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Groundwater Vulnerability Assessment Using Drastic Model in Bist Doab: Punjab (India)

Abstract

Ground water is one of the precious resource and is replenish able water on the earth's surface. It is reliable source of water as compare to the surface water. Though ground water is safe and not easily polluted but once it is polluted, it is very long process to procure ground water. Due to the less availability of surface water, changing land use and land cover and increasing demand for water have been over- exploited in the manners of its pollution and depletion. Ground water pollution in Bist Doab was a complimentary curse that came intotheexistence with Green Revolution.

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Keywords: Groundwater Vulnerability, Drastic Model.

Introduction

The Green Revolution, beginning in India in 1966. It was a big gift to the agro-economy of India. The key pillars of this revolution were HYV seeds, promoted irrigation facilities, chemical fertilizers and use of pesticides. This revolution has boost- up the agriculture sector, but for a long time it was a curse on our environment. It has led to soil contamination, soil erosion, reduced soil fertility, reduced genetic diversity, ground water pollution, decline water depth, water logging, and reduced nutritious foods (Bidwai, 1988; Kang, 1982; Haddaet al.2000).

In Punjab, most studies dealing with Green Revolution look into problems relating to encroachment of agricultural land, ground water pollution, water logging, ground water depletion, loss of soil fertility, soil erosion, land degradation, depletion of forests etc (Singh, 1975 & 1977; Shiva, 1991; Sharma,1995; Sharma, et al., 2014;Brar, 1999 & 2013; Banerjee et al., 2000, Uppal, 1972 ; Benbi, 2006; Kaur, 2014; Singh, 1965; Joshi, 2009; Mawi, 1965; Kumar et al., 2015; Krishan, et al. 2014). Land of Punjab has a great importance and is divided into three natural regions: Malwa (between Sutlej and Ghaggar), Bari (Between Beas and Ravi and Bist Doab also known as Doaba (between Beas and Sutlej).

Bist Doab extends over a vast region. Land of Bist Doab is most valuable to agricultural activities by its irrigation characteristics through tube wells, rivers and canals. After green revolution, there are so many changes that have taken place in agricultural as well as economic perspective. Bist Doab is highly populated region of the Punjab state. Most of the population depends upon agriculture for their livelihood. Irrigation facilities from groundwater extraction are the backbone of the agriculture in Bist Doab. Therefore, it is important to know the quality and quantity of the groundwater for the sustainability of the study area. In agriculture, advancement in technology like HYVseeds, use of fertilizers, pesticides and the irrigation facilities turn the overall scenario of the Bist Doab. The use of HYV seeds, fertilizers, pesticides and irrigation facilities flourished the financial conditions of the farmers. The farmers of Bist Doab had low fertilized land earlier, increased their productivity with the help of fertilizers and irrigation facilities with the construction of the canals. The fields those are barren or left vacant earlier and have less productivity, are now more productive and grown more after the above said practices induced. Now a time, Bist Doab is known as rich in agriculture. But every change has a positive and negative impact on the environment and social life. Maximum uses of fertilizers and pesticides have also negative impact in Bist Doab. The use of fertilizers has increased the productivity now days, but for long time period, it decreases the fertility of the soil and increases the contamination of ground water. Pesticides and fertilizers mixed with the soil andleachingtotheearth'ssurfaceandcontaminatetothewaterandsoil that raised the problem of groundwater pollution in the study area (Chopra and Sharma, 1993; Singh, 2005; Kaur, 1970; Kaur, 1986; Bhardwaj, 1964; Lapworth et al., 2014; Sharma et al., 1989; Aggarwal et al., 2009; Singh, 1987, Singh, 2001; Rani, 2014, Kaundal, 2012; Banga,1978; Brar, 1999; Shiva, 1991).

