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Groundwater Vulnerability Assessment using DRASTIC Method in Jabalpur District of Madhya Pradesh

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Abstract: ***Groundwater is indispensable to humankind, but with increasing load over this precious resource it has become necessary to study it in detail with geological as well as hydro-geological aspects to understand the nature of the groundwater resource of a region and also include socioeconomic aspect in order to manage it well and use it in a sustainable way, vulnerability assessment of the resource is conducted to highlight the areas which are more susceptible to degradation and later on suitable decision can be taken to safeguard the resource. In the present study such as attempt has been made to account the groundwater vulnerability using as overlay index method, DRASTIC, which is used to prepare a vulnerability map using GIS, of the study area, Jabalpur District, Madhya Pradesh. This method accounts for the aquifer parameters like depth to water, net recharge, aquifer media, soil media, impact of Vadose zone and hydraulic conductivity. The DRASTIC Vulnerability index (DVI) is calculated as the sum of product of ratings and weights assigned to each of the parameter on the scale of 1 to 10 and 1 to 5 respectively. The vulnerability index ranges from 47-209 and is classified into three classes and it was deduced that approximately 15%, 76% and 9% of the area lies in low, medium and high vulnerability zones. Further the study of population growth water demand by various sectors are also assessed to find the overall vulnerability in terms of groundwater development which shows that if the current trend of growth in population industrial and agricultural sector continues, soon the district will fall into exploited zone. The map formed can be used for the management decision for sustainable use of the aquifer.***

Index Terms: ***Jabalpur District, Ground water vulnerability, DRASTIC parameters, Geographic Information System GIS)***

I. INTRODUCTION

Groundwater is one of the major sources of replenish-able water on the earth and constitutes approximately 30.1% of fresh water from the total water of which only 0.86% is fresh water and total available water is 0.022%. The groundwater is comparatively safe and reliable source as compared to surface water. Though not easily polluted, but once it is polluted it's exhaustively expensive, time consuming and extremely difficult to remediate this precious source of the contaminants it has been polluted with and replenish the lost integrity and sometimes it's impossible to restore. Due to increasing population, other anthropogenic activities (like agriculture, industrial, domestic waste, etc.) changes in topography and relief, and land use land cover pattern, this resource has faced many changes that have deteriorated it and its been over exploited and stressed due to ever increasing water demand and less availability of surface water.

Hence, there is a need to study this indispensable resource in detail and vulnerabilities associated with it so that preventive measures can be anticipated in advance. Vulnerability is an ever changing concept; it was first introduced in France in 1960s to create awareness among the people and scholars towards groundwater health (Vrba and Zoporozec, 1994). Literal definition of vulnerability assessment means that it is a system that can identify the problem, the weakness that might make the system to succumb at the time of crisis or destabilization or any system which is sensitive to damage by one or the other or combination of factors. It analyzes all the available means by which the system might get harmed and locates the most vulnerable or weak point and thereafter, measures can be taken to prevent, protect and avoid further damage of the ground water system. However, scientists have given various definitions to groundwater vulnerability. The main aim of the project is to assess the most vulnerable areas of the study area that are susceptible to the exploitation and overall contamination owing to their geological setting and other anthropogenic factors like groundwater draft, land use land cover changes, depth to groundwater level, aquifer media, soil type, topography, hydraulic conductivity, ground water recharge etc. there are many parameters which can be considered for the purpose of vulnerability. The identification of the vulnerable area would help in managing the local groundwater resource from over-exploitation and further deterioration and measure can be taken to improve the aquifer quantity and quality. Groundwater vulnerability assessment is done on the idea that the aquifer is not of same features at all the locations and that some specific land area are more vulnerable to deterioration in terms of quality and quantity (Gogu and Dassargeus, 2000). Hence, it delineates the area which are more vulnerable or susceptible to contamination, and can help scientists to remediate (if contaminated), protect and prevent (if highly vulnerable) and policy makers to manage the resource in sustainable manner so as to assure the sustainable use of this precious resource, therefore leading to sustainability which is now the core aim of all the economies' of the world. The aquifer vulnerability is of two types.

