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Groundwater Potential Zonation of Punjab Using GIS and Remote Sensing Tools

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Abstract

Water is an important resource in a variety of economic activities, from agriculture to industry. Due to its intrinsic properties, ground water has become a highly important source of water supplies in all climatic zones of Pakistan. The results of GIS-based analytical methodologies used for groundwater potential zonation in Punjab, Pakistan, are presented in this study. The goal of this research is to find areas with shallow groundwater potential. In ArcGIS software, the investigation is carried out utilizing the weighted overlay approach, fuzzy logic, and AHP analysis tools. Land use, slope, geology, geomorphology, distance to water bodies, permeability, soil, faults, drainage density, and rainfall were chosen as input layers for this study because these parameters all have an impact on groundwater to varying degrees. These input map layers were first georeferenced with UTM Zone N43, datum WGS 1984, and translated to raster form, after which they were classified according to their expected significance in groundwater zonation using the weighted overlay approach. As weighted overlay methodology is biased towards prioritizing layers, the other two studies were then used to check for chronology in the maps that had been examined and to find out the most reliable model. The maps created from the three approaches were validated through the groundwater data collected for different regions of Punjab. The AHP analysis method turned out to be the most suitable one and matched the validation map more precisely, which concluded that 3% of the regions lie in very shallow zones, 38% in shallow zones, 27% in moderate zones, 14% in deep zones, and 18% in very deep zones. Finally, the study identifies the most advantageous places in Punjab where groundwater can be found at specified depths. This information on groundwater potential will be important in identifying ideal places for water extraction and the installation of recharge wells.

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1. Introduction

Groundwater has always played a vital role in meeting freshwater requirements and expanding irrigated agriculture in many areas of Pakistan. Concerning today, groundwater depletion is one of the major problems in Punjab. Allocation of groundwater recharge resources is the necessary measure taken for it. The groundwater has been depleting adversely throughout Punjab, with deep cones of depressions being made that are ultimately intersecting with each other, which is a major concern. The surface water supplies are sufficient to irrigate 27% of the area, where the remaining 73% of the land is irrigated using groundwater, either directly or indirectly. More than 90% of total groundwater abstraction is used in Punjab province. Pakistan's total groundwater extraction is over 60 billion m3. Groundwater access has aided farmers in securing food for the growing population (Qureshi, 2020). 70% of domestic water nationwide, 90% of domestic water in Pakistan's rural areas, and more than 50% of agricultural water come from groundwater. It is crucial to reducing the effects of rainfall and more erratic canal water delivery. However, despite Pakistan's reliance on groundwater, little is known about how it is changing, and the nation has a long history of failing to create an effective groundwater management strategy.

Unregulated pumping has led to groundwater depletion and the drying up of wells in parts of Punjab (Lyton & Saeed, 2021). Pakistan has around 1.2 million tube wells that take 61.7 billion m^3 of water for agriculture irrigation each year, and groundwater supplies are depleting at a rate of 0.16 to 0.55 metres (6 to 21 inches) per year across Punjab province and two districts of neighbouring Khyber Pakhtunkhwa province (Khan et al., 2015). Groundwater access has aided farmers in securing food for the growing population. Unchecked groundwater exploitation, on the other hand, has resulted in serious environmental issues. Rapidly dropping groundwater levels in irrigated areas and rising soil salinization issues are among them. Groundwater levels have decreased below 6 metres in more than half of Punjab's irrigated districts, resulting in higher pumping costs and deteriorated groundwater quality. Despite the critical role that groundwater plays in agricultural output and economic prosperity, it has not received the attention it deserves. It's become a pumping arms race in the absence of an appropriate management policy; the individual with the biggest pump usually wins.

Groundwater withdrawals are currently exceeding renewals, turning this boon into an impending tragedy. Poor groundwater management is mostly caused by a lack of regard for the law, a lack of needed data and information, a lack of political will, and institutional arrangements (Qureshi, 2020). The importance of various hydrogeological factors, such as geomorphology, geology, land use and cover, faults, rainfall, distance to waterbodies, slope, soil cover, drainage density, surface temperature, etc., in controlling the groundwater potential of any area has already been reported by several scientific communities. However, the degree to which they affect it may vary depending on the location and the time of year (Sener et al., 2005; Ganapuram et al., 2009; Avtar et al., 2010). ArcGIS is used to prepare and synthesise the groundwater zonation map of Punjab by considering effective parameters through which the groundwater is influenced to varying degrees. The use of GIS and remote sensing seems to be of great benefit as compared to the traditional methods of drilling boreholes, which are time- and budget-consuming. Three approaches, namely weighted overlay, fuzzy logic, and AHP analysis, were employed for this purpose. The weighted overlay approach is a collection of procedures used in site selection or proving reasonableness. It's a method for applying a standard set of attributes to varied and unique contributions to perform an integrated analysis.

Appropriateness models identify the best or most popular locations for a certain wonder. Fuzzy logic attempts to answer problems by combining a wide range of data and heuristics to get a variety of accurate conclusions, as it is a variable processing method that permits many truth values to be processed with the same variable. The Analytic Hierarchy Process (AHP) is a pair-wise comparison strategy that uses an eigenvalue technique. It uses a numerical fundamental scale of 1 to 9 to calibrate the quantitative and qualitative performance of priorities. The AHP ensures that collective decisions are involved, as it uses the notion of building hierarchies to solve issues. The hierarchy enables evaluation of the contribution made by individual criteria at lower levels to criteria at higher ones. The validation of the most reliable map was done by gathering real-life water well data acquired across the whole of Punjab. The resultant maps will assist us in a more detailed analysis of the groundwater potential of different regions of Punjab, through which groundwater recharge recommendations can be introduced, followed by the introduction of further policies for the installation of pumping and recharge wells. Groundwater zonation mapping serves as the primary stage in highlighting regions according to their groundwater potentials. These maps will provide information about the groundwater potential in different areas of Punjab and help in the safeguard of adversely depleted regions with deep cones of depression. The detailed study of the proposed zoned maps could produce the most suitable sites for development projects in Pakistan.

2. Study Area

Punjab, the region of five rivers, Pakistan's most populous province, and once known as the granary of the east, is the country's lifeblood. It is situated on 31.1704° N, 72.7097° E coordinates and has a population of 235 million people. Although the province is mostly flat, there are some steep places in the north-west and extreme south-west (figure 1). There is also the Potohar plateau, which is near the mountains, and Cholistan, a desert belt in the south-eastern region of the country. This province is home to all the country's major rivers, including the Indus, Jhelum, Chanab, Ravi, and Sutlej. Even though the region is a historic floodplain, the Indus River's exceptional flooding in the summer of 2010 was extremely devastating in Punjab, affecting millions of people (by some estimates, one-half of all Pakistanis affected were in Punjab).

Punjab's main source of income and employment is agriculture. Much of the province used to be arid wastelands that were unsuitable for settlement, but that changed after a large network of irrigation canals was developed using the waters of the Indus tributaries in the early twentieth century. The settlement area, which had previously been limited to the north and northeast, was expanded to embrace the entire province, and irrigated land now accounts for almost three-quarters of the province's cultivable territory. The main crops are wheat and cotton. Rice, sugarcane, millet, corn (maize), oil seeds, legumes, fruits, and vegetables are among the other crops farmed. Large amounts of livestock and fowl are raised. Punjab is located on the eve of the monsoon season. The weather is often hot, with significant seasonal differences between summer and winter. The average June temperature on the plains is in the mid-90s Fahrenheit (mid-30s Celsius), while the average January temperature is in the mid-50s Fahrenheit (low 10s Celsius). Except in the sub-Himalayan and northern parts, yearly precipitation is minimal, and it drops dramatically from north to south or southwest, from 23 inches (580 mm) in Lahore in east-central Punjab to just 7 inches (180 mm) in Multan in the southwest.

