



Mapping groundwater potential zones in the central part of Indian Punjab

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Abstract

This research work is proposed as a contribution for developing a methodology involving various factors controlling the availability of groundwater resources, keeping in view of choosing the location of drilling in future and increasing chances of taking water more productively, thereby, satisfying the increasing demand of water locally for the people. In the present study, a fence diagram of district Ludhiana in the central part of Indian Punjab has been developed using Rockworks software based on the lithology of 171 boreholes to identify the groundwater bearing zones for future development of groundwater resources which revealed two distinct features viz. sand and clay/heavy soil. Few clay/heavy soil layers were depicted intervening the multiple aquifers while thick sandy beds made the area favorable for groundwater development. The multi parametric data comprising aquifer thickness and its permeability, depth of water levels at different locations, stage of groundwater development, water level elevations and groundwater quality for irrigation purposes was spatially analyzed and integrated on a GIS platform to generate thematic maps. Only 11.6% of area within the district had water table depth less than 10 m i.e. suitable for using horizontal centrifugal pumps. It was inferred that 15.7% and 77.5% area in the district lied in good and moderate groundwater potential zones category respectively, whereas only 6.7% area lied in poor sector, especially in the central part of Ludhiana district. Based upon the analysis, further increase in extraction of groundwater was not recommended in this area.

Keywords: delineation, fence diagram, GIS, groundwater, groundwater potential zones, rockworks, weighted overlay analysis

1. Introduction

Irrigated agriculture in India is largely dependent on groundwater resource. Groundwater- irrigated areas have higher productivity than canal-irrigated areas offering greater control over water supply (Patle *et al.* 2016) [11]. However, during the previous four decades, unchecked withdrawal of groundwater for irrigation in parts of arid and semi-arid regions in India has acutely depleted the aquifers. Punjab has developed its water assets adequately due to the occurrence of green revolution and a mesh of irrigation canals has been laid. But, the state's water resources have been antagonistically influenced due to intensive agriculture. The drop of water table in Indian Punjab has been noticed in more than 80 percent area of the state. The declining rate of water table in Punjab has been observed as 90 cm/year (2000-2005), 75cm/year (2005-2008) and 45 cm/year (2008-2013) mainly due to intensive rice-wheat cropping sequence (Jalota *et al.* 2018) [8].

A paradigm shift from "groundwater development" to "groundwater management" has been noticed in the past two decades in the country. Aquifer mapping plays an important role to understand the sustainability of groundwater development. This would help accomplishing drinking water security, enhanced irrigation facility and sustainability in water resources development in many parts of urban India and in large parts of rural India. Fence diagrams show the 3-D geometry of the various lithologic units. Identification of subsurface data, for example, geological structure, weathered/crack thickness, lithology, and stratigraphy, depending on geologic system, is challenging because of the inconstancy of geologic environments and the scantiness of geologic data (Trabelsi *et al.* 2013; Chopra and Krishan 2014) [17, 5]. Such innovations have many benefits over

prior routine techniques, on account of their examination of large volumes of data and facility of integration and have turned out to be effective for contemplating geographical, geomorphologic, structural, and hydrodynamic conditions alongside traditional surveys (Saraf and Choudhury 1998) [13]. Several researchers in the past have used Geoinformatics techniques along with remote sensing for the delineation of groundwater potential zone with successful results (Abdalla 2012; Abuzied 2016; Pratap *et al.* 2000; Shahid *et al.* 2000; Jothiprakash *et al.* 2003; Ganapuram *et al.* 2009; Abadi and Shammaa 2014; Siddha and Sahu 2018) [2, 3, 12, 14, 9, 6, 1, 6, 1, 15]. The type and number of themes used for the assessment of groundwater resources by Geoinformatics techniques varies considerably from one study to another. In most studies, local experience has been used for assigning weights to different thematic layers and their features.

To date, very few studies have been conducted for Indian Punjab using Geoinformatic techniques. In the backdrop of this, it seems imperative to have a detailed study for delineating groundwater potential zones in Indian Punjab by considering suitable thematic layers that have ambiguous or direct control over the groundwater occurrence utilizing Geoinformatic technology. Thus, the present study has been carried out with the specific objectives to delineate the groundwater potential zones acting as a guide map for hydrogeological research, to guide the implementation of future points of water and hence reducing the costs of hydrogeological investigations.

2. Materials and Methods

To understand the subsurface strata, lithologies play an important

role and are a key component for creating fence diagram. Additionally, these are helpful in demarcating groundwater potential zones. Rockworks and ArcGIS are the convenient software tools that are used to meet the objectives.