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The first is intrinsic vulnerability which is due to the geology of the aquifer like clay layer thickness, overlaying media, lateritic layer thickness etc. (A. E. Edet, 2004). And second one is, ‘specific’ or ‘integrated’ vulnerability, which is obtained for a specific contaminant (Madl-Szonyi and Fu¨ le, 1998) or some integrated sources combined with the integrated vulnerability (Vrba and Zoporozec, 1994). Ground water is the major source of water in the study area; however canal supply is also there but the major source of water remains groundwater. There is no data available to check the vulnerability of the underlying aquifer, be it intrinsic or impact of socio-economic activities. However, an attempt has been made to use the available data to compute intrinsic vulnerability and also considering the socio-economic aspect by the use of population and economic growth in terms of industrial and agricultural growth. There are many techniques that exist for computing groundwater vulnerability, however the most simple and widely used techniques is DRASTIC index that measures intrinsic vulnerability developed by Aller et. al, 1998. Intrinsic vulnerability is independent of the nature of contaminant and the condition of the area where it is released but it takes into account the hydrological, geological and hydro-geological characteristics of the area under study (Zwahlen, 2004). The data was then validated using the monitored fluoride concentration measured in 20 locations in the district.

II. BACKGROUND

There have been many methods deployed until now by various scientists, however the choice of the technique depends on the data available to a great extent and also the type of aquifer being studied, the vulnerability can be assessed by numerous methods which further can be categorized into three main procedures viz, statistical methods, process based simulation methods and overlay index methods (Tesoriero et al., 1998):

A. Overlay Index Methods

Several vulnerability assessment techniques have been developed. The most exhaustively exploited methods used are: the DRASTIC system (Aller et al. 1987), the GOD system (Foster 1987), GLA (Hölting et al., 1995), KAVI (Beynen p.e. ET AL, 2012) the AVI rating system (Van Stempvoort et al. 1993), the SINTACS method (Civita 1994), PI (Goldscheider et al., 2000), the ISIS method (Civita and De Regibus 1995), the Irish perspective (Daly et al. 2002), RISKE (Petelet - Giraud 2000), the German method (Von Hoyer and Sofner 1998) and EPIK (Doerfliger et al. 1999). Vulnerability assessment techniques has been performed by Gogu and Dassargues (2000) and Gogu et al. (2003), which showed that there is a wide range in the results provided by each method and that, in many cases, there was disagreement. The reason for this is that aquifer vulnerability is not a measurable quantity, making the choice among the several methods quite an ambiguous task. In recent studies (Dixon et al. 2002; Dixon 2005), however, it was attempted to compare the results of vulnerability assessment methods with aquifer water quality data and perform a method sensitivity analysis. Thirumalaivasan D. et al (2002), developed a software package AHP-DRASTIC which is integrated with Arc-view GIS, that derive ratings and weights of modified DRASTIC model parameters for specific vulnerability assessment. Babikar S. et. Al (2005) have used DRASTIC for aquifer vulnerability in Kakamigahara Heights, Gifu Prefecture central Japan and concluded that the Net Recharge is the limiting parameter along with hydraulic conductivity and are most useful for aquifer vulnerability. Dixon B. (2005) incorporated GIS, GPS, remote sensing, and fuzzy rule based model to generate groundwater sensitivity maps of Woodruff County of the Mississippi Delta region of Arkansas and compared them with DRASTIC and water quality data obtained through field investigation. Gemitzi A. et al (2006) used GIS for data acquisition, fuzzy logic for factor standardization and decision making techniques like multi criteria evaluation to highlight the areas which are highly vulnerable to contamination in Eastern Macedonia and Thrace (Northern Greece), an area of approximately 14,000 km2. They used three group of factors comprising, intrinsic aquifer, external stress due to human activities and geological set up such as salt water intrusion or geothermal fields and formulated three vulnerability maps which were combined to produce final vulnerability map. Almasri (2008) has used DRASTIC for vulnerability assessment of Gaza Coastal Aquifer (GCA), reported that the vulnerability to nitrate contamination and the aquifers is high and these formations are most sensitive to depth of the water table. Rahman A. (2008), Al-Adamat R.A.N. et al (2003) used DRASTIC model in GIS environment for aquifer vulnerability assessment of Aligarh, India, Jordan respectively, and found that these are aquifer are high to medium on the vulnerability scale and pose a concern for the local people, hence management and sustainable solutions should be taken. Sener E. & Sener S. & Davraz A. (2009) used DRASTIC along with GIS (Geographic Information System) and a regional scale aquifer vulnerability map had been prepared using overlay analysis. Stournaras G. (2011) delineate protection zone using PRESK method an adaptation of RISKE (Petelet - Giraud 2000) in Loussi karst terrain for carbonate aquifer. Kavouri K. et al. (2011) studied aquifer vulnerability using PaPRIKa specialized method for karst aquifer which is updated derivative of RISKE and EPIK method. Beynen P.E. Et al. (2012) studies the Florida Aquifer system, USA with GIS environment and developed Karst Aquifer Vulnerability Index (KAVI) with land use coverage to create a specific ground water vulnerability model and concluded that KAVI reproduce best result for spatially varying nitrate concentration and most sensitive parameter for the aquifer is hydraulic conductivity.

