# IDENTIFICATION OF ALTERNATIVE LANDFILL SITE USING QGIS IN A DENSELY POPULATED METROPOLITAN AREA

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Abstract: Appropriate landfill site selection for disposal of solid waste is a very complicated assignment, as it needs multicriteria analysis of various parameters. In this study, we have used QGIS for identification of alternative landfill site in Gurugram district, a satellite city of New Delhi. Various criteria are analysed for selecting the landfill sites. Weight and rank are assigned to the criterion such as road networks, presence of water bodies, residential locations, and depth of the underground water table by using the Analytic Hierarchy Process (AHP). Five possible landfill sites have been identified for solid waste disposal based upon the AHP method analysis and overlay analysis in GIS tool in Gurugram district. The methodology used in this paper is very efficient for performing multicriteria analysis and can be generalised for selecting landfill sites in other areas with similar demographics.

Key words: solid waste management, vector data, landfill site selection, multicriteria analysis

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## Introduction

Many people are migrating from rural to urban habitats due to various reasons such as industrialisation, better employment opportunities, and availability of livelihood and other basic amenities. This higher rate of population growth in metropolitan and National Capital Region (NCR) creates several problems in the physical environment. Urbanisation affects the health of the people; increases pressure on water, sanitation and health services; and deteriorates environment. Unprecedented and unplanned growth of urbanisation creates a heap of solid waste, whose management has become a very daunting task and critical issue in such highly populated areas (Koushki et al. 1997). Solid waste is a broader term, which includes the used, rejected and worthless solid particles generated from residential, commercial and industrial activities in a defined area. It comprises organic materials, plastic papers, metals, glasses, etc. Solid waste is harmful as it has hazardous effects on the environment and public health (Erwanto et al. 2018). The main reasons for larger waste production in cities are a higher rate of population growth, development of industries and excess use of plastic items.

Solid waste management is a crucial and complex activity that involves effective disposal of solid wastes. Inappropriate solid waste management causes air, water and soil pollution (Djokanovic et al. 2016). In the developing world the process of selecting a landfill site for dumping solid waste has become a frail activity. Setting up of landfill sites does not materialise due to various issues such as government regulations, lack of municipal funding, less availability of land for landfills, social and political opposition, etc. (Makan et al.



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2012). Owing to these reasons, this issue has become central for the technocrats, administrators and research community involved in the regime of public health sanitation and urban planning (Mahini and Gholamalifard 2006).Various researchers have applied the weighted linear combination of GIS with Analytical Hierarchy Process (AHP) to identify the landfill sites for the location mentioned in their researches (Akbari et al. 2008, Qisheng, Dong 2012, Hanine et al. 2016, Rahmat et al. 2016). Multicriteria decision support system is effective in selecting landfill site as various factors such as distance from a residential city, transport facility, depth of the underground water table, etc. need to be considered with their proper weight (Ghobadi et al. 2013).

The advancement in the landfill site selection using GIS and multicriteria decision analysis (MCDA) methods with the advantages and disadvantages of various MCDA techniques in conjunction with GIS was discussed by Abujayyab et al. (2017). Landfill site selection is a very complex task and analytical tools are required for decision-making purpose. Baiocchi et al. (2014) used Boolean logic, index overlay and fuzzy gamma for the identification of disposal sites in the metropolitan regions of Italy. Chang et al. (2008) used fuzzy multicriteria analysis with GIS for finding a landfill site in Harlingen in South Texas. They carried out a two-stage analysis using fuzzy multicriteria decision-making (FMCDM) as a tool with GIS. Unsuitable regions were identified using GIS, and Monte Carlo simulation was used to perform sensitivity analysis for finding the potential sites. Ding et al. (2018) used AHP and entropy method for finding the weights of factors. The factors were categorised and the criteria weights were assigned carefully. Elhamdouni et al. (2017) used the AHP method and geoinformation tools for finding suitable landfill sites; they also stated that improper management of household waste is harmful for natural resources, environment and health of the people. Suitable landfill site selection method was made by Gorsevski et al. (2012) in the Polog region in Macedonia using the AHP and ordered weighted average (OWA) techniques. They stated that the landfill site selection depends upon scientific analysis along with public and political opinion. Markov chain based simulated annealing algorithm in GIS was applied by Muttiah et al. (1996) to find the landfill site in Indian Pine watershed of Indiana. Selection of the landfill site using GIS, MCDA and overlay analysis is done by updating the knowledge base (Sumathi et al. 2008). Multicriteria evaluation method (MCE), cellular automata (CA) and GIS were used to present a prototype based on simulation model (Wu 1998). It has been found using GIS and multicriteria decision analysis (MCDA) that Kayapa district is the most appropriate area for landfill purpose in Bursa Province of Turkey (Yildirim et al. 2018). Spatial data and attribute data play a crucial role in the analysis, identification and selection of landfill site. Further, MCDA in GIS and assigning suitable weight using the AHP method are effective in the identification of landfill sites based on these data (Okot et al. 2019).

