 https://doi.org/10.1051/e3sconf/202343403019

Mapping groundwater vulnerability using drastic method

Meutia Nurfahasdi[1*], *Agnes* Yofita Zega[2], *Agree Manganju Evannels* Silalahi[2], *Dally Raj* Singh[2], *Aziz* Babayev[3], *Shakhlo* Aitova[4]

[1]Department of Environmental Engineering, Faculty of Engineering, Universitas Sumatera Utara, Jl. AlmamaterKampus USU Medan 20155, Indonesia
[2]Undergaduate student of the Department of Environmental Engineering, Faculty of Engineering, Universitas Sumatera Utara, Jl. AlmamaterKampus USU Medan 20155, Indonesia
[3]TIIAME National Research University, Tashkent 100000, Uzbekistan
[4]Urgench State University, Urganch 220100, Uzbekistan

Abstract. Preventive management and protection of groundwater were to create a groundwater vulnerability map. This map provided information distribution on the level of vulnerability to groundwater contamination in an area. The impact made considered in making regional decisions to create a sustainable development framework. The DRASTIC method is an instrument for evaluating the vulnerability of groundwater pollution. The DRASTIC methods can use evaluate vulnerabilities of groundwater contamination which seven parameters: the depth of the groundwater table (D), rainPL (R), aquifer media (A), soil texture (S), topography (T), the influence of unsaturated zones (I), and hydraulic conductivity (C). The additional parameter is the use of land resulting from vulnerability. The parameter data will be poured into a map using ArcGIS and analyzed using the DRASTIC rating index. Eight attributes are included in the modified DRASTIC model, including hydraulic conductivity of the aquifer, topography, impact of the vadose zone, depth to water table, net recharge, aquifer media, soil media, and aquifer media. In a GIS system, these layers were combined using the Raster Calculator tool. The modelx was further validated using fifteen groundwater composite samples that were also gathered. Based on the results of the analysis, groundwater vulnerability in Terjun's landfill from the five parameters, the value of the DRASCTIC index is 137 which indicates the vulnerability of groundwater is at medium/moderate. Aquifers next to floodplain areas are very sensitive, whereas those next to terrace areas are less vulnerable, according to the results. The model's findings confirm that the topography, soil media, and aquifer depth indicated the strongest correlations with vulnerability. A positive association between the vulnerability classes and the three groundwater quality measures electrical conductivity was also found during the validation of the final DRASTIC map. Although the levels of contamination at this time are below acceptable bounds, the possibility of additional contamination cannot be completely eliminated and is really rather plausible.

1. Introduction

With the rise in water demand, the population trended to continue. In order to meet the rising demand for water, water resources must be developed. Throughout the nation, aquifers hold hundreds of billions of cubic meters of water. Geological, hydrogeological, hydrological, hydro chemical, and geophysical site investigations are related to groundwater exploration. This degradation depletes the groundwater level and decreases the quality of these waters. The availability of significant amounts of high-quality data is crucial for the validity and reliability of groundwater analysis. A powerful tool for hydrogeological research can be created by organizing all the data into a logical structure that is supported by a computational environment [1]. The Drastic method can detect areas with a high potential for groundwater exploration. According to Elfarrak et al. (2013) [2] groundwater vulnerability map is a fundamental document for regional development. The site of development projects hurt the quality of groundwater resources. The condition of groundwater vulnerability can easy informed through the media of images, namely groundwater vulnerability maps [3].

*Corresponding author: meutia.nurfahasdi@usu.ac.id

Groundwater is referred to as being vulnerable to contaminants [4]. Under different agronomic management approaches, pesticide properties, and hydrogeological sensitivity circumstances, contaminants applied at/or near the soil surface can move to the intended aquifer. The assessment of groundwater vulnerability is based on the supposition that the physical environment may protect groundwater to some extent from influences from the environment and people, particularly from contaminants that infiltrate the subsurface zone [3, 5, 6]. There isn't, however, a definite, all-encompassing approach to groundwater risk. According to Mimi et al. (2011) [7], the groundwater vulnerability assessment techniques can be divided into three categories: Process-based simulation assessment is followed by statistical assessment and assessment using overlay and index methods. DRASTIC [8], GLA [9], SINTACS [10], EPIK [11], PI [12], and COP [13] are a few examples of groundwater vulnerability approaches. The study will aid decision-makers by offering useful data for formulating plans for the catchment area's land-use management.

