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Artificial Ground Water Recharge Zones Mapping Using Remote Sensing and GIS : A Case Study

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Abstract : Artificial recharge plays a vital role in the sustainable management of scarce groundwater resources. This study proposes a methodology to delineate artificial recharge zones using remote sensing (RS) and geographical information system (GIS) for augmenting groundwater resources in Bist Doab basin of Indian Punjab, which has been facing severe water shortage due to shift in cropping pattern over the past few years. The thematic layers considered in this study are: geomorphology, geology, drainage density, slope, soil texture, aquifer transmissivity and specific yield which have been prepared using maps conventional field data. Different themes and their corresponding features were assigned proper weights based on their relative contribution to groundwater recharge in the area, and normalized weights were computed using the Saaty's analytic hierarchy process (AHP). These thematic layers were then integrated in the GIS environment to delineate artificial recharge zones in the study area. The artificial recharge map thus obtained divided the study area into four zones, viz., 'poor,' 'moderate', 'good' and 'very good' based on the analysis that influence the ground water discharge. The results inferred that the eastern portion of the study area was found not suitable for artificial recharge due to its poor infiltration ability and where as middle and western portion of the study area falls under good and very good zones. The results of this study could be used to formulate an efficient groundwater management plan for the study area so as to ensure sustainable utilization of scarce groundwater resources.

Key words: Artificial Ground Water recharge zones; Remote sensing and GIS; Water scarcity; analytic hierarchy process; Groundwater management

INTRODUCTION

Groundwater is one of the most valuable natural resource which supports human health, economic development and ecological diversity (Jha *et al.*2006). It is essential to maintain proper balance between the groundwater quantity and its exploration to prevent from rapid decline of ground water table that affects sustainable production. Unfortunately, the excessive use and continued mismanagement of this vital resource led to ever-increasing water demand and increasing pollution of freshwater resources and degraded ecosystems worldwide (e.g., Clarke, 1991; Falkenmark and Lundqvist, 1997; de Villiers,2000; Tsakiris, 2004). For example, in north-eastern region of Indian Punjab, the ground water exploration has increased tremendously over the past few decades, resulting in drying up of shallow wells and increase in the pumping cost (Rodel et al.2009). In addition, shifting of cropping pattern from traditional maize-wheat to rice-wheat over the years by expecting more economic benefits added more pressure on this natural resource. In the due course of time, to meet the irrigation demand, number of tube wells has been increased from 0.192 to 1.165 million in the last 35 years (Aggarwal *et al.*, 2009). This eventually results in extra power consumption for lift irrigation due to adjustment for crop water requirements which may affect both economic and ecological balance of the state in the ensuing years. Artificial recharge of aquifers is emerging as a powerful tool in water resources management (Ma and Spalding, 1997). The most widely practiced direct recharge techniques like surface flooding, ditch and furrow systems and stream channel modification has got the edge of advantage in replenishing ground water supplies in the metropolitan and agricultural areas, where the groundwater overdraft is severe and the benefit of filtering effect due to transmission of water through aquifer (Basagaoghu and Mariono, 1999 and Asano, 1985). However, to implement artificial groundwater recharge, it is essential to delineate the potential groundwater recharge zones using latest techniques such as remote sensing and GIS as the traditional methods are indirect, time consuming and uneconomical, particularly dealing with large basins.

As groundwater is dynamic and interdisciplinary in nature, an integrated approach of remote sensing (RS) and GIS technique is very useful in various groundwater management studies. RS and GIS is capable of developing information in different thematic layers and integrating them with sufficient accuracy within a short period of time. It is useful to the concerned decision-makers and practicing hydrogeologists in the efficient planning and management of vital groundwater resources. An extensive literature survey on the applications of RS and GIS on the identification of artificial recharge and potential zones inferred that few researchers like Saraf and Choudhury 1998; Anbazhagan *et al.* 2005; Ravi Shankar and Mohan 2005; Ghayoumian et al. 2007; Jasrotia *et al.*, 2007; Chenini *et al.* 2009; Dias *et al.*, 2009; Chowdhury *et al.*, 2010) have reported their results in rocky terrains except Saraf and Chadhury 1998. Limited studies are reported in large basins, especially in Indian subcontinent and therefore there is need to conduct more studies in different hydrological regimes. Hence, the main objective of the present study is to identify the active groundwater recharge zones in Bist Doab basin, Indian Punjab by generating different thematic maps, and considering their relevance to groundwater occurrence with available field data and conventional maps.

STUDY AREA

The study area (Fig 1) is located in the north-east part of Indian Punjab, popularly known as Bist Doab basin (bist is an abbreviation for the twin rivers Beas and Sutlej, and doab, a Persian

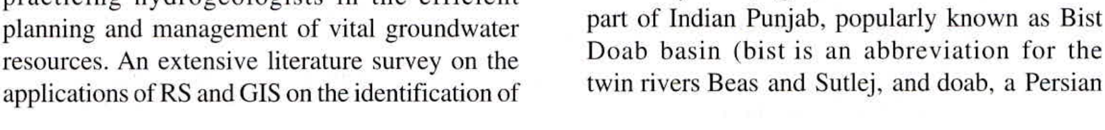

Fig. 1. Location map of the study area.

