ARTICLE IN PRESS

Saudi Journal of Biological Sciences xxx (xxxx) xxx

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Original article

Development & application of Conceptual Framework Model (CFM) for environmental risk assessment of contaminated lands

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ARTICLE INFO

Article history:
Received 9 May 2021
Revised 19 June 2021
Accepted 23 June 2021
Available online xxxx

Keywords:
Environmental risk assessment
Cancer risk effect
Dumping site
Contaminated land
Conceptual framework model
Potential Ecological Risk Index
Environmental management

ABSTRACT

Dumping sites are the most common types of contaminated lands as they pollute the environment. Environmental management of contaminated sites cannot be delivered effectively and efficiently without robust holistic & integrated risk assessment. Previous studies reveal the absence of a risk assessment model that holistically integrates all essential factors progressively and categorically. The study aimed to develop a holistic & integrated Conceptual Framework Model (CFM) for environmental risk assessment and to apply developed CFM on real-world existing Mahmood Booti Open Dumping Site (MBODS). CFM developed in this study had three main tiers i.e., baseline study, hazard identification & exposure assessment, and risk estimation. For the application of CFM, baseline data were collected and assessed. Water, leachate & soil samples were collected within 1000 m across the site and analyzed for physio-chemical parameters and heavy metals to estimate risk. Results of applied CFM depicted that Physico-chemical analysis of leachate, water, and soil revealed significant pollution levels. Heavy metal analysis exhibited that Ni, Pb, Mn, and Cr levels exceeded the allowable limits of the "World Health Organization" in leachate, water, and soil samples. It also revealed the existence of metals at the source (dumping site itself), pathway, and receptor of the dumping site. E_r^i value for Ni, Pb and Cd from the study area manifested a serious probable risk to ecological integrities. Results for PERI from dumpsite demonstrated a serious ecological risk. It can be concluded that although Mahmood Booti dumping site has been at post-closure stage, it is a momentous source of hazardous toxic contaminants to the nearby inhabitants. The work presented in this paper may reproduce repeatedly to create site-specific risk assessment models of other contaminated lands in a cost-effective, consistent and cohesive manner. Application of CFM at Mahmood Booti Dumping site described detailed risk assessment which helps further in risk management.

1. Introduction

Municipal Solid Waste dumping areas can cause harm to the built environment as well as natural environment (Butt et al., 2019). Dumping sites are more common in developing world due to a lack of resources and management expertise (Ferronato and Torretta, 2019). These sites are considered as a pollutant source that may have the ability to contaminate all the four main spheres of the environment i.e., lithosphere, hydrosphere, atmosphere, and biosphere (Butt et al. 2017).

Risk assessment (RA) is a scientific tool to support decision-makers in addressing health effects and their acuteness. It also helps to create priorities and allocation of resources. The use of RA in the field of waste management has been widely used especially in planning of a landfill site. It can also helpful in operating and post-closure phases of a landfill. A few studies have been found for the study area such as Haydar et al. (2012) estimated the effect of dumping site on groundwater that water samples near the vicinity of sites were contaminated by bacteriological contaminants. Aiman et al. (2016) studied the levels of heavy metals (Pb, Zn, Cd, Cr, Ni, Mn, Fe and Cu) for several environmental mediums.

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sjbs.2021.06.069
1319-562X/

Please cite this article as: A. Alam, Muhammad Nawaz Chaudhry, A. Mahmood et al., Development & application of Conceptual Framework Model (CFM) for environmental risk assessment of contaminated lands, Saudi Journal of Biological Sciences, https://doi.org/10.1016/j.sjbs.2021.06.069

Mahmood, Khalid, Batool, Chaudhry, & Daud (2015) estimated the dumping site by using Geographic Information System (GIS) and considered four parameters i.e. threat to the residential area, surface water bodies, road network, and fluvial sediment sequence to groundwater. There is no single study that covers all the aspects of risk assessment.

There are many computer models to assess the risks related to landfill sites like LandSim, GasSim, GasSimLite, RIP – Repository Integration Program, 3MRA – Multi-media, Multi-pathway, and Multi-receptor Risk Assessment, RockPlot 2D and, RockPlot 3D. RockPlot 2D and RockPlot 3D (RockWare, 2016) are beneficial in the geology module of the baseline study of a given landfill. "**LandSim software**" contributes only as a portion of a "total risk analysis process". The "**GasSim software",** only deals with landfill gas and does not consider the leachate measurement/analysis. Likewise, the "**HELP program**" deals with "design features of landfill" (i.e. Liners, capping) and a few other features (such as surface runoff, precipitation). It is found that unfortunately, no computer model addresses "Risk Assessment (RA)" that holistically integrates all essential factors progressively and categorically. It is also found that all the above-mentioned models are very expensive. The closest possible match of holistic model was proposed by Butt et al. (2017) but that model has several knowledge gaps like that model is still a conceptual model, not ready-to-use; its practical application was not illustrated to a real-world landfill and it only covers landfill leachate.

Thus, there is an escalating need for a more integrated and holistic environmental risk-assessment approach even for legislative purposes. This study is with the fundamental idea to develop a bespoke risk assessment approach that is readily useable thereby avoiding procurement of expensive computer software packages, which are not easily accessible for developing countries. This study aimed to carry out a comprehensive risk assessment of contaminated sites (dumping sites) by developing and applying a conceptual framework model. Based on these facts from the study area, a Conceptual Framework Model (CFM) for environmental risk assessment was developed and applied. The parameters of simplicity, effectiveness, and efficiency were the main characteristics of the model. Furthermore, this model will be adaptable and flexible for other contaminated sites. The model despite being holistic and integrated could be cheaply and swiftly applicable. The application of the framework covers holistic baseline study, physio-chemical analysis of leachate, groundwater & soil, heavy metal analysis, risk estimation, and evaluation of all the potential human health risks and ecological risk for the study area.

2. Methodology

2.1. Conceptual framework model (CFM) for environmental risk assessment (ERA)

The underlying context of the Conceptual framework model (CFM) development was based on the need for a risk assessment specifically for contaminated lands such as dumping sites. Based on the information gathered from literature review, anecdotal exchange with users and experts, it was decided that the CF development option should involve the formulation of a knowledge-based model which may find practical acceptance within the industry, consultancy services and the public sector. A systematic review was done for the development of CFM. The following factors were considered for conceptual framework development:

- Encompassing all possible characteristics of dumping sites and their characteristics
- Considering all other features and scenarios that could render a risk assessment more easily especially in context of developing world.
- User-friendly, economical, quickly applicable and easy to use.
- Encapsulates all the knowledge gaps that exist in previous studies.
- Focuses on environmental as well as ecological aspects like leachate, groundwater, soil and air.

CFM for environmental risk assessment of contaminated sites (Fig. 1) such fas dumping site has three main tiers:

1. Tier 1-Baseline Study
2. Tier 2-Hazard identification and Exposure Assessment
3. Tier 3-Risk Estimation

Tier 1 of CFM deals with Baseline Study (BS) that involves a wide range of modules and sub-modules (such as geology, hydrogeology, topography, meteorology, geography, site management, human influence). The baseline study parameter is included in CFM because BS is the most initial step in any risk assessment approach as it gathered and organized the basic information. Modules and sub-modules of baseline study depend on site-specific characteristics. The better and stronger is BS, the more effective and efficient is risk assessment.

Tier 2 of CFM deals with hazard identification and exposure assessment. This parameter was selected in CFM as literature review illustrates that it provides a foundation for ERA. The degree of exposure plays a key role for a risk to exist. In this study, hazards were identified at a pollution source, pathway and receptor.