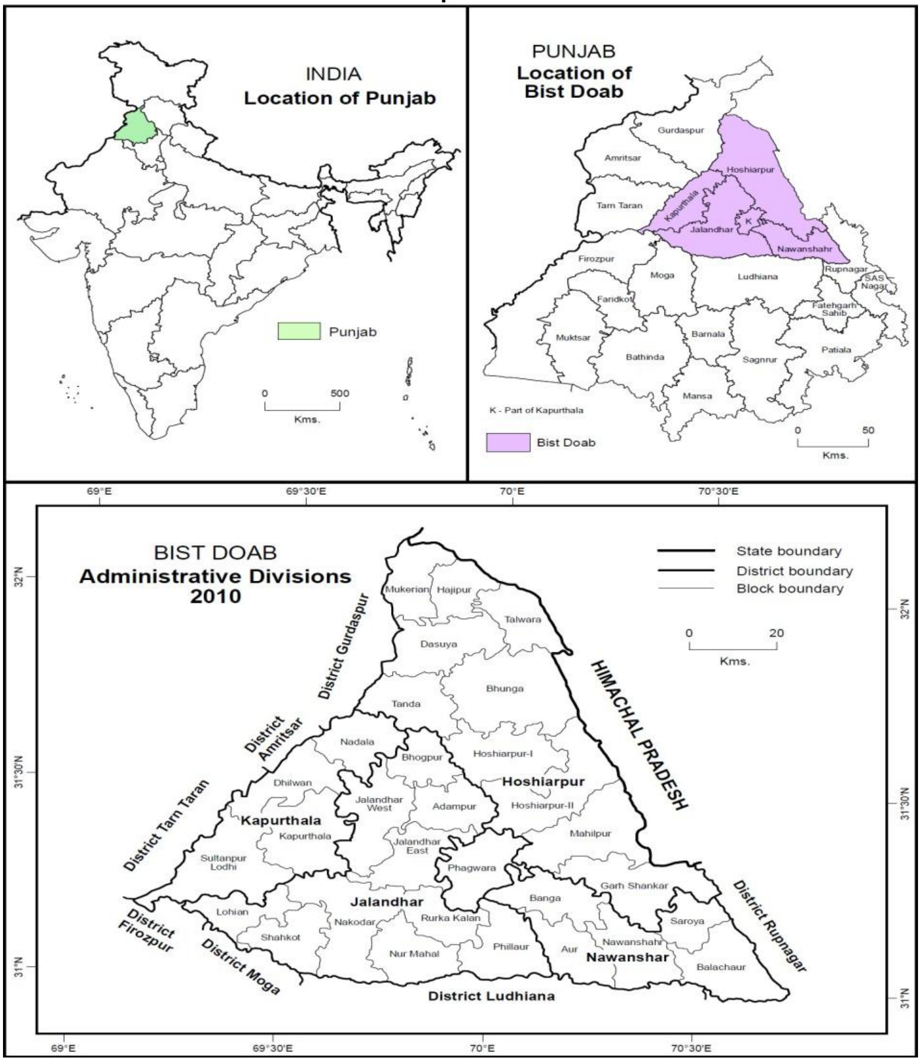
The concept of groundwater vulnerability was introduced by France in 1960's to aware people against groundwater health. Several ground water vulnerability assessment methods have been developed by researchers; but, all reports classify ground water vulnerability assessment methods into three categories such as overlay and index methods, methods employing process-based simulation models and statistical methods. The DRASTIC model is most simple and one of the widely used vulnerability mapping method, which belongs to the overlay and index category. Now a day, lots of studies of ground water vulnerability have been evaluated (Al-Adamatet al., 2003; Thapinta and Hudak, 2003; Rahman, 2008; Atkinson et al., 1992; Zhang et al., 1996; Mohamed, et al., 2016; Prasad and Shukla, 2014; Gupta, 2014; Harter and Walker, 2001; Babikar, et al., 2005; Baalousha, 2006; Sharma, et al.2014).

DRASTIC Model, which is proposed by Aller et al., 1987, has been used to assess groundwater potential to pollution in the study area.

Study Area

Bist Doab is a triangular shaped region of Punjab. The area bounded by Sutlej on the south, Beas on the North West and Siwalik ranges running in the NE-SE. The area received its name (Bist Doab) at the time of Emperor Akbar. Bist drives by combining the first letters of the name of the Rivers Beas and Sutlej. Doab drives its name from the Persian words 'Do' and 'Ab'. 'Do' means 'two' and 'Ab' means rivers- a landmass lying between two rivers. The study area covers an area of 8915 sq, km, 37 towns and has 5580 villages. The region consists of four district and thirty one blocks. It extends from 30^0 57' to 32^0 7' North latitude and from 75^0 4' to 76^0 30' East longitude. It is surrounded by Malwa in South after SutlejRiver and Majha region in the NW after Beas. Himachal Pradesh lies to its eastern side behind the Siwalik ranges. Bist Doab looks like a triangle with its base in south formed by course of river Sutlej. Its apex lies in North to the Mukerianblock that is the part of Hoshiarpur district. It constitutes 17.8 percent of the total area ofPunjab.

Map 1.1



Physiography

Whole of the Bist Doab is a flat plain. Physiographically it may be divided into two major regions:

1. TheHills
2. ThePlains.

The Hills

The hills cover only 12.8% of the total area of the Bist Doab. They lie in a narrow belt along the eastern boundary of the region. The height ranges from 500 to 750 meters above sea level. This region has scanty natural vegetation and this resulted in the severe erosion by running water. The hills are so badly denuded that they give appearance of bad land topography. Underground water table in this region is very deep. Agriculture depends mostly on rainfall. Due to scarcity of water, agriculture is practiced only on a limited proportion of this area. Agriculturally it is least developed area of the BistDoab.