term meaning a land mass lying between two rivers). Climatologically, the study area is a part of the Indo-Gangetic alluvial plain and there exists a choe ridden (ravine-ridden) belt bordered by the Shivaliks called Kandi. It is a triangular in shape, covering an area of 9060 km² and geographically lies between latitudes 30° 572 253 N and 32° 82 153 N and longitudes 75° 012 103 E and 76° 482 153 E. The catchment area lies in the districts of Hoshiarpur, Kapurthala, Nawanshahar, Jalandhar, and Nurpur Bedi block of Ropar district and bounded by Katar Dhar range of Siwalik hills in the north-east, the river Beas in south- west and the river Sutlej in east-south..The topography of the area is almost plain except some portion of Hoshiarpur district and Nurpur Bedi block of Ropar district which is undulated (Fig. 2). The tract slopes are varying with a gradient ranging from 1 in 500 to 1 in 2000 from North to South. The Shivalik area is at an altitude of 400 to 730 meters above sea level and made up of fluvial deposits of conglomerates, clays and silts. The low Shivalik hills demarcates the Himalayas from the plains. The Bist Doab region is characterized by a continental subhumid climate, with extreme hot and extreme cold conditions. The region lying near the foot hills of Himalayas receives heavy rainfall and the region lying at a distant from the hills is scanty. The annual rainfall varies from 630 to 1200 mm. The major part of annual rainfall (more than 70%) is experienced during south-east monsoon period. The normal onset of the monsoon in the study area is in the first week of July.

METHODOLOGY

Preparation of thematic maps

In the present study, integrated RS and GIS techniques were used for the delineation of artificial recharge zones by considering a multiparametric data set comprising seven thematic layers, viz., geomorphology, geology, drainage

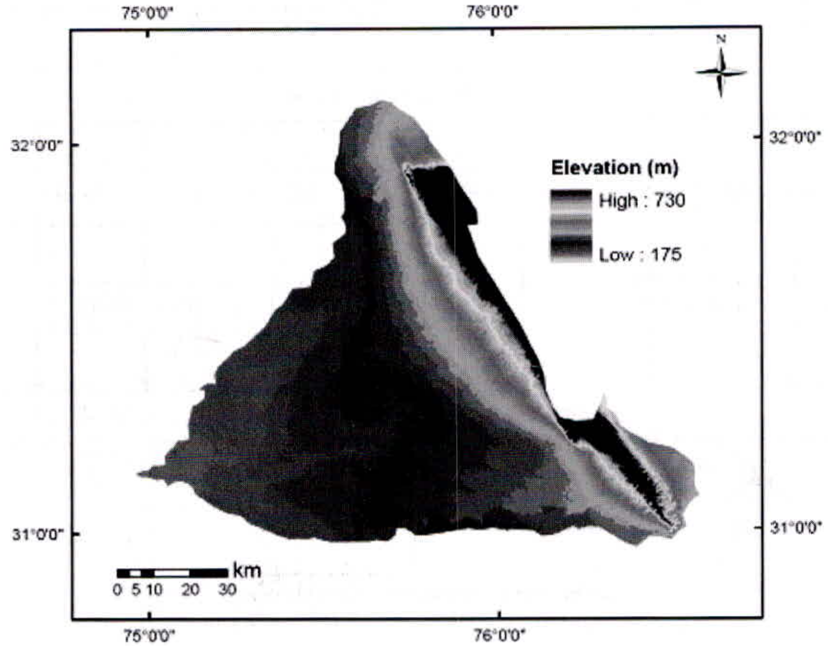

Fig. 2. Topographic map of the study area.

density, slope, soil texture, aquifer transmissivity and specific yield. The maps of geomorphology and soil texture were collected from Punjab Remote Sensing Centre and National Bureau of Soil Survey and Land Use Planning (NBSS), whereas geology map was obtained from the Geological survey of India (GSI). Thematic layers of aquifer transmissivity and specific yield were prepared from the field data collected by Central Ground Water Board (CGWB). On the contrary, thematic layers of geomorphology, geology, soil texture, aquifer transmissivity and specific yield were derived from the paper format maps which initially were scanned, rectified with well-known GCPs and then finally digitized using ArcInfo GIS software. To prepare the drainage density map, the drainage network for the study area was derived initially from SRTM (Shuttle Radar Topography Mission) data and on screen digitization from topographic map. After preparing the drainage network map, the entire area was divided into micro-watersheds of area ranging from 500 to 100 ha. The micro-watershed boundary map was intersected with the drainage map in order to calculate drainage density for each micro-watershed expressed in terms of length of channels per unit area (km km^{-2}). After getting drainage densities for each micro-watershed, the entire area was divided into suitable drainage density zones. Slope maps of the study area were prepared from SRTM data using ArcInfo GIS software. After preparing all the thematic layers, different features/ classes of the individual themes have been identified and then assigned suitable weights according to their relative importance in groundwater recharge in the study area by Saaty's analytic hierarchy approach (AHP). All the weighed thematic layers were integrated using ArcInfo GIS software to demarcate artificial recharge zones.

Weights assignment and integration of thematic layers

Analytic Hierarchy Approach (AHP) developed by Saaty (1980) was used as a decision-aiding method to finalize the weights assigned to different

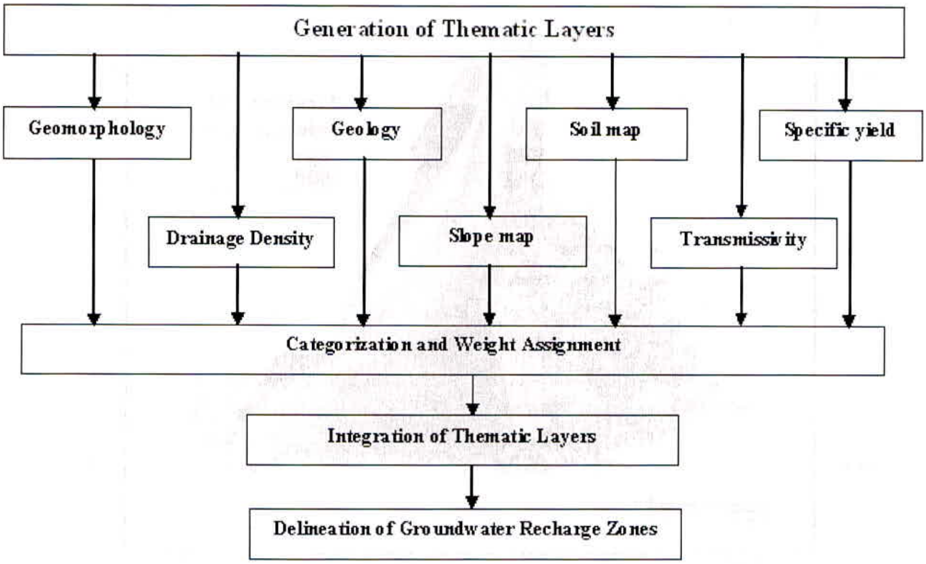

Fig. 3. Flowchart for delineating artificial recharge zones using integrated remote sensing and GIS techniques

