Chapter 77
Implementation of GIS-AHP Framework for the Identification of Potential Landfill Sites in Bengaluru Metropolitan Region, India

A. D. Aarthi, B. Mainali, D. Khatiwada, F. Golzar, and K. Mahapatra

Abstract Uncontrolled open dumping and burning of municipality solid waste (MSW) has resulted in soil, water, and air pollution in many urban cities in India. Landfills are the most common cost-effective solution for MSW management in many developing countries like India. However, the identification of suitable landfill sites always remains a challenging task as it involves selection of several environmental criteria set by the local authorities. The objective of this study is to identify the most potential landfill sites proposed by the Government in Bengaluru Metropolitan Region, Karnataka state, India using Geographic Information System enabled Analytical Hierarchy Process based multi-criteria evaluation technique. Several criteria and constraints as recommended by the local authorities along with the proximity to the solid waste processing plants are used to identify the potential landfill sites in the study region. The study identified three highly suitable sites (Neraluru, Gudhatti, Madivala) for landfills which are not only environmentally sustainable but also economically attractive as they are closer to the solid waste processing plants minimizing the transportation cost involved in the disposal of solid waste from the source to the final disposal sites in the study region.

Keywords Municipal solid waste · Landfill site selection · Circular economy · GIS enabled AHP technique · Bengaluru Metropolitan region

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77.1 Introduction

Management of Municipal Solid Waste (MSW) has been a major challenge and is receiving growing attention in many urban cities because of its environmental and economic impact (Sharma and Chandel 2021). MSW can be converted into energy using advanced conversion technologies, known as Waste to Energy (WtE) systems. However, uncontrolled open dumping and burning of MSW result in soil, water, and air pollution and thus landfills are one of the most preferred waste management techniques due to its least-cost solution in developing countries like India (Ali et al. 2021). At present, Bengaluru Metropolitan Region (BMR) generates around 3056 tonnes of MSW per day with a per capita waste generation of 363 g. By 2031, BMR is expected to generate 13,911 tonnes of MSW per day. Thus, there is a need for additional landfill sites for the proper disposal of the generated waste considering the population growth and city expansion plan (Revised Structure Plan of BMR 2031). The current study identifies the most suitable sites for potential engineered[1] landfill sites closer to MSW processing plants in the disposal of solid waste in BMR considering the environmental criteria through the methodological framework based on Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) based Multi Criteria Evaluation (MCE) technique.

77.2 Literature Review

MSW is considered a source of energy (Kaur et al. 2023) and there are several studies in the estimation of energy recovery potential through different WtE technologies. Despite modern WtE conversion technologies, engineered or sanitary landfills would play a key role in the management of MSW especially in Indian cities. AHP, a MCE technique, decomposes a complex multi criteria decision making process into several simple alternatives in the form of a hierarchy (Saaty 1990). Integrated GIS and AHP approach have been implemented for landfill site selection in various research (Kamdar et al. 2019). However, limited studies had been reported that utilize combined GIS and AHP based MCE approach in the identification of landfills in India. This current study will fill in the identified knowledge gap, thereby contributing to the optimal landfill selection through economic, environmental, and social criteria.

The Bruhat Bengaluru Mahanagara Palike (BBMP) is the administrative body responsible for civic amenities and some infrastructural assets of BMR (https://bbmp.gov.in/indexenglish.html). Solid waste management is an essential municipal service for which 50–60% of the BMR's budget is allocated. Open dumping and open burning of MSW, non-availability of source level waste segregation, and lack of information on the tracking system of the vehicles are some of the major challenges faced by the planning authorities in BMR (Surendra et al. 2021). Currently, BMR

[1] An engineered landfill is a site where controlled disposal and scientific treatment of solid waste is done.

does not have any appropriate scientific treatment techniques for treating the waste before sending them to landfill. This has led to the development of various unauthorized dumpsites. At present, landfills exist at Mavallipura, Mandur, Doddaballapur and Bommanahalli in BMR. The municipality needs more landfill sites to manage the increasing MSW generation in the city. The government has proposed potential landfill sites in Gudhatti, Neralur, Bendiganahalli of Attibele hobli, Madivala, Gowrenahalli and Samanduru in Anekal hobli, Galipuje, Honnaghatta of Doddaballapur Taluk, Chikkabonahalli of Devanahalli Taluk and Kalarikaval village in BMR.