2.1 Study Area

The study was planned to be conducted in district Ludhiana, which lies in the central part of Indian Punjab covering an area of 3767 km² (Fig. 1). It is bounded between East longitude 75° 18' and 76° 20' and North latitude 30° 34' and 31° 01'. The district has twelve development blocks viz. Dehlon, Doraha, Jagraon, Khanna, Ludhiana-I, Ludhiana-II, Machhiwara, Pakhowal, Raikot, Samrala, Sidhwan Bet, and Sudhar. Ludhiana plays an important role in directing the shape of Punjab agriculture and is considered to be most advanced agricultural district. The climate of study area is portrayed by dryness aside from the brief monsoon season, a sweltering summer and bracing winter. From about the mid-November to the early part of March is the cold season and the succeeding time frame up to about the end of the June is the hot season. The south-west monsoon is constituted by the months of July, August and first half of September while, the period from mid-September to around mid-November may be termed as transitional period or post-monsoon. The normal annual precipitation of the district is 680 mm which is distributed unevenly over the region.

2.2 Creation of Fence Diagram

To create the fence diagram, data comprising location of 171 points along with the lithology data was prepared and imported into the Rockworks software. After scanning the boreholes in Rockworks, a lithologic model was developed which showed the variation of lithology from point to point.

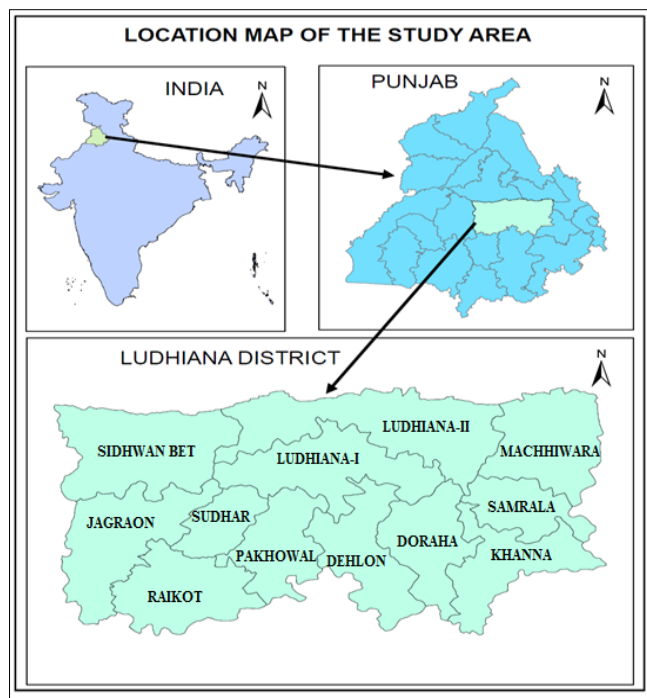


Fig 1: Location map of the study area in Indian Punjab

Then, fence diagram was made which depicted the 3-D variation of lithology at different places. This fence diagram along with the

lithologs of different locations was used to calculate the cumulative thickness of the aquifer at the respective locations. After the preparation of the fence diagram, sectional views were created by selecting various point locations for easy understanding of the subsurface strata.

2.3 Delineating Groundwater Potential Zones

To delineate the groundwater potential zones, the parameters that were chosen included aquifer thickness, aquifer permeability, water table depths at different locations during pre-monsoon 2015, stage of groundwater development, groundwater quality for irrigation, and slope of water level elevation. The flow chart of the methodology is shown in Fig. 2. The longitude and latitude of various points were projected onto the basemap of the study area by using Geographical projection system-World -UTM 1984. The raster interpolation of the data was done using Inverse Distance Weighted (IDW) method.

The cumulative aquifer thickness was calculated with the help of lithology by considering 8 m and above permeable layer (sand), because the submersible pump set needs to have submergence of about 5 m in this region for extracting sufficient water for longer period.

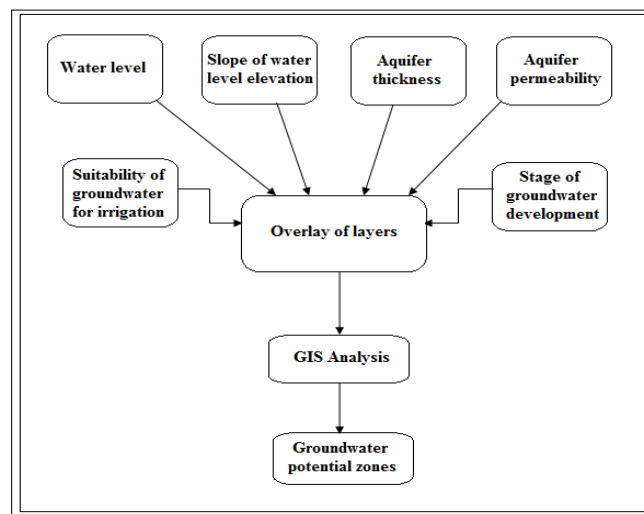


Fig 2: Flowchart of methodology adopted to delineate groundwater potential zones

The information regarding the hydraulic conductivity is very scanty as the State Government agencies have carried out very few pumping tests in the study area. Thus, this parameter was estimated indirectly with the help of well logs. To calculate the aquifer permeability the well logs of a number of bores drilled by various state agencies over the study area were collected and analyzed by assigning average values of hydraulic conductivity to different layers (Todd 1980). The following equation (Jain 1995) was used:

