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Groundwater assessment of municipal solid waste dumping site Dubagga, Lucknow region, using vulnerability mapping

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Abstract: Groundwater is the principal source of water in this area. Agricultural practices within the basin are widespread and located close to groundwater wells. The study aims at evaluating the groundwater vulnerability to contamination in the vicinity of a Municipal solid waste landfill site, Dubagga, Lucknow, India, using DRASTIC model integrated with GIS tool has been used to evaluate the groundwater vulnerability of this area. The generated vulnerability map was then validated using physic- chemical and heavy metals analysis of samples collected from the dumping site's nearby wells to determine the area that poses the greatest danger of pollution. According to the vulnerability map, the study area was divided into three vulnerability classes ranging between a minimum value of 110 and a maximum value of 170. The vulnerability map revealed in the Lucknow, Dubagga, Municipal solid waste landfill site was very highly vulnerable to groundwater contamination. The resulting vulnerability map was then validated using a physico- chemical and Heavy metals analysis of samples collected from nearby wells of the dumping Site to assess the area which is of more potential risk to pollution. From the results of the study, Due to the all above parameters data, it is obvious from the foregoing data that the quality of groundwater around the Municipal open dumping site is deteriorating. It is clear that the concentrations of Mg^{2+}, F^{-} and Cr^{6+} exceeds their respective permissible limit in groundwater samples. Quality of groundwater is unfit of drinking in GW5 and GW6 sample and very poor in GW3 and GW8 sample and poor in GW1, GW2, GW4, GW7 and GW9 sample due to the high and low concentrations of all parameters. Then the DRASTIC model validation with water quality parameters is applicable and both results shows the same sampling locations with very high concentration, high concentration and moderate concentration.

Keywords: Groundwater, Vulnerability, Physico-chemical and heavy metals concentration, Standard DRASTIC model, GIS.

1. INTRODUCTION

Groundwater vulnerability is the foundation for assessing the risk of groundwater pollution and developing a management strategy to protect groundwater quality. The concept of groundwater contamination vulnerability is founded on the idea that the physical environment can protect groundwater from natural and human impacts on contaminants in the groundwater. The hydrogeological characteristics that play an essential role in the transmission and transformation of groundwater contaminants are referred to as groundwater vulnerability. The assessment of groundwater vulnerability has become a significant tool for preventing groundwater pollution.

The DRASTIC model was developed by the US Environmental Protection Agency, which is an overlay and index method and is one of the most popular standardized methods for evaluating groundwater vulnerability to contamination (Aller et al., 1987). Because the essential inputs for its application are easy to use, require special data, and may explain groundwater vulnerability, the DRASTIC approach in a Geographic Information System (GIS) environment has been widely employed in many nations. The transport of pollutants from the ground surface to the saturated zone is controlled by seven hydrogeological factors. Groundwater vulnerability maps are used to identify locations that are more prone to pollution than others, as well as to identify places where water quality can be improved.
Due to leachate percolation, landfill leachate is thought to be the primary source of groundwater contamination in the dumpsite's region.

A lot of research on the impact of leachate on nearby groundwater have been published. Groundwater monitoring around landfill sites is required to determine the level of pollution. The DRASTIC model was used to create groundwater vulnerability and risk maps by incorporating the most critical hydrogeological parameters that cause and manage groundwater contamination. By overlaying the available hydrogeological data on a Geographical Information System, a groundwater vulnerability map was created. Geographical Information System was also used to create a groundwater vulnerability map by overlaying the available hydrogeological data.

2. MATERIALS AND METHODS

2.1 Study area:

The research region is in India's Lucknow District, in the Dubagga Area. Lucknow is the capital and largest city of the Indian state of Uttar Pradesh, as well as the administrative centre of the district and division of the same name. It is India's most populated city and the country's twelfth most populous metropolitan agglomeration. It shares an international border with Nepal and is located on India's northern Gangetic plains. The geographical location of **Lucknow** is between 26.50^0 North and 80.50^o **East**. It is with a zone of 2528 sq. km and a population of 4,589,838. The district has a population density of 1,815 inhabitants per square kilometer. Its population growth rate over the decade 2001-2011 was 25.79% Lucknow has a sex ratio of 906 females for every 1000 males, and a literacy rate of 79.33% (Census of India, 2011).

Dubagga landfill lies at 26^{0}52’28.36” North and 80^{0}51’16.90” East. It is located at 160 meter distance of the Chandoia Village in north near Musabagh and western direction of Lucknow city (Fig. 1) is low lying area and close to the fish market and Kadimikabristan, receives about 1000 Metric tons municipal solid waste daily. The Dubagga landfill started in the year 2007 and still in use. It extends over a zone of roughly 61420.08 m^2. About 2500 MT/day of waste is dumped and the landfill height is about 4 m to 5 m **(Shobi Ali et.al, 2018).**

Fig. 1 Location map of study area

The 9 sites around the Dubagga municipal solid waste disposal site were used to construct this study area map. Each site's latitude and longitude were listed in table 1, and the study map of the area was created using the area's latitude and longitude. And all hydro geological data for the months of January, February, and March 2021 were chosen.

Table 1 : Specified locations

Sample no.	Sampling location	Sampling type	Locations
GW1	Madir	Hand-pump	26^{0}54’09.73”N 80^{0}52’21.73”E
GW2	Namaste city	Hand-pump	26^{0}54’0”N 80^{0}52’02”E
GW3	Farm-1	Tube-well	26^{0}53’48.84”N 80^{0}52’22.01”E
GW4	SS & company office site	Tube-well	26^{0}53’57.98”N 80^{0}52’09.90”E
GW5	Dubagga chauraha mod	Hand-pump	26^{0}53’51.1”N 80^{0}52’13.7”E
GW6	M.C. saxena college mod	Hand-pump	26^{0}53’58.64”N 80^{0}52’29.50”E
GW7	Farm- 2	Tube-well	26^{0}53’47.83”N 80^{0}52’02.74”E

GW8	Construction plant site	Tube-well	26⁰53’51.72”N 80⁰52’24.92”E
GW9	Chand traders	Tube-well	26⁰53’57.5”N 80⁰52’07.2”E

2.2 DRASTIC model

Using Arc Map 10.5, the DRASTIC model was utilised to create a vulnerability map for the research area. On the basis of hydrogeologic and anthropogenic factors, the groundwater vulnerability map determines the region most vulnerable to groundwater contamination. The map was created by combining the seven data layers using a Geographic Information System. It's calculated with the weighted sum overlay approach in the ArcMap toolbox's spatial analyst tool. The seven hydrogeological raster inputs were compiled in the weighted sum overlay method specifying the weight for each input, which is then processed into the final vulnerability map. The flow chart of methodology for groundwater vulnerability analysis is given in Figure 2.