77.3 Data and Methods

77.3.1 Study Area

Bengaluru is the capital city of Karnataka state and the fifth largest city in India and is called the IT (Information Technology) capital of India. BMR located in southern India (Fig. 77.1) on the Deccan Plateau covers an area of 8005 km^2 and is the second largest metropolitan in India with a population of 12,765,000 as of 2021. BMR includes the districts of Bengaluru Urban, Bengaluru Rural and Ramanagara and is considered one of the fastest developing metropolitans in Asia (Dittrich 2004). With an increased population level, rapid industrialization, increase in the number of IT parks, and a rise in the standard of living of people, the generation rate of MSW accelerates (Naveen and Sivapullaiah 2020) making BMR one of the filthiest metropolitans in India.

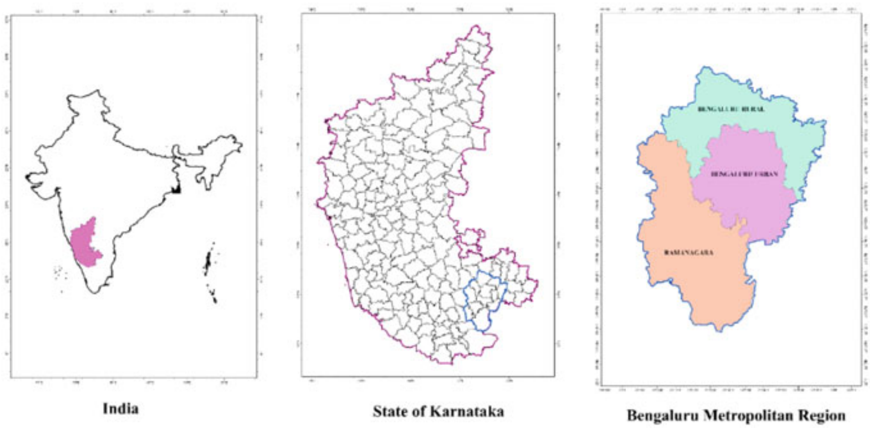

Fig. 77.1 Location map of the study region

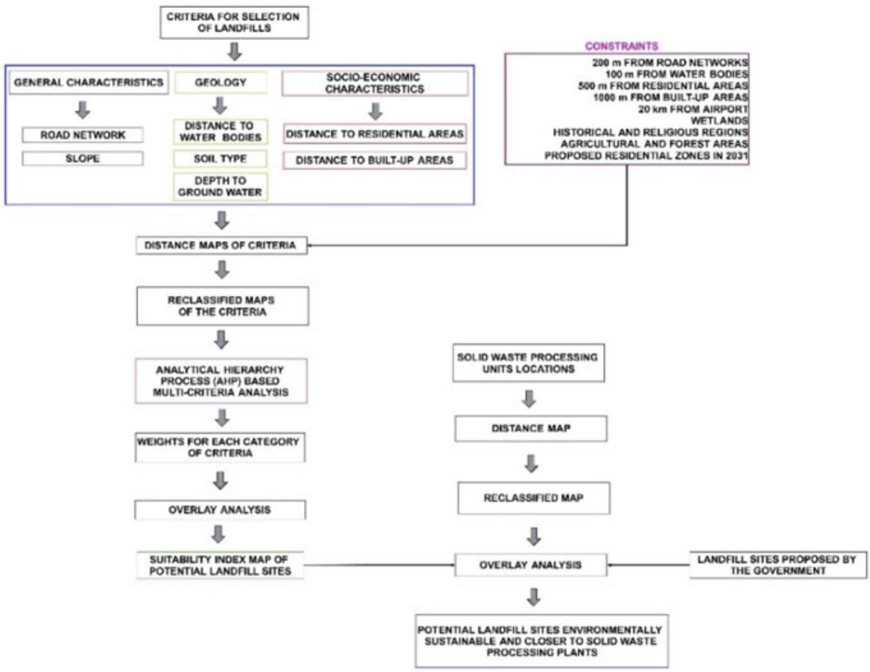

Fig. 77.2 GIS enabled AHP technique adopted for the identification of potential landfill sites in BMR

