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Application of GIS and DRASTIC Modeling for Evaluation of Groundwater Vulnerability near a Solid Waste Disposal Site

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Abstract

The study aims at evaluating the groundwater vulnerability to contamination in the vicinity of a solid waste disposal site, Njelianparamba, a municipal dumping site in Kozhikode, Kerala, India, using DRASTIC model using Geographic Information System environment. Vulnerability maps are intended to show areas of most potential to groundwater contamination on the basis of hydrogeological conditions and human impacts. The DRASTIC model consists of seven hydrogeological parameters that affect groundwater quality. The ESRI GIS software, Arc Map 10.1 was used to create the groundwater vulnerability map by overlaying the seven layers. The resulting vulnerability map was then validated using chemical and bacteriological analysis of samples collected from nearby wells of the dumping site to assess the area which is of more potential risk to pollution. According to the vulnerability map, the study area was divided into three vulnerability classes ranging between a minimum value of 120 and a maximum value of 243. The vulnerability classes are moderate vulnerable, high vulnerable and very high vulnerable. The vulnerability map revealed that the eastern and south eastern portion of Njelianparamba dump site was very highly vulnerable to groundwater contamination. This is probably due to the lower sloped terrains towards the eastern portion which allows percolation of contaminants into the groundwater.

Keywords

Groundwater Vulnerability, DRASTIC Model, Geographic Information System, Hydrogeological Parameters

1. Introduction

Conservation and monitoring of groundwater resources are crucial since deterioration of groundwater quality

has been reported to be one of the major problems faced all over the world due to urbanization, industrialization, irrigation activities and municipal landfill leachate [1].

Landfill leachate is considered as the main cause of groundwater contamination in the nearby areas of the dumpsite [2]. Leachate consists of organic matter (biodegradable), ammonia-nitrogen, heavy metals, chlorinated organic and inorganic salts, which are a great threat to the surrounding soil, groundwater and even surface water [3] [4]. The composition of leachate does not vary and it differs with different sites and environmental conditions, depending on the nature of the waste deposited, rainfall, soil characteristics, and on age of the landfill [5] [6]. The groundwater vulnerability to contamination depends on intrinsic susceptibility and anthropogenic contamination. Many studies have been conducted related to groundwater vulnerability due to landfill leachate [2] [7]. There is a need for groundwater monitoring around the landfill sites to understand the degree of contamination.

Groundwater vulnerability to contamination was defined by International Association of Hydrogeologist as the "Vulnerability is an intrinsic property of a groundwater that depends on the sensitivity of that system to human and natural impacts" [8]. The groundwater vulnerability to contamination is based on the concept that physical environment can provide protection to groundwater against natural and human impacts with respect to contaminants in the groundwater [9]. Groundwater vulnerability deals with the hydrogeological parameters which affect different contaminants in various ways based on their interactions and chemical properties. Vulnerability assessment is a predictable tool to demarcate areas that are more likely to contamination as a result of anthropogenic activities.

DRASTIC model was introduced by the US Environmental Protection Agency to assess groundwater pollution potential [10] [11]. The DRASTIC model in a geographical information system environment was used in many vulnerability studies to evaluate the vulnerability of the study area [12]-[15]. The regions which are more vulnerable to contamination can be identified using groundwater vulnerability mapping based on the hydrogeological parameters that affect and control the movement of groundwater [10]. The output of the groundwater vulnerability studies can provide information that can be used to prevent further pollution of contaminated areas. The main objective of the present study is to assess the groundwater vulnerability in the vicinity of a municipal solid waste disposal site at Njelianparamba using a DRASTIC model and to validate the model using real time collected on water quality from the field.

