POTENTIAL SITE SELECTION FOR GROUNDWATER RECHARGE USING ADVANCED GEOSPATIAL TECHNIQUES

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ABSTRACT: Freshwater demand is increasing rapidly due to a significant increment in population day by day. Whereas, groundwater resources are depleting at high speed in fulfilling the water needs of different sectors. The world uses 67% of groundwater for agriculture, 22% for domestic and 11 % for the industrial sector Twenty-five percent (25%) of global groundwater withdrawals sustains agricultural productivity in Pakistan, India, Nepal and Bangladesh. Pakistan is the fourth largest user of groundwater among all countries (after India, the USA and China) Punjab is the largest populace province of Pakistan where around 90% of the population is dependent on groundwater to fulfil their domestic, agricultural industrial needs. It has been reported that in many parts of the country ratio of groundwater recharge to discharge is 0.8 which also results in a rapid decline in the water tables country. This study aimed at the assessment of the potential sites for groundwater recharge in Jand tehsil using a geospatial approach. Presently, the study area experiencing the seepage/mixing of wastewater with the groundwater due to poor drainage and sewerage network. Therefore, availability of fresh drinking water becomes a serious challenge in Jand and demands an artificial groundwater recharge system to fulfill the water needs. Several relevant criteria have been incorporated in this research to delineate the potential zones i.e. Drainage Density, Slope, Rainfall, land use/Landcover, Geology, and Soil. To precisely identify the sites, an Analytical Hierarchy Process has been employed to calculate the weight of each criterion. Subsequently, each factor is multiplied by its respective weights to develop the potential site suitability map. Results of the study revealed the three best groundwater recharge sites and classified the suitability of the study region as; high suitable (34%) moderate suitable (35%) and low suitable area around 31%. This research illustrates the strength of Geospatial techniques in proposing the potential ground recharge regions and hence rainwater and groundwater resources can be managed efficiently.

Keywords: Site Selection, Groundwater, Recharge, Geospatial Techniques**,** Pakistan

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INTRODUCTION

Groundwater is the basic and vital source of water supply for all purposes. Globally around 12666 billion cubic meters (BCM) of groundwater is available annually, out of which 986 BCM per year is used in the world today (Villholth et al. 2016). The world uses 67% of groundwater for agriculture, 22% for domestic and 11 % for industrial sector (van der Gun et al. 2012). More than 40% of global food production is produced from groundwater (Foster et al. 2015). One billion farmers in India, China, Bangladesh and Pakistan rely on groundwater for Agriculture (Villholth et al. 2009). Groundwater provides potable water to approximately 2 billion people which is equivalent to 33% of the global population (Villholth et al. 2016). India, China and Pakistan alone account for one-third of global groundwater use (Sharma et al. 2006).In these countries, farmers are pumping groundwater faster than nature is replenishing it, causing a continuous drop in groundwater tables thereby causing depletion of groundwater resources (Bhatti et al. 2015). On a global level, the key issues that need to be addressed to ensure the sustainability of groundwater resources are the depletion of stored groundwater (dropping water levels) and groundwater pollution (Villholth et al. 2016).

Pakistan is the fourth largest user of groundwater among all countries (after India, USA and China). The agriculture sector is the largest consumer of groundwater within Punjab and provides water for approximately one-half of the total crop water requirements (Bhatti et al. 2015; Haq et al. 2010). The harsh environmental conditions are therefore not being optimally exploited in many areas of the Punjab (Abbaspour et al. 2009; Bastani et al. 2010;). Groundwater is a very important water resource in arid and semi-arid areas (Todd et al. 2005; Mukherjee et al. 2012). The majority of the population in the province of Punjab relies on domestic and agricultural usage of groundwater. In Punjab, about 90% of the population is dependent on groundwater for domestic needs (Haq et al. 2010). Punjab has a highly transmissive and unconfined aquifer system. With the rapid increase in population, the water needed for food production, and urban and industrial uses has increased which has resulted in more dependence on groundwater. There were around 20,000 private tube wells in Pakistan in 1960 which was gone up to 1.357 million by 2001 (Agricultural Statistics of Pakistan 2017-18; Yu et al. 2013).