Tier 3 deals with risk estimation. Concentration assessment (CA) of groundwater and soil was done to estimate the ecological as well as human health risk. CA is important in estimating risks because concentrations of all likely hazards are estimated. Statistical descriptions such as hazard quotient, cancer risk analysis, potential ecological risks were used to evaluate ecological and human health risks.

2.2. Selection of study area

For the application or practical demonstration of CFM, "Mahmood Booti Open Dumping Site" (MBODS) was selected as it is the oldest waste disposal site of Lahore located at 31°36033.0000 N and 74°2310.2400E (Fig. 2). It was a sanctioned dumpsite in Lahore owned by City District Government Lahore (CDGL) since 1997. The site covers an area of 32 ha.

2.3. Collection of data for baseline study

Baseline data regarding seven essential modules such as "geology, hydrogeology, topography, meteorology, geography, site management and anthropology/human influence" was collected by field survey, relevant department/ authorized organization and site inspection.

2.4. Collection & preparation of samples (water, leachate & soil)

Leachate (n = 20) and soil (topsoil) samples (n = 20) (depth of 0.5–1.0 m) were collected randomly from the 10 points, covering the entire site. Leachate samples were collected from the small leachate ponds that existed at site as MBODS did not have an appropriate leachate collection system. Water samples (n = 14) were collected from seven points located within 1500 m from MBODS covering the surroundings of dumpsite having different depths. Fig. 3 shows the map of sampling data set for leachate, groundwater

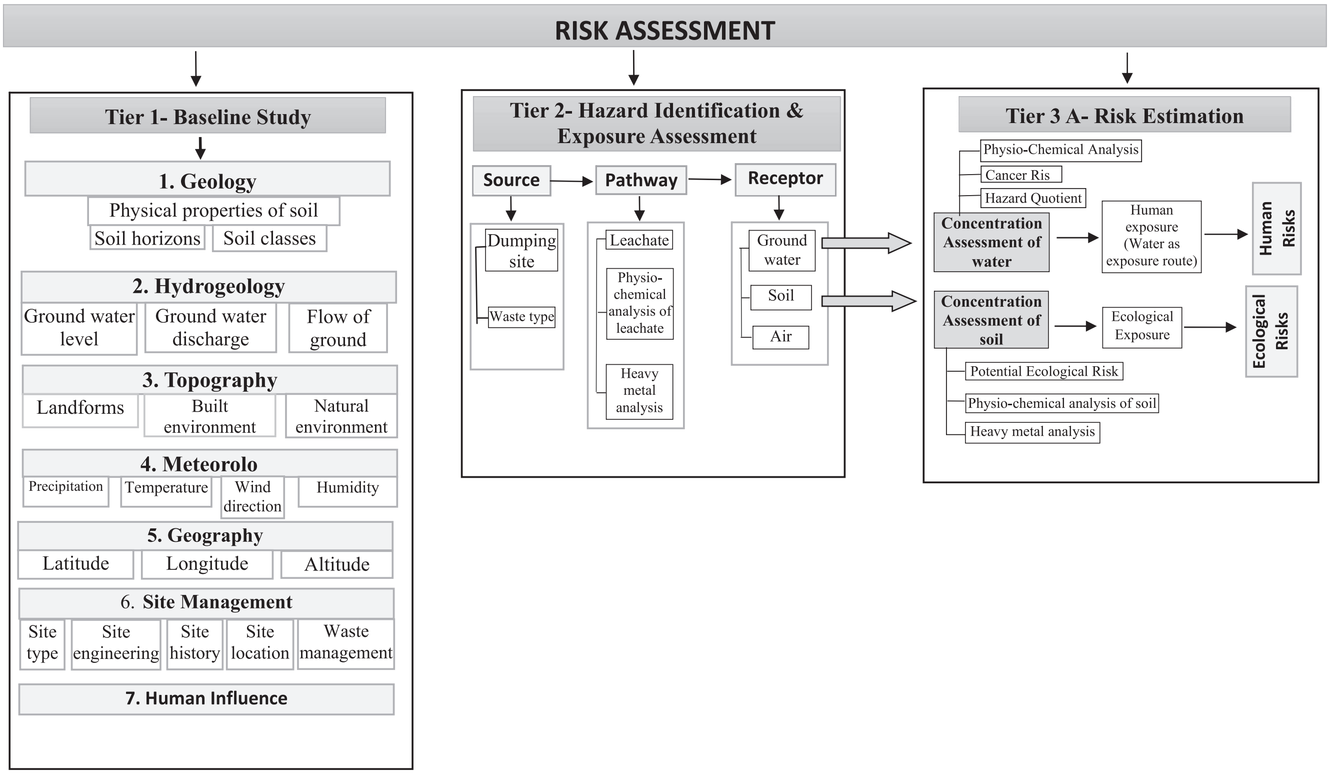

Fig. 1. CFM for Environmental Risk Assessment of Contaminated Sites.

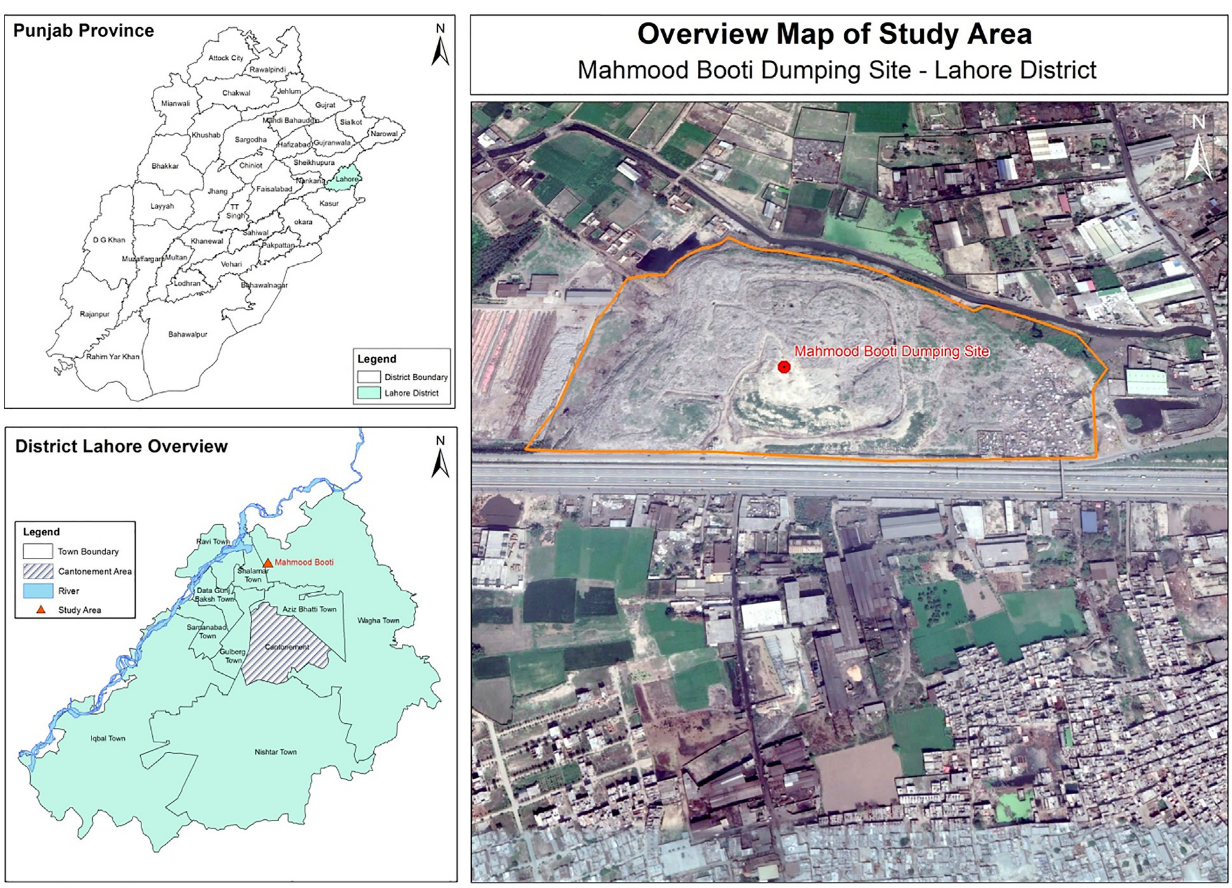

Fig. 2. GIS Map of Study Area- Mahmood Booti Dumping Site.