2. Materials and Methods

2.1. Study Area

Njelianparamba, a solid waste dumping site of Kozhikode Corporation is situated in Cheruvannur Nallalam area, Kerala, India. An average of 200 tonnes of waste per day is dumped in 18 hectares. The area is located between latitude of 11˚13'30"N to 11˚11'N and longitude of 75˚48'E to 75˚50'30"E. The site is one of the primary industrial areas of the Kozhikode district. A number of small, medium and large industrial units on clay, agro-forestry, chemical and metals are located in and around the site. The height of the dump is about 3 to 4 m above ground level and average of 60 - 80 tonnes of organic waste (vegetable, meat and fish waste) from markets and households are deposited in to the dump daily. The landfill originally accepted only non-hazardous solid wastes but now receives both degradable and non-degradable waste including hazardous waste. Organic solid wastes are treated at the waste treatment plant at Njelianparamba. However, there is no leachate treatment facility in the dump yard. The leachate from the plant and trench yard is collected in a pond on the north east side of the site.

The study area is characterised by a humid tropical climate with high rainfall. The climate is divided in to four seasons—summer, south west tropical monsoon period (SW), north east tropical monsoon period (NE) and winter. The SW and NE monsoons are responsible for 82.77% of the total rainfall in the area. June to November is the rainy season in the study area (monsoon season) during which time about 70% of the rainfall is contributed by the SW monsoon. The average annual rainfall recorded in the area during the study period is 2777 mm [16]. The mean maximum temperature is 31.67˚C and the minimum is 22.97˚C. The relative humidity ranges from 74% to 92% during morning hours and 64 to 89% in evening hours. Physiographically the area lies in the middle portions of the Kozhikode district with an elevation ranging from 15 to 50 m above the mean sea level. **Figure 1** shows the location map of the study area.

2.2. Hydrogeology

The geological formations of Njelianparamba primarily consist of porous laterite and forms potential phreatic-
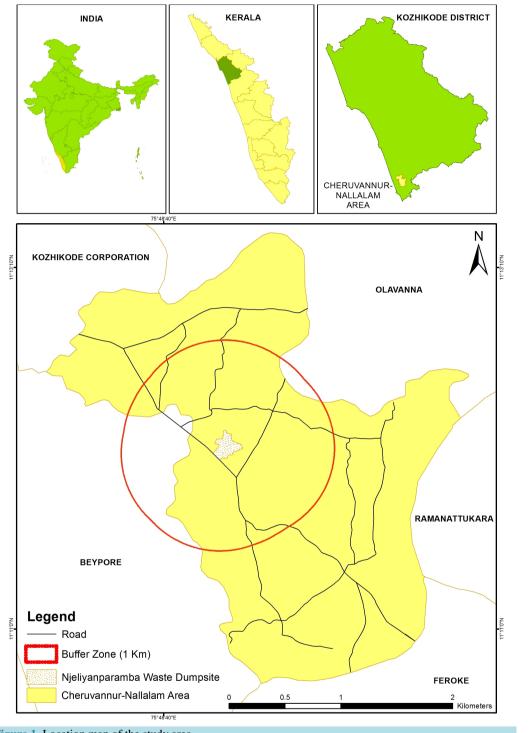
Figure 1. Location map of the study area.

aquifers; it comes under the midland terrain of Kozhikode district [17]. Lateritic soil is derived from laterite under a tropical climate with alternating wet and dry conditions. The soil is reddish in colour, moderately permeable with an infiltration rate that enables absorption of most of the rain. The pH of the soil ranges from 5.5 to 6.5 and the texture is sandy loam. Groundwater occurs under phreatic conditions in weathered crystalline rocks and under confined to semi-confined conditions in deeper crystalline formations. Dug wells are the principle water supply for drinking and other purposes in the study area. The average groundwater level during the pre-monsoon

period is 2 to 16 mbgl (metres below ground level), whereas the water table level in post-monsoon is 0.38 to 9 mbgl. The effects of leachate percolation are observed in many nearby dug wells in the form of a brown oily appearance and unpleasant foul smell.