Groundwater is widely used in Punjab due to its availability at shallow depths and relatively acceptable quality. Many factors influence groundwater consumption in Punjab, including farming patterns, cropping intensity, agro-climatic conditions, and available groundwater quality. The Punjab province has three distinct climate zones. Upper Punjab receives more than 500 mm of yearly rainfall (high rainfall zone), middle Punjab 300–400 mm (medium rainfall zone), and lower Punjab 100–150 mm (dry zone). Cropping patterns in these zones vary depending on surface and groundwater availability. Even though rice is a major crop farmed in these areas, groundwater usage is minimal in high rainfall zones compared to small and medium rainfall zones. Due to the reduced water requirements of these crops, groundwater use is generally low in locations where wheat-cotton cropping is more widespread. Groundwater use is significant in sugarcane and fodder-dominant areas because of high water demand.

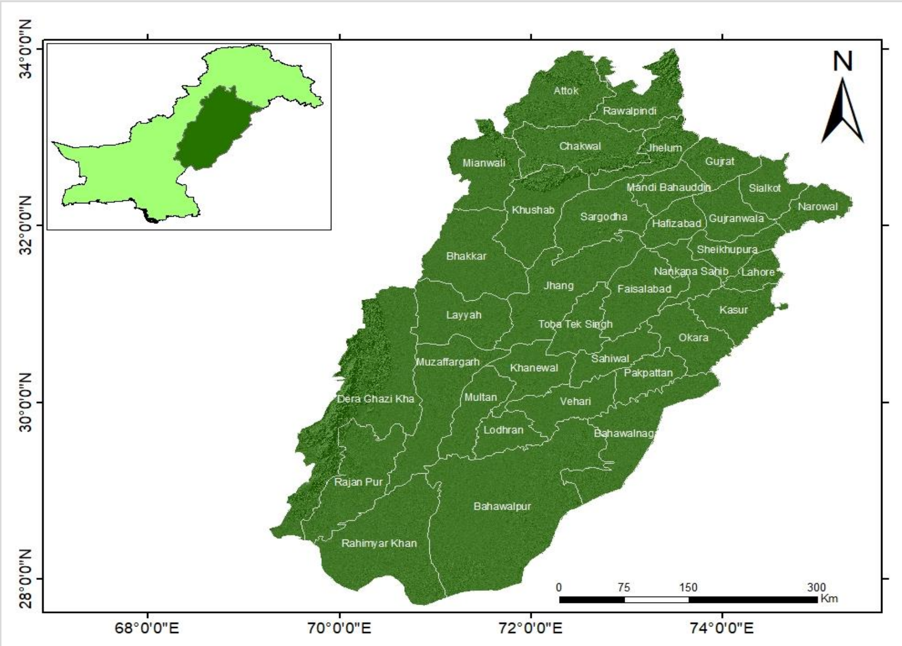

Fig. 1. Location map of study area, the Punjab Province.

3. Material and Methodology

Three methods were taken into consideration to create groundwater potential maps: weighted overlay, fuzzy logic, and the analytical hierarchy process using remote sensing data. Ten different layers, i.e., soil, rainfall, geology, geomorphology, permeability, faults, drainage density, distance to water bodies, land use, and slope, were considered. The layers of drainage density, distance to water bodies, and slope were acquired from the ASTER DEM of 12m horizontal resolution using the hydrology tool in ArcMap 10.8.

Other layers were prepared by converting rasterized images gathered from respective organizations into digital ones using Universal Transverse Mercator (UTM) N43 and datum WGS 1984. After performing weighted overlay, fuzzy logic analysis and AHP analysis were done to check for the feasibility of maps. The flowchart in figure 2 gives methodology utilized in this research.

Input Layers

Groundwater is one of the most important natural resources in tropical climates, particularly in their semi-arid, arid, and wet and dry sections, and the land use gives the area urbanized by population and used for agricultural purposes. The map was downloaded from Global Map V.3 (Global Version). Firstly, the map was added to GIS, and the input map was extracted for Punjab by overlaying the shape file of the country boundary of Punjab. Later, the project raster was run on the extracted map, in which we georeferenced the map with UTM Zone 43N, followed by weighted overlay analysis as shown in figure 3.

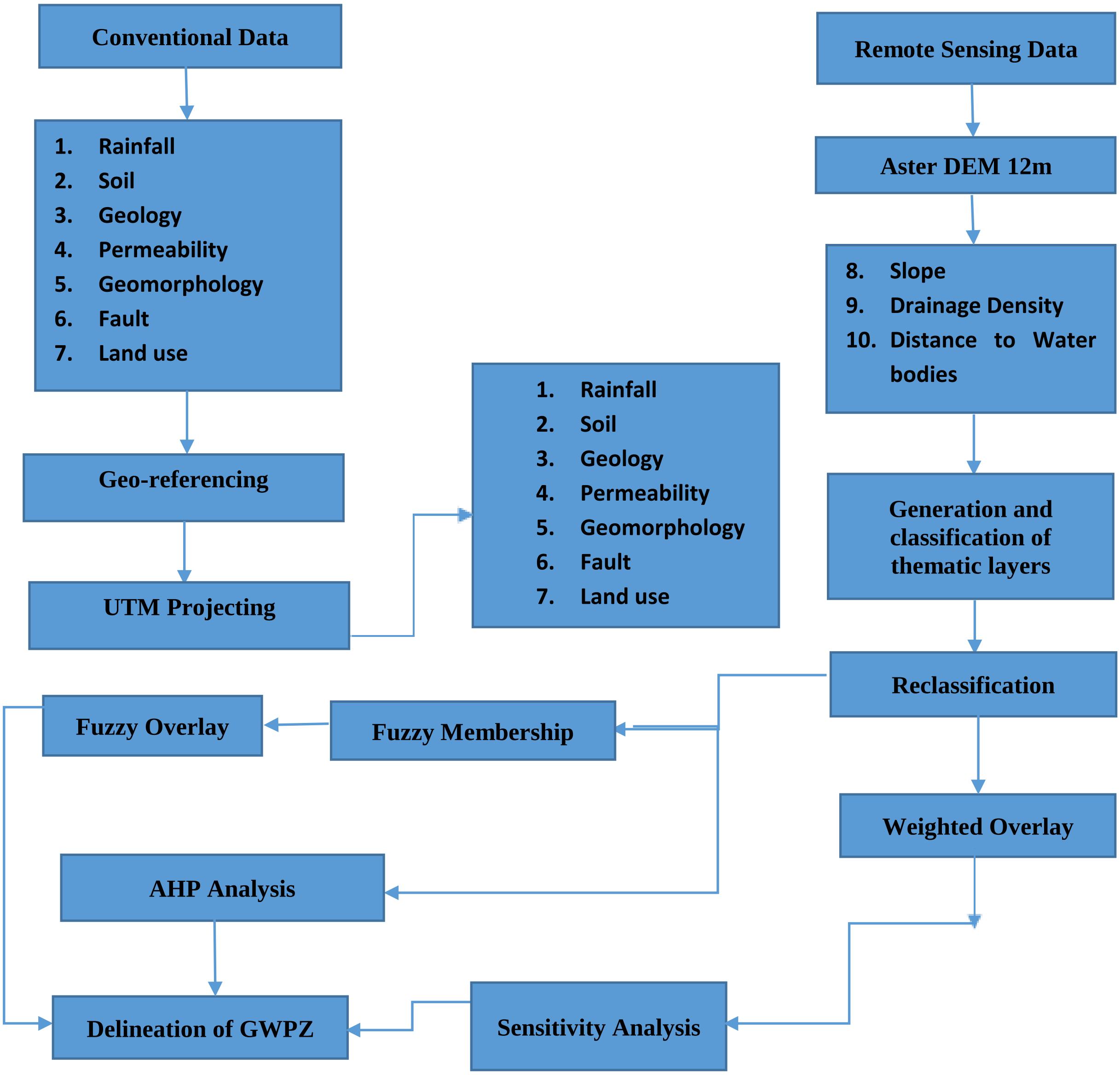

Fig. 2. Flow chart of the research methodology.

