Proceedings of the 6th International Conference on Civil Engineering for Sustainable Development (ICCESD 2022), 10~12 February 2022, KUET, Khulna, Bangladesh (ISBN-978-984-35-1972-6)

AN INTEGRATED FUZZY APPROACH FOR ENVIRONMENTAL RISK ASSESSMENT OF A LANDFILL SITE IN KHULNA

Saptarshi Mondal[1*], Islam M. Rafizul[2] and Rhyme Rubayet Rudra[3]

[1] *student, Department of Civil Engineering, Khulna University of Engineering & Technology, Bangladesh, *Corresponding Author: E-mail:* saptarshimondal322@gmail.com

[2] *Professor, Department of Civil Engineering, Khulna University of Engineering & Technology, Bangladesh, E-mail:* imrafizul@yahoo.com

[3] *student, Department of Urban and Regional Planning, Khulna University of Engineering & Technology, Bangladesh, mail:* Rubayet1717054@gmail.com

***Corresponding Author**

ABSTRACT

Environment management is our biggest concern with the understanding of the structure and function of the earth system, as well as the way in which human relate to the environment. Improper management of environment causes environmental pollution and risk to environment and human health. Day by day, environment management is degrading and this affects so much on human and the other surroundings. Khulna city is facing severe environmental degradation and public-health due to improper management of landfill site and uncollected waste from roadside and human areas. In this research, to methodically evaluate both probabilistic and fuzzy uncertainties linked with site characteristics, environmental guidelines, and health impact criteria, an integrated fuzzy risk assessment has been created. Probability of environmental guideline violation and Hazard Index (HI) are divided into "low", "low-medium", "medium", "medium-high" and "high" in these five categories. The general risk level (GRL) is divided into six categories as "low", "low-medium", "medium", "medium-high", "high", "very-high". The fuzzy input parameters, probability of environmental guideline violation and hazard index are compiled with the fuzzy output parameter, GRL to calculate site score through fuzzy operation. This process has been applied to the soil, leachate, groundwater and surface water of the Rajbandh landfill site in Khulna city. Surface water samples, groundwater samples, soil samples and leachate samples have been collected from 15 sampling points at Rajbandh landfill site, Khulna. The site score of every borehole for soil, leachate, surface water and groundwater of the landfill site also has been calculated and given the recommended risk management action according to the site score (output GRL). Site score value of sample no. 6 of surface water is 60.2 which is in moderate condition, and risk management action of this site is "Contain the area and limit the use of groundwater". This study's risk assessment approach provides a one-of-a-kind tool for methodically measuring several uncertainties in management of polluted sites, as well as more realistic assistance for remediation-related decisions.

Keywords: Risk assessment; Landfill site; Site score; Uncertainty

1. INTRODUCTION

Large amounts of municipal solid garbage have been generated as a result of population increase, fast urbanization and industrialization, and changing standards and lifestyles in today's society. In terms of environmental management, the amount of solid waste generated, and its disposal are key challenges. Landfilling is the most common, oldest, and least expensive method of disposing of solid waste. Municipal solid waste (MSW) management is one of the most pressing issues confronting city planners around the world (Dhia, 2013). The bulk of discarded homogeneous and heterogeneous materials in an urban environment is known as MSW (S.M. Rafew, 2021). When MSW landfills do not have liners and leachate is not collected and treated before being discharged, it can contaminate both groundwater and surface water (I. M. Rafizul*, 2016). Rainwater percolates through the landfill site, dissolving various organic and inorganic compounds included in the solid waste, resulting in leachate generation. Landfill leachate has the ability to contaminate nearby soil, as well as groundwater and surface water supplies, posing a health risk. Risk assessment is an important step in the process of making informed decisions about how to clean up and manage these contaminated sites. It provides solid foundations for analyzing and ranking the severity of pollution at a location. The randomness inherent in nature, as well as a lack of appropriate knowledge connected to the odds of risk occurrence and the potential consequences of such occurrence, limit risk insight. As a result, risk evaluation is inextricably tied to uncertainty (WAGNER, 1992) (Clark D. Carrington and P. Michael Bolger U.S. Food and Drug Administration, 1998). Neglecting ambiguity in the assessment methods could have negative repercussions. For instance, overdesigning remediation systems may result in a waste of money and resources, whilst underestimating dangers may result in no or restricted steps toward site management, endangering human health and the natural environment (Jianbing Lia, 2007) .

Previously, there was a substantial amount of research published on methodologies for conducting risk assessments at contaminated sites under varied source and/or aquifer circumstances. For example, (Yong W. Lee, 1994) proposed a fuzzy-set-based approach for estimating human-health risk from groundwater contamination and evaluating potential regulatory actions; to account for uncertainty, (Hamed, 1997) used first- and second-order reliability approaches in a risk assessment framework. By describing key factors as probability distribution functions, (Bill Batchelor, 1998) created a stochastic risk assessment model for a location. (Aral, 2004) performed a health risk analysis of multi-pathway exposure to contaminated water by generating fuzzy membership functions of risks and probability distributions of risks for various alpha-cut levels of the membership function, with the pollutant concentration and cancer potency factors treated as fuzzy variables and the remaining modeling parameters treated with probability density functions.

2. METHODOLOGY

This study was assessed on the surface water, ground water, soil of 15 different boreholes at Rajbandh landfill site, Khulna. In laboratory, the concentration of heavy metals; Fe, Mn, Cu, Zn, Cr, Pb and As; in surface water, groundwater, leachate and soil were collected from a secondary source. These seven heavy metals are also considered indications of urban pollution (Xuedong Wang *, 2021) (Ming Chen, 2008) (Ackah, 2019). From the concentration of the heavy metals, the probability of environmental guideline violation was evaluated comparing with the standard value of the heavy metals. From that the hazard index was also collected. Here the probability of environmental guideline violation was evaluated for the heavy metals of every 15 boreholes of surface water, groundwater, leachate and soil as well as for the whole surface water, groundwater, leachate and soil along with the evaluation of hazard index of the heavy metals of every 15 boreholes. The membership function of fuzzy sets was constructed based on the probability of environmental guideline violation of heavy metals. Also, the membership function of fuzzy sets was constructed based on the hazard index of the heavy metals. The extent of the general risk levels [0, 100] is subjectively given to the fuzzy sets in order for them to have single numerical site risk scores (Mohamed, 1999). The membership function of fuzzy sets of the probability of environmental guideline violation, the membership function of fuzzy sets of hazard index and general risk levels were compiled to calculate the site score of the site (output value of GRL) through fuzzy rule base operation. From the calculated site score we can recommend the risk management actions.

2.1 Description of Study area

The waste disposal site at Rajbandh, Khulna was selected as case study. The geological coordinate of the radial centre of the sampling points are 22.794722 (Latitude) & 89.499722 (Longitude).

2.2 Probability of Environmental Guideline Violation

In this study Fe, Mn, Cu, Zn, Cr, Pb and As heavy metals are taken for the evaluation of risk assessment. The concentration of this heavy metals is found from the secondary sources for every borehole **(Rafizul, 2019)** . The mean value and standard deviation are determined for the calculation of the probability of environmental guideline violation by comparing their concentration with the standard value of the concentration of those heavy metals.