The DRASTIC model is based on seven parameters, corresponding to seven layers to be used as input parameters for modelling. The **DRASTIC** model is considered for seven hydrogeological parameters which are **D**epth to water, net **R**echarge, **A**quifer media, **S**oil media, **T**opography, **I**mpact of vadose zone media, and hydraulic **C**onductivity of the aquifer (Aller, 1987). The characteristics would be weighted and rated based on their relative susceptibility to the pollutant and contribution to the possible contamination. DRASTIC assigns weights and ratings to each of the seven factors, which are divided into two classes on a scale of 1 to 10, with one denoting the least vulnerable and ten denoting the most vulnerable areas. This rating would be further scaled into weights based on the importance of the parameter in determining aquifer characteristics, which are scaled from 1 to 5, where, 1 is least significant and 5 is most significant. The DRASTIC vulnerability index can be calculated by linear addition of the weights and rating.

DRASTIC Index = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw

Where,
r = rating value assigned to units of parameters
w = weight assigned to each parameter.

2.3 Sample Collections:

A total of nine sampling locations were chosen in the vicinity of the Dubagga municipal dump. Table 1 lists all of the sampling locations. Plastic containers were used to collect groundwater samples. As part of the quality control process, all bottles were washed and rinsed with water before being collected. In March 2021, ground water samples were taken at each location. The sampled water was handled on the spot, preserved in polythene bottles, and transported to the laboratory in an icebox at 4 ° C.

Table 2: List of parameters analyzed and methodology followed

Parameters	Methodology	Units
Electrical Conductivity (EC)	PH meter	μs/cm
PH	PH meter	-
Total Dissolved Solid (TDS)	Gravimetric method	mg/l
Total Hardness (TH), Calcium as (Ca^{2+}), Magnesium as (Mg^{2+})	EDTA Titrimetric Method	mg/l
Total alkalinity (TA)	Titration method	mg/l
Chloride as (Cl^-)	Argentometric Method	mg/l
Nitrate as (NO_3^-), Chromium as (Cr), Fluoride as (F^-), Iron as (Fe), Sulphate as(SO_4^{2-})	UV Spectrometric Method	mg/l

The results of the physico-chemical parameters and concentration of groundwater are compared with the limits prescribed by Bureau of Indian Standard (BIS) shown in table 3 and compared march sampling data. All parameters and methods prescribed in Table 2.

Table 3. BIS Standards

Parameters	BIS Standard (Desirable limit)	BIS Standard (Permissible limit)
PH	6.5 – 8.5	6.5 – 8.5
EC	-	-
Total Dissolved Solid	500	2000
Total Hardness	200	600
Calcium	75	200
Magnesium	30	100
Total Alkalinity	200	600
Chloride	250	1000
Nitrate	45	NR
Sulphate	200	400
Fluoride	1	1.5
Chromium	0.05	NR

3. RESULTS AND DISCUSSIONS

3.1 DRASTIC Model: The DRASTIC Model results are given below-

D (Depth to water table): The distance between the ground surface and the water table is referred to as the depth to water table. The depth of material in which a contaminant moves before reaching the aquifer is determined by this zone. As a result, the greater the depth of the water, the lower the risk of pollution. Groundwater levels were received for this study from the Ground Water Department of the University of Pennsylvania. The data was interpolated using the Inverse Distance Weighted (IDW) method to create the depth to water table layer in raster format, which was then classed based on the ranges and ratings**.**The depth to groundwater vary from 8.5 to more than 13 m. Therefore, four classes were used for the studied basin. These are < 9, 9 – 11, 11 – 13 and more than 13 m, and the rating of these ranges are 10, 5, 3 and 2 respectively. And the weight is 5.

R (net Recharge): Precipitation and runoff in the basin, which infiltrates through the ground surface to reach the water table, are the main sources of recharge in the study region. The total amount of water per unit area that moves to the water table is referred to as net recharge. The India Meteorological Department (IMD Site) provided monthly rainfall statistics. The Inverse Distance Weighted (IDW) method was utilised to interpolate the data in order to create a raster format of the rainfall data layer, which was then classed based on the ranges and ratings. The net recharge vary from 5 to more than 9.5 mm. Therefore, five classes were used for the studied basin. These are 5 – 6, 6 – 8, 8 – 9, 9 – 9.5 and more than 9.5m m, and the rating of these ranges are 1, 3, 6, 8 and 9 respectively. And the weight is 4.

A (Aquifer media): The nature of aquifer bodies, whether consolidated or unconsolidated, is referred to as aquifer media. Porosity and permeability levels above that level indicate a higher risk of aquifer vulnerability. In this aquifer media is obtained from the Central Ground Water Board report Northern region Lucknow. In this study area the basic rock formation type is Sand. The rating is 8 for the aquifer media, and the weight is 3.

S (Soil media): The uppermost layer of the earth surface is employed as the model's soil media. The amount of recharge that can infiltrate into the ground is mostly determined by the soil .The loose and unconsolidated formation of loamy soil has got higher rating compared to other type. The soil media obtained from the Central Ground Water Board report Northern region Lucknow. In this region soil types are loamy soil, silty soil and clayey soil. And the ratings of these soils are 5, 4 and 3 respectively and the weight factor is 2.