2.3. DRASTIC Model

A GARMIN GPS was used to record the latitude and longitude of sampling points which were imported into the GIS platform. 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 [18]. The parameters would be weighted and rated according to their relative susceptibility to the pollutant according to their relative contribution to the potential contamination [10]. DRASTIC assigns the weights and ratings would be 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 would be 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. The DRASTIC vulnerability index can be calculated by linear addition of the weights and rating. The equation for calculating the DI is

$$\text{DRASTIC Index} = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw \tag{1}$$

where D the is depth to water table, R the net recharge, A the aquifer media, S the soil media, T the topography, I the impact of vadose zone, C the hydraulic conductivity, r is the rating value assigned to units of parameters and w is the weight assigned to each parameter.

The DRASTIC model was used to prepare a vulnerability map for the study area using ArcMap 10.1. Groundwater vulnerability map identifies the region, most potent to groundwater contamination on the basis of hydrogeologic and anthropogenic factors. The map was developed by using Geographic Information System to combine the seven data layers. It is determined by using the weighted sum overlay method under the spatial analyst tool in the ArcMap tool box. 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 GW vulnerability analysis is given in **Figure 2**.
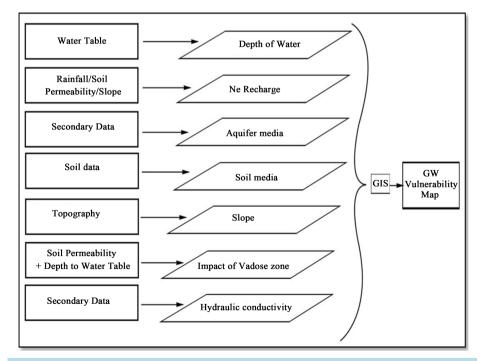

Figure 2. Methodology for groundwater vulnerability study.

2.4. Sampling and Analysis

Sampling and analysis of the groundwater samples were conducted according to the Standard Methods for Examination of Water and Wastewater [19]. A random sampling method was used followed to study the impact of solid waste leachate on groundwater quality. A total of 29 sampling sites were randomly chosen with a buffer zone of 1 Km radius from the landfill site. Out of these sites, 20 groundwater samples were collected within the buffer zone and 9 samples from outside of the zone. To validate the vulnerability map, a total of 29 groundwater samples were collected and analysed for total dissolved solids and *E. coli*. Pre-cleaned polyethylene bottle of 1 lire capacity were used for the analysis of total dissolved solids and sterilized bottle for bacteriological analysis. The total dissolved solids was analysed by gravimetric method and the bacteriological analysis was done by the Multiple Tube Dilution technique.

About 57 soil samples were collected, out of which, 49 samples were collected within the buffer zone and 8 samples from outside the buffer zone. These samples were analysed for texture analysis using hydrometer method to determine the soil media map [20]. All the chemicals used in this study were of analytical reagent grade. To ensure standard quality control/quality assurance procedures, replicates were analyzed for each sample.

3. Results and Discussion

3.1. Depth to Water Table

The depth to water determines the depth of material through which a contaminant must travel before reaching the aquifer, and it may help to determine the amount of time during which contact with the surrounding media is maintained. The deeper water table levels imply lesser chance for contamination to occur. A total number of 29 wells locations were selected from the study area to calculate the average depth to water table. Depth of groundwater ranged from 5 - 15 m. The depth to water table map was then classified into ranges defined by the DRASTIC model and assigned rates ranging from 1 (minimum impact on vulnerability) to 10 (maximum impact on the vulnerability) are shown in **Figure 3**.
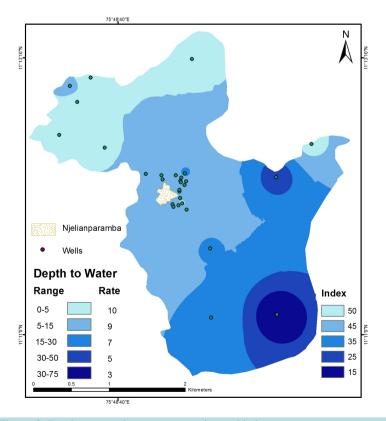

Figure 3. Depth to ground water range, rating and index map.

