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Baseline study in environmental risk assessment: site-specific model development and application

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Abstract: Environmental risk assessment is one of the key tools in environmental engineering. This risk assessment can be qualitative or quantitative and it is based on preliminary studies i.e., baseline study for waste disposal sites. Even though the literature exists on baseline study in general, still there is a lack of guidance regarding development of a site-specific baseline study model for a waste disposal site. This study has two-fold aim, firstly, how to develop site-specific baseline study model for a selected dumping site, and secondly, how this site-specific baseline study can support the environmental engineering via mathematical risk estimation. Mahmood Booti Open Dumping Site (MBODS) is selected to demonstrate the development and application of site-specific baseline study model. This is followed by building a framework that shows how the output of the baseline study can lead to environmental engineering via mathematical risk estimation. The paper provides a mechanism of how to construct a bespoke baseline-study model that is readily useable, avoiding procurement of expensive computer software and yet smoothly connecting with the follow-on stages of the risk assessment. The work presented in this paper can be reproduced repeatedly to create site-specific baseline study models for risk assessment of other waste disposal sites in a cost-effective, consistent and cohesive manner.

Introduction

At national and global level, industrial revolution, urbanization and increasing trend of population not only increase our standard of living but also result in greater quantities of waste generated. Waste management and its proper disposal in landfills/open dumps are one of the major environmental issues that pose hazards and risks to the environment and human health. Landfill/dumping sites are harmful for the environment along with all three principal spheres, i.e., hydrosphere, lithosphere and atmosphere (Szymanski et al. 2016; Butt et al. 2019; Jagod, 2018; Mahmood et al 2020). However, despite this fact and the faith in sustainability, landfill is the least preferred option. It is still a typically most applicable waste management option, not just in Pakistan but around the globe in developed or developing countries because of its simplicity and quick waste disposal.

However, in order to ensure that landfills meet environmental standards, a detailed environmental risk assessment exercise is required. In some countries, it is legislative requirement, as in the UK (Regulation 15 of Waste management regulation). Developing countries also have legislation regarding environment and waste management. Environment was considered as a provincial subject in constitution of Pakistan in 2012. According to Policy and Regulation on SWM Pakistan 2010, it is reported that there are five stages in the process of establishing solid waste and landfill facility and the following aspects must be considered at each stage: 1. The need for having disposal facility 2. Appropriate site selection for solid waste disposal 3. Installing, commissioning, and operating solid waste disposal and landfill facility 4. Monitoring, evaluating, and reporting of solid waste disposal and landfill facility 5. Cessation of landfill facility. Establishment guidelines organized the rules and regulations viz, Pakistan Environment Protection Act (PEPA) 1997, Guidelines to prepare and review National Environmental Quality Standards (NEQS), Policy and Regulation on SWM Pakistan, 2010).

Risk assessment (RA) is an essential part of risk management such as in financial risk management, credit risk management, engineering risk management, and other aspects; it plays a significant decision-support role for risk managers to adopt reasonable risk prevention measures and strategies (Mahmood et al., 2015a; Mahmood et al., 2014b; Zhang et al. 2016). The infrastructure of developing countries is highly vulnerable and also highly interconnected (Vrabel et al. 2015; Smol et al. 2020) so risk assessment and management plays a very crucial role in managing resources. However, for a risk assessment to be valuable, it needs to be based on a strong preliminary examination that is generally called baseline study. This is because the information gathered in the baseline study is used as an input to subsequent stages of the risk assessment process (Mahmood et al 2014b; Mahmood et al., 2015b; Butt et al. 2017).

