Evaluation of Groundwater Vulnerability to Contamination in Coimbatore District

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ABSTRACT

Groundwater usage in the world is widely reported to increase because of the uncertainties attached with the availability of surface water. Groundwater resources are looked upon as the alternate source of freshwater on account of its widespread and continuous availability in proximity to the point of use or living place, less vulnerability to contamination and low cost of extraction in both urban and rural area of developed and developing countries of the world. Such a scenario has led to the degradation and depletion of groundwater resources in many parts of the world. The study area, Coimbatore district, is a rapidly urbanizing and industrializing city in the southern part of India which relies upon the groundwater resources for meeting the agricultural, industrial and domestic requirements. In view of this evaluation of groundwater resources and an understanding of the vulnerability of the aquifer to contamination become essential for the effective management of groundwater resources. The vulnerability of the groundwater to contamination is assessed using DRASTIC and Pesticide DRASTIC index in the GIS environment. The study showed that the high vulnerability areas are characterized by shallow water table of less than 4 m, gentle topography, sandy loam soils, thinner vadose zone and underlying geologic formations with well-developed fissures and fractures.

Keywords: Groundwater, Vulnerability, GIS, DRASTIC,

1. INTRODUCTION

Groundwater is one of the most widely distributed and used natural resources. It forms an integral part of the earth's hydrological cycle by initiating much geologic process, sustaining fresh water sources and by supporting human water needs. The contribution from groundwater is vital. As many as two billion people depend directly upon aquifers for drinking water, and 40 per cent of the world's food is produced by irrigated agriculture that relies largely on groundwater (UNEP, 1999). In recent years, the uncertainties attached with the surfacewater availability on the earth's surface has increased the dependency on the groundwater resources.

The increased use of groundwater resources has greatly increased the contamination of aquifers from various point and non-point sources. The aquifers, once contaminated are difficult to remediate. Therefore, the prevention of contamination becomes a critical tool in the rational management of groundwater resources and subsequent land use planning.

Vulnerability assessment has been recognized for its ability to delineate areas that are more likely than others to become contaminated as a result of anthropogenic activities at or near the earth's surface (Babiker et al., 2005).It becomes an essential prerequisite in the regions where the groundwater resources are under greater stress because of the agricultural, industrial and urban activities

The concept of groundwater vulnerability to contamination was developed by Margat in France in 1968 (Margat, 1968). It is a relative, amorphous, dimensionless concept based on the assumption that the geological environment may provide some degree of protection to groundwater against the natural and human impacts, especially with regard to contaminants entering the soil-rock medium. Since then many approaches and methods were developed.

Considering all the factors, Vrba and Zaprozec (1994) distinguished aquifers vulnerability to contamination as intrinsic/ natural, specific and integrated vulnerability. The first two terms are defined solely as a function of geological, pedalogical, hydrological and hydrogeological factors and the latter two terms are defined by potential impact of specific land use /land cover and the contaminants over time and space.

Several methods and approaches were developed to assess the vulnerability of the aquifer such as process based, statistical and overlay-index method. The most widely used aquifer vulnerability assessment method is index and overlay method. In this method, hydro geological parameters are rated on a scale according to the contamination potential and relative weightages are assigned for each parameter which influences the probability of pollution in the aquifer. Several methods such as DRASTIC (Aller *et al.,*1987), GOD (Foster et.*al.*1987), AVI (Stempvort.1993),SINTACS (Civita, M. & De Maio, M.1997) DRARCH(Guo *et al.*2007), Susceptibility Index (SI) (Stigter et al., 2000) etc. have been developed over the years which assess vulnerability using various hydrogeological and anthropogenic components such as landuse/land cover etc. In recent years Geographic Information System (GIS) have been widely used in vulnerability studies.

2. MATERIAL AND METHODS
2.1 STUDY AREA

The study area, Coimbatore, is the second largest district and is located in the southern part of Tamil Nadu, India. It spreads over an area of 4714.22 km^2. Coimbatore is one of the rapidly industrializing and urbanizing cities in Tamil Nadu(Fig.1). Coimbatore district relies on the groundwater resources for its domestic, industrial and agricultural requirements to a great extent since it does not have any major perennial source of surface water supply. It has an extensive system of tanks fed by streams and rainwater, and this has been the major source of groundwater recharge for hundreds of years.