and soil. Each sample was kept in 1 Liter labeled pre-rinsed bottles and bags (for soil). Sampling procedure reported by (Mahmood, & Malik, 2014; Zahra et al., 2014; Aiman et al., 2016) was adopted for groundwater, leachate and soil samples collection.

2.5. Sample analysis for risk assessment

Leachate, groundwater and soil were analyzed for physico-chemical parameters and heavy metal analysis. The parameters for analysis were selected due to their importance in leachate composition and their pollution potential on groundwater resources. “Standard methods for the examination of water and wastewater” were followed for sample testing (APHA 2005). Soil, (USEPA, 2007), water and leachates (USEPA, 2007b) samples were prepared for heavy metal analysis via acid digestion method and analyzed by using atomic absorption spectrophotometer.

2.6. Human risk estimation

2.6.1. Hazard Quotient (HQ)

HQ was determined by using the formula:

$$HQ = CDI/RfD \quad (1)$$

where CDI refers to “chronic daily intake” (mg/kg day) and RfD refers to “reference dose” of the compound (mg/kg day). HQ < 1 is considered non-hazardous. Chronic daily intake (CDI) of each metal was measured with the help of following equation (ISPRA 2013):

$$CDI = [(C_{water} \times WI \times ED \times EF)/(BW \times AT)] \quad (2)$$

where C_{water} is the concentration of a pollutant in the water, WI refers to “water intake”, ED is the “exposure duration”, EF refers to “exposure frequency”, BW refers to “body weight”, and AT refers to “average exposure time”.

2.6.2. Cancer risk effect (CRE)

Carcinogenic effects on humans through ingesting contaminated water were calculated via below given formula:

$$CRE = CDI \times SF \quad (3)$$

where SF refers to “slope factor” (1/kg/mg/day), and it is the upper-bound lifetime likelihood of a person to develop cancer by having contact with a potential carcinogen (USEPA 2009). CRE < 10^{-6} was considered negligible.

2.7. Ecological risk estimation

2.7.1. Potential ecological risk index (PERI)

Risk from selected heavy metals in soil on the environment can be calculated by first determining the ecological risk coefficient (E_r^i) of a single metal and then potential ecological risk index of all metals (PERI). E_r^i of heavy metals can be determined by the formula (IRIS, 2018):

$$E_r^i = C_f^i \times T_f^i \quad (4)$$

where C_f^i is the contamination factor of the metal and T_f^i is the toxic response of the metal. However, the contamination factor (C_f^i) for each heavy metal may be calculated by the following formula (IRIS, 2019):

$$C_f^i = C_s^i/C_r^i \quad (5)$$

where C_s^i is the concentration of heavy metal in the sample and C_r^i is the concentration of heavy metal as recommended by WHO standard. $E_r^i < 40$ means low ecological risk; $40 < E_r^i \leq 80$ means moderate ecological risk; $80 < E_r^i \leq 160$ means high ecological risk; $160 < E_r^i \leq 320$, severe ecological risk; and $E_r^i > 320$ means serious ecological risk. The sum of the ecological risk coefficients (E_r^i) of all

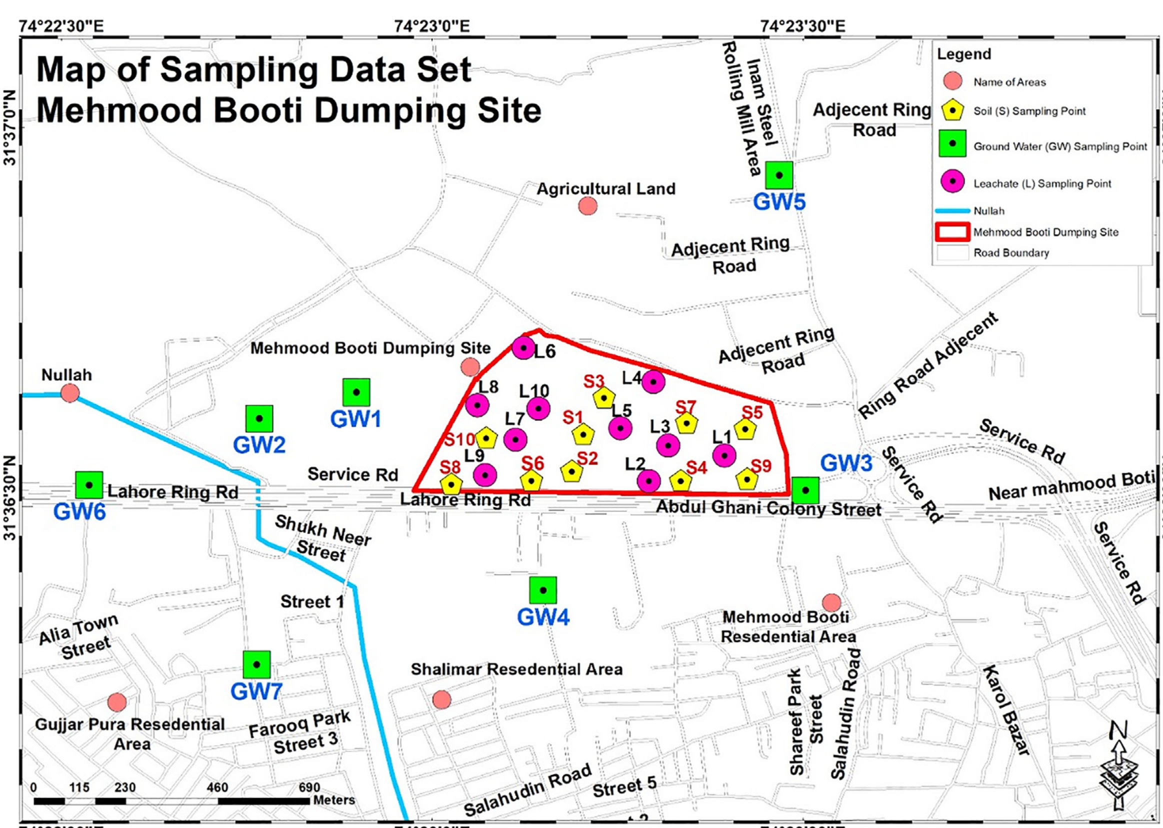

Fig. 3. Map of Sampling Data Set Mahmood Booti Dumping Site.

heavy metals was then used to determine potential ecological risk index (PERI) by the following formula (USEPA 2009):

$$PERI = \sum E_r^i \quad (6)$$

The criteria of evaluation for potential ecological risk index (PERI) are PERI < 150 means low ecological risk; 150 < PERI < 300 means moderate ecological risk; 300 < PERI < 600 means high ecological risk; and PERI ≥ 600 means significantly severe ecological risk.