2. Drastic Method

This research data includes primary data and secondary data. Primary data in groundwater table depth and soil texture are collect through surveys and direct mapping at the study site. Secondary data is in the form of a 2021 Landsat (Google Earth) image map. The method used as a reference in calculating the level of groundwater vulnerability is the DRASTIC method. The US Environmental Protection Agency developed the DRASTIC techniques [14]. The DRASTIC technique was previously used in HSB; however, it is crucial to understand whether or not this model accurately represents the vulnerability system in use both globally and in this particular region. Therefore, the primary goal of the current study, which is the first effort in the area, is to compare the DRASTIC approach of another suggested model. Because these two models can be used to describe the region's aquifer qualities, they were chosen alongside the DRASTIC and COP models. Additionally, the two models used various application rates, weight values, and potential susceptibility system characteristics such aquifer features and unsaturated zone. The results then need to be validated, therefore nitrate content in groundwater was employed as this area qualifies as a "arable territory" due to its potential for farming. Because the use of fertilizers and pesticides is a common practice, it has an impact on the quality of the groundwater [15]. The DRASTIC model is the most relevant, practical, and widely used tool to assess groundwater susceptibility to a wide range of possible contaminants. In order to determine how easily aquifers can be contaminated, the Environmental Protection Agency (EPA) of the United States developed this model. Its moderate vulnerability zone covered two distinct geological and hydrogeological regions. The first are the mountains that surround HSB and contain the karstic and fissured aquifer. The area's southwest (which includes the zone of the Derbandikhan reservoir) is covered by Quaternary deposits in the second region. The high-water table level and high rate of coarse grain particles, such as rock, sand, and rock pieces, can be used to identify this. In addition, the zone with minimal vulnerability, which comprises 166 km2 or 13% of the basin's overall surface area, is ranked third in terms of spreading. The area of high susceptibility is located in the middle of the basin and only comprises 64 km2, or 5% of the total area. According to Twana et al. (2016) [16], this area is characterized by a water table that is somewhat high and the proximity of a few springs with cracked limestone. This study's major goal is to assess the Terjun's Landfill's vulnerability using the DRASTIC index model and the modified DRASTIC index model (risk map). Groundwater quality and vulnerability are managed effectively by combining DRASTIC index parameters with geographic information system (GIS) approaches. By offering useful data for the creation of plans for the catchment area's land-use management, this effort will assist decision-makers. This research will also pinpoint regions that are more vulnerable to contamination and might benefit from additional conservation efforts [17]. In order to develop pollution liability insurance and evaluate the economic effects of disposal costs in particularly vulnerable areas, DRASTIC may be used to evaluate land use activities. The methodology may be used as a textbook in college courses to instruct students on the principles of resource preservation and contamination potential. Finally. Data gaps that affect the evaluation of the potential for pollution can be found using DRASTIC. For instance, there could be reason for more hydrogeologic parameter reconnaissance, which would serve as a stronger data foundation for future resource assessments or another DRASTIC analysis [8].

Given these facts, the main objectives of the work are to identify the most vulnerable aquifer contamination zones using the DRASTIC and certain hybrid DRASTIC techniques, as well as to pinpoint the most significant hydrogeological factors influencing ground water pollution in this district. This research may also be helpful in discussions that compare several modified DRASTIC models. The results of this analysis can be applied to other Medan neighborhoods with similar hydrogeological and socioeconomic characteristics [18]. In order to attain intrinsic groundwater vulnerability, the extent of groundwater contamination was investigated by creating seven map layers using the DRASTIC Model, which is recommended by the United States Committee of Environmental Protection Agency. Each hydrogeologic location has physical characteristics that can influence the risk of ground-water pollution. Regarding the relative significance of the several physical features that determine pollution potential, a wide range of technical positions were taken into consideration. The chemistry of the aquifer, the temperature, the transmissivity, the tortuosity, the gaseous phase transport, and other variables were assessed. The presence of mappable data has also been considered [8].