77.3.2 Methodology

77.3.2.1 Selection of Potential Criteria and Constraints

To identify potential landfill sites in BMR, general, geological, and socio-economic criteria as recommended by Health et al. (2023) are considered including (i) Road network, (ii) Soil types, (iii) Water bodies, (iv) Depth to Groundwater, (v) Residential Areas, (vi) Built-Up areas available from OpenStreet Map[2] and (vii) Slope derived from SRTM (Shuttle Radar Topography Mission) 1 Arc-second Global data available from U.S. Geological Survey (USGS)[3] as described in Fig. 77.2.

[2] https://www.openstreetmap.org/#map=4/62.99/17.64 (as accessed on <25 May 2021>).

[3] EarthExplorer (https://earthexplorer.usgs.gov/).

77.3.2.2 AHP Based Multi-Criteria Technique for Landfill Site Selection

AHP was developed in 1970s (Saaty 1977) to solve various multi-criteria decision-making problems (Mardani et al. 2015). In the current study, seven criteria as mentioned in Sect. 77.3.2.1 are used to prepare the distance maps through proximity analysis in an ArcGIS environment. The distance maps are further reclassified into 5 categories including 5(Excellent), 4(Good), 3(Average), 2(Poor), and 1(Bad) based on their importance in the identification of landfill sites. These reclassified maps of the criteria are used to derive the weights through AHP analysis.

77.3.2.3 Preparation of Landfill Suitability Index Map

The weight maps of the criteria obtained through AHP technique are used to prepare the suitability index map through overlay analysis (Vázquez-Quintero et al. 2020) in an ArcGIS environment. The suitability index map is categorized into 5 classes including excluded, unsuitable, moderately suitable, suitable, and highly suitable based on the suitability index values of 0–25, 25–50, 50–60, 60–70 and 70–100 respectively (Ohri et al. 2015).

77.3.2.4 Identification of Potential Landfill Sites Based on the Distance Between Collection Points and Suitable Sites

The logistics cost involved in carrying the solid waste from the source points to the final disposal locations is huge (Martinez et al. 2019) and finding cost-effective and environmentally sustainable landfill sites is very essential for an efficient management of solid waste. In BMR, there are 201 number of solid waste processing plants and the potential landfill sites are selected from the landfill suitability map identified through AHP technique based on its proximity to the solid waste processing plants.

77.4 Results and Discussions

77.4.1 Preparation of Input Parameters for AHP Based Multi-Criteria Analysis

The proximity and reclassified maps of seven criteria (Sect. 77.3.2.1) are prepared. The reclassified maps of the criteria (Fig. 77.3a–g) are used as input parameters for AHP analysis for the weight generation for the categories of the criteria. Figure 77.3h

