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Evaluation of Aquifer Vulnerability Using Drastic Model And GIS: A Case Study Of Mysore City, Karnataka, India.

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Abstract

This investigation was carried out to determine the aquifer vulnerability using DRASTIC method which correlated well with the physico-chemical characteristics of groundwater in Mysore city. The main objective was to determine the susceptible zone for groundwater pollution by integrating hydrogeologic layers in Global Information System (GIS) environment. The methodology entailed documentation stage followed by field phase involving collection of 53 groundwater samples from the study area during pre and post monsoon seasons. The layers such as depth to water-level, recharge rate, aquifer media, soil permeability, topography, impact of vadose zone and hydraulic conductivity were integrated in the DRASTIC model using GIS spatial analysis tools and techniques. The aquifer analysis highlighted that the vulnerability range were with from < 70 and > 100. It was found that, when the net recharge is high, the vulnerability was also found very high. The nitrate concentration in groundwater was within the WHO permissible limit in the pre monsoon, in 95% of the samples. But, in the post monsoon season, 70% of the samples exceeded the permissible limit. A positive correlation was observed between groundwater vulnerability and concentration of nitrate in groundwater. GIS application of the DRASTIC model was found to be a suitable method for analyzing the groundwater vulnerability in a city environment like Mysore.

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Keywords: DRASTIC; physico-chemical; groundwater; GIS; aquifer; topography; vodose zone; Vulnerability Index.

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1. Introduction

Groundwater makes up about twenty percent of the world's fresh water supply, which is about 0.61% of the entire world's water resource, including ocean and permanent ice. Global groundwater storage is roughly equal to the total amount of freshwater stored as snow and ice pack, including in the north and south poles. This makes it an important resource which can act as a natural storage that can buffer against shortages of surface water, as in times of drought Richard (2005). Day-by-day dependence on groundwater is increasing phenomenally due to population growth. Human activities have negative impact on the groundwater quality. This may result in temporary or even permanent loss of the resource. According to Al-Zabet (2002), vulnerability refers to the sensitivity of an aquifer system to deterioration due to an external action. In the last few decades, many techniques have been developed to assess groundwater vulnerability, including index, rating, hybrid, statistical and simulation methods by Voudouris (2009). The DRASTIC method has been most commonly used for mapping vulnerability in porous aquifers (Aller et al., 1987). The objective of this study was to determine the aquifer vulnerability by integrating the DRASTIC model into GIS. The hydrogeologic parameters were processed and mapped to delineate areas susceptible to contamination producing a risk assessment map of Mysore City.

2. Study Area

Geographically, Mysore city is located between 12.18° North latitude and 76.42° East longitude with an altitude of 770 meters above Mean Sea Level. It is spread across an area of 128.42 km^2 (50 sq mi) at the base of the Chamundi Hills in the southern region of Karnataka. The average annual rainfall is about 800 mm. The general slope of the city is from North to South. The general ground elevation of the city varies from both the Northwest to the Northeast portion (with the difference of 40 m) and the North to the South (with the difference of 25 m). The types of soil found in this city are red soils, alluvial calcareous clay soils and alluvial clay soils. Main rock types are Igneous and metamorphic in origin. Some of the minerals found are kyanite, sillimanite, quartz, magnesite, chromite, soapstone, felsite, orundum, graphite, limestone, dolomite, siliconite and dunite. Karnataka Municipal Reforms Cell, DMA, GoK (2011).

3. Methodology

The DRASTIC model was adapted in the present study to investigate the vulnerability of ground water. To apply the DRASTIC model seven parameters are necessary, such as depth to water level, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity. The data relating to depth of water and net recharge were collected from the Department of Mines and Geology, Mysore. The data relating to aquifer media and soil media have been collected from Soil Survey of India, Bangalore. The topography of study area was prepared based on the Shuttle Radar Topographical Mission (SRTM) satellite data. The impact of vadose zone and hydraulic conductivity were prepared based on the data collected from Geological Survey of India, Bangalore. The data collected were converted into digital format to insert into the Geographical Information System (GIS) environment. The ArcGIS 9.1 was used to manipulate the data and the weightage of each parameter was assigned as per Aller et al. (1987). The technique of “inverse distance weighted” (IDW) interpolation in GIS was used to prepare the data for the entire city using sample points of net recharge and depth to water levels. The DRASTIC formula was used in ArcGIS raster calculator to find out the vulnerability of ground water. The 100 meters spatial pixel resolution (raster Grid) raster layer was used for all raster manipulations. Once the spatial vulnerability of groundwater was detected using Arc GIS, the primary sample, water quality data retrieved from 53 samples of groundwater were used to assess the accuracy of DRASTIC model. Field sampling was done in the pre-monsoon (PRM) season in March, 2011 and in the post-monsoon (POM) season in October, 2011. In each season 53 groundwater samples were randomly collected covering the entire city. Each groundwater sample was collected in 1 liter plastic container and prior to collection as part of our quality control measure all the bottles were washed with non-ionic detergent and rinsed with de-ionized water. Before doing the final water sampling, the bottles were rinsed three times with well water at the point of collection. Each bottle was labeled according to sampling location and all the samples were preserved at 4ºC after being transported to the laboratory. The samples were analyzed using standard procedures mentioned in