B. Process Based Simulation Methods

These methods are more complex and constitute and explicit and require large data. These are complex models and it varies from simple to complex 3-D simulation models. Behaviour Assessment Model (Jury and Ghodrati, 1989), and Attenuation Factor (Rao et. al. 1985) is analytical solution of advection dispersion equation are used to measure groundwater vulnerability.

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Meeks and Dean (1990) used a one-dimensional advection-dispersion transport model to develop a leaching potential index, which simulates vertical movement through a soil to the water table. Soutter and Pannatier (1996) used cumulative pesticide flux reaching mean water table depth and the total quantity of pesticide applied and expressed the groundwater vulnerability as the ratio of the above two. Neukam C. and Azzam R. (2009) used numerical simulation model of water flow and solute transport with transient boundary and links them to unsaturated strata and hydrologic & hydrogeologic characteristic and uses transit time t50. Meta models has also been used for vulnerability assessment of the aquifer. Meta Model is the "model of a model" based on multiple regression analysis, Kriging, Artificial Neuraal Network (ANN) etc. Complex simulation models had been approximated using a statistically significant function (Wu and Babcock, 1999; Pineros Garcet et al., 2006).

C. Statistical Method

These methods are generally based on probability theory and require extensive field data, thence, derive the response variables such as contaminant probability, occurrence and concentration. Using this method one can predict the occurrence or non-occurrence of a contaminant (specific vulnerability) in the area of interest. Recently, logistic regression (Worrall and Kolpin, 2004), principal component analysis (PCA) multivariate analysis and other techniques have also been used for aquifer vulnerability assessment integrated with one or the other technique and later on the results help in decision making, management and planning. Worrall (2002) and Worrall and Kolpin (2003) used Bayesian probability method to observe the presence or absence of contaminant in the catchment of a borehole, this method require intensive monitored data and it does not require variables to explain the vulnerability. Lucas L. (2008) used Principal component analysis and GIS approach to assess potential pollutant source and identify variations in concentration of chlorinated solvents in groundwater in industrial areas. The work describes the results of Variability Index Method (VIM) the uses environmental data and reveals aquifer properties and impact of anthropogenic activities (industries). This technique exposes contaminated sites and also provides support for remediation measures. Masetti M. et al. (2011) used weight of evidence(WofE) (van Westen et al., 2003; Neuhäuser and Terhorst, 2007; Poli and Sterlacchini, 2007; Masetti et al., 2008) which is a Bayesian method in which the known response values are taken as training sites to generate predictive map showing vulnerability. Marcomini A. et al. (2011) used multi criteria decision analysis and spatial variability to analyze contaminated sites which are harmful to many different receptors based on their vulnerability to contamination in the upper Silesia region of Poland. Pandey V P. et all (2011) used composite indicators to develop a framework for groundwater sustainability and prepared 'groundwater sustainability infrastructure index (GSII)', as a measure of groundwater sustainability. The index consisted of five components with sixteen indicators. The study was conducted in Kathmandu Valley, Nepal. Most of the studies conducted have separately studied the vulnerability of the groundwater resources and the socio-economic aspects of the study area. Both the vulnerability assessment and socioeconomic factors are interrelated with each other, therefore, in this study both these parameters are taken simultaneously for the study area of Jabalpur District, M.P.

III. Study Area

The study area, Jabalpur district lies in the central part of Madhya Pradesh, India, extends between the parallels of latitude 22°49' and 23°07' north and meridian of longitude 79°21' and 80°35' east. It covers an area of 4978.2 sq.km. with mean elevation of 425.726 m and average slope of 7.562%. Major physiographic units of Jabalpur includes Vindhyan tract which forms the western boundary of the district, The Southeastern plateau of Satpura, The Bhitrigarh range runs across the northern part of the district from Southwest to Northeast. Jabalpur lies at the junction of the Vindhyan and Satpura range. The Narmada and its tributaries, the Hiran and the Gaur drain the district. The slope of the river is towards west and of Hiran is towards southwest.