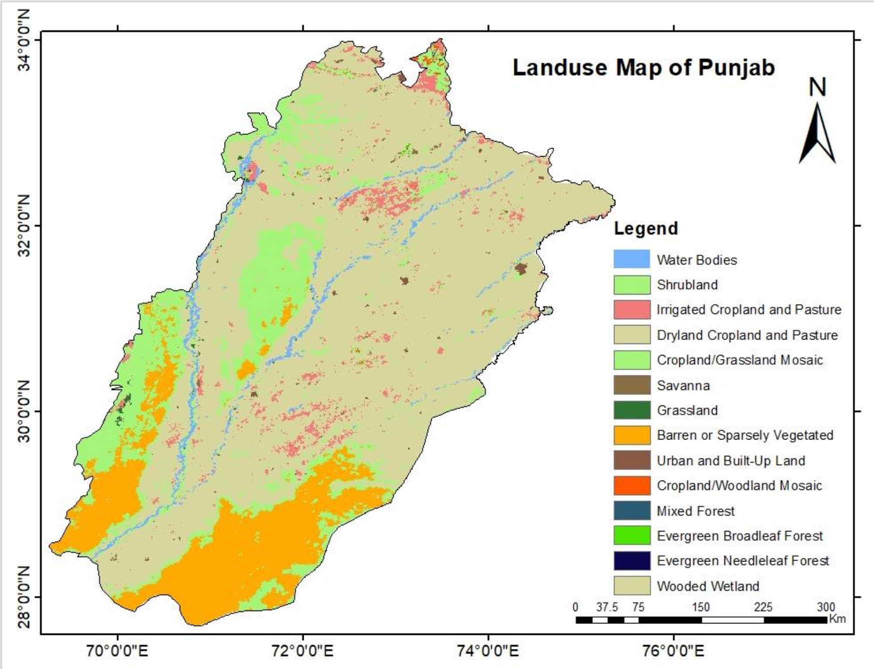

Fig. 3. Land use map of Punjab Province.

The layers of slope shown in figure 4, drainage density in figure 5, and distance to water bodies in figure 6 were created using the hydrology tool in ArcMap 10.8 by means of an ASTER DEM of 12m horizontal resolution. The horizontal spacing of the contours explains the slope. The highest rate of change in value from each cell to the surrounding cells is used to calculate the slope in the elevation raster. In both vector and raster representations, the slope values are determined in percentages or degrees. Furthermore, high-drainage-density terrains have low recharge rates, whereas low-drainage-density terrains have higher recharge rates. High drainage density favors runoff, resulting in weak GWPZs (groundwater potential zones), and vice versa. The presence of local alluvial layers is primarily located near river courses, especially in semi-arid locations; hence, distance to hydrographic networks is crucial in hydrogeological investigations corresponding to impact water bodies present in the concerned region.

Because over two billion people drink groundwater every day, understanding, protecting, and sustaining groundwater flow is vital. Geologic formations such as fractures and faults can influence groundwater flow. Faults can act as a barrier slowing down groundwater flow, a conduit speeding up groundwater flow, or an extraordinary combination of both slowing down and speeding up groundwater flow. The fault map was acquired from the Geological Survey of Pakistan. Multiple ring buffers were applied to highlight the distances. Furthermore, understanding the geology of the bedrock is essential for understanding the amount of groundwater that can be pumped from a well in each location. Bedrock in various parts of the world is made up of sedimentary layers with a lot of pore space between the individual mineral grains. These strata can produce aquifers, or conduits for groundwater movement, that are laterally extensive and at predictable depths, from which seemingly endless volumes of high-quality groundwater can be drawn. The data for faults shown in figure 7 and the geology shown in figureFig. 8 was acquired from the Geological Survey of Pakistan.

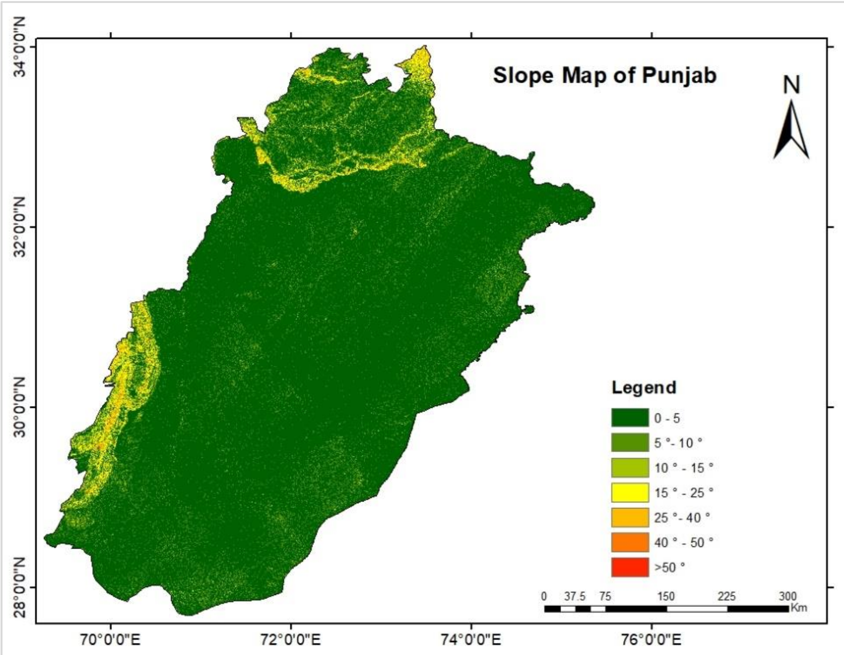

Fig. 4. Slope map of Punjab Province.

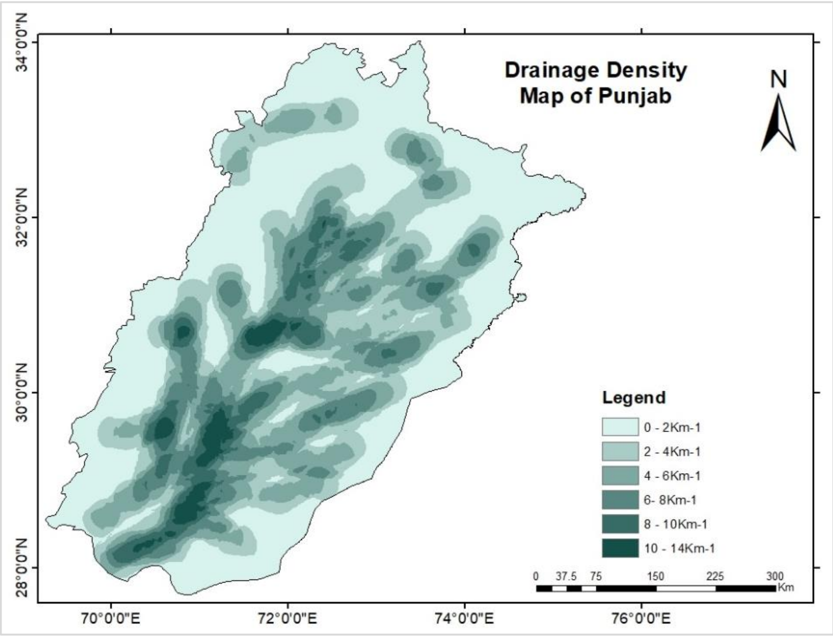

Fig. 5. Drainage density map of Punjab Province.

