage capacity is known as GWP [53]. Groundwater yield per year (GWP) is the volume of groundwater that can be extracted from the aquifer on a continuous basis without producing any long-term decline in the recharge of the aquifer or compromising the chemical or physical quality of the aquifer [54]. Although groundwater is a renewable resource, its replenishment has been greatly reduced during the previous four to five decades due to human activity and unequal growth. Designing and constructing works that would enhance groundwater recharge processes depend heavily on this information [55]. Planning and long-term development require a better understanding of a region's groundwater potential. The primary focus of reviewed studies is GWPZ estimation and identification [55].

III. Material and Method

A. Method

RS and geospatial analysis were integrated with S-DSS and AHP methodology for the recognition of groundwater potential zones in the studied region [56, 57]. In response to the decrease in the sustainable development aspect in the research area, population density map, percentage of poverty and distance to the main river have been integrated in order to find the best spot where the existence of groundwater is important to raise the agricultural lives of people [58]. AHP is one of the popular methodologies of decision making, offering a systematic way of measuring several criteria and their weight against each other in a hierarchical framework. AHP uses a three-tiered pairwise comparison matrix to determine the choice's relative weight or importance. Criteria include the following: 1) Every level of the hierarchy, beginning at the top, has a comparison matrix created. 2) The consistency ratio can be found using 3) Determine each person's weight or relative importance in the hierarchy in respect to the others. (C. R.) [57].

B. Acquisition of Data

Data gathering was an integral part of the study in that it provided the researchers with the necessary knowledge to study the groundwater potential zones. Accurate and relevant data gathering ensures the trustworthiness and efficiency of ensuing Procedures for analyzing and deciding decisions [58]. High-resolution Digital Elevation Models (DEMs) were created to examine topographical and hydrological characteristics that impact groundwater potential [59]. Therein lies the reason behind constructing maps of land use and cover for metropolitan areas, range lands, and water bodies to distinguish various types such as agriculture and vegetation. Yet according to the soil maps, there is identified a type of soil that really has an influence on the actual recharging or storage of the groundwater [58]. To understand the hydrological regime and the water supply, hydrological data on among other things, precipitation, drainage patterns, and stream networks were gathered [3] in the research area. Other supplementary information, for example, socioeconomic indicators and population density were considered to set the scene and provide light on the water and socioeconomic circumstances requirements within the area under study as the research evidence [58].

C. Making a Map of Groundwater Potential

A combination of several thematic levels using the AHP was done to create a map of groundwater potential [28]. Normalized weights were calculated every one of the ten parameters' feature classes [59]. The mass of overlay analysis tool laid over progressively ArcGIS's 10 themes. All the thematic layers, contributing significantly to groundwater, acted in collaboration in generating the final map of a groundwater potential zone. A set of classes with weighted thematic levels that corresponded to them were developed to prepare the data. Each layer was using the WGS 1984 datum for projection [60] after it was resized using a set grid size of 10 m×10 m. This approach has widely been adopted in several studies. The integration of many heterogeneous datasets allows for comprehensive views of the groundwater potential and allows for effective management of the groundwater resources. After the theme layers were categorized according to the GWPI, into various groundwater potential zones, the superimposition was done by producing a composite Eq. (1) as shown in map [1].

$$GWPZ = \sum_m j - i \sum_n i - 1\, N_{wj} - N_{wi} \quad (1)$$

where m represents the total number of thematic layers; n = number of total classes in each thematic layer. And N_{wj}= normalized weight of the j-th thematic layer, and N_{wi}=normalized weight of the i-th class of thematic layers" [1].

D. Criteria Selection

Finding zones of possible groundwater in semi-arid areas requires selecting the appropriate parameters. These standards represent the elements influencing the total groundwater potential, including groundwater availability, recharge, and storage. An inventory of potential Using expert comments and a review of the literature, parameters pertinent to evaluating the potential of groundwater were developed [19]. To indicate the proportional importance of each parameter in affecting groundwater potential, assign it a weight. Using suitable strategies for making decisions derived from the Analytic Hierarchy Process (AHP) procedures, we establish weights [61, 62]. Ten components, combining geological, topographical, hydrological, and socioeconomic features improved the precision of our results. For some of the selected components employed in the investigation. Table 1 shows the mathematical equations [58].