2.3 Fuzzy sets for the Probability of Environmental Guideline Violation

Fuzzy sets are formed for every borehole sample. These fuzzy sets are formed after the determined value of the probability of environmental guideline violation. Every different fuzzy sets will be determined for every different borehole.

2.4 Fuzzy Environmental-based Risk Assessment

A comparison of pollutant concentration with its associated environmental guideline is used in the environmental-guideline-based risk assessment. (Hwang, 1992) conversion scale figures that were used to systematically transfer language concepts to their appropriate fuzzy sets. All linguistic expressions of "HIGH" vs "LOW" are covered by these scale figures. The linguistic-term conversion technique entails first choosing a figure that contains all of the verbal terms provided by the decision-maker, and then utilizing the membership function specified for that figure to reflect the meaning of these verbal terms. Based on the probability of environmental guideline violation, the membership function of fuzzy sets can be constructed according to (Hwang, 1992). In this study, “L”, “L-M”, “M”, “M-H” and “H” represents “Low”, “Low-to-medium”, “Medium”, “Medium-to-high” and “High” respectively. For example, from figure 1, we can indicate if the probability of environmental guideline violation is 36.5% (0.365) , the associated probability of environmental guideline violation can be classified as "medium" in nature (with a membership grade of 0.25) and partly ‘‘low-to-medium’’ (with a membership grade of 0.75).

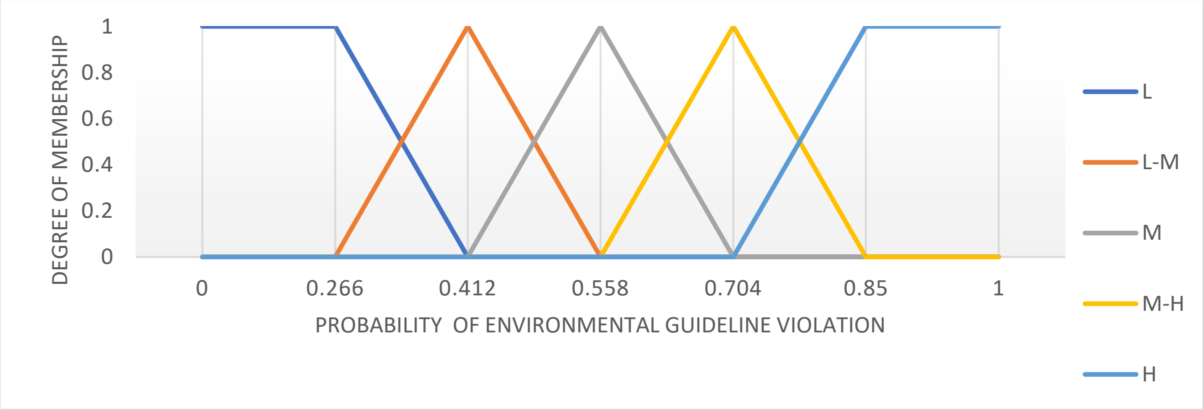
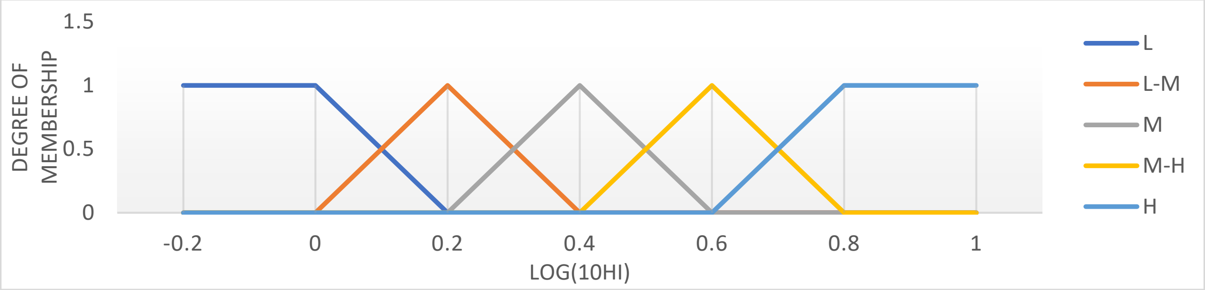


Figure 1: Membership function of fuzzy environmental risks associated with probability of violating groundwater quality guideline for groundwater location 1.

2.5 Fuzzy Health Risk Assessment

For the quantification of human health risk, pollutants can be categorized as carcinogens and non-carcinogens (J. B. LI, 2003) (Fei Li, 2017). In this study we will analysis for non-carcinogens pollutants. Hazard Index (HI) is taken for the non-carcinogens pollutants (E. Kentel, 2004). For the different value of hazard index may lead to different perception of health risk, leading to different decision action. It also may lead to different site score value as well as lead to different site management action. Here we have got the values of hazard index from a secondary source. The values are scaled down as the form of (log 10HI) along the horizontal axis after forming the fuzzy sets with these scaled down values (Jianbing Li, 2007). Fuzzy sets with membership function are sown in the figure (2). In this figure, 50% value of hazard index indicates both risk level of medium with membership value of 0.5 and risk level of medium-to-high with membership value of 0.5.



igure 2: Membership function of health risk associated with Hazard Index (HI)

2.6 General Risk Level

The general risk level is calculated using an integrated approach that considers both environmental and health risk issues. The use of fuzzy membership functions and fuzzy rules will be used to offer a fuzzy inference procedure for facilitating this type of risk estimation. A conditional part (e.g., antecedent) and a conclusion part are frequently included in the rules (e.g. consequence). As example, ‘‘if the probability of environmental guideline violation is LOW and health risk is MEDIUM, then the general risk is MEDIUM’’. In this kind of fuzzy rules, the input variables are 'probability of environmental guideline violation' and 'health risk,' while the output variable is 'general risk level'. This kind of a set of rules is known as the rule base (Mohamed, 1999). The general risk level is categorized into ‘‘low’’, ‘‘low-to-medium’’, ‘‘medium’’, ‘‘medium-to-high’’, ‘‘high’’ and ‘‘very-high’’, the membership functions that can be established for these related fuzzy occurrences according to (Hwang, 1992) and (Mohamed, 1999) as shown in Fig. 3. The general risk will be determined using a set of fuzzy rules in this investigation. “AND” is used as the fuzzy logic operator to join factors in the sake of the rules. Table 1 shows the 25 fuzzy rules that were obtained according to (Jianbing Li, 2007). These Fuzzy rules are adopted in such way that indicated if environmental-guideline-based risk is low and health risk is low then general risk level will be low. Also, if the environmental-guideline-based risk is low and the health risk is high then the general risk level will be high. The range of the general risk levels [0, 100] is subjectively given to the fuzzy sets in order for them to have single numerical site risk scores (Mohamed, 1999).

