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Assessment of Groundwater Potential in District Chakwal, Punjab: A GIS and Remote Sensing Perspective

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Abstract. The existing fresh water resources are insufficient to fulfill the water requirements for different uses such as drinking, agriculture irrigation and for industrialization purposes. Present study carried out for the identification of groundwater potential zones by using Geographical Information System and Remote Sensing Techniques in the district Chakwal, a water scarce area lying in the Pothohar region of Punjab province, Pakistan. The land-use/land cover, geology, rainfall, drainage density and slope data have been incorporated to identify groundwater potential zones. Freely available landsat satellite data for landuse/landcover classification and Digital Elevation Model (DEM) for the extraction of slope, drainage network have been used. However, available geological maps for the study area were incorporated as an input raster layers in analyses. Weighted Overlay analyses were performed to produce the resultant map showing the spatial distribution pattern of ground water potential. Results showed the water potential zones as; (i) unsuitable area=2756 sq.km, (ii) moderately suitable area=3256 sq.km and (iii) suitable land=3256 sq.km. North side of the district shows better water potential in comparison to the south of study area. This can be due to hard rocks in the south of study area causing inference in ground water recharge. The present highlights the usefulness of processed remote sensing satellite data and GIS techniques used for the production of ground water potential zone map.

Keywords: geographical information system (GIS), remote sensing, landuse landcover (LULC), groundwater, water quality, spatial data integration, weighted overlay

Introduction

Water is an important component for the living as 3% freshwater is available out of overall water on the earth (Azizullah *et al*., 2011). Only 0.01% of this is accessible for the daily use of humans (Hinrichsen and Tacio, 2002). World Health Organization (WHO) estimated 1.7 million deaths and 54.2 million disabilities due to unsafe water. The currently available water is insufficient to fulfill all the human needs like drinking, irrigation and farming. It is estimated that groundwater contributes 30.1% to the world fresh water. In 100% of the earth's water 97% is saline water which cannot be used for domestic and drinking reasons and remaining 3% is characterized as fresh water. In available fresh water, 68.7% is preserved in the form of ice sheets and glaciers (Baker *et al*., 2016). In Pakistan, the importance of water is exceeding due to the agricultural nature of the economy. Overall, 90% water refund is used for the agricultural sector, with more than 25% increase in the country's overall GDP and a population of 45% get jobs (WHO and UNICEF, 2012). It has been observed that the water demand in Pakistan will increase as the population will rise upto 348 million by 2050 which is now on 194 million (Population Reference Bureau, 2014). On the other hand, the rate of precipitation is less than the evapouation rate in the country. It causes a constant decrease in the amount of water in its rivers, lakes and ground water (Azizullah *et al*., 2010). Nowadays, Pakistan is examined under the stressed condition as the water resources are not satisfactory (Aquastat- FAO, 2012). Earlier in 2035, it is considered that Pakistan will be declared as water "scarce" state (Population Reference Bureau, 2014).

Groundwater potential is the word describes the amount of water existing in an area and is a function of numerous hydrological and hydrogeological elements. The point of view of hydrogeological investigation, the period can also be described as a groundwater opportunity in a definite area. Although a lot of fresh water is available on earth, but it is not appropriate for all uses (Al-Abadi and Al-Shamma'a, 2014). GIS and RS techniques are commonly used for the management of natural resources (Krishna *et al*., 2011; Magesh *et al*., 2011; Dar *et al*., 2010). These techniques are very effective for the

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demarcation of potential ground water area. The extensive use of satellite data in integration with the conventional maps and ground data has made it easier to give basic and key information for potential ground water zone (Sheffield *et al*., 2018) With the passage of time Remote sensing has become an effective tool to measure and monitor the ground water properties, as it can cover the large areas in a short time. Remote sensing data can provide helpful information on rocks, topography, land-use, etc. Ground water potential zone includes faults, routes, soil, rainfall, texture and lithology (Taheri *et al*., 2015; Kumar and Shankar, 2014; Singh, 2014).