Most of the Punjab area is characterized as semi-arid to arid, natural, and green fields. A potential assessment of groundwater in Pakistan is becoming a major issue due to water shortages. Some techniques exist for assessing the yield of groundwater (Nampak et al. 2014). The approaches used for groundwater investigation using geographical, hydrogeological, and geophysical techniques are generally non-économical (Singh et al. 2003). In a recent analysis, the application of the GIS method saves time and resources (Manap et al. 2014). A well-known method for processing large volumes of spatial data is the GIS technique utilized in water resources management (Rahmati et al. 2014b). Analytical hierarchical process (AHP) technology has been used for groundwater potential mapping in several studies (Jha et al. 2010; Rahmati et al. 2014a). Modern computational methods are used in mapping the potential of the groundwater, such as numerical modelling (Chenini et al. 2010), artificial neural networks (Lee et al. 2012b), fuzzy logic (Ghayoumian et al; 2007) etc. Since last few decades, Pakistan is facing water scarcity issue as its fresh surface water and groundwater resources are depleting rapidly. Therefore, it’s the need of hour to adopt modern techniques and methods which could help in saving the water resources. In recent times groundwater recharge by rainfall water is widely in practice and proved quite successful in many countries. So far number of researches have been conducted in Pakistan about site selection of groundwater recharge based on conventional and obsolete methods. Theses traditional approaches involve huge resources and time which make the decision making process very complex. In recent times, applications and utilization of geospatial technologies in this domain reported as quite effective and efficient. Therefore, keeping in view the efficacy of geospatial technology, this research aimed at assessing the potential sites for groundwater recharge using multicriteria analysis. Main objective of this study is to map the spatial distribution pattern of each selected criterion across the study region. Furthermore, calculate the relative weightage of each parameter was key component of this study which is done by using Analytical Hierarchy process (AHP). Based on these individual parameters a composite map showing the influence of each parameter is generated which describes the potential of groundwater recharge sites in different regions of the study area.

MATERIAL AND METHODS

Study Area: This research aimed at assessing the competence of the AHP models in the Attock Plain, for groundwater capacity. The study region lying at the northwestern edge of Attock Jand with longitudes 71° - 50’ to 72°-48’ and latitudes 33°-0’ to 33°-56’(Fig. 1). From a Geological point of view, this region is situated in the Attock-Cherat and Kala Chitta Ranges and the Indus Braided Plain (Warwick & Survey, n.d.). The geological system plays an important role in the occurrence of groundwater in the study area. In Jand, groundwater is considered unconfined and recharged on the whole surface by infiltrating precipitation and streams that flow into the underground system. The larger portion of the population living in rural areas of the study region depends on dairy and crops. In Jand, groundwater is the major source being used for drinking purposes (Tahir 2011). Agricultural and residential cover the major portion of land uses within this plain. The study area experiences a 43°C average mean daily temperature in summer, while the average minimum daily temperature in winter is 1°C.

Data and its Sources: In the present study, a potential zone for the recharging of groundwater is characterized by the use of Remote sensing and GIS tools. Datasets being used for this research include advanced earth observation satellite imagery of ALOS, Digital Elevation Model (DEM), precipitations, soil map, slope, geological maps and watercourses.