Relevant literature study in the research area reveals that the issue of identification of suitable site involves various social, economic and environmental factors, making it a very complex and multi domain task. In addition, it emerges that GIS is effective to store, manipulate and analyse spatial data, and the AHP method developed by Saaty (1980) is very useful in solving decision problem. In our study, we have used the integration of GIS and the AHP method for finding a landfill site for Gurugram district. Presently, a landfill site located in village Bandhwari in the Arawali Hill region is prescribed by the government authorities for dumping the solid waste, where daily garbage is being dumped by using vehicles including 235 mini tipper, 27 tractor trolley, 36 dumper, 11 JCB, 8 hook loader, etc. to gather a huge mountain of waste, and this process is going on for last more than 11 years. The present scenario of dumping solid waste in Gurugram is not in conformity with the various essential parameters such as underground water table, distance from residential locality, distance from highway and even the capacity of site. Due to this landfill, the underground water in Bandhwari and nearby areas has become unsuitable for drinking purpose because it was contaminated with harmful elements such as Boron (B), Manganese (Mn), Iron (Fe), Chlorides ($Cl^-$) and Nitrates ($NO_3^-$). This landfill is very harmful for underground water and surface water but it could not be shifted elsewhere due to lack of alternatives. The solid wastes in landfill consist of heavy metals, solvents and pesticides. During rainfall, the chemicals from solid waste percolate through the soil and pollute the underground water that is used for drinking and agriculture. Polluted underground water is very harmful for human beings and unfit for domestic purpose. Presently, the landfill site at Bandhwari village consists of 3.5 million tonnes of untreated waste. The concentrations of pollutants like Fluoride ($CaF_2$), Cadmium (Cd), Mercury ($Hg^{2+}$) and Magnesium ($Mg^{2+}$) all surpass the safe limits. The villages and towns in the district presently have no such prescribed arrangements for dumping a huge amount of solid waste. In our study, we have carried out an analysis using GIS and AHP in the QGIS platform using MCDA to suggest an alternative landfill site for the Gurugram district. This alternative site will more appropriately satisfy the prescribed norms of the agencies involved in environmental protection and will be in accordance with the instructions of the government and local bodies regarding resident safety. The study is unique in the sense that no scientific study of similar nature has been reported for this region.

## Study area

Gurugram is a densely populated satellite city of New Delhi. It is located in the core NCR that produces approximately 1200 metric tonnes of solid garbage per day. This city has unrivalled urban growth and immigration from the past