In last few years, a number of techniques have been used by various researchers to map site selection for ground water potential zones (Oikonomidis *et al*., 2015). Adeyeye *et al*., (2019) proposed that integration of remote sensing and Geographical Information System (GIS) techniques are very crucial in identification and estimation of ground water potential. Pham *et al*. (2019) explains that groundwater is one of the most significant natural properties in the world and requires state of the art technology to monitor and control it. A geospatial database has been prepared by using ten criteria i.e. aspect, river density, slope, rainfall, lithology, plan curvature, wetness index, soil, and land-use and to prepare the database 34 wells of ground water also included from Vadodara district, India. The results described that Geospatial techniques are quite significant for the ground water potential mapping. Konkul *et al*. (2014) used a similar method for the mapping of hydrogeological features and ground water potential for Huay Sai (Thailand) by using potential surface analysis. Though, GIS and RS are the useful tools in ground water exploration mapping. With the advancement in the technology of space, it is now possible to use RS techniques to estimate surface and ground water over large areas (Behzad *et al*., 2019; Jahan *et al*., 2019; Murmu *et al*., 2019; Shailaja, *et al*., 2019; Elbeih, 2015).

Due to the growing population of in study area (district Chakwal), the local population is facing severe water shortages. As people are more dependent on ground water, the water level is declining, that will cause many problems in the future. Lack of the availability of clean water will not only cause many problems like low yield of crops, less food but will also lead to many diseases. To avoid all these problems, there is a dire need to use the best strategy to identify the ground water potential zones. The purpose of this research is to provide a reliable and cost-effective way to identify ground water potential zones. Advanced geospatial and remote sensing techniques provides an efficient way to meet our goal with the help of freely available data. This will not only save money but also our time. Identification of ground water potential zones on a regional scale with in short time and resources is quite significant. Main objectives of this study are (i) selection and ranking of relevant criteria for water potential assessment (ii) spatial distribution mapping of each individual criteria across the study area (iii) ground-water potential mapping and zonation to categorize the high, medium and low water potential zones.

Martials and Methods

The area selected for our research is district Chakwal. This district is surrounded by Attock and Rawalpindi in the north Khushab in the south and Jhelum in the east and Mianwali in the west (Fig. 1). The total area covered by Chakwal district is 6609 sq. kilometers. It is located on 32.8322° N, 72.6151° E in the north of Punjab province. It has a population of 1.496 million according to the 2017 census of Pakistan. Study region observed most rainfall during the monsoon season is from mid-July to mid-September at the range of 350-500 mm. However, winter rains begin in January and last until early March. The monthly mean temperature ranges between 5.9–38.4 °C. January is the coldest and June is the hottest months of the year. Winter temperatures often drop below zero, usually in December and January (Akram *et al*., 2020).

Remote sensing and GIS techniques have been adopted to meet the objectives of the research. A number of criteria, land-use/landcover, slope, drainage density and

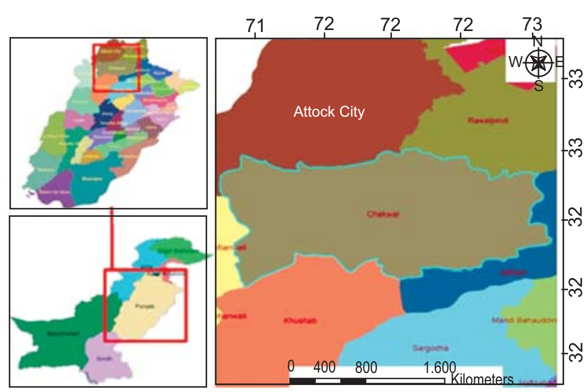

Fig. 1. Study area and location map.