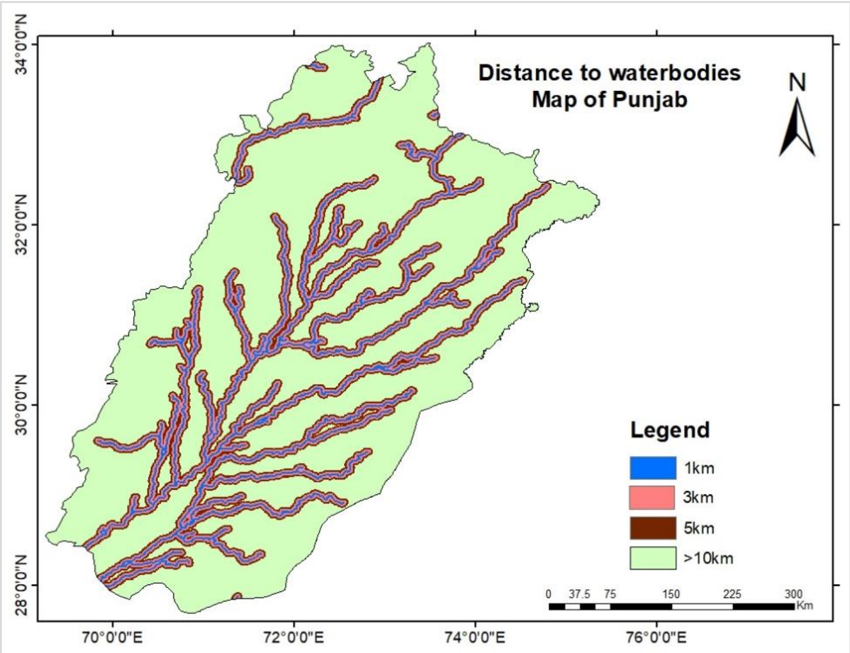

Fig. 6. Distance to waterbodies map of Punjab Province.

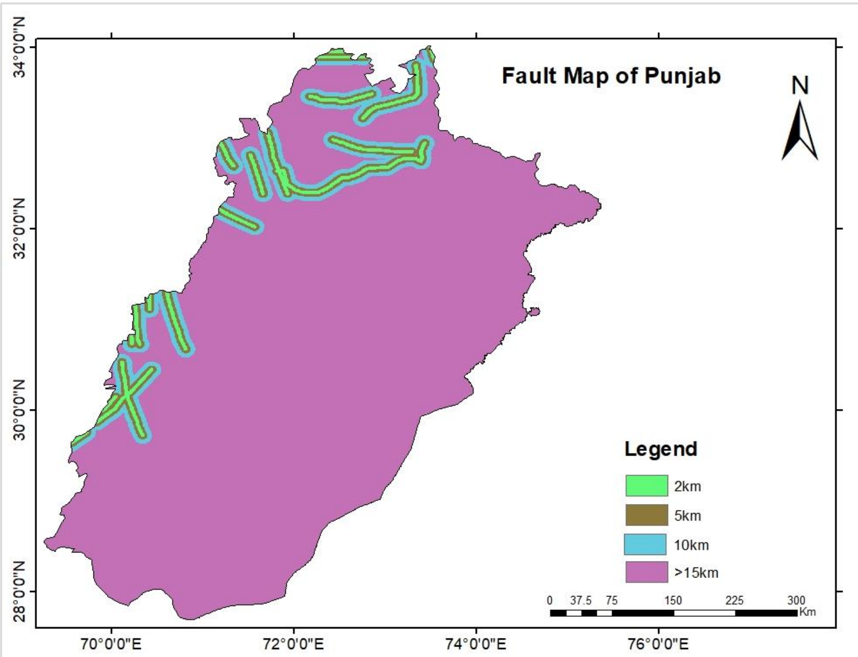

Fig. 7. Fault map of Punjab Province.

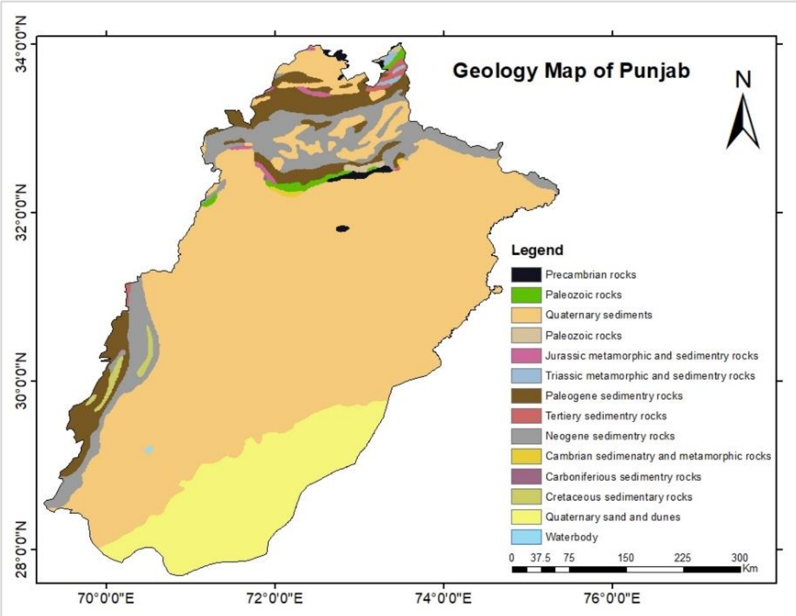

Fig. 8. Geology map of Punjab Province.

The structural evolution of geological formation determines the geomorphology (figure 9Fig.) of a place, and it has become an important input in the planning of many development projects. Many of the characteristics are favorable for groundwater occurrence and are categorized according to groundwater potentiality. The data for the permeability layer was acquired from sciencedirect.com from a journal called Geoscience Frontiers, Volume 11, Issue 5, September 2020 (Arshad et al., 2020).

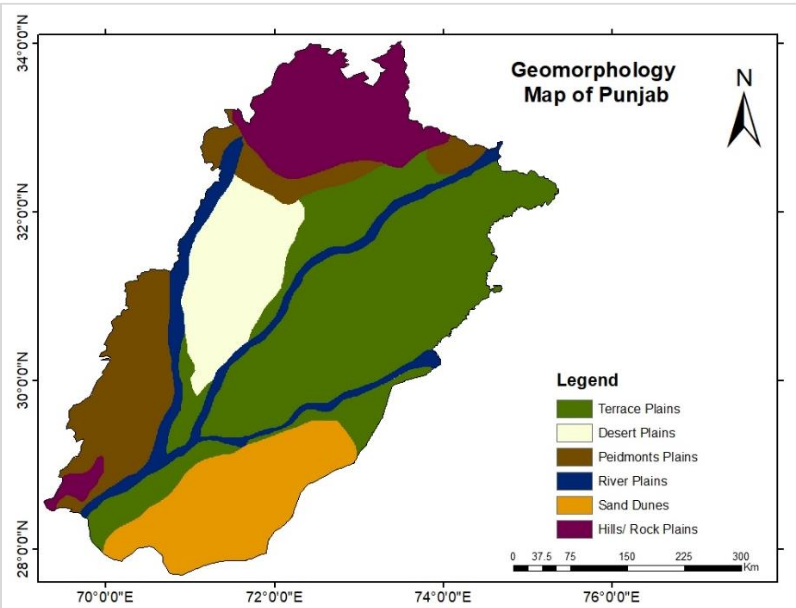

Fig. 9. Geomorphology map of Punjab Province.