themes and their features used in artificial recharge zoning. The advantage of using AHP is that it allows the users to assess the relative weight of multiple criteria in an intuitive manner, thereby group decision making is possible, where group members can use their experience, values and knowledge to breakdown a problem into a hierarchy and then solve by AHP steps. It also incorporates systematic checks on the consistency of judgments which has an additional edge compared to other multi-attribute value process. However, in the present study, the weights to different thematic layers and their features were assigned based on personal judgments or local experience. The qualitative evaluation of different features of a given theme was performed based on the categories such as: poor (weight = 1-2); moderate (weight = 2-4); good (weight = 4-6); very good (weight = 6-8); excellent (weight = 8-9). After finalizing suitable weights of the themes and their individual features by considering their hydro-geologic importance in artificial groundwater recharge, the normalized weights of the individual themes and their features were obtained by the Saaty's AHP.

RESULTS AND DISCUSSION

Geomorphology

Geomorphologically, the area consists of four main zones such as Structural hills, Piedmont Plain, Alluvial plain, and Flood plain (Fig. 4):-

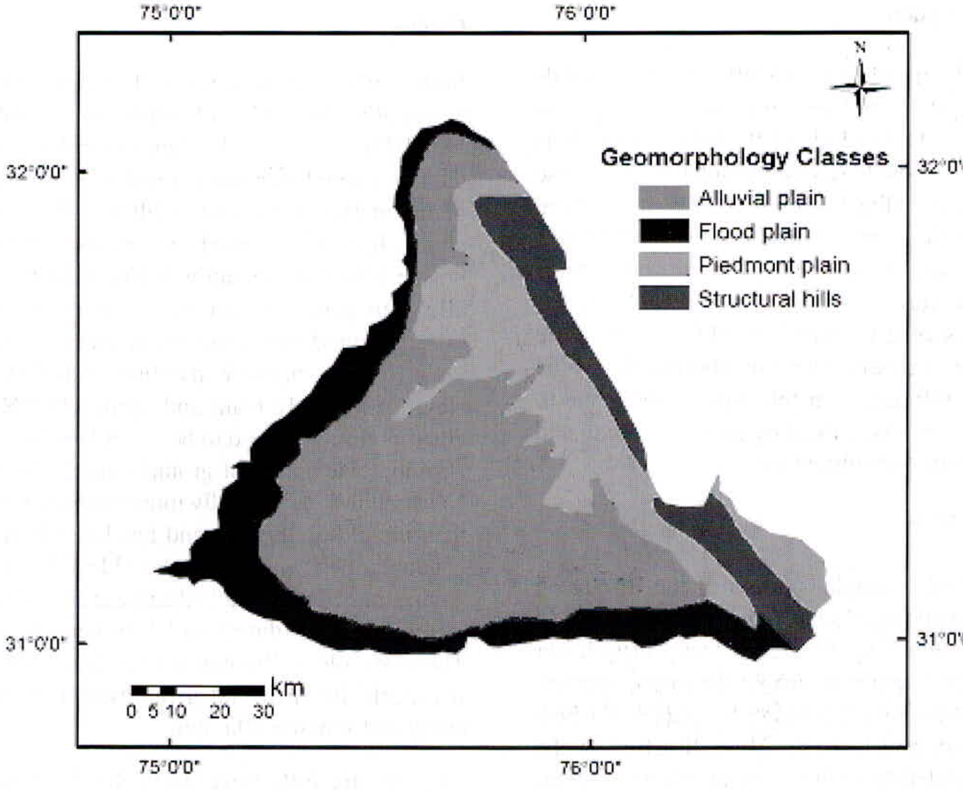

Fig. 4. Geomorphology map of Bist Doab Basin

Structural hills

The north-eastern portion of the Bist Doab tract forming boundary with the neighbouring Himachal Pradesh comprises the sub-mountainous zone where upper Siwaliks rocks are exposed and covered about an area 1200 Sq.Kms, out of which about 900 Sq.Kms lies in the Punjab tract. The altitude of these low hills varies from 300-600 m. They are made up of predominating bands of clays alternated with sands of varying grade. Easy erodability of sediments and their abrupt rise from the foreland are responsible for rise of many small seasonal streams which causes extensive erosion. The hills are covered with sparse vegetation, mainly bushy in nature and the tree cover varying from 10 to 30% at some places.

Piedmont Plain

The piedmont plain is a gently sloping towards south-west to undulating zone which occurs parallel to the foothills of the hilly terrain. It is made up of loose to semi-consolidated very coarse materials including boulders, etc, which is derived from the hilly terrain and deposited on the lower slopes in the shape of fans and at a later stage, merged to form a continuous zone parallel to the hills. This zone is characterised by the presence of extremely dissected large number of sub-parallel streams. Infiltration in this zone is moderate to high. The area is marked by poor vegetation and is under rain fed cultivation.