3.2. Net Recharge

Net recharge is the amount of water which penetrates the ground surface and reaches the water table, recharge water represents the medium for transporting pollutants. Recharge water is thus available to transport a contaminant vertically to the water table and horizontally within the aquifer. Rainfall is an important factor which transports surface pollutants and landfill leachate by infiltration. Recharge data were not available for the study area. Therefore, net recharge was calculated by a combination of ratings for slope, soil permeability and rainfall following the method given by [21].

$$\text{Recharge value} = \text{Slope}\ (\%) + \text{Rainfall} + \text{Soil permeability} \tag{2}$$

The range, rating and index of net recharge are given in **Figure 4**. The slope (%) in the study area was derived from the NASA SRTM (Shuttle Radar Topographic Mission) data that provides the digital elevation model (DEM) obtained from the USGS ftp site. The soil permeability map was generated from soil texture data. The CWRDM rainfall stations maintained by the meteorological observatory were used to measure the rain fall (3200 mm) in the study area. The net recharge map was generated by superimposing the net recharge parameters, according to the values given in **Table 1**.
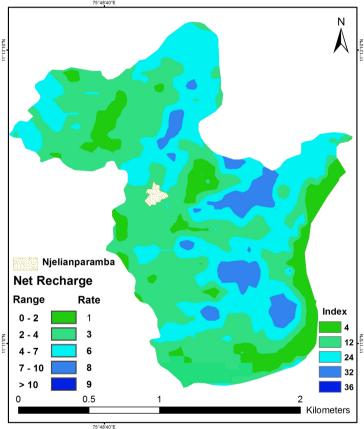

Figure 4. Net recharge range, rating and index map.

Table 1. Data used for measurement of net recharge in the study area.

Slope %	Rating	Rainfall (mm)	Rating	Soil Permeability	Rating	Net recharge	Rating
0 - 2	10					0 - 2	4
2 - 6	9					2 - 4	12
6 - 12	5	3200	4	1 - 100	1	7 - 7	24
12 - 18	3					7-10	32
>18	1					>10	36

3.3. Aquifer Media

Aquifer media refers to consolidated or unconsolidated rock which serves as an aquifer. It is the saturated zone material, which controls the pollutant attenuation processes which determine the flow rates and types of contamination. The sand and gravel are the basic rock formation in the study area. The assigned rating for aquifer media is found to be 8. The range, rating and index of aquifer media given in **Figure 5**.

3.4. Soil Media

Soil media refers to the weathered portion of the earth surface characterised by considerable biological activity. Soil acts as a transport media for contaminants to travel vertically into the groundwater because of its ability to infiltrate impurities through rainfall recharge. Soil pollution potential is mostly affected by the soil types. Soil types were analysed and identified from different sampling stations using soil texture analysis. Based on soil texture, the soil map was classified into three classes—sandy loam, loam and clay loam with ratings 6, 5 and 3 (**Figure 4**). The rating value of 6 was covering the greatest area of the study area. This result was then compiled in to a soil media map using the USEPA DRASIC system. The range, rating and index of soil media of the study area are shown in **Figure 6**.

3.5. Topography

Topography refers to the slope of the land surface. It indicates that plain surfaces will let the runoff water to remain on the surface and allow contaminant percolation to the saturated zone and also indicates that steeper slopes can be a sign of higher groundwater velocity. Slope classes with their range, rating and index of the study area are shown in **Figure 7**. A digital elevation model (DEM) was used to extract the slope of the study area.
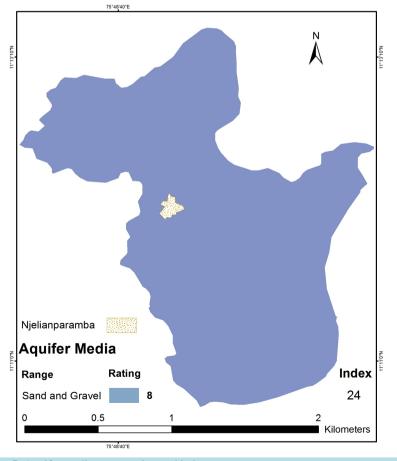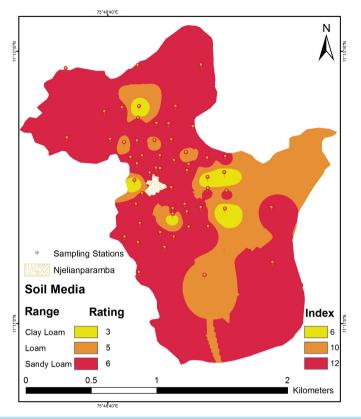