3. Results

This section deals with the detailed risk assessment of Mahmood Booti Dumping Site (MBODS) by the application of the developed holistic Conceptual Framework Model (CFM).

3.1. Tier 1: Baseline study

3.1.1. Geology

Results of geological study show that MBODS consists of two clay layers i.e. 18.2 m and 3 m thick, thus the entire clay thickness is 21.2 m between surface and water table (Fig. 4). Therefore, leachate will take 7.12 days to reach the groundwater due to underlying geology. Fig. 5 shows the contours and leachate accumulation at Mahmood Booti Dumping site.

3.1.2. Hydrogeology

The depth of the water table near MBODS is 26.21 m on average, with a variation of 10.67 m between the minimum and maximum depth. The movement of groundwater beneath site is towards the residential part of the city which contains some tube wells that are in use for drinking water. "Hydrogeological data" illustrates that the "flow velocity" of groundwater ranges between 1 and 1.5 cm/-day and the direction of the "groundwater" under this site is from the "North to the South" (Fig. 6). The entire area is a part of Indus Fluvial Plain constituted by Indus River and its tributaries including River Ravi. The entire fluvial package is composed of channel belts, flood plains, levees, and back-swamp deposits. The fluvial deposits are composed predominantly of alternating sand and silty clay horizons. While sandy horizons are mostly thick and continuous, silty clay deposits occur as discontinuous layers. The aquifer is therefore regarded as unconfined. About 80% recharge of the Lahore aquifer is from River Ravi.

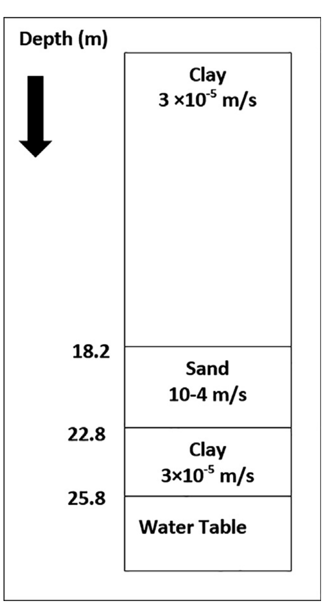

Fig. 4. Sediment Configuration of MBODS.

3.1.3. Topography

This module deals with the map of the site which helps to locate the roads, agricultural land, housing society, river, drains (Fig. 7). Approximately 9490 houses were present within the risky area of MBODS. The MBODS is 3.5 km away from the left bank of River Ravi. It is located on the left bank edge of first paired fluvial terrace of River Ravi. North of the site is mostly occupied by agricultural fields. The residential area is situated in the South of the site at a distance of about 210 m. The ground level of MBODS, the road, and the residential area here is more or less the same. However, the road is not significantly higher than the ground, thus, the road cannot play a role of a barrier between the MBODS and the population. Overall, the height of the waste heaps on MBODS is significantly higher (i.e. a few meters) than the residential area and leachate can flow from site to residential area during high rainfall.

3.1.4. Meteorology

In meteorology module, data regarding Precipitation, humidity were collected from Meteorology department of Lahore. The precipitation records of the last ten years show that the average maximum reaches during July that is 175.33 mm. Historically, the highest rainfall recorded on 13 August 2018 was equal to 221 mm (8.7 in) during 24 h (Pak Meteorological Department). The months of May, June and July are extremely hot in the study area ranging from 40 to 48 °C (104–118 °F). During the last ten years, the highest temperature was recorded equal to 48 °C (118 °F), on 9th June 2017 (Pak Meteorological Department). The average humidity in study area ranges from 42% to 83.7% during morning hours, whereas it reaches up to 93% in summers. The maximum humidity levels in study area reach two hottest months (July and August) and two coldest months (December and January).

3.1.5. Geography

Geography module covers these aspects as follows: the site lies at Latitude 31.6098, Longitude 74.3867, Elevation 210 m, in the northern side of Lahore, and it has been in use for MSW dumping from 1997 until 2016. The MBODS lies at the outskirt of City falling in Wagha Town, along the curbside of Ring Road. Initially, when it was used as dumping site, it was a faraway place from City area. Now, as the city has grown to a Metropolitan, it is the part of City as only within a short distance of 1 km, there is a thickly populated area of Gujjar Pura. Moreover, it is sharing its common boundary with the rich agricultural land.

3.1.6. Site management

Factors such as "site history, site type, site location, site design, and engineering (e.g. liners, drainage system), waste management activities, environmental monitoring, waste types, leachate type and its components" are included in site management.

City District Government Lahore owned the MBODS that was considered as the only legal site in Lahore. The site is lying in a flood plain area of river Ravi and it is 3.5 Km away from the river and it has a flat alluvial plain. The total area of the site is 633 Kanal, out of which approximately 300 Kanal was given to the Lahore Compost in 2005, through an agreement by CDGL. The remaining 333 Kanal areas have been used for waste disposal (Lahore Waste Management Company). MBODS is a "non-engineered open dumping site" as the site is not employed by bottom liners or side liners. The system for leachate collection and its proper treatment is not present at the site. The site is still active in terms of waste degradation that is not stable (Haydar et al., 2012). During operational phase of MBODS, it received about 1200–1500 tons/day of MSW and this quantity is approximately 30–40% of the overall daily MSW of

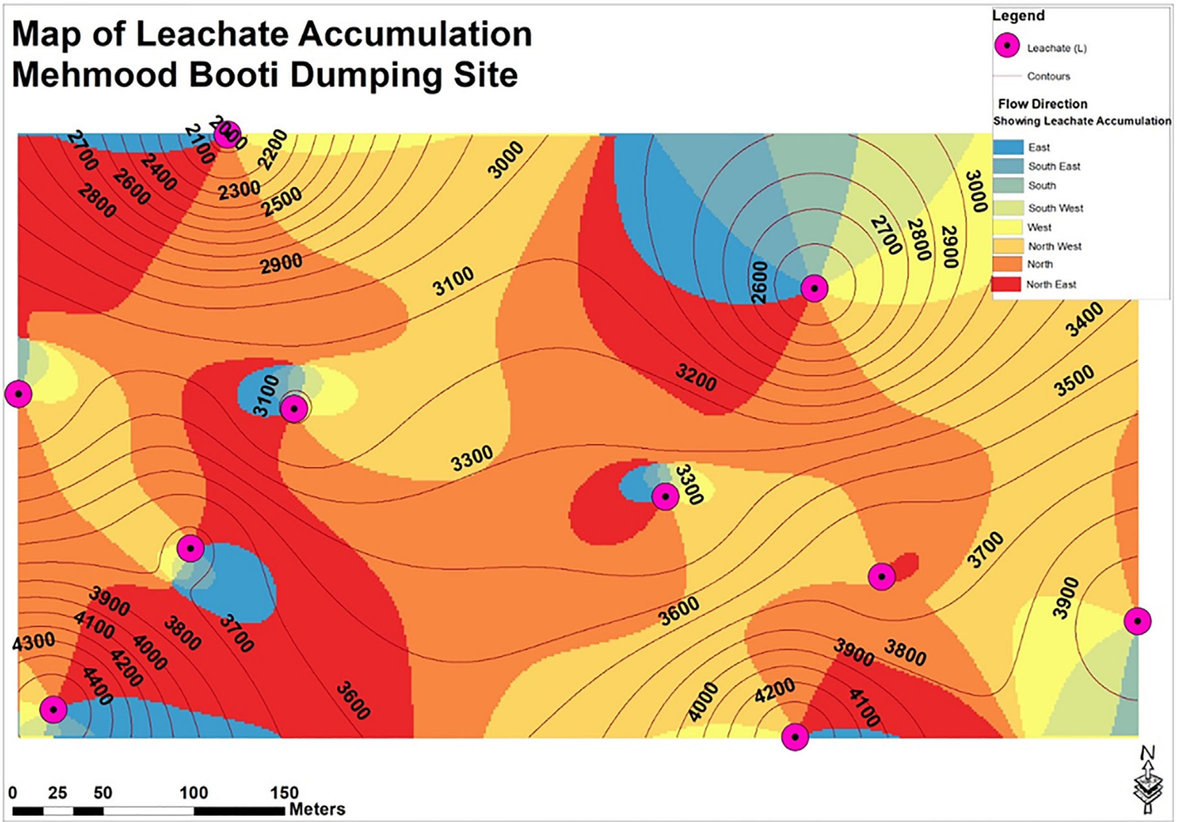

Fig. 5. GIS map of contours and leachate accumulation at Mahmood Booti Dumping Site.