Table 1. Selected factors expressed mathematically

No	Factor	Formula	Description	References
1	Lineam ent Density	LD = ∑i=1nLi\sum_{i=1} ^{n} Li ∑i=1nLi	The watershed's lineament lengths are indicated.	[59]
2	Draina ge Density	DD = ∑i=1mLi·Ai\sum_{i=1}^ {m} Li \cdot Ai∑i=1mLi·Ai	as well as how long each stream is in the mesh.	[63]
3	Degree of slope	SD = ATAN (dzdx)×180π\left(\frac{dz}{ dx}\right) \times \frac {180} {\pi} (dxdz)×π180	The rate at which elevation changes (dz) and the horizontal distance (dx) are used to compute the slope.	[18]
4	TWI	TWI = ln (As)ln (As)ln (As)	TWI is the topographic wetness index, representing soil moisture accumulation.	[64]
5	TPI	TPI = Mo−∑I = 1nMo- \sum_{i = 1} ^{n}Mo−∑I = 1n	TPI is the model point's elevation assessed, considering surrounding points.	[28]
6	S.P.I	Tan(β) = SPI.	reflecting the accumulation of upslope area-flow, and β denoting the topographic gradient's degree.	[19]

The scientific literature has extensively documented utilizing the AHP technique in studies of groundwater potential [28, 62]. As indicated in Table 2, this method makes it easier to evaluate a variety of elements in groundwater research and permits the inclusion of subjective viewpoints. This methodical approach facilitates decision-making, aids in the thorough evaluation and prioritization of variables, and advances knowledge of groundwater potential. By using pairwise comparisons presented in a matrix format, Classifying and ranking the identified criteria is made simpler by AHP. The relative preferences of the factors are measured by the pairwise comparison matrix [62]. Gambo suggested using a comparison scale of 1 to 9 to characterize the degree of relevance, where 1denotes equal importance and 9 denotes excessive importance in relation to others (Table 2) [58].

Table 2. The relative significance of Saaty is measured using the Capable 4 Scale, which goes from 1 to 9 [58]

Scale	1	2	3	4	5	6	7	8	9
Importance	Very Weak	Weak	Moderate	Strong	Strong Plus	Very Strong	Very Strong Plus	Extremely Strong	Extreme

E. Consistency Ratio

The consistency index and consistency ratio have been widely adopted in various processes for determining decisions, such as groundwater potential mapping, to check on the reliability of paired comparisons used to produce groundwater potential maps using criterion weighting. As such, by allowing a reliable and robust weighting process, the ratio of consistency provides a evaluation of the degree of judgment consistency quantitatively [61]. By paired comparison, a metric called the Consistency. Ratio (C.R.) is used to assess how inconsistent decisions made in criterion weightings are. It measures the deviations from determinism or how far a matrix is from obeying the model of consistency [61]. The general acceptance of C.R. score is 0.1 or 10%. The consistency index which is represented by the Eq. (2). CR = CI. RI where C.R. is the largest eigenvalue and λmax is the R.I., stands for the random consistency index, n for the number of input components employed, and consistency ratio. The consistency index in this case is called CI, and it is obtained from Eq. (3). The term

"RI" refers to the arbitrary measure of the number of comparison components (Table 2) [61].

$$\text{The CI} = \lambda\text{max} - \text{n n}- 1 \quad (2)$$

CR was generated by our use of Alonson and Lamata's linear fit.:

$$\text{CR} = \lambda\text{max} - \text{N } 7699\ .2\text{N} - 3513\ .4 - \text{N} \quad (3)$$

Table 3. Elements that affect GWPZ ranking [58]