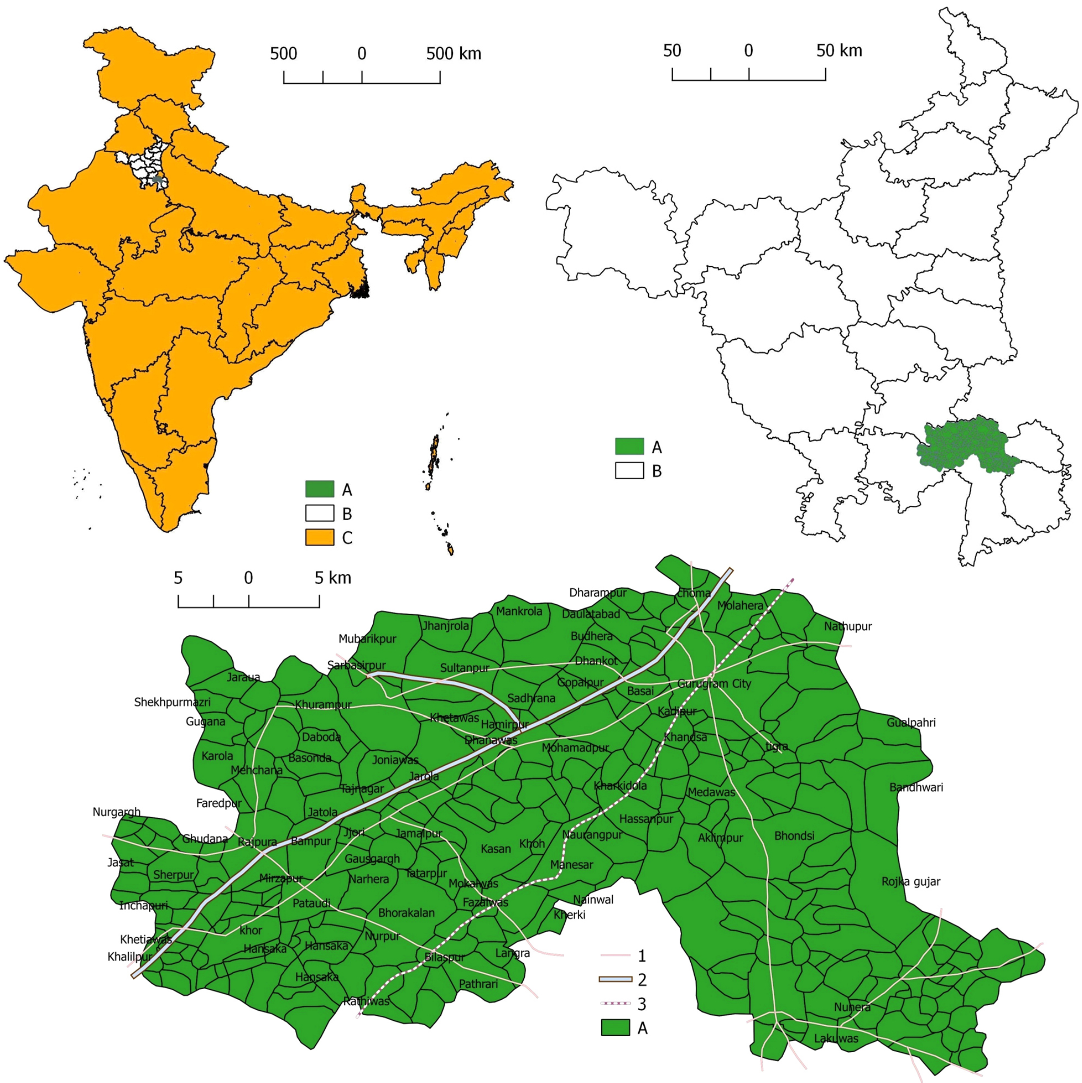


Fig. 1. Location map of the study area.
A – Gurugram district, B – Haryana, C – India, 1 – road network, 2 – railway line, 3 – national highway (NH-8).

two decades, which has led to huge solid waste generation similar to other metro areas in the country like Mumbai and Delhi. In Mumbai and Delhi, waste management is a big concern and is handled carefully; but no such context specific efforts have been taken for Gurugram. Gurugram city is at the top in the Information Technology sector growth rate in India, but the condition of waste management is still critical and needs immediate solution. Solid waste production has increased two fold during the last decade, making Gurugram one of the worst polluted cities in India. Geographically, it is a significant place in the northern part of India, which lies between 27°39'00"N and 28°32'25"N latitudes and between 76°39'30"E and 77°20'45"E longitudes, covering an area of 1258 $km^2$. Gurugram city is the fastest urbanising city in India, and is known as *Millennium City*. It has a rapid population growth rate, i.e. 74% growth during the last decade. The population of the city as per 2011 census data is 1,514,432 (Misra et. al 2018). The present site of solid waste dumping in Bandhwari village is located at the outskirts of the district on the Faridabad roadside. It has been found that the groundwater of Bandhwari and nearby areas has been contaminated due to dumping of solid waste, and an alternative landfill site selection is much essential for Gurugram district. Figure 1 depicts the locations of study area in the geographical map of India.