A common technique for evaluating aquifer vulnerability is DRASTIC. The US Environmental Protection Agency was the organization that invented this technique. For this model, the assessment of aquifer vulnerability uses hydrogeological characteristics. The fieldwork was done in December, after the monsoon season. In order to assess the depth to the water's surface and to perform on-the-spot measurements of nitrate and TDS in the field, a total of 40 well locations have been chosen throughout the basin [19]. Depth to Water Table, Net Recharge, Aquifer Media, Soil Media, Topography, Impact of Vadose Zone, and Hydraulic Conductivity of Aquifer are the components of the acronym DRASTIC. The DRASTIC method has three urgent parts: weight, rating, and ranges to determine the level of vulnerability of groundwater. The pollution can be from the sum of the score values for each DRASTIC parameter which produces a DRASTIC Index value (Equation 1), where R: Rating, and W: weights. Factors influencing the DRASTIC method include existing land use patterns, spatial extent, locations of potential contamination sources and their seasonal and temporal variations [20]. For simplicity, these elements have been organized into the acronym DRASTIC. Section 3, DRASTIC: A summary of the Factors, contains a thorough explanation of the significant mechanisms considered within each component as well as a summary of the factor's importance. Although not all-inclusive, it was concluded that this list, when taken as a whole, met the minimum requirements for determining the general contamination potential of each hydrogeologic context [8].

$$DRASTIC\ Index\ /\ DI = DR*DW+RR*RW+AR*AW+SR*SW+TR*TW+IR*IW+CR*CW \quad (1)$$

Information:
D: The depth of the groundwater table
R: Rainfall
A: Media Aquifer
S: Soil texture
T: Topography (slope)
I: Media unsaturated zone
C: Hydraulic conductivity
R: Value of each parameter
W: The weight of each parameter

3. Results and Discussion

Method DRASTIC is used to evaluate groundwater vulnerability to contaminants with prioritized factors influencing hydrogeology groundwater movement. Method This can know groundwater vulnerability in a manner general with the use of seven parameters, namely: depth groundwater level, rate of charging return bulk rain, constituent media aquifer, constituent media soil, texture soil, topography, non-zone forming media water saturation and conductivity hydraulics. The intrinsic vulnerability index was evaluated using a weighted average of the seven DRASTIC model parameters. The degree of groundwater contamination was estimated using this comparison [21].

Table 1. Level of Groundwater Vulnerability and Distribution

DI value	Vulnerability Level	Characteristic
<60	Very Low	No possible happening pollution
61 - 100	Low	Only can be polluted by pollutants some are discarded in a manner Keep going continuously the period for a relatively long time
101 - 140	Currently	Can be polluted by some discharged pollutants in a manner continuously
141-180	Tall	Can be tainted by all pollutants, unless required power absorb tall and easily changed in various scenario
>180	Very high	Can be tainted by all pollutants in time relatively short and deep various scenarios

Source: (Putranto, T, 2016)

Analysis results of each DRASTIC parameter are displayed in a form map that has scores from results multiplication weight and class. Weight and class values compared straight with level groundwater vulnerability, increasingly tall mark weight, and class so mark DRASTIC the higher and marked level groundwater vulnerability to contaminants are also increasingly high. At the regional level, the DRASTIC vulnerability index is helpful in prioritizing areas into high, moderate, and low vulnerability regions, which might then be investigated in greater detail on the ground [22].

 https://doi.org/10.1051/e3sconf/202343403019

According to Puputranto et al. (2016) [23], the level of groundwater vulnerability is known based on the mark shown in Table 1.

3.1 Groundwater Depth

Groundwater depth becomes a reference in see transportation to burden polluters with thick layers of land or the rocks above groundwater level [24]. Groundwater depth is obtained through the results measurement minimum distance from the groundwater table to the surface. The more groundwater than the process of transportation burdens, the more far and long ago vulnerability pollution is rated lower, and vice versa. Groundwater depth on method DRASTIC own mark weight 5 for level vulnerability. The result of sampling depth of groundwater in the Terjun's landfill research area can be seen on the map following this:

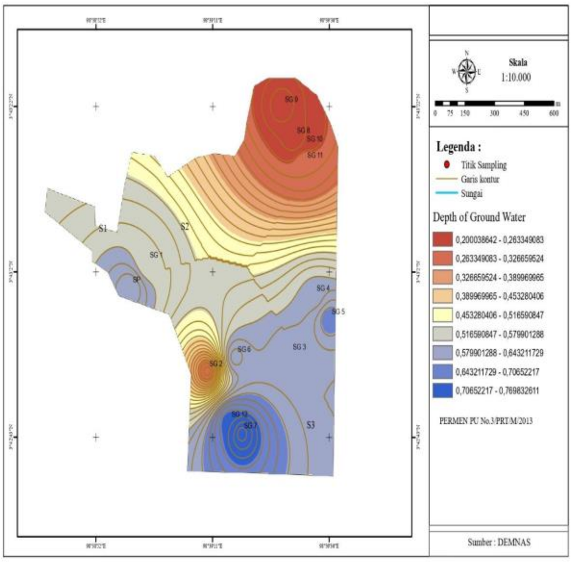

Fig. 1. Depth Map Groundwater Level in the Terjun's Landfill Research Area

Depth groundwater level determines the necessary distance passed contaminants to reach the aquifer and determines the time contact with the surrounding media. Based on the data that has been got so can done assessment and weighting from depth land can be seen in Table 2.

Table 2. The Weighting of Groundwater Depth Parameters

Depth groundwater level (m)	Classification (m)	Mark	Weight
0.2 – 0.78	0 – 1.5	10	5

3.2 Rainfall

Amount bulk Rain describes the amount of water absorbed in land to reach the groundwater table [24]. Rainfall helps transportation burden pollutants in a manner vertically going to the groundwater table and horizontally inside the aquifer. If charging bulk rain tall so potency groundwater pollution the bigger because will impact to dilution cause burden polluter easy dissolved and into groundwater in a manner free. Precipitation on method DRASTIC own mark weights 4 for level vulnerability. Based on data from BPS can be seen amount bulk rain that occurred in the Terjun's landfill research area during One year, along with direction surface water and groundwater flows we look on the map is shown in Figure 2.
Bulk data Rain obtained from station data Belawan Maritime Meteorology in Medan Belawan, so can done assessment and weighting from amount bulk possible rain seen in Table 3 below:

Table 3. Weighting of Rainfall Parameters

Aquifer Media	Parameter Classification	Mark	Weight
Alluvium young	Sand or gravel	8	3

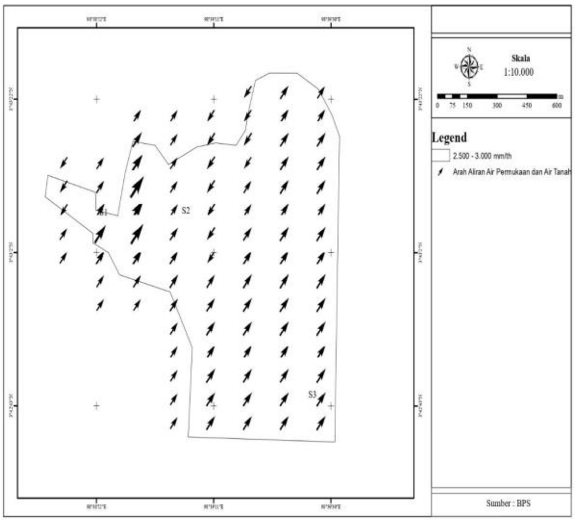

Fig. 2. Rainfall Map in the Terjun's Landfill Research Area

3.3 Compiler Media aquifer

Aquifer is a formation rock to produce enough deep water. Aquifer media show the ability of rock in store groundwater to influence the amount of finished surface material contaminated in penetrating layer aquifers. The taller ability aquifer in withhold burden polluter so time travel movement burden polluter will the more in so that groundwater contamination will the smaller. aquifer data obtained from drill data on site research. Compiler media aquifer on method DRASTIC own mark weight 3 for level vulnerability. Based on DEMNAS data obtained, then can view the media compiler aquifer in the Terjun's landfill research area on the map following this (Figure 3):