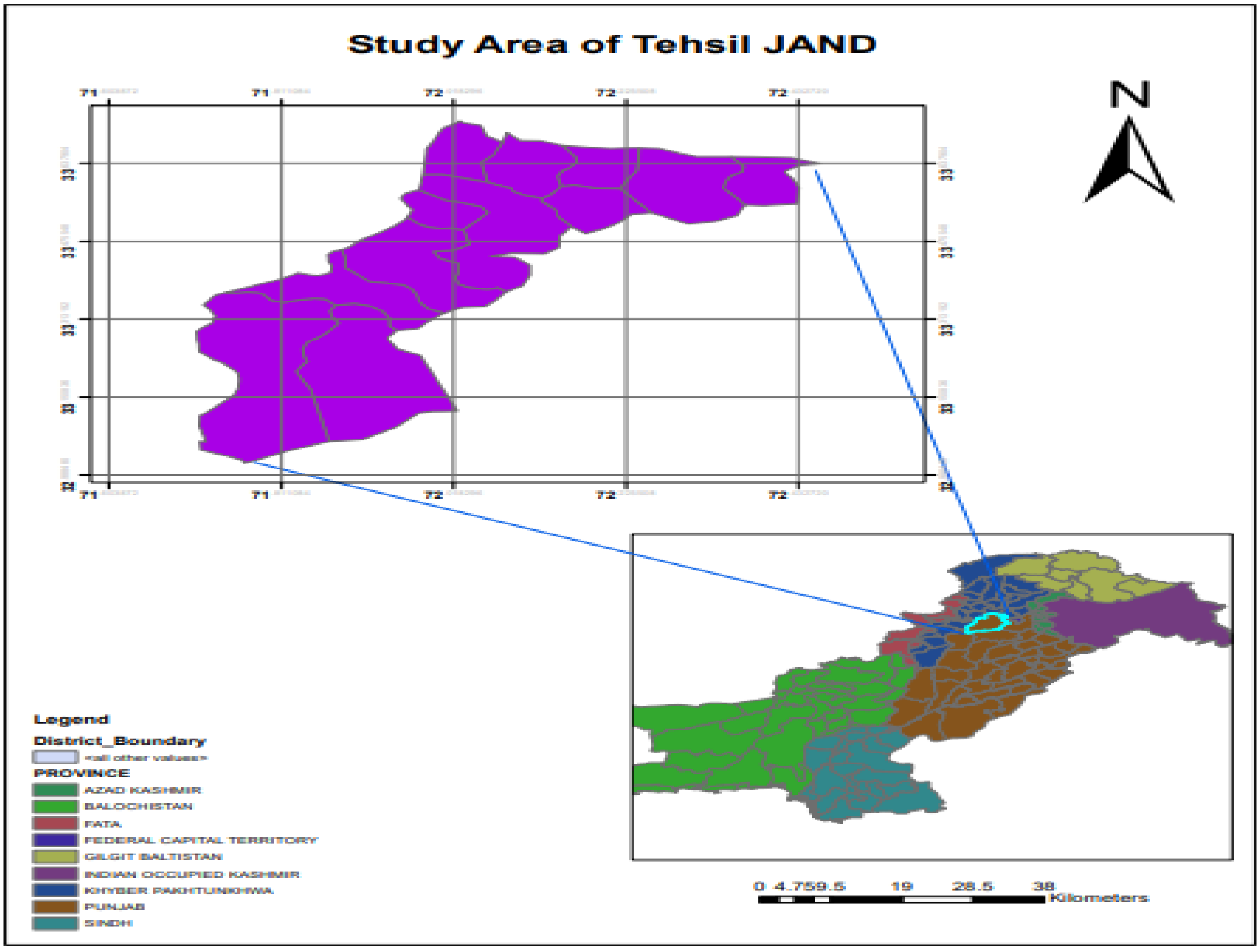

Figure 1: Location Map of the Study Area

METHODOLOGY

The adopted methodology is a mixture of the Analytical Hierarchy-Analysis (AHP) process and it was practical to bring a final product with a Weighted-Sum-Overlay. The groundwater potential mapping consists of three main steps; i) spatial database construction (conditioning factors related to land groundwater potential), ii) analysis of relationships between hydrogeology infiltration (with high productivity) and iii) groundwater conditioning factors in this investigation, AHP technique was used to map groundwater potential in Punjab, Pakistan on the Attock (Jand) plain. Data in the field of analysis varies according to the number of conditions. A conditioning factor was chosen for six thematic layers, including rainfall, slope, drainage density, geology, soil, and land cover. These conditioning factors provide a reliable database for an accurate forecast of the study area in the GIS environment. Precipitation is one of the key hydrological elements and was seen as an important recharge source (Magesh et al. 2012; Shekhar and Pandey 2014). Adiat et al. (2012) demonstrated the important impact of rainfall on percolation and GWPM precision. Monthly rainfall data have been collected from the USGS database for a period of 35 years (1981–2015). Precipitation spatial distribution mapping consists of four main classes; 221 to 341, 342 to 460, 461 to 579, and 580 to 700 mm/year (Figure 2a). According to this map, the average annual rainfall is comparatively higher in the northern areas than in the south.