$$K = \frac{\sum_{i=1}^n k_i b_i}{\sum_{i=1}^n b_i} \tag{1}$$

Where,

k_i = hydraulic conductivity of i^{th} water bearing bed, m

b_i = thickness of i^{th} water bearing bed, m

The database file containing water levels for various locations was imported into the ArcGIS and interpolation was done using Inverse Distance Weighted (IDW) method. The data for stage of

groundwater development (CGWB 2017) and groundwater quality for irrigation was collected from the published sources. Based on the water level elevation, contours were formed in the ArcGIS software which helped to calculate the water level elevation slopes. The following formula was used:

$$\text{Water Level Elevation Slope} = \frac{\text{Contour interval (m)}}{\text{Distance between the contours (m)}} \quad (2.)$$

The thematic maps of the above-mentioned parameters were created using ArcGIS software. The thematic map of groundwater quality for irrigation was prepared by geo referencing and digitizing map taken from published literature (Kumar *et al* 2011). For this, the traced map was scanned and added to ArcGIS. The scanned image was then geo referenced by assigning real-world coordinates for different points obtained from the base map of the study area by using UTM projection and WGS 84 datum. After referencing, the image was rectified to project image onto a common image surface. Then, features from the traced map were captured as coordinates in point, line, or polygon format and digitized. The thematic maps were developed by considering four class intervals. The mean value of each class interval for all the parameters was computed independently. The effect of each parameter was considered by assigning weights to each class interval after carefully observing the number of observations having more or less value than the mean value of the parameter. The weights were assigned as 1-3 (poor), 3-5 (moderate), 5-8 (good) and 8-10 (very good) for identification of groundwater potential zones. These thematic maps were then overlaid and respective percentage of influence was assigned to each layer. As per objectives of the study, aquifer thickness and its permeability play an important role to know its potential. Therefore, higher percentage of influence (25 per cent) was assigned to each of aquifer thickness and aquifer permeability. The influence of water level and stage of groundwater development layers was considered as 15 percent, whereas, groundwater quality and slope of water level elevation layers were provided with 10 percent of influencing factor. After overlaying all six layers, the groundwater potential zones were delineated within the GIS environment.

3. Results and Discussion

The fence diagram (Fig. 3) of the study area constructed by synthesizing various sub-surface sections showed that at most of the locations, upper layer consists of loam soil. The clay/heavy soil layers below the surface soil intervening these aquifer groups pinch out against the sand zones at a few places as identified from the fence diagram. The fence diagram is useful in identifying the availability of aquifer zones at different locations in the district.

3.1 Sectional View of the study area

To understand the sub surface strata as per fence diagram, three sections namely A-A', B-B' and C-C' were identified in the North-South direction and section D-D' was identified along East-West to cover the whole study.

Section A-A' (Fig. 4a) in the north-south direction across blocks Sidhwan Bet, Jagraon and Raikot reveals that sand layers are dominant in this part, however, the presence of heavy soil layers are visible from Jagraon to Raikot.

Section B-B' (Fig. 4b) was identified in the North-South direction while moving from Ludhiana-II, Ludhiana-I and Pakhowal of the central part of Indian Punjab. This section shows that fragments of clay/heavy soil appeared within the range of 150-250 m above mean sea level and these fragments changed into large chunks near 100 m above the mean sea level in the regions of Ludhiana-II and Pakhowal.

Section C-C' (Fig.4c) was marked in the study area towards North-South direction while moving from the blocks Machhiwara, Samrala and Khanna. The impermeable layer i.e. clay/heavy soil occurs at shallow as well as deeper depths in the Khanna block whereas from 180-250 m above the mean sea level massive chunks of sand layers were found which can be the source of groundwater as well as considered for groundwater development.

Section D-D' (Fig.4d) was considered in the West-East direction of the study area to understand the variation in lithology from blocks Jagraon, Sudhar, Pakhowal, Dehlon, Doraha and Khanna. The wells along these areas vary from 170 m to 210 m in elevation. The areas between Sudhar and Doraha consist of more thickness of sand (permeable layer) as compared to the areas Khanna and Jagraon b