No	Factors	Weight (%)	Various classes	Potentiality for groundwater	Assigned rank
1.	Rainfall (in mm)	25.92	367–480 6 481–550 4 551–633 3 634–750 2 751–995	Very Small Small Moderate peak Very peak	6 4 5 2 1
2.	Lineament Density (km/km_2)	16.97 0–4.16	16.97 0–4.16 8 4.17–10.7 6 10.8–17.5 4 17.6–25.3 3 25.4–44.2	Very Small Small Moderate Peak Very peak	8 6 4 3 2
3	Types of soils	15.01	Utisols Oxisols Vertisols Inceptisols Entisols Histosols Alfisols Aridisols	Very Peak Peak Peak Peak Small Peak Small Peak Small Small Small	5 4 4 2 2 2 1 1
4	Density of the dra inage (km/km_2)	8.75	0–3.00 3.00–8.26 8.27– 13.2 13.3–18.7 18.8–31.5	Very Small Small Moderate Peak Peak	7 5 4 1 1
5	Rock Structure	11.97	Mi- Q- T- pCm-	Very Paek Peak Small Very Small	7 5 3 2
6	Slope (in degree)	7.86	0–0.69 0.7–1.8 1.9–4.4 4.5–9.6 9.7–29	Very Peak Peak Moderate Small Very Small	8 6 4 3 2
7	LULC	3.71	Water Tree Built-up Cropland Rangeland Moderate 1	Very Peak Peak Very Small Moderate	6 5 3 2 1
8	TWI	4	−8.39–5.83 −5.82–5.13 −5.12–4.49 −4.48–2.81 −2.8–−0.618	Very Peak Peak Moderate Small Very Small	8 6 4 3 1
9	TPI	2.76	−38.9–3.3 −3.29–0.735 0.734–0.548 −0.549–4.07 −4.08–42.9	Very Peak Peak Moderate Small Very Small	6
10	SPI	2.33	0–1.4 1.5–6 6.1–13 14–25 26–73	Very Peak Peak Moderate Small Very Small	

F. Drainage and Lineament Density

Drainage density (d in the Fig. 1) is considered an important measure of the occurrence and recharge of groundwater in any groundwater potential study. It gives an idea about the relation between surface and subsurface formations which are computed by dividing the total drainage of a basin by its area [23]. Low drainage density areas have less runoff and more soil penetration, enhancing the chance of groundwater recharge and infiltration. On the other hand, higher drainage densities tend to increase surface runoff that negatively impacts the recharge and permeability processes [65, 66].

On the other hand, it is seen that “precipitation-intensive drainage systems may enhance the infiltrating and recharging potential, especially in fragmented landscapes.” Lineament density in hydrogeological surveys (f in the Fig. 1) depicts the geological features such as faults and fractures acting as conduits for groundwater flow. Potential groundwater zones can be delineated with the help of these lineaments. which show the areas rich in secondary porosity [65]. Higher lineament densities reflect increased permeability and, hence, delineate promising zones for groundwater resources [57]. Lineament density has been continuously highlighted in research works as an essential factor in studies related to groundwater. Lineament analysis is applied to recognize aquifer zones and understand the pattern of groundwater flow with a view to mapping groundwater resources in various geological settings [67].

