QUANTUM GIS BASED SUITABILITY ANALYSIS FOR EFFECTIVE PLANNING OF SOLID WASTE MANAGEMENT OF KATHMANDU VALLEY

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Abstract

Due to unplanned urbanization and rapid increase in population, solid waste management has become a global problem. Improper site selection for waste disposal can cause various economical, morphological and environmental losses as well as adversely impacting human habitat. Waste disposal sites are an easier and economical solution for the solid waste management of urban places. Kathmandu valley has been generating thousand metric tons of garbage on a daily basis which will overtake the carrying capacity of current disposal site in the near future. So, Kathmandu valley was selected as the study area to assess alternative waste disposal site here. Among many methods, Geographic Information System (GIS) in integration with Multi-Criteria Decision Analysis (MCDA)–based Analytic Hierarchy Process (AHP) method has proven to be one of the effective ways. MCDA based AHP method in QGIS was done for the determination of waste disposal sites. Quantum GIS software is a free and open-source GIS software. QGIS permits free modification to carry out complex and specialized operations. The study aims to identify the suitable site for waste disposal such that effective management of waste can be obtained using FOSS-Geo QGIS. In this study, eight criteria were considered, among them seven were factors and one was constraint. The factors included distance to water bodies, distance to road, distance to settlement area, slope percentage, soil type, geology and land-use and the constraint included national park. The standardization of the criteria was done by reclassification in order to use a common scale of measurement. The weight for each criteria was obtained from the AHP pairwise comparison matrix. The normalization of the weightage was performed and the consistency ratio of 0.064 was obtained which validated the consistency of the matrix. The result of the study is suitability map indicating low-suitable to high-suitable areas with restricted areas included. 8% of the total study area lies in the restricted area and about 1% of the total area was found to be suitable for waste disposal. Almost all of the study area has been found to be unsuitable for waste disposal so, waste disposal site for Kathmandu valley must lie outside the valley. The use of QGIS in spatial analysis for the effective identification of the suitable waste disposal site minimizes the environmental risk and aid in a better world for the future generation. Such analysis helps to advocate the use of FOSS in geoinformatics.

Keywords: GIS, MCDA, Waste Disposal, QGIS, Geospatial Technology, FOSS

1 Introduction

Lack of appropriate solid waste management system, unplanned and increasing urbanization and increase in population has resulted in problems in selection and management of proper solid waste dumping sites in developing countries (Zehra et al., 2019). Land filling of the waste without applying any particular techniques is a traditional method for the solid waste management which is still prevalent in developing countries (Kumar et al., 2014). Municipal solid waste management has been a major global problem. In the UK, out of 400 million tonnes of waste each year, 35 million tonnes is municipal waste (Koshy et al., 2007). As per an article published in The Himalayan Times on July 17, 2016, Kathmandu Metropolitan City transported 300 tonnes of garbage daily to the landfill located at Okharpauwa.

Kathmandu valley has an approximate population of 2.54 million and has population growth rate of 6.5% per year which imples that it is one of the rapidly growing metropolitan cities in South Asia (Timsina et al., 2020). Kathmandu valley consists of three districts of Nepal i.e. Kathmandu, Bhaktapur and Lalitpur. Bhaktapur Municipality has satisfactory results in the city's sanitation however, dumping and spreading of waste and covering with a thin layer of soil in several locations is common practice there (Ranjit et al., 2019). For Lalitpur and Kathmandu, all waste is disposed at Okharpauwa landfill site which is located 43km from Kathmandu according to Solid Waste Management Service Improvement Plan (SWM SIP).

Improper ways of waste disposal may cause serious damage in human health and deterioration of environmental constituents. Selection of appropriate solid waste disposal sites should take many considerations such as cultural, environmental, social, spatial, etc. For the manipulation of such data, GIS technology can be useful which allows users to store, process, analyze and handle big data both spatial and non-spatial (Kumar et al., 2014). Use of GIS along with Multi criteria evaluation (MCE) enhances the decision making process as it provides environment for collecting, managing and organizing large number of spatial and attribute data (Malczewsku, 2004). MCE allows users to make best choice among several criteria which makes it a widely accepted tool. GIS helps to perform operations such as buffer, overlay, reclassification, etc. and MCE helps to weight criteria based on their priority and subjective values (Christian & Macwan, 2017). Analytical Hierarchy Process (AHP) can be an effective and practical method while making decisions where different criteria with different units need to be considered (Triantaphyllou & Mann, 1995). This research will use Free and open source GIS software i.e. Quantum GIS for analysis, manipulation and display of spatial and attribute data and AHP for determining the suitable waste disposal site for the Kathmandu Valley of Nepal. Free and Open Source Software (FOSS) are those kinds of software which provide users freedom to run, program, study about the mechanism of the process, share the copies and edit and modify the program as per their needs and requirements (Free Software Foundation, 2021).