A. Geology and Hydrogeology

The District consists of formations ranging from Proterozoic to Pliestocene age. It is divided into four geological groups namely; The Mahakoshal group, which earlier was referred to as Bijwaras, this region is composed of meta volcanic and meta sediments. The Mahakoshal rocks are folded and deformed in the Son valley while Bijwaras of the area are not that deformed. The Bijwar group is separate litho-stratigraphic unit younger than Mahakoshal group. The Vindhyan Group, consist of Kaimur sandstone, Jhiri shale, Upper Rewa Sandstone, and Sirbu shale. These form a ridge in the NE-SW direction along northwestern border of Jabalpur district with Damoh district. Gondwana Super Group, clay and sandstone are formed of Jabalpur and unconformably overlie over Vindhyan Super group. Lameta group and Deccan Trap, Lameta's siliceous limestone and sandstone and overlying Deccan Trap lie over unconformably over Mahakoshals and Gondwana to the south of Jabalpur. Laterite and Alluvium, laterite occurs as a thin layer over the above discussed group. The Narmada and Hiran form alluvial tract along the river in Shahpura and Patan blocks.

B. Soil

The Jabalpur district contains mainly three types of soil namely heavy soil, medium black soil and light soil. Heavy soil: covers 45% of the area, blocks that cover this type of soil areJabalpur, Patan, Shahpura, Panagar. This soil is high in organic content and retails quite amount of water.Medium Black soil: covers 25% of the area, includes Majholi, Sihora, Shahpura. This soil is moderate in water retention and organic content.Light Soil: covers 30 % of. the area; include Kundam, some parts of Jabalpur, Sihora. This soil is low in organic content and is gravel and sandy type of soil.

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C. CLIMATE

The climate of the Jabalpur consists of the three main seasons, winter season which starts from the middle of the November and continues till the end of February; then follows summer from March till early June and the monsoon season starts from June and continues till the end of September.

C.1. TEMPERATURE

The Jabalpur district is located in tropical part of the country and experiences extremities of the temperature. There is a continuous rise in temperature from March to mid of June and May is the hottest month of the year with the mean daily maximum and minimum normal temperature of 41.9oC and 25.9oC. The winter season have lowest temperature ranges between 9oC to 26.9oC. The trend analysis shows that the temperature has risen in the past hundred years and further testing the data for the significance confirmed that there is increasing trend at 95% confidence level and that there is a significant rise in the temperature.

C.2. RAINFALL

The annual average rainfall of Jabalpur varies from 1100 mm to 1400 mm. Trend analysis shows the rainfall trend in the past hundred years, the trend line clearly shows the declining trend. The trend is there but it is not significant when tested through Man-Kendall significance test at 95 % confidence level and it showed that the trend is insignificant.

IV. MATERIALS AND METHODOLOGY

The data used has been given in the Annexure; the main data used was groundwater exploration data, CGWB report, population data, hydro-meterological data, Aster DEM, with resolution 30 m. The method used to assess the groundwater vulnerability is DRASTIC method which is proposed by Aller et al (1987) can be applied on the regional scale and intrinsic vulnerability of the aquifer under study can easily be obtained. This is one of the most widely used method among the many available owing to the fact that it is very easy to apply in the data insufficient area, where monitoring has been scarce, and also allows systematic evaluation of the parameters under study. This type vulnerability assessment gives fair preliminary results for identifying vulnerable area and later on focus on management plans, policy planning and decision making. The seven parameters that are taken in to consideration under this are, depth to water table, net recharge, aquifer media, soil media, topography, impact of Vadose zone and hydraulic conductivity. These parameters have been defined in the Table given below:

Table 1 Data used for the Hydro-Geological Parameters for DRASTIC Model

S No.	Data Type	Sources	Format	Output Layer
1	Water level Map	CGWB Report	Map	Depth of Water (D)
2	Average annual rainfall	IMD Data	Table	Recharge (R)
3	Geology Map	CGWB Report	Map	Aquifer (A)
4	Soil Map	CGWB Report	Map	Soil (S)
5	Topographical Sheet	Satellite data (Aster DEM)	Map	Topography (T)
6	Geological Profile	CGWB Report	Map	Impactof Vadose Zone (I)
7	Hydraulic Conductivity	CGWB Report	Table	Hydraulic Conductivity (C)

For overlay analysis the weights and ratings are given to each of the seven parameters, each is classified in to classes on the scale of 1-10, in which 1 denotes least vulnerable while 10 is for the most vulnerable areas. This rating is further scaled into weights based on the importance of the parameter in determining aquifer characteristics, these scaled on 1-5 where, 1 is least significant and 5 is most significant.