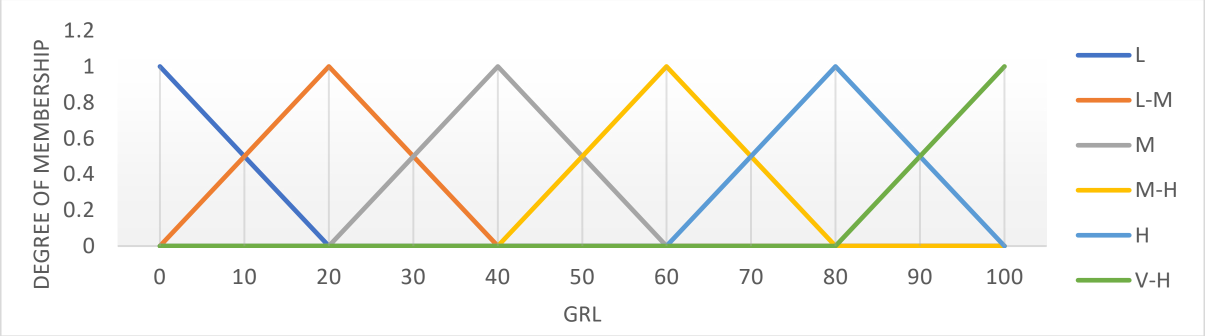


Figure 3: Membership functions of general risk level.

3. RESULTS AND DISCUSSION

3.1 Landfill Monitoring

In this study different parameters in terms of site sore with probability, were considered to assess the level of contamination of the selected landfill site and hence discussed in the following sub-headings. Fuzzy operations are done for the groundwater, leachate, soil and surface water and General Risk Level (site score) are found from the fuzzy operation results. General Risk level (site score) with respect to probability of environmental guideline violation (P) and Hazar Index (HI); General risk level individually for environmental guideline violation and Hazard Index are analyzed and hence discussed below.

3.1.1 Site Score Analysis for both Probability of Environmental Guideline Violation and Hazard Index:

By the combination of P and HI along with their fuzzy membership function with the membership function of GRL, the site score was found through the fuzzy operation. Site score were calculated for each 15 samples for soil, leachate ,groundwater & surface water; different site score value indicates different risk management action. For example, from figure (4), Site score of the groundwater sample 4 is 40.9 which is between 40-60 that indicates to take interim control measures and limit access to the site according to table (2). From the figure (4), if the value of any probability of environmental-guideline violation (P) or hazard index (HI) changes a little the value of site score changes much as well as risk management action also changes according to the site score. The change of the value of GRL (site score) indicates different risk management action. Such as if the value of GRL is 80, it tells about the site to take all necessary steps to treat the site. So risk management action depends on the value of site score which also depends upon the probability of environmental-guideline violation (P) and hazard index (HI). Table(2) shows the risk management action according to their site score value (Jianbing Li, 2007).

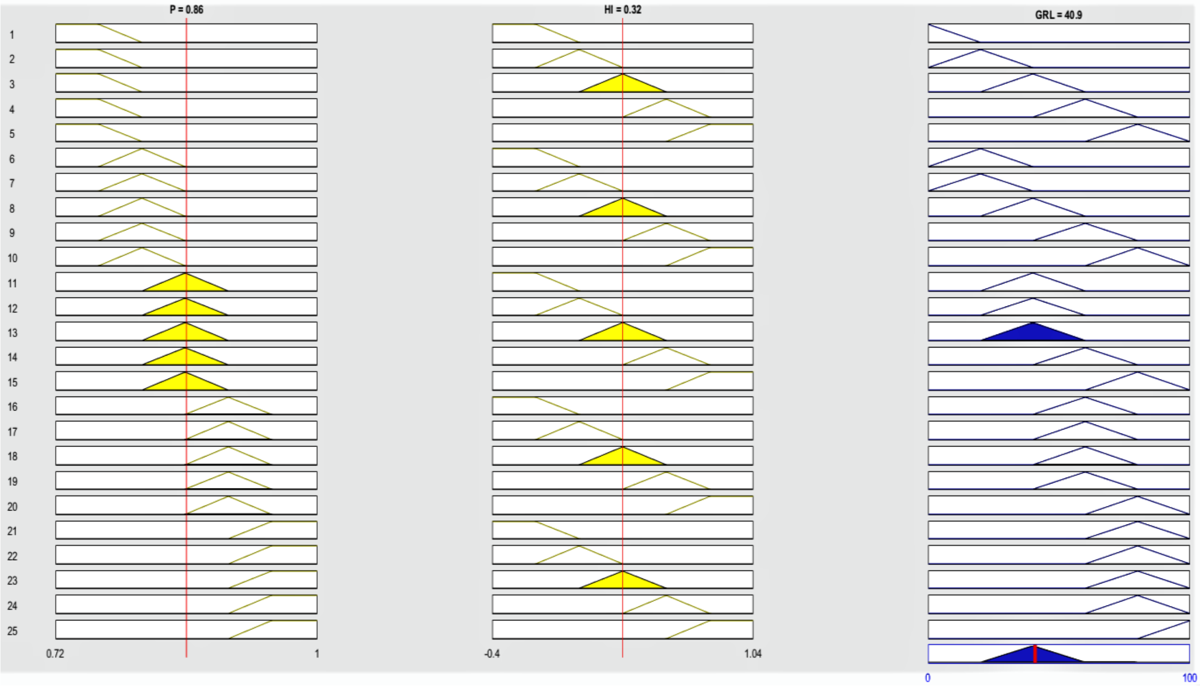
Table 1: Fuzzy rule base (After “ (Jianbing Li, 2007)”)

If environmental-guideline-based risk is	**If health risk is**	**The general risk level (GRL) is**
Low	Low	Low
Low	Low-to-medium	Low-to-medium
Low	Medium	Medium
Low	Medium-to-high	Medium-to-high
Low	High	High
Low-to-medium	Low	Low-to-medium
Low-to-medium	Low-to-medium	Low-to-medium
Low-to-medium	Medium	Medium
Low-to-medium	Medium-to-high	Medium-to-high
Low-to-medium	High	High
Medium	Low	Medium
Medium	Low-to-medium	Medium
Medium	Medium	Medium
Medium	Medium-to-high	Medium-to-high
Medium	High	High
Medium-to-high	Low	Medium-to-high
Medium-to-high	Low-to-medium	Medium-to-high
Medium-to-high	Medium	Medium-to-high
Medium-to-high	Medium-to-high	Medium-to-high
Medium-to-high	High	High
High	Low	High
High	Low-to-medium	High
High	Medium	High
High	Medium-to-high	High
High	High	Very high