Alluvial Plain

The central triangular portion of the Bist Doab Tract is made up of clay and sand mixed soils of alluvial origin. The soils are fine loamy in the lower reaches and coarse loamy in the upper reaches. This zone is gradually sloping towards S-W which can be inferred from the flow direction of the streams and rivers as the two major rivers i.e., Beas and Satluj meet in the S-W corner of the tract. The area is under intensive cultivation and irrigated by both canals as well as tube wells. The unit has low to moderate infiltration capabilities.

Flood Plain

The undulating or gently sloping area along the Beas and Satluj rivers is known as mand or bet. It is a landform composed primarily of unconsolidated material deposited along the banks of the rivers and subjected to periodic or occasional flooding. A narrow strip of land constituted by variable proportions of sand, silt and clay mixed together, acts as a good source of ground water recharge. The area has been brought under intensive cultivation as the fear of flooding in the area has been minimized by providing flood protection measures through earthen bunding along the banks of the two rivers. Most of the palaeochannels of river Beas and Satluj lies within this zone.

Geology

In the study area, three types of geology, namely newer alluvium, older alluvium, and siwalik are found (Fig. 5). Newer alluvium generally occupies the low ground area and is restricted to the flood plains of Beas river and smaller valleys of the choes. It consists mostly of greyish and light brown coarse to medium grained sand. Older alluvium generally occupies a comparatively raised ground and consists of dirty brown to yellowish brown, medium to fine sandy soil, silty clay, loam, sandy loam and sandy clay. Newer alluvium is considered to be water bearing and is an important source of groundwater in the area. Newer alluvium is usually more coarsely grained than the older alluvium and has large hydraulic conductivities. In general, the older alluvium is compositionally similar to the newer alluvium, but is more consolidated and less transmissive. Therefore, older alluvium is considered to be less favorable for artificial groundwater recharge compared to newer alluvium.

The Siwalik hills runs North-South along the eastern boundary of the study area and expose a North-South trending anticline of Siwalik

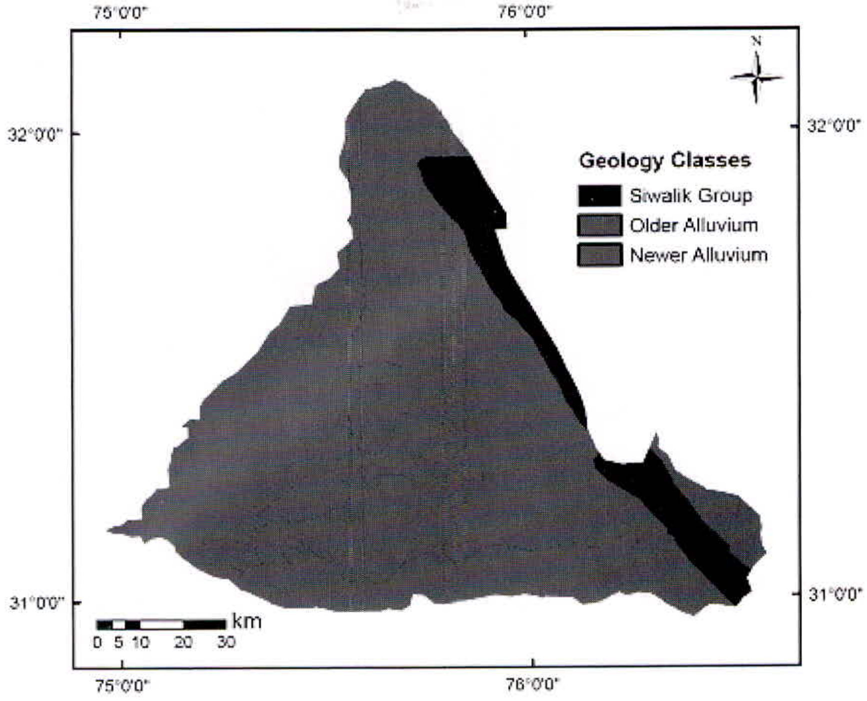

Fig. 5. Geology map of Bist Doab Basin

formation. In general, Siwalik range trend NW-SE direction and generally considered as poor zone of groundwater recharge. The Siwaliks here are composed of conglomerate beds, friable sand stones, silt stone and clay stones. Conglomerates are not cohesive and consist mainly of cobbles and pebbles of quartzites. The sandstone present shows poor stratification and are generally ungraded as to grain size. They are feldspathic, micaceous and current bedded and some of them have clearly been derived from the breakdown of central Himalayan granite.

Slope

A slope map of the study area prepared from SRTM data is shown in (Fig. 6).The slope percentage in the area varies from 0 to 45%. The land slopes from east to west. The gradient is much more in the east than in the west. In relation to groundwater, flat areas where the slope amount is low are capable of holding rainfall, which in turn facilitates recharge, whereas in elevated areas where the slope amount is high, there will be high run-off and low infiltration.

On the basis of slope, the study area is divided into five slope classes. The areas having 0 to 1% slope fall into the 'very good' category because of the nearly flat terrain and relatively high infiltration rate. The areas with 1 to 3% slope are considered as 'good' for groundwater storage due to slightly undulating topography with some runoff. Most of the study area (80%) falls under these two categories. The areas having a slope of 3 to 5% cause relatively high runoff and low infiltration, and hence are categorized as 'moderate.' The fourth (5–10%) and fifth (>10%) categories are considered as 'poor' due to higher slope and runoff.