Environmental Risk Assessments are progressively being practiced in landfill areas at planning, operational and completion stages (Butt et al. 2016atmosphere, hydrosphere and eventually adversely impact the biosphere. Therefore, environmental risk assessment of a landfill has to be more integrated and holistic by virtue of its nature of being a multidimensional pollutant source. Despite this, although various risk assessment approaches have been adopted for landfill waste disposal sites, there are still wide--ranging knowledge gaps and limitations which need to be addressed. One important knowledge gap and limitation of current risk assessment approaches is the inability to fully identify, categorise and aggregate all individual risks from all combinations of hazards, pathways and targets/receptors (e.g. water, air, soil and biota; Butt et al. 2014; Environment Agency, 2011). For this resolution, a baseline study requires to be more integrated than ever, mainly when environmental regulations are playing a pivotal role in the employment of risk assessment. Thus, primarily in the case of landfills, the baseline study requires interpreting a broad range of disciplines, i.e., hydrogeology, geology, and hydrology (Butt et al. 2017). Landfill setup characteristics may differ extensively from one to another concerning landfill, their management practices and their surrounding situations like diversity of pathways and receptors, etc. So, a comprehensive holistic risk assessment system is needed to summarize all potential factors, characteristics and aspects under one umbrella/roof so that risk assessors could be able to elucidate what has not been included and why. A holistic baseline study can be commendably beneficial to provide assistance to solving concerns of discrepancy and lack of holism in RA.

Background and Problem statement

Environmental engineering can be regarded as a practical site for risk management, whereas risk assessment is very crucial. In other words, output of risk assessment information as an input to environmental risk engineering. The knowledge gap in previous studies is that there is a lack of relationship between baseline study, mathematical risk estimation and environmental engineering.

An environmental risk assessment cannot be holistic, integrated, and effective without a correspondingly holistic, integrated, and effective baseline study. This is because the data and information come from the baseline study, which is the preliminary, initial, first stage of the entire risk assessment process. However, rendering a baseline study holistic, integrated, and effective can be a cumbersome, difficult, and expensive exercise. For a given landfill risk assessment, it is not easy to establish how to carry out a baseline exercise that is cheaper, simple, and still sufficiently holistic and effective. Despite all the information in the relevant literature, whether these are computer-aided models or non-computer methodologies, there are no guidance and exemplary case studies that could assist in deciding what to include and what to exclude from a site-specific baseline exercise. Therefore, the site-specific baseline study is just appropriate in depth and breadth, which is neither insufficient and yet not unnecessarily deeper and broader than required. This is termed as knowledge gap and this research paper emphasizes this.

This study has a two-fold aim, firstly to develop a specific baseline study model for dumping sites. Secondly to establish a relationship between baseline study, mathematical risk estimation and environmental engineering. This study also demonstrates how based on the available approaches in the relevant literature to date, a site-specific Baseline Study Model (BSM) can be designed and developed and then applied to a real-world landfill/dumping site. The idea is the ability to design, develop and apply such a site-specific BSM for any given landfill risk assessment is economical, simple, less time-consuming, sufficiently effective, and requires less or no software usage skills. Thus, this paper will provide an opportunity that is more productive for developing countries where resources are relatively short and limited. The aim was accomplished via the following key objectives:

- Review the relevant literature on landfill risk assessments and investigate computer-aided approaches, particularly in connection to baseline study.
- Identify the most holistic and integrated baseline study approaches that can more readily be transformable into a site-specific baseline study model.
- Select an appropriate real-world landfill/dumping site to demonstrate the process of transformation into a site--specific baseline study model.
- Collate appropriate data regarding the selected landfill/dumping site and then apply this data to shape and refine the site-specific baseline study model.
- Develop the relationship between baseline study, mathematical risk estimation and environmental engineering.

Methodology

State-of-the-Art of Baseline study

A review of the literature regarding computer models reveals the absence of a software model for Risk Assessment (RA) that holistically integrates all essential factors progressively and categorically (Butt et al. 2016). The main factor that is absent in all computer aided models is baseline study itself which is the main emphasis of this recent study.

Following is the list of computer-aided models for risk assessment and baseline study;

1. LandSim (Environment Agency, 2003),
2. HELP – Hydro-geological Evaluation of Landfill Performance (Scientific Software Group, 2012)
3. GasSim (Golder Associates, 2016),
4. GasSimLite (Environment Agency, 2011),
5. RIP – Repository Integration Program (Landcare Research, 2003),
6. 3MRA – Multi-media, Multi-pathway, and Multi--receptor Risk Assessment (EPA, 2004)

In the above-mentioned list, the first four computer software packages are precisely planned for landfills, though the features of RIP (number 5 above) were consequently extended to take landfills into account on a large scale and 3MRA (number 6 above) is not only for landfills but also for other waste management problems. Some other computer software have been also investigated but they are not specifically related to landfills, and may be used to fortify some of the features of landfill risk assessment. For example, RockPlot 2D and RockPlot 3D (RockWare, 2016) are beneficial in the geology module of the baseline study of a given landfill, which subsequently can be of assist in the risk assessment approach.