rainfall have been used to iground water potential zones. Landsat 8 imagery is used to perform supervised classification to get land-use/landcover. Digital elevation model (DEM) has been used to evaluate slope and drainage density. Geospatial data differentiate the location of objects on the surface of earth, such as natural or manmade features. Data stored in the form of latitude and longitude and is commonly known as the data that can be mapped. To meet the goal, DEM and landsat imagery obtained from the website USGS. Geological sheets have been collected in hard form and then vector data is prepared from them. Following phases were performed for image classification; i-e (i) Stacking the layers of satellite imagery (ii) connection with the Google earth (iii) signature file for the supervision, (iv) supervised classification. The purpose of this process is to integrate multiple layers of downloaded imagery based on row and column. Afterwards, stacking of bands was performed in order to prepare a composite image for analysis (Fig. 2).

Once the linkage of ERDAS software established with the Google earth, supervise classification was performed as this approach is preferred over non-supervisory method because supervisor may improves accuracy in the process on the basis of defined training samples/ sites. These training samples should also take by conducting the ground survey to enhance the results. (Fig. 3) demonstrates the land use classes extracted in this process.

After classification of LULC, Digital Elevation Model (DEM) was processed to delineate the stream network and catchments existing in study region. Drainage density represents how fine a watershed is drained. The drainage density is calculated by using SRTM (30 meter)

Fig. 2. Image stacking and linking with google earth.

Fig. 3. Landuse landcover classes.

digital elevation model (DEM) by performing watershed analysis (Fig. 4).

Slope is among one of the key variables that directly affects the penetration of rain. In addition, steep slopes recharge less because water moves faster from the ground during the rains, leaving insufficient time to reach the soil and regenerate the saturated area. The slope was also calculated by using this processed DEM. Rainfall criteria was also crucial, while estimating the ground water potential. Rain is an important part of the water cycle and is responsible for collecting most of the fresh water on earth. Rainfall data is collected in raster from and to process the raster data weighted overlay. As all the relevant criteria were prepared and standardized, weighted overly tool was used to overlay

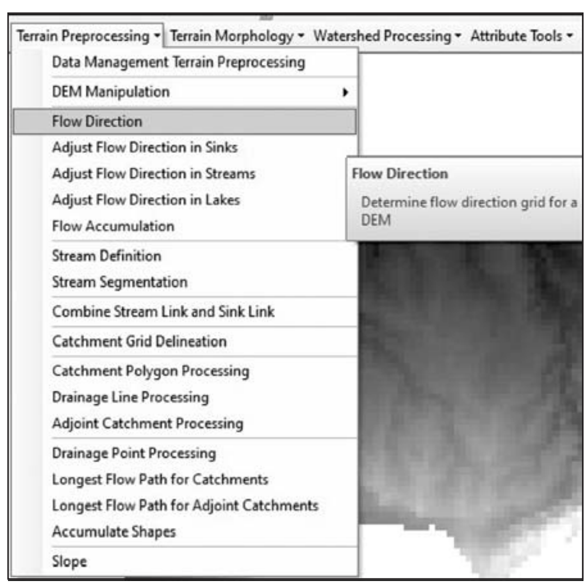

Fig. 4. DEM processing, flow direction.

all the criteria on a common platform by incorporating the weightage of each individual criterion. Weighted overlay analysis resulted with the surface depicting the status of water table potential across the study area. Lastly, secondary data of ground water table for the study region were acquired from NESPAK to verify the results. Data were in excel format which was processed in Arc map and converted in shapefile to examine the spatial patterns. In (Table 1) ground water table points were well spatially distributed across the district and are quite helpful in accuracy assessment.