APHA (2006). pH, EC and TDS were measured on spot using a waterproof PCS Tester -35, Ca and Mg were analyzed titrimetrically using EDTA method, Na and K were determined by flame photometry. HCO_3 and Cl were estimated by titrimetric method. SO_4 was determined using Nephelometer and NO_3 was determined by UV spectrophotometer.

4. Hydrogeologic Factors

4.1 Depth to water level (D)

The depth to groundwater level is the distance, in feet, from the ground surface to the water table level. March and October month's data (Table 1) for depth to water level measured in feet were used; the sample locations were created in the GIS environment using their appropriate latitude and longitude, then depth to water level as an input data and the IDW interpolation maps (Figure 1) were created for both months separately adopting the hundred meter grid interval.

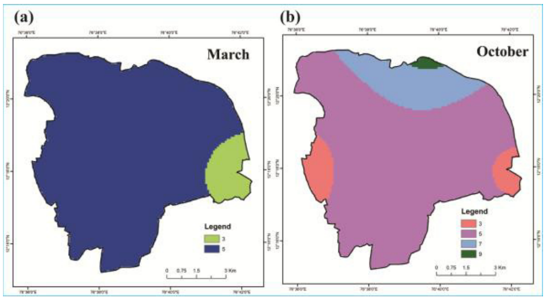

Fig. 1. Depth to Water level (a) March and (b) October

Table 1: Depth to Groundwater, Weight:5

Months	Ranges	Rating	Index
March	50 -75	3	15
	30 -50	5	25
October	50 -75	3	15
	30 -50	5	25
	15 -30	7	35
	5 - 15	9	45

4.2 Net Recharge (R)

Precipitation is the primary source of recharge, it infiltrates through the ground surface to the aquifer on an annual basis. More recharge leads to greater chance for the contaminants to reach the water table. The grid layers (Figure 2) for net recharge were developed from the recharge data sets (Table 2). Recharge rates for the aquifers were usually derived from groundwater flow models and represent averages over large areas. All the values of this study were in the range of 0-2 to 10+ inches per month.

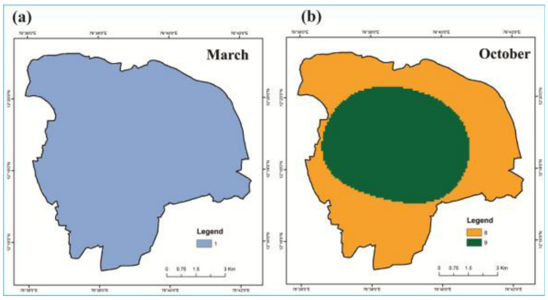

Fig. 2. Net Recharge (a) March and (b) October

Table 2: Net Recharge, weight: 4

Months	Ranges (mm /month)	Rating	Index
March	0 - 2	1	4
October	7 - 10	8	32
	10 +	9	36

4.3Aquifer Media (A)

Aquifer media refers to the consolidated or unconsolidated rock that serves as an aquifer. Larger the grain size and more fractures or openings within the aquifer, results in higher permeability, and thus vulnerability of the aquifer. The variable A (Aquifer media) was evaluated from the data retrieved from geological map (Figure 3). Based on this information, the aquifer media were classified. (Table-3).

4.4 Soil Media (S)

Soil media is the upper weathered zone of the earth which averages to a depth of six feet or less from the ground surface. Soil media was evaluated from the map obtained from the Remote sensing application centre, Mysore (Figure 4). Based on Aller et al. (1987) method, the soils types were classified and values were assigned (Table 4).