The above-mentioned six software packages do not holistically summarize numerous factors of risk assessment and particularly the baseline study for landfill. For instance, the LandSim software which is purely for landfill RA, does not propose a whole risk assessment system. It may contribute only as a portion of a total risk analysis process (Robinson, 1997). The GasSim software only deals with landfill gas and does not consider the leachate measurement/analysis. Likewise, the HELP program encompasses only a few features of landfill risk assessment. It mainly contains design features of landfills (i.e. Liners, capping) and a few other features such as surface runoff, and precipitation. These models are expensive. The cost of LandSIM model student version is £425+ 20% VAT (94519 PKR) and for commercial purposes, its cost is £850 + 20% VAT (189038 PKR). The cost of GASIM for commercial use is £1000 (193,291 PKR) while for academic users (no helpdesk facility) is £250 (48,322 PKR).

Non-computer aided approaches are also studied specifically for the perspective of a baseline study of landfill risk assessments. A review of the literature illustrated that there is no holistic model for baseline study for landfills that contains all the aspects and factors in a systematic manner except (Butt et al. 2017), and his study proposed a holistic conceptual model for risk assessment and baseline study that covers all the parameters in a comprehensive, algorithmic and a sequential way. In the present study, the baseline study part of holistic conceptual model for risk assessment proposed by (Butt et al. 2017) is adapted to cater to specific characteristics of a real-world contaminated land/landfill scenario. This is with the fundamental idea to develop a bespoke baseline model that is readily useable thereby avoiding the procurement of expensive computer software packages, which are not easily assessable for developing countries. Furthermore, there is no single computer model that deals with the all the eight modules and their sub-modules, thereby requiring multiple computer software packages to address wide-ranging aspects of the baseline study.

Site-Specific Baseline Study Model (BSM): Designing and Development

Butt et al. (2017) anticipated the eight essential modules for a holistic conceptual baseline study model. The following framework (Figure 1) for baseline study was adopted and adapted after (Butt et al. 2017) according to characteristics of the given scenario, i.e., Mahmood Booti Dumping Site (MBODS). This current framework covers seven modules instead of eight, as hydrology element is merged into other appropriate factors of BSM as follows. The atmospheric aspects of hydrology such as precipitation are addressed in meteorology, whereas ground-related hydrological aspects such as groundwater table and its flow are addressed in the hydrogeology section.

The methodology that was selected to apply is holistic and integrated but it is not a ready-to-use or off-the-shelf model. Thus, it was not applied as it is and it required a considerable amount of adaptation around a specific landfill scenario. Furthermore, it is a conceptual framework, therefore, has to be adapted around the characteristics of a specific landfill.

Even though it is holistic and integrated, it is still indicative and does not cover or provide a full account of all eventualities. The indicative contents of Butt et al. (2017) model were applied and transformed into site-specific BSM as per information and data available specific to the study area.

Site-Specific Baseline Study Model (BSM): Application

Description of Study Area

Lahore is located between longitudes 74.012° E to 74.641°E and between latitudes 31.24°N to 31.751°N with an elevation range of 143 to 159 m above MSL (Mean Sea Level). Lahore is the second largest city in Pakistan having an area of 1,772 square kilometers. Lahore district is bordered on the north and west by the district of Sheikhupura, on the east side by the country of India (international border) and on the south by Kasur district (Muhammad and Zhonghua, 2014; Ahmad et al. 2012, Alam et al. 2017). Mahmood Booti Open Dumping Site (MBODS) is the oldest municipal disposal site of Lahore located between 31°36033.0000N and 74°2310.2400E; 3.5 km away from the River Ravi (Figure 2). It was an authorized dumping site in Lahore owned by City District Government Lahore (CDGL) and a Turk company Oz Pak since 1997. The study area is located on a territory of 32 ha (Alam et al. 2021a).

Data collection

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.