The study area enjoys a sub- tropical climate and the weather is pleasant during the period from November to January. It receives rainfall under the influence of both the southwest and northeast monsoon. What is the climatology of Coimbatore with regards to rainfall and temperature?

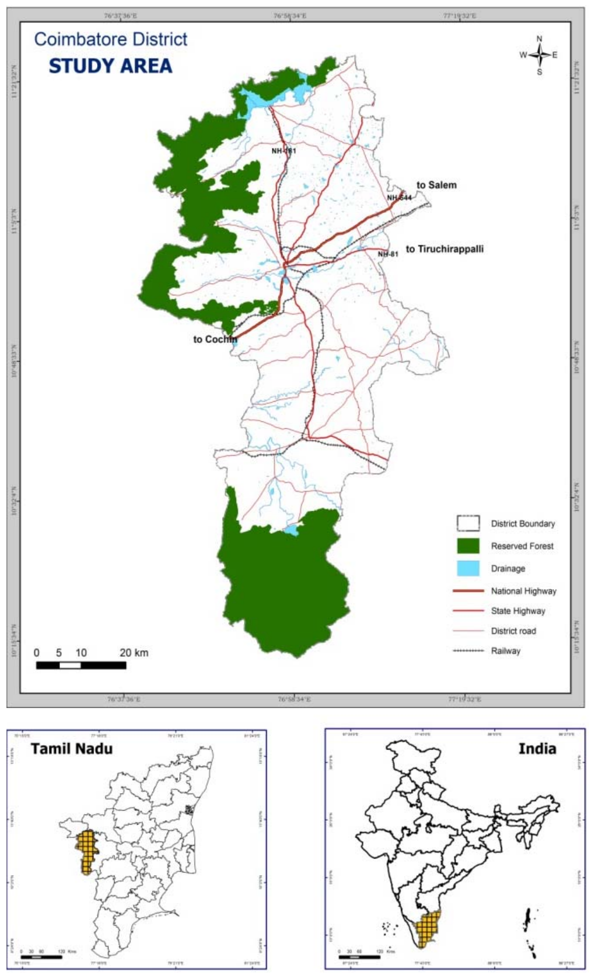

Fig.1 Location

The study area is underlain by porous and fractured formations, ranging in age from Archaean to Recent. The important aquifer systems in the District are constituted by (1) Unconsolidated formations and (2) Weathered and fractured crystalline formations (CGWB, 2014).The study area is dominated by hard rock formations with stretches of fluvial formations occurring in the western part of the study area adjacent to the river courses. The river alluvium occurs along the major stream courses. The hard consolidated crystalline rocks which occupy more than 50 per cent are represented by weathered and fractured Granites, gneiss, charnockites, khondalites and intrusive rocks. The study area being a hard rock region, the groundwater occurs in joints, fractures and weathered zones. The biotite gneissic rocks form better potential zones than the charnockite and granitic aquifers (Fig. 2).

The average depth of the ground water level is 12.43 m and the level fluctuates up to 5 m between the post monsoon and pre monsoon seasons. The shallow water table noted during the rainy season declines afterwards in February which indicates the influence of rainfall intensity and abstraction on the depth of the groundwater level. The higher yielding capacity of wells in the study area show a greater fluctuation in the groundwater level.