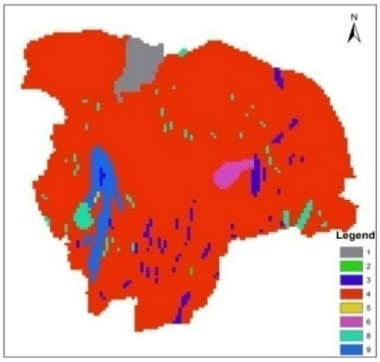

Fig. 3. Aquifer media

Table 3: Aquifer Media, Weight: 3

Aquifer	Rating	Index
Quartz mica schist/metapelites and carbonates	9	27
Amphibolites/ hornblende schist with crystalline limestone	8	24
Medium grained, grey adamellite and granodiorite	7	21
Anorogenic younger granites	6	18
Fuchsite quartzite with kyonite	5	15
Metabasalt	4	12
Ultramafics and meta Ultramafics	3	9
Charnockite	2	6
Dolerite	1	3

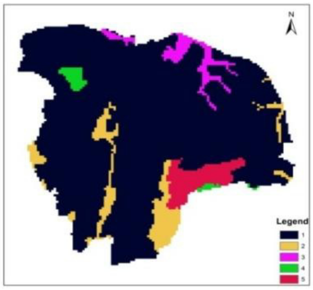

Fig. 4. Soil Media

Table 4: Soil Media, Weight: 2

Soil types	Rating	Index
Red gravelly loam soils	5	10
Red gravelly clay soils/ Gravelly clay soils	4	8
Alluvial calcareous clay soils	3	6
Alluvial clay soils	2	4
Deep red clay soils	1	2

4.5 Topography (T)

Topography refers to the slope of the land surface. Topography helps to manage the likelihood that a pollutant will run off or remain long enough to infiltrate into the ground surface. Where slopes are low, there is little runoff, and the potential for pollution is greater. Conversely, where slopes are steep, runoff capacity is high and the potential for pollution of groundwater is lower. Most of the slopes in this study area were in the range of 0-2 and 2-6 percent. (Table 5)

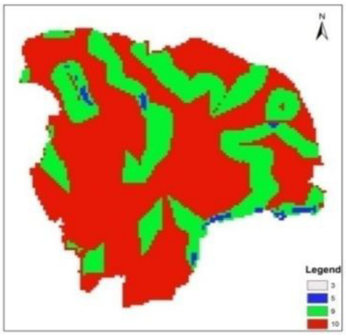

Fig. 5. Topography

Table 5: Topography, weight:1

Slope Ranges (%)	Rating	Index
0 – 2	10	10
2 – 6	9	9
6 – 12	5	5
12 - 18	3	3

4.6 Impact of the Vadose Zone Media (I)

The vadose zone is the unsaturated zone above the water table. The data for the variable I (vadose zone) was retrieved from National Bureau of Soil Survey Bangalore in the form of report and the information was converted into map (Figure 6).Values were assigned to the same (Table 6).

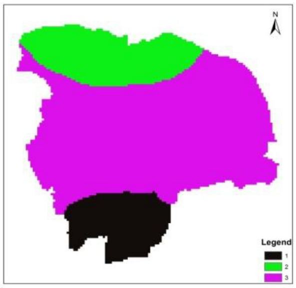

Fig. 6. Vadose zone

Table 6: Impact of Vadose zone, Weight: 5

Ranges	Rating	Index
Gravelly clay soils	3	15
Clayey loamy soils	2	10
Clay soils	1	5

4.7 Hydraulic conductivity (C)

Hydraulic conductivity refers to the rate at which water flows horizontally through an aquifer. As hydraulic conductivity increases, groundwater velocity as well as the speed at which pollutants are transported also increase, in turn rising aquifer vulnerability. It is difficult to achieve an accurate estimation of hydraulic conductivity and it is also considered as a limitation of the DRASTIC method as it was agreed by Fritch et al. (2000); Stigter et al. (2006); and Martinez-Bastida et al.(2010).The bedrock aquifers in this study comprise of hydraulic conductivity values in the range of 1-700 gpd/ft. These values were assigned based on hydraulic conductivity of common rock types which is discussed in the open report “Guide to Permeability Indices” by Lewis et al. (2006). Based on the hydraulic conductivity of the rock types, map (Figure 7) was created showing their respective values (Table 7)