Table 1. Groundwater table data for results validation

Borehole no	Northing	Easting	Water Level (meters)
E-18	32.99876894	73.12237693	16.64
E-20	32.96326833	72.98718537	18.1
E-27	32.85922967	72.80212469	10.17
S-53	32.85291992	72.57805339	9.66
S-55	32.98199282	72.34477309	9.98
S-57	33.05448029	72.21591014	10.35
S-23	33.10733084	72.88098843	17.16
S-50	33.04087725	72.60881407	19.09
S-53A	32.95408366	72.71236672	17.24
S-57A	32.71896234	71.91722489	19.35
S-58	32.89484956	72.00467851	11.08
E-18A	32.78585928	73.25763211	49
E-21	32.77437896	73.08662134	26
E-23	33.02813172	71.95161629	21.3
E-26	32.67028948	72.76041119	43
E-26A	32.90150529	72.19614937	41
S-40	33.13431078	72.71340182	27
S-41	32.78249544	72.12905954	32
S-40A	32.73427398	72.48004773	48
S-44	32.85155716	73.14614083	44
S-45	32.63960831	72.01423001	45.7
S-45A	32.94463369	72.58456946	40

Results and Discussion

Image classification results revealed the following four major classes in study area are (i) built-up (ii) water bodies, (iii) vegetation and iv) barren land calculated area of each class was as; vegetation (1922 sq.km), water bodies (35 sq.km), built-up (1130 sq.km) and barren land (3837 sq.km) respectively. Results depicting that barren land were found the larger area in comparison to other classes, however vegetation is ranked second highest. North-west of the district Chakwal has been observed with some dense pockets of buildup (Fig. 5).

Figure 6. showed the spatial distribution pattern of slope status across the district Chakwal slope was classified

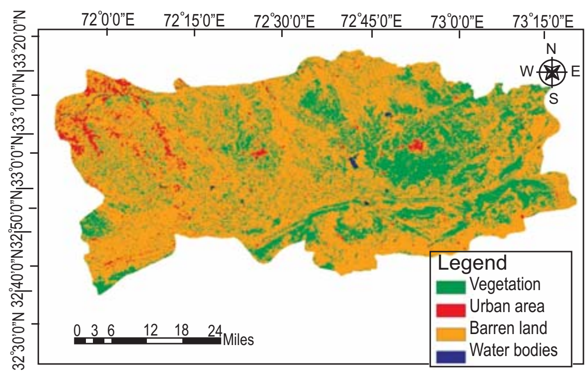

Fig. 5. Landuse landcover classes.

as; moderately suitable and unsuitable based their literature. Figure revealed that more than 70% of the district falls in unsuitable category in terms of ground water recharge / infiltration. However, around 20% are observed with moderate suitability, while less than 3% area with suitability status. Drainage density was one of the most important parameters for hydrology studies. Drainage patterns and densities give a good indication of the hydrogeological features of the region. DEM is processed to get the drainage density parameter. Drainage density was reclassified into three classes, suitable (9), moderately suitable (5), unsuitable shown in (Fig. 7). Results showed that high suitability of drainage density exist in the southern side of the district due to presence of river. Whereas, the entire upper northern region is falls in unsuitable class because of hard rocks existence over there.

The type of rocks and geology greatly affects groundwater availability; some rocks are highly resistant to groundwater fragments and have a significant effect on recharge, while some rocks allow water to charge

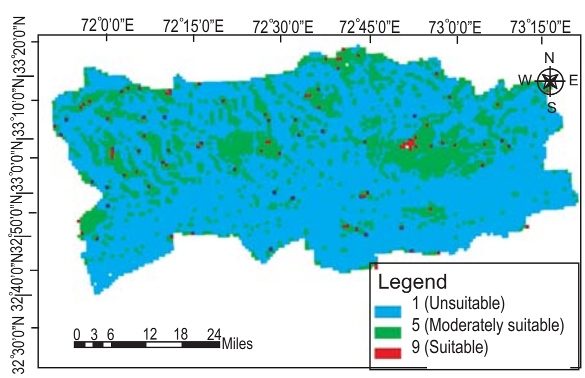

Fig. 6. Suitability map of slope.