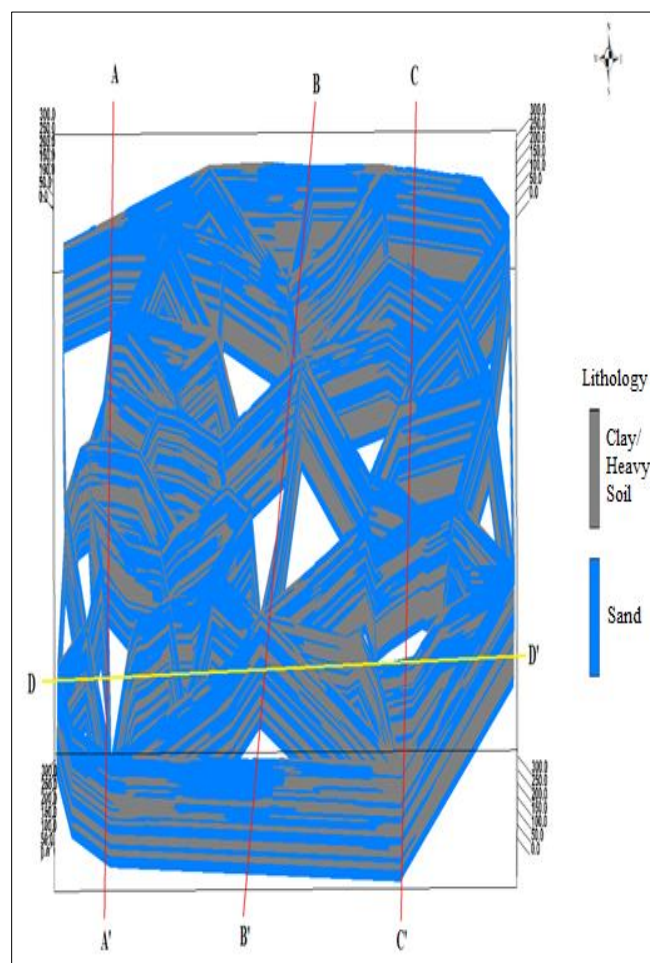


Fig 3: Fence diagram of the study area in Indian Punjab

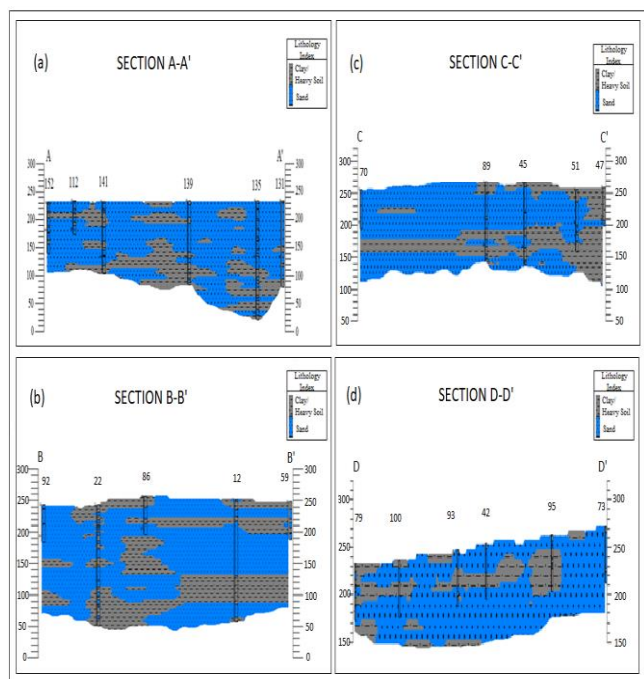


Fig 4: Sectional view from north to south in (a) western part, (b) central part and (c) eastern part of the study area; (d) Sectional view from west to east in southern part of the study area

3.2 Thematic Maps for Various Parameters

The thematic maps of various parameters for the central region of Indian Punjab created under GIS environment are discussed below.

3.2.1 Aquifer thickness

The thematic map of the cumulative aquifer thickness of study area (Fig. 5a) up to borehole depth 100 meters showed that 48.7% area has aquifer thickness 25 – 50 m while 46.5% area lies in the range 50 - 75 m. Only a marginal share of 3% and 1.74% was identified in the ranges 0 – 25 m and 75 - 100 m, respectively. This indicates that abundant groundwater resource exists in the central part of the state, however, due to intensive rice-wheat cropping system, the shallow aquifers are being depleted and the stress is being laid on deep aquifers to meet the irrigation demand of the area. Aquifer thickness has a positive role on groundwater potential development because more thickness renders enhanced resource availability.

3.2.2 Aquifer permeability

Groundwater potential of an area is directly proportional to the permeability of aquifer. It can be seen from Fig. 5(b) that the aquifer permeability for the central part of Punjab lies between 0 – 40 m/day. The maximum area of 2129.07 km² (56.62%) lied in the permeability range of 10 - 20 m/day with most of it appearing in north-east and south-east region of the study area. The aquifer permeability less than 10 m/day was spread over an area of 1145.26 km² (30.45%) mostly in the south-west region of Ludhiana district. Only 428.7 km² area lied in the range of 20 – 30 m/day permeability, covering 11.4% of the total area of the district, whereas, aquifer permeability over 30 m/day covered an area of 56.91 km² (1.51% of the total area) in the blocks of Ludhiana-II, Sidhwan Bet, Doraha and Raikot. This indicates that

about 70% area has good permeability zones that resulted in large scale adoption of rice-wheat in the region.