T (Topography): The slope of the surface under examination is included in topography. The chance of a contaminant infiltrating the ground surface is determined by the slope. Pollution levels are predicted to be higher in places with lower slopes. The slope of the research region was extracted using a digital elevation model (DEM) and a topographical map was made from it. The slope Vary from 0 to more than 6%. Therefore, five classes were used for the studies. These are 0- 2, 2-3.5, 3.5-5, 5-6 and >6%, and the rating of these ranges are 10, 9, 5, 3 and 1 respectively. The weight for the topography is 1.

I (Impact of vadose zone): The unsaturated zone above the water table is referred to as the vadose zone. The texture and nature of the vadose zone have an impact on the time it takes for a pollutant to transit through it. The ratings for the vadose zone are usually very similar to those for the aquifer media.The vadose zone in the research area is mainly composed of sand. The impact of the vadose zone ratings is 8, and the weight is 5.

C (hydraulic Conductivity): The rate at which water flows in an aquifer is referred to as hydraulic conductivity. Hydraulic conductivity levels above a certain threshold indicate a higher risk of contamination. The hydraulic conductivity were obtained from the soil permeability geological survey of india. In this study the
Hydraulic conductivity vary from 0.91 to 3.1 m/day. Therefore, five classes were used for the studies. These are 0.91 – 0.99, 0.99 – 1.2, 1.2 – 2.3, 2.3 – 2.8 and 2.8 -3.1 m/day, and rating of these are 1, 4, 5, 6 and 8 respectively. The weight of hydraulic conductivity is 4.

3.2 Vulnerability map:

To make the vulnerability map, all seven parameter index map layers were layered with the Geoprocessing tool's weighted sum overlay, which is part of the Arc toolbox's Spatial Analyst extension. This approach combines the produced map layers by multiplying each by its assigned weight and rate, then adding them all up to get the index.. The study area was divided into three vulnerability classes ranging between a minimum value of 110 and a maximum value of 170. These classes are moderate vulnerable, high vulnerable and very high vulnerable. The ranges for moderate 110 - 135, high 136 - 157 and very high 158 – 170 vulnerability. These as shown in the vulnerability zone map in Figure 2.

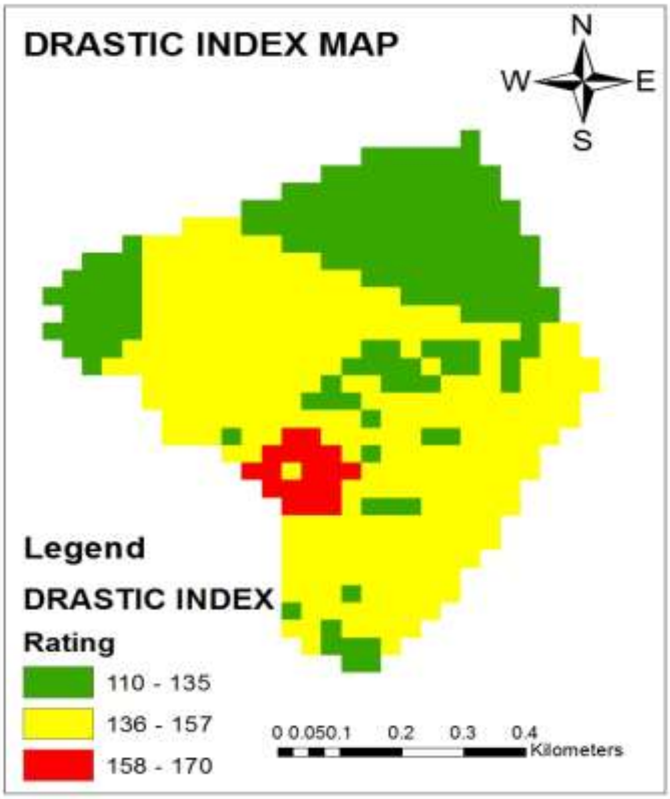


Fig. 2 DRASTIC index map

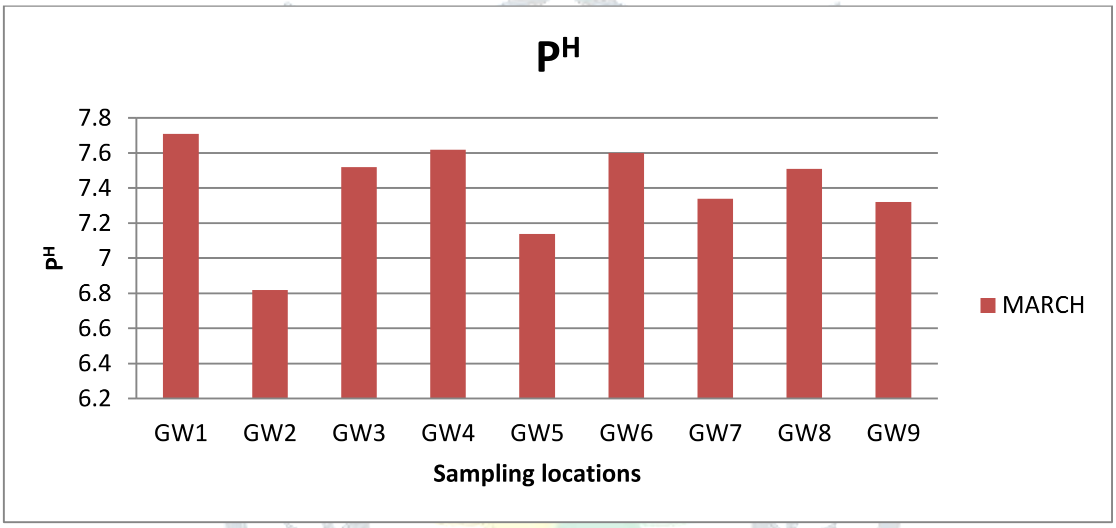
3.3 Physic-chemical characteristics of groundwater samples