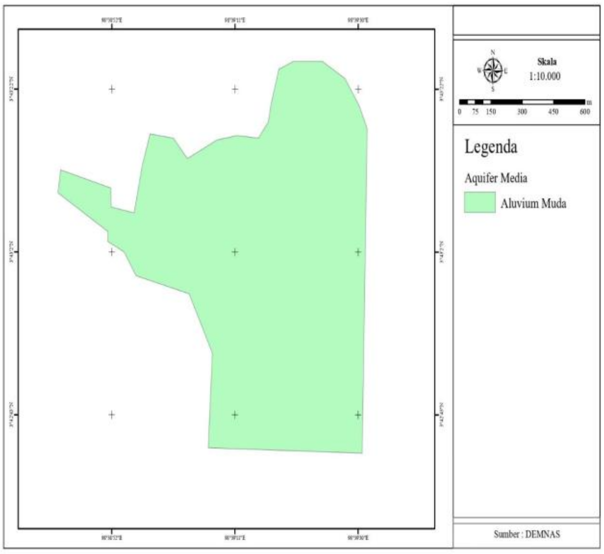

Fig. 3. Compiler Media Aquifers in the Terjun's Landfill Research Area

Table 4. Weighting of Composing Media Parameters Aquifer

Rainfall (mm/year)	Classification (mm/year)	Mark	Weight
2,500 – 3,000	2,500 – 3,000	8	4

The more loose and big size pores between items, then productivity aquifer the more height and capability of the aquifer media for pass water and contaminants will be high. Based on the data that has been obtained so can done assessment and weighting of the composing media possible aquifer can be seen in Table 4.

3.4 Soil Texture

Texture land relates with type land to be influential to absorption burden pollutants [24]. Texture land impact significant to movement burden pollutants to the land increasingly rough texture land so level absorption the taller so that groundwater vulnerability the higher. On the contrary, more and more fine texture land so level absorption is lower because movement burden polluters become limited. Determination type land obtained from observation and mapping on site research. texture ground on method DRASTIC own mark weight 2 for level vulnerability. Land on site study dominated by land loose (loam). Based on DEMNAS data then can be seen texture land in the Terjun's landfill research area on the map following Figure 4.

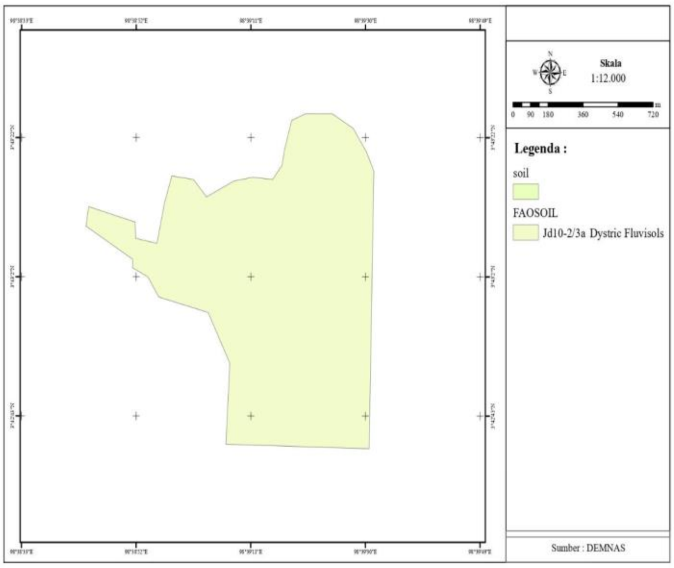

Fig. 4. Soil Texture Map in the Terjun's Landfill Research Area

Soil materials with texture fine or size grain small like clay and silt will have the ability to limit movement of substance pollutants. Based on the data that has been obtained so can done assessment and weighting texture land can be seen in Table 5.

Table 5. Weighting of Groundwater Depth Parameters

Soil Texture	Parameter Classification	Mark	Weight
Dystric Fluvisol	loam	5	2

3.5 Topography

Topography or tilt slope show a chance of rain to absorb into land [24]. Principle gravity will speed up movement and burden polluters, where the steeper tilt slope tends to hold water to groundwater, no easy contamination. On the contrary, more and more sloping tilt slopes tend to hold water and increase absorption so that speed up movement burdens pollutants. Topography on the method DRASTIC owns mark weight 1 for level vulnerability. Based on DEMNAS data, topography in the Terjun's landfill research area on the map is highlighted in Figure 5.
Research area own classification tilt slope somewhat sloping that has score or value 9. Based on the data that has been obtained so can done assessment and weighting topography or tilt land that can be seen in Table 6 below.