Table 2 Drastic Rating and Weighting Values for the Various Hydrogeological Parameter Settings (Aller et al. 1987; Al-Zabet 2002)

DRASTIC Parameters	Range	Rating	DRASTIC Weight	Total Weight
Depth to Water Table	0 - 2.5 2.5 - 4 4 - 6.5 6.5 - 9 9 - >12.5	10 7 5 3 1	5	50 35 25 15 5
Net Recharge	438.8-477.7 477.7-522.1 522.1-569.3 569.3-622.1 622.1-672.1 672.1-708.2	1 3 5 7 9 10	4	4 12 20 28 36 40
Aquifer Media	Alluvium Limestone Conglomerate Volcanic Flysch	10 9 8 7 3	3	30 27 24 21 9
Soil Media	Absent Gravel-sand Gravel Sandy Clay Clay Loam	10 9 8 3 2	2	20 18 16 6 4
Topography	0 to <2 2 to <6 6 to <12 12 to 18 >18	10 9 5 3 1	1	10 9 5 3 1

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DRASTIC Parameters	Range	Rating	DRASTIC Weight	Total Weight
Impact of Vadose zone	Limestone Sand-Gravel Gravel-sandy-clay Sandy Clay Tuff Clay	10 8 7 6 3 1	5	50 40 35 30 15 5
Hydraulic Conductivity (m/day)	0-29.005 29.006-72.7 72.7-116.4 116.4-160.1 160.1-203.79 203.79-247.84	1 3 5 7 9 10	3	3 9 15 21 27 30

The DRASTIC vulnerability index (DVI) is calculated by linear addition of the weights and rating, the formula is given below:

$$DVI = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w$$

Where,
D_r = Rating for the depth to water table
D_w = Weight assigned to the depth to water table
R_r = Rating for aquifer recharge
R_w = Weight for aquifer recharge
A_r = Rating assigned to aquifer media
A_w = Weight assigned to aquifer media
S_r = Rating for the soil media
S_w = Weight for the soil media
T_r = Rating for topography (slope)
T_w = Weight assigned to topography
I_r = Rating assigned to impact of vadose zone
I_w = Weight assigned to impact of vadose zone
C_r = Rating for rates of hydraulic conductivity
C_w = Weight given to hydraulic conductivity

The rating ranges were determined depending on the study area. Knowledge of the hydrogeology and geology of the study area helps in determining the ratings for any given study area. They are given in the table given below:

When the DVI is calculated it was divided into further classes. It shows the areas susceptible to groundwater contamination relative to others. Higher values depict greater vulnerability to groundwater contamination. In this study, all the maps are prepared using GIS techniques. The maps are digitized and are converted into layer through geo-referencing using ArcGIS. The rates and weighting were assigned to the layers and final DVI index was calculated and a vulnerability map of the area was prepared keeping in mind the hydrological and geological properties the vulnerable areas were delineated as high, medium, and low vulnerability.

A. Depth to Water Table (D)

It is very important from the point of view of the groundwater aquifer as this factor determines the depth to which a contaminant would have to travel before it reaches the water table, i.e. saturated zone of the aquifer (Al-Zabet, 2002). For this data provided had 20 point data, static piezometric heads for those 20 locations had been taken as the average of the decade (1990-1999), water table depth map had been taken from the CGWB report, it was digitized and converted to raster format. The depth of the water table ranges from 0-14.9 m meter below ground level (mbgl). The ratings were 10 and 7 as the ground water table is at a good height. The depth to water table map is given in the **Figure 1**