The height and pitch angle were taken as surface indicators for evaluating the potential of soil water (Ettazarini 2007; Al Saud 2010). Climate changes in different altitudes have caused differences in soil and vegetation types (Aniya 1985). To map the slope in the study area, the Digital Elevation Model of 30m resolution has been processed. Previous studies have shown that the pitch angle largely controls the soil recruitment process (Prasad et al. 2008) and that it is therefore an effective factor in groundwater potential spatial prediction. The slope angle map was grouped into five classes according to the quantile classification scheme (Tehrany et al. 2014) (Figure 2b). After classification and standardization of the slope parameter, the drainage system of one environment is characterized by the geological formation (bedrock), soil, rainfall capacities, type of vegetation, infiltration rate, and slope angles (Manap et al. 2014). The drainage density is considered to have reduced infiltration and increased surface runoff due to the proximity of the distance between the stream channels (Magesh et al. 2012). This means that the drainage density is an inversely permeable function; areas that have a high drainage density aren't suitable for developing groundwater (Dinesh Kumar et al. 2007). The Line Density tool in ArcGIS 10.2 has been used to evaluate the drainage density of the study area. The amount of drainage density is identified by the ratio of the sum of stream lengths to the size of the area of the grid which is considered by Adiat et al. (2012) and Mogaji et al. (2014). In the study area, a mesh network of 10 km^2 with a fishnet tool in a GIS environment has been created according to the calculated drainage density of the study area (Rahmati et al. 2014a).

$$Dd = \sum^{i=n}{}_{i=1\ Di/\ A\ Km/km^2}$$

Wherever altoDi is the total of the stream lengths of the mesh I (km and A is the grid area (km2). The drainage density spatial distribution behavior in the study area has been divided into five classes (Fig. 2c) which shows that the central area of the study contains high drainage densities. Moreover, south-east and south-west regions depict high values of drainage density.