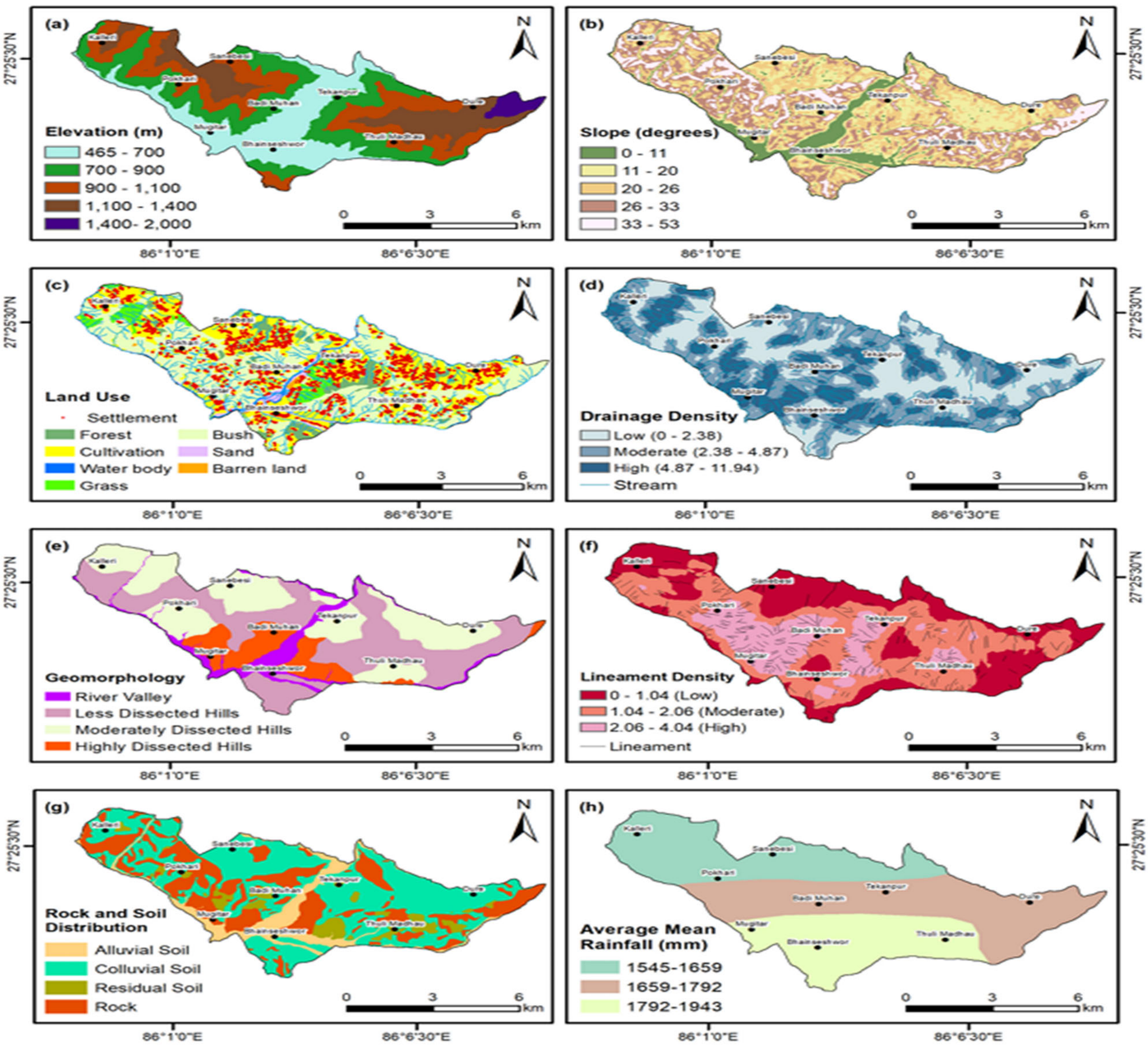

Fig. 1. Shows thematic maps used to map groundwater potential. Elevation (a), slope (b), land use (c), drainage density (d), geomorphology (e), vegetation density (f), rock and soil distribution (g), and rainfall (h)[3].

G. Slope in LULC (d) and Degree (c)

Because it directly controls stormwater movement and passage as well as groundwater flow direction. A crucial element in mapping groundwater potential is the gradient. In (Fig. 1), the land surface slope has a prominent effect on groundwater recharging, steeper and higher gradients result in less recharge because of Surface runoff has risen and shorter infiltration times. On the other hand, low gradient regions encourage groundwater accumulation and runoff discharge. Assessing water resources and comprehending the dynamics of water flow within catchments Need topographical data that offers information about the relief efforts, infrastructure, and shape of a certain location [68]. These facts determine the flow rates or recharging of aquifers. Groundwater recharge capacity and slope are inversely connected; steeper slopes typically have lower infiltration and recharge rates and higher runoff rates. The water Because larger slope angles offer higher flow velocities over land, they lessen incursion into aquifers [69].

On the other hand, regions with decreasing slope angles allowed more surface water to seep and intrude into the subsurface aquifers. Five groups were created from using the slope map, which showed a range of 0 to 30 degrees, according to the relative importance of each group to groundwater penetration and presence [58].

H. Pattern of Rainfall (h) and Topographic Wetness Index (TWI) (e)

Precipitation, the primary mechanism for replenishing groundwater, is essential to groundwater potential modeling since it has a direct impact on aquifer zone identification and water availability [70]. Researchers commonly use data from sources like the InfraRed Precipitation Group Climate Hazards with Station (CHIRPS) to examine the rates and patterns of precipitation in a watershed.

