Municipal Solid Waste Landfill Sites Selection for Visakhapatnam City under Vision 2020 Using GIS and AHP

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Abstract:

Municipal solid waste management is considered as one of the most serious environmental and social issue challenging municipal authorities in all major cities in India. The main problem is selecting a suitable landfill site for Solid Waste Management (SWM). Land filling is now accepted as the most widely used method for addressing this problem in all countries of the world. However, appropriate site selection for land filling is a problem in waste management and therefore needs to be addressed. This study aims at selecting a suitable solid waste landfill site for Visakhapatnam City, India for its future needs. A set of four main criteria and 13 sub criteria are considered for identifying suitable sites. The combination of GIS and the Analytic Hierarchy Process (AHP) has been used to give weights to different criteria. Relative Importance Weightage (RIW) of each parameter over the other is calculated by pair-wise comparison using the 9-point scale. The suitability index (0.1-0.6) values are determined for five classes (excellent, good, moderate, poor and very poor) for land fill siting. The study also aims at generating an optimal route to the suitable sites identified from the waste transfer station by using Network Analyst module of ArcGIS software such that the total system cost can be minimized.

Key words: Municipal Solid waste management (MSWM), GIS, analytic hierarchy process (AHP), Suitability index, Landfills, Relative Importance Weightages (RIW), Visakhapatnam city, India.

Introduction:

The process of waste management consists of collection, transport, processing, recycling or disposing of waste, and monitoring of waste material. In the wake of unprecedented growth in population of the urban centres, the problem of solid waste management has assumed a gigantic proportion in the less developed parts of the world. Management of solid waste is now a major global concern that is increasing day by day (Rahman et al. 2008). The traditional methods of solid waste management i.e. land filling of waste without applying any proper technique is still in vogue in most of the less developed countries (Sunil Kumar et al...
In fact, landfill is an essential part of any waste management system and is a widely used method. (Mahini and Gholamalifard 2006). Of the various techniques of solid waste management, landfill is the most popular and widely prevalent technique in India. According to an estimate, per capita municipal solid-waste generated daily in India ranges from a low of 100 g in small towns to a high of over 500 g in big cities (Jayasheela et al. 2007). This translates into approximately 80,000 metric tonnes daily or 30 million metric tonnes annually. Further, only about 60 to 80% of the waste generated is collected and disposed of at present, while the rest is allowed to decay on the roads, streets, or in the drains etc. This poses serious health and environmental problems for the city dwellers (Sunil Kumar et.al 2011).

After the implementation of Municipal Solid Wastes (Management and Handling) Rules, 2000 in India, it became mandatory for municipalities to dispose their wastes in scientific manner at sanitary landfill sites. As per the rules, all the municipalities were to set up waste processing and disposal facilities by the end of March 2003 (MoEF, 2000) but still many cities have not been able to implement them. Only few metro municipalities have so far constructed the sanitary landfill sites (Central Pollution Control Board (CPCB), 2007). In others, it is still either in planning or construction stage. Several major cities in the country are facing the problem of locating suitable landfill sites for MSW disposal (Anurag Ouri & Prabath Kumar Singh, 2013).

Visakhapatnam is the second biggest city in undivided Andhra Pradesh after Hyderabad. Once a small fishing village has evolved into major port city in south India over the decades and considered as the fastest growing city in India. The total area of the city is 540 sq.km (GVMV, 2012) and with Greater Visakhapatnam Municipal corporation jurisdiction of 111sq.km with a growing population of more than 30.82 lakhs. The city is the biggest economic hub with both public and private sector undertaking like Visakhapatnam Steel Plant, Visakhapatnam Port, National Thermal Power Corporation, Hindustan Petroleum Corporation, Hindustan Zinc, Hindustan Shipyard, Bharat heavy Plates and Vessels and any more private companies are located in and around the city generating huge amounts of waste. The Public Health and Sanitation Department of GVMC is responsible for collection, transportation and disposal of solid waste generated in Visakhapatnam City.

Among all processes involved in solid-waste management including collection, transportation, processing, recycling and land filling, disposal of waste in a suitable landfill is the most crucial one because wastes dumped in open space or in unsuitable sites are a serious threat to environment and human health (Sunil Kumar et.al 2012). Selection of a ‘landfill-site’ is an important component of urban planning, and belongs to the domain of science, social sciences, public health and planning (Yagoub & Buyong, 1998). Selection of a landfill for disposal of solid wastes requires processing and evaluation of a significant amount of spatial data with respect to various parameters governing the suitability of a site (Ojha et al. 2007).