2 Literature review

Most number of world population resides in urban areas. To accommodate growing population, the infrastructures of urban areas should be suitable for a healthy living (Ramaswamy & Madakam, 2013).

Waste management has influence on social, economic and environmental factors. Migration of people from rural to urban areas has caused increase in solid waste generation. Various factors such as population demographics, amount of waste produced, and related stakeholders should be considered by authorities for solid waste management (Ahmad & Kim, 2020). It is necessary to manage waste in smart manner, be up to date about situation about waste collection and provide timely information about waste data to concerned authority. The waste management should be efficient and smart so that there is real time notification to the stakeholders about when to collect waste, type and amount of waste generated by population. Considering this factors, a cloud based waste management system was suggested by Aazam et al. (2016) in their study. They have suggested to equipp waste bins with sensors, which keep track about level of waste in them and update the status to cloud. This helps in easy access to data and plan for optimum route for waste collection.

Ravi & Jawahar (2017) had incorporated the idea of big data management by using technologies like Internet of Things (IoT) for solid waste management. They suggested developing portals for solid waste processing which takes classified information about solid waste. They had proposed algorithm for classification of the waste in which waste are classified into dry, wet and hazardous categories. This helps concerned stakeholder to determine if the waste are to be reused, recycled or disposed.

Akther et al., (2016) proposed solid waste generation, collection, separation and reduction handling model through their study. They identified all the waste generation sites within their study area i.e. area under the jurisdiction of Rajhdhani Unnayan Kartipokkho of Dhaka. They scored the waste sites based on their proximity to various sites such as hospitals, mosques, residential areas, etc and performed the data management, analysis and display using ESRI ArcGIS 10 software.

In the Indian socio-economic and regulatory condition, a GIS based environmental decision support system for solid waste management was developed by (Yadav, 2013). He considered geology, groundwaret depth, water supply well points, hydraulic conductivity, land-use/land-cover, slope, drainage pattern, roads and airport locations as criteria and AHP for weighing them. He used suitability index 0-10 which was generated using weighted linear combination and classified that into excluded, less preferable, suitable and best suitable categories. The study helped to identify suitable solid waste disposal sites which helped in minimun negative effects on enviroment and public health.

Using GIS and Remote Sensing (RS) technique, Zehra et al., (2019) investigated for suitable site for municipal solid waste management in Jacobabad city in 2019. They considered environmental, social and technical factors such as land use/ land cover, distance from residences, proximity to road, school, health facilities, reservoirs, railways, parks and flood susceptible areas as factors for determining suitable sites. They used Landsat 8 image to create land use/ land cover map. They further suggested to conduct geotechnical and hydroecological analyses to finalize suitable site obtained from study.

For the purpose of providing alternative solid waste disposal site in the Guwahati Metropolitan Area, India, in 2020, Hazarika & Saikia used GIS based MCDA-AHP method. They considered seven criteria namely land use, slope, elevation and proximity to wetlands, rivers, road and airports and categorized the area into most suitable, highly suitable and moderate, low and least suitable for waste disposal. In this research, they had emphasized on problem faced by low and middle income cities for proper waste management waste.

Kumar et al. (2014) integrated RS with GIS based MCDA with AHP for selection of suitable solid waste disposal site in Lucknow, India. They used India topographical map sheets, satellite images of IRS-1C/1D LISS-III 23.5 m resolution and IKONOS satellite's 1m resolution data. For multicriterion layers preparation, landuse/ landcover, geomorphology, soil texture, surface water bodies, habitation, transport network, slope and ground water were considered. They illustrated the capacity of Remote Sensing data for the preparation of multi criteria layers and thematic map and their analysis through their research.

Since Nigeria was having serious issues regarding improper dumping of solid waste, in 2015, Ngumom & Terseer used Spot5 satellite image, DEM, ground control points collected by GPS and topographic map to identify suitable sites for waste disposal. They used RS technique, Arc GIS along with MCA for the study. The study suggested very low, low, moderate and highly suitable areas for solid waste disposal considering drainage, river, elevation, settlements, important places and roads as factors.