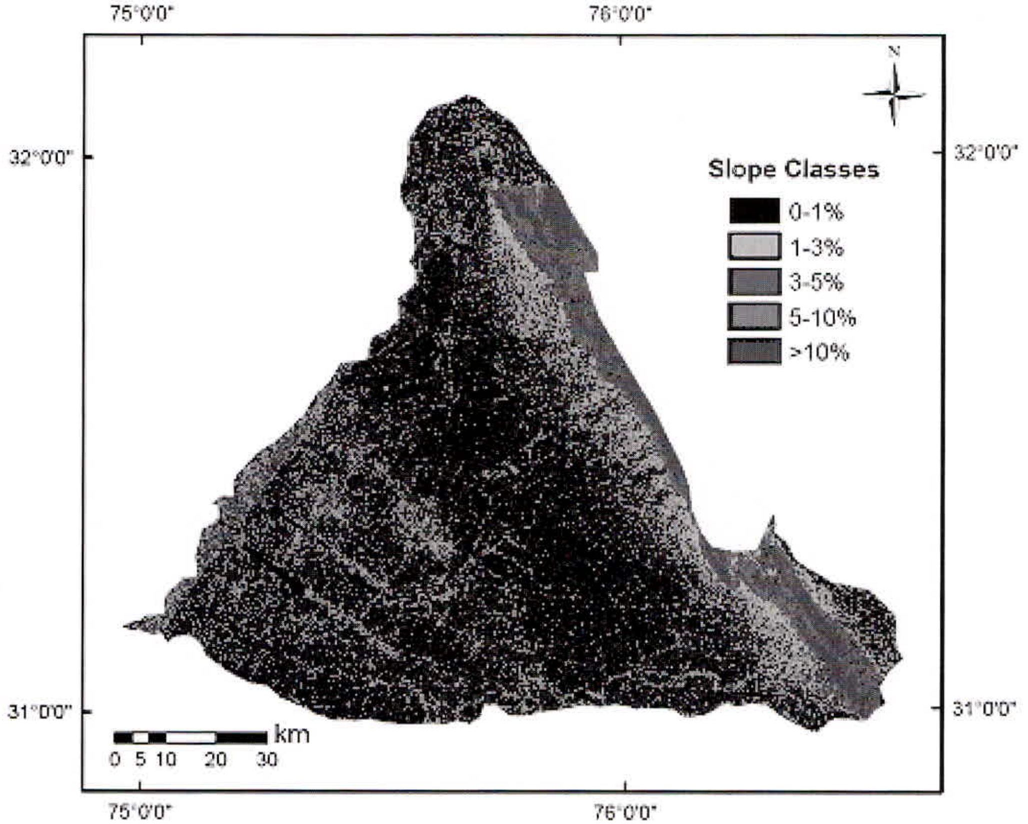

Fig. 6. Slope map of Bist Doab Basin

Drainage Density

The drainage density, expressed in terms of length of channels per unit area (km/km^2) indicates an expression of the closeness of spacing of channels. It thus provides a quantitative measure of the average length of stream channels within different portions of the whole basin. The drainage density is an inverse function of permeability and thus indirectly indicates the suitability for groundwater recharge of an area. Drainage density measurements have been made for all the micro-watersheds in the study area and the drainage density map is shown in Fig.7 Based on the drainage density of the micro-basins, it was grouped into three classes: (1) <0.5 km km^{-2}, (2) 0.5-1 km km^{-2} and (3) >1 km km^{-2} as illustrated in Fig 6. Accordingly, these classes have been assigned as 'good', 'moderate' and 'poor' categories, respectively. Most of the study area (95%) has a drainage density of 0–0.5 km km^{-2}.

Aquifer Transmissivity

The Aquifer properties data for the study area were obtained from Central Ground Water Board (CGWB), and they represent horizontal transmissivity. The aquifer transmissivity is defined as the groundwater discharge through unit width of the aquifer for the fully saturated depth under a unit hydraulic gradient. The transmissivity values in the study area vary from 0 to 7000 m^2/