Lahore. This site managed the waste collected from the major towns of Lahore such as "Shalimar Town", "Data Town", "Aziz Bhatti Town", and "Gulberg Town". Biodegradable wastes are the most dominating waste types, i.e. 63%, followed by Nylon (11.62%), Textile (9.09%), Diaper (3.11%), and Combustibles (2.12%). Site investigation illustrated that recently, in 2018, the regulatory authority (Lahore Waste Management Company) covered only front area (approximately 1 Kanal) of site with soil and small trees are planted on it to rehabilitate it but the remaining area of the site is still not properly covered. Consequently, during rainy season, the rain on solid waste may significantly escalate the generation of leachate that would ultimately find its way into groundwater bringing out "hydrogeological" contamination. It was visually observed that the dumping of waste at the site was not constant and waste was not dumped scientifically and systematically. It seems like a huge heap of waste up to a height of 20–25 feet.

3.1.7. Anthropology/human influences

All potential and possible past, present or future anthropogenic activities such as extraction and mining, groundwater abstraction, development, and construction are included in the human influences/anthropology. *For the real case of* MBODS, the quality of nearby groundwater has been demonstrated as unsafe for drinking purposes according to WHO standards (Butt and Gaffar, 2012; Mahmood et al., 2013). In Lahore, mostly drinking water is supplied by the extraction of groundwater. Therefore, protection level of the groundwater around MBODS is a significant environmental consideration. Aiman et al., 2016 illustrated that concentration of selected heavy metals (i.e., Lead, Iron, Cadmium, Manganese and Copper) exceed the allowable limits of "World Health Organization" (WHO) and "US Environmental Protection Agency" (USEPA) in water, soil, sediments of MBODS. Lead and Cadmium caused high health risks (HR > 1) to indigenous inhabitants through intake of dust and drinking water near MBODS. It was also reported that the potential risk of cancer in the study area (MBODS) due to lead is higher as prescribed in USEPA standard values via intake of water. In Lahore, the rate of groundwater abstraction is maximum and a cone-like depression has been developed that has affected the vulnerability in two ways (Mahmood et al., 2016). At first, the water table has been dropped down to the depths of more than 40 m, causing maximum score of Groundwater for MBODS. Secondly, as MBODS is situated at the periphery of the city, the consequence of leachate always moves towards the center of the city, due to the depression slope.

3.2. Tier 2: Hazard identification & exposure assessment

Baseline data helped identify hazards along with the source, pathway and receptor. In the current scenario, pollution source was dumping site itself and its waste types. The whole dumping site was a point source. Site was in the post-closure phase but the dumped waste was in the phase of degradation. MBODS is the only contamination source because no other contaminated land exists in the surrounding. (Alam et al., 2017) also supported this fact that no other dumping site lies in the neighborhood area that may be considered for the combined detrimental effect on the environment. Leachate is considered a pathway hazard because it greatly affects the receptors i.e., soil and water (Fig. 1). Leachate is a potential hazard because site does not have an appropriate collection system and leachate quantity increases during monsoon. Leachate leaches into the soil and affects the groundwater.

3.3. Tier 3: Risk estimation

3.3.1. Physico-Chemical analysis of Leachate, water and soil

Heavy metal and physio-chemical characteristics were estimated for leachate, water and soil samples from MBODS and are presented in Table 1. Results show that physio-chemical and heavy

Table 1
Physiochemical & Heavy Metal values of leachate, Water & Soil.

Parameters	Leachate			FEPA Standard (Ojoawo et al., 2012)	Water			WHO Standard (2011)	Soil			FAO (2007)
	Mean	Range			Mean	Range			Mean	Range		
		Min	Max			Min	Max			Min	Max	
pH	8.59	8.5	8.8	**5**	7.567	6.7	8.28	**6.5–8.5**	8.26	7.5	9.6	**6.5–8.5**
TDS (mg/l)	8582.75	12,170	14,480	**–**	337.7714	121	562.3	**250**	363.2	264	526	**1000**
EC (μS/cm)	3545.3	3268	3972	**125**	338.14	168	589	**250**	25.31	2.5	61.7	**300–500**
COD (mg/l)	2442.75	3200	3784	**75**	25.71	7	68	**250**	–	–	–	**–**
BOD_5 (mg/l)	818.6	1200	1720	**30**	13	6	20.8	**30**	–	–	–	**–**
Organic matter (%)	–	–	–	**–**	–	–	–	**–**	0.747	0.63	0.84	**3**
Alkalinity (mg/l)	349.25	225	298	**75**	126.57	65	250	**100**	136.8	98	186	**–**
Hardness (mg/l)	363.15	430	452	**200**	148.42	40	380	**100**	350.6	246	586	**500**
Chloride (mg/l)	218.45	230	378	**100**	108.68	35.5	270	**250**	19.16	1.8	52.2	**250**
Nitrate (mg/l)	119.5	122	175	**20**	18.95	14	30	**50**	0.0381	0.03	0.061	0.1–2.0
Phosphate (mg/kg)	202.05	80	92	**50**	6.32	0.3	10	**50**	12.622	3.125	82	10–20
Sulphate (mg/l)	159.903	300	360	**100**	24.34	9.2	42	**200**	–	–	–	–
Potassium (mg/kg)	–	–	–	**–**	–	–	–	**–**	217.6	114	385	0.075
Ni (ppm)	0.44133	0.23	0.66	**0.01**	0.148	0.028	0.361	**0.020**	3.745	0.66	7.24	0.006
Pb (ppm)	0.9113	0.59	0.646	**0.05**	0.3303	0.12	0.6879	**0.003**	2.1036	0.52	6.28	<0.001 (100mg/kg)
Mn (ppm)	0.83863	0.31	1.52	**0.05**	0.1461	0.0147	0.6243	**0.5**	2.7	0.83	4.98	–
Cr (ppm)	0.84105	0.07	1.962	**0.20**	0.1419	0.0273	0.486	**0.050**	0.0335	0.02	0.05	0.1
Cd (ppm)	0.50133	0.65	1.32	**0.01**	0.003	0.003	0.05	**0.003**	0.4745	0.025	1.38	3 mg/kg
Cu (ppm)	0.1024	0.003	0.285	**0.50**	0.4189	0.0031	0.7772	**2.00**	0.7	0.3	0.9	0.27
Zn (ppm)	0.0934	0.001	0.45	**<1**	0.0567	0.003	0.24	**0.05**	1.52	0.8	2.3	0.6
Fe (ppm)	27.9	18.6	37.2	**20**	0.058	0.013	0.15	**1.0**	14.87	9.2	20.7	–

metal parameters of leachate exceeded FEPA (Federal Environmental Protection Agency) standards. Water analysis shows that few parameters are within a permissible range. Soil analysis also elucidated the presence of contaminants in it. The physiochemical properties and the concentration of heavy metals in leachate, soil and water sample depend chiefly on the water content and waste characterization of the Municipal Solid Waste (Denutsui et al. 2012).