## Data sources

The spatial data of the road network, boundary maps, census data 2011, etc. for the area under study were collected from the Society for Geoinformatics and Sustainable Development (SGSD), and the data related to underground water table, water bodies and water quality were collected from Gurujal office, a government agency enshrined with such responsibility. All the data used in the study are authentic, as they have been received from responsible and authorised agencies and used after verification.

## Materials and methods

A field study was carried out by visiting the current landfill site at Bandhwari village in Gurugram to understand the actual situation of dumping method, and a review of literature was done by collecting and studying the reports and the spatial and non-spatial data for GIS and AHP analysis from official administrative data (Gurujal office, Gurugram and SGSD). Feasibility of the study is accomplished for different landfill sites using QGIS Software platform. The Solid Waste Management (SWM) Rules (2016) issued by the Ministry of Environment, Forest and Climate Change, Government of India, that are applicable to Haryana were used to assign weight and ranks to various factors under AHP (Alkaradaghi et al. 2019). The SWM Rules (2016) formulate the criteria for landfill site selection and restrict construction of a landfill site in the vicinity of 200 m from any human habitation, 200 m from a highway, 200 m from ponds and 20 km from any airport. The spatial data of the road network, boundary map of Gurugram and population data census 2011 were taken from the SGSD, and the underground water table data and the water body quality data were taken from Gurujal office and fed to QGIS for decision-making and analysis. Suitable and unsuitable areas for landfill purpose were identified by using the AHP method and spatial analysis tools in QGIS Software. Overlay analysis was performed using the geoprocessing tools in QGIS to find the landfill sites for the study area. The sequence of work in this study is presented as a flow chart in Figure 2.

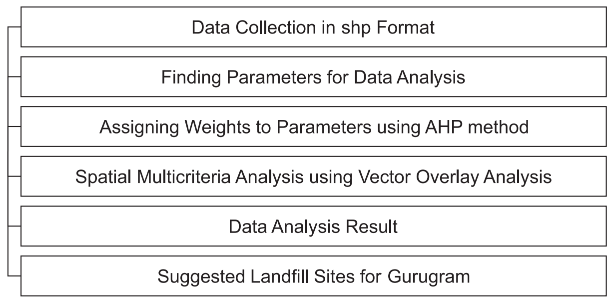


Fig. 2. Flowchart of methodology.

## Criteria for selection of solid waste dumping site

In literature, various researchers have proposed different criteria for the selection of landfill site in their respective study areas. In India, the SWM Rules (2016) is the first and only policy document to set norms and regulations regarding solid waste management. The SWM Rules (2016) prescribe norms and put restrictions on the construction of landfill site in the vicinity of 200 m of any human habitation, 200 m of a highway, 200 m of ponds and 20 km of any airport. Based upon literature review done in the section Introduction of this paper and with compliance to the SWM Rules (2016) we have identified four most important criteria, as listed below, for deciding a suitable landfill site for Gurugram district:

1. Distance from residential locations,
2. Depth of underground water table,
3. Transport connectivity and
4. Presence of water bodies.

All these parameters are selected based on literature review and the specifications mentioned under Schedule I of the SWM Rules (2016). We have not considered distance from airport as there is no airport in Gurugram district. However, finding a landfill site that can satisfy all parameters is a very tedious task due to the conflicting nature of parameters (Uyan 2014). This study has set a trade- off between various conflicting parameters to find an optimal solution to the problem. Various researchers to find the best possible landfill site use decision analysis methods along with GIS techniques.