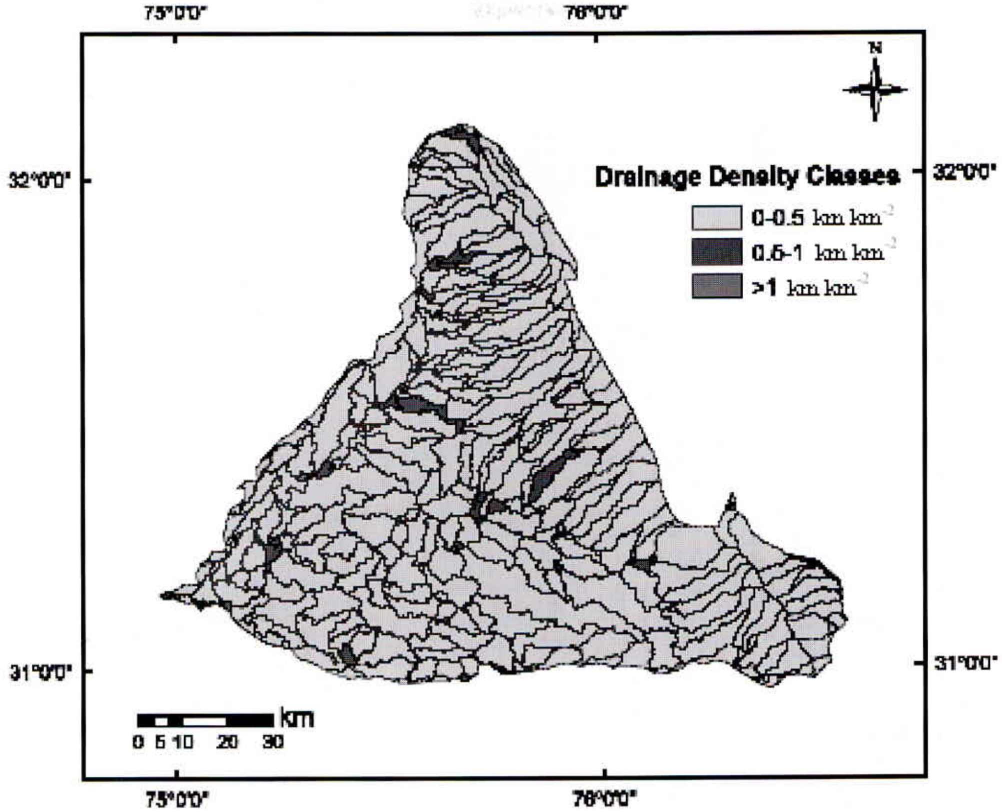

Fig. 7. Drainage density map of Bist Doab Basin

day. Based on these transmissivity values, the area was divided into three transmissivity classes, namely 'low' (<1000 m^2/day), 'moderate' (1000–2000 m^2/day) and 'high' (>2000 m^2/ day), as shown in Fig 8. From the classification, it is inferred that the north-eastern portion of the study area has a low aquifer transmissivity, whereas the western portion of the area falls in the high transmissivity zone.

Specific Yield

Specific yield indicates the amount of water released due to drainage from lowering the water table in an unconfined aquifer. Groundwater recharge is also dependent on the value of specific yield. Fine-grained sediment has a lower specific yield than more coarsely-grained sediment and poorly sorted material is less porous than well-sorted material. Based on the specific yield values, the study area was divided into three classes: (a) <0.06, (b) 0.06-0.1 and (c) >0.1 as shown in Fig.9. Accordingly, these classes have been assigned as 'poor', 'moderate' and 'good' categories, respectively. It is evident from the Fig. 9 that the eastern side of the study area have a lower specific yield than western side.

Soil

The soils of the bist doab region have developed under semi-arid condition and vary from sandy to

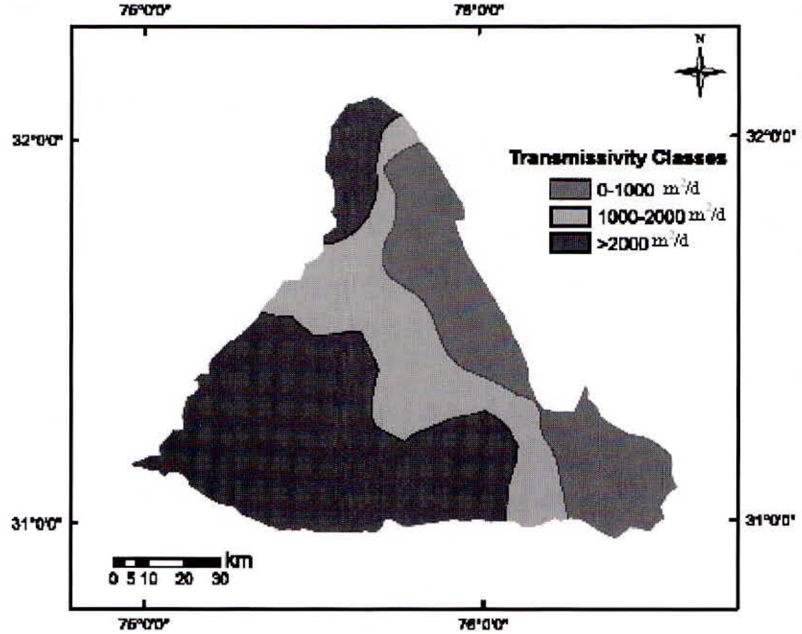

Fig. 8. Transmissivity map of Bist Doab Basin

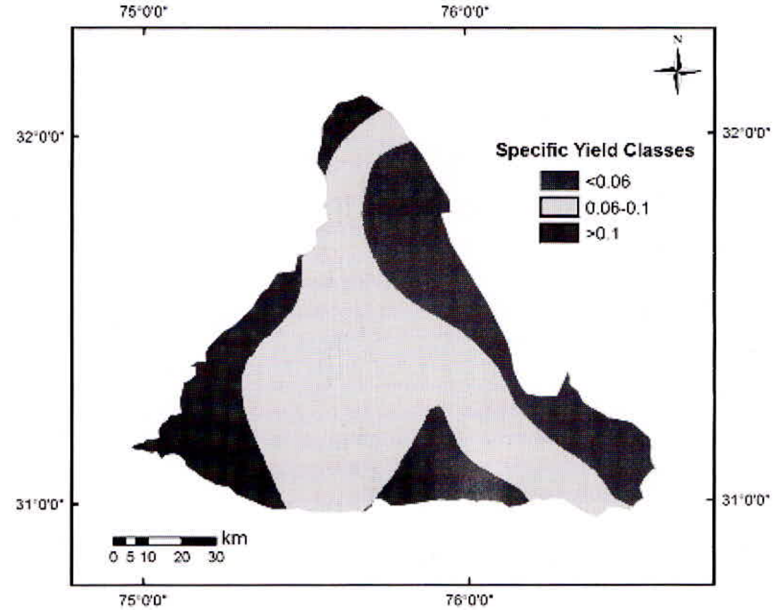

Fig. 9. Specific yield map of Bist Doab Basin

clayey in nature. The pH values ranges from 7.8 to 8.5. Soils of eastern part of the region are dominated by loamy condition. Sub soils are invariably heavier than top soil. In the extreme east, the soil becomes pebbly. The soils of the area are alluvial in origin and can be widely described as arid and brown soil or tropical arid brown. A soil texture map was prepared from the soil map obtained from the National Bureau of Soil Survey and Land use Planning (NBSS). Accordingly, the study area is classified into four soil classes namely sandy skeletal, sandy, coarse loamy, and fine loamy (Fig. 10). It was found that, major portion of the study area was covered with coarse loamy soil (49%). Based on these, classes have been assigned as 'good' and 'moderate' respectively.