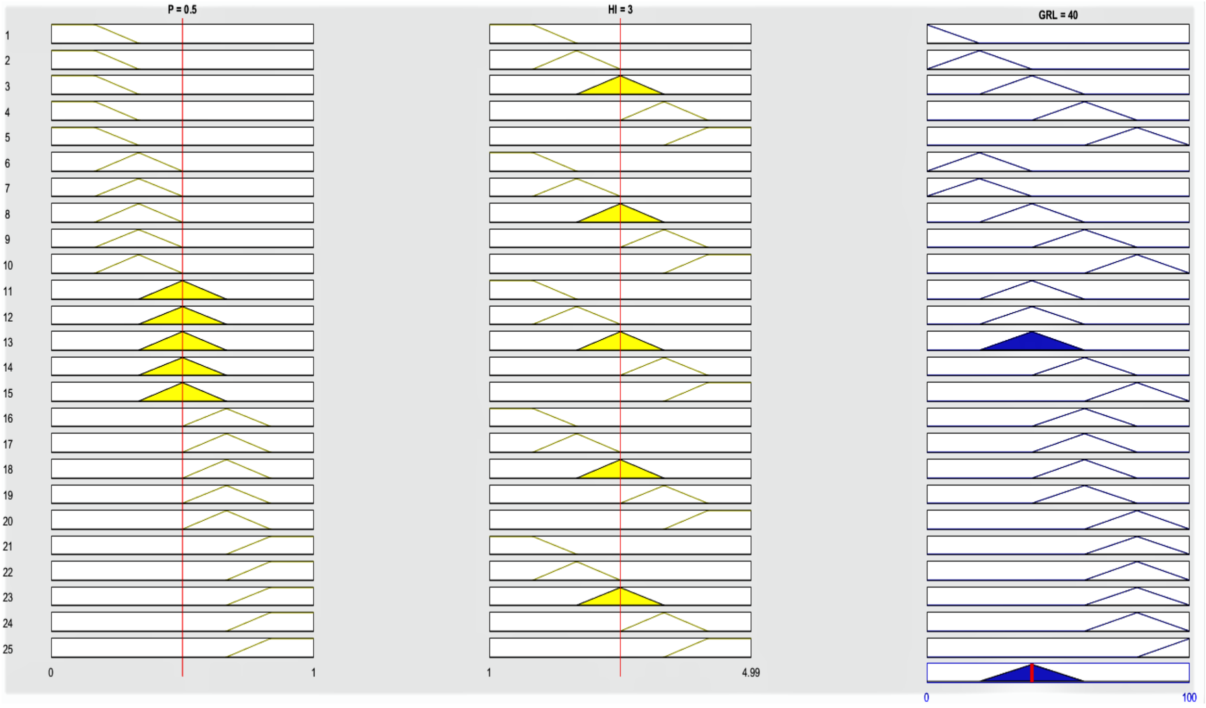
Table 2: Recommended risk management actions

Calculated Site Score	Risk management action
90-100	This location has to be cleaned up right now.
70-90	Take all necessary steps to treat the site.
50-70	Contain the area and limit the use of groundwater.
30-50	Take intermediate monitoring measures and moderate access to the site.
10-30	The place has to be kept under surveillance.
0-10	No actions are required.

(a)



(b)



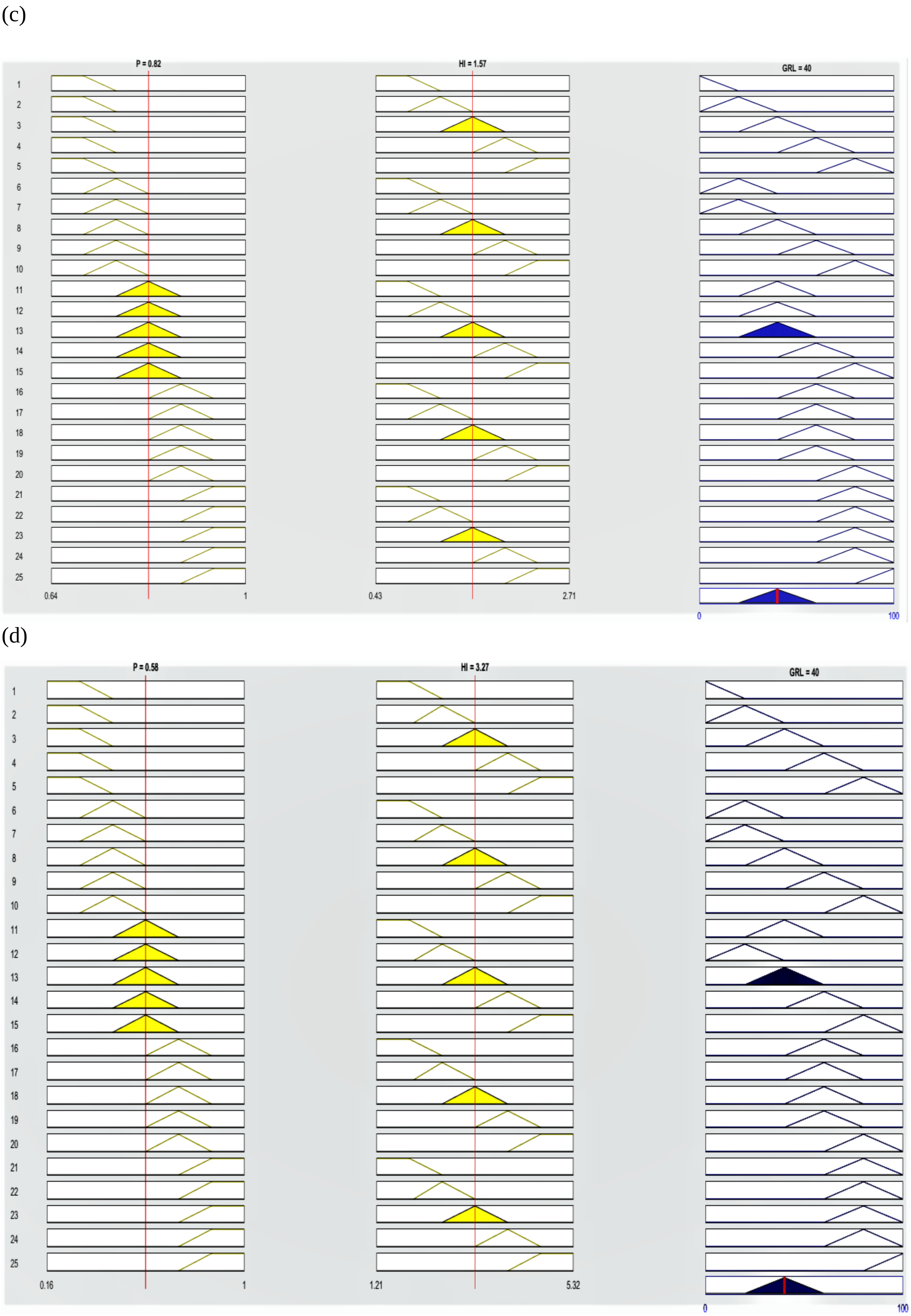


Figure 4: Site score for both probability of environmental guideline violation for (a) groundwater, (sample no.4), (b) surface water, (sample no.3) , (c) leachate, (sample no.3), (d) soil, (sample no.1).

Table 3: Site score and risk management for Leachate samples.