Data Application in Conceptual Model

After collecting data, it was applied in the baseline conceptual model. Baseline data and information was collected/stored systematically and categorically in an organized and standardized format and this information will be helpful in the next stages of risk assessment. The seven modules of the site-specific BSM mentioned in Figure 1, particularly prepared for MBODS, can now be used to inform the follow-on stages of risk assessment when it is carried out in future. Below is a succinct account in the form of a Table 1 which contains information on the parameters of the site-specific BSM.

Relationship between Baseline study, Mathematical Risk Estimation and Environmental engineering

The use of risk assessment and management in the legislation requires an accurate quantitative determination of risk,

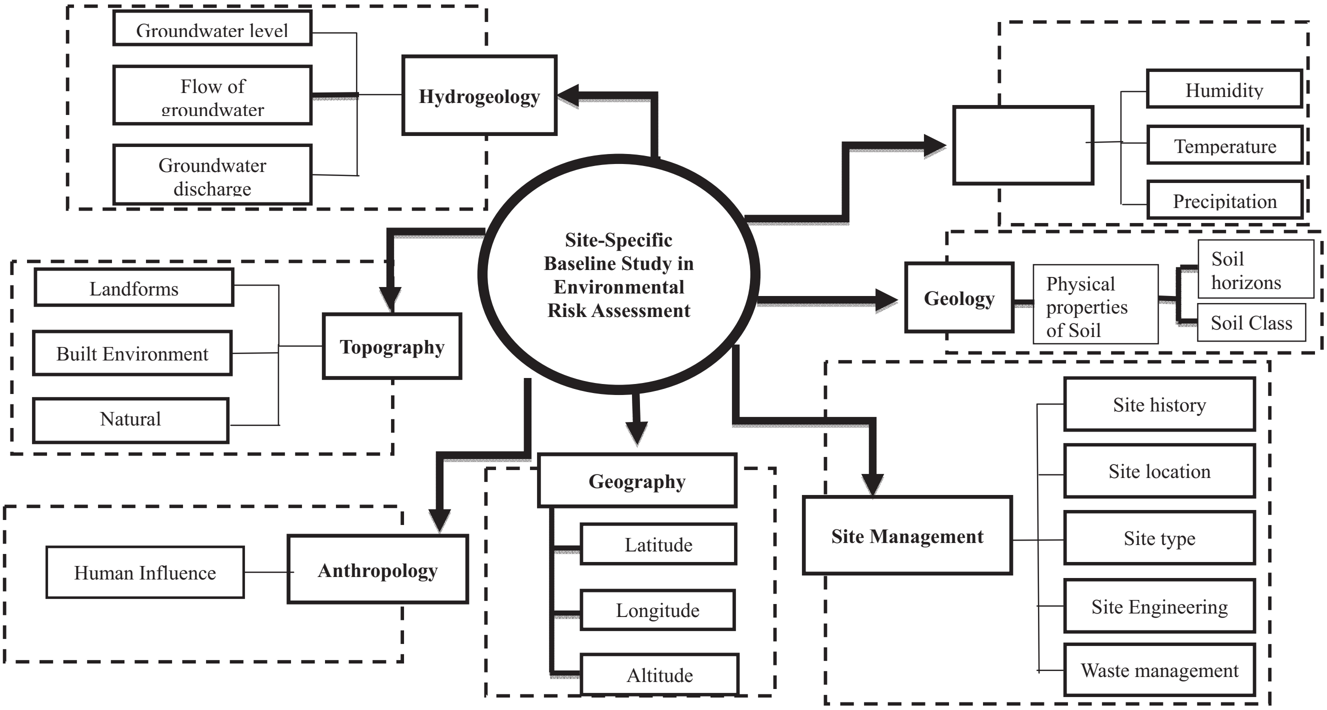

Fig. 1. Site-specific holistic baseline conceptual mode

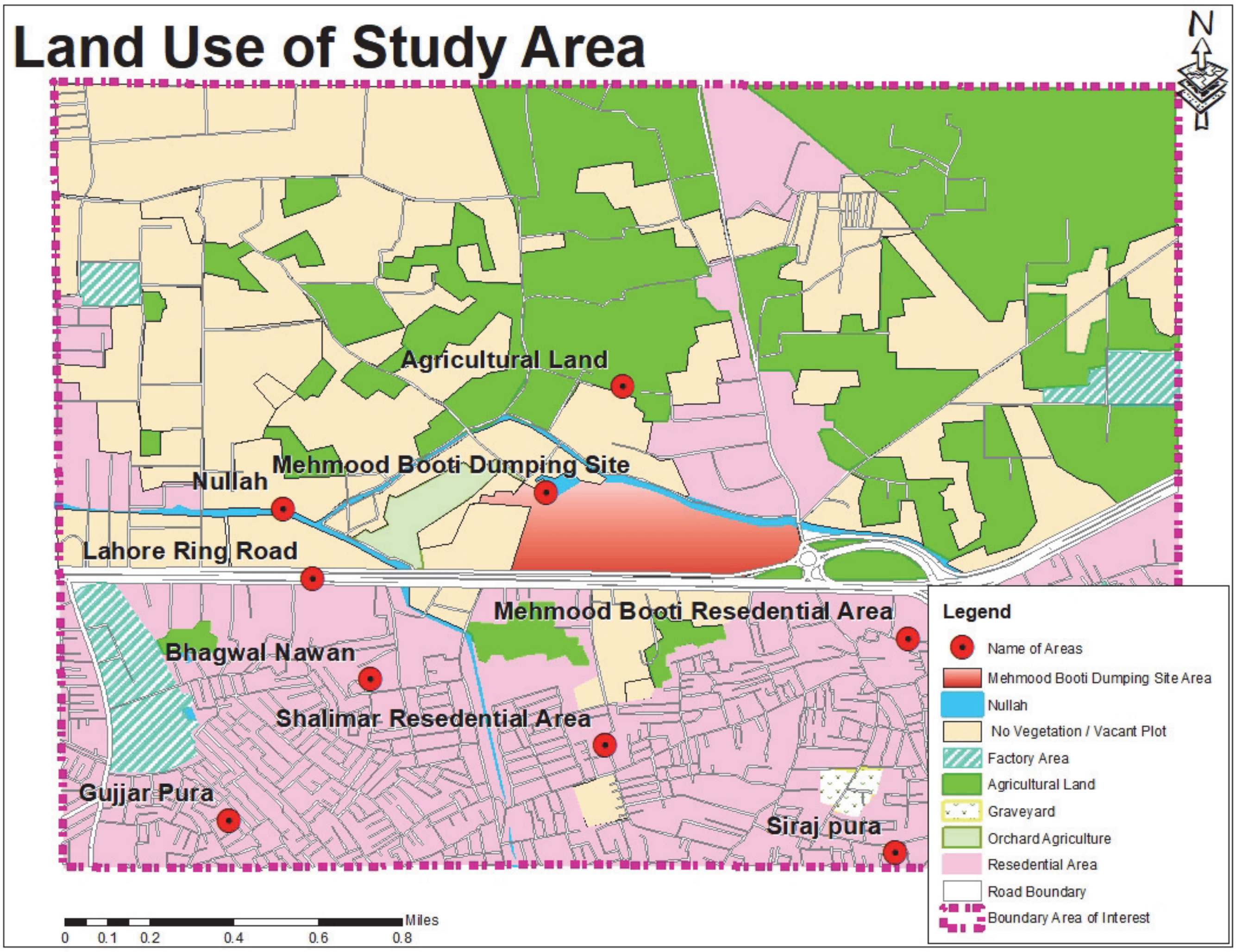

Fig. 2. Map of study area and its land use

Table 1. Practical Demonstration of BSM and its role in Risk Assessment (RA)