Municipal Solid waste is not appropriately segregated before dumping, thus, organic, inorganic, heavy metals, vegetables and other materials get through without any initial treatment. MBODS is not sheltered with clay layer to elude rainwater diffusion, due to rainy season the leachate amount increases (Haydar et al., 2012). The contaminants have transformed groundwater chemistry, and landfill leachate has a weighty contribution to it. Presently, these contaminants are part of groundwater. MBODS Landfill is not appropriately preserved, consequently, it can be predicted that contaminants will accumulate with time in groundwater. There is adulteration established in groundwater system because of mistreatment, this is one of the foremost concerns for contaminant transportation from neighborhood areas to the focal region of Lahore city.

3.4. Human health risk assessment

3.4.1. Hazard Quotient

Table 2 shows the value of hazard quotients for the heavy metals detected in water samples. Results depict that all water samples had HQ < 1 for heavy metals. It has been seen that underground flow of water at study area was from North to South, so water samples collected near to North site were less contaminated. Mahmood et al. 2013, also identified the groundwater flow in downslope region from Mahmood Booti dumping site. Fig. 6 also shows the flow of groundwater is from North to South.

3.4.1.1. Cancer risk effect (CRE). Carcinogenic effects on humans via ingestion of contaminated water were calculated (Table 3). CRE < 10^{-6} was negligible. Ni, Pb, and Cd presented a carcinogenic risk for inhabitants of the study site via intake of water. Cr demonstrated a significant non-carcinogenic risk to the residents in the vicinity of dumping site. In our study, level of carcinogenic risk for lead was matched with the previous reports from China and Thailand and it found in greater levels (Wongsasuluk et al., 2014; Zheng et al., 2013; Du et al., 2013).

3.5. Environmental/Ecological risk estimation

3.5.1. Potential ecological risk index (PERI)

Potential ecological risk (E_r^i) assessment for soil was investigated via E_r^i for each metal and potential ecological risk index (PERI) for multi-metals and findings are represented in Table 4. E_r^i level for Ni, Pb and Cd from main study site was >380 (i.e. 4744.98) which exposed a serious potential hazard to ecological entities. E_r^i of metals such as Mn, Cr, Cu and Zn was found <40, that recommended a low ecological risk for ecological entities (Table 4).

where Tri is the toxic response factor like : Pb = Cu = 5, Cd = 30, Cr = 2, and Zn = 1 (Hakanson, 1980), Ni = 5 (T and O, 2014; Izah

Table 2
Hazard Quotient (HQ) of the heavy metals detected in water samples.

Metals	Mean	CDI (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient (HQ)
Ni	0.148	0.0011585	0.02	0.057925
Pb	0.3303	0.0025855	0.036	0.718194
Mn	0.1461	0.0040027	0.14	0.028591
Cr	0.1419	0.0011108	1.5	0.000741
Cd	0.003	2.348E-05	0.0005	0.04696
Cu	0.4189	0.0114767	0.037	0.310181
Zn	0.0567	0.0004438	0.3	0.001479
Fe	0.058	0.000454	0.7	0.000649

Source of RfD values: USEPA, 2014; IRIS, 2019: Integrated Risk Information System.

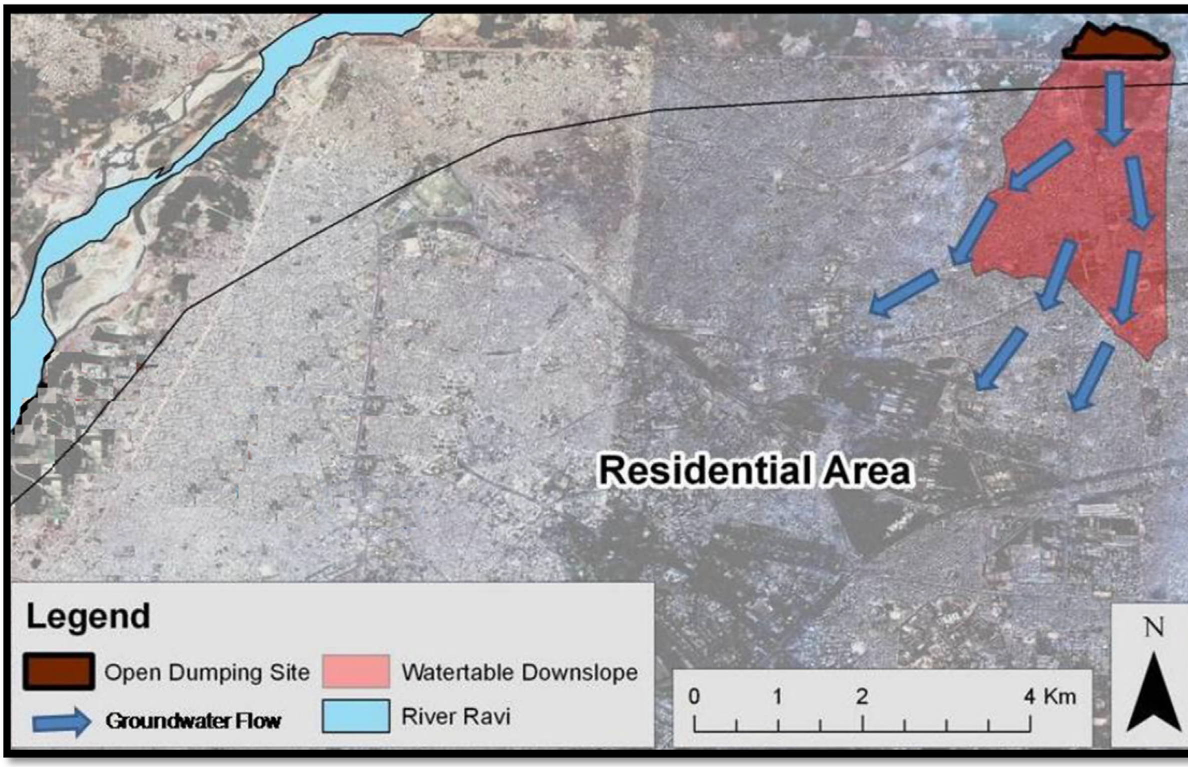

Fig. 6. Hydrogeology: Flow of groundwater at study area (Mahmood et al., 2013).