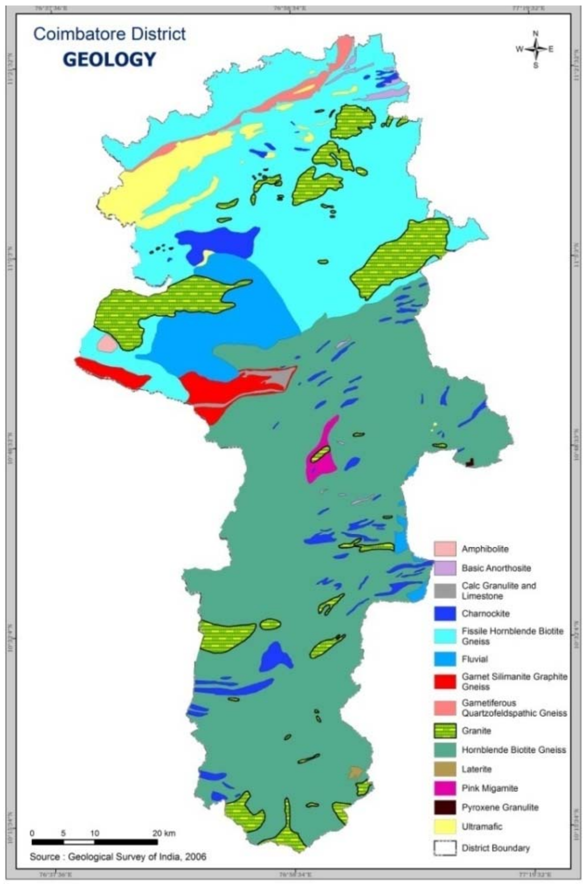

Fig. 2 Geology

It is widely reported that there has been degradation in water quality and quantity in the study area(CGWB, 2014).The quality of groundwater in Coimbatore District is witnessing serious risk of contamination as a result of increase in point and non-point source of pollution. The untreated effluents released into the water bodies results in eutrophication which is an indicator of severe contamination of the water resources. The excessive application of fertilizers and pesticides has resulted in the increased incidence of Total Dissolved Solids (TDS), Chloride and Nitrate in the top of unconfined aquifer. Also the water table (i.e., depth to water from ground level) of the study area has gone down drastically due to indiscriminate pumping of groundwater. In view of this an evaluation of groundwater resources and an understanding of the vulnerability of the aquifer to contamination is essential.

2.2. METHODOLOGY

The present study applied DRASTIC model, one of the widely used overlay and index method for assessing the aquifer vulnerability in GIS environment. It is a standardized numerical system developed by Aller et al., in 1987 for the United States Environment Protection Agency (USEPA) to evaluate the groundwater vulnerability to contamination in varied hydro geological settings. This method integrates the maps of various factors which controls the movement, residence time and attenuation capacity of the contaminants into the aquifer from various sources of pollution. In this method, parameters are rated on a scale according to the contamination potential and relative weightages are assigned for each parameter which influences the probability of the pollution in the aquifer. It is based on the assumption that contaminants on the ground surface are flushed into the groundwater by precipitation and the mobility of water.

The method uses seven physical and hydro geological factors i.e. Depth to water table (D), net recharge(N), aquifer media (A), soil media (S), topography (T), Impact of vadose zone (I) and hydraulic conductivity(C) (Aller et al., 1987).

A two tier numerical system called weight and rank is adopted based on Delphi technique (Aller et al., 1987). Each of the parameters is assigned with a weight ranging from 1 to 5 based on its importance (most important as 5 and least as 1). The weights are constant and cannot be changed. The parameter are rated with a rank ranging from 1 – 10 depending upon its role in impacting contamination and mapped in GIS. The final index is obtained by the weighted sum of the factors.

In the study, vulnerability is assessed using Pesticide DRASTIC model besides, Generic DRASTIC model. The drastic method results in intrinsic vulnerability based on physical factors whereas the other method assesses specific vulnerability with respect to agriculture and human activities.

The DRASTIC Index is calculated using the following equation.

Drastic index (Di) = DrDw + ErEr + ArAr + SrSw + TrTw + IrIw + CrCw

Where, ‘r’ is rank and ‘w’ is weightages.

In the agricultural areas it is better to rescale the weightages and ranking ranges of the drastic model parameters due to agricultural land use and nitrate concentration resulting from pesticides and fertilizers (Shirazi et al., 2012).

The pesticide drastic model uses the same parameters but with different weightages assigned to parameters such as soil media (S), topography (T), Impact of vadose zone (I) and hydraulic conductivity(C) (Secunda et al., 1998).

Table 1. Assigned Weightage and Ranks for the parameters used in DRASTIC (Aller et al., 1987) and Pesticide DRASTIC.