Sindhu & Manickam (2018) performed raster analysis in Quantum GIS using several data like land-use, land cover, distance from road, lake, river, urban and rural settlement to identify suitable waste disposal site in Thiruwallur District, Tamilnadu. After assigning weights and ranks to all factors they prepared final suitability map for waste disposal site categorized into highly suitable, moderately suitable, least suitable and not suitable area.

Randazzo, et al. (2018) researched in Sicily of Italy to test a methodology of GIS based MCDA to identify suitable landfills for Municipal solid wastes. They divided the study area into restricted and potential sites for landfill and later reevaluated the potential sited by MCDA method as per eight criteria i.e. geology, gydrogeology, land use, land slope, distance from road, residential areas, protected areas and wind direction as per weight estimated by AHP. They concluded that GIS based MCDA provides powerful tool in order to identify suitable areas for landfill.

3 Method and materials

3.1 Study area

Kathmandu Valley (Kathmandu, Bhaktapur, Lalitpur) extends from 85° 11′ E to 85° 33′ E longitude and 27° 24′ N to 27° 49′ N with an area of 933.18 km^2 as shown in figure 1. It is a bowl-shaped valley surrounded by Nagarjun, Phulchowki, Shivapuri and Chandragiri Hills. The total population of Kathmandu valley is 2,517,023 (CBS, 2014). The centralization of various facilities such as education, medical, governance, economy and other productive activities has led to rapid population growth in Kathmandu valley (Dong & Karmacharya, 2018). The altitude of the study area varies from 420m to 2828m from the mean sea level (m.s.l).

3.2 Software used

Various software is available for collection, management, analyzing, presenting and dissemination of geospatial data. In this study, Quantum GIS was used. QGIS is a free and open source software (FOSS). Although both proprietary commercial software and open source GIS software are available, use of FOSS- Geo in researches seems to be comparatively less. Use of FOSSs can solve the problem of copyright licensing and purchase cost. QGIS allows viewing, editing and analysis of geodata as well as preparation and export of maps. Being an open source software, it permits modification freely to carry out complex and specialized operations. Different kinds of spatial operations such as raster to vector conversion, vector to raster conversion, buffer, Euclidean distance, reclassification, union, weighted summation were performed on QGIS.

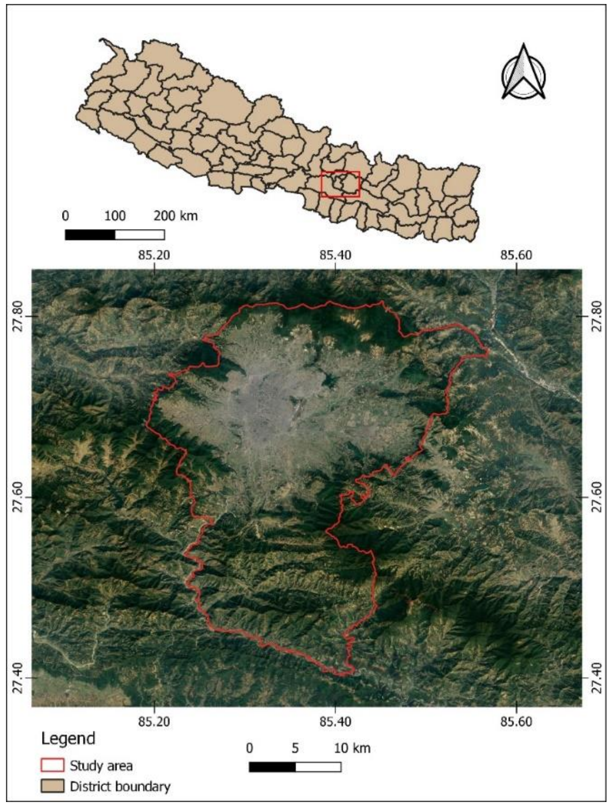

Figure 1: Location of the study area

3.3 Data and sources

In order to generate the criteria layers in QGIS, data from various sources were sought (table 2). For the evaluation, eight criteria were considered, among them seven were factors (road network, water body proximity, settlement proximity, slope, geology, soil and landcover) and one was constraint (national park). The data were projected into EPSG:32645 - WGS 1984 UTM Zone 45N. The vector criteria layers were transformed into raster data and all the raster data were resampled with 30m spatial resolution.