When compared to soils with larger sand particles shown in figure 10, soils with smaller particles (silt and clay) have a larger surface area, and such a type of sand may hold more water. In other words, fine soil, which has a high proportion of silt and clay particles, has a greater capacity to hold water. Moreover, permeability refers to how quickly water may flow through rock or unconsolidated sediment, as well as how easy it will be to remove the water for human needs. It is one of the most important parameters that would assist in groundwater zonation. The data for the soil layer was acquired from 'citypulse.com.pk' published in 1978 under the direction of Dt. M. Bashir Chouhri, Director General, 'Soil Survey of Pakistan'. Later, the data for permeability was extracted from the soil layer shown in figure 11. The soil types in Punjab regions were later interpreted to check which soil is permeable to what extent.

Rainfall has a major role in groundwater recharge because it is the primary source of groundwater recharge. Precipitated water that reaches the surface of the ground may partially permeate into the ground or partially discharge into streams as surface runoff. If the soil is wet, infiltrating water is stored as soil moisture and later recharged to groundwater level. Groundwater level will eventually decrease owing to deeper percolation or evapotranspiration if no water supplies are continuously provided by rainfall or other sources of replenishment. The rainfall data was acquired from Pakistan Meteorological Department in the form of rasterized image and generated map shown in figure 12.

Groundwater potential zonation maps of Pakistan were created by using weighted overlay analysis, fuzzy logic, and AHP analysis in ArcGIS. Some of the weighted overlay analyses were run by giving different weights to different parameters, along with the equally weighted overlay, in which the same weight was given to all layers, as shown in Run 1. In equally weighted analysis, we give weight to all the layers equally, which shows that all layers we are using for the analysis have equal influence (Surjit Saini, 2010). In weighted overlay, sensitivity analysis was performed in which different weights were assigned to each layer (Table 1). The results of the sensitivity analysis are shown from Run 2 to Run 6. After giving all the layers their appropriate weights, a groundwater potential map with several opportunity areas could be developed. A comparison of all runs shows the different percentages of groundwater in different aspects.

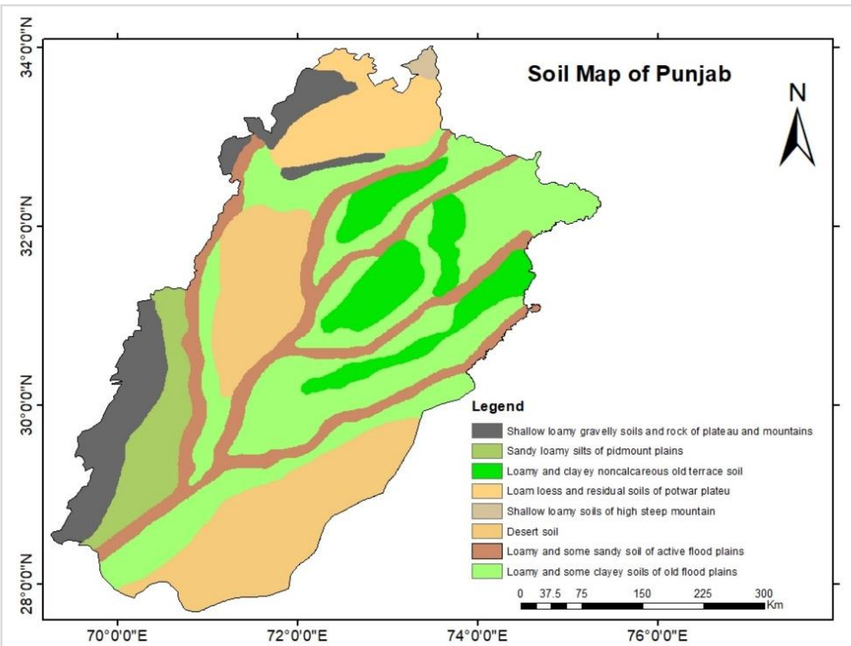

Fig. 10. Soil map of Punjab Province.

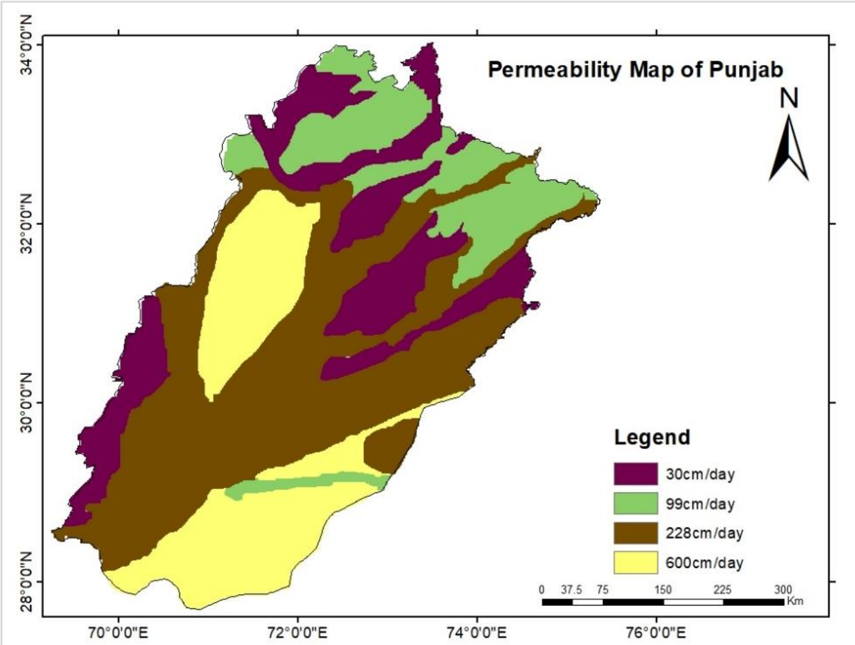

Fig. 11. Permeability map of Punjab Province.

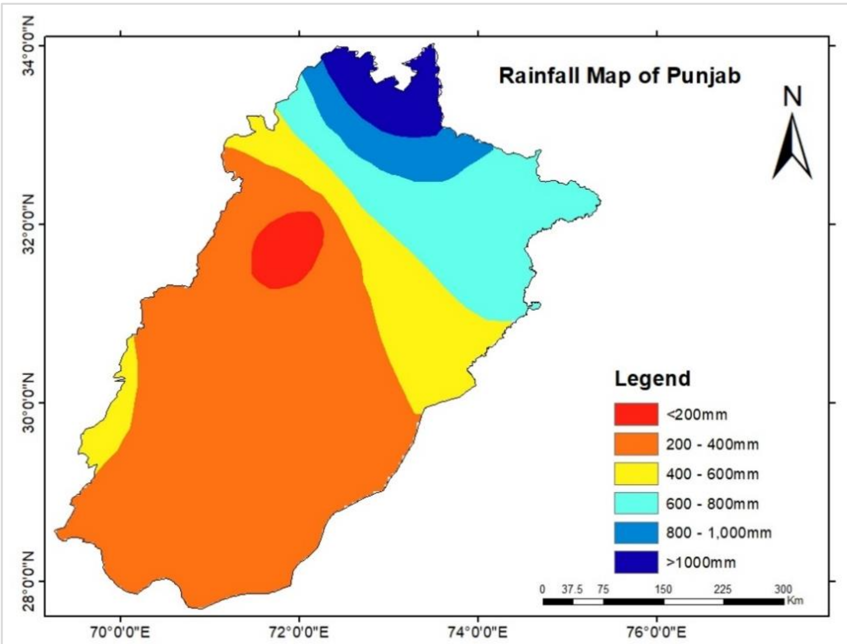

Fig. 12. Rainfall map of Punjab Province.