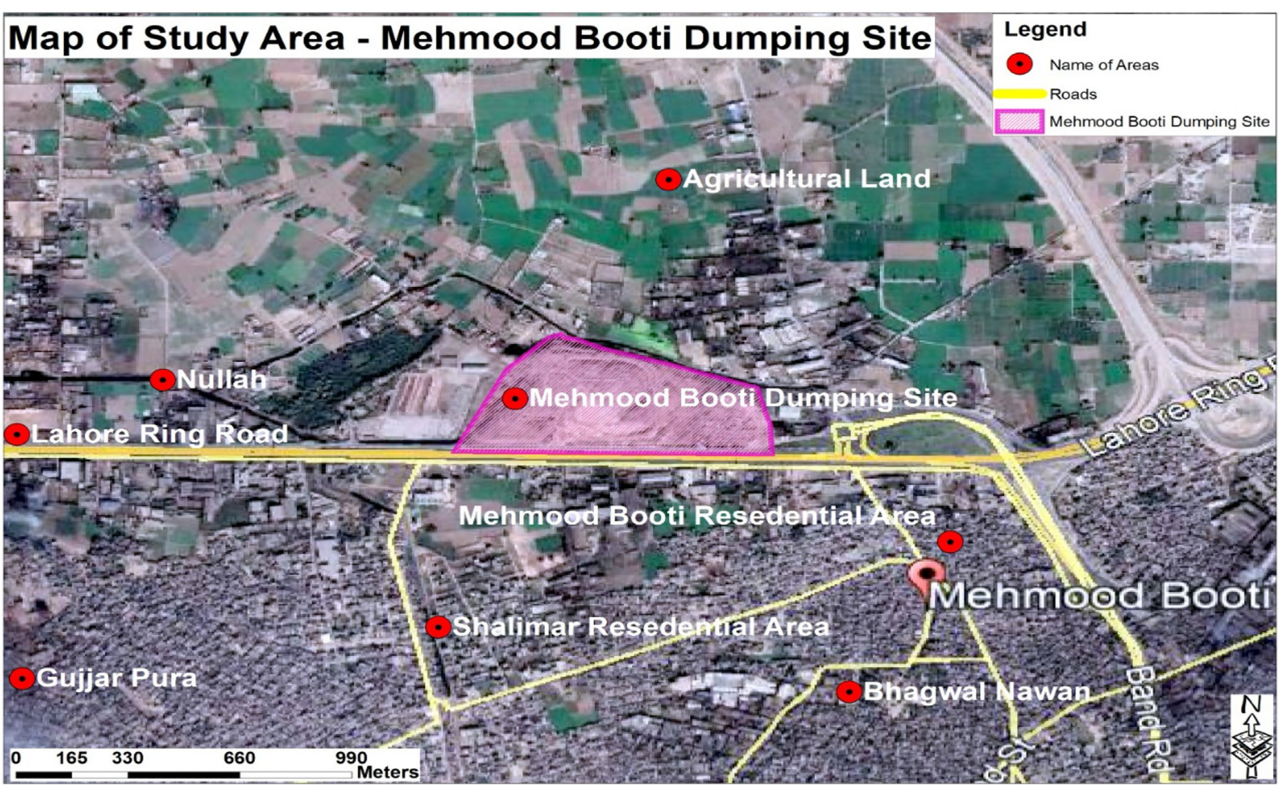

Fig. 7. Topographic Map of Mahmood Booti Dumping Site (showing roads and nearby area).

et al., 2018), and Cif is the contamination factor (PatrickIwuanyanwu and Udowelle, 2017).

All the parameters of CFM along with their estimated risk for Mahmood Booti Dumping Site are mentioned in below-given Table 5:

4. Discussion

Developed CFM for risk assessment was applied on real world existing contaminated site to show the demonstration of Conceptual framework model. It also established the holistic and compre-

Table 3
Cancer Risk effect of the heavy metals detected in drinking water samples.

Metals	Mean	CDI (mg/kg/day)	Slope Factor (SF)	CRE
Ni	0.148	0.001159	0.84	9.73E-04
Pb	0.3303	0.002586	0.0085	2.20E-05
Cr	0.1419	0.001111	0.501	5.57E-04
Cd	0.003	2.35E-05	6.3	1.48E-04

Table 4
Potential Ecological Risk Index of the heavy metals detected in soil.

Metals	Mean	Contamination Factor (C_f^i)	Toxic Response Factor (T_f^i)	Ecological Risk E_r^i	Risk
Ni	3.745	0.02	5	936.25	Serious
Pb	2.1036	0.003	5	3506	Serious
Mn	2.7	0.5	5	27	low
Cr	0.0335	0.05	2	1.34	low
Cd	0.4745	0.003	30	4744.98	serious
Cu	0.7	2	5	1.75	low
Zn	1.52	0.05	1	30.4	low

hensive risk assessment of dumping site at Lahore which will be helpful in risk management.

4.1. Baseline study of MBODS

Baseline study of contaminated site gathered and organized the basic information that is helpful in risk assessment. In the present study, geology module deals with fluvial sediment configuration to groundwater depth and other geological properties. Results regarding geology of current study is supporting the findings of Mahmood et al., 2015 that due to clay layers, leachate will take time to reach groundwater. The data regarding geology aspect can contribute to the follow-on stages of "risk assessment" in several manners. For example, geological data may illustrate the length of "unsaturated zone" of the pathway that leads from the landfill to a given "environmental receptor" (Butt et al., 2017). Geological data can also explicate "chemical reactions" that may take place between "leachate contents" and "geological materials", etc. Hydrogeological module explained ground water level, boreholes (present or not), direction of flow of groundwater and groundwater discharge Results of Hydrogeological findings of MBODS supports the facts given by (Alam et al. 2017) and (Haydar et al., 2012) that groundwater flows from North to South. Population living at South side will be more affected by consuming groundwater as compared to people living at North of dumping site. The data from this module will be helpful in the "exposure assessment stage" of a "risk assessment" in relation to identify pathways that lead from hazards to receptors. This hydrogeological information also establishes the direction of leachate flow (Butt et al., 2017). Regarding topography of MBODS, (Mahmood et al., 2016) also illustrated that residential area exists at South of site and population will be at risk from contaminated land. Meteorological findings illustrated that high precipitation during monsoon season will generate high quantities of leachate.

Table 5
CFM parameters and their related risk.

Parameters of CFM	Impact	Risk
Geology: The total clay thickness is 21.2 m between the bottom of MBODS and the water table.	Clay layers have low permeability. They scavenge the pollutants. Water was comparatively low contaminated. This phenomenon increased the soil contamination (as given in physio-chemical & heavy metals parameters)	Low
Topography : The residential area exists in the South and it stretches about 210 m distance from the site, containing 9490 houses. River is situated 3.5 km away from the site.	Residential area is not in the safe zone. Dumping site is affecting the nearby area. Landfill should not be located within 30.48 m of any stream or river. This site is in the safe zone from river.	Medium to high
Meteorology: The average maximum reach of precipitation is 175.33 mm. In the last ten years, an average of the maximum temperature found in summer 40.5 °C.	Leachate quantity increased during heavy rainfall. High temperature increased the emissions of Greenhouse Gases (GHGs) due to high rate of microbial activity.	Medium to high
Site management: It is non-engineered open dumping site. No bottom liners; No leachate collection system; No gas collection system. During operational phase of MBODS, it received about 1200–1500 tons/day of MSW and this quantity is approximately 30–40% of the overall daily MSW of Lahore.	It is non-engineered site. So, leachate is produced. Landfill Gas and particulate matter is polluting the atmosphere.	High ecological risk
Physio-chemical analysis of leachate	All parameters exceeded the standard for leachate. Leachate contaminated the soil and groundwater.	High to severe
Physio-chemical analysis of water	Majority of parameters are within range of WHO standard. It may be due to purification ability of soil.	Low risk
Physio-chemical analysis of soil	All parameters of soil were high as compared to FAO (Food and Agriculture Organization) standard value because soil is in direct contact of waste.	High ecological & human risk
Heavy metal analysis of leachate	Heavy metals such as Ni, Pb, Mn, Cr, Cd, & Fe were high as compared to FEPA standard.	High ecological & human health risk
Heavy metals analysis of water	Ni, Pb, Mn were the main metals that were detected in water samples and these metals level were high as compared to WHO standard.	Medium to high human health risk
Heavy metal analysis of soil	Ni, Pb, Mn, Cu & Zn was in high quantity in soil as compared to FAO standards	High ecological risk
Hazard Quotient	All water samples had HQ < 1 for heavy metals. Groundwater flow at study area was from North to South, so water samples collected near to North site were less contaminated.	Low human health risk
Cancer Risk Effect (CRE)	Ni, Pb, and Cd presented carcinogenic risk for inhabitants of the study site via intake of water. Cr demonstrated a significant non-carcinogenic risk to the residents in the vicinity of dumping site	Medium to high Human health risk
Potential Ecological Risk Index (PERI)	PERI is serious for Ni, Pb and Cd and it is low for Mn, Cr, Cu, Zn.	High ecological risk