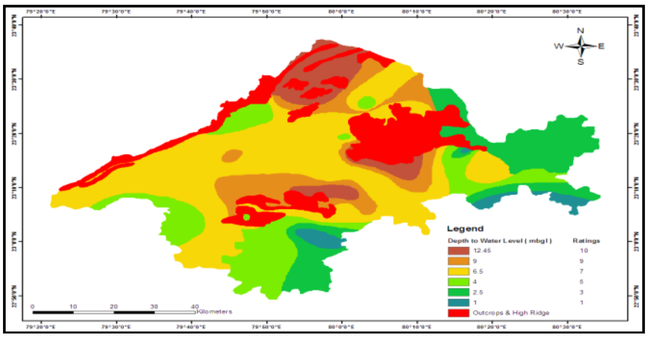

Figure 1 Map Showing Depth to Water Table, Jabalpur District

B. Net Recharge

Yet important factor for groundwater vulnerability, as the contaminant moves with the rainfall water as infiltration and goes down deep into the aquifer saturated layer. In the study area precipitation is the major source of groundwater recharge. The net recharge has been calculated as 30-40 % of the rainfall (Baalousha, 2006). There have been five stations in the district as explained in the study area, rainfall from these stations has been used to calculate the net recharge; the duration, intensity or distribution does not affect the average annual net recharge (Al-Zabet, 2002). The rainfall data has been taken from IMD, the data has been interpolated using the technique, Inverse Distance Weight (IDW) interpolation in the ArcGIS spatial analyst tool. The map for the net recharge is given in the Figure 2. The recharge value ranges from 400-650 mm and rating value lies in range of 10 to 1.

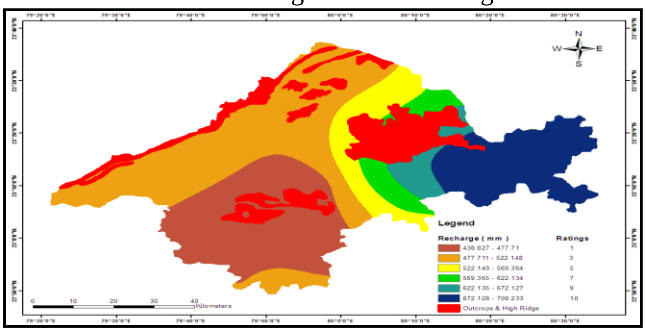

Figure 2 Map Showing Net Recharge, Jabalpur District

C. Aquifer Media

This parameter represents the geological formation of the aquifer in the upper layer, the map was prepared from the hydrogeological map (CGWB report) and litholog of the area and the DRASTIC ratings was assigned, given in the table. It governs the time, route followed by the contaminant to reach the water table, various formations have different degree of permeability and rating is assigned to each of them based on their permeability.

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The alluvial aquifers are the most vulnerable to contamination and hence it was assigned the rating of 10 as the permeability is very high. The quartzite is the least vulnerable due to impermeable nature and rating is 1, areas with volcanic aquifers, in the given study area there is more of basalt aquifers, the rating is 2 or 3 as these are also impermeable structures. Furthermore, karstic limestone and conglomerates, which are permeable karstic rock units, have high permeability; therefore, these units were assigned with ratings of 9 and 8, respectively. The map showing aquifer media is given in the Figure 3.

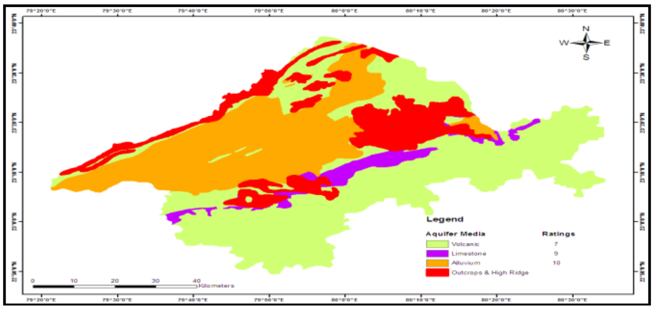

Figure 3 Map Showing Aquifer Media, Jabalpur District

D. Soil Media

It represents the top soil layer extending not more the few meters from the surface, it is the weathered zone. It has significant impact on the movement of the amount of recharge water which infiltrates deeper into the aquifer, hence it also affects the downward movement of the contaminants into the Vadose zone (Lee, 2003). The rating was assigned from 10 (no soil) to 1(clay loam). The soil media is given in the Figure 4 below.