Table 1. Different weightages of each layer in sensitivity analysis.

<table>
<tr><th rowspan="2">Layers</th><th rowspan="2">Run 1 (Equally)
%</th><th colspan="5">Sensitivity Analysis (%)</th></tr>
<tr><th>Run2</th><th>Run3</th><th>Run4</th><th>Run5</th><th>Run6</th></tr>
<tr><td>Land Use</td><td>10</td><td rowspan="3">20</td><td>10</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>Soil</td><td>10</td><td rowspan="3">20</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>Geology</td><td>10</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>Geomorphology</td><td>10</td><td>10</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>Distance to waterbodies</td><td>10</td><td>5</td><td>5</td><td rowspan="3">20</td><td>5</td><td>5</td></tr>
<tr><td>Rainfall</td><td>10</td><td>5</td><td>5</td><td>5</td><td rowspan="3">20</td></tr>
<tr><td>Permeability</td><td>10</td><td>5</td><td>5</td><td>10</td></tr>
<tr><td>Drainage Density</td><td>10</td><td>5</td><td>5</td><td>5</td><td rowspan="3">20</td></tr>
<tr><td>Slope</td><td>10</td><td>5</td><td>5</td><td>5</td><td>10</td></tr>
<tr><td>Fault</td><td>10</td><td>5</td><td>5</td><td>10</td><td>5</td></tr>
</table>

4. Results and Discussions

The present study emphasized the importance of groundwater potential zonation at the regional level by using simple yet reliable GIS-based procedures. Groundwater potential zonation maps of Pakistan were created by using weighted overlay analysis, fuzzy logic, and AHP analysis in ArcGIS. Some of the weighted overlay analyses were run by giving different weights to different parameters, along with the equally weighted overlay, in which the same weight was given to all layers, as shown in Run 1. In weighted overlay, sensitivity analysis was performed in which different weights were assigned to each layer. The results of the sensitivity analysis are shown from Run 2 to Run 6. Moreover, in the AHP analysis, firstly, we added all 10 layers in the AHP priority calculator, and we got 45 combinations. Then we rated those combinations based on our judgement, keeping in mind various views and logic and calculating separate priorities for all layers. The consistency ratio turned out to be 0.085, which indicated it was good because it should be less than 0.1.

4.1 Equally Weighted overlay Analysis

In this combination (equally weighed), shown in figure 13, the dark blue region shows areas with very shallow water levels with an equally weighted overlay. Similarly, the brownish color represents areas with deep groundwater. It turned out that in an equally weighted overlay, much of the region lied in a shallow groundwater zone. This could indicate the impact of land use (population, industry) and impermeable soil in those regions.

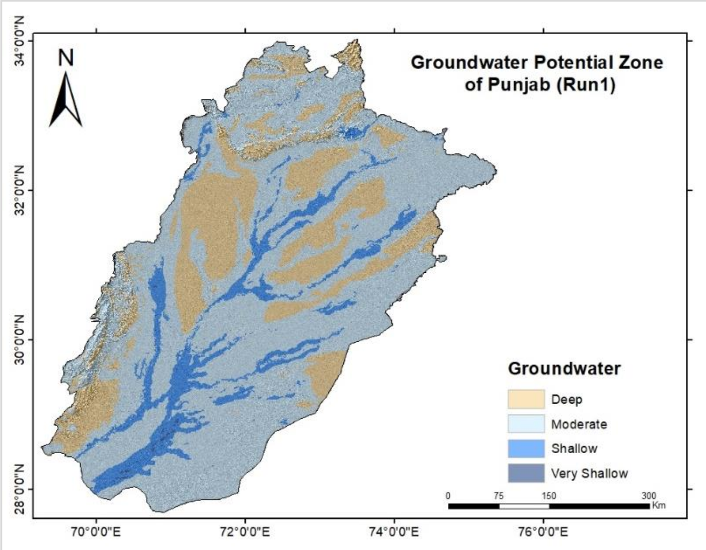

Fig. 13. Result of equally weighted overlay analysis.

4.2 Weighted Overlay Analysis using Combination 1

In combination 1, shown in figure 14, we can see in that map suitable areas, i.e., the areas in blue color, indicating the reason for the correct weight assigned to certain layers. Most of the areas shown in the analyzed map indicate a moderate depth for groundwater.

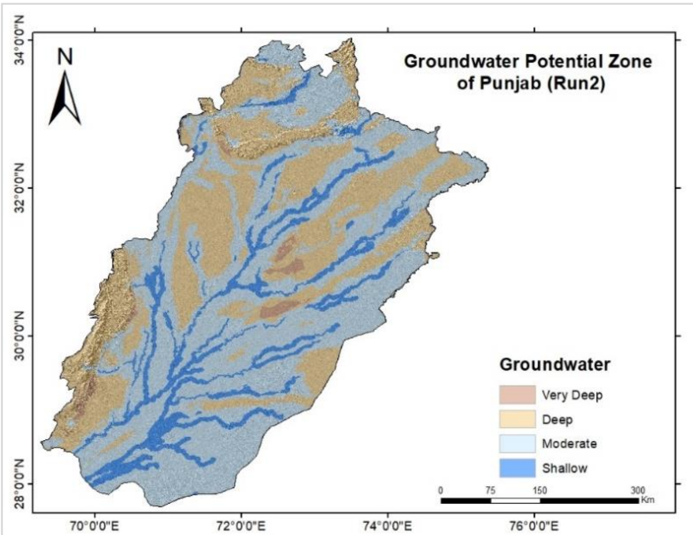

Fig. 14. Result of sensitivity analysis by applying weighted overlay analysis using combination 1.

4.3 Weighted Overlay Analysis using Combination 2

Observing figure 15, the dark blue color is increased concerning the other two analyses above. This indicates the influence of the layers given maximum weightage, indicating that permeability, rainfall, and distance to waterbodies are major parameters.

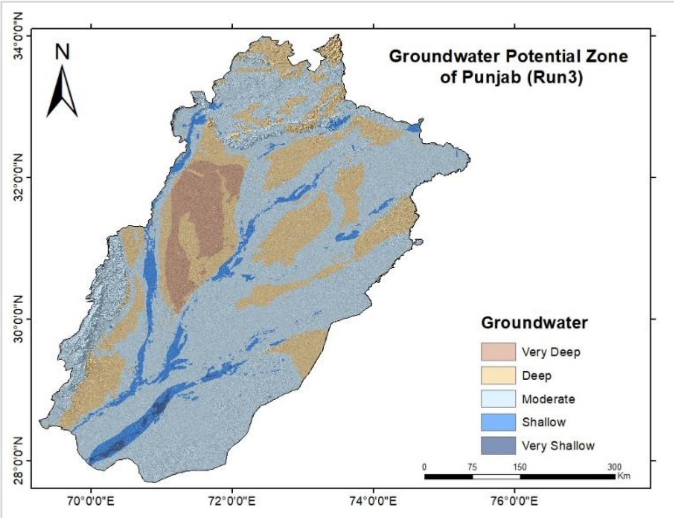

Fig. 15. Result of sensitivity analysis by applying weighted overlay analysis using combination 2.