Table 6. Weighting of Topographic Parameters

Tilt slope (%)	Classification (%)	Mark	Weight
2 – 6	2 – 6	9	1

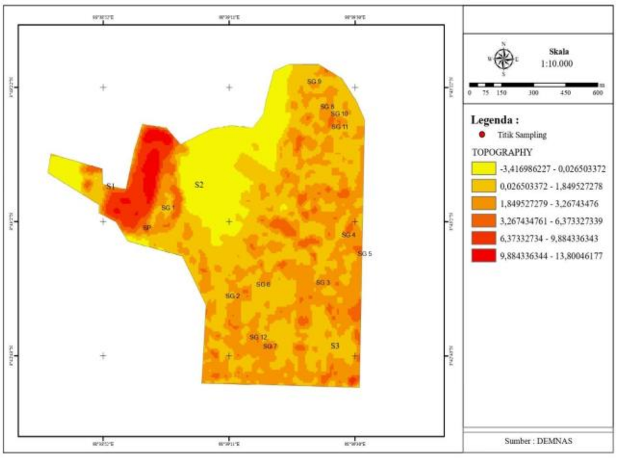

Fig. 5. Topographical Map of the Terjun's Landfill Research Area

3.6 Impact of The Vadose Zone

Impact of the vadose zone function for control burden contaminants on site research [24]. Impact of the vadose zone data obtained from results observations and drill data in the field. Vadose zone media type fed up influential to movement of water from surface going to groundwater level because influenced by size grain land or rock. grain sized land more size and condition porous land will help its moving contaminants going to aquifer. The vadose zone has a mark weight 5 for level vulnerability. Based on DEMNAS data vadose zone saturation in the Terjun's landfill research area on the map is shown in Figure 6.

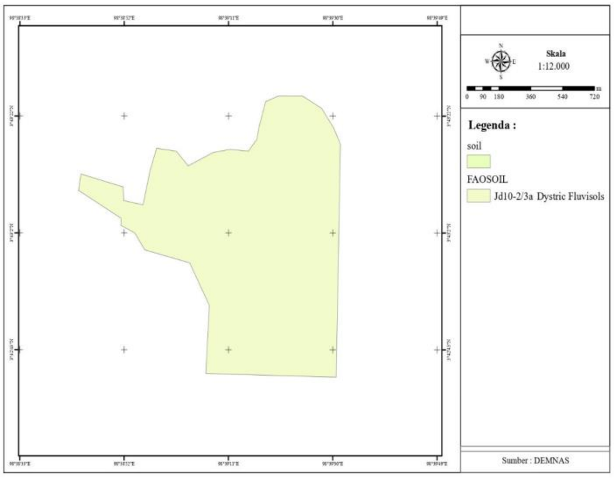

Fig. 6. Vadose Zone Map Saturated in the Terjun's Landfill Research Area

Based on the data that has been obtained Terjun's landfill research area dominated by soil that has sand and gravel material, so can done zone assessment and weighting saturated is shown in Table 7.

Table 7. Weighting of Vadose Zone Parameters

Vadose zone media	Parameter Classification	Mark	Weight
District Fluvisols	Sand and gravel	4	5

3.7 Conductivity Hydraulic

Conductivity hydraulic ability to land in pass water and load polluter to permeability - dependent aquifer media intrinsic to material and level saturation [24]. Conductivity data hydraulic obtained from pumping test activities in the wells dig residents on site research. conductivity hydraulic on method DRASTIC own mark weight 3. Based on constituent media type aquifer, mark from conductivity hydraulics on the map is shown in Figure 7.