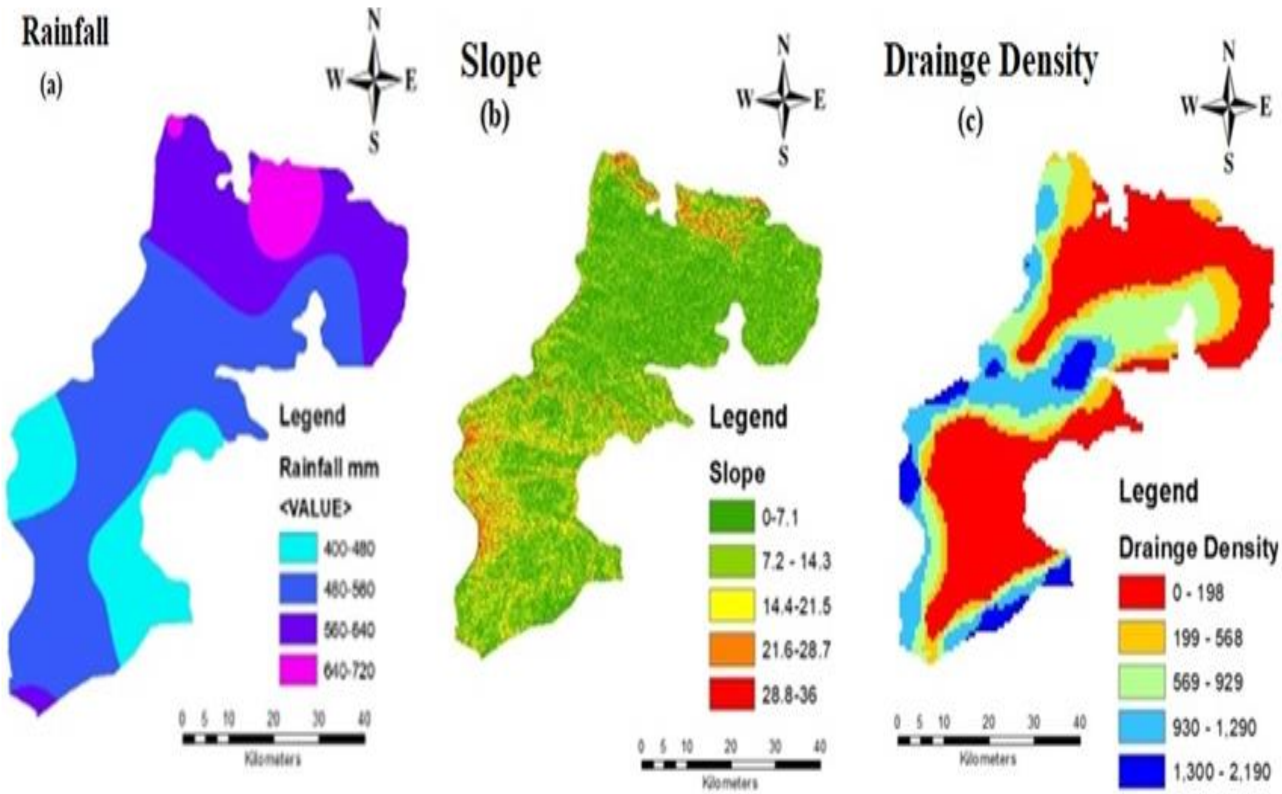

Figure 2: Spatial Distribution of Rainfall Pattern, Slope and Drainage Density

Soil type is very crucial and plays a fundamental part in aquifer materials (Ayazi et al. 2010; Chowdhury et al. 2010). This research consists of the compilation of the soil map (1:100,000-scale) and the related reports from the Pakistan Soil Survey and the soil map was classified into 6 groups (Fig. 3a). The Characterize of geology plays a fundamental part in aquifer materials (Ayazi et al. 2010; Chowdhury et al. 2010). The study consists of the compilation of the geological map (1:100,000-scale) and the related reports from the Geological Survey of Pakistan. All of this secondary data were rectified and digitized and consequently, the geological map was classified into 3 groups (Fig. 3b). Afterwards, landuse landcover which is very crucial in groundwater recharge prepared by using the object-based Image Analysis (OBIA) Existing Landcover is treated by the relevant terrestrial type for recharge potential zoning hence uppermost rank. Finally, the Land cover map was classified into 5 groups as shown in Fig. 3c. Lastly, to determine the weight of each selected parameter, a globally recognized Analytical Hierarchy Process (AHP) based paired comparison matrix was developed. The developed matrix resulted in a value of 0.086 for the consistency ratio which is within the permissible limit and indicates that comparisons made in the matrix are consistent.