3.2.3 Water table depth

Pre-monsoon depth to water level during the year 2015 ranged up to 40 m as shown in Fig. 6(a). Most of the area was spread in the range of 10 – 20 m depth below ground level (bgl) with share of 57.44 percent (2159.96 km²). Water table less than 10 m bgl occurred in the blocks of Machhiwara, Ludhiana-II, Sidhwan Bet, Samrala and Doraha having combined area of 435.85 km², which was 11.59 percent of the total area. Only a marginal share lied between 30 – 40 m depth of water table covering an area of 21.41 km² (0.56%) and existed as small patches only in the blocks of Ludhiana-I and Raikot. The average water table depth in the central part of Indian Punjab was 6.0 m in 1980 that increased to 9.0 m in 1995, and 21.0 m in 2013 (Jalota *et al.* 2018)^[8].

3.2.4 Stage of groundwater development

The Fig. 6(b) revealed that 49.75 per cent area lied in the range 176 - 212% groundwater development, while, 38.74% area has groundwater development between 140 - 176%. Around 6.71% of the district's area lied in the range of 212 - 248% whereas, the least over exploited regions included parts of Machhiwara, Doraha and Jagraon lying within the range of 104 - 140% groundwater development covering 4.80% of the total study area. The whole district has stage of groundwater development more than 100% indicating over-exploitation of groundwater in the region. Thus, there is a need to adopt recharge measures or go for crop diversification to reduce irrigation water demand for growing crops.

3.2.5 Water level elevation

The Fig. 7(a) shows that water level elevation varied between 204 - 261 m, with 31.08% lying in the range of 219 – 233 m elevation and 27.43% of the districts area lying between the elevation of 204 – 219 m. Water level elevation is maximum in the blocks of Machhiwara, Samrala, Khanna, Doraha and Ludhiana-II lying within the elevation range of 247 – 261 m, covering an area of 21.93% followed by 19.56% of area which lied in the range of 233 – 247 m elevation. The blocks of Machhiwara, Samrala, Khanna and Doraha had 1:4000 slope whereas, the slope was 1:3000, 1:2000 and 1:1000 in the elevation range of 233 - 247 m, 219 – 233 m and 204 – 219 m respectively. In general, the water level elevation slope increased while moving from East to West direction. The eastern part of the district has values of water level elevation slope less than the values of slope in the western part. The changes in different flow gradients are mainly due to the variation in over-exploitation of groundwater and less recharge in different parts of the district.

3.2.6 Groundwater quality

The groundwater in the study area is extensively used for irrigation. Its suitability for irrigation was assessed based on Electrical Conductivity (EC) and Residual Sodium Carbonate (RSC) values. The salinity of groundwater generally depends on measured electrical conductivity. The groundwater quality map (Fig. 7(b)) revealed that most of the area in Ludhiana district i.e 56.16% lied in the range of EC < 2 dS/m and RSC = 2.5-5 me/l which was considered to be marginally fit for irrigation while 43.18% of the area lied in the fit category having EC < 2 dS/m

and $RSC < 2.5$ me/l. Only 0.66% of the total area lying in Sudhar block was considered to be unfit for irrigation (Kumar *et al.* 2011)^[6]. The cropped area under the unfit region of Sudharblock and

the blocks having marginally fit groundwater quality can also be irrigated using drip irrigation method for optimal yield.