Geographical information system (GIS) with multi-criteria decision analysis (MCDA) technique have been found to be useful for initial screening of suitable sites. Several studies (Shukla et al., 2012; Moeinaddini et al., 2010; Sener et al., 2010; Guiqina et al., 2009; Ohri and Singh, 2009; Gemiti et al., 2007; Mahini and Gholamalifard, 2006; Javaheri et al., 2006; Melo et al., 2006; Kontos et al., 2005; Natesan and Suresh, 2002; Lin and Kao, 1998; Champartheep et al., 1997; Siddiqui et al., 1996) have used combination of GIS and MCDA in landfill site selection (Anurag Ohri & Prabhat Kumar Singh, 2013). Using GIS and AHP, the present study endeavors to locate best suitable sites for GVMC with a vision for 2020.

Material and methods:

In the present study three different sources are used to collect the required data. The three sources are remote sensing satellite data from National Remote Sensing Agency (NRSA), Survey of India (SOI) topographic maps, and field surveys.
sheets and related Government and private agencies for existing data products. The data types, important features and corresponding data sources used in the present study are listed in Table 1.

Table 1:

| S. No | Data Type                  | Features                                                                 | Source of Acquisition                                      |
|-------|----------------------------|--------------------------------------------------------------------------|-------------------------------------------------------------|
| I     | Satellite Image            | IRS P6 – LISS III                                                        | National Remote Sensing Agency (NRSA)                       |
| II    | Thematic Data              |                                                                          |                                                             |
| 1     | Land use/Land cover        | Built-up land, agricultural land, water bodies, BSA, land with scrub,    | Toposheets of Survey of India. State Forest Department.     |
|       |                            | land without scrub, single and double crop, plantations etc.            | Satellite data from NRSA                                    |
| 2     | Geomorphology              | Pediplain-inselberg complex, Pedi plain with moderate weathering,      | Satellite data + SOI Toposheet                               |
|       |                            | Pediplain with shallow weathering, Residual hill, Pediment, Alluvial    |                                                             |
|       |                            | plain, Valley fill etc.                                                 |                                                             |
| 3     | Geology                    | Granite, Pegmatite, AAG, AMG, AT etc.                                    | Visakhapatnam quadrangle map from Geological Survey of     |
|       |                            |                                                                          | India, Hyderabad                                            |
| 4     | Structures                 | Conformed lineaments, Inferred lineaments, faults etc.                  | Visakhapatnam quadrangle map and Satellite data            |
| 5     | Soil                       | Clay, gravelly clay, gravelly loamy etc.                                 | Satellite data + Land use and Soil Survey Department        |
| III   | Topographic Data           |                                                                          |                                                             |
| 1     | Base map                   | Rivers/water bodies, major roads, railways.                               | Toposheets of Survey of India                              |
| 2     | Drainage map               | Drainage pattern, rivers, tanks                                          | Toposheets of Survey of India                              |
|       |                            |                                                                          | Updated using the satellite data                           |
| 3     | Transportation Network map | Major settlements, major roads and minor roads                            | Survey of India Toposheet                                   |
| 4     | Watershed map              | Watersheds, drainage pattern, major water bodies                        | Survey of India Toposheet                                   |
| 5     | Slope map                  | Slope classes 1 to 6                                                     | Survey of India Toposheet                                   |
| IV    | Data derived from other    |                                                                          |                                                             |
|       | thematic and topographic   |                                                                          |                                                             |
|       | maps                       |                                                                          |                                                             |
| 1     | Physiography               | Hills, Undulating land and plains                                        | Survey of India Toposheet                                   |
| 2     | GW Potential map           | Classification into high, medium and low based on yield/availability     | Satellite data                                              |
| 3     | GW table map               | High, medium and low zones depending on depth of water table            | Central/State ground water board                            |
| 4     | Infiltration rate map      | High, medium and low zones depending on infiltration rate               | Soil map, agriculture department, infiltration, geomorphology map |
| V     | Collateral Data            |                                                                          |                                                             |
| 1     | Demographic data           | Population density                                                      | Bureau of Economics and Statistics Division                 |
| 2     | Rainfall Data              | Rainfall                                                                 | Bureau of Economics and Statistics Division                 |
| 3     | Existing ground water      | Ground water quality                                                     | Central Ground Water Board, State Ground Water Department  |
|       | quality data               |                                                                          | and APPCB                                                   |
Description of the study area:

The study area is located approximately between 82°47’30.8” and 83°28’42” East Longitude and between 17°26’30” & 18°03’52” North latitude. The ground levels vary from 2 meters to 600 meters above mean sea level (MSL). Visakhapatnam is the second biggest city in undivided Andhra Pradesh after Hyderabad. Once a small fishing village has evolved into major port city in south India over the decades and considered as the fastest growing city in India. The total area of the city is 540 sq.km (GVMV, 2012) and with Greater Visakhapatnam Municipal corporation jurisdiction of 111sq.km with a growing population of more than 30.82 lakhs. According to GVMC at present the quantity of waste generated is around 737 tons per day with an average per capital solid waste generated by the city works out to around 489 gm/capital/day. The Public Health and Sanitation Department of GVMC is responsible for collection, transportation and disposal of solid waste generated in Visakhapatnam City. Fig 1.

Methodology Adopted for Analysis:

In the wake of a huge amount of wastes coming from different zones, the current disposal site at Kapulapadu disposal site is not only overfilled but also the height of the dumping mound has gone up to nearly 15 m from the ground. An alternate sites for dumping of solid wastes is, therefore, urgently required. In order to locate suitable sites in the vicinity of Visakhapatnam city, Remote Sensing, Geographical Information Systems (GIS) and a Multi criteria decision analysis technique viz., Analytical Hierarchy Process (AHP) model has been used (Thomas L. Saaty 1980). The study also aims at generating an optimal route to the suitable sites identified from the waste transfer station.

For the present study, the spatial –AHP technique was applied to identify and rank potential sites for solid waste disposal. In the first phase, ERDAS and ARC/INFO software are used to generate topographic, thematic and spatial data corresponding to layer including settlements roads, topography, geology, land use, geomorphology, aquifers and surface waters, soil etc. from IRS-P6, LISS-III satellite imagery, Survey of India topo maps, existing datasets and field data. The spatial and attribute digital database generated are further integrated for subsequent data analysis in GIS.

In the second phase, criteria to be considered for municipal solid waste disposal sites selection are identified and broadly grouped into exclusionary and non-exclusionary criteria. Fig:2
Fig: 2

Methodology for Analytic Hierarchy Process
Identification of Decision factors:

The primary factors that contribute significantly to the site selection criteria include the topographical information, geological factors, factors ensuring environmental acceptability, hydrological factors, physical feasibility and political restrictions. These factors were classified into two groups, namely, the exclusionary criteria and the non-exclusionary criteria.

Relevant exclusionary criteria were also obtained from the guidelines of Municipal Solid Wastes (Management and Handling) Rules, 2000, Ministry of Environment and Forests, New Delhi. Based on these criteria, buffer maps depicting the unsuitable areas surrounding major roads, rivers, habitation, lineaments, airport etc. for construction of a landfill are prepared.

All the non-exclusionary criteria are arranged in a hierarchical structure. The non-exclusionary criteria are the ones for which the pair-wise comparison of AHP is applicable. The Level I comprises the goal i.e., selection of best site for solid waste disposal which in turn comprises of four decision factors arranged at Level II of this structure viz., geological, topographical, environmental; and hydrological criteria. Geological criteria are in-turn divided into two sub-factors as geology and soil at Level III. Similarly, topographical criteria are subdivided into slope, land use / land cover and geomorphological characteristics; hydrological criteria are classified as ground water potential, infiltration rate and groundwater table; environmental criteria are divided into groundwater quality and air quality at Level III. All the criteria at Level III are converted into spatial maps from satellite imagery and SOI topo sheets using Remote sensing and GIS software. The remaining attributes are placed at level IV and further rated according to their importance for landfill siting using the 9-point scale of Saaty (Wael M. et.al 1996). Fig.3

RIW of Decision criteria at Level I to Level IV:

The criteria placed at level II of the hierarchical structure include the hydrological, topographical, environmental and geological factors. The hydrological parameters comprising of groundwater potential, infiltration rate and groundwater table are given absolute importance over topographical, environmental and geological criteria for selection of landfill site in the present study area. Since the immediate impact of any landfill is the contamination of groundwater resource caused due to leaching of pollutants from the disposal site, hydrological conditions are given higher weightage compared to other criteria. Once an aquifer is polluted, its impact can be felt on the entire fracture zone making the groundwater unsuitable for any further use. Change in climatic conditions also have an impact on the groundwater potential and depth and since the life of a landfill is proposed to be minimum of ten years, utmost care is taken to prevent contamination of underlying groundwater. Topographical criteria comprising of land use / land cover, slope and geomorphology are given secondary importance with respect to site selection, keeping in view the morphological and terrain conditions of the present study area. Once the hydrological conditions is known, the next step is to select a site, which is vacant and not suitable for any development activity and is easily accessible. Environmental criteria viz., groundwater quality and air quality are placed at third level since the impact on the environment is observed only after a landfill is set-up and the waste is dumped. Geological criteria for the present study is given least priority when compared to hydrological, topographical and environmental criteria, since there is very little variation in the geological condition of the study area i.e. 90% of the study area falls under granitic terrain.
The relative importance weight assigned to each hierarchy element is determined by normalizing the eigenvector of the decision matrix. Eigenvector values are estimated by multiplying all the elements in a row and taking the Nth root of the product, where N is the number of row elements. Normalization of the eigenvector is accomplished by dividing each eigenvector element by the sum of the eigenvector elements (Siddiqui et al, 1996). The calculation of the estimated Eigen element (EEE) and RIW at different levels of decision hierarchy are prepared. Level 1 and Level II calculation of EEE and RIW are given below. Table 2 &3
Table 2: Level 1 depicting the goal of the present study

| Suitable site for solid waste disposal | Geological | Topographical | Hydrological | Environmental |
|---------------------------------------|------------|---------------|--------------|---------------|

Table 3: Calculation of EEE and RIW of decision criteria at LEVEL II

|                | Geological | Topographical | Hydrological | Environmental | EEE    | RIW -I |
|----------------|------------|---------------|--------------|---------------|--------|--------|
| Geological      | 1          | 1/7           | 1/9          | 1/6           | 0.2267 | 0.0328 |
| Topographical   | 7          | 1             | 1/7          | 7             | 1.6266 | 0.2365 |
| Hydrological    | 9          | 7             | 1            | 6             | 4.4093 | 0.6411 |
| Environmental   | 6          | 1/7           | 1/6          | 1             | 0.6147 | 0.0894 |

Aggregating the RIW to Calculate Suitability Index:

After the RIW of each element of each theme to be considered for site selection are calculated, the individual weightages are aggregated and evaluated for estimation of the suitability index. The suitability index for each cell is determined and applied in Arc View GIS software for the selection of a final waste disposal site. The suitability index values obtained in the present study ranged in between 0.1046 and 0.5821. The higher the suitability index, the more suited it is for landfill siting.

Table 4: Categorization of Suitability index and corresponding class

| Suitability Index | Class    |
|-------------------|----------|
| 0.5 – 0.6         | Excellent|
| 0.4 – 0.5         | Good     |
| 0.3 – 0.4         | Moderate |
| 0.2 – 0.3         | Poor     |
| 0.1 – 0.2         | Very Poor|
Results and Discussion:
Relative importance weightage (RIW) of each feature of the thematic layers is calculated and used in the estimation of suitability index values. The suitability index is determined by aggregating the RIW at each level of hierarchy. Based on the suitability indices values obtained, entire area is categorized into five classes, as excellent class with suitability index ranging from 0.5 to 0.6, good class with suitability index ranging from 0.4 to 0.5, moderate class with suitability index ranging from 0.3 to 0.4, poor class with suitability index ranging from 0.2 to 0.3 and very poor class with suitability index ranging from 0.1 to 0.2 with respect to landfill siting. Higher the suitability index, the more suited is the site for waste disposal and lower the value, lower is the suitability. The suitability map prepared for the present study is depicted in Fig:4

GIS analysis led to a short list of sites, the attribute evaluation (distance from the point of waste generation, area covered, distance to nearest road or water body, population density surrounding the site etc.) of each of these individual sites was performed to determine which site possessed the best compromise of features for developing a landfill and are selected and ranked accordingly. Therefore, keeping in view the aerial extent of the site, ground water levels, existing land use / land cover, geomorphology and the distance of the site from the point of waste generation, few sites from each of the excellent, good and moderate suitability classes were selected. Apart from the above, the scrub forest is not considered for selection of sites. The list of sites selected in present study is given in table 5.
The attributes of all these sites were evaluated and sites ranked in order of suitability for developing a landfill. The below table presents the attributes of Excellent sites.