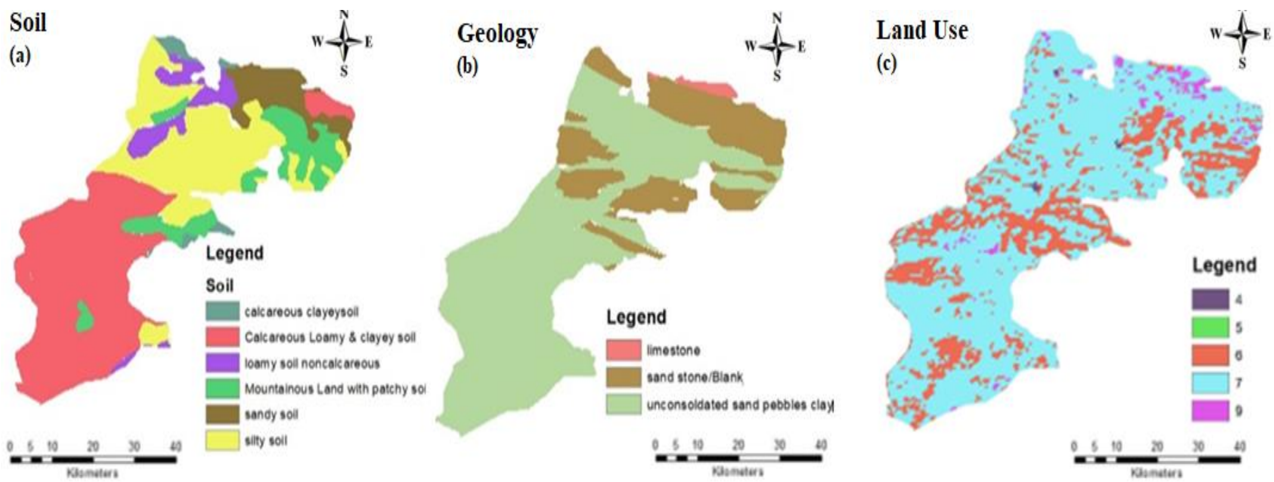

Figure 3: Spatial Distribution of Soil Pattern, Geology and Landuse

RESULT AND DISCUSSION

All of the mapped factors were reclassified and ranked from low to high suitability classes as per their characteristics. Figure 4 represents the spatial distribution pattern of suitability for the precipitation, slope and drainage density parameters across the study area. Northern parts of the region experienced more than 550mm up to 720mm mean average rainfall across the year and ranked with 6 and 7 scores respectively. In the case of slope, higher slopes cause high runoff and result in less groundwater recharge and vice versa.

Therefore, some regions in the north and mostly in the southwest are resulted with slopes up to 36 degrees and have been ranked with less suitability scores i.e. 2 and 3. Whereas, the north-east and major middle portions of the study having less slope ranked with high suitability scores. In the study area, high drainage density was observed in the south-east, south-west with some pockets in middle regions ranked with high suitability scores, while almost all northern regions were assigned with the lowest score due to poor drainage density.

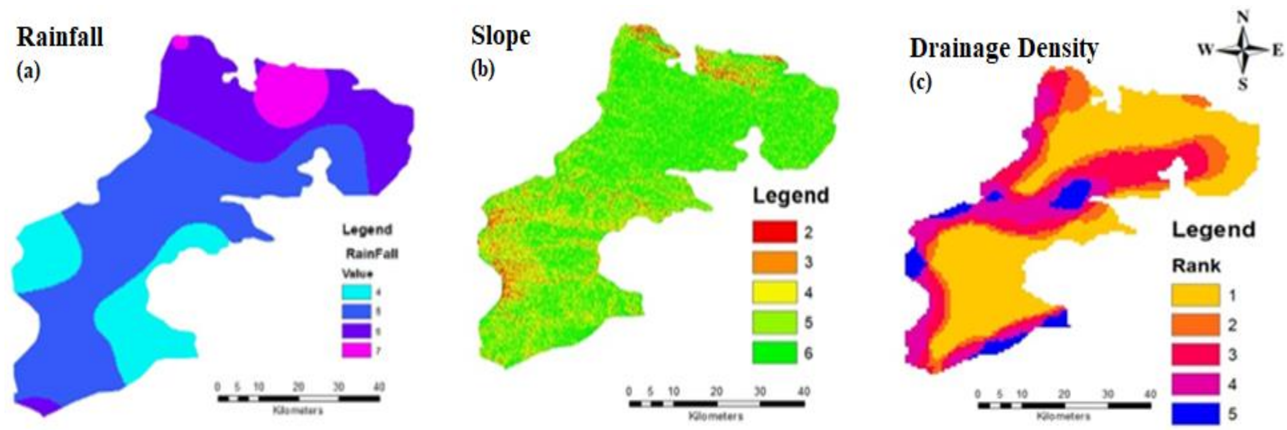

Figure 4: Suitability Status of Rainfall, Slope and Drainage Density

Figure 5 illustrates the suitability status of soil, geology and land use land cover. Silty and Sand soil covering an area of 11 and 14 per cent of the study area ranked with the highest scores 5 and 6 respectively due to their nature of high permeability. Whereas, Calcareous Loamy Clayey Soil covering 41% region ranked with the lowest score due to its permeability nature. In the scenario of geology, 72 & of the region is comprised of unconsolidated sand rocks ranked with the highest score of 5 due to its favorable nature in groundwater recharge.

Whereas northern parts of the study area are mostly covered with limestone and sandstone were ranked with less score. For the land use land cover factor, the built-up area covering almost 12% of the study region ranked with the lowest score, whereas agriculture/mixed class covers around 78% area was assigned with a high score.