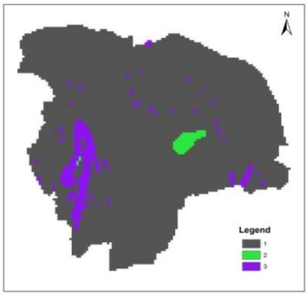

Fig. 7. Hydraulic conductivity

Table 7: Hydraulic conductivity, weight:3

Ranges (m/ day)	Rating	Index
300 – 700	4	12
300 – 700	4	12
100 – 300	2	6
100 – 300	2	6
100 - 300	2	6
1 – 100	1	3
1 – 100	1	3
1 – 100	1	3
1 - 100	1	3

6. Result and Discussion

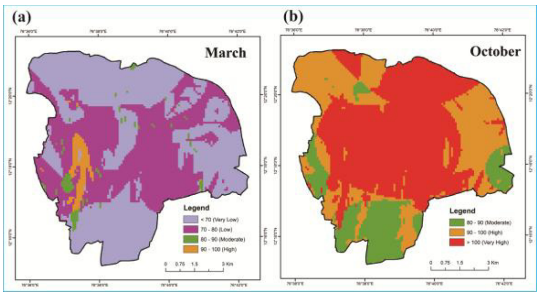

Fig. 8. Vulnerability map (a) March month (b) October month

The vulnerability maps obtained for March and October months evidenced the potential and sensitivity of the aquifers for contamination (Figure 8). Vulnerability ranges were categorized based on DRASTIC index values, and they were less than 70 as very low, 70 - 80 low, 80 – 90 moderate, 90 – 100 high and more than 100 as very high. The month of March showed low vulnerability index with some parts having moderate and high index values, but month of October resulted in very high vulnerability representing more than 100 index values. In the month of October groundwater level ranged 30 – 50 feet/month with rating of 5 and index value of 25. Net recharge was 7 and 10+ mm/month in the high vulnerability area with 8 and 9 rating and 32 and 36 index values respectively. Seventy percent of the high vulnerability area is covered with deep red clay soil, 10% alluvial clay soil, 10% alluvial calcareous clay soil and 10% red gravelly loam soil. Under aquifer media, Metabasalt constitute 70% of high vulnerability area with 10% quartz mica schist/metapelites, 10% Ultramafics/ Meta Ultramafics, 5% Amphibolites/Hornblende Schist and 5% Anorogenic younger granite. Sixty percent of the high vulnerable area consists of 0-2% slope ranges, 38% of the area has 2- 6% slope ranges and 2% of the land is having 6- 12% slope ranges all together constituting the topography of high vulnerable area. Gravelly clay soils represent the vadose zone of the area. Hydraulic conductivity ranged from 1-700 m/day.

Physico-chemical characteristics of groundwater samples are presented in Table 8. Table 9 represents the results compared with the Bureau of Indian Standards (2003) and World Health Organization Standards (2004) with the percent compliance to assess the quality of groundwater in Mysore city for drinking purposes. Groundwater was slightly alkaline in nature showing pH of 7.79-8.69 and 7.55-8.71 during PRM and POM seasons respectively. Eighteen percent and 20% of samples were out of permissible limits of BIS in PRM and POM seasons respectively, as far WHO standards all samples were within limits. pH has no direct adverse effects on health; however, higher values of pH hasten the scale formation in water heating apparatus and high pH induces the formation of trihalomethane which is toxic, Trivedy and Goe (1986). Electrical conductivity of water varies directly with the temperature and is proportional to the dissolved mineral matter content. In the present study, conductivity ranges were 300-1613µs/cm and 288- 1306 µs/cm during PRM and POM, respectively. The elevated values of EC in PRM season indicated inorganic pollution of the water samples. For total dissolved solids, 55 % and 47 % with BIS and 63% and 47% with WHO standards were out of permissible limits in PRM and POM season, respectively.