## Results and discussion

This research applied multicriteria analysis on spatial data in the AHP at the QGIS platform to find an alternative solid waste disposal site. The QGIS is open source software used in GIS exercises and applications using both the raster and vector data. All the norms prescribed by the legislation are fed to the software to ensure its strict compliance. Based on the data fed to software, a GIS analysis of all the four criteria was carried out to scan the whole district, as discussed in the subsequent subsections.

### Residential area analysis

Residential areas were identified by applying data query on the spatial data fed to QGIS software. Then the buffer analysis tool was used to create a buffer of 500 m around these areas as prescribed by the SWM Rules (2016). This buffer

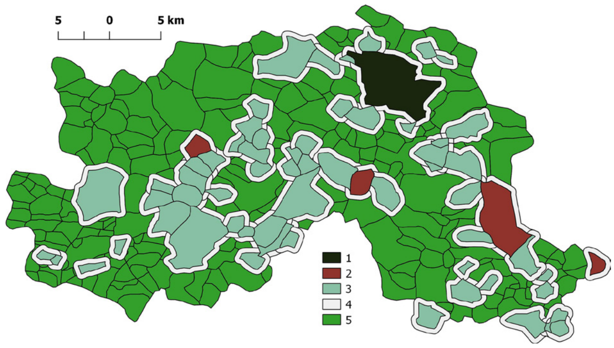


Fig. 3. Residential area analysis for Gurugram district. 1 – high population density, 2 – medium population density, 3 – low population density, 4 – 500 m buffer around the residential zone, 5 – Gurugram district boundary.

output helps in finding the grounds in the study area for solid waste dumping. The area under study covers majority of urban locality and a few are rural areas. The densely populated areas are Gurugram, Sohna, Farukhnagar, Hailey Mandi, Pataudi and Manesar having population density greater than 500 persons per square kilometre. Figure 3 shows the residential locations in Gurugram district where a buffer of 500 m is created around all the residential locations using GIS functions to ensure a distance of 500 m between the proposed site and residential colonies according to the SWM Rules (2016).

### Underground water table analysis

The underground water table plays a pivotal role in sustainable development of a habitat, and its contamination is a serious health hazard. The areas with deep underground water table are less prone to contamination through leachate,

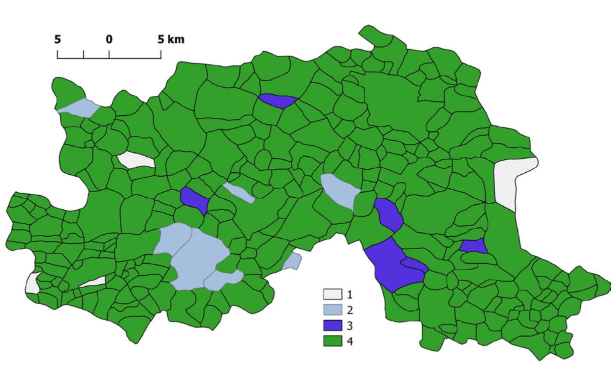


Fig. 4. Analysis of depth of underground water table analysis in Gurugram district (>20 m).
1 – 20–30 m, 2 – 30–40 m, 3 – 40–50 m, 4 – Gurugram district boundary.

and therefore, they are considered as the most suitable for landfill site selection (Tałałaj and Biedka 2016). Applying data query on the available data of Gurugram district by using QGIS, regions having a water table greater than 20 m were identified. Deep water table regions were categorised into three ranges. Figure 4 shows the underground water table in Gurugram district.

## Water bodies analysis

Landfill sites near water bodies cause water pollution that result in outbreak of diseases and epidemics. As per the regulatory provisions under the SWM Rules (2016) the landfill site must be 200 m away from any pond or similar water body. We applied data query on the available data to find the regions, which have worthless ponds. Figure 5 shows the water bodies analysis in the Gurugram district, which was obtained from SQL query dissemination in QGIS.