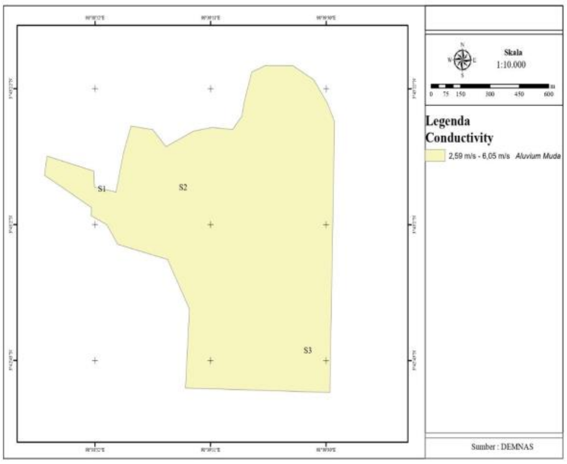

Fig. 7. Conductivity Map Hydraulics in the Terjun's Landfill Research Area

Based on the data that has been obtained show mark from conductivity hydraulics in the Terjun's landfill research area of 2.59 m/s to 6.05 m/s, so can done assessment and weighting For conductivity hydraulics can be seen in Table 8.

Table 8. Weighting of Conductivity Parameters Hydraulic

Conductivity Media Type	Classification (m/s)	Mark	Weight
Young Alluvium	2.59 – 6.05	4	3

3.8 Index DRASTIC

In know level vulnerability with method DRASTIC, got done with formula calculation as following:

Index DRASTIC (DI) = $D_R * D_W + R_R * R_W + A_R * A_W + S_R * S_W + T_R * T_W + I_R * I_W + C_R * CW$

Based on table grade obtained from every parameter, then found mark Index DRASTIC namely:

DI = (10*5) + (8*4) + (8*3) + (5*2) + (9*1) + (4*5) + (4*3)
= 137

Index Value DRASTIC obtained determined that the Terjun's landfill research area This own level moderate vulnerability.

4. Conclusion

The results of the groundwater susceptibility research at the Terjun's landfill can be concluded that the geological area studied has an alluvium formation consisting of loose material-sized gravel, sand, silt, and clay. The hydrogeology area of Terjun's landfill studies the movement of groundwater in the northeast direction. The aquifer productivity in the study area is moderate to high, with flow through the inter-grain spaces.

From the results analysis carried out via DRASTIC parameters, it was concluded that the Terjun's landfill research area's level of vulnerability can be seen through a Mark Index DRASTIC of 137, where the groundwater in the study area can be continuously polluted by some discharged pollutants.

Recommendations made to minimize groundwater vulnerability to contaminants are: (1) socialization of groundwater use as a source alternative to final raw water sources; (2) groundwater monitoring in a manner that periodically covers groundwater quality and quantity; (3) manufacturing regulation area about channel wastewater disposal and construction channel wastewater disposal; (4) enforcement regulation area about the rubbish and waste industry; and (5) outreach wastewater treatment house stairs at a nearby location with a good dig.

References

1. R.C. Gogu, G. Carabin, V. Hallet, V. Peters, A. Dassargues, GIS-Based Hydrogeological Databases and Groundwater Modeling, *Hydrogeology Journal* **9**, 555-569 (2001)