Leachate sample	Distance (m)	Site Score	Risk management action
1	0	50	Take intermediate monitoring measures and moderate access to the site.
2	30	50	Take intermediate monitoring measures and moderate access to the site.
3	35	40	Take intermediate monitoring measures and moderate access to the site.
4	50	40	Take intermediate monitoring measures and moderate access to the site.
5	60	40	Take intermediate monitoring measures and moderate access to the site.
6	62	40	Take intermediate monitoring measures and moderate access to the site.
7	72	40	Take intermediate monitoring measures and moderate access to the site.
8	80	40	Take intermediate monitoring measures and moderate access to the site.
9	92	40	Take intermediate monitoring measures and moderate access to the site.
10	100	40	Take intermediate monitoring measures and moderate access to the site.
11	106	40	Take intermediate monitoring measures and moderate access to the site.
12	120	40	Take intermediate monitoring measures and moderate access to the site.
13	125	40	Take intermediate monitoring measures and moderate access to the site.
14	130	40	Take intermediate monitoring measures and moderate access to the site.
15	135	40	Take intermediate monitoring measures and moderate access to the site.

Table 4: Site score and risk management for soil samples

Soil Sample	Distance (m)	Site score	Risk management action
1	0	40	Take intermediate monitoring measures and moderate access to the site.
2	10	40.1	Take intermediate monitoring measures and moderate access to the site.
3	30	40	Take intermediate monitoring measures and moderate access to the site.
4	45	40	Take intermediate monitoring measures and moderate access to the site.
5	50	40	Take intermediate monitoring measures and moderate access to the site.
6	60	40.3	Take intermediate monitoring measures and moderate access to the site.
7	70	40	Take intermediate monitoring measures and moderate access to the site.
8	80	40	Take intermediate monitoring measures and moderate access to the site.
9	90	40	Take intermediate monitoring measures and moderate access to the site.
10	105	40	Take intermediate monitoring measures and moderate access to the site.
11	120	40	Take intermediate monitoring measures and moderate access to the site.
12	126	50	Take intermediate monitoring measures and moderate access to the site.
13	135	50	Take intermediate monitoring measures and moderate access to the site.
14	140	50	Take intermediate monitoring measures and moderate access to the site.
15	145	40	Take intermediate monitoring measures and moderate access to the site.

Table 5: Site score and risk management for surface water samples

Surface water sample	Distance (m)	Site score	Risk management action
1	10	50	Take intermediate monitoring measures and moderate access to the site
2	30	50	Take intermediate monitoring measures and moderate access to the site
3	50	40	Take intermediate monitoring measures and moderate access to the site
4	90	40	Take intermediate monitoring measures and moderate access to the site
5	120	40	Take intermediate monitoring measures and moderate access to the site
6	135	60.2	Contain the area and limit the use of groundwater.
7	145	40	Take intermediate monitoring measures and moderate access to the site
8	185	40	Take intermediate monitoring measures and moderate access to the site
9	220	40	Take intermediate monitoring measures and moderate access to the site
10	245	40	Take intermediate monitoring measures and moderate access to the site
11	250	40	Take intermediate monitoring measures and moderate access to the site
12	255	40	Take intermediate monitoring measures and moderate access to the site
13	250	40	Take intermediate monitoring measures and moderate access to the site
14	270	40	Take intermediate monitoring measures and moderate access to the site
15	280	40	Take intermediate monitoring measures and moderate access to the site

Table 6: Site score and risk management for groundwater samples

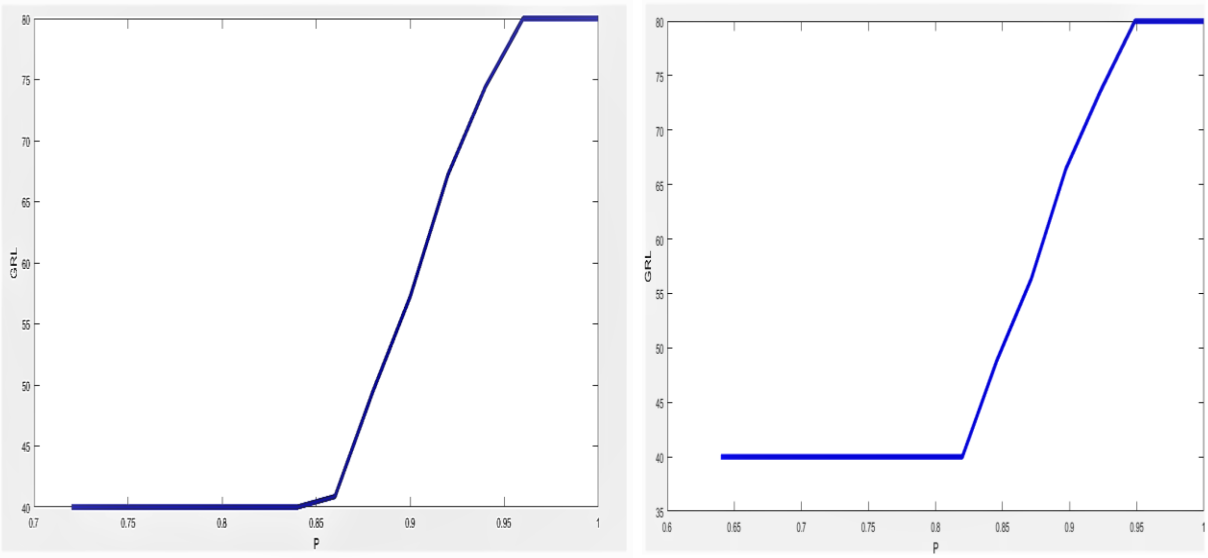
Groundwater sample	Distance (m)	Site Score	Risk Management action
1	13	40.4	Take intermediate monitoring measures and moderate access to the site
2	180	40.4	Take intermediate monitoring measures and moderate access to the site
3	215	40.1	Take intermediate monitoring measures and moderate access to the site
4	215	40.9	Take intermediate monitoring measures and moderate access to the site
5	217	40.0	Take intermediate monitoring measures and moderate access to the site
6	230	40.0	Take intermediate monitoring measures and moderate access to the site
7	235	40.0	Take intermediate monitoring measures and moderate access to the site
8	260	40.3	Take intermediate monitoring measures and moderate access to the site
9	285	40.0	Take intermediate monitoring measures and moderate access to the site
10	290	40.0	Take intermediate monitoring measures and moderate access to the site
11	320	40.0	Take intermediate monitoring measures and moderate access to the site
12	334	40.0	Take intermediate monitoring measures and moderate access to the site
13	348	40.0	Take intermediate monitoring measures and moderate access to the site
14	355	40.5	Take intermediate monitoring measures and moderate access to the site
15	355	42.3	Take intermediate monitoring measures and moderate access to the site