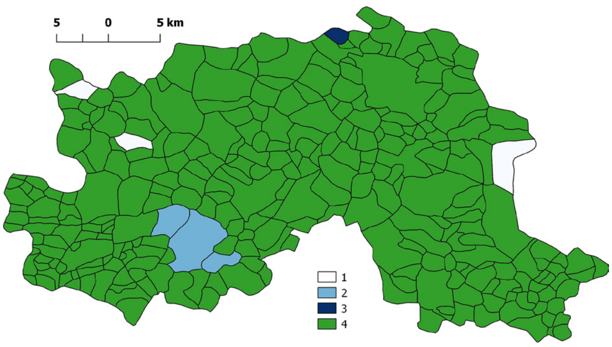


Fig. 5. Water Bodies Analysis for Gurugram district. 1 – dried ponds, 2 – sewage contaminated ponds, 3 – dirty pond, 4 – Gurugram district boundary.

## Road network analysis

The availability of approachable road network to the new landfill site is a necessary requirement for a landfill site. As per the legislative norms, no solid waste dumping site should be established within 200 m of a national highway. The national highway (NH-8) passes through Gurugram, dividing main Gurugram into old and new Gurugram segments. Therefore, a buffer zone of 200 m around the national highway is required to be created to ensure spatial layer and transport connectivity to different areas. Figure 6 shows the road network analysis in Gurugram district obtained over the QGIS platform.

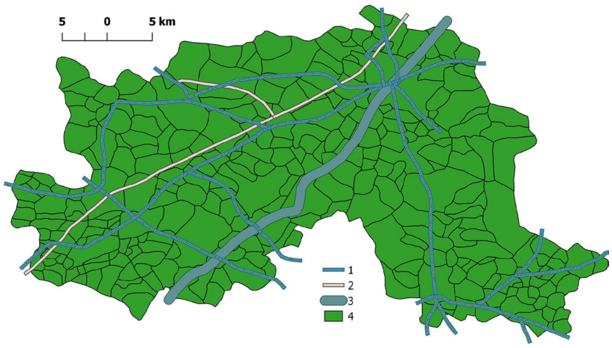


Fig. 6. Road Network Analysis for Gurugram district. 1 – road network, 2 – railway line, 3 – 200 m buffer around national highway (NH-8), 4 – Gurugram district boundary.

## Implementation of AHP in GIS

The solid waste disposal site for district Gurugram was earmarked by applying the AHP method in GIS tool. Weight and ranking were assigned to each layer based on its importance. All criteria for finding of landfill site are important and weight is assigned to each criterion according to its total impact on the whole process for decision making (Kapilan, Elangovan 2018). Thus, different weights were given to different criteria on the basis of their relative importance in the landfill site selection. In the AHP method, a composite decision problem is decomposed into easy decision steps to form a hierarchical structure and a score of 1–9 is used to show the relative preference of one factor over another in the pairwise comparison matrix. Strength of importance to different criteria was assigned with the help of preference value scale summarized in Table 1. Similarly, the four identified parameters for the study were assigned ranks using the AHP method, as shown in Table 2. The AHP technique involves three main steps to make decisions.

Table 1. Preference value scale.

| Strength of importance | Description |
|---|---|
| 1 | Equal value |
| 2 | Equal to moderate value |
| 3 | Moderate value |
| 4 | Moderate to strong value |
| 5 | Strong value |
| 6 | Strong to very strong value |
| 7 | Very strong value |
| 8 | Very to extremely strong value |
| 9 | Extreme value |

Table 2. Pairwise comparison and relative weights of different parameters.

| Sr. no. | Parameters for landfill site selection | Depth to groundwater | Proximity to residential area | Proximity to NH-8 | Presence of ponds | Criteria weights |
|---|---|---|---|---|---|---|
| 1. | Depth to Groundwater | 1.00 | 5.00 | 4.00 | 7 | 0.6038 |
| 2. | Proximity to Residential Area | 0.20 | 1.00 | 0.50 | 3 | 0.1365 |
| 3. | Proximity to National Highways (NH-8) | 0.25 | 2.00 | 1.00 | 3 | 0.1958 |
| 4. | Presence of Ponds | 0.14 | 0.33 | 0.33 | 1 | 0.0646 |

1. Finding the essential criteria for data analysis in the problem (landfill sites),
2. Rating of criteria according to the importance on preference value scale,
3. Evaluation of consistency using pairwise comparison matrix to calculate the consistency ratio. This stage involves the following procedure:

– calculating the criteria weight for each criterion,
– calculating the highest Eigen Value $\lambda_{max}$,
– evaluating consistency index using the equation:

$$\text{Consistency Index} = (\lambda max - m) / m - 1,$$

where 'm' is the number of comparable elements,
– finding the correct value of the random index,
– calculating the consistency ratio.