Relevant features from the Baseline Study CONCEPTUAL model of Butt et al., 2017	Application of Site-Specific Baseline Study Model (BSM) on MBODS	Follow-on Risk Assessment Stages (Site-specific Examples)
Geology ● Earth materials ● Configuration ● Properties ● Classification	**Geology** ● **Earth Materials and Configuration** The site consists of two clay layers, i.e., 18.2 m and 3m thick, thus the total clay thickness is 21.2 m between the bottom of MBODS and the water table. These two clay layers are separated by that of the sand 4.6 m (see Figure 4) ● **Physical properties and Classification** Soil Horizons (AP (0–11 cm), CB (11–23 cm), C1 (23–43 cm), C2 (43–66 cm), C3 (66–90 cm), C4 (90–19 cm), C5 (119–138 cm), C6 (138–162 cm), C7 (162–180 cm); Soil classes (Loamy, silt loam, sandy loam, silt loam, very fine sandy loam, loamy very fine sand)	**Exposure Assessment in RA:** In Exposure Assessment, the identification of pathway with its individual links is a crucial stage of the RA. In the site-specific case, the total thickness of the unsaturated zone of the pathway can be quantitatively measured by adding the individual thicknesses of two clay layers and one sand, i.e., Total unsaturated zone of the pathway = Top clay thickness + Sand layer + Second clay thickness Total unsaturated zone of the pathway = 18.2 + 4.6+ 3 Total unsaturated zone of the pathway = 25.8
Hydrology ● Atmospheric waters ● Lithospheric waters	● The **atmospheric aspects** of hydrology such as precipitation are addressed in meteorology module. ● The **lithospheric aspects** such as groundwater table and its flow are addressed in the hydrogeology modules.	Not applicable
Hydrogeology ● Groundwater level ● Groundwater flow ● Groundwater direction	**Hydrogeology** ● **Groundwater level** The average depth of the water table is 26.21 m, with a variation of 10.67 m between the minimum and maximum depth. ● **Groundwater flow** The "flow velocity" of groundwater ranges between 1–1.5 cm/day. ● **Groundwater direction** The direction of the ground water under this site is from the "North to the South".	The information regarding Hydrogeology, topography and meteorology would be useful in the stages of **Migration Assessment** and exposure assessment of RA as follows: ● The groundwater flow is from North to South, indicated in hydrogeology module, therefore, the contaminants of leachate in the groundwater are not flowing in the direction of the river but opposite. ● Therefore, population is exposed to leachate contaminants via the groundwater consumption. ● As indicated in topography, ground levels are more or less the same between the population and MBODS levels, therefore during heavy rainfalls, in particular, the contaminated surface water/leachate can run off the waste heaps into the residential area which is just 210 m away. The population would be dermally exposed to this hazard. ● High temperatures particularly in summers which may creek up to even more than 40°C (and in future even higher due to climate change) would contribute to the escalation of leachate evaporation, not to mention the landfill gas would also next with the open atmosphere which have odor as well. Thus, the wind, which blows in different directions during the day and seasons of the year, would carry the airborne contaminants and odor from the landfill to the population in the area around the clock. In this case the exposure medium is the polluted atmosphere and the exposure route is respiration.
Topography ● Built environment (e.g. residential areas and human populations, groundwater abstraction well) ● Natural environment (e.g., water bodies like rivers)	**Topography** ● Built environment: with reference to Figure 4, the residential area exists in the South of MBODS which is nearly across the road that separates the site and the human population. This area stretches from about 210 m distance from the site, further in the South, containing 9490 houses. Some of the population source water for human consumption from the groundwater wells which exist within the residential area. ● Natural environment: river is situated 3.5 km away from the site as shown in Figures 4b & 5.	
Meteorology ● Precipitation ● Temperature	**Meteorology** ● **Precipitation** The average maximum reach of precipitation is 175.33mm. ● **Temperature** In the last ten years, an average of the maximum temperature found in summer (May to September) is 40.5°C and average of the minimum temperature found in winter (November to March) is 7°C.	

Geography ● Latitude ● Longitude ● Altitude ● Site location	Geography ● Latitude (31.6098) ● Longitude (74.3867) ● Altitude (210 m) ● The site lies in the North of the city Lahore.	For the hazard's concentration assessment stage of the RA, the survey strategy and sampling techniques (including location, spread, and the like) can be informed by the site-specific geographical parameters indicated in the left cell of the Table.
Site Management ● Site type ● Site Area ● Site engineering ● Site history ● On-site waste management practices	**Site Management** ● **Site type** It is an open dumping site. The site contains municipal solid waste and a limited degree of construction waste. ● **Site area** The total area of the site is 633 kanal. ● **Site engineering** Its non-engineered open dumping site. No bottom liners No leachate collection system No gas collection system **S● ite history** The MBODS commenced operations for the receipt of waste in 1997 and closed for the receipt of waste in 2016. ● **On-site waste management practices** 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.	● The hazard identification and categorization stage of the RA can be informed in terms of leachate quantity and quality as follows: ✓ The area of the site and the precipitation/rainfall per year can be used to calculate leachate quantity. ✓ The quantity and composition of waste in MBODS would inform about the estimation of leachate quality. ● Since the site is without liners, therefore there is no man-made barrier between the leachate at the bottom of the waste heap and the natural ground, thereby the leachate percolates the ground more readily. This information will be helpful in the migration assessment stage of the risk assessment.
Human influences ● Groundwater abstraction and consumption	**Anthropology/Human Influences** ● Groundwater is used in the following ways: ✓ For local industry use ✓ For domestic use: drinking/ingestion, shower/dermal and other domestic activities by the nearby population.	This information can assist in the **Significance Assessment Stage** of RA as follows: Industrial use of contaminated water may be not as harmful as for the domestic uses. However, this needs to be further investigated, when the follow-on stages of RA would be carried out.