Table 1: Geospatial data used in the study

Factor	Description	Type	Source
Road	Transportation facilities e.g.: Main highway, roads	Vector	ICIMOD
Water	Drainage system which includes streams, rivers	Vector	Humanitarian Data Exchange
Settlement	Residential sites	Vector	Open Street Map
Slope	Rising or falling surface in percent	Raster	Humanitarian Data Exchange
Geology	Physical structure of the earth based on water absorptivity	Vector	ICIMOD
Soil	Fertility of the surface	Vector	SOTER
Land-cover	Type of land covered by surface e.g.: forest, barren area, grassland and so on	Raster	ICIMOD
Protected area	Conserved area for natural and ecological values	Vector	ICIMOD

3.4 Criteria description

3.4.1 Road network

The proximity to road should be taken into consideration as it represents the accessibility to the disposal site itself. According to Kazuva et al. (2020), the waste disposal site should neither be too far as it will result in excessive transportation costs, nor it should be at the site where landfill vehicles interfere with the normal vehicular traffic. Thus, a low suitable score was assigned at a distance less than 500m and it was followed by high suitable score at a distance greater than 500m.

3.4.2 Water body proximity

The waste disposal site near the water bodies should be avoided in order to prevent from contamination (Hazarika et al., 2020). Considering the environmental health of the water body, the site which is at a distance more than 2000m was assigned to be highly suitable.

3.4.3 Settlement proximity

High importance is attributed to settlement proximity for the waste disposal site. Various problems to human health may arise if the waste disposal site is located near settlement area or at least there will certainly be presence of unpleasant odors. Hence, direct distance of settlement proximity was taken into account, assigning distance less than 2500m to be unsuitable.

3.4.4 Slope

Slope is one of a crucial factor for selecting the waste disposal site because very steep slopes will result in high excavation costs. Digital Elevation Model (DEM) was used to compute slope percentage of the study area on the pixel basis. The slope of less than 10% was assigned to be highly suitable.

3.4.5 Geology

The geological map of the study area has various rock formations. It was categorized on the basis of permeability to determine the regions which would make the groundwater more susceptible to defilement by leachate. The geological feature having less permeability was considered to be highly suitable.

3.4.6 Soil

Global Action Programme (GAP) states that the fertile soils ought to be maintained a strategic distance in any engineering projects to be carried out to develop land and water resources (Yesilnacar & Cetin, 2005). Therefore, the soils were classified in terms of fertility where high fertility was assigned as unsuitable for waste disposal site.

3.4.7 Landcover/Landuse

The land cover and use includes the natural and human landscape which may be effected by the menaces imposed by landfill adjacency (Ebistu & Minale, 2013). Examining the characteristics of land coverage, barelands and grasslands were considered as suitable sites.

Table 2:Factors for selection of waste disposal and their rank

Factors	Classes	Rank
Distance from road (m)	<500	1
	>1500	2
	1000-1500	3
	500-1000	4
Distance from water body (m)	<1000	1
	1000-1500	2
	1500-2000	3
	>2000	4
Distance from settlement area (m)	<1500	1
	1500-2500	2
	2500-3500	3
	>3500	4
Slope (%)	>20%	1
	15-20%	2
	10-15%	3
	0-10%	4
Geology	High permeability	1
	Moderate permeability	2
	Low permeability	3
	Least permeability	4
Soil Type	Eutric REGOSOLS/CAMBISOLS, Chromic LUVISOLS	1
	Humic/Chromic/Ferralic CAMBISOLS	2
	Gleyic CAMBISOLS	3
	Dystric REGOSOLS	4
Landcover	Water bodies	1
	Built up area	2
	Agriculture area/forest/shrubland	3
	Barren area, grasslands	4

3.4.8 Protected area

The protected area is the constraint in this study which includes Shivapuri National Park. The waste disposal site located within 750m buffer from its surrounding was taken as restriction.

3.5 AHP for factors organization and analysis

The factors were superimposed with AHP, which is one of the widely used MCDM tool for processing multiple important objectives and weighting the criteria (Ozkan et al., 2019). The AHP allows to assign a priority among various alternatives and integrating multidimensional measures into a single scale of priorities (Saaty, 1980).