The criteria weight was calculated by averaging all the elements in rows of normalised pairwise comparison matrix (Saaty 2008). In the next step, consistency was checked to determine accuracy of calculated values. The consistency index (CI) can be calculated using equations Consistency Index = (λmax − m) / m − 1, where 'm' is the number of comparing elements whose value in a specific case of this study is m = 4; can be calculated using the highest Eigen value = 4.1007 appeared in the calculation. Finally, the consistency ratio was obtained by dividing the consistency index (CI) by the random index (RI). The judgements with a consistency ratio < 0.1 are inconsistent and considered as unacceptable, as proved by Saeedi et al. (2020). The consistency index of the randomly generated pair wise matrix is random index, which is tabulated in Table 3 for the 10 criteria.

For m = 4, the calculated value of random index (RI) comes out to be 0.90 and the final score of consistency ration (CI) calculated from equation came out as 0.037311. Since the value of consistency ratio = 0.037311< 0.10, consistency is acceptable. The results of the pairwise comparison matrix are summarised in Table 3.

## Landfill suitability

Suitable landfill sites were identified using the integration of GIS and the AHP method. The permissible consistency ratio (0.037) was computed from the pair wise comparison matrix. The criteria weight obtained for each parameter is shown in Table 4. The criteria weight obtained are used to rank the spatial data layer and to perform vector overlay analysis for determining the landfill suitability map. In this study, an analysis of residential area, road networks, depth of the underground water table and presence of water bodies showed them to be in conformity with the SWM Rules (2016). Hazardous gases released from landfill sites may spread diseases in the nearby

Table 3. Random Index for different 'm' values.

| 'm' value | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Random Index (R.I.) | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

Table 4. Calculated value of criterion weight, CI, RI, CR.

| Sr. no. | Parameters for landfill site selection | Criteria weight | $\lambda_{max}$ | Consistency index [CI] | Random index [RI] | Consistency ratio [CR] |
|---|---|---|---|---|---|---|
| 1. | Depth to groundwater | 0.6038 | 4.1007 | 0.03358 | 0.90 | 0.037311 |
| 2. | Proximity to residential area | 0.1365 | | | | |
| 3. | Proximity to NH-8 | 0.1958 | | | | |
| 4. | Presence of ponds | 0.0646 | | | | |