4.4 Weighted Overlay Analysis using Combination 3

The analysis of this combination shown in figure 16 reveals that the dark blue zone is reduced again as compared to the previous combination, indicating that it is less suitable than the previous run. The major regions remain moderate, with an almost negligible rate of very deep groundwater.

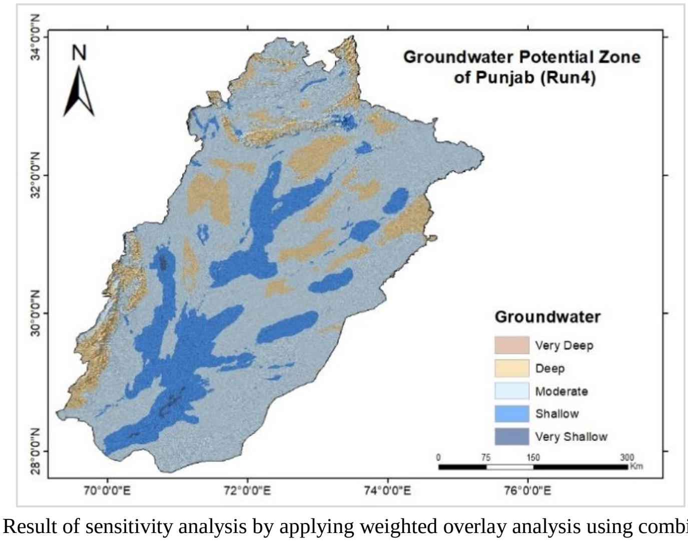

Fig. 16. Result of sensitivity analysis by applying weighted overlay analysis using combination 3.

4.5 Weighted Overlay Analysis using Combination 4

Figure 17 shows that the dark blue region also dominates but, to some extent, is less favourable than combination 3. One reason is that the rainfall in the deserted areas is sandy. The soil is permeable, but there is less rainfall. The brownish region also dominates the western belt, indicating greater depth, but this was not the case in previous analyses. This is due to the lower percentage given to the slope. Figure 18 showed the moderate zone of Groundwater mostly.

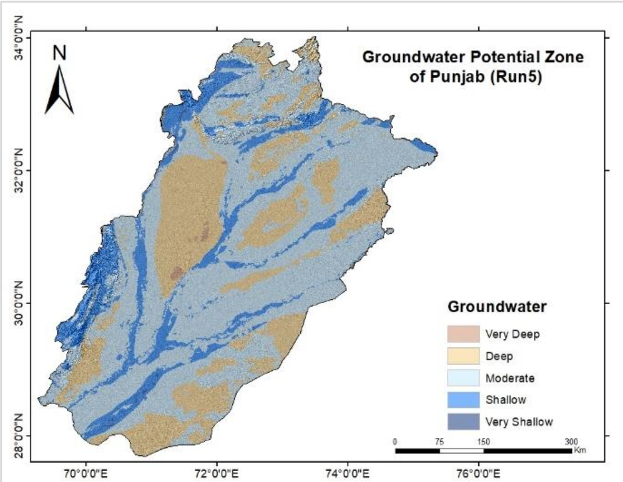

Fig. 17. Result of sensitivity analysis by applying weighted overlay analysis using combination 4.

4.6 Weighted Overlay Analysis using Combination 5

Following are percentages of Groundwater in Weighted Overlay Analysis shown in table 2.

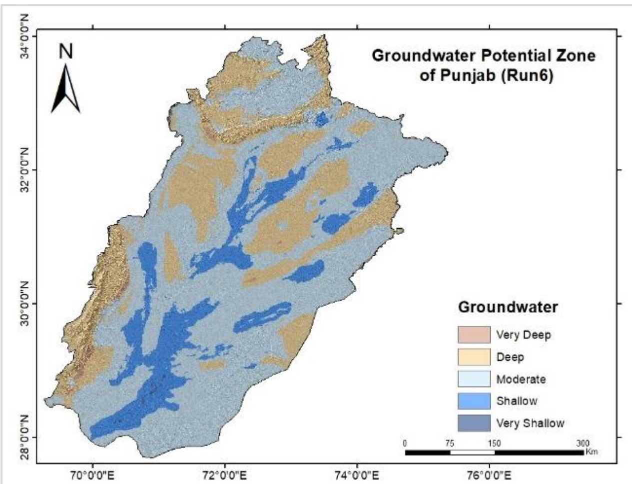

Fig.18. Result of sensitivity analysis by applying weighted overlay analysis using combination 5.

Table 2. Percentages of groundwater in weighted overlay analysis.

Groundwater	Percentages					
	Run1	**Run2**	**Run3**	**Run4**	**Run5**	**Run6**
Very Deep	0%	12.91%	12.53%	0.05%	5.96%	12.56%
Deep	54.84%	31.03%	51.34%	34.03%	51.24%	50.87%
Moderate	14.80%	45.87%	13.60%	15.44%	10.96%	10.21%
Shallow	23.82%	10.28%	13.17%	43.77%	28.83%	24.72%
Very Shallow	2.92%	0%	9.34%	6.64%	3.00%	1.60%

4.7 Fuzzy Logic analysis

In fuzzy logic analysis, first we created fuzzy memberships for every layer using the Spatial Analyst tools > Overlay > Fuzzy Membership. The membership used in this analysis was a Gaussian membership. After getting the membership type of all 10 values, we used the Gamma overlay type using a fuzzy overlay with a standard value of 0.9. The classification of depth follows the rules: >.56 (very deep), 0.56-0.62 (deep), 0.62-0.68 (moderate), 0.68-0.74 (shallow) and <0.74 (very shallow).

The map by fuzzy logic (figure 19) indicates that it is dominated by dark blue regions that contain groundwater in lower depths. Most of eastern Punjab is covered in these regions. The regions coinciding with Sindh and Baluchistan, which are lower western Punjab and southern Punjab, excluding the areas near the Indus River, are found to have groundwater at greater depths.

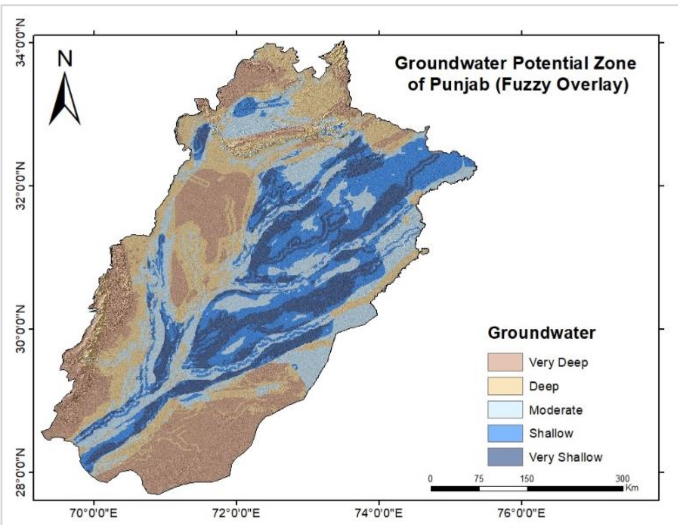

Fig. 19. Result of fuzzy overlay analysis for groundwater zonation of study area.