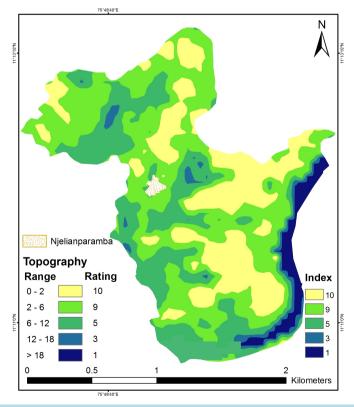**Figure 5.** Aquifer media range, rating and index map.

Figure 6. Soil media range, rating and index map.

Figure 7. Topography range, rating and index map.

3.6. Impact of Vadose Zone

The vadose zone is mainly the unsaturated above the water table which controls the passage and filters the contaminants into the saturated zone. The vadose zone in the study area is mainly composed of sand and gravel. It is rated as 8 according to the USEPA-DRASTIC method. The vadose zone range, rating and index are shown in **Figure 8**.

3.7. Hydraulic Conductivity

Hydraulic conductivity is the ability of an aquifer to transport water and control the groundwater flow rate under a constant hydraulic gradient. It determines the rate of flow of contaminant material through groundwater, as it is controlled by the amount and void spaces, porosity, fracturing etc. A low conductivity means high resistance against contamination and high conductivity indicates high vulnerability while transportation [22]. Hydraulic conductivity value was obtained from the soil permeability class based on the United State Department of Agriculture [23] as shown in **Table 2**. The texture analysis data from the soil media layer was used to determine soil permeability for the study area. The indigenous value for hydraulic conductivity was found to be within the range of 1 - 100 gpd/ft^2 with a rating of 1 [10]. The range, rating and index for hydraulic conductivity of the study area are shown in **Figure 9**.
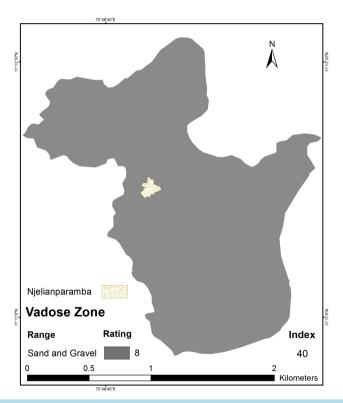

Figure 8. Vadose zone range, rating and index map.

Table 2. Soil permeability class [23].

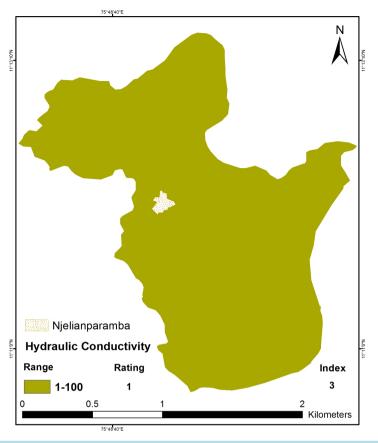| Texture class	Texture	Permeability rate	Permeability class
Coarse	Gravel, coarse sand Sand, loamy sand	> 20 inches/h 6.20 inches/h	Very rapid Rapid
Moderately coarse	Coarse sandy loam, sandy loam, fine sandy loam	2 - 6 inches/h	Moderately rapid
Medium	Very fine sandy loam, loam, silt loam, silt	0.60 - 2 inches/h	Moderate
Moderately fine	Clay loam, sandy clay loam, silty clay loam	0.20 - 0.60 inches/h	Moderately slow
Fine	Sandy clay, silty clay, clay (<60%)	0.06 - 0.20 inches/h	Slow
Very fine	Clay (>60%), clay pan	<0.06 inches/h	Very slow

Figure 9. Hydraulic conductivity range, rating and index map.