Parameters	Range	Rank	Weightage	
			DRASTIC	Pesticide DRASTIC
Depth to water level (in meters)	0-4	10	5	5
	4-12	9		
	12-20	7		
	>20	3		
Net Recharge	Poor	1	4	4
	Moderate	2		
	Good	3		
	Excellent	4		
Aquifer Media	Charnockite	7	3	3
	Fluvial	9		
	Gneiss	8		
	Granite	7		
	Intrusives	6		
	Khondalite	5		
	Laterite	4		
Soil Media (Based on Texture)	Clay loam	5	2	5
	Loamy sand	8		
	Sand	10		
	Sand Clay loam	6		
	Sandy loam	7		
Topography (in Percentage)	0-2	10	1	3
	2-6	9		
	6-12	7		
	12-18	5		
	>18	2		

2.3. Description of the Parameters

The following seven parameters which represent different hydrogeological settings and the human influence were used for the assessment purpose which affects the movement of the groundwater into, through and out of the aquifer (Saidi et al. 2011). Each of the parameters is classified into ranges or into significant media types and assigned with ranks ranging from 1 (least contamination potential) to 10 (highest contamination potential). The parameters are then given weights from 1 (least significant) and 5 (greater significance).

In the present study, the parameters are assigned with two different weights. The weight assigned to the Pesticide Drastic Models is different with more importance given to the Soil (S), Topography (T), Vadose Zone (I) and Conductivity (C).(.) The weightages and ranks for the models are given in Table 1.Theparameters were then mapped into thematic layers and analyses was carried out to delineate the zones vulnerable to contamination in the GIS environment.

2.3.1 DEPTH TO WATER LEVEL (D)

This refers to the depth of water level from surface. It is important because it determines the length of the path which a contaminant has to travel before reaching the water table. As the groundwater level goes deeper the chances of contamination decreases whereas the shallow water levels are associated with higher contamination risks.

The average depth to water level in the study area varies from 2.62 m to 40.22 m below groundwater level. The shallow water level of < 4 m bgl is noted in the gneissic rocks region whereas the deeper water table is noted in unconsolidated rock formation predominantly found in the western and central part of the study area. The groundwater level is found to be between 2 and 4 m in the southern region which receives rainfall from both the seasons are assigned with ranks ranging from 8 to 10 where the travel time of contaminant is less. The deeper water table (>12 m bgl) which is reported in the central and western part of the study area may be attributed to the widespread overdraft of groundwater for irrigation purpose and domestic purpose where the population concentration is higher. The areas with shallow water tables are assigned with higher ratings indicating higher vulnerability (Table 1) (Fig. 3).

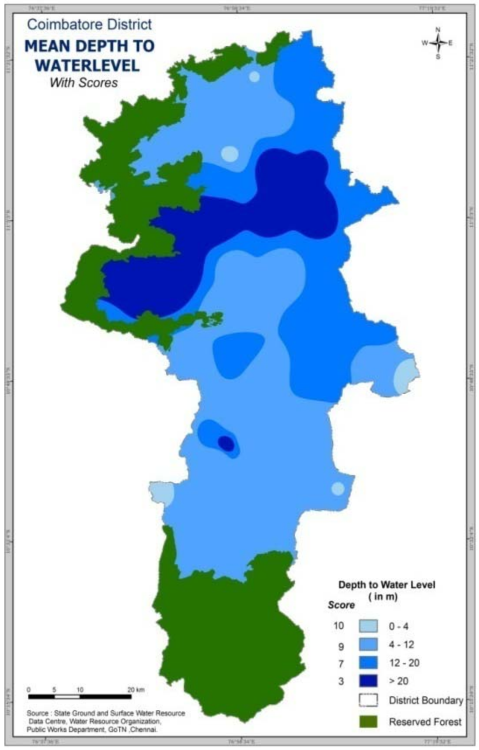

Fig. 3 Depth to Water Level

2.3.2 NET RECHARGE (R)

Net recharge (R) is the total quantity of water that infiltrates from the ground surface to the water table on an annual basis. It is the principal factor for percolating and transporting contaminant vertically to the water table and horizontally within the aquifer. The higher the recharge, the greater the chance of contamination.The higher recharge potential is given with higher ranks (Table 1).

The recharge is found to be high in the region such as southern part of the study area and rank of 4 is assigned. And higher recharge potential is found in the region which is underlain by limestone formation which has high permeability. The higher recharge potential is reported not in the region with high rainfall (>850 mm) but in the areas with rainfall between 500 – 700 mm where the slope percentage is less than the 2 per cent and the soil permeability is higher due to the highly weathered rock structures(Table 1)(Fig. 4).