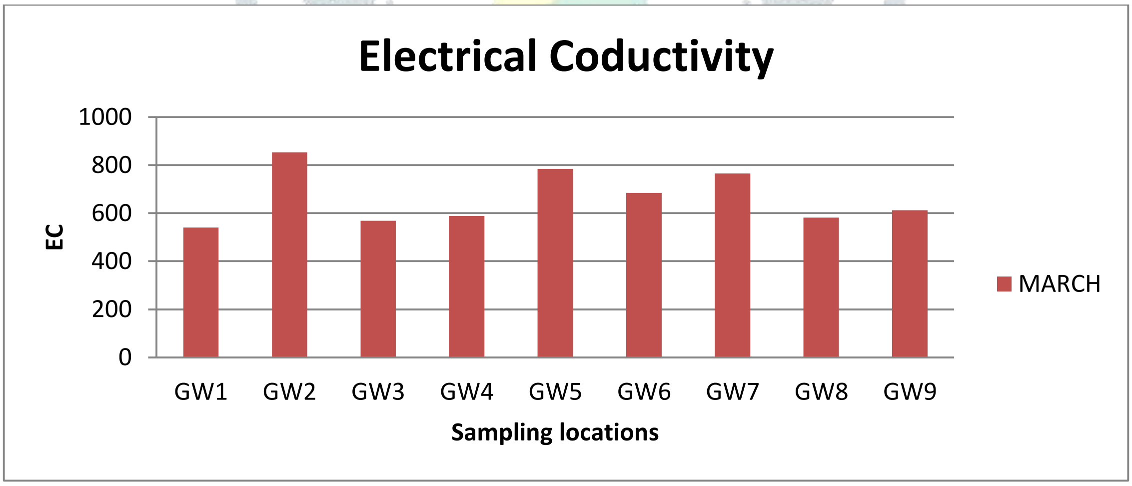
The physic-chemical and heavy metals characteristics of groundwater samples was statistically analyzed and the results are shown in fig. 3 descriptive statistics of the groundwater quality, acceptable limits for various parameters as per the BIS (2012).

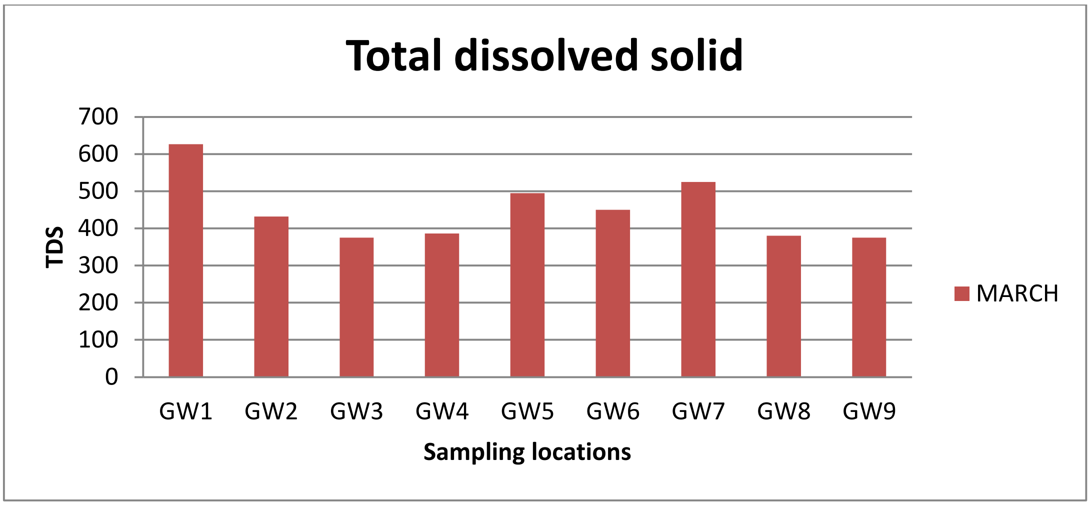
The water quality analysis of different ground water samples have been carried out for p^H, Electrical conductivity, TDS, Ca ion, Mg ion, total hardness, total alkalinity, chloride, sulphate, nitrate, fluoride and Chromium. The result of groundwater samples collected from different sources is presented in table 1. The p^H is observed in the range between 6.82 - 7.71 in March. It is observed that all the samples comes under the BIS limit (6.5-8.5) for P^H. In case of electrical conductivity it is found 541 - 854 (µs/cm) in March. It represents the measures of number of ions present in water. The TDS of the samples are varying from 375 - 626 (mg/l) in March and all comes umder desirable limit but GW1 sample exceed their acceptable limit.

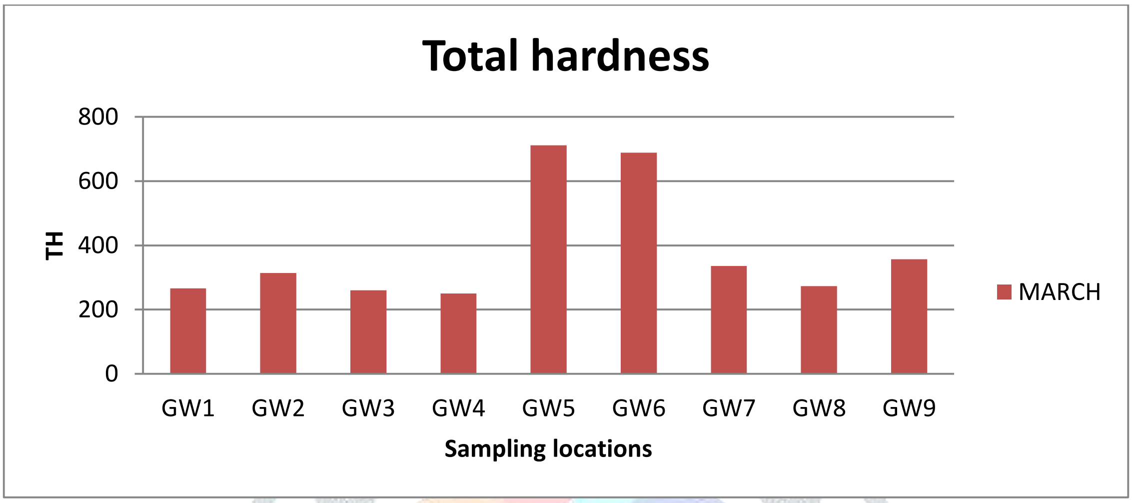
The same trends of calcium ion is observed in range of 39.2 – 132.4 mg/l in March and the Sample of GW3, GW7 and GW8 with in desirable limit of Ca^{2+} and GW1, GW2, GW4, GW5, GW6 and GW9 samples exceeds their desirable limit. And magnesium ions are observed i.e. concentration range 8.2 – 99.4 mg/l in march. Sample of GW2, GW4 and GW9 with in Mg^{2+} desirable limit and the sample of GW1, GW3, GW5, GW6, GW7 and GW8 exceed Mg^{2+} desirable limit. The Total hardness (TH) values groundwater samples are found in between 250 – 711.5 mg/l in March. All Sample exceeds their acceptable limit and GW5 and GW6 exceed TH permissible limit. which found higher than desirable limit and higher than the permissible limit both then more concentration of TH. All samples are comes in very hard category of water as all samples are greater than 180 mg/l. Total alkalinity (TA) as $CaCO_3$ in groundwater ranges from 193.9 – 256.3 mg/l in March. Sample of GW2 with in desirable limit and all samples exceeds desirable limit. Cl^- in the groundwater found in range of 18.6 – 57.1 mg/l in March. In which the concentration of Cl^- is observed all with in desirable limit..