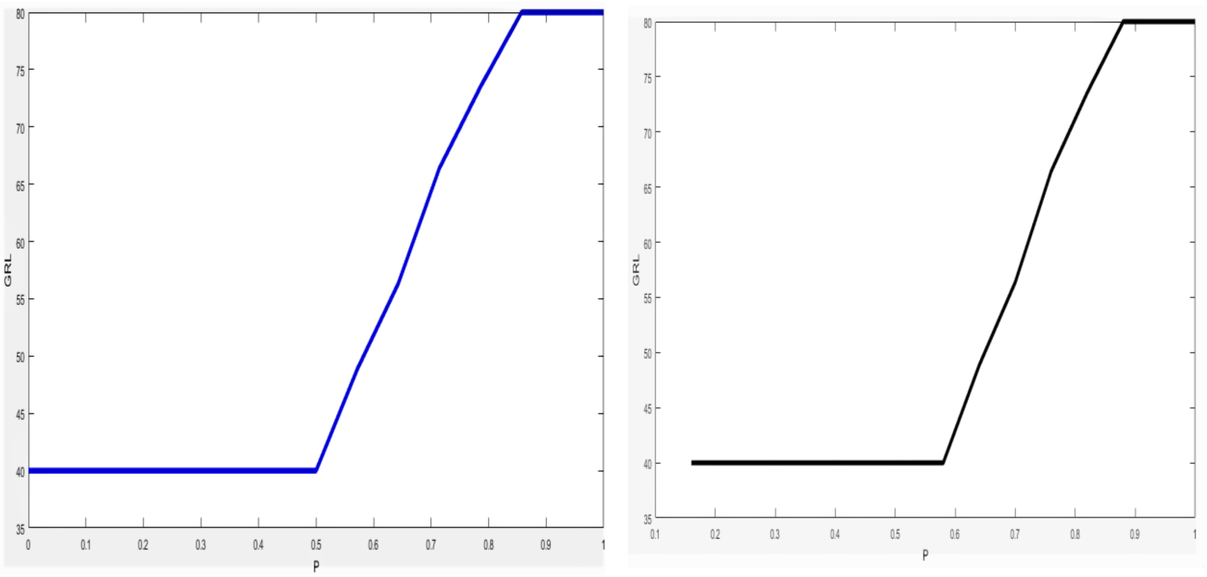
.

3.1.2 Site Score Analysis For Probability Of Environmental Guideline Violation

Probability of environmental guideline violation is similar to environmental-guideline-based risk assessment and it is defined as the risk owing to violation of environmental guidelines or regulations. In this study, probability of environmental guideline violation is obtained by comparing the concentration of contaminated heavy metals with the standard value of concentration of those heavy metals. Site score and probability of environmental guideline violation (P) are related with each other. If the value of P increase, the site score may increase. For example, from the figure (5(a)), if the value of P remains less than 86%, the site score value remains 40. For the value of P of 86%, the site score value increases and it is 40.9. Further increase of the value of P, the site score value increases rapidly and site management action also changes. For example, from the figure (5(a)), for the value of P of 90%, the site score is 57. So the risk management action will be the "Contain the area and limit the use of groundwater". The maximum value of GRL (site score) for the probability of environmental guideline violation is 80. So the maximum critical stage of the evaluation of site's risk management of the probability of environmental guideline violation for the sites is to "Take all necessary steps to treat the site".

(a) (b)





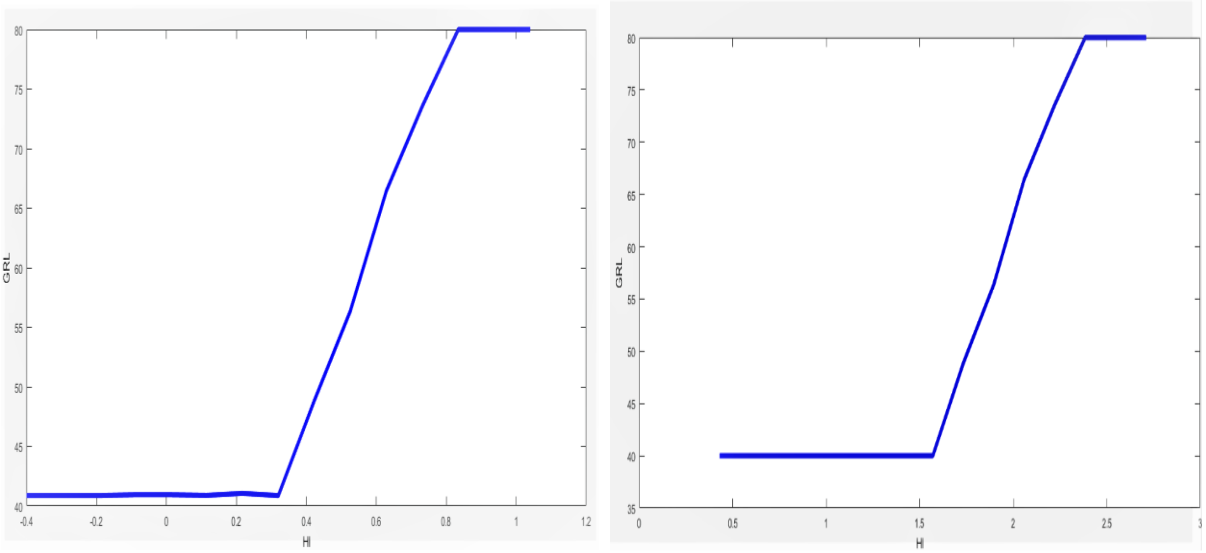
(c) (d)

Figure 5: Site score against probability of environmental guideline violation for (a) groundwater (sample no.4), (b) surface water (sample no.3), (c) leachate (sample no.3), (d) soil (sample no.1)

3.1.3 Site Score Analysis for HI:

Hazard Index is directly associated health risk (HR) criteria. Health risk defines as the risk of health impacts owing to chronic intake of the contaminant (Rafizul, 2019). The calculation of HR is based on the health impact criteria. For the quantification of health risk, health risk assessment (HRA) approach is needed. HRA approach includes quantification of hazard index (HI). So heath risk and hazard index are directly connected to each other. Daily chronic intake (CDI) and reference dose (RFD) is needed for the quantification of HI. HI defines as the proportioner of CDI and RFD. In this study, the values of HI are collected from a secondary source.

Site score and Hazard Index (HI) are related with each other. The site score increases with the increase of the value of HI after a definite value. For example, from the figure (5(b)), the value of site score remains 40 within the value of 1.57 of HI. For a little increase of the value of HI after 1.57, the value of site score increases rapidly. As the value of HI being 2.25, the site score value will be 73 which is between 70-90 that indicates. Take all necessary steps to treat the site. In this study, the maximum value of GRL (site score) for hazard index is 80. So the maximum critical stage of the evaluation of site's risk management of hazard index for the sites is "Take all necessary steps to treat the site".



(a) (b)