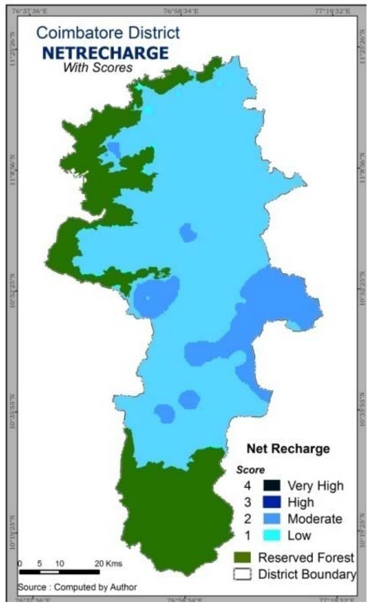

Fig. 4 Net Recharge

2.3.3 AQUIFER MEDIA (A)

It refers to the nature of geologic formation (consolidated / unconsolidated) which yield sufficient water for use. It controls the route and path length of a contaminant which in turn determines the attenuation or purification capacity. The aquifer media in the study area is composed of hard rock formation like gneiss occupying 77 % of the study area followed by charnockite, fluvial and granites.

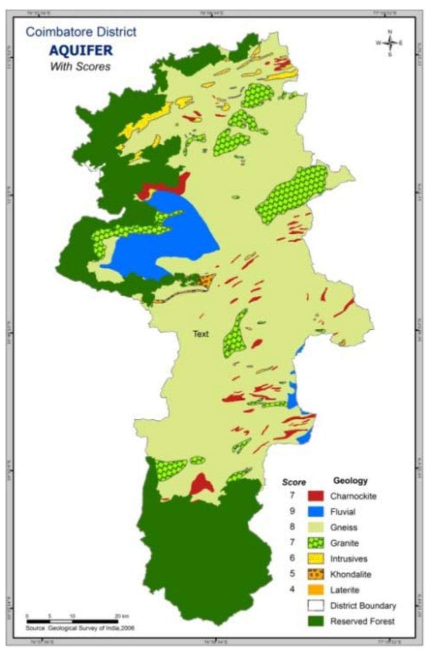

Fig. 5 Aquifer Media

The unconsolidated formations are found in the western part along the course of the river Noyyal and granitic rocks are found spread over the study area. The charnockite aquifer is dominantly found adjacent to the river course in the south eastern and western part of the study area. The deeply weathered and fractured rocks are assigned with higher ranks of 7-9 (Table 1) (Fig. 5)

2.3.4 SOIL TEXTURE (S)

Soil has a significant impact on the amount of recharge which can infiltrate into the ground. Presence of fine textured materials in soil like clay, silt and organic matter decreases the permeability and restricts the contamination loading.

The soil media of the study area is classified based on texture into clay loam, loamy sand, sand, sandy clay loam and sandy loam. The soil is found to be loamy sand in the northern, eastern and southern part of the study area. The sandy clay loam soil is also found extensively over the study area. These soils have restricted infiltration capacity with 10-20 per cent of clay content which considerably reduces the permeability rate.

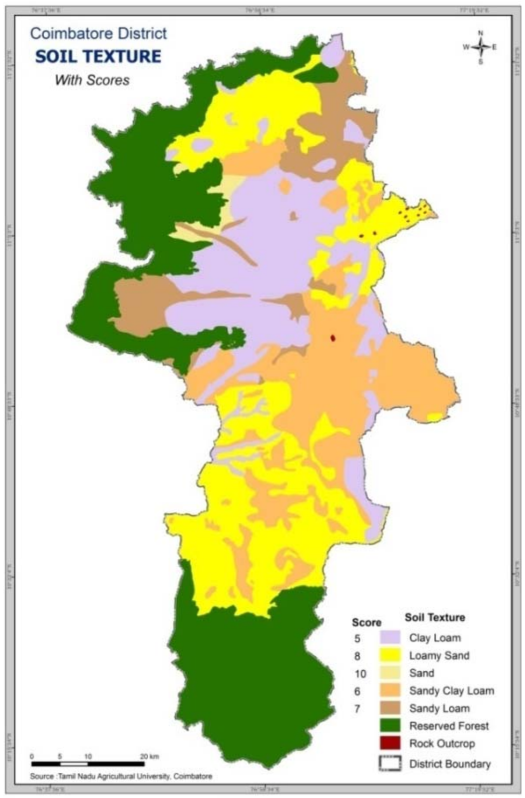

Fig.6 Soil Texture

The clay loam textured soil (>40 per cent clay) is found in the central part and appears in narrow patches around the study area and lower rank of 2 to 4 is assigned. They have high shrink and swell potential which delays the entry of contaminants into the subsurface and hence reduce the level of contamination to some extent. The sandy soil is assigned with the high rank of 10 because of the high infiltration which may transport large amount of contaminants (Table 1) (Fig. 6)