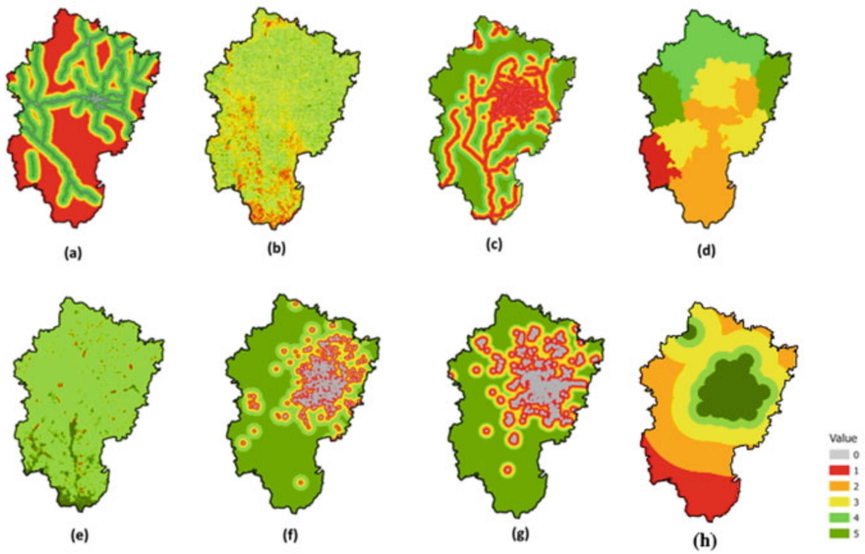

Fig. 77.3 Reclassified Maps of **a** distance to road network; **b** slope; **c** distance to waterbodies; **d** depth to groundwater; **e** soil types; **f** distance to residential areas; **g** distance to built-up areas; **h** distance to solid waste processing plants location

represents the reclassified map of solid waste processing plants and contains 5 classes including 5, 4, 3, 2 and 1 indicating a distance of 5 km, 10 km, 20 km, 40 km and greater than 40 km respectively from the solid waste processing plants locations. Figure 77.3h is used in the identification of potential landfill sites based on its proximity to the waste processing plants based on the landfill suitability map prepared through AHP technique.

77.4.2 Preparation of Suitability Index Map for Landfill Site Selection in BMR

The weights of each category of the criteria derived through AHP technique are given in Fig. 77.4. The numbers inside the parentheses in Fig. 77.4 correspond to the reclassified values of the criteria as described in Sect. 77.3.2.2 and Fig. 77.3. Each criterion is reclassified into 5 classes as suggested by Health et al. (2023) and is shown as the category values of each criterion in Fig. 77.4. The weight maps of the criteria obtained through AHP technique thereby are used to prepare the suitability index map (Fig. 77.5a) through overlay analysis in ArcGIS environment.

Based on the analysis, regions around Kudur, Gummanahalli, Karahalli, Sonnanayakanapura, Channapatna and Uyyamballi are considered highly suitable for the establishment of landfills in BMR. According to Revised Structure Plan of

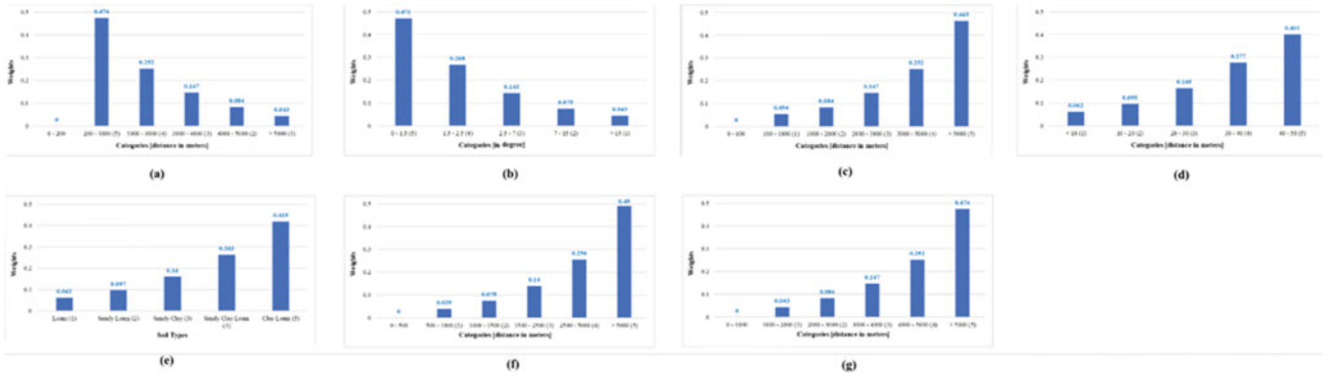

Fig. 77.4 Weights assigned to the categories of criteria for the identification of potential landfill sites in BMR. **a** Road network; **b** slope; **c** distance to waterbody; **d** depth to groundwater; **e** soil types; **f** distance to residential areas; **g** distance to built-up areas