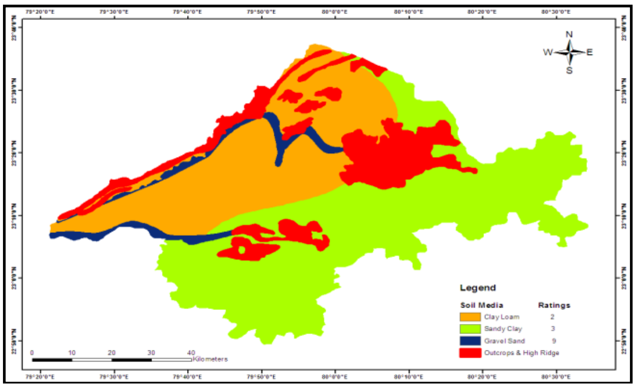

Figure 4 Map Showing Soil Media, Jabalpur District

E. Topography

It refers to the slope-aspect of an area. Slope plays a major role in the flow rate of the water that falls on the surface. Hilly terrain have high slope and hence high runoff, therefore the time of contact of water is less and so is the time of infiltration (less vulnerable), however areas with the lower slope withstand water for a longer period of time and hence allows more water to infiltrate (more vulnerable). For the map preparation SRTM data of the area was used to derive the DEM and then using 3D analyst tool the slope of the area was derived, and the ratings as specified in the table were used to make the vulnerability map. The topography map of the study area is given in the Figure 5.

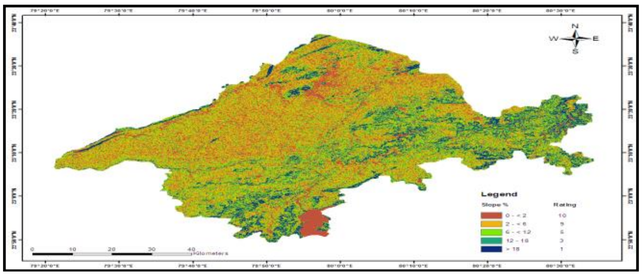

Figure 5 Map Showing Topography, Jabalpur District

It is the area which lies above the saturated zone; it is made of unsaturated and saturated zones and it varies at depths. Like the soil media it also plays an important role in percolation of the recharge water to the aquifer and therefore the contaminants as well. The Vadose zone in the given study area consists of gravel, clayey, sandy-gravel, limestone, and clay, have been observed in the Jabalpur district. The units having clay and loam are less vulnerable as they do not contain much of the water in the vadose zone however; gravel, sandy and limestone areas contain groundwater and hence are vulnerable. They have been assigned rating from 10 to 1 according to their properties. The map showing the vadose zone of the study area is given in the Figure 6.

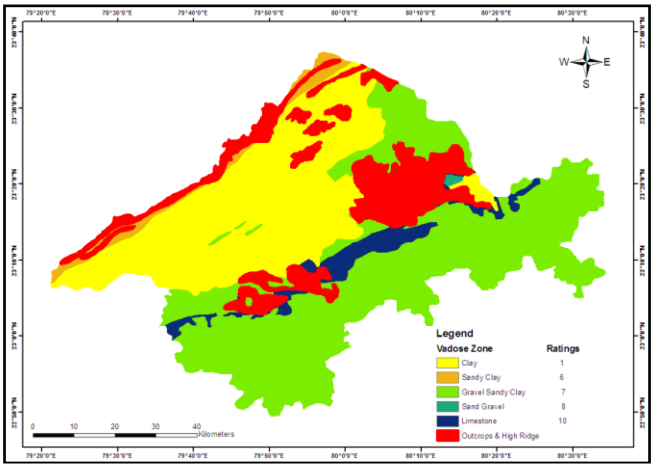

Figure 6 Map Showing Vadose zone, Jabalpur District

F. Hydraulic Conductivity

Hydraulic conductivity is an important aquifer parameter which is characteristic of the geological properties. It governs the rate at which the water flows in the aquifer's saturated zone. Hence, contaminant transportation is checked by hydraulic conductivity of the aquifer system. The hydraulic conductivity values were taken from the CGWB groundwater exploration study, 1999. Hydraulic conductivity of the alluvial aquifers varies between 8.72 × 10-6 and 2.242 × 10-4 m/s (Seyman 2005). Clayey units have least permeability (10-9m/s) while limestones have higher values (10-3m/s) and hence are more vulnerable as compared to the other two units. The ratings and distribution have been given in the table. The map showing hydraulic conductivity is given in **Figure 7**