2.3.5 TOPOGRAPHY (T)

Topography or the slope variability of the land surface is a significant factor in controlling the travel time of the contaminant. The slope of the study area has been reclassified and assigned ranks and weightages (Table1). The gentle topography would result in the contaminant remaining on the surface for a long time whereas in the steep slopes, the contaminant materials will flow as run off reducing the rate of infiltration.

The study area is an undulating plain region with slope gradually decreasing from west to east. The higher slope of more than 18 per cent is found in the northwestern and southern part of the study area. The higher rank is assigned to gentle slope (< 2º) which facilitates low run off having greater contamination potential (Fig. 7).

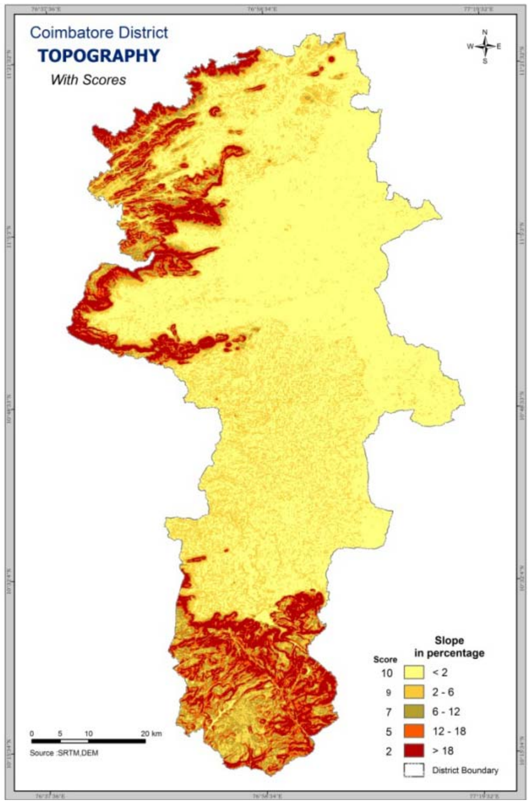

Fig. 7 Topography

2.3.6 IMPACT OF VADOSE ZONE (I)

It refers to the unsaturated zone lying below the ground surface and water level. The impact of vadose zone is the ability to control water movement and attenuation capacity. It has high impact on water movement if it is composed of permeable materials.

The vadose zone is found to be with higher contamination potential i.e. high impact in the areas with high infiltration (< 4mm), sandy loam and loam textured soil. The contamination potential is also high in highly weathered gneissic rocks which possess well developed fractures and joint systems which in turn favours the percolation of more water into the subsurface with less time to attenuate the contaminant plume. They are assigned with rank ranging from 8 to 10 (Table 1). The presence of restricted drainage condition to some extent reduces the contaminant infiltration by slowing down the movement of water which in turn increases the attenuation capacity. The central and western part of the study area has lower impact due to the texture of the soil which is composed of higher clay content and less development of fractures and fissures in the rocks (Fig.8).

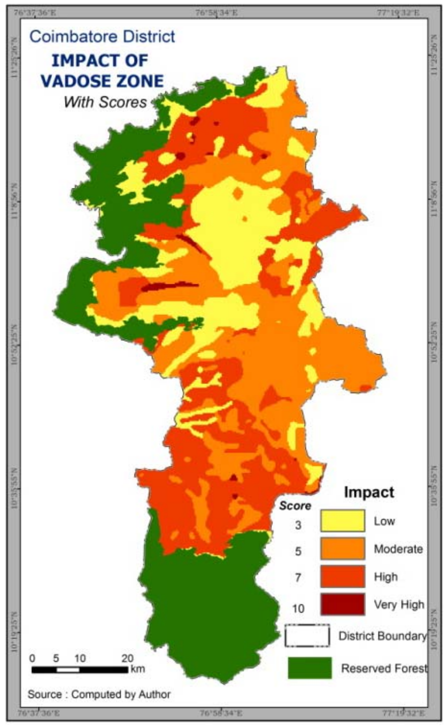

Fig. 8 Impact of Vadose Zone

2.3.7HYDRAULIC CONDUCTIVITY (C)

It refers to the ability of an aquifer to transmit water. It plays a significant role in controlling the migration and dispersion of contaminants from the source point within the saturated zone and consequently plume concentration in aquifer. The weightage assigned is 3 for DRASTIC model and 2 for PDRASTIC model (Table 1).