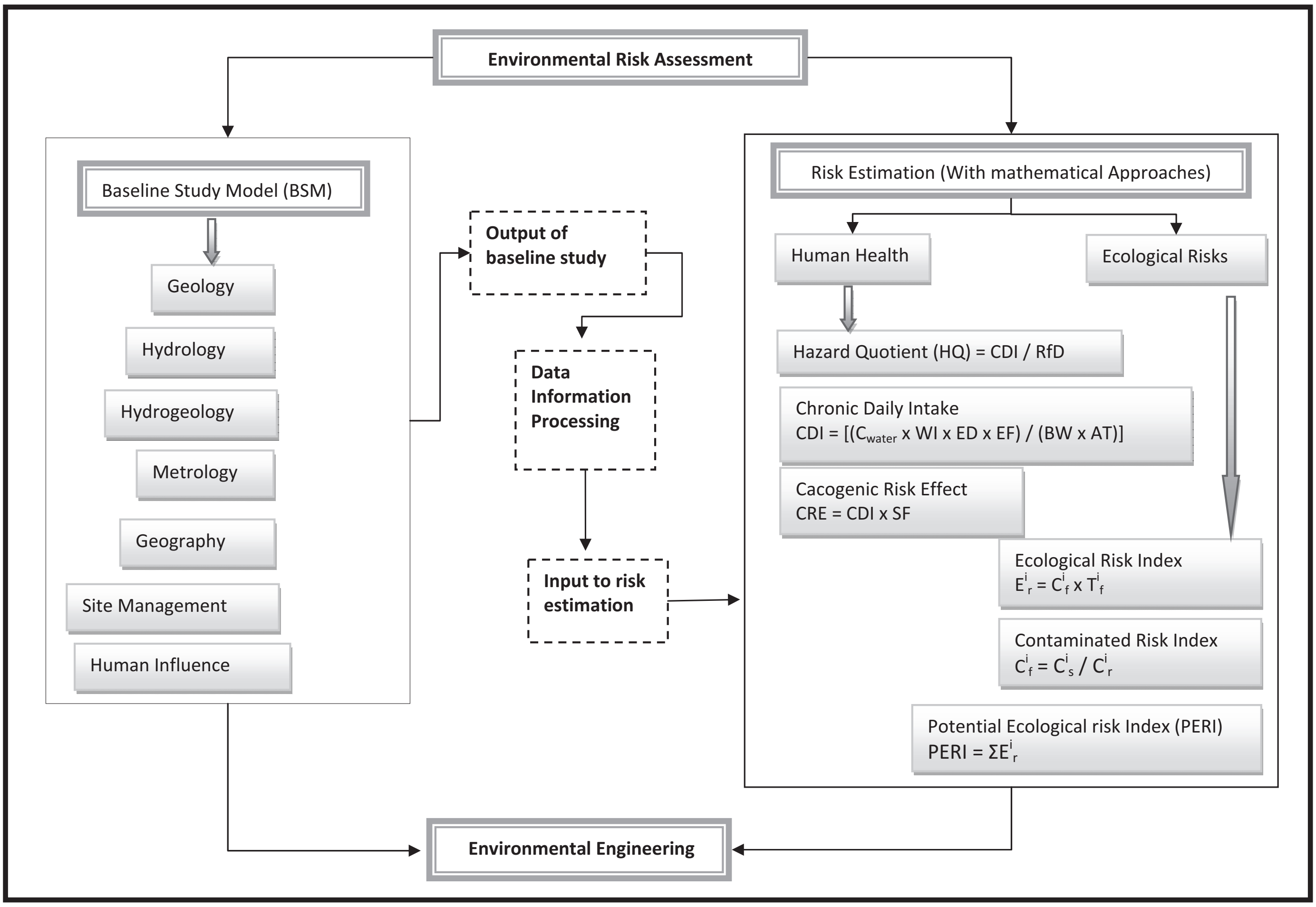

Fig. 3. Framework of Relationship Between Baseline Study Model, Mathematical Risk Estimation and Environmental Engineering

therefore, mathematical risk estimation is essential to quantify the risk. The output of Baseline study is the input of Mathematical risk estimation. Figure 3 illustrates that there are two kinds of risk: Human Health risk and ecological risk. The following equations will be used to determine human health and ecological risks.

Hazard Quotient (HQ) for Human Health Risk

HQ was determined by using the formula:

$$HQ = CDI / RfD \tag{1}$$

Where:
CDI is Chronic daily intake (mg/kg day); RfD is reference dose (mg/kg day).
HQ < 1 is considered as non-hazardous. Chronic daily intake (CDI) of each metal was measured with help of the following equation (Smol et al. 2020; ISPRA 2013):

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

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.

Cancer Risk Effect (CRE) for Human Health Risk

Carcinogenic effects on humans through ingesting contaminated water were calculated via the formula given below (USEPA 2009):

$$CRE = CDI \times SF \tag{3}$$

SF = Slope factor (1/kg/mg/day)
CRE < 10^{-6} considered as negligible.

Potential Ecological Risk Index (PERI) (for Ecological Risks)

Risk from selected heavy metals in soil on the environment can be calculated at first by determining the ecological risk coefficient (E^i_r) of a single metal and then potential ecological risk index of all metals (PERI). E^i_r of heavy metals can be determined by the formula (Singh et al. 2018; Alam et al. 2021b)

$$E^i_r = C^i_f \times T^i_f \tag{4}$$

where C^i_f is the contamination factor of the metal and T^i_f is the toxic response of the metal. The contamination factor (C^i_f) for each heavy metal may be calculated by the following formula:

$$C^i_f = C^i_s / C^i_r \quad (5)$$

where C^i_s is the concentration of a heavy metal in the sample and C^i_r is the concentration of a heavy metal as recommended by WHO standard.
E^i_r <40 means low ecological risk;
40 < E^i_r ≤80 means moderate ecological risk;