Table 6:

| List of Sites Selected in the Present Study |
|--------------------------------------------|

| Excellent | Location |
|-----------|----------|
| Site 1    | Between Ardhanapalem and Kottavalasa – NE of Kottavalasa and North of Visakhapatnam |
| Site 2    | Between Gangupudi and Gajapatinagaram – North of Visakhapatnam |
| Site 3    | Between Kottavalasa and Rayapurajupeta – North-west of Kottavalasa |
| Site 4    | Between Boduvalasa and Kottavalasa – South West of Kottavalasa and North West of Pendurthi |

| Good | Location |
|------|----------|
| Site 1 | Between Pappulampalem and Relli – East of Kottavalasa and North of Pendurthi |
| Site 2 | Between Relli and Ardhanapalem – North East of Kottavalasa and North of Visakhapatnam |
| Site 3 | Between Kottavalasa and Erravanipalem – North of Pendurthi |
| Site 4 | Between Boduvalasa and Kottavalasa – South West of Kottavalasa and North West of Pendurthi |

| Moderate | Location |
|----------|----------|
| Site 1 | Between Batajangapalem and Sabbavaram – West of Visakhapatnam and NE of Anakapalli |
| Site 2 | Between Paidivada agraharam and Jagannadhapuram – West of Visakhapatnam and NE of Anakapalli |
## Attributes of Sites Selected Under Excellent Category of the Study Area

| Site | Location | Area (Acres) | Distance from VSKP | GWT | GWP | GWI | LULC | HGM | Physiography | GWQ | Soil | Geology | Description |
|------|----------|--------------|-------------------|-----|-----|-----|------|-----|--------------|-----|------|---------|-------------|
| 1    | Between Ardhanareswaram and Kottavalasa NE of Kottavalasa and North of Visakhapatnam | 300 | 24 | 5 - 15 | Moderate to Poor | Low | LS/LWS | PP | Undulating land | Good | Clayey | Khondalites/ Lentinites | Surrounded by estuaries and 10 Kms away from Pendurthi |
| 2    | Between Gangapurddy and Gajapatigaram - North of Visakhapatnam | 104 | 31 | 5 - 15 | Moderate to Poor | Low | Gullied | PP | Gentle Slope | Good | Clayey | Khondalites/ Lentinites | Surrounded by wastelands and 6 Kms away from Kottavalasa |
| 3    | Between Kottavalasa and Ravugupeta - North-west of Kottavalasa | 78 | 30 | 5 - 15 | Moderate to Poor | Low | LS/LWS | PP | Gentle Slope | Good | Clayey | Khondalites/ Chamrockites and Lentinites | Surrounded by gullies and 5 Kms away from Kottavalasa |
| 4    | Between Bodivalasa and Kottavalasa - South West of Kottavalasa and North West of Pendurthi | 97 | 21 | 5-15 | Poor | Low | Gullied | PIC | Gentle Slope | Good | Clayey | Khondalites/ Lentinites | Surrounded by wastelands and 6 Kms away from Pendurthi |

## Optimum Route Analysis for Transportation of Solid Waste

Transportation of waste from transfer stations to the land fill sites is also one of the important task in Municipal Solid waste management (Tchobanoglous et al., 1993). Therefore, optimization of the route or selection of the shortest route to the dumpsite considering the type of road, traffic flow, volume of traffic, transportation costs including the fuel efficiency is very much essential. In the present study by using The Arc View Network Analyst (AVNA) extension module different route maps are generated from transfer station to the dumpsites. Different route maps are prepared for all the five types of sites; map below is one such route map transfer station to excellent sites. Fig.5
Conclusion:
Selection of landfill sites depends on a set of social, economic and environmental factors. A comparison of such a large number of indicators is possible only with techniques that are capable to handle different types of data. GIS and AHP techniques are quite useful as they are capable to handle huge multi-type data—both spatial and non-spatial. AHP and GIS are thus very appropriate techniques in identifying sites for solid waste management.

References:
1. Akbari, V., Rajabi, M. A., Chavoshi, S. H., & Shams, R. (2008). Landfill site selection by combining GIS and fuzzy multi criteria decision analysis, case study: Bandar Abbas, Iran. World Applied Sciences, 3(1), 39–47.
2. Anurag Ohri & Prabhat Kumar Singh (2013) GIS based environmental decision support system for municipal landfill site selection. Management of Environmental Quality an International Journal DOI:10.1108/MEQ-08-2012-0056.
3. Central Pollution Control Board (CPCB) (2007), Management of Municipal Solid Waste, Central Pollution Control Board, New Delhi.
4. Central Public Health and Environmental Engineering Organization (CPHEEO) (2000), Manual on Municipal Solid Waste Management, 1st ed., Central Public Health and Environmental Engineering Organization, New Delhi.
5. Chang, N., Parvathinathan, G., & Breeden, J. B. (2008). Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. Journal of Environmental Management, 87, 139–153.