The Plains

The plains cover 87.2 percent of total area of Bist Doab. They range an elevation from500m in the north east to 213 m in south west. The alluvial soils of these areas are fertile, easily workable, respond well to irrigation and fertilizers and therefore excellent for raising crops. These areas in general are flat. But on the bases of micro-variations they may be subdivided into threeparts:

Flat Upland Plain

Upland plain covers central part of the Bist Doab. It accounts for about 47% of the total area of the study region. It covers most of the Jalandhar district and adjoining parts of the Kapurthala district. Slightly higher than the adjoining flood plains; these are the flats and featureless except some local minor irregularities. The area having elevation varying from 216 m in the southwest to 254 m in north and to277 m in the south east. It is composed of deep alluvium. The depth of sub-soil water in this tract ranges between 5 to 10 m. The aquifers were full of water and thus furnish a rich reservoir for the development of tubewell irrigation but at present due to over exploitation these are in critical condition. There is extremely gentle gradients drainage problem in some of itsparts.

Flood Plains

Flood plains of the Beas and Sutlej rivers constitute a unique type of terrain unit. It is known as bet, running along both sides of these rivers. The flood plains form irregular linear strips ranging in width from 4 to 12 miles. It constitutes 14.7 percent of the total geographical area of the Bist Doab. The bet of Beas is more marshy and wider in extend as compare to the bet of Sutlej. The area is wider in the east, narrow in the center and wider in the west. It's loamy and silt loam soils are very fertile, water table is high. The flood plain region is highly suitable for cultivation of rice during Kharif season and wheat during Rabi season.

Choes and Plains along the Siwalik Hills

Choes are situated at the foothills of the Siwalik mainly in Hoshiarpur district. As its name indicated this terrain unit is infested with a large numbers of seasonal streams known as Choes, sloping in the East West direction. It varies in elevation from 900 to 1500feet.

Plains are spread immediately next to the Siwalik Hills towards their west and cover parts of Dasuya, Hoshiarpur, Garhshankar and Balachaur tehsils. It slopes from the hills to plain and varies in elevation from 500 m at the foot of the hills to 250 m towards the plains. A large number of seasonal streams emanating from the neighbouring hills traverse this sub region. As a result it suffers from large scale dissection and soil erosion. The sub soil water is deep and inadequate. Degraded soils, considerable dissection and deep water table have restricted the development of irrigation and agriculture in this part of the Bist Doab.

Climate

The Bist Doab is characterized by a continental semi-arid to sub humid climate, with sharply varying winter and summer temperature. The summer season (April to October) is very hot and June is the hottest month with the average temperature of 34ºC. The highest temperature during these months frequently touches 40ºC. This hot spell is broken by the onset of monsoon in the first week of the July, thus the temperature comes down. Winters (October- March) are fairly cold with an average temperature of 12ºC and January is the coldest month. During this month temperature reaches 0ºC.

Vegetation

Except in the Siwalik Hills, natural vegetation has been removed from the face of Punjab due to the extension of settlements and for the purpose of agriculture. The natural vegetation of the region is of dry deciduous type. However intensive cultivation necessitated by population pressure and lack of arable land has resulted in clearance of entire upland plain for agriculture. The forests are found in hilly and foothills parts in the east, while the fertile and flat plains are sparse in vegetation. Vegetation includes*Kikar*(*Acacia arabica*), *Ben* (*Zizyphusjujuba*), *Sheesham/ Tahli*(*Dalbergiasissoo*),*Dhrek*(*Melia azedarach*), Mango/ *Amb*(*MangiferaIndica*), *Neem* (*AzadirachtaIndica*), *Pipal*(*Ficusreligiosa*). Mangotrees are found scattered or in small groves. Man has planted many useful trees along roads, railway lines, canals, around settlements and irrigationwells *Pipals*and*Borhs/ Barh*are associated with settlements and wells. These are grown mainly for the purpose of shade. *Safeda*(*Eucalyptus)* and Poplar (*Populus*) are planted along the seasonal streams and on hill slopes to check surface run-off and soil erosion. The wood of *Kikar,* Mango, *Sheesham*and Bamboos is used for making house structure, agricultural implements, furniture and other domestic articles.

Apart from trees, rough grasses like *Kans*(*Saccharumspontaneoum*) and *Reeds* (*Phragmites*) are found along Choes of foothill plains. These are used for making paper, ropes, mats and also provide material for thatching roofs, making basket, fuel and for brooms.

Materials and Methodology

DRASTIC Model with GIS and Erdas has been used to assess groundwater potential to pollution (and exploitation) of the study area. It is one of the most widely used method. One advantage to use this model is that required inputs are generally available or easy to obtain from the government organisations. This type of assessment gives fairly results of the vulnerable area. This study will help to focus on management plans to procure the vulnerable area.

The DRASTIC model is using the hydro geologicalfactors that include the major seven geological and hydro-geological factors controlling groundwater movement of the region. The word DRASTIC is comprising by the initial letters of these seven factors e.g. (D) refers to Depth of the groundwater, (R) refers to the net Recharge, (A) refers to the Aquifer media, (S) refers to the Soil media, (T) refers to the Topography of the region, (I) refers to the Impact of vadose zone, (C) refers to the Hydraulic Conductivity of the aquifer. However data for impact of vadose zone and hydraulic conductivity were not available, therefore geology map was used to know the impact of the vadose zone and permeability above water level data was used to know the hydraulic conductivity of the study area. Thedata used in the DRASTIC Model has been collected from various government organisations and reports and the list of data was given below in the table1.1.