4.8 AHP analysis

In the AHP analysis, first, we added all 10 layers in the AHP priority calculator, and we got 45 combinations. Then we rated those combinations on our judgment keeping in view various views and logic and calculating separate priorities of all layers. The consistency ratio turned out to be 0.085 which indicated it is good because it should be less than 0.1. The classification ranges for AHP are: 4.35 (very deep), 4.35-5.2 (deep), 5.2-6.05 (moderate), 6.05-6.95 (shallow), and <6.35 (very shallow) shown in figure 20Fig. .

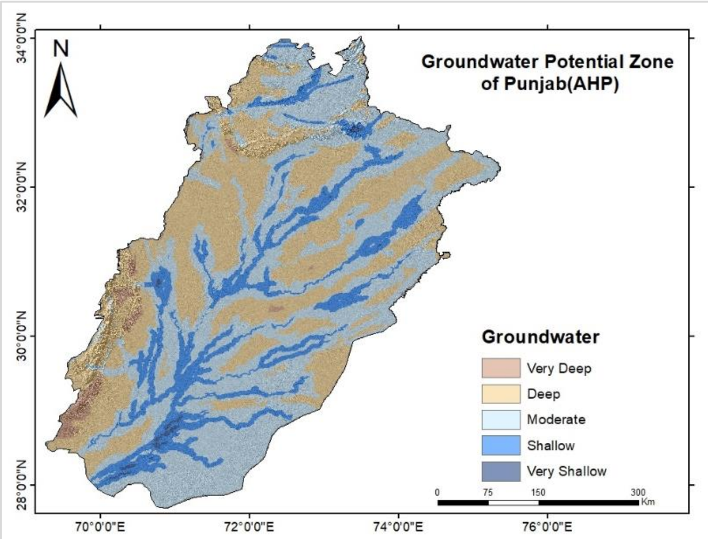

Fig. 20. Result of AHP analysis for groundwater zonation of study area.

After all the results from the three analytical methods, we compared the three methods to check for relevance (figure 21) and percentage groundwater is shown in Table 3.

Table 3. Comparison of all the analyses done for groundwater potential zonation.

Groundwater	Percentage		
	Weighted Overlay	**Fuzzy Overlay**	**AHP**
Very Deep	0%	24.08%	18.30%
Deep	54.84%	22.27%	14.45%
Moderate	14.80%	22.19%	26.78%
Shallow	23.82%	17.39%	37.48%
Very Shallow	2.92%	14.06%	3%

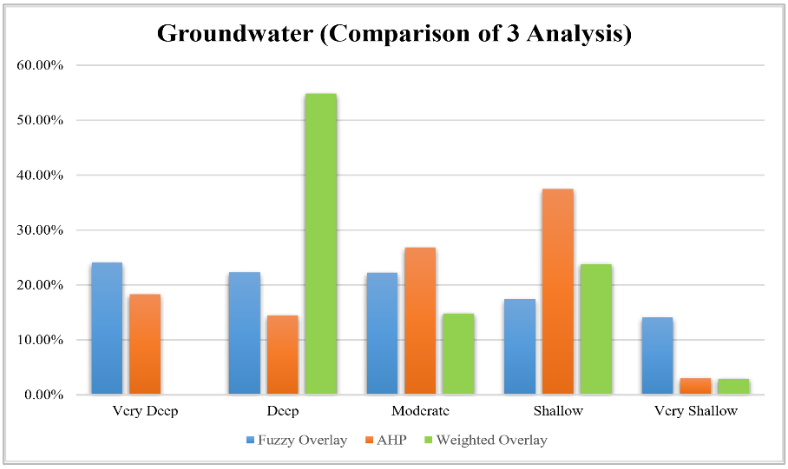

Fig. 21. Comparison of results of all the three analyses showing in bar chart.

5. Validation

After performing all the analyses and getting resultant maps, these maps were validated in figure 22 by gathering original groundwater data from all regions of Punjab. The gathered data points were then shown on maps to check for authenticity. These data points are collected from household well pumps. After showing the household well pumps on the map, the maps are validated by the actual depth of groundwater. The actual depth indicators of groundwater, acquired from WASA, are 0–15.24 meters (very shallow), 15.24–30.48 meters (shallow), 30.48–91.44 meters (moderate), 91.44–152.4 meters (deep), and >152.4 meters (very deep). The validated and interpreted maps were then spatially and qualitatively analyzed to look for authenticity, which turned out to be 70%. After validation, the most feasible method was found, which turned out to be AHP analysis, which coincided greatly with the validated map through spatial analysis.

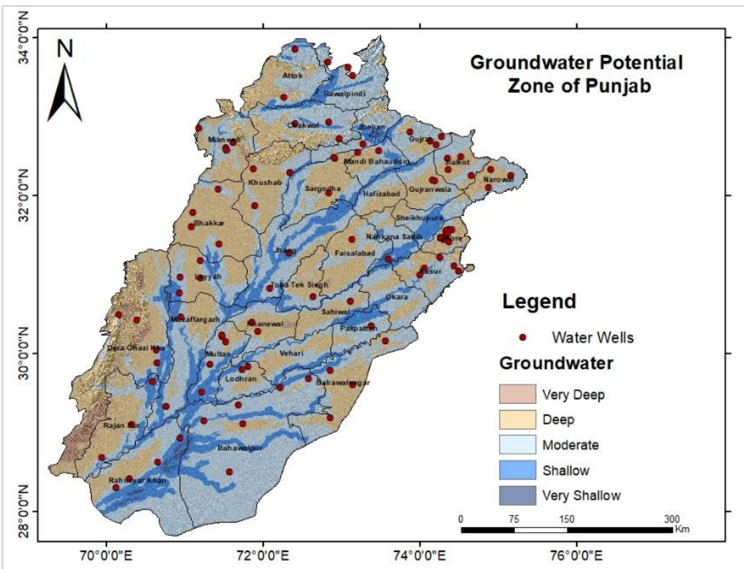

Fig. 22. Groundwater potential zonation of Punjab Province.

6. Conclusion

The GIS-based groundwater potential zonation maps could be helpful in regional-level studies. Three methods, named weighted overlay analysis, fuzzy logic analysis, and AHP analysis, were performed. Different results were obtained from different techniques. In an equally weighted overlay analysis, most regions of Punjab fell under the shallow and deep groundwater potential zones. The 2.29% of the regions lied in the very shallow zone, 23.82% in the shallow zone, 14% in the moderate zone, 54.84% in the deep zone, and 0% in the very deep zone. Talking about fuzzy logic analysis, 14.06% of the regions were in the very shallow zone, 17.39% in the shallow zone, 22.19% in the moderate zone, 22.27% in the deep zone, and 24.08% in the very deep zone. In AHP analysis, 3% of the regions lied in the very shallow zone, 38% in the shallow zone, 27% in the moderate zone, 14% in the deep zone, and 18% in the very deep zone. The validated and interpreted maps were then spatially analyzed to look for authenticity, which turned out to be 70%. After validation, the most feasible method was found, which turned out to be AHP analysis, which coincided greatly with the validated map through spatial and qualitative analysis. Overall, the regions near the Indus River have high potential for groundwater at shallow depth. The southwestern belt of Punjab has a low potential for groundwater, which particularly includes the districts of DG Khan, Rajanpur, and Layyah. The recharge water wells are suggested to be installed in these regions, which have very low groundwater potential. These maps are intended to serve as “guide maps” to trigger more detailed project-specific analysis of groundwater potential in Punjab province. It is recommended that the detailed study of groundwater potential zones marked by the research result in the most precise and best suitable regions to utilize groundwater for sustenance purposes and to use data with better resolution for more refined results in future studies. The regions that couldn’t be validated can be interpolated or extrapolated keeping in mind the parameters effecting that region and developing a groundwater regulatory framework for optimal groundwater use in different regions.

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