6. Chang, N.B. and Davila, E. (2006), “Siting and routing assessment for solid waste management under uncertainty using the grey mini-max regret criterion”, Environmental Management, Vol. 38 No. 4, pp. 654-672.

7. Charnpratheep, K., Zhou, Q. and Garner, B. (1997), “Preliminary landfill site screening using fuzzy geographical information systems”, Journal of Waste Management and Research, Vol. 15 No. 2, pp. 197-215.

8. Guiqin, W., Li, Q., Guoxue, L., & Lijun, C. (2009). Landfill site selection using spatial information technologies and AHP: a case study in Beijing, China. Journal of Environmental Management, 90, 2414–2421.

9. Javaheri, H., Nasrabadi, T., Jafarian, M.H., Rowshan, G.R. and Khoshnam, H. (2006), “Site selection of municipal solid waste landfills using analytical hierarchy process method in a geographical information technology environment in Giroft”, Iranian Journal of Environmental Health Science & Engineering, Vol. 3 No. 3, pp. 177-184.

10. Jayasheela, Arabi, U., & Ali, M. S. (2007). Urban solid waste management in Karnataka: a case study of a city corporation. Nagarlok, 39(1), 50–55.

11. Mahini, S. A., & Gholamalifard, M. (2006). Siting MSW landfills with a weighted linear combination methodology in a GIS environment. International Journal of Environmental Science and Technology, 3(4), 435–445.

12. Melo, A.L.O., Calijuri, M.L., Duarte, I.C.D., Azevedo, R.F. and Lorentz, J.F. (2006), “Strategic decision analysis for selection of landfill sites”, Journal of Surveying Engineering, Vol. 132 No. 2, pp. 83-92.

13. MoEF (2000), Municipal Solid Waste (Management and Handling) Rules, Ministry of Environment and Forests, Government of India, New Delhi.

14. Moeinaddini, M., Khorasani, N., Danehkar, A., Darvishsefat, A.A. and Zienalyan, M. (2010), “Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: Karaj)”, Waste Management, Vol. 30 No. 5, pp. 912-920.

15. Ohri, A. and Singh, P.K. (2009), “Landfill site selection for municipal solid waste using geographic information system and multi-criteria decision analysis”, The 24th International Conference on Solid Waste Technology and Management ICSW 2009 Proceedings of the International Conference in Philadelphia, PA, pp. 932-941.

16. Ojha, C. S. P., Goyal, M. K., & Kumar S. (2007). Applying fuzzy logic and the point count system to select landfill sites. Environmental Monitoring and Assessment, 135, 99–106.

17. Saaty, T. L., (1997). A scaling method for priorities in hierarchical structures. J. Math. Psycho., 15: 234-281.

18. Saaty, T.L., How to Make A Decision: the analytic Hierarchy Process, Interfaces, 24, pp 19-43, 1994a.

19. Shukla, G., Shashi, M. and Jain, K. (2012), “Decision support system for selecting suitable site for disposing solid waste of township”, International Journal of Remote Sensing and GIS, Vol. 1 No. 1, pp. 2-11.

20. Siddiqui, M.Z., Everett, J.W. and Vieux, B.E. (1996), “Landfill siting using geographic information systems: a demonstration”, Journal of Environmental Engineering, Vol. 122 No. 6, pp. 515-523.

21. Sunil Kumar & Mohammad Izhar Hassam (2012) Selection of a Landfill Site for Solid Waste Management: An Application of AHP and Spatial Analyst Tool. J Indian Soc Remote Sens DOI 10.1007/s12524-011-0161-8.

22. Sumathi, V.R., Natesan, U. and Sarkar, C. (2008), “GIS-based approach for optimized siting of municipal solid waste landfill”, Waste Management, Vol. 28 No. 11, pp. 2146-2160.
23. Tchobanoglous, G., Theisen, H., Vigil, S. A., (1993). Integrated solid waste management: Engineering principles and management issues. McGraw-Hill, N. Y. USA.
24. Wael M. Jabre and Faraj Elawar, A Methodology for Siting a Water Harvest Reservoir, Proceedings MTM-IV, 1996 pp 347-355.
25. Yagoub, M. M., & Buyong, T. (1998). GIS Applications for Dumping Site Selection. The Eighteenth Annual ESRI User Conference 27–31 July, 1998, San Diego, California, USA.
26. www.gisdevelopment.net/application/utility/transport/utility tr 0004.htm