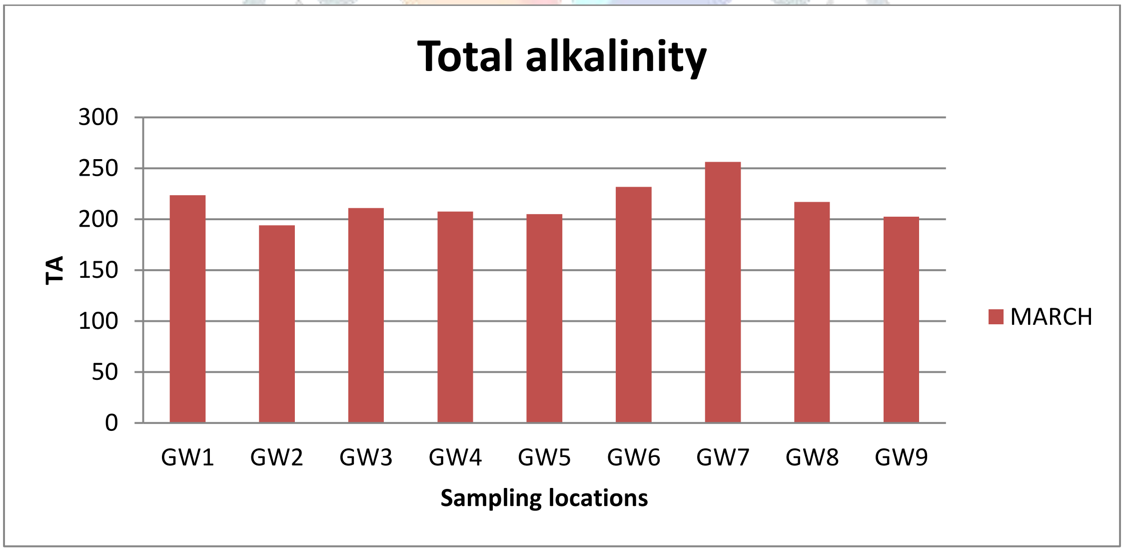
The nitrate fixation was additionally inside as far as possible (45 mg/L) in all the testing areas yet higher most importantly in area (GW6) and range between 3 – 26.12 mg/l in March. The SO_4^{2-} concentration in samples is within permissible values of BIS (200 – 400) mg/l and WHO guidelines for all the gathered examples range between 13.5 – 45.52 mg/l in March. The concentration of F^- in the gathered water tests range from 0.64 – 1.2 mg/l in March. F^- concentration up to 1 mg/l is necessary for development of teeth but more than it may causes dental fluorosis and more than 1.5 mg/l causes skeleton fluorosis. But the concenctration of F^- exceeded their desirable limit in GW5 and GW6. But the concentration Chromium ion is exceed the permissible limit in groundwater sample in 3 location GW1, GW5 and GW6 as 0.11, 0.14 and 0.15mg/l respectively in March as the permissible of chromium ion is 0.05 mg/l.