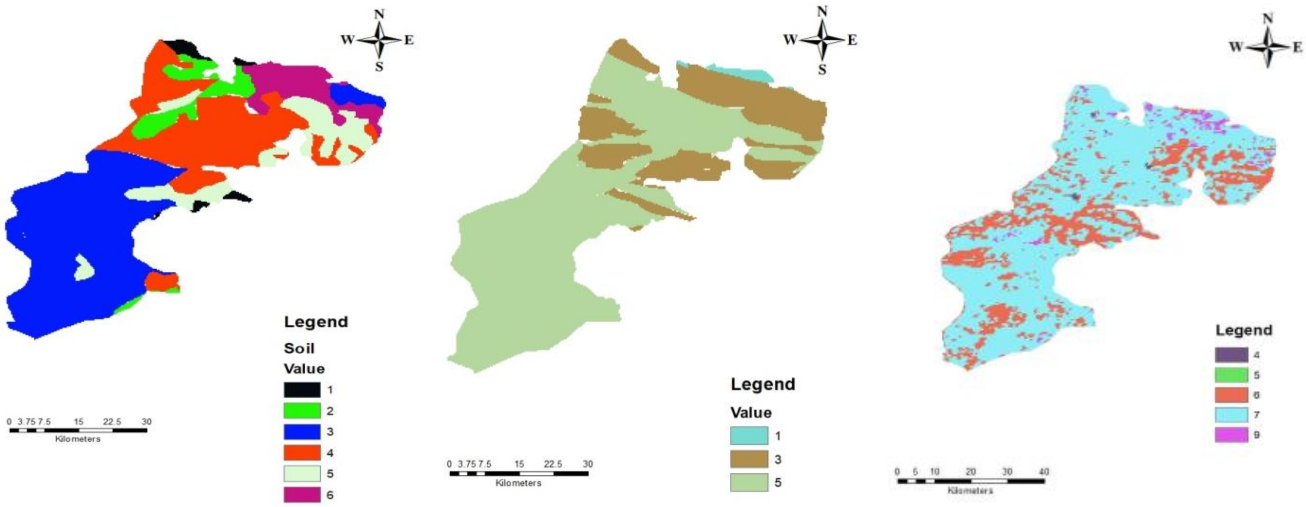

Figure 5: Suitability Status of Soil, Geology and Landuse

AHP Matrix resulted in Rainfall, land use, and Soil parameters with relatively high importance followed by slope, drainage density and Geology. Furthermore, intra-class ranking was performed and each factor was overlaid and multiplied by their respective weights by using weighted overlay analysis (Table 1).

The output map represents the spatial behaviour of groundwater recharge by incorporating the influence of each factor in the final composite map. The resultant map shows high suitability observed in northern regions, especially in north-east parts with around 34% area, however moderate suitable area with 35% is mainly found in the middle and along the southern border of the study area. Whereas, from above this borderline in the southern region, the less suitable area witnessed extends to the middle of the study area (Figure 6).

Table 1: Inter and Intra class ranking of criteria

Factors	Class	Ranking Within Criteria	Area Km2	Area (%)	Score (%)
Geology	Unconsolidated pebbles	5	1592.4	76.506	11
	Sand Stone	4	384.03	18.44	
	Limestone	3	95	4.569	
Soil	Calcareous Clayey Soil	1	42.75	1.9	18
	Calcareous Loamy Clayey Soil	2	927.8	41	
	Non-Calcareous Loamy Soil	3	76.5	3.4	
Rainfall	400-480	1	168.46	7.4	21
	481-560	2	908.98	39.9	
	561 - 640	3	1104.73	48.5	
	641 - 720	4	96.08	4.2	
Land use/ Land cover	Urban Built-up	1	69.988	3.36	21
	Unclassified	2	32.324	1.55	
	Non-vegetated	3	287.399	13.81	
	Forest	4	111.035	5.33	
	Agriculture Land	5	1580.88	75.94	
Slope (%)	0 - 7.1	6	1356.28	59.71	15
	7.2 – 14. 3	5	631.45	27.8	
	14.4 - 21. 5	4	192.4	8.47	
	21.6 - 28.7	3	64.08	2.82	
	28.8 - 36.00	2	27.32	1.2	
Drainage Density	0-198	1	1111.09	48.9	14
	199-568	2	310.83	13.68	
	569-929	3	411.83	18.12	
	930-1290	4	317.07	13.95	
	1291-2190	5	121.29	5.34	