The study area, which is underlain by hard rock formations with deep weathering has a high ability to transmit water along with the presence of loamy textured soil, has a rank of 9 indicating the higher contamination potential. The northern part of the study area, despite the presence of loamy texture with underlain pediment structure, transmits lesser amount of water. This reduces the contamination potential in the study area (Fig.9).

The unconsolidated formations with sand and gravel content have moderate conductivity (40-80 m/day) because of the presence of higher clay content. The limestone formations in the western part have higher conductivity where the dissolution of carbonate minerals may increase the contamination potential.

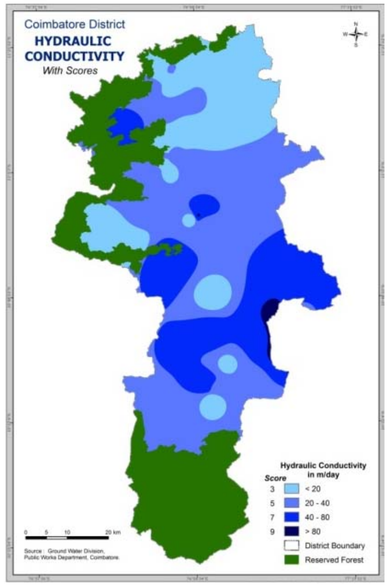

Fig. 9 Hydraulic Conductivity

3. Results and Discussion

3.1. Vulnerability Mapping

Vulnerability mapping involves combination of thematic maps of selected physical and geologic factors into a groundwater vulnerability map which identifies different areas of the sensitivity of groundwater to natural and human impacts. Vulnerability maps are valuable guides in planning and can help planners make informed, environmentally sound decisions regarding land use and protection of groundwater quality. Secondly, vulnerability maps can be used for the first cut screening of an area for regional planning, which would allow planners to direct emphasis to areas of highest priority (Vrba and Zeporozec, 1994).

3.1.1 Generic DRASTICModel (DRASTIC Index)

The assessment of vulnerability to contamination using generic DRASTIC method shows that about 81 per cent of the study area has moderate to high vulnerability. This method takes into account only the hydro geologic factors for assessment purpose. This model shows only 0.52 per cent of the area as extremely high vulnerable areas. The vulnerability is found to be high to extremely high in the southern part of the area where intensive agriculture is practiced. In the north western part, along the Bhavani river course high vulnerable areas are identified. (Fig.10).

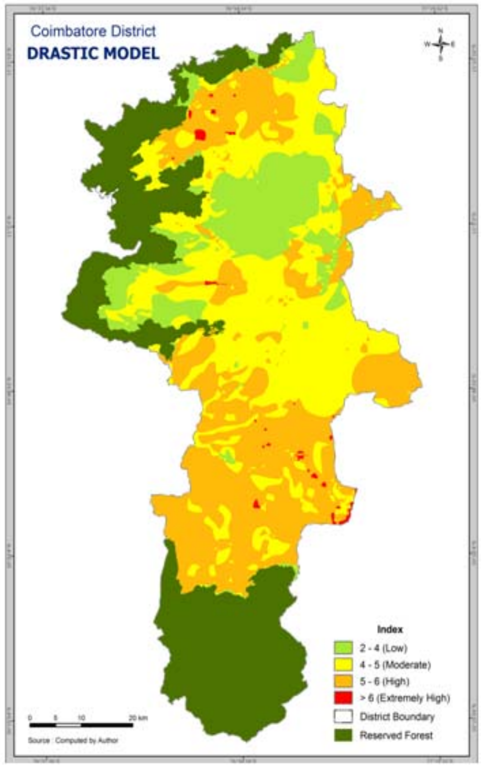

Fig.10 DRASTIC Model

3.1.2Pesticide DRASTIC Model (PDRASTIC Index)

In the pesticide DRASTIC Model weightages assigned to parameterssoil media (S), topography (T), Impact of vadose zone (I) and hydraulic conductivity(C) has been modified. It was created to assess the agricultural process that determines the fate and transport of a non-adsorbed, non degrading solute leaching to groundwater.