80 < E^i_r ≤160 means high ecological risk;
160 < E^i_r ≤320, severe ecological risk;
E^i_r >320 means serious ecological risk.

The sum of the ecological risk coefficients (E^i_r) of all heavy metals was then used to determine potential ecological risk index (PERI) by the following formula (USEPA 2009):

$$PERI = \Sigma E^i_r \quad (6)$$

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;
- PERI ≥ 600 means significantly severe ecological risk.

Applications of these mathematical equations were not in the scope of current study.

Concluding Remarks

This research results from the fact that there does not exist any holistic and integrated baseline study model that encapsulates all the aspects/factors which are required in the follow-on stages of a risk assessment exercise. The computer models that exist are non-integrated as they address different aspects of the baseline study, i.e., geology, hydrogeology and the like, one at a time, but none integrates all the aforesaid aspects as a one-unit computer model. Regardless of the fact that computer models are non- integrated, they are not economical either as they consume time to be learnt and therefore require experts. On the other hand, non-computer aided approaches of baseline study have also been investigated. The closest possible match has been Butt et al. 2017 and that is still a conceptual model, not ready-to-use or off-the-shelf. Still, this conceptual model has to be adapted for a given scenario of a real-world landfill.

This paper has also demonstrated the relationship between baseline study, mathematical risk estimation and environmental engineering. The output of baseline study is an input of risk estimation. Mathematical risk estimation is very important for risk assessment and management in environmental engineering.

The illustration 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 baseline study as a crucial part of the risk assessment exercise and environmental risk management, which is cost effective, holistic in nature and operatively simple.

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