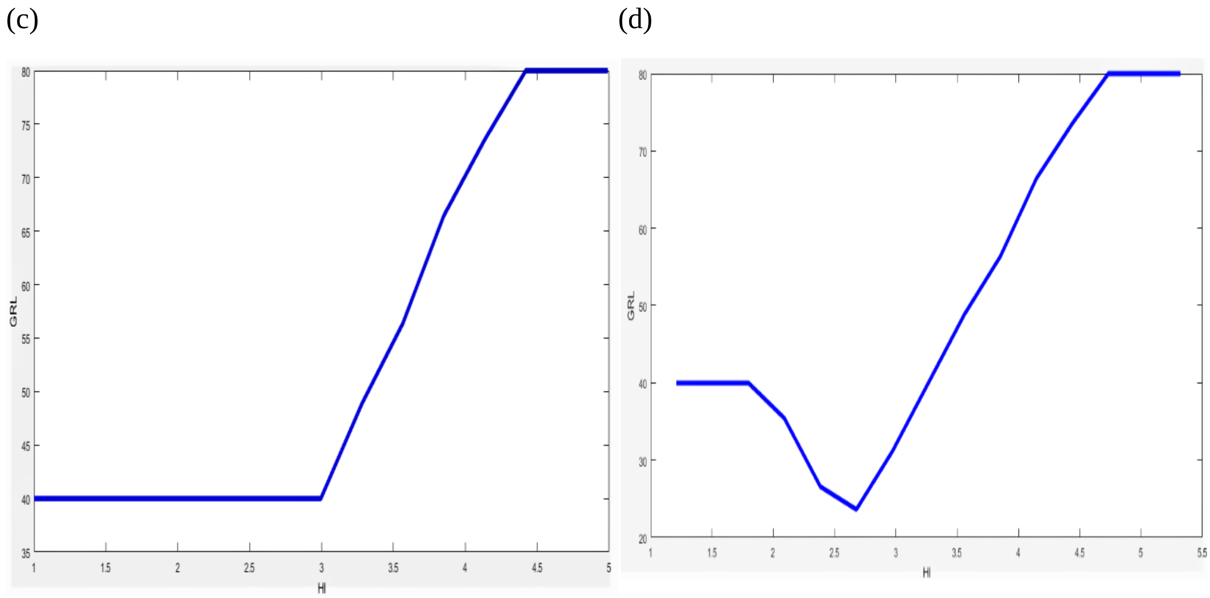
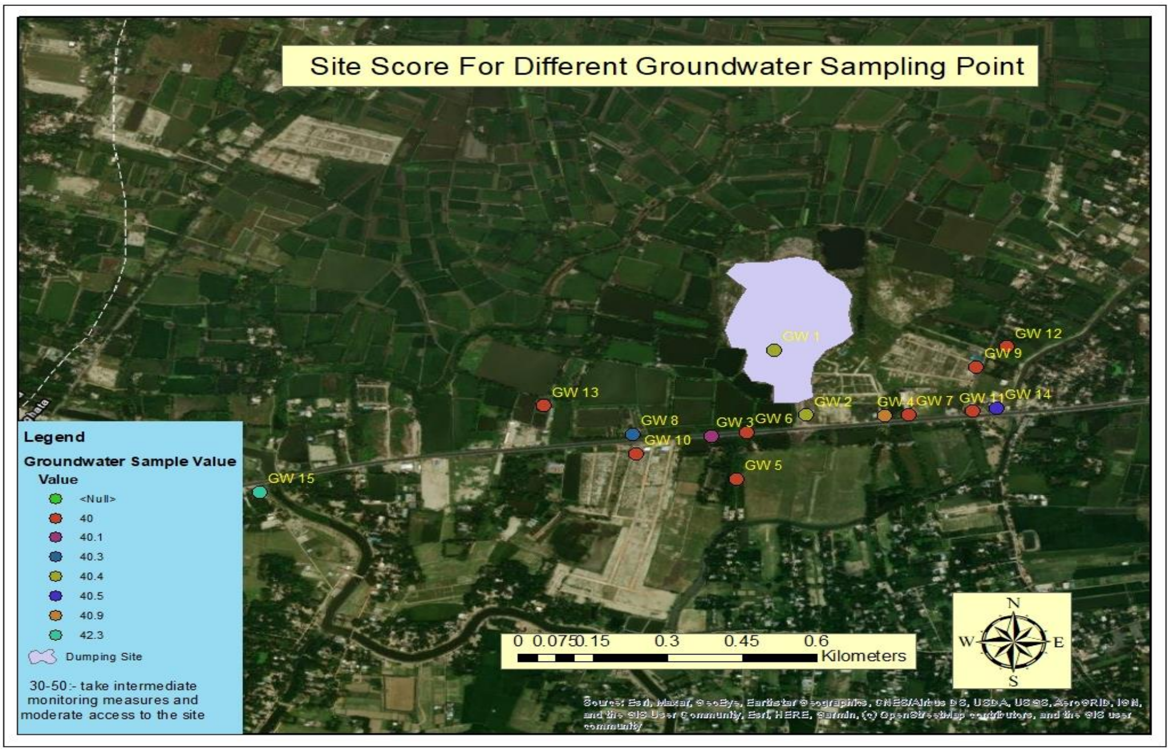


Figure 6: Site score against hazard index for (a) groundwater(sample no.4), (b) surface water (sample no.3), (c) leachate (sample no.3), (d) soil (sample no.1).

3.1.4 Maps with the Different Sampling point for groundwater, leachate, soil and surface water:

Location maps for every sample of groundwater, surface water, leachate and soil were constructed through GIS. Every location's distance, altitude and longitude were collected from secondary source. With the distance, altitude and longitude of every sampling point, GIS maps were formed for groundwater, leachate, soil and surface water sample. Every map shows the location with their site score value for every 15 points of the collecting sample. Every map shows the location with their site score value for every 15 points of the collecting sample. Location maps with the site score of every point as well as risk management action are shown in figure 7.

(a)