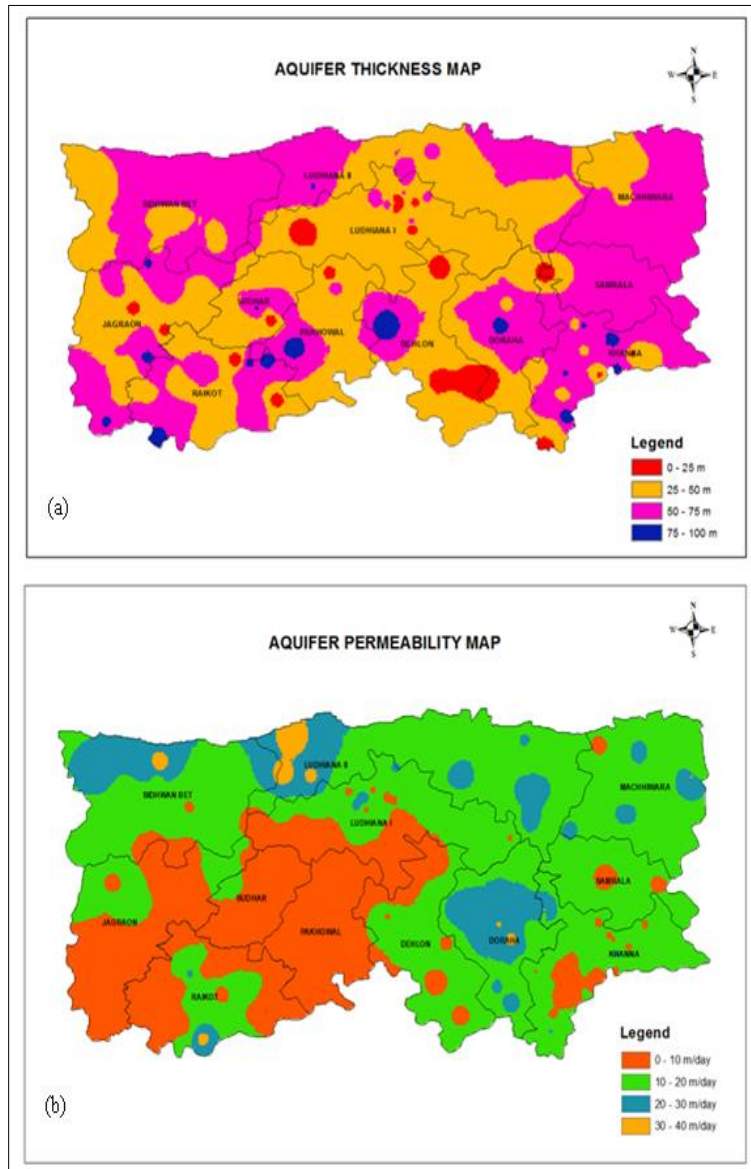


Fig 5: (a)Aquifer thickness map of the study area; (b) Aquifer permeability map of the study area

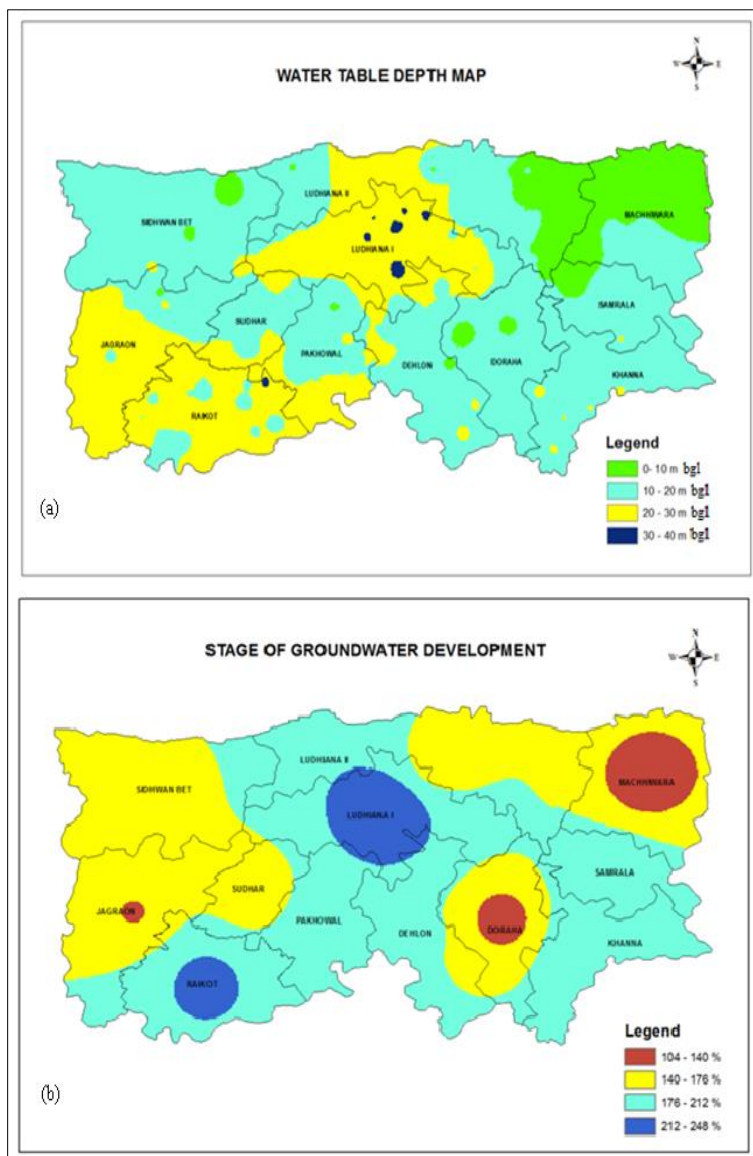


Fig 6: (a) Water table depth map of the study area; (b) Stage of groundwater development map in the study area