Table 1.1

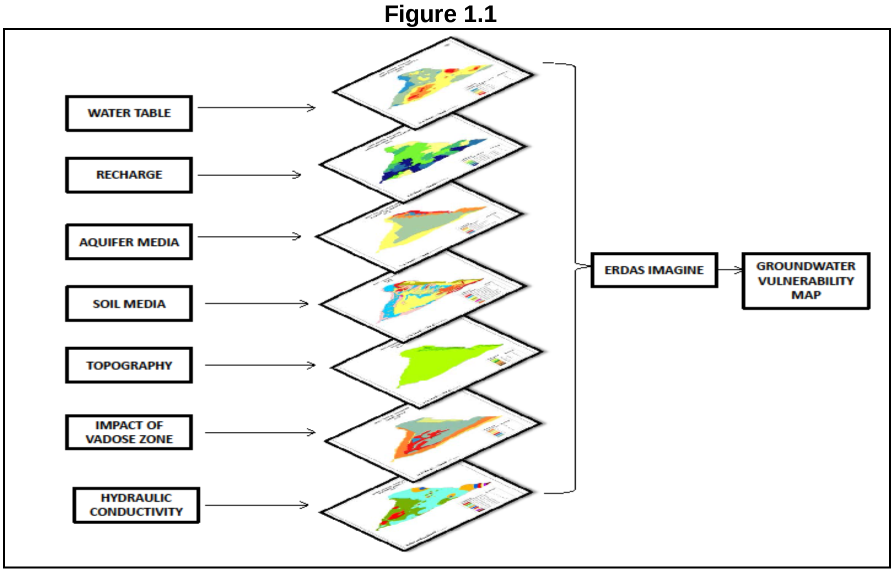
S.No.	Data Type	Source	Format	Output Layers
1	Water Depth	Water Resource &Environment Directorate, Punjab	Table	Depth of Water (D)
2	Recharge	Water Resource &Environment Directorate, Punjab	Table	Recharge (R)
3	Aquifer	CGWB	Map	Aquifer Media (A)
4	Soil	NBSSLU	Map	Soil Media (S)
5	Slope	DEM	Map	Topography (T)
6	Geology	GSI	Map	Impact of Vadose Zone (I)
7	Permeability	Water Resource & Environment Directorate, Punjab	Table	Hydraulic Conductivity (C)

Here, all the seven hydro-geological raster layers have been used to produce final vulnerability of the ground water. Standard values for all the parameters regarding their weight and rate are given in the table 1.2. Each parameter is classified into class on the scale of 1-10 in which 1 denotes least vulnerable while 10 denotes to high vulnerability. This rating is further scaled into weights based on the importance of the parameters from 1-5, where1 denotes to the least important or significant to analyse vulnerability and 5 is more significant and important. The flow chart of the methodology for the ground water vulnerability analysis is given in the figure 1.2. The DRASTIC model or index was calculated in ERDAS Imagine using theequation

$$DI= D_rD_w+ R_rR_w+A_rA_w+S_rS_w+T_rT_w+I_rI_w+C_rC_w$$

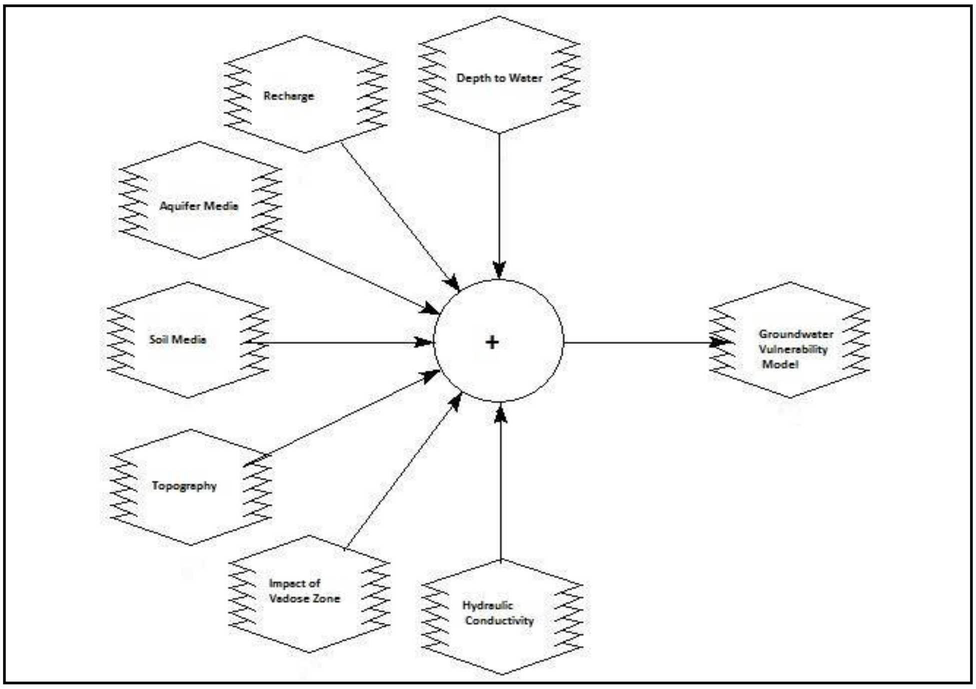
r denotes to rating of the factor and w denotes to weight assigned to thefactors.