3.8. Vulnerability Map

To create the vulnerability map, all the seven parameter index map layers were overlaid using the Geoprocessing tool, weighted sum overlay falling under the Spatial Analyst extension in the Arc toolbox. This method overlay the resultant map layers, multiplying each by their given weight with their corresponding rate (as per the USEPA), summing them together to get the index. The study area was divided into three vulnerability classes ranging between a minimum value of 120 and a maximum value of 243. These classes are moderate vulnerable, high vulnerable and very high vulnerable as shown in the vulnerability zone map in **Figure 10**. The vulnerability classes were categorized according to the USEPA DRASTIC Index and vulnerability class [10], as given in the **Table 3**.

According to vulnerability map of the study area, the eastern and south eastern portion of Njelianparamba dump site was very highly vulnerable to groundwater contamination. This is probably due to the lower slope terrains towards the eastern part that is mostly covered with loam and sandy loam which allows enhanced percolation of contaminants into the groundwater. About 75% of the study area falls under high vulnerability class including the areas close to Njelianparamba dump site.

3.9. Validation of DRASTIC Model

A total of 29 groundwater samples were collected from different vulnerability zones of the study area. A buffer zone of 1 km from the Njelianparamba dumping site was considered to assess the correlation between distance and the selected contamination detection factors. For validation of the vulnerability index map, a chemical and bacteriological parameter was considered to justify with the USEPA DRASTIC vulnerability index. The samples were analyzed for the estimation of total dissolved solids and *E. coli* as per the standard procedure [19] and the results were produced in the form of maps as shown in **Figure 11** and **Figure 12**. These maps along with the buffer zone were then correlated with the vulnerability map to interpret the problematic areas.
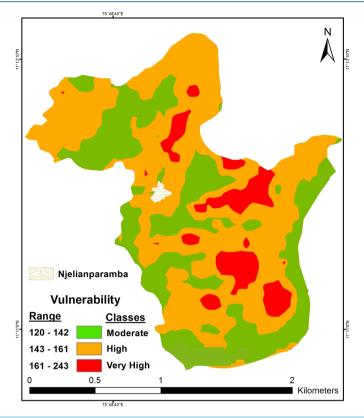
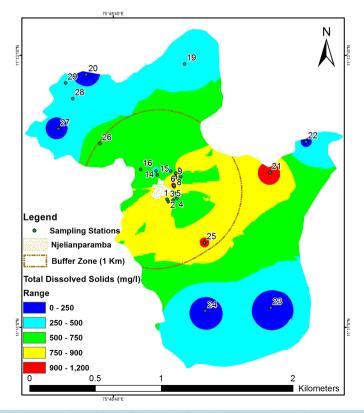**Figure 10.** Groundwater vulnerability map of the study area.

Figure 11. Concentration of total dissolved solids in different vulnerability zones.
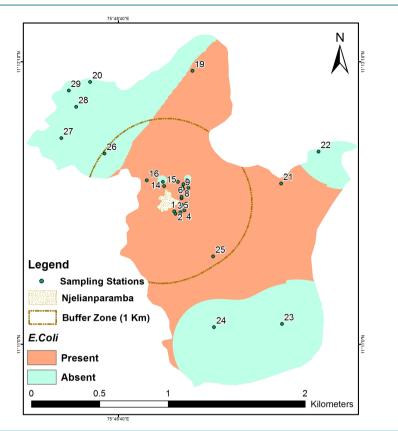
Figure 12. *E. coli* in different vulnerability zones.

Table 3. DRASTIC Index and vulnerability class.