The primary supply of water in arid environments is precipitation, which has a major impact on groundwater recharging and water buildup [71, 72]. While heavy rains can cause flash floods, severe storms can cause recharges, underscoring the importance of precipitation duration and intensity in regulating infiltration and runoff rates. According to research, Annual precipitation and the potential for groundwater recharge are positively correlated; higher rainfall is linked to higher recharge potential (h in the Fig. 1) [65]. The Topographic Wetness Index (TWI) is another helpful topography indicator for assessing groundwater potential (e in Fig. 1). Through describing the relationship between surface moisture and landscape slope, it offers spatially based insights into water accumulation [63]. While lower-lying regions have greater topographical wetness, which improves the potential for water storage, steeper slopes and higher elevations typically have greater runoff, which restricts groundwater availability [73]. To measure wetness throughout a watershed, Digital Elevation Models (DEMs) are used to compute TWI, accounting for local slope and contributing area. This measure helps identify areas that are susceptible to runoff and have significant groundwater potential [74]. The significance of TWI in assessing groundwater potential in a variety of terrains, including dry and semi-arid areas, is still supported by scientific research [75].

I. (f) Topographic Position Index (TPI) and Stream Power Index (SPI)

When examining the potential of groundwater, SPI is one of the most crucial indicators. since it provides vital information related to the potential for erosion caused by water flow on hillsides. The hydraulic grade it provides is a hill concerning the water flow rate and amount of water upstream [76]. The procedure in Table 1 was used to determine the SPI, which computes the index as a function of the tilt angle's tangent and contributing area (A). Similarly, researchers can use the SPI presented in b in Fig. 1 to outline areas with a high risk of erosion that may have consequences on the recharging and storing of groundwater [76, 77]. The TPI is among the most crucial variables utilized in modeling the potentiality of groundwater because it reflects the relation of elevation and topographic position for a certain cell about its surrounding cells. Equation in Table 1 was applied using specialized software like ArcGIS to calculate the TPI [28, 76]. The TPI values for the research region are obtained. The resultant TPI values from this calculation have been useful in the automatic classification of geomorphological features across the landscape. These values were utilized in the mapping of several landform categories such as plains, valley floors, and ridges based on the TPI values [1]. While positive values of TPI indicate higher altitudes, negative values show that cells are lower than their neighboring cells. Mapping groundwater potential using TPI is shown in (f in the Fig. 1). This information is vital for the planning and control of groundwater supplies [78].

J. Geology (g) and Soil Types (g) of the Study Area

Soil is a very critical component of groundwater potential modeling as It has an immediate impact on the permeability, porosity, as well as geometric characteristics of rock to determine GPZs within a given area [5, 79]. The quantity of flow and infiltration occurring depends much upon the type of soil, as observed in (g in the Fig. 1). The size of grains and concerned pore networks along with their arrangement involves much influence in the water movement [80]. So, porosity and permeability are directly related to soil texture. Infiltration rates are lower in soils with fine grains and well-sorted components, like sand, than in coarse-grained soils [81]. The USDA classification is generally recognized in the literature based mostly on the FAO-UNESCO classification [58]. According to the USDA soil taxonomy, the dominant soil of the research area is enveloped with soil orders Alfisols, Histosols, Entisols, Inceptisols, Vertisols, Utisols, and Oxisols [58].

Since They have a direct impact on the event, transport, regarding groundwater availability, the geological features in f in the Fig. 1 are essential to the research. related to the potential of groundwater. The geological setup is required for the determination of potential aquifer systems and the assessment of the groundwater resource [82].

K. Stream Order and Elevation

An elevation model, also known as a digital elevation model, shows the ground surface's height in relation to a vertical reference. It is an important tool, which gives enough details for planning and charting a region's topography and hydrology [59, 83]. The SRTM-DEM elevation map used in this investigation was obtained According to Satellite Model of digitized elevation from Radar Topography Mission (a in the Fig. 1).

The topography or elevation differs much over the area and ranges approximately from 340 to 778 m above ground level. Elevation information has already been used for many research analyses to demarcate the ground water potential with topographic relationship. Ravi [83] have executed DEM data on demarcation of ground water potential bearing area. Groundwater resource man-agement is supported and a thorough understanding of groundwater dynamics is made possible by the integration of elevation da-ta with other pertinent factors [58].