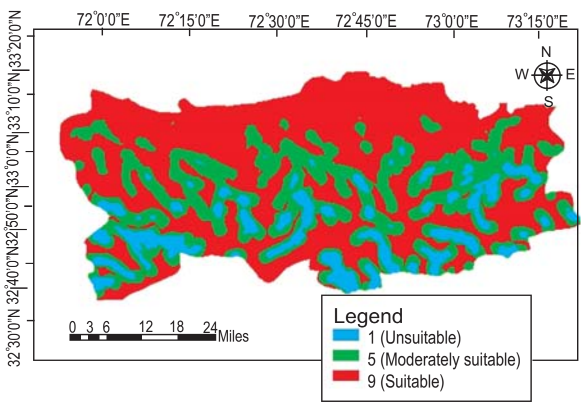

Fig. 7. Drainage density suitability map.

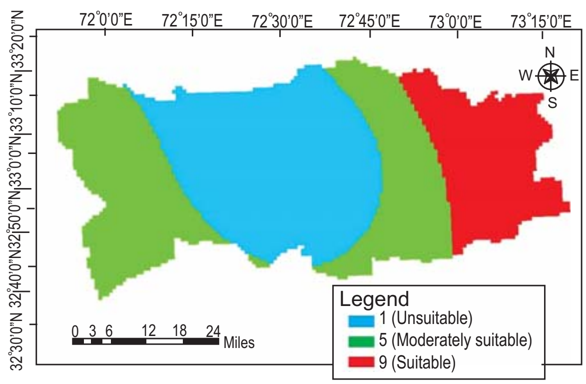

Fig. 9. Rainfall suitability map.

groundwater. Digitized geological sheets were merged with land-use / landcover data and divided the output into three classes (suitable, moderately suitable and unsuitable) based on their role in ground water potential zoning (Fig. 8). High suitability was observed in north-east region along with some segregated pockets in central parts and few in south-west. Average rainfall patterns were also spatially developed in the study region and classified into the same three categories. Low rainfall observed in central part of the region, while east of the study area resulted with high rainfall (Fig. 9).

All the mapped criteria were standardized over same scale and subsequently overlaid based on their relative importance. This analysis equal scale to overlay multiple raster's and assigns weights according to their importance and the output raster is classified into 1 to 9 classes where, 1 represents the unsuitable and 9 represents the highly suitable areas.

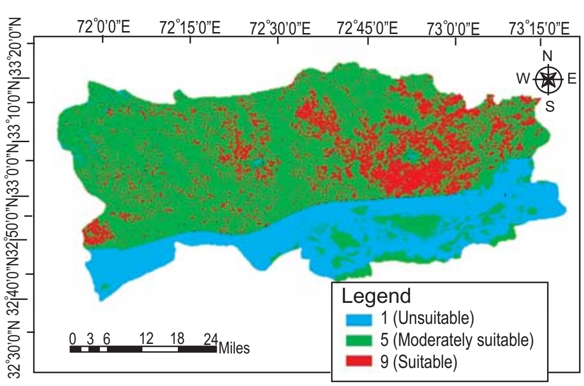

Fig. 8. Land-use/landcover and geology suitability map.

Criteria were assigned weights as; land-use / landcover and geology = 45, drainage density = 25, slope = 10, and rainfall = 20 respectively. The results of weighted overlay resulted with the ground water potential suitability incorporating the influence of each criteria as pert their importance. Suitable area for groundwater potential was observed with the 777 sq.km, however moderately suitable area found 3256 sq.km whereas unsuitable area was 2756 sq.km, Resultant map overlaid with the Google imagery and depicted that localities lying in the southern parts of the study area i.e. Kalar kahar, Munara, Ghool, Katasand Peer da Khara etc. falling in the low potential zone. However, Chakwal city, Begal, Chkral, Dudial localities are lying within the high potential zone of the district. Moderate water potential zones usulally covered northern parts of the study region, encompassing on Patwali, Patalian, Multan Khurd, Talagang, kot gulla loacalities (Fig. 10).