The weightages assigned has been increased for S (from 2 to 5), for T (from 1 to 3) on the assumption that these parameters has more influence in increasing contamination whereas for the parameters I the weightages has been decreased (from 2 to 5) and C (from 1 to 3) The modification in the weightages assigned to the parameters has resulted in the subsequent increase of the area represented under high to extremely high category.

In the Pesticide DRASTIC method cumulatively 62 per cent of the study area falls under high to extremely high as against 42 per cent cumulatively in the Generic DRASTIC method. (Table 2)

Table 2 Areal Extent of Vulnerability Zones – Coimbatore District

Vulnerability Zones	Low		Moderate		High		Extremely High	
Vulnerability Index	Area* (in km^2)	%	Area* (in km^2)	%	Area* (in km^2)	%	Area* (in km^2)	%
Drastic	616.48	18.17	1337.71	39.44	1420.38	41.87	17.51	0.52
Pesticide Drastic	323.45	9.54	964.16	28.42	1569.18	46.26	535.29	15.78

The extremely high vulnerability areas are found in the northwestern part and in the southern parts of the study area. It is observed that the agricultural land and the settlement areas are more vulnerable to contamination. (Fig.11).

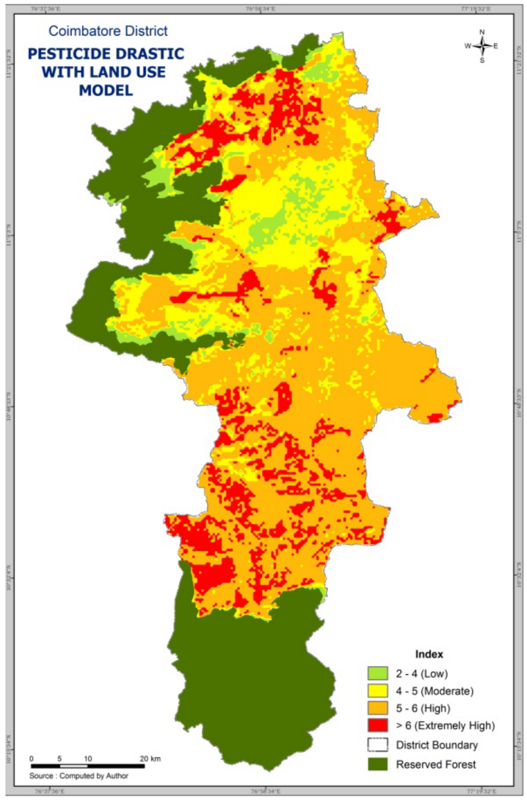

Fig.11 Pesticide DRASTIC Model

4. CONCLUSION

The present study assesses the groundwater vulnerability to contamination in Coimbatore district using Generic DRASTIC and Pesticide DRASTIC in GIS environment. The vulnerability map obtained from the DRASTIC method gives locations which must have high priority in terms of protection and pollution prevention (Sener et al.., 2009).

In the DRASTIC Method of assessing vulnerability, 81% of the total study area is found to be with moderate to high vulnerability (moderate- 39.44% and High 41.87%) and only 0.52 per cent of the total area is identified as extremely high vulnerable areas.

In the Pesticide DRASTIC Method the weightages of parameters S and Thas been increased whereas weightages has been decreased for I and C according to their potential in increasing the contamination probability of the aquifer. Such modification in the weightages assigned to the parameters has resulted in the subsequent increase of the area represented under high – extremely high category. The cumulative percentage of area under high – extremely high vulnerability was 62 per cent which is against 42 per cent of the study area in the Generic DRASTIC method.

The results of the study showed that zones with higher vulnerability are found in the south, central and northwestern part of the study area. It is observed that vulnerability is high in the areas adjacent to the water bodies and in the intensively cultivated areas. The high vulnerability areas are characterized by shallow water table of less than 4 m, gentle topography, loamy sand textured soils, thin vadose zone and underlain geologic formations that have well-developed fissures and fractures. The areas adjacent to the elevated region characterized by thicker vadose zone, steep slope and lower conductivity in the central part are identified as areas with less vulnerability to contamination in DRASTIC and PDRASTIC model

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