IV. Results

Finding the prospective zones for groundwater: An integrated approach in AHP, distant sensing, and spatial data analysis has effectively discovered the zones of groundwater potentials in the semi-arid area.

The different layers of data regarding line density, drainage density, indicator of topographic location, stream power, and topographic wetness geology, soil type, slope, land cover, and many more can be integrated to determine the spatial distribution of groundwater potential within the study area. Distribution of rainfall pattern is done. For analysis purposes, the research region was separated into discrete prospective zones for groundwater according to their relative appropriateness regarding groundwater formation, accessibility as well as storage. The possibility index for groundwater using a range of classifications from extremely low to high groundwater potential was presented in Fig. 2.

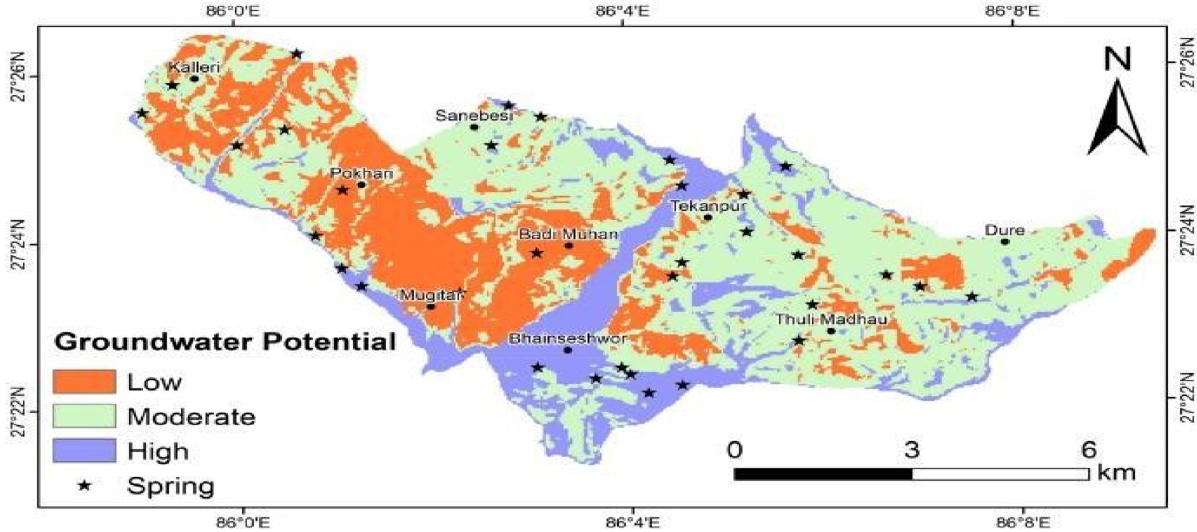

Fig. 2. An outline of the study region's groundwater potential with existing springs [3] In the Nepal Himalaya's mid-hill region, in the Rambachan District.

A very high elevation was used to assess the groundwater potential of the study area.

The resultant groundwater potential zone map presented in Fig. 2 showed that the entire area falls within the high potential groundwater zone, followed by the moderately high potential zone. A zone of low potential Mild slopes, well-drained and water-retaining soils, close accessibility to long-term water supplies and mild precipitation (480–633 mm) were all components of the extremely low potential zone, extremely high potential zone, and percentage. These advantageous circumstances mean that it is more probable that communities in these places will have access to and be able to exploit groundwater resources more effectively for survival [58]. Additionally, there is virtually little groundwater potential which makes the option available when mechanical use of groundwater during the dry season is considered for alleviating poverty especially in places having no or the least river services throughout the year. But ensuring only sustainability to groundwater calls for optimum water resource management in those places of the region where some areas have already been identified as low potential groundwater zones. These are characterized by steep slopes, basement development, poor drainage of soils, and more distance to supplies. It is relevant to recognize and understand such limitations and problems regarding the groundwater resource in these areas to create appropriate solution[s] [58].