Figure 1.1



Firstly ratings were given to all seven layers in arc GIS software and then multiplying the ratings with appropriate DRASTIC weight in ERDAS Imagine (Figure 1.1). Finally, DRASTIC Index (DI) has been expressed numerically through calculating algebraic sum of the ratings and weights of all the factors.The range has been given by using quantile classification method to develop the desired pattern in the map. Through this method, range has been distributed into equal groups of interval, where DRASTIC value is going high, groundwater becomes more vulnerable. Final vulnerability range came out to be 93 to 138.

Figure 1.2



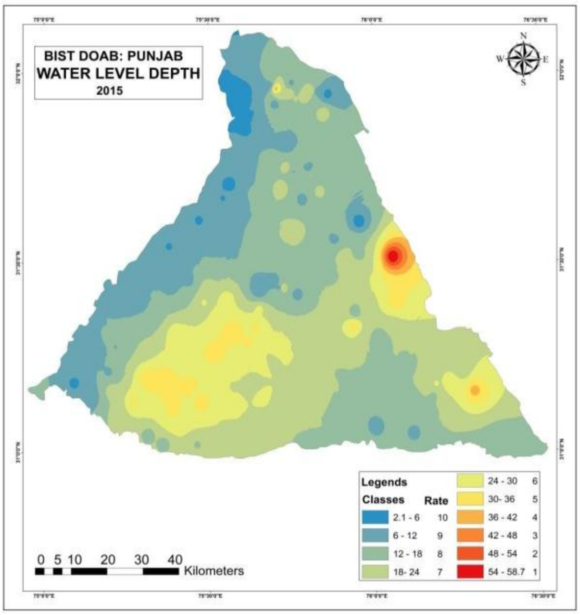
Analysis and Results

The DRASTIC model was used to produce the map of groundwater vulnerability of the study area.

Depth to Water Table

Depth to water table means the depth from the ground surface to the water table. The depth to water is important because it determines the depth of material through which a contaminant must travel before reaching the aquifer. Deeper water table levels imply lesser chance for contamination to occur. The data on depth of water table has been collected from tubewells by Water Resource and Environment Directorate, Mohali (Punjab). Total 168 locations have been taken as average of groundwater depth for the year 2015. The data has been interpolated using the technique Inverse Distance Weight(IDW) interpolation inspatial analyst tool in Arc GIS. Maps of depth to water table range, rating, weight and index have been prepared. The depth of groundwater table varies from2.45 to 40.5 mbgl. Depth to water table has been classified into 10 classes from 1 to 10. The highest depth was assigned by lowest rate 1 and the lowest depth was assigned by highest rating 10.

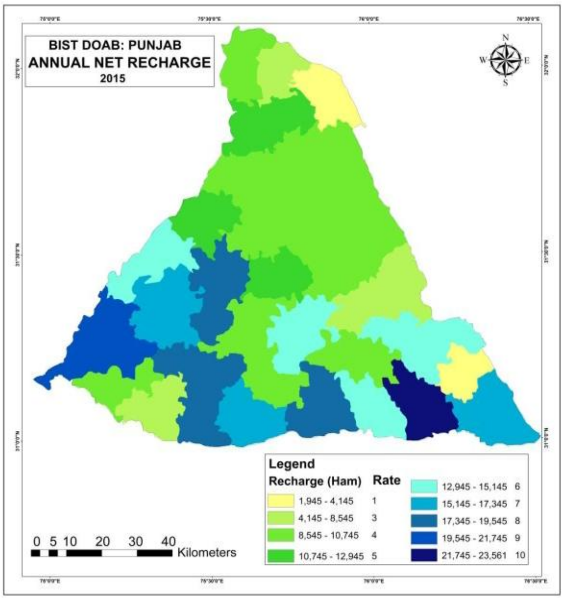
Map 1.2



Net Recharge

In spite of depth to water table, net recharge is another important factor for groundwater vulnerability, as contaminants moves with the water (from rainfall, surface water of canal, return flow from irrigation, tanks, ponds and with the water conservation structure) through infiltration and goes down deep in the aquifer media. The leakage of water increases the potential for recharge to penetrate pollutants into the aquifer.In the study area recharge practices has been enhanced by artificial recharge through the construction of reservoirs, tanks and ponds in the Siwalik Hills and irrigation practices inthe whole study area. Data on net recharge has also been collected in tabulation form from Water Resource and Environment Directorate, Mohali (Punjab) for block level in unit of hectare per meter (Ham). Maps of annual net recharge have been prepared through the choropleth technique in ArcGIS and Erdassoftwares. Net recharge has been classified into 5 categories rating from 1 to 10. Net recharge has been ranging from 1945 to 23561 Ham. Rank 1 was assign to low rate of recharge whereas rank 10 was assigned to high rate of recharge (Map1.2).