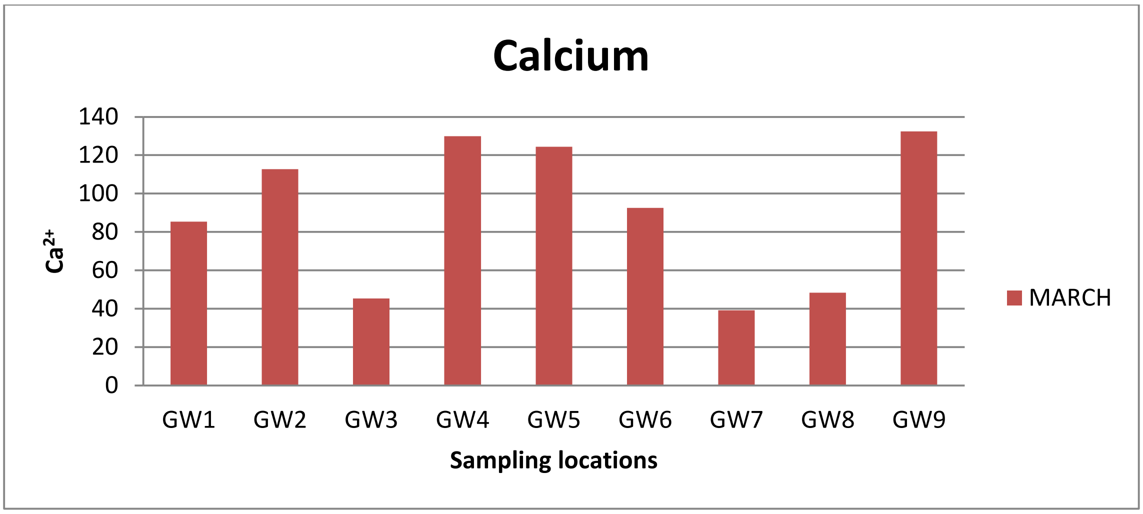


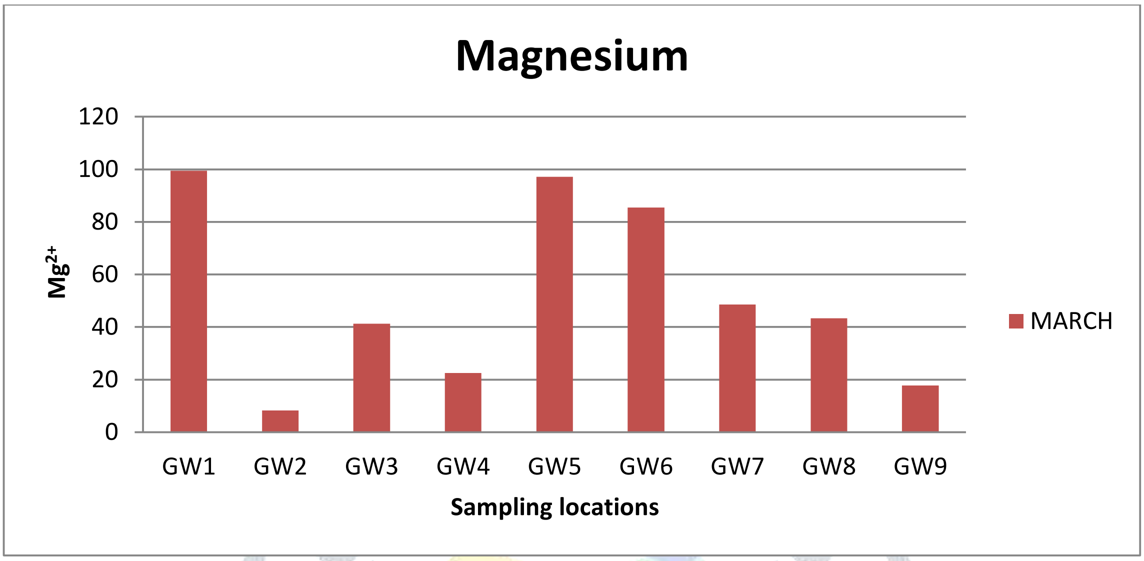


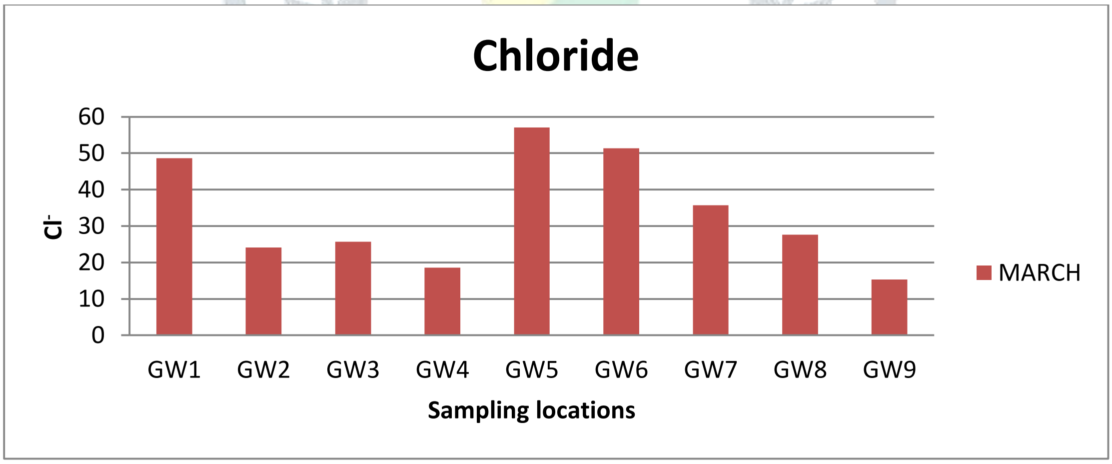

Total dissolved solid
TDS
700
600
500
400
300
200
100
0
GW1 GW2 GW3 GW4 GW5 GW6 GW7 GW8 GW9
Sampling locations
MARCH

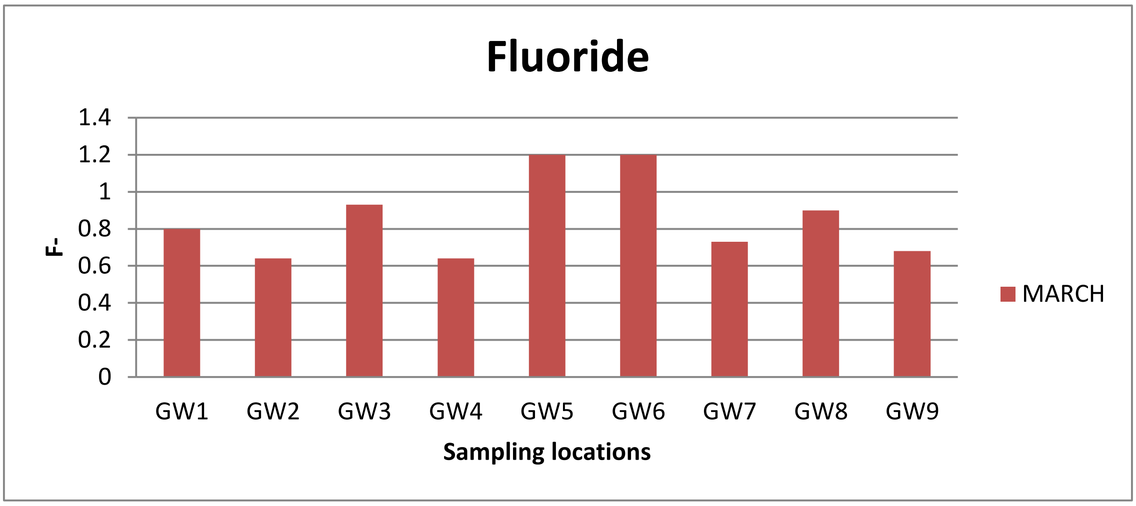

Total hardness
TH
800
600
400
200
0
GW1 GW2 GW3 GW4 GW5 GW6 GW7 GW8 GW9
Sampling locations
MARCH