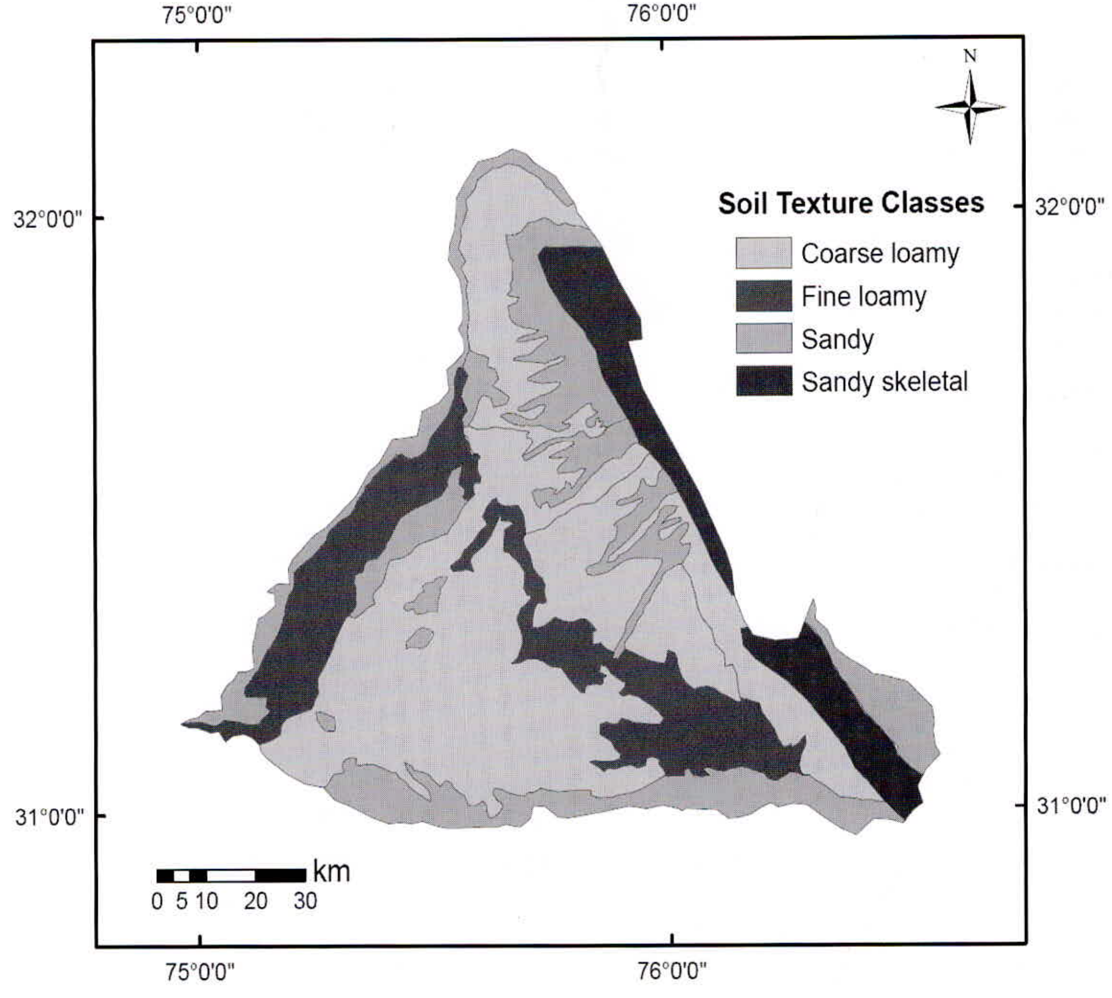

Fig. 10. Soil texture map of Bist Doab Basin

Demarcation of Groundwater Recharge Zones

The groundwater recharge zones were obtained by overlaying all the thematic maps in terms of weighted overlay methods using ArcInfo GIS software (Fig 11). Suitable weights were assigned to the seven themes and their different features as described in "Weights assignment and integration of thematic layers," and are presented in Table 2 and Table 3. The normalized weights of the individual themes and their different features were calculated by AHP. The study area has been divided into four zones, namely poor, moderate, good, and very good, based upon the analysis of the seven factors which influence groundwater recharge. It is evident from the Fig. 11 that eastern portion of the study area is not suitable for artificial recharge due to its poor infiltration ability. Middle and western portion of the study area falls under good and very good zones. It thus clearly indicates that, the results are consistent with the results based upon seven factors which influence groundwater recharge.

CONCLUSIONS

Bist-doab basin is located in the north-eastern part of Punjab, India, has been suffering from severe water shortages for the past few years due to increased crop water requirements. The over-exploitation of groundwater has resulted in lowering the groundwater table in different parts of the study area, thereby aggravating the water availability problem.

The recharge zone map of Bist-doab basin indicates that eastern portion of the study area is not suitable for artificial recharge due to its poor infiltration ability. Middle and western portion of the study area falls under good and very good zones. Relatively very good amount of groundwater depth in the basin suggests greater availability of dynamic underground storage during the non-monsoon (dry) period and hence is favorable for artificial recharge. On the other hand, the 'moderately suitable' zones have average groundwater depths during the non-monsoon period, suggesting availability of underground storage for recharge in these zones also. Poor availability of ground water in the basin suggests preventing further installation of bore wells in the study area which conserves time, energy and cost.

Since the interdisciplinary nature of groundwater necessitates the integrated and conjunctive analysis of a large volume of multidisciplinary data, the decisions regarding groundwater recharge zones and structures require enormous amount of time, labor and money. The integrated approach using RS and GIS techniques can greatly minimize the time, labor and money and thereby enable quick decision-making for efficient utilization of ground water resources. Despite the inherent limitations of multi-criteria analysis, still, it is a valuable practical tool for the areas/regions where data scarcity is often an obstacle for solving water related problems.