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

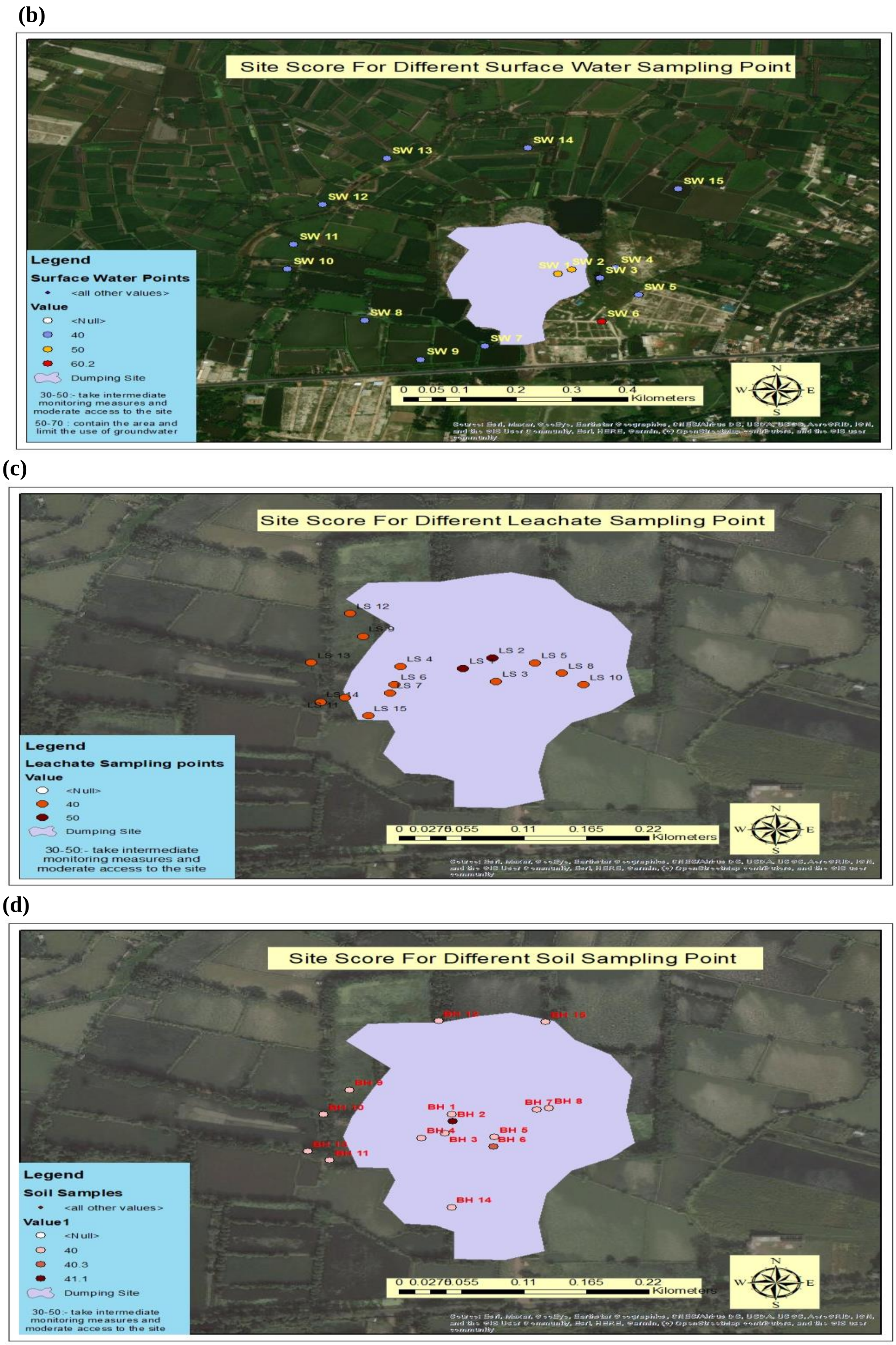


Figure 7: Site score and risk management for the all points of (a)groundwater samples, (b) surface water samples, (c)leachate samples, (d)soil samples.

4. CONCLUSION:

In this study, an integrated fuzzy risk assessment approach was developed for the quantification of fuzzy uncertainties associated with site condition, environmental guideline violation and hazard index. The link between the two sorts of uncertainties was also established successfully. This process includes (a) determination of the concentrations of heavy metals; Fe, Mn, Cu, Zn, Cr, Pb and As which were taken for the risk assessment, (b) adopting fuzzy membership functions to evaluate environmental guidelines and their health implications, (c) adopting fuzzy and stochastic inputs to quantify environmental and health concerns, (d) adopting A fuzzy logic technique to determine generic danger levels, (e) determination of Site score of the sites through fuzzy operation, (f) indicating risk management action according to their site score value. Site score of any site indicates what risk management action should be taken for that site. Site score and their risk management action are shown in table-3, 4, 5, 6. As the increase of the value of both environmental guideline violation and hazard index or only environmental guideline violation or only hazard index of a site, the site score value also increases which may lead to different risk management action of that site. As the maximum site score values are between 30-50, so "Take intermediate monitoring measures and moderate access to the site" is applicable for those sites. As heavy metals of the sites are polluted, so authority should take action and take interim measures and limit access to the site.

REFERENCES

Ackah, M. (2019). Soil elemental concentrations, geoaccumulation index, non-carcinogenic and carcinogenic risks in functional areas of an informal e-waste recycling area in Accra, Ghana. *Chemosphere, 235*, 908-917.

Aral, E. K. (2004). Probabilistic-fuzzy health risk modeling. *Stochastic Environmental Research and Risk Assessment*, 324-338.

Bill Batchelor, l. M. (1998). STOCHASTIC RISK ASSESSMENT OF SITES CONTAMINATED BY HAZARDOUS WASTES. *ASCE Library*, 380-388.

Clark D. Carrington and P. Michael Bolger U.S. Food and Drug Administration, H.-3. W. (1998). Uncertainty and Risk Assessment. *An International Journal, 4*(2), 253-257.

Dhia, A. A. (2013). Minimization of environmental risk of landfill site using fuzzy logic, analytical hierarchy process, and weighted linear combination methodology in a geographic information system environment. *Environ Earth Sci, 68*(5), 1375–1389.

E. Kentel, M. M. (2004). Probabilistic-fuzzy health risk modeling. *Stoch Envir Res and Risk Ass, 18*(5), 324–338.

Environment), C. (. (1996). *A Framework for Ecological Risk Assessment: General Guidance*. Ottawa, ON, Canada: National Contaminated Sites Remediation Program.

Fei Li, Z. Q. (2017). Spatial Distribution and Fuzzy Health Risk Assessment of Trace Elements in Surface Water from Honghu Lake. *International Journal of Environmental Research and Public Health, 14*(9), 1011.

Hamed, M. B. (1997). On the Performance of Computational Methods for the Assessment of Risk from Ground-Water Contamination. *National Ground Water Association*, 638-646.

Hwang, S.-J. C.-L. (1992). *Fuzzy Multiple Attribute Decision Making* (1 ed.). Manhattan,USA: Springer, Berlin, Heidelberg.

I. M. Rafizul*, M. A. (2016). Assessment of Treatment Efficiency of Lysimeter Leachate Using Leachate Pollution Index. *Iranica Journal of Energy and Environment, 7*(1), 72-83.

J. B. LI, G. H. (2003). Integrated Fuzzy-Stochastic Modeling of Petroleum Contamination in Subsurface. *Energy Sources, 25*(6), 547–563.

Jianbing Li, G. H. (2007). An integrated fuzzy-stochastic modeling approach for risk assessment of groundwater contamination. *Journal of Environmental Management*, 173–188.

Jianbing Lia, G. H. (2007). An integrated fuzzy-stochastic modeling approach for risk assessment of groundwater contamination. *Journal of Environmental Management*, 173–188.

Ming Chen, X.-m. L.-m.-x.-j.-m. (2008). Total concentrations and speciation of heavy metals in municipal sludge from Changsha, Zhuzhou and Xiangtan in middle-south region of China. *Journal of Hazardous Materials, 160*(2-3), 324-329.

Mohamed, A. C. (1999). Decision analysis of polluted sites — a fuzzy set approach. *Waste Management, 19*(7-8), 519-533.

Rafizul, P. K. (2019). HUMAN HEALTH RISK ASSESSMENT DUE TO THE PRESENCE OF HEAVY METALSIN SOIL OF WASTE DISPOSAL SITE AT KHULNA IN BANGLADESH. *Journal of Engineering Science, 10*(1), 1-12.

S.M. Rafew, I. M. (2021). Application of system dynamics model for municipal solid waste management in Khulna city of Bangladesh. *Waste Management, 129*, 1-19.

WAGNER, J. M. (1992). Groundwater Quality Management Under Uncertainty: Stochastic Programming Approaches and the Value of Information. *28*(5).

Xuedong Wang *, C. Z. (2021). Probabilistic-fuzzy risk assessment and source analysis of heavy metals in soil considering uncertainty: A case study of Jinling Reservoir in China. *Ecotoxicology and Environmental Safety, 222*(1), 112-537.

Yong W. Lee, M. F. (1994). FUZZY DECISION MAKING IN GROUND WATER. *WATER RESOURCES BULLETIN NITRATE RISK MANAGEMENT*, 135-147.