The pair-wise comparison was carried out with nine-point scale value which includes values 9, 8, 7, 6...., 1/7, 1/8, 1/9, which indicates 9 as extreme preference, 7 as very strong preference, 5 as strong preference and so on down to 1 which represents no preference. The preference data were collected from various literatures corresponding to the hierarchical structure. Thus, the pair-wise comparison aids to simplify the criteria by evaluating the independent contribution of each criterion with each other. The square matrix was organized for pairwise comparisons of various criteria (Bhushan & Rai, 2004).

The principal eigenvalue and their corresponding eigenvector was developed among the relative importance within the criteria from the comparison matrix. The weights for each element were generated from the normalized eigenvector. The subjective judgment from AHP were checked via consistency index. The consistency index (CI) was calculated as:

$$CI = (\lambda_{max} - n) / (n - 1) \qquad (1)$$

Where CI = Consitency Index

λ_{max} = maximum eigenvector of the matrix

n = order of the matrix

After comparing CI with random index, Consistency Ratio (CR) was derived from their ratio. The consistency ratio should be ≤ 0.1 (Saaty, 1990). The pairwise comparison is assumed to be inconsistent if the CR exceeds the threshold, the process has to be reviewed in such case. The random index for this study was 1.32 for 7 order of matrix and the computed λ_{max} was 7.511, generating the consistency index of 0.085. The matrix was found to be consistent as the CR was 0.064. However, the different experts might have distinct judgment when the factors are compared in pairs.

The final step involved multiplying each factors by weight and aggregating them to determine global rating. In this regard, the rating scale of 1 to 4 was considered that indicates 1 as unsuitable, 2 as least suitable, 3 as suitable and 4 as highly suitable. The suitability was evaluated by weighted summation of factors which is expressed by given formula (Hwang & Yoon, 1981).

$$S = \Sigma\, Wi\, Ci \qquad (2)$$

Where, Wi = relative importance of weight given to the factors

Ci = criteria

The restriction model was prepared for the national park. The national park and its surrounding up to 750m was taken as a restricted site which was indicated by Boolean expression where 1 was taken as non-restricted site and 0 as restricted site. Eventually, the application of FOSS-Quantum GIS aided in overlay analysis of suitable factors and constraint to produce the final suitability map with various suitability levels.

4 Result and findings

4.1 Generation of criteria maps

Data were obtained from different sources as shown in table 1. Spatial operations such as clip, buffer, euclidean distance and reclassification were performed to obtain the criteria maps. Area of high suitable, suitable, least suitable and unsuitable as per each criteria is illustrated in table 3.

Out of total study area, about 56% area fall under unsuitable category in regards to water body because there are rivers like Bagmati, Bishnumati, Dhobi khola, Hanumante khola, Manohara khola which dissect the Kathmandu valley. 21% of the study area was found to be highly suitable for water body proximity factor. Similarly, most of the area in terms of road proximity and settlement proximity was found to be unsuitable for waste disposal because with the rapid increase in population growth, the settlement and road infrastructure have been tremendously established. Only 2% of the total study area lie under suitable and highly suitable in settlement proximity for waste disposal. Considering the slope factor, 34% of the total area fall under highly suitable category as Kathmandu valley is a valley itself which means there is low area land between hills. There is very less area that has highly suitable site for waste disposal based on soil type because most of the area of Kathmandu valley has Silty Clay soil which are composed of intermediate sized particles that makes it fertile (KC & Dahal, 2020). Likewise, only 8% of the extend of study area is highly suitable, followed by 12%, 24% and 54% as suitable, least suitable and unsuitable respectively. In the context of land cover, most of the area was found to be suitable for the waste disposal site.

Table 3: Area coverage of different factors

Factors	Unsuitable	Least suitable	Suitable	Highly suitable
Distance from water body	56%	14%	9%	21%
Distance from road	39%	18%	17%	27%
Distance from settlement area	96%	2%	1%	1%
Slope	53%	6%	7%	34%
Soil	47%	32%	20%	1%
Geology	54%	24%	14%	8%
Land cover	1%	18%	78%	2%

4.2 Generation of suitability map

The final suitability map was analyzed by overlaying suitability factors and restriction factor. As a result, about 48% of the total study area was found to be restricted and unsuitable in which restricted area lie on the northern part, whereas unsuitable area lies on the center and its surrounding part of the valley. There regions are mainly comprised of built-up areas with dense population and industrial sites. Thus, such areas should be excluded from the waste disposal site as it may lead to serious environmental and health problems. The least suitable site is about 51% of the total area and suitable site is about 1%. This means there are no highly suitable area for the waste disposal in Kathmandu valley from our study.