Total hardness ranged from 89-363 mg/L in PRM season and 90-340 mg/L in POM season; 5% of samples in PRM and 2% in POM season exceeded the threshold range of BIS and WHO standards. Hardness is indication of deposits of Ca and Mg ions. Ca and Mg ions concentration were measured separately. Thirteen percent and 6% of samples exceeded BIS in PRM and POM seasons respectively for Ca, whereas 15% of samples exceeded WHO limits in PRM season and in POM season all samples were within the range. Compared to Ca, more number of samples was out of range for Mg concentration; 88% in PRM and 90% in POM for BIS, and all samples in WHO were within the prescribed range. NO_3 concentration was relatively very high in POM i.e., 60% and 58% of samples were out of range for BIS and WHO standards, respectively. Nitrate, the most highly oxidized form of nitrogen compounds is commonly present in surface and groundwater because it is the end product of the aerobic decomposition of organic nitrogenous matter. Rising nitrate levels have raised an alarm because of the possibility of adverse effect on humans and animals. Methaemoglobinaemia or blue baby disease- is caused by the reaction of nitrate with hemoglobin, the oxygen carriers in blood, producing methaemoglobin, which strangles the oxygen carrying capacity of the blood. Nitrate can wear down body’s immune system while its derivatives may be carcinogenic. Cl values ranged from 81 to 312 mg/L and 56.8 to 262.7 mg/L for the respective PRM and POM seasons. Nine percent samples in PRM and 3% samples in POM exceeded the range prescribed by BIS and WHO standards. Chlorides indicate the presence of weathered silicate rich rocks beneath the overburden and leaching from soil due to infiltration from the landfill and other anthropogenic activities. This agreed with the findings of Igbinosa and Okoh (2009); Srinivasamoorthy et al. (2009). Na, K and SO_4 values were within the prescribed limits of both BIS and WHO standards.

Table 8.Chemical parameters in groundwater of Mysore City during PRM and POM seasons.

Parameters	PRM (n=53)			POM (n=53)		
	Min	Max	Std. Dev	Min	Max	Std. Dev
pH	7.79	8.69	0.185321	7.55	8.71	0.228697
EC(µs/cm)	300	1613	250.3066	288	1306	231.9832
TH(mg/l)	89	363	59.54456	90	340	42.87559
TDS (mg/l)	79	880	190.0999	207	927	164.7745
Ca2+(mg/l)	30	150	30.44569	16	88	16.96408
Mg2+(mg/l)	20	98	21.82505	15	141	24.85308
Na+(mg/l)	4.0	11	1.900139	5	77	22.13824
K+(mg/l)	0.1	10.7	1.556351	1	12	1.977519
CO32-(mg/l)	22	139	30.72176	50	100	26.4287
HCO3- (mg/l)	150	750	116.2222	150	500	72.98329
SO42-(mg/l)	0.3	33	7.707919	0.2	15.3	3.170801
Cl-(mg/l)	81	312	55.12469	56.8	262.7	44.69197
NO3- (mg/l)	20.75	80.45	19.24705	9.2	423.2	89.82689

Table 9. Groundwater results showing percentage of samples out of permissible limits when compared with BIS and WHO standards. (*PL: Permissible limits, WPL : Within permissible limits)

Parameters	BIS	PRM (% of samples out of PL)	POM (% of samples out of PL)	WHO	PRM (% of samples out of PL)	POM (% of samples out of PL)
pH	7.0- 8.5	18	20	6.5-9.2	WPL	WPL
EC(µs/cm)	-	-	-	400	85	89
TDS(mg/l)	500	55	47	500	63	47
TH(mg/l)	300	5	2	300	5	2
Ca(mg/l)	75	13	6	100	15	WPL
Mg(mg/l)	30	88	90	150	WPL	WPL
Na(mg/l)	-	-	-	200	WPL	WPL
K(mg/l)	13	WPL	WPL	200	WPL	WPL
NO3(mg/l)	45	8	60	50	6	58
SO4(mg/l)	150	WPL	WPL	200	WPL	WPL
PO4(mg/l)	-	-	-	-	-	-
Cl(mg/l)	250	9	3	250	9	3

7. Conclusion

In order to assess the aquifer vulnerability for contamination potential, the combined use of DRASTIC and geographical information system (GIS) is highly reliable method. In the study area DRASTIC index value recorded < 70 to more than 100. The main reason for very high vulnerability in the month of October is the high net recharge (10+mm) and 60 % of the area has 0-2% slope ranges, which allowed the water to percolate more easily into the soil. High net recharge correlated well with the slope of the region. Very high nitrate concentration in the post monsoon season (October) gives more credence to the vulnerability model. Linear combination of DRASTIC method, GIS and Physico-chemical analysis of groundwater result are very effective and practical in assessing groundwater pollution risk.

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