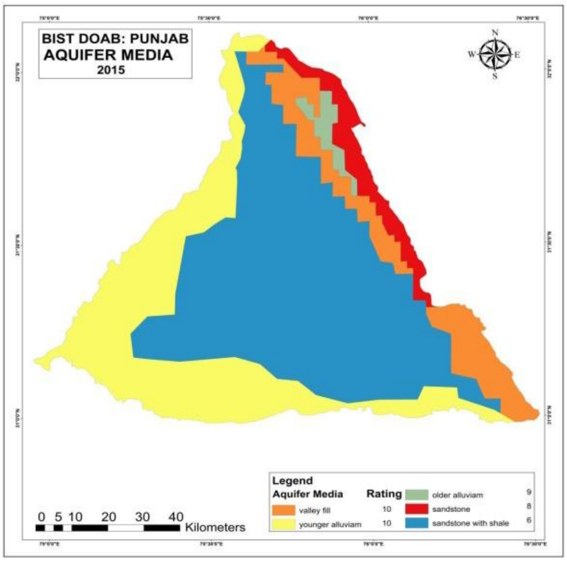
Map 1.3



Aquifer Media

Aquifer media refers to the consolidated or unconsolidated medium which serves as aquifer. This parameter represents the geological structure of the aquifer, through which seepage of water have to travel to reach ground water table. Geological structure layers have different degree of permeability and rating is assigned to each of them based on their permeability. Aquifer media map has beengenerated from CGWB reports. It was digitised and converted to raster format. Five classes of aquifer media has been identified in the study area. The newer alluvium and valley fill are most vulnerable and assigned to 10 rate. Older alluvium are less permeable as assigned by rate 9 followed by sandstone by rate 8. Whereas sandstone with shale have assigned by rate 6 due to least permeability in comparison to others (Map1.4).

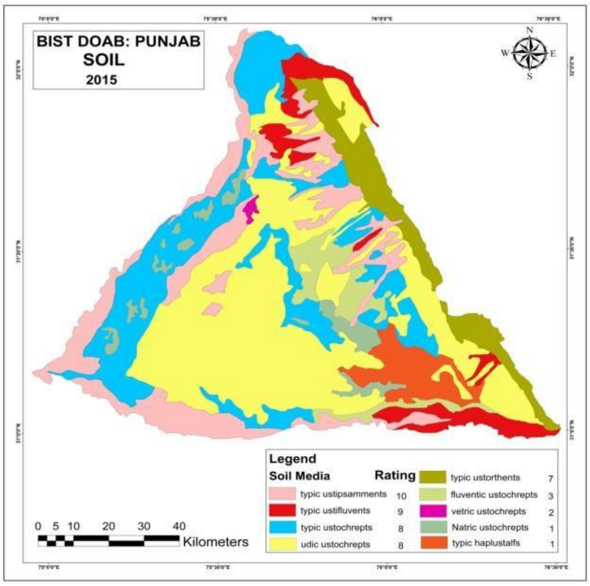
Map 1.4



Soil Media

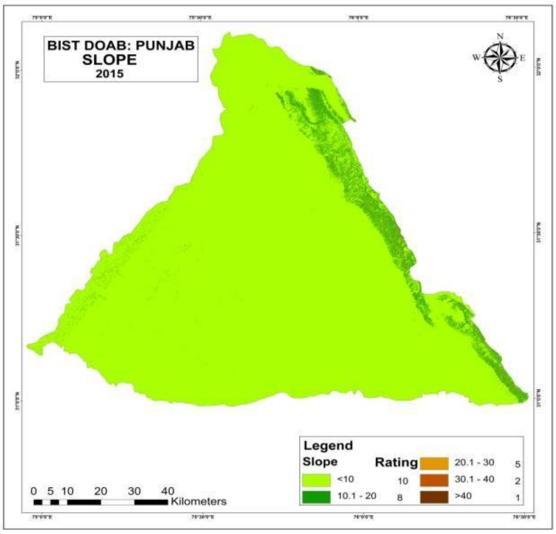
It refers to the topmost portion of the vadose zone. It is also known as weathered zone. It plays a significant role in the recharge of ground water. Water can penetrate vertically with the pollutants into the vadose zone. A soil map was prepared through the digitization process and further converted to raster format. It was collected from the soil map of Punjab by National Bureau of soil survey and land use planning. Soil of the study area has been classified into nine categories. The rating was assigned from 0-10 on the bases of the permeability of the soil e.ghigher permeabilityof the soil means higherrating (10) and lowest permeable soil means low vulnerability and rating by 1. Rate of the soil classes has been explained by table 1.2.