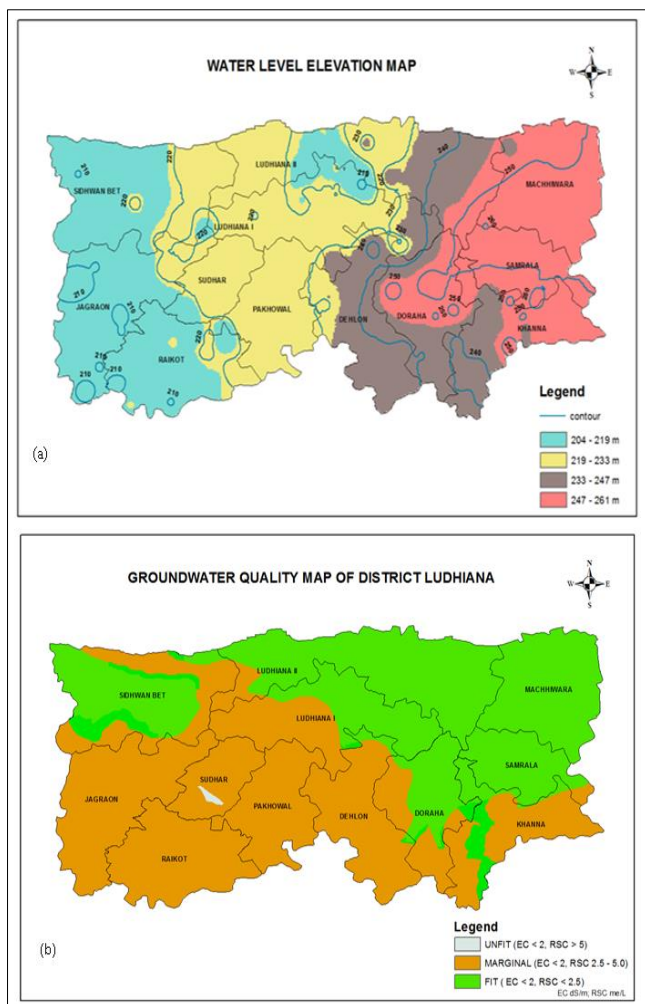


Fig 7(a): Water level elevation map of the study area; (b) Groundwater quality map of the study area

3.3 Groundwater Potential Zones

Table 1 shows the area under different groundwater potential zones which were identified after overlaying all the six parameters by using the methodology explained earlier. It was found that 2916.21 km² area (77.5%) occurred as moderate groundwater potential zone which covered most parts of the district. Good groundwater potential zones covering 591.83 km² of the total area (15.7%) were spread in the parts of Machhiwara, Ludhiana-II, Doraha, Khanna and Sidhwan Bet block, whereas, poor groundwater potential zones appeared only in the blocks of Ludhiana-I, Sudhar, Jagraon and Raikot with an area of 251.46 km² (6.7%). Good groundwater potential zones acquiring approximately 16% of the area reflects aquifer capacity and conductive hydrogeological conditions for large-scale development. The groundwater potential zones that were delineated have been portrayed in Fig. 8. The good groundwater potential zones are mainly due to seepage from nearby canal network in addition to available canal water supplies for irrigation. There is need to reduce the groundwater withdrawal from the poor as well as moderate groundwater potential zones through crop diversification and adoption of on-farm water saving techniques, thereby, reducing the stage of groundwater development

Table 1: Area under different groundwater potential zones

Category	Area (km ²)	Percentage (%)
Very good	0.49	Less than 0.5
Good	591.83	15.7
Moderate	2916.21	77.5
Poor	251.46	6.7

The variable groundwater potential zones are due to changes in cumulative thickness of aquifers resulting from uneven bedrock topography, spatial variability of aquifer permeability, different levels of groundwater exploitation and variation in water level slopes.

4. Conclusions

The predominant cropping pattern of wheat and paddy rotation has caused rise in demand of water for irrigation. Hare-brained policies for surface water irrigation, inordinate groundwater lifting because of free electricity along with extensive irrigation and agrarian operations have created a situation where in the state's groundwater assets have exhausted at an appalling rate. For a large number of years, the water-basin agencies, related to planning, management and protection of water resources, have attempted to find suitable method in order to develop a policy for identifying the most favourable locations for the water points. Against this the present study has been undertaken based on various factors which affect the delineation of groundwater potential zones. The fence diagram along with the sectional views created by selecting various point locations for an easy understanding of the subsurface strata of the district using Rockworks software revealed the geometry, spatial thickness and extent of aquifer. The thematic maps were created in the GIS environment for identifying the areas having high aquifer potential zones. Only 11.6 percent of the study area had water table depth less than 10 m, suitable for the use of horizontal centrifugal pumps. Nearly 15.70% of the study area has good groundwater potential zones, whereas, about 77.50 % was categorized as area having moderate groundwater potential zones. In the poor and moderate groundwater potential areas, there is a need to reduce the groundwater extraction and encouraging water harvesting and artificial recharge of groundwater in addition to crop diversification.