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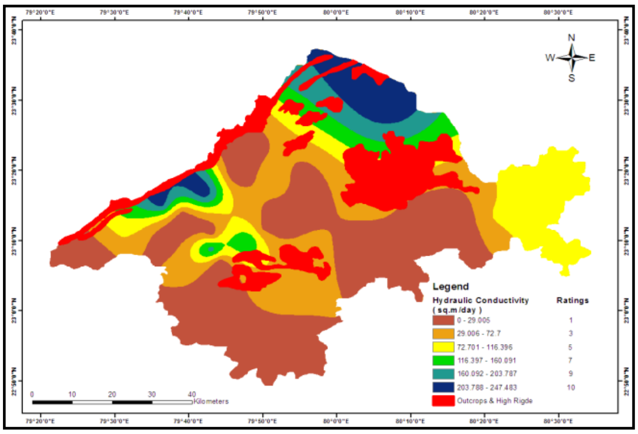

Figure 7 Map Showing Hydraulic Conductivity, Jabalpur District

All the above seven hydrogeological GIS layers have been used to generate the final vulnerability map. Using the table the rating and weights were assigned to the layers and final vulnerability range came out to be 47 to 209. The ranges have been given by using quantile classification method to develop the desired patterns in the map. This method distributes the range into equal groups of interval. Category ranges determined randomly will give imprecise results which are unreliable.

V. Results and Discussion

The DRASTIC Method used produced the map given below showing the area of low, medium and high vulnerability. The district's geological and hydro-geological set up determines the aquifer characteristics and in the present study area the groundwater resources are well protected by the soil, aquifer media, vadose zone, and also topography. Around 70% of the area shows moderate vulnerability and around 20% shows low vulnerability while less than 10 % of the area is highly vulnerability. The high, medium and low vulnerability has been assigned as given in the Table 2. The eastern part of the Kundam and Sihora district are highly vulnerable, while the other major portion of the district is moderately vulnerable to groundwater contamination.

Table 3 Classes of DRASTIC Vulnerability Index

DRASTIC vulnerability index	
Low	47-101
Medium	101-155
High	155-209

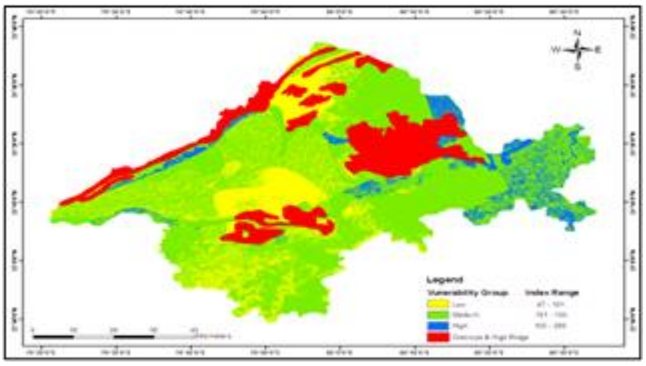

Figure 8 Drastic Vulnerability Map

The population of the district is increasing and so is the water demand and hence, the stress on groundwater also increases, which would further increase the groundwater exploitation. It shows that the vulnerable zones can be used as the high recharge zones and that care should be taken to prevent any leaching of contaminants on it. Measures can be taken to reduce pollution by anthropogenic activities (land use land cover changes).

VI. CONCLUSION

The method used is very good for regional scale assessment due to the availability of certain parameters, however, it suffers from many flaws and due to this is only the relative indices, the rates and the weights are based on the expert opinion. The results showed that there is a need to manage groundwater resources in a sustainable way; to avoid over exploitation and contamination of ground water. Also, allowing sufficient recharge to prevent draft exceeding the recharge. This study highlighted areas of high vulnerability and medium vulnerability; where specific measures can be taken to improve the condition of the groundwater resources, like sites for artificial rainwater harvesting to restore the depleted resource, and also sites where contamination can cause irreversible damage, can be prevented.

The highlighted areas should be monitored extensively for further analysis.

VII. Limitations

This type of study require large amount of field investigation and monitoring, since in such a short time it was not possible, the data used is here is from CGWB report groundwater exploration conducted in 1999.

Specific contaminant data was not available for the area to validate the DRASTIC vulnerability map; hence the results remain in ambiguity. Different approach can also be used to assess the groundwater vulnerability. For example, land use land cover data can be used to assess the area where this resource is under stress. Furthermore, collection of new data would help in carrying out the study further; other methods can also be used to assess the same. Many other parameters like social perception of the people, government policies can be included and studied in detail.

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