2. H. Elfarrak, M. Hakdaoui, A. Fikri, Development of Vulnerability through the DRASTIC Method and Geographic Information System (GIS) (Case Groundwater of Berrchid), Morocco, *Journal of Geographic Information System* **6**, 45-58 (2014)
3. J. Vrba, A. Zoporozec, Guidebook on Mapping Groundwater Vulnerability, 16th Edition, International Contributions to Hydrogeology (IAH), Hannover (1994)
4. J. Margat, Vulnerabilite des nappes d'eau souterraine a la pollution, BRGM-Publication 68 SGL 198 HYD, Orleans (1968)
5. U.S. Abdullahi, Evaluation of Models for Assessing Groundwater Pollution in Nigeria, *Bayero Journal of Pure and Applied Science* **2**, 138-142 (2009)
6. I. Hamdan, A. Margane, T. Ptak, B. Wiegand, M. Sauter, Groundwater Vulnerability Assessment for the Karst Aquifer of Tanour and Rasoun Springs Catchment Area (NW-Jordan) Using COP and EPIK Intrinsic Methods, *Environmental Earth Sciences* **75**, 1474 (2016)
7. Z. Mimi, N. Mahmoud, M. Madi, Modified DRASTIC Assessment for Intrinsic Vulnerability Mapping of Karst Aquifers: A Case Study, *Environmental Earth Sciences* **66**, 447-456 (2011)
8. L. Aller, T. Bennett, J. Lehr, R. Petty, G. Hackett, DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Setting, EPA (Environmental Protection Agency), EPA/600/2-87/035 (1987)
9. B. Hoelting, T. Haertlé, K.-H. Hohberger, K.H. Nachtigall, E. Villinger, W. Weinzierl, J.-P. Wrobel, Konzept zur Ermittlung der Schutzfunktion der Grundwasserüberdeckung, *Geologisches Jahrbuch Reihe C Band C* **63**, 5-24 (1995)
10. M. Civita, M. Demaio, SINTACS: Un systema parametrico per la valutazione e la cartografia della vulnerabilità degli acquiferi all'inquinamento (methodologia e automatizzazione), Pitagora Editrice, Bologna (1997)
11. N. Doerfliger, P.-Y. Jeannin, F. Zwahlen, Water Vulnerability Assessment in Karst Environments: A New Method of Defining Protection Areas Using a Multi-Attribute Approach and GIS Tools (EPIK Method), *Environmental Geology Journal* **39**, 165-176 (1999)
12. N. Goldscheider, M. Klute, S. Sturm, H. Hötzl, The PI Method—A GIS-Based Approach to Mapping Groundwater Vulnerability with Special Consideration of Karst Aquifers, *Zeitschrift für Angewandte Geologie* **46**, 157-166 (2000)
13. J.M. Vias, B. Andreo, M. Perles, F. Carrasco, I. Vadillo, P. Jimenez, Proposed Method for Groundwater Vulnerability Mapping in Carbonate (Karstic) Aquifers: The COP Method-Application in Two Pilot Sites in Southern Spain, *Hydrogeology Journal* **14**, 912-925 (2006)
14. L. Aller, T. Bennet, J.H. Lehr, R.J. Petty, DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeological Settings, EPA (1985)
15. T. Huang, Z. Pang, W. Edmunds, Soil Profile Evolution Following Land-Use Change: Implications for Groundwater Quantity and Quality, *Hydrological Processes* **27**, 1238-1252 (2012)
16. O. Twana, S. Ali, A. Al-ansari, S. Knutsson, Groundwater Vulnerability Using DRASTIC and COP Models: Case Study of Halabja Saidsadiq Basin, Iraq, *Engineering* **8**, 741-760 (2016)
17. I. Hamdan, A. Abdulla, A.H. Mu'ayyad, Groundwater Vulnerability Assessment for the Corridor Wellfield Using DRASTIC and Modified DRASTIC Models: A Case Study of Eastern Jordan, *Open Journal of Geology* **10**, 991-1008 (2020)
18. S. Paul, C. Das, An investigation of groundwater vulnerability in the North 24 parganas district using DRASTIC and hybrid-DRASTIC models: A case study, *Environmental Advances* **5**, 100093 (2021)
19. A. Bera, P.M. Bhabani, C. Puja, A. Ghosh, Groundwater vulnerability assessment using GIS-based DRASTIC model in Nangasai River Basin, India with special emphasis on agricultural contamination, *Ecotoxicology and Environmental Safety* **214**, 112085 (2021)
20. J. Wang, J. He, H. Chen, Assessment of groundwater contamination risk using hazard quantification, a modified DRASTIC model and groundwater value, Beijing Plain, China, *Science of the Total Environment* **432**, 216-226 (2012)
21. A. Neshat, B. Pradhan, M. Dadras, Groundwater Vulnerability Assessment Using an Improved DRASTIC Method in GIS, *Resources, Conservation and Recycling* **86**, 74-86 (2014)
22. D. Thirumalaivasan, M. Karmegam, K. Venugopal, AHP-DRASTIC: Software for Specific Aquifer Vulnerability Assessment using DRASTIC Model and GIS, *Environmental Modelling & Software* **18**, 645-656 (2003)
23. T. Putranto, D. Widiarso, F. Yuslihanu, Studi Kerentanan Air Tanah Terhadap Kontaminan Menggunakan Metode Drastic di Kota Pekalongan, *Jurnal Teknik* **37**(1), 28-29 (2016)
24. A. Supriatna, S. dan Notodarmojo, Pengembangan Kriteria Penilaian Metode Drastic dalam Analisis Kerentanan Pencemaran Air tanah di Kota Bandung, *Jurnal Teknik Lingkungan* **25**(2), 108-112 (2019)