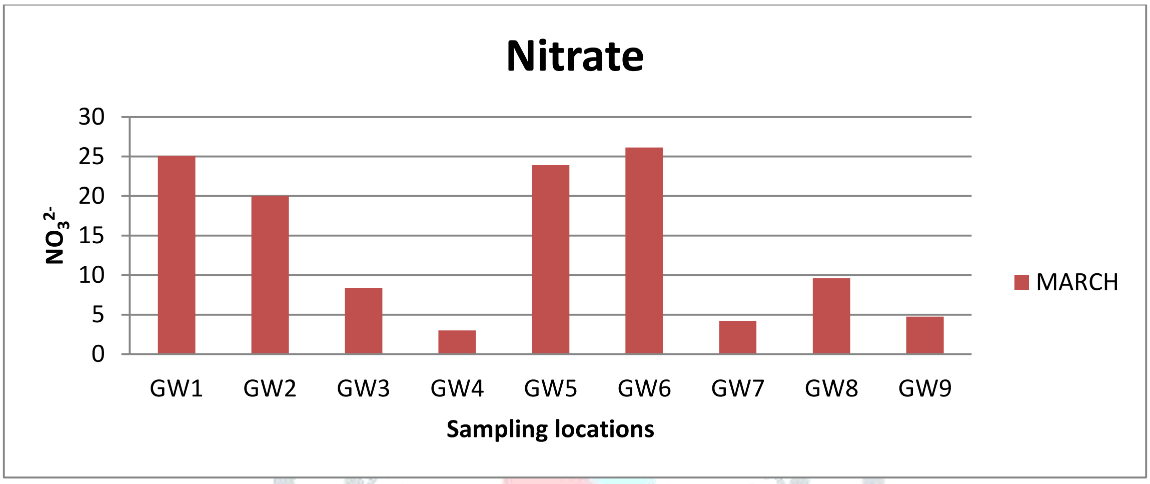

Total alkalinity
TA
300
250
200
150
100
50
0
GW1 GW2 GW3 GW4 GW5 GW6 GW7 GW8 GW9
Sampling locations
MARCH

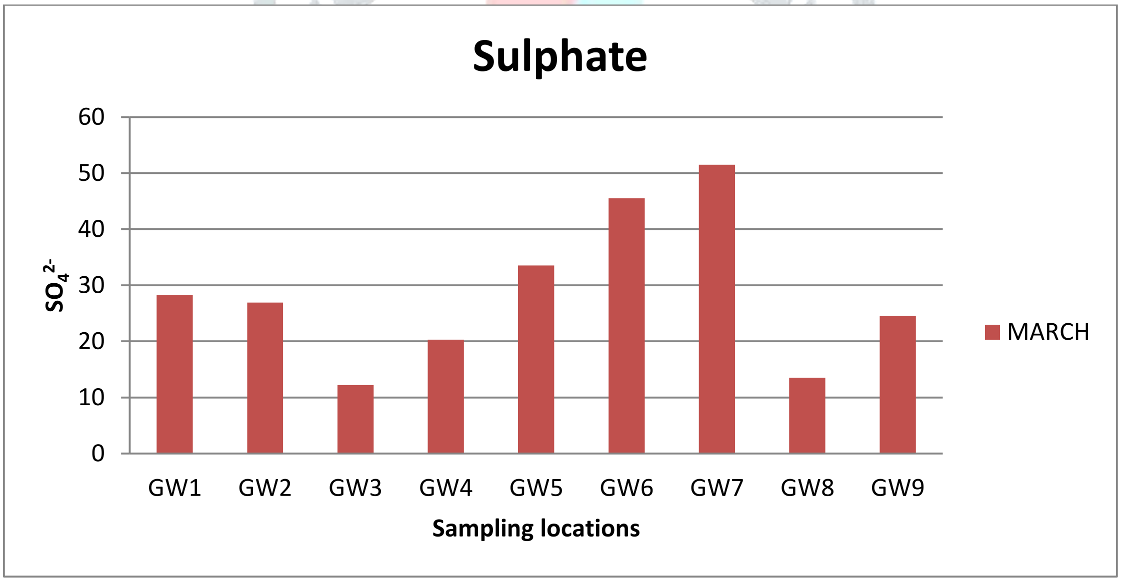

Calcium
140
120
100
80
60
40
20
0
Ca^{2+}
GW1 GW2 GW3 GW4 GW5 GW6 GW7 GW8 GW9
Sampling locations
MARCH


Magnesium
120
100
80
60
40
20
0
Mg^{2+}
GW1 GW2 GW3 GW4 GW5 GW6 GW7 GW8 GW9
Sampling locations
MARCH


Chloride
60
50
40
30
20
10
0
Cl^-
GW1 GW2 GW3 GW4 GW5 GW6 GW7 GW8 GW9
Sampling locations
MARCH


Fluoride
1.4
1.2
1
0.8
0.6
0.4
0.2
0
F-
GW1
GW2
GW3
GW4
GW5
GW6
GW7
GW8
GW9
Sampling locations
MARCH


Nitrate
30
25
20
15
10
5
0
NO_3^{2-}
GW1
GW2
GW3
GW4
GW5
GW6
GW7
GW8
GW9
Sampling locations
MARCH


Sulphate
60
50
40
30
20
10
0
SO_4^{2-}
GW1
GW2
GW3
GW4
GW5
GW6
GW7
GW8
GW9
Sampling locations
MARCH