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Table 1. Saaty's scale of preferences in the pair-wise comparison process (Saaty, 1980)

Numerical rating	Verbal judgements of preferences between alternative *i* and alternative *j*
1	*i* is equally important to *j*
3	*i* is slightly more important than *j*
5	*i* is strongly more important than *j*
7	*i* is very strongly more important than *j*
9	*i* is extremely important than *j*
2, 4, 6, 8	Intermediate values

Table 2. Weights of seven themes used for artificial recharge zoning

Theme	**Assigned weight**	**Normalized weight**
Geomorphology	7	0.23
Geology	6	0.20
Slope (%)	5	0.17
Drainage Density (km km^{-2})	4	0.13
Aquifer Transmissivity (m^2 day^{-1})	3	0.10
Specific yield	3	0.10
Soil texture	2	0.07

Table 3. Assigned and normalized weights for the individual features of the themes for artificial recharge zoning

Theme	**Class/feature**	**Recharge prospect**	**Assigned weight**	**Normalized weight**
Geomorphology	Flood plain	Very good	7	0.35
	Piedmont plain	Very good	6.5	0.32
	Alluvial plain	Good	5.5	0.28
	Structural hills	poor	1	0.05
Geology	Younger alluvium	Very good	7	0.48
	Older alluvium	Very good	6.5	0.45
	Siwalik group	poor	1	0.07
Slope (%)	0–1	Very good	6.5	0.36
	1-3	Good	5.5	0.30
	3-5	Moderate	3.5	0.19
	5-10	Poor	1.5	0.08
	>10	Poor	1.2	0.07
Drainage Density	0-0.5	Good	4	0.47
(km km^{-2})	0.5-1	Moderate	3	0.35
	>1	Poor	1.5	0.18
Aquifer Transmissivity	>2000	Good	5	0.50
(m^2 day^{-1})	1000-2000	Moderate	3.5	0.35
	<1000	Poor	1.5	0.15
Specific yield	>0.1	Good	5	0.50
	0.06-0.1	Moderate	3.5	0.35
	<0.06	Poor	1.5	0.15
Soil texture	Sandy skeletal	Good	5	0.34
	Sandy	Good	4	0.28
	Coarse loamy	Moderate	3.5	0.24
	Fine loamy	Moderate	2	0.14

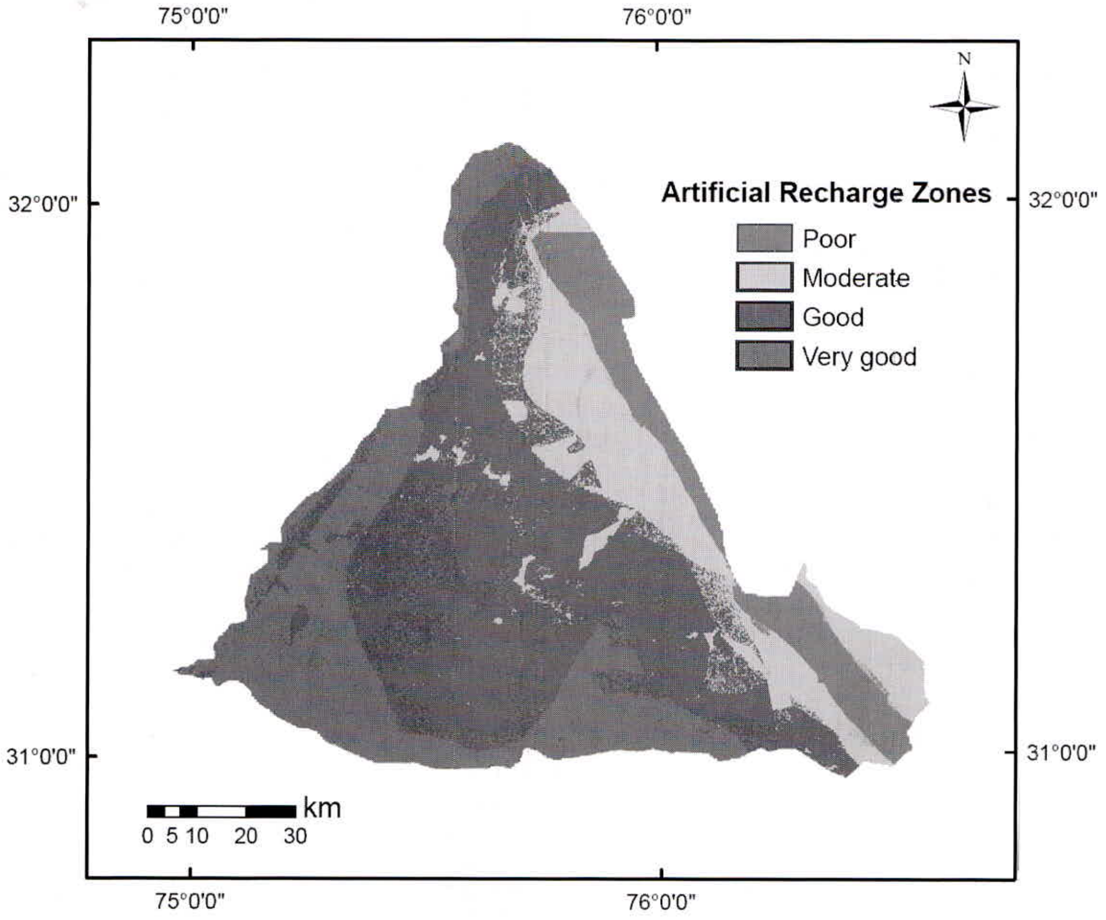

Fig. 11. Artificial recharge zone map of Bist Doab Basin

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