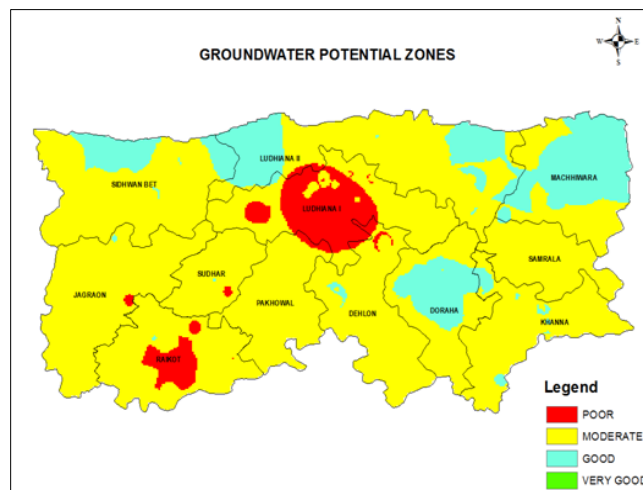


Fig 8: Groundwater potential zones in the study area

Portraying the potential groundwater zones in Ludhiana district of Indian Punjab utilizing ArcGIS was found productive to limit money, time and labor; thus, helps in sustainable management of water resources. For probing of groundwater potential zones, this is an empirical method using ArcGIS and succeeds in proposing potential locales for groundwater zones.

This study plays a crucial role in outlining the clay/heavy soil and aquifer zones, which helps to decide the type of well and depth to be drilled for the future groundwater exploitation or exploration programs. The outcomes of the current study can fill in as regulations for planning groundwater recharging projects in district in the coming times to ensure sustainable groundwater utilization. An accurate location of boreholes and finding most reasonable operating flows would create a real decision-making aid tool for management of water resources and act as an element of direction of all-inclusive strategies for exploitation and development of water as an asset.

5. References

1. Abadi AA, Shammaa AA. Groundwater potential mapping of the major aquifer in Northeastern Missan Governorate, South of Iraq by using Analytical Hierarchy Process and GIS. *J Env Earth Sci*. 2014; 4(10):125-149.
2. Abdalla F. Mapping of groundwater prospective zones using remote sensing and GIS techniques: A case study from the Central Eastern Desert, Egypt. *J African Earth Sci*, 2012; 70:8-17.
3. Abuzied SM. Groundwater potential zone assessment in Wadi Watir area, Egypt using radar data and GIS. *Arab J Geosci*, 2016; 9:501-520.
4. Central Groundwater Board (CGWB). Dynamic groundwater resources of India. Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India, Faridabad, 2017.
5. Chopra RPS, Krishan G. Analysis of aquifer characteristics and groundwater quality in Southwest Punjab, India. *J Earth Sci Eng*, 2014; 4:597-604.
6. Ganapuram S, Kumar GT, Krishna IV, Kahya E, Demirel MC. Mapping of groundwater potential zones in the Musi basin using remote sensing data and GIS. *Adv Eng Soft*, 2009; 40:506-518.
7. Jain AK. Development of an expert system for optimal utilization of water resources. Dissertation, Punjab Agricultural University, Ludhiana, India, 1995.
8. Jalota SK, Jain AK, Vashisht BB. Minimize water deficit in wheat crop to ameliorate groundwater decline in rice-wheat cropping system. *Agril Water Mgt*, 2018; 208:261-267.
9. Jothiprakash V, Marimuthu G, Muralidharan R, Kumar N. Delineation of potential zones for artificial recharge using GIS. *J Ind Soc Rem Sens*. 2003; 31(1):37-47.
10. Kumar R, Singh B, Singh D, Thind HS. Underground water quality of the Punjab. Department of Soil Science, Punjab Agricultural University, Ludhiana-141004, India, 2011.
11. Patle GT, Singh DK, Sarangi A. Modelling of declining groundwater depth in Kurukshetra district, Haryana, India. *Current Sci*, 2016; 111:717-723.
12. Pratap K, Ravindran KV, Prabakaran B. Groundwater prospect zoning using remote sensing and geographical information system: A case study in Dala-Renukoot area, Sonbhadra district, Uttar Pradesh. *J Ind Soc Rem Sen*, 2000; 28:249-263.
13. Saraf AK, Choudhury PR. Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. *Int J Rem Sen*, 1998; 19:1825-1841.
14. Shahid S, Nath SK, Roy J. Groundwater potential modelling in a soft rock area using a GIS. *Int J Rem Sen*, 2000; 21:1919-1924.
15. Siddha S, Sahu P. Assessment of groundwater potential of Gandhinagar region, Gujarat. *J Geo Soc Ind*, 2018; 91:91-98.
16. Todd DK. *Groundwater hydrology* (ed.) 2ndedn, John Wiley and Sons. Inc. New York, 1980, pp. 535.
17. Trabelsi F, Tarhouni J, Mammou AB, Ranieri G. GIS-based subsurface databases and 3-D geological modeling as a tool for the setup of hydrogeological framework: Nabeul-Hammamet coastal aquifer case study (Northeast Tunisia). *Environ Earth Sci*, 2013.
18. Weissmann GS, Carle SF, Fogg GE. Three-dimensional hydrofacies modeling based on soil surveys and transition probability geostatistics. *Water Resour Res*, 1999; 35:1761-1770.