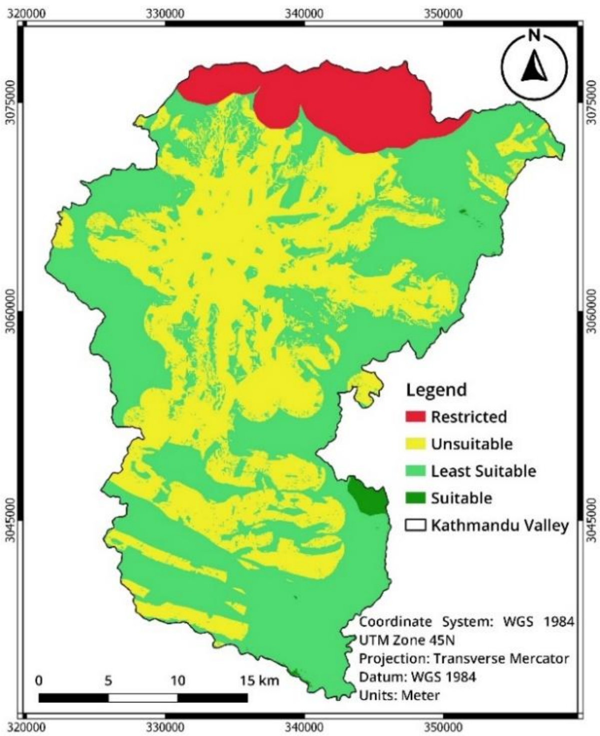

Figure 2: Final suitability map

Table 4: Area-wise suitability levels

Suitability Level	Area coverage (ha)	Percentage of total area
Restricted	7488.74	8%
Unsuitable	37439.33	40%
Least suitable	47311.36	51%
Suitable	540.53	1%

5 Conclusion and discussion

The linkage of FOSS with geospatial theme has a great potential for solving the real-world issues like solid waste management. Solid waste management is one of the many problems that both developed and developing countries face due to the growing population. Kathmandu valley has a population growth of 6.5% per annum. More population produces more waste which needs to be managed by authorities. Determination of a proper solid waste disposal site facilitates monitoring of environmental factors and proper operations of the site. Several environmental, economic and social factors need to be considered while selecting a waste disposal site. Due to several considerations, there is a big volume of data which needs to be collected, managed, stored, analyzed and displayed. Use of the GIS based MCDA method for suitability analysis of waste disposal sites is an ideal solution for this problem.

This study was based on data from Kathmandu Valley, Nepal. Kathmandu valley is one of the most populated places of Nepal. The current solid waste disposal site of Kathmandu Valley sometimes become inoperable due to different reasons like protest by locals and damage of road networks during monsoon. In this study, GIS was integrated with AHP-MCDA for identifying suitable sites for solid waste disposal in Kathmandu Valley which integrated various features which influences the selection of suitable waste disposal sites. AHP was done to determine weight for all the factors considered which were land-use/land-cover, geology, soil, and distance from road network, water bodies and settlement. The method helped to rank and weight the several factors which were considered during the study.

The study showed that there is inadequate land for the establishing the waste disposal site in Kathmandu valley. There should be adaptation of incisive planning for the waste reduction policies. The findings of this study could provide an important statistic to the concerned authorities for the planning, maintenance and development of the waste disposal sites.

It is necessary to plan for a sustainable solution for waste disposal sites. All the landfill sites will be full in future. To increase the longevity of such sites, the waste materials should be categorized into decomposable and non-decomposable wastes. Those waste which can be decomposed should be turned into compost and can be used in vertical or horizontal farming. Also non-decomposable wastes can be categorized so that they can be recycled and reused. Concerned authorities should inform and guide the general public to manage solid wastes in their home by making composts from decomposable waste.

Quantum GIS can be used for spatial database management, analysis and dissemination through maps. FOSS can be a powerful instrument for performing scientific and systematic researches, assisting to a fruitful result for decision making process. The use of FOSS should be encouraged at different sectors and its user community should be supported in order to develop more tools/plugins.

The main limitation of this study is that all the data used were obtained from secondary data sources. So, the data used may not be accurate and relevant to the current date. It is recommended that assessment of suitable sites for waste disposal can be improved by incorporating more detailed, robust and reliable data and methodology. Furthermore, optimal site should be selected considering further field investigation, geotechnical and hydrological aspects, site lifespan and other minuscule factors.

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8 Author/s biography

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