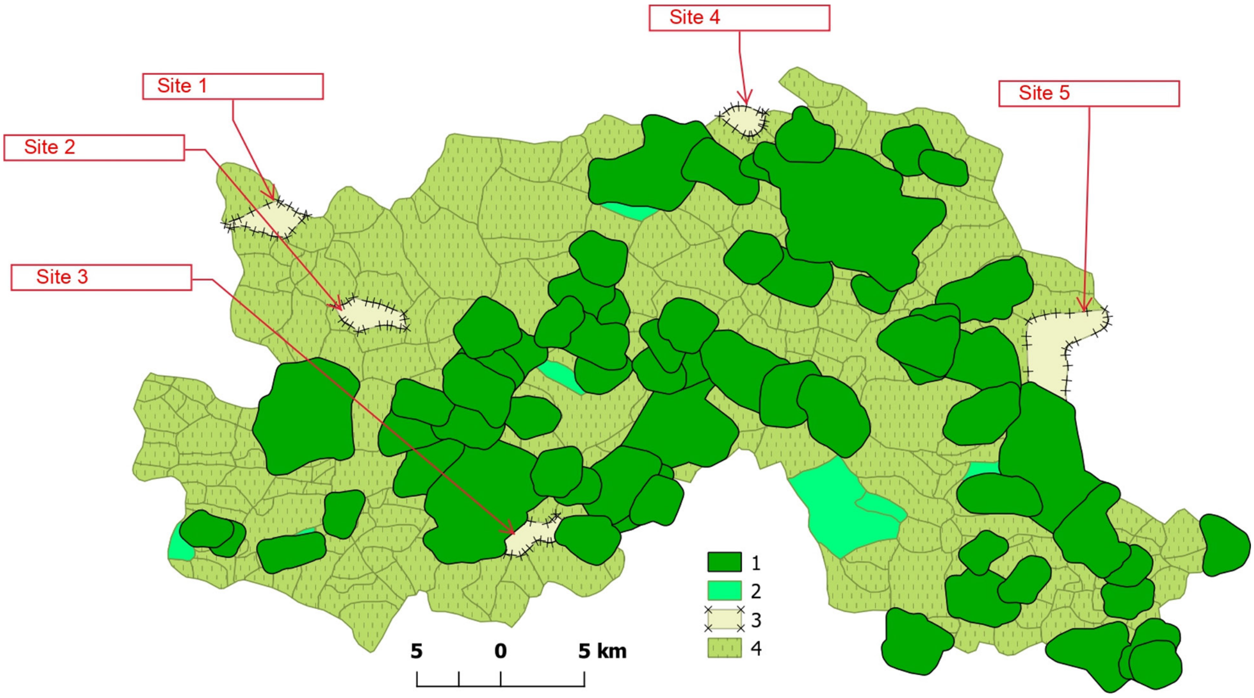


Fig. 7. Map for suggested landfill sites.
1 – unsuitable zones, 2 – suitable zones, 3 – landfill sites, 4 – moderately suitable zones.

residential areas and contaminate the underground water or waterbodies by infiltrating the leachate. Leachate comprises heavy metals (Xie et al. 2015) which contaminate the groundwater. Therefore, we considered a buffer zone of 200 m around the residential areas to spot suitable areas for selection of landfill sites. Therefore, areas with deep underground water table and having no ponds were optimal for this purpose and were identified. Regions within 200 m of highway were also neglected for aesthetic reasons. The spatial data layers were classified into three ranges in the constraint map, and Boolean values were assigned to these classes to find suitability map. The vector overlay operations were performed using geoprocessing tools in QGIS environment and the resultant map showed unsuitable zones, moderately suitable zones, suitable zones and five different landfill sites for Gurugram district. These five landfill sites fulfilled the constraints of our four identified parameters mentioned in the SWM Rules (2016). Unsuitable zones are the areas, which violate the SWM Rules (2016). Moderately suitable zones and suitable zones were also identified using mathematical overlay functions in QGIS. The GIS based vector analysis and the AHP method resulted in five possible landfill sites in Gurugram district. These sites were ranked and potential landfill sites are identified by considering proximity to the Municipal Corporation of the city Gurugram and availability of the road network. Site 4 and Site 5 were identified as potential sites as they are near to the Municipal Corporation of Gurugram city and road network is available for these sites. The identified sites are depicted in Figure 7.

## Conclusions

The QGIS, having several salient features, proved to be an important software for finding landfill sites in Gurugram district. Maps were created in QGIS in compliance with the SWM Rules (2016). Spatial information about the criterion was processed and analysed to get the location of the landfill sites. In this study, we found five most suitable sites for dumping of solid waste in Gurugram district by focusing on residential area analysis, road networks, depth of the underground water table and presence of waterbodies. Data in spatial and non spatial format were added to the QGIS software. Buffer zones were created for areas with high population density and national highways as per the SWM Rules (2016). Regions with a deep underground water table and without ponds were identified through SQL query dissemination. Overlay analysis using mathematical intersection and disjoint tools in QGIS was performed on these parameters to get the suitable landfill sites. The AHP method used with GIS tool for decision making segregated the suitable and unsuitable areas on the basis of preferences.

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### Authors' contributions

Savita Kumari Sheoran supervised the research and provided the academic material for the review. Vinti Parmar conducted the review, collected data, carried out implementation and concluded the study. Savita Kumari Sheoran analysed data and work and critically reviewed the contents of the paper. All authors had approved the final version.

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