Map 1.5



Topography

It refers to the slope characteristics of the land surface of the study area. It plays an important role in the flow rate of the water that fall on thesurface. Siwalik Hills arehilly terrain and have high slope means high runoff and less time to penetrate the water into the aquifer. However the area with lower slope hold more water for long time allows more water topenetrate are more vulnerable and assignedwith the rank 10. For datapreparation ofslope aspect SRTM data was used toderive DEM. Slope map was prepared through the 3Danalyst tool in Arc GIS. Five slope classes have been Identified and explained under thetable1.2.

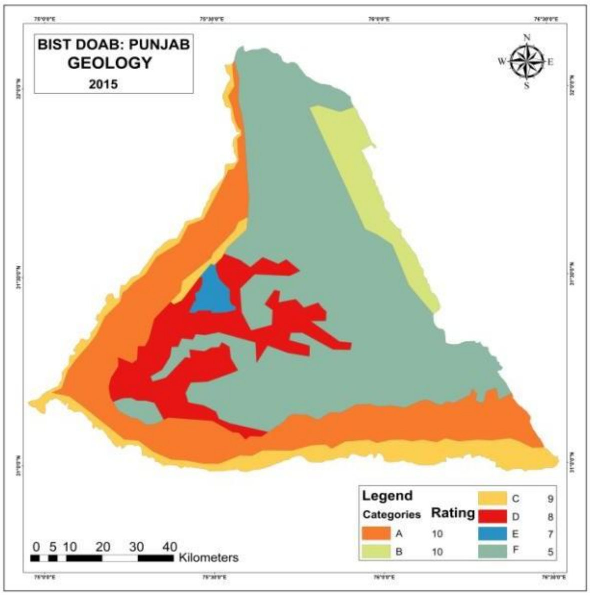


Map 1.6

Impact of Vadose Zone

It refers to the zone below the soil layer and above the water table, which is saturated or non-saturated. Like the other above said parameters, it also plays an important role in the percolation of groundwater recharge with all the contaminants into the aquifer. The vadose zone in the study area has been calculated through the geological map prepared

Map 1.7



by Geological Survey of India. All the geological layers have been extracted in shapefile and further converted into raster format. Total 6classes have been identified in Bist Doab. Blue grey to light grey micaceous sand with inter bands of purple and red clay have high vulnerability due to its permeability rate.

The rating for different vadose zone classes has been defined under the table 1.2. Representative classeshave been explained below.

1. Blue grey to light grey micaceous sand with inter bands of purple and redclay.
2. Friable grey micaceous sandstone, brown red purple clay andconglomerate.
3. Loose grey micaceous sand along the stream courses.
4. Undifferentiated Aeolian flat/sand sheets and newerdunes.
5. Undifferentiated semi consolidated and stabilized older dunes with kankar and some carbonaceous material.
6. Red drift sandy loam with kankar, sticky clay, grey medium to course micaceous sand with kankarsubroundedtosubangularunsorted pebbles, gravel and cobble in adjoining foothills.

Hydraulic Conductivity

It refers to the rate at which the water flows in the aquifer saturated zone. Here, permeability in m/day data has been collected in table format and interpolation has been done in the spatial tool in Arc GIS. It was unpublished data collected fromthe 'Water Resource and Environment Directorate,Mohali, Punjab'. Hence contaminants transportation has been checked on the bases of permeability. 81 sites have been taken up to know the permeability of the groundwater. Low rate of permeability has shown low vulnerability and higher range of permeability has shown higher vulnerability of groundwater. The rate and distribution of permeability range has been given in the table1.2.