DRASTIC index	Vulnerability class
1 - 100	Low
101 - 140	Moderate
140 - 200	High
>200	Very high

In the case of validation using total dissolved solids, a total of 20 groundwater samples were found to be within the buffer zone and 9 samples laid outside the buffer zone. The dissolved solids concentration in samples that laid inside the buffer zone, were detected between a range of 500 - 1200 mg/l which is above the permissible limit as prescribed by Bureau of Indian Standards [24]. This indicates that leachate percolation is maximum at 1 km distance from the dumping site. The samples collected from outer portion of buffer zone were within the permissible limit of 500 mg/l except the sample 21, which falls under very high vulnerable zone. The samples collected at greater distances from the dumping site had lower concentration of dissolved solids.

The *E. coli* bacteria were found to be present in samples in vicinity to the dumping site particularly within the buffer zone of 1 km. Most of the samples within the buffer zone had the presence of *E. coli*. This validates that the area surrounding the dumpsite is contaminated in correlation to the highly vulnerable area present in the vulnerability map. But an exception of 3 samples (26, 13 and 14) within the buffer zone did not have the presence of *E. coli* bacteria which can be due to the presence of residual chlorine detected in these samples; indicating the presence of regular chlorination of the wells. The samples outside the buffer zone were free from Ecoli except sample 21and 19 lying towards the eastern portion of the study area. Both of these samples fall under the very high vulnerable class in the vulnerability map which explains the presence of bacteria.

4. Conclusion

The DRASTIC model in a geographical information system environment was used to determine the groundwater vulnerability to contamination in the vicinity of a solid waste disposal site, Njelianparamba, a municipal dumping site in Kozhikode, Kerala, India. The ArcMap 10.1 was used to prepare a vulnerability map for the study area. According to the vulnerability map, the study area was divided into three vulnerability classes ranging between a minimum value of 120 and a maximum value of 243. The vulnerability classes are moderate vulnerable, high vulnerable and very high vulnerable. It can be concluded from the vulnerability map, that the eastern and south eastern portion of Njelianparamba dump site was very highly vulnerable to groundwater contamination. This is probably due to the lower sloped terrains towards the eastern portion which allows percolation of contaminants into the groundwater. The resulting vulnerability map was then validated using a chemical and bacteriological parameter analysed 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, it is clear that the concentrations of total dissolved solids and *E. coli* were correlated in different vulnerable zones; which validated the results obtained.

References

[1] Gupta, N. (2014) Groundwater Vulnerability Assessment Using DRASTIC Method in Jabalpur District of Madhya Pradesh. *International Journal of Recent Technology and Engineering*, **3**, 36-43.

[2] Kale, S.S., Kadam, A.K., Kumar, S. and Pawar, N.J. (2010) Evaluating Pollution Potential of Leachate from Landfill Site from the Pune Metropolitan City and Its Impact on Shallow Basaltic Aquifers. *Environmental Monitoring Assessment*, **162**, 327-346. http://dx.doi.org/10.1007/s10661-009-0799-7

[3] Renou, S., Givaudan, J.G., Poulain, S., Dirassouyan, F. and Moulin, P. (2008) Landfill Leachate Treatment-Review and Opportunity. *Journal of Hazardous Materials*, **150**, 468-493. http://dx.doi.org/10.1016/j.jhazmat.2007.09.077

[4] Robinson, A.H. (2005) Landfill Leachate Treatment. *Membrane Technology*, 6-12. http://dx.doi.org/10.1016/S0958-2118(05)70435-3

[5] Iaconi, C.D., Ramadori, R. and Lopez, A. (2006) Combined Biological and Chemical Degradation for Treating a Mature Municipal Landfill Leachate. *Biochemical Engineering Journal*, **31**, 118-124. http://dx.doi.org/10.1016/j.bej.2006.06.002

[6] Park, S., Choi, K.S., Joe, K.S., Kim, W.H. and Kim, H.S. (2001) Variations of Landfill Leachate's Properties in Conjunction with the Treatment Process. *Environmental Technology*, **22**, 639-645. http://dx.doi.org/10.1080/09593332208618244

[7] Mor, S., Ravindra, K., Dahiyaa, R.P. and Chandra, A. (2006) Leachate Characterization and Assessment of Groundwater Pollution Near Municipal Solid Waste Landfill Site. *Environmental Monitoring Assessment*, **118**, 435-456. http://dx.doi.org/10.1007/s10661-006-1505-7

[8] Jaroslav, V. and Zoporzec, A. (1994) Guidebook on Mapping Groundwater Vulnerability. *International Contributions to Hydrogeology*, Verlag Heise, Hannover, **16**, 129.