V. Discussion

A. *Consequences for Alleviating Poverty in Many Ways*

The reduction of multilayered poverty in semi-arid regions depends on the demarcation and characterization of zones of groundwater potential [21, 31, 69]. Groundwater is an important asset that contributes positively to human existence through industrial and domestic usages, sprinkling agricultural regions, and provision of potable water. Numerous studies have examined its function in reducing poverty and found many advantages [63]. Access to safe drinking water, which is usually more dependable and less contaminated than surface sources, is one of the main benefits of groundwater. This lowers health risks and enhances general well-being, which is especially important for underprivileged groups that frequently rely on contaminated water [84]. Additionally, irrigation is supported by groundwater, increasing agricultural output and raising earnings for households that are more susceptible [58]. Communities who depend significantly on agriculture for their livelihoods need this economic boost. Furthermore, groundwater helps communities cope with scarcity by serving as a buffer against natural disasters like floods and droughts [85]. In places affected by poverty, it improves resilience and safeguards livelihoods by storing water during times of abundance [82]. All things considered, efficient groundwater management can greatly lower poverty and raise living standards in these areas.

B. *Verification of the GWPZ Study*

Utilization of AHP, GIS, and remote sensing to determine the groundwater potential Data from the study region's actual drill output and depth confirmed the conclusions. Kriging interpolation was used to assess the groundwater's spatial distribution, and the result is Fig. 2, which shows the groundwater distribution concerning the yield of the boreholes in liters per second.

According to the study, the groundwater can be reached at different levels, and its average production is 2.5 L/s per second at a depth of 60 m. These findings offer insightful data regarding groundwater potential across different regions, facilitating well- informed choices on development and management programs for water resources. Stronger submersible pumping engines are said to increase borehole yields, increasing groundwater availability for agricultural, residential, and industrial uses. Sustainable abstraction methods are required to prevent the aquifer from being depleted beyond its recharge capability [61, 86]. To verify the Groundwater Potential Zone (GWPZ) map in respect to the site's topography, a satellite-based digital interpretation technique was applied, as seen in (f in the Fig. 1.) For precise groundwater potential mapping, recent research highlights the incorporation of cutting-edge methods like AHP and kriging [27, 72]. These techniques have been successful in pinpointing possible groundwater zones, which helps reduce poverty in areas with limited water resources. Recent research emphasizes the need for a comprehensive strategy for managing groundwater that takes population dynamics, land-use patterns, and climate change into account [58]. Policymakers can better address the unique requirements of communities that are at risk by incorporating socioeconomic data into evaluations, which increases the efficacy of programs aimed at reducing poverty [36]. New approaches have showed promise in reducing overexploitation and restoring groundwater levels, including artificial recharge methods like rainwater collecting and community- based groundwater management [18]. Real-time data monitoring and sensor technology advancements allow dynamic groundwater management. By placing Internet of Things-based sensors in boreholes, groundwater levels and quality may be continually monitored, allowing for prompt interventions [58]. Such sophisticated management systems have the potential to significantly reduce poverty by ensuring sustainable access to water sources.

VI. Conclusion

The paper points out how vital groundwater is for agricultural, drinking, and economic purposes in semi-arid regions. Groundwater quality and supply are said to have serious problems, which are brought about largely by population development and insufficient management techniques. The research successfully delineated GWPZs by applying remote sensing and the AHP, which indicated that 59.5 percent of the examined area is covered by the significant component. This geographical research emphasizes the need for systematic reviews and evidence-based decision-making in groundwater management.

It further calls for the integration of surface and groundwater resources into one system for the long-term management of groundwater. This calls for the establishment of proper monitoring systems, the implementation of limitations to groundwater extraction, and the involvement of local citizens in decision-making processes regarding groundwater management. These efforts will increase the effectiveness of managing groundwater by addressing gender and socioeconomic justice, building greater awareness of the need to conserve groundwater, and undertaking continuous research into management decisions. With such ideas, stakeholders could enhance the sustainability of groundwater, hence improving agricultural production and economic resilience in the region.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

Kabiru Abdullahi Abdulhamid conceived the research, concept, designed the review structure, performed the literature search, and drafted the research paper. Muhammad Dimyati provided guidance on the review framework, critically revised the manuscript for important Intellectual content, and supervised the overall preparation of the review. Both authors had read and approved the final version.

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