These results revealed that maximum district is falling in low and medium groundwater potential zones. The calculated results were further verified with the secondary water table data obtained from NESPAK in order to assess the accuracy of the adopted technique. After overlaying the water table data, it was observed low potential zone usually having low very low water table. Similarly, medium and high-water potential zones observed with relatively better water depth (Fig. 11).

Conclusions

Results depicted that only 777 sq. km falls under good/high potential region, while 3256 sq. km area is under medium potential zone, and 2756 sq. km area reflecting the low water potential region. Results illustrating that larger area of Chakwal district is lying

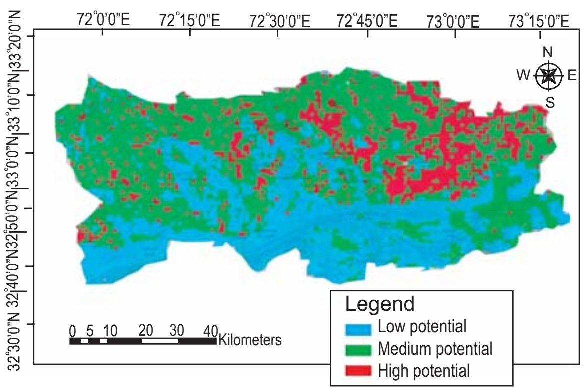

Fig. 10. Groundwater potential map.

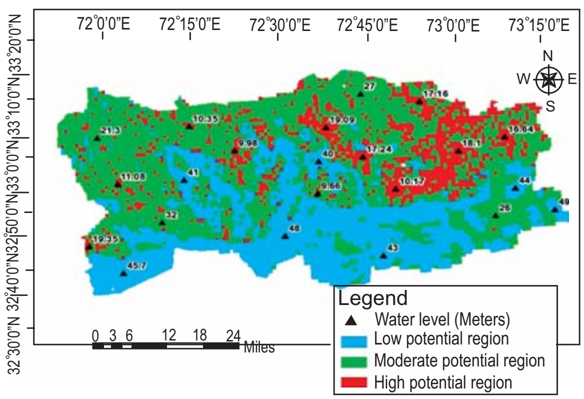

Fig. 11. Validation of the results.

in low water potential zone covering number of localities i.e. Kalar kahar, Munara, Ghool, Katasand Peer da Khara etc, this region is highly composed or comprises on hard rocks causing low infiltration and groundwater recharge. However, north-east parts of the study area found with moderate groundwater potential covering Patwali, Patalian, Multan Khurd, Talagang, kot gulla loacalities, while high ground water potential is observed in Chakwal city, Begal, Chkral, Dudial localities where high deposits of alluvium and soils are found. Furthermore, available groundwater is found at large depth and extraction of this water causes high cost. Due to these groundwater availability issues, agriculture sector in this region is not performing well and farmers are highly dependent of rain to fulfill their crop water needs. This study illustrated the efficacy of advanced Remotes sensing and GIS techniques in assessing the water potential mapping in an effective time and cost-based manner. This research proved the efficacy and significance of remote sensing and geographical information system techniques in mapping ground water potential.

Recommendations

- However, relevant stakeholders and agencies should come forward to conduct such studies by aiding research grants in order to devise concrete strategies which would be helpful in eradicating the water scarcity and efficient use of ground water resources in region.
- More parameters may be included to improve the precision. Though inclusion of number of parameters may increase the processing time and cost to a significant level.
- Precision estimation and data quality is a difficult task. In our study accurate assessment is not probable due to lack of ground information. Current pandemic of COVID-19 restricts the field visit and subsequently validation of the results by primary data. Therefore, accuracy assessment is done by secondary data acquired from NESPAK.

Conflict of Interest. The authors declare no conflict of interest.

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