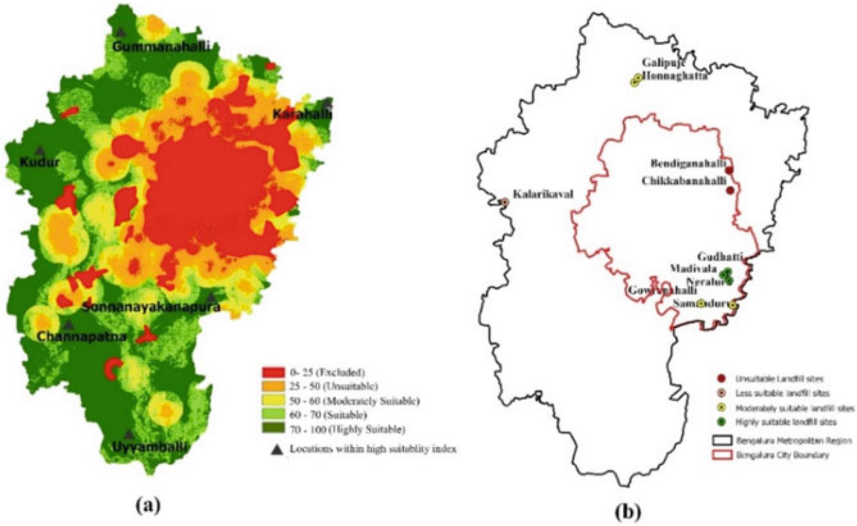

Fig. 77.5 Suitability index map for landfill in BMR. **a** Landfill suitability map based on AHP technique; **b** potential landfill sites based on (**a**) and closer to solid waste processing plants

BMR (2031), the Government has proposed to set up landfill sites in BMR by 2031 as described in Sect. 77.2. Based on the suitability index map (Fig. 77.5a) prepared through AHP analysis along with the reclassified map of solid waste processing plants (Fig. 77.3h) the proposed landfill sites are categorized as highly suitable, moderately suitable, less suitable and unsuitable as shown in Fig. 77.5b. The proposed sites at Madivala, Neraluru, Gudhatti are considered highly suitable for landfill establishment as they fall within the high suitability index for landfill selection and lie within 10 km from the solid waste processing plants. Hence, when setting up the landfills, the Government may give preference to these three sites for setting up of landfills in BMR. Galipuje, Honnaghatta, Samanduru, Gowrenahalli sites fall under moderate landfill suitability index and lie 20 km away from the processing plants making them moderately suitable landfill sites in BMR. Though the landfill site at Kalarikaval comes under high suitable landfill index, since it is located at a distance of 40 km from the solid waste processing plants which may make the transportation of the MSW to this landfill expensive, this landfill site is categorized as less suitable. If there are any solid waste processing plants established closer to this landfill sites, then it may serve as a potential site in the future. Bendiganahalli and Chikkabanahalli sites lie closer to the solid waste processing plants (within 5 km). However, these regions are expected to undergo urban developments in the future (Revised Structure Plan of BMR 2031) and are not recommended for the setting up of landfill sites considering the negative impacts of a landfill on the health of the people living nearby them. Probably the Government might have considered these landfill sites as they lie closer to the processing plants which may reduce the transportation cost of the MSW which contributes a huge share in the budget of BMR. The results of the analysis would be useful to the local planning authorities to decide upon giving preference to sites while establishing the landfills in BMR.

77.5 Conclusions

In the current study, to identify potential landfill sites in BMR, GIS enabled AHP technique was implemented based on general, socio-economic, geological criteria and constraints. The landfill suitability map prepared through AHP analysis categorized the study region into five categories as excluded, unsuitable, suitable, moderately suitable, and highly suitable. Considering the increasing solid waste generation, the Government has proposed to set up new landfill sites in the study region by 2031. Based on the landfill suitability map, the study categorized the proposed landfill sites as highly suitable, moderately suitable, less suitable and unsuitable based on its location to the solid waste processing plants. Results of this study identified three potential sites at Gudhatti, Madivala and Neraluru as highly suitable which would help the local authorities while planning to set up the landfill sites in the future. The metropolitan region is thriving to achieve sustainable waste management in the future through reusing, recycling, and energy conversion of solid waste which might reduce the amount of waste disposed in the landfills thereby increasing the lifespan of the existing landfills and may possibly reduce the need for new landfills in the future. This needs further attention in the research.

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