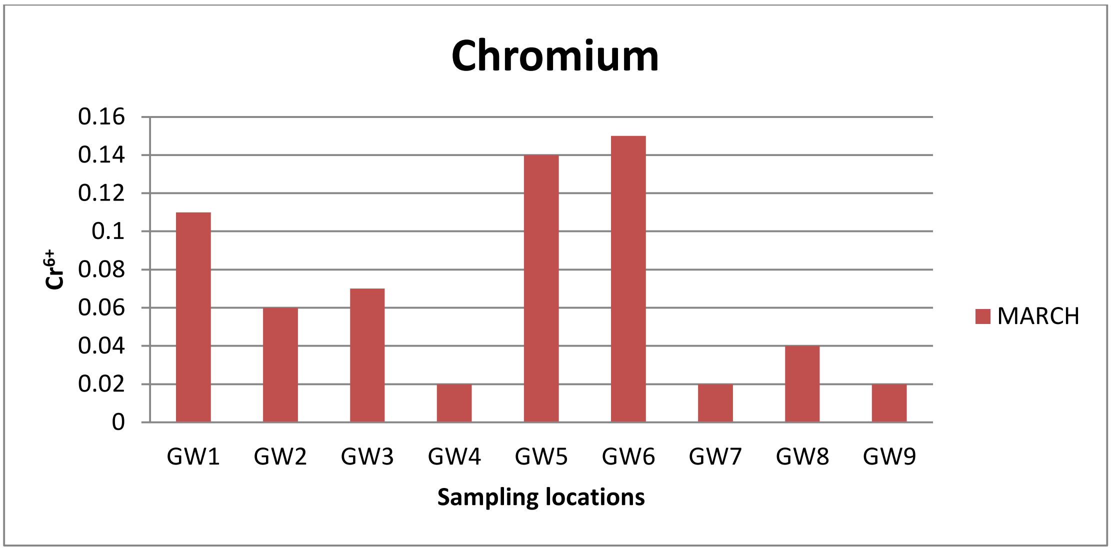


Fig. 2. Concentration of P^H, EC, TDS, TH, TA, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^{2-}, SO_4^{2-}, F^-, and Cr^{6+} groundwater.

3.4 Validation of DRASTIC model

For validation of the vulnerability index map, a physico-chemical and heavy metals parameter was considered to justify with DRASTIC vulnerability index. The p^H and EC was measured . It is observed that all the samples comes under the BIS limit. The TDS concentration in samples that laid GW1 and GW7 exceed their desirable limit as prescribed by Bureau of Indian Standards , and all with in the desirable limit but in some sampling location it was in border that sites were GW5, GW6 and GW2. The TH is observed that the 2 samples, GW5 and GW6 exceed their permissible limit. And all other samples GW1, GW2, GW3, GW4, GW7,GW8 and GW9 exceeds their desirable limit. The TA is measured that the eight samples exceeds their desirable limit only one sample with in the desirable limit that is GW2. The Ca^{2+} is observed that the 7 samples exceeds their desirable limit and only two samples that is GW7 and GW8 with in the desirable limit. The Mg^{2+} is measured that the 6 samples exceeds their permissible limit and only 3 samples that is GW2, GW4 and GW9 with in the desirable limit. The Cl^- is observed that the all samples with in the acceptable limit. The NO_3^{2-}concentration is measured that the all samples with in their acceptable limit. The SO_4^{2-} content is measured that the all samples with in their acceptable limit. The F^- content in groundwater is measured that the GW5 and GW6 exceeds their desirable limit and remaining 7 samples with in their acceptable limit. And the Cr^{6+} concentration is observed that the GW2, GW4, GW7, GW8 and GW9 With in their acceptable limit and GW5, GW6, GW3 and GW1 exceeds their acceptable limits. Due to all above data in this study area Mg^{2+}, F^- and Cr^{6+} exceeds their respective permissible limit in groundwater samples. Then the Quality of groundwater is unfit of drinking in GW5 and GW6 sample and very poor in GW3 and GW8 sample and poor in GW1, GW2, GW4, GW7 and GW9 sample due to the high and low concentrations of all parameters.

The results shows that vulnerability index ranges from 110 to 170 and is classified into three classes i.e., 110 to 135, 136 to 157 and 158 to 170 corresponding to moderate, high and very high vulnerability zones respectively. From the table 1 location sites GW5 and GW6 are very high vulnerability. GW4, GW3, GW7, GW8) and GW9 are high vulnerability. And GW2 and GW1 are moderate vulnerability. Then the DRASTIC model validation with water quality parameters is applicable and both results shows the same sampling locations with very high concentration, high concentration and moderate concentration.

4. CONCLUSION

Due to the Municipal Solid Waste Landfill Site Dubagga in Lucknow, the pollutant that is predominantly responsible for ground water contamination in the research region. As a result, determining vulnerability has become a crucial component of this effort. The groundwater vulnerability was determined using the DRASTIC model in a geographic information system context. The results shows that vulnerability index ranges from 110 to 170 and is classified into three classes i.e., 110 to 135, 136 to 157 and 158 to 170 corresponding to moderate, high and very high vulnerability zones respectively.

From the table 1 location sites GW5 and GW6 are very high vulnerability. GW4, GW3, GW7, GW8 and GW9 are high vulnerability. And GW2 and GW1 are moderate. The resulting vulnerability map was then validated using a physic- chemical and Heavy metals analysis of samples collected from nearby of the dumping Site to assess the area which is of more risk to pollution. From the results of the study, Due to the all above parameters data, It is clear that the concentrations of Mg^{2+}, F^- and Cr^{6+} exceeds their respective permissible limit in groundwater samples. Quality of groundwater is unfit of drinking in GW5 and GW6 sample and very poor in GW3 and GW8 sample and poor in GW1, GW2, GW4, GW7 and GW9 sample. It is clear that the concentrations of all water quality parameters were correlated; which validated the results obtained. Then the DRASTIC model validation with water quality parameters is applicable and both results shows the same sampling locations with very high concentration, high concentration and moderate concentration.

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