Map 1.8

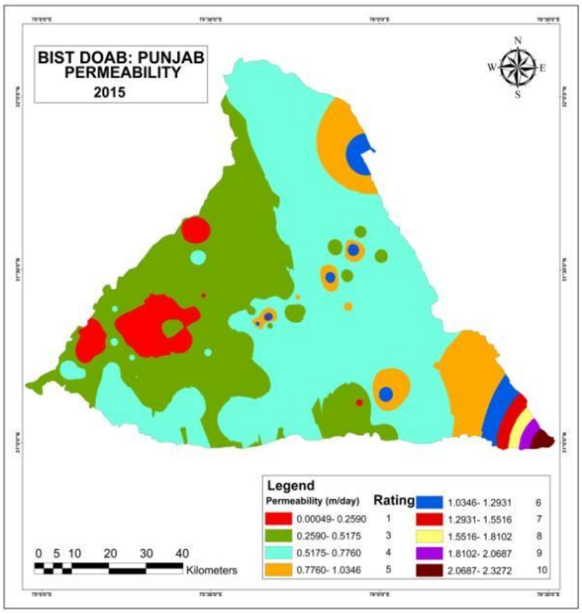


Table 1.2

SL. NO	DRASTIC PARAMETRES	RANGE	RATING	DRASTIC WEIGHT	TOTAL WEIGHT
1	DEPTH WATER TABLE	2.1-8.5	10	5	50
		8.5-16.5	9		45
		16.5-24.5	7		35
		24.5-30.5	4		20
		30.5-58.7	1		5
2	RECHARGE	1945-9045	1	4	4
		9045-12445	3		12
		12445-15045	5		20
		15045-17445	7		28
		17445-23561	10		40
3	AQUIFER MEDIA	Sandstone	8	3	24
		Sandstone with Shale	6		18
		Old Alluvium	9		27
		Newer Alluvium	10		30
		Fill Valley	10		30
4	SOIL MEDIA	TypicUstochrept	8	2	16
		TypicUstorthents	7		14
		Udic Ustochrepts	8		16
		TypicUstipsamments	10		20
		Typic Ustifluvents	9		18
		FluventicUstochrepts	3		6
		TypicHaplustalfs	1		2
		VetricUstochrepts	2		4
		NatricUstochrepts	1		2
5	TOPOGRAPHY (Slope)	0-10	10	1	10
		10-20	7		7
		20-30	5		5
		30-40	2		2
		40-50.7	1		1
6	IMPACT OF VADOSE ZONE (Geology)	1.	10	5	50
		2.	10		50
		3.	9		45
		4.	8		40
		5.	7		35
		6.	5		25
7	HYDRAULIC CONDUCTIVITY (Permeability)	0.000049-0.2590	1	3	3
		0.2590-0.5175	3		9
		0.5175-0.7760	4		12
		0.7760-1.0346	5		15
		1.0346-1.2931	6		18
		1.2931-1.5516	7		21
		1.5516-1.8102	8		24
		1.8102-2.0687	9		27
		2.0687-2.3272	10		30

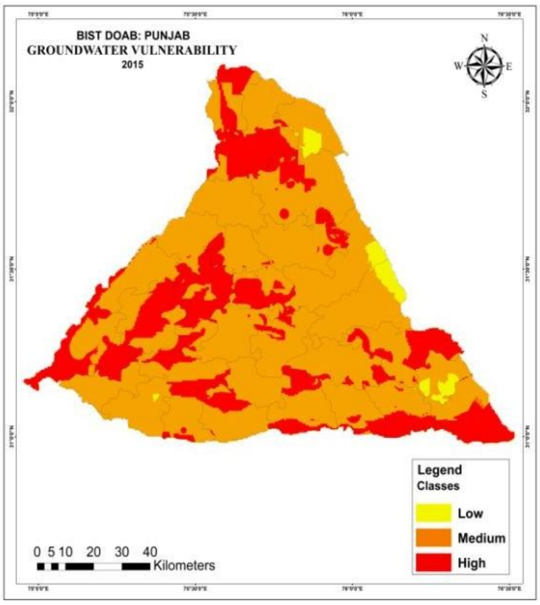
This model has identified the area, which are more likely to susceptible to ground water contaminants in relation to each other. The maximum DRASTIC score is 138 and lowest score is 93. The higher DRASTIC score indicates to greater ground water vulnerability. The DRASTIC score further divided into three classes: low vulnerability (93-108), moderate vulnerability (109-123), high vulnerability (124-138) (Table 1.3). The DRASTIC vulnerability map shows the predominance of moderate vulnerability and was seen all over the blocks of the Bist Doab which covered an area of 70.62%. About

2.32 % of the study area lies in the low vulnerable zone. This category partially covered the block of southern Talwara, pockets of Eastern Hoshiarpur-I and Hoshiarpur-II and southern Saroya block. It was also seen in small pockets of Shahkot. While 27.04% area lies in high vulnerable zone. Map shown that Jalandhar West, Adampur, Dasuya and SultanpurLodhi were fully covered by high vulnerable zone whereasMukerian, Bhunga, Hoshiarpur-I, Mehatpur, Nakodar, Nurmahal, Phillaur, Aur, Nawashaher, Balachaur, Mahilpur and Phagwara blocks were partially covered in high vulnerable zone. The high, medium and low vulnerability ranges has been assigned in category as given in table1.3.

Table 1.3

Groundwater Vulnerability		
Category	**Range**	**Area in %**
Low	93-108	2.32
Medium	109-123	70.62
High	124-138	27.04
Total	93-138	100

Map 1.9



The population of the study area is increasing with the passing years, so the demand of water for daily use and agriculture is also increasing to increase productivity of the fields. Hence the stress on groundwater also increases, which is the root cause of groundwater exploitation. Map shows that high vulnerable zones are high recharge zone and full precaution should be taken to procure any leaching of contaminants onit.

Conclusion

DRASTIC model was used to evaluate vulnerability of groundwater is a useful model for regional scale assessment. A GIS technique has provided efficient tools to handling and analysis of a large quantity of spatial data. On the bases of data, thematic maps have been constructed, classified and encoded employing various maps by GIS function, according to the expert's opinion. The results shown that 97.66% area was covered by moderate and high vulnerability zones in which 70.62% area was under moderate vulnerability and 27.04% was going to high vulnerability zone. These areas are mainly in the north-west, central parts and south- east corner of the study area where the physical factors like gentle slope, high permeable soil and high recharge zone are very well supporting the chances of getting shallow aquifer water polluted. It means there is an urgent need to sustain groundwater to avoid contamination of thegroundwater.

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