4.2. Risk estimation of MBODS

Table 1 depicts that the leachate sample possesses usually high levels of pollutants. The pH value of leachate samples was determined between 8.5 and 8.8, showed the alkaline nature of leachate and it is amber in color. Because of anaerobic decomposition, low quantity of free volatile acids, as fatty acids would be incompletely ionized and it leads to high level of pH. Waste disposal of about ten years at landfills may also lead to alkaline pH of leachate (Abd El-Salam and Abu-Zuid, 2015). The comparatively high value of electrical conductivity EC (3545.3 μS/cm) shows the occurrence of dissolved inorganic constituents in the samples. The TDS levels in leachate samples were 8582.6 mg/L. BOD and COD_5 levels were high as compared to standards because of high levels of organic and inorganic pollution. Leachate indicated high hardness and alkalinity in the current scenario. Anions for example sulphate, nitrate, chloride, and phosphate (Table 1) had higher values than FEPA levels. Leachate had dark brown color and, Nagarajan et al. 2012 suggested that this dark color was generally because of the steel carp disposal into the dump site and oxidation of ferrous into ferric form.

The comparative evaluation of physico-chemical parameters for water with WHO allowable limits (WHO, 2011) elucidates that numerous factors surpassed the allowable drinking level. The pH ranges from 6.7 to 8.2 which was within WHO limit. It designates that water of studied region is somewhat alkaline. Alike outcomes were described by Butt and Gaffar 2012. The electrical conductivity (EC) is an indicator that represents the amount of dissolved substances in water. The EC values exceeded as compared to WHO standards in few water samples. Higher EC levels are mainly due to dissolved matter of inorganic salts, acid and bases (Raju 2012). The range of COD in water samples was 7–68 mg/l and BOD_5 in the range of 6–20.8 mg/l**.** The TDS ranged between 121 and 562.3 mg/l which is in the WHO allowable limit. Excessive amounts of dissolved solids (TDS) may affect the individuals having kidney and heart diseases and it can also cause gastrointestinal diseases (Mendoza, et al., 2017). It may also lead to high turbidity (Akinbile and Yusoff 2011). The alkalinity levels in MBODS' water varied from 65 to 250 mg/l. Bali and Devi, 2013 evaluated that alkaline water is may be due to the existence of compounds of carbonate, bicarbonate and hydroxide of Ca, K, and Na. In current samples, 380 mg/l was the highest value of hardness. Hardness chiefly denotes the deposition of Ca or Mg ions though it does not lead to any serious health issue but existence of Mg and Ca ions might preclude water from forming leather with soap, producing interference in the financial management of water resources (Majolagbe, Adeyi, Osibanjo, Adams, and Ojuri, 2017). The chlorides levels in water samples ranged from 35.5 to 270 mg/l and these were in the allowable standard limit but the occurrence of chlorides deduces pollution, so treatment has been required before its consumption (Ali and Yasmin, 2014). The levels of nitrate vary from 14 to 30 mg/l, and it exists within permissible levels of WHO limits i.e. 50 mg/l. Aerobic decomposition of organic nitrogenous matter results into nitrates and it mainly found in surface and ground waters and are measured as reasonably oxidized form of nitrogenous substances. Phosphate and Sulphate levels fall within WHO limits. The chief cause of phosphate manifestation in groundwater is primarily because of industrial wastewater, domestic sewage, detergents, and fertilizers through agricultural runoffs (Han et al., 2014).

The pH of soil samples showed the alkaline nature of soil. Organic Matter (OM) mean value was 0.747%. The recurrent accumulation of simply decomposable organic deposits initiated the production of multifaceted organic composites that keep soil particles into structural elements refer as aggregates. These aggregates facilitate keeping a loose, open granular situation. It makes water capable to enter and percolate downward via soil with waste matter (Abd El-Salam and Abu-Zuid, 2015). Nitrogen and chloride values were lower than the FAO standard value. Nitrogen is imperative as a significant component in protein formation (macromolecule) that is a chief constituent of the nucleus and protoplasm. Nitrogen supply is vital for the utilization of carbohydrate. Deficiency of nitrogen leads to the deposition of carbohydrate in non-reproductive cells resulting in a condensed cell wall. Nitrogen conjointly governs the use of potassium, phosphorous and further components (Aigberua and Tarawou, 2018). Excess nitrogen can enhance the majority of fodder crops and may detain maturing in cereals and it leads the crop at risk for fungal attack. Yellow color of foliage and lack of growth may be seen due to Nitrogen shortage. In this study, phosphorus varies from 3.125 to 82 mg/kg. Low values of obtainable phosphorus showed that there's no component of domestic wastes like soaps, and detergents present in the dumpsite (Sohail et al., 2017).

4.3. Ecological risk estimation

Findings for PERI from main waste dumping area >380 (i.e., 9247.2) revealed a serious risk to ecological entities. Cadmium reflected a significant high risk to ecological integrities as compared to other metals among inspected metals. Heavy metals like Pd, Cd, Zn, Cu, and Ni can alter the soil chemistry and may impact the plants and organisms that are soil-dependent for nutrition. Risk to the soil is one of the fundamental environmental problems related to the dumping sites (Parth et al., 2011). Subsequently, the waste disposed of directly onto the soil, pollutants comprising heavy metals freely penetrate and greatly affects the soil and also disturb the abundant vegetation of the area (Pastor and Hernández, 2012; Li et al., 2019). Disposal sites are sources of ecological risks because of leachate production and its migration via waste (Gworek et al., 2016).

5. Conclusions

This research is based on the fact that there does not exist any holistic and integrated risk assessment model that encapsulates all the aspects/factors which are required in the risk assessment exercise. The existing computer models are non-integrated and expensive as expertise are required to learn about them.

This paper provides a detailed holistic risk assessment of MBODS which is helpful in risk management. Risk assessment of study area shows that the leachate from dumpsite had contaminated the groundwater and soil. Physico-chemical analysis reveals that disposed waste altered the soil fertility. In the current study area, pollutants and heavy metals at source (dumping site itself), pathway (leachate) and receptor (water and soil) were also detected. E_r^i value for Ni, Cd and Pb from study area demonstrated a serious potential risk to ecological entities whereas E_r^i value for Mn, Cr, Cu and Zn suggested a low ecological risk. Likewise, findings for PERI from dumping site established a serious risk to ecological components and nearby inhabitants. Cadmium & lead cause non-carcinogenic health risks to human. Reported levels of heavy metals exceeded WHO allowable values. The MBODS is at post- closure stage but still, it is a latent source of toxic contaminants to the nearby population. Therefore, it is suggested that waste management and its proper disposal should be up to the mark and effective so that the harmful effects would be minimized. There is a need for proper authority to further monitor closed dumping areas/sites along with remediation procedures. Proper environmental sanitation procedures in addition to government policies on SWM and its disposal should be legislated and stringently imposed.

The framework in this paper can be reproduced for other landfills/ dumping sites in other parts of Pakistan and likewise other developing countries. In conclusion, this paper has established the Conceptual Framework Model (CFM) for risk assessment exercise and environmental risk management, which is cost-effective, holistic and operatively simple.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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