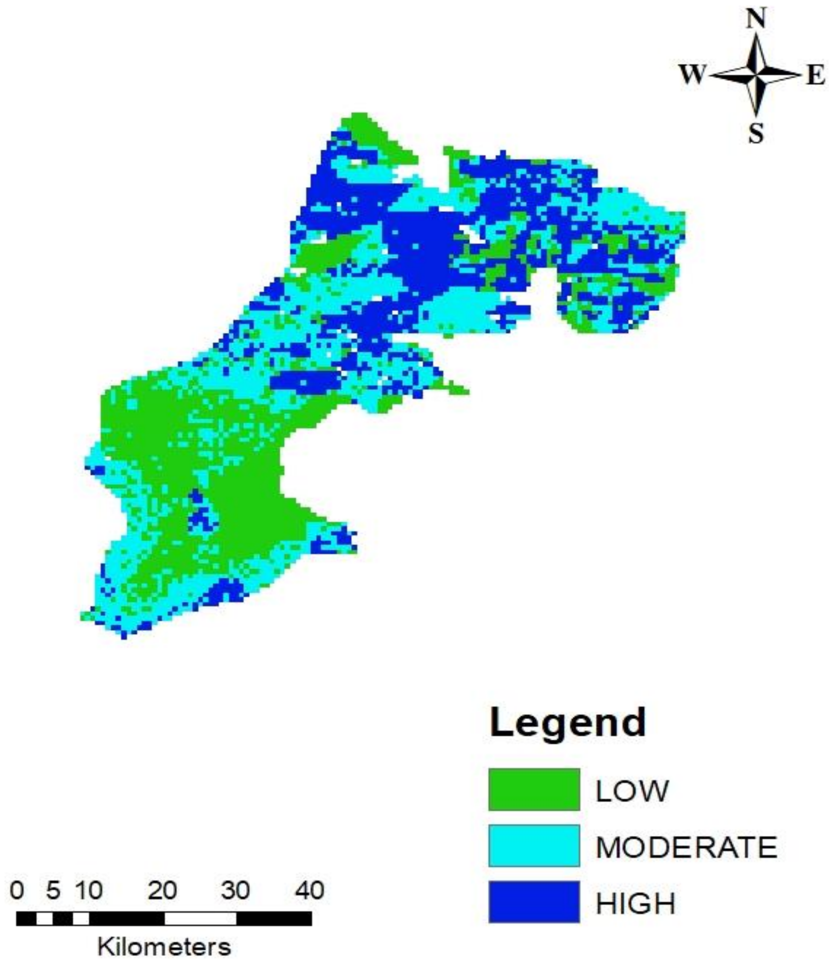

Figure 6: Groundwater Potential Map

Conclusion: Assessing the potential of groundwater has become an important element for land-use development and implementation authorities, and in the past, many approaches were used. For this analysis, the AHP approach has been used to develop groundwater potential maps. First, groundwater conditioning factors were developed using input layers (slope angle, soil map, geology map, rainfall, drainage density, and land cover). GWPMs were developed from the map index calculated using the AHP model and the results were presented in GIS using the above conditioning factors. The results showed that the potential of soil water is largely controlled by slope angle, soil map, geological map, precipitation, drying rate, and soil cover factors. In conclusion, the results of this study have demonstrated that the AHP model can successfully be used in three areas for the mapping of groundwater potential. This can therefore be useful to associated agencies because of the potential map. To conclude, the results of this study revealed that the AHP model may efficiently be used in the three areas of the mapping of groundwater potential. For related agencies in Punjab, the result of the groundwater mapping may also be helpful for a detailed assessment of groundwater development and the management of water supplies for long-term planning. This research is critical in today's age for quickly identifying the potential for groundwater resources in the region. Modern models are simultaneously dominant and capable of exploring potential mapping of groundwater resources. Identification of groundwater potentials is quite significant for decision-making in groundwater resource management and identification of areas vulnerable to the potential management of land resources.

Conflict of Interest: There is no conflict between authors and co-authors.

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