[9] Baalousha, H. (2006) Vulnerability Assessment for the Gaze Strip Palestine Using DRASTIC. *Environmental Geology*, **50**, 405-414. http://dx.doi.org/10.1007/s00254-006-0219-z

[10] Aller, L., Bennett, T., Lehr, J., Petty, R. and Hackett, G. (1987) DRASTIC: A Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Setting. US Environmental Protection Agency Report EPA/600/2-87/035, 622.

[11] United States Environmental Protection Agency (1994) Handbook: Groundwater and Wellhead Protection. Report No. EPA/625/R-94/001, US EPA, Washington DC, 239.

[12] El-Naqa, A., Hammouri, N. and Kuisi, M. (2006) GIS-Based Evaluation of Groundwater Vulnerability in the Russeifa Area, Jordan. *Revista Mexicana de Ciencias Geológicas*, **23**, 277-287.

[13] Prasad, K. and Shukla, J.P. (2014) Assessment of Groundwater Vulnerability Using GIS-Based DRASTIC Technology for the Basaltic Aquifer of Burhner Watershed, Mohgaon Block, Mandla (India). *Current Science*, **107**, 1649-1656.

[14] Awawdeh, M., Obeidat, M. and Zaiter, G. (2015) Groundwater Vulnerability Assessment in the Vicinity of Ramtha Wastewater Treatment Plant, North Jordan. *Applied Water Science*, **5**, 321-334. http://dx.doi.org/10.1007/s13201-014-0194-6

[15] Khan, A., Khan, H.H., Umar, R. and Khan, M.H. (2014) An Integrated Approach for Aquifer Vulnerability Mapping Using GIS and Rough Sets: Study from an Alluvial Aquifer in North India. *Hydrogeology Journal*, **22**, 1561-1572. http://dx.doi.org/10.1007/s10040-014-1147-8

[16] IMD (2013) Normal South West Monsoon Rainfall Data. Indian Meteorological Department, Kozhikode District, Ke-

rala, India.

[17] CGWB (2009) Groundwater Information Booklet of Kozhikode District, Kerala State. Central Ground Water Board, Ministry of Water Resources, Government of India.

[18] Aller, L., Bennet, T., Lehr, J.H., Petty, R.J. and Hacket, G. (1985) DRASTIC: A Standardized System for Evaluating Ground Water Pollution Using Hydrological Settings. Prepared by the National Water Well Association for the USEPA Office of Research and Development, Ada, OK, USA.

[19] APHA, AWWA, WEF (2012) Standard Methods for Examination of Water and Waste Water. 22nd Edition, American Public Health Association, Washington DC.

[20] Baruah, T.C. and Barthakur, H.P. (1997) A Text Book of Soil Analysis. UBS Publishers Ltd., New Delhi.

[21] Piscopo, G. (2001) Groundwater Vulnerability Map, Explanatory Notes, Castlereagh Catchment. NSW Department of Land and Water Conservation, New South Wales, Australia.
http://www.water.nsw.gov.au/__data/assets/pdf_file/0008/549377/quality_groundwater_castlereagh_map_notes.pdf

[22] Rahman, A. (2008) A GIS Based DRASTIC Model for Assessing Groundwater Vulnerability in Shallow Aquifer in Aligarh, India. *Applied Geography*, **28**, 32-53. http://dx.doi.org/10.1016/j.apgeog.2007.07.008

[23] USDA (1994) United State Department of Agriculture, Permeability Key.
http://www.nrcs.usda.gov/mo10/mo10guides/permkey/

[24] BIS (2012) Indian Standard Drinking Water Specification. Bureau of Indian Standards, New Delhi, IS 10500:2012.