Selection of Suitable Site for Solid Waste Management in Part of Lucknow City, Uttar Pradesh using Remote Sensing, GIS and A.H.P. Method

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***Abstract*— Municipal solid waste generation is among the most threatening the global environmental health hazards. The problem of environmental pollution due to waste disposal can be overcome by selecting suitable sites. Many criteria of site selection depend on considering several independent factors such as geomorphology, land use, surface water bodies, soil, distance from road/railway line, habitation/residential area, groundwater table, geology/lithology and slope and the use of a multi criteria evaluation method seems inevitable. The use of Remote Sensing data in conjunction with GIS, is a vital tool for preparation of multi criterion layers and analytical hierarchy process (AHP) model which are extremely useful for pairwise comparison of multi criterion layers. The present study, based on remote sensing, GIS and AHP is an endeavours to select most suitable site for solid waste disposal in south-eastern part of Lucknow city, Uttar Pradesh, in the study area, seven sites were identified in which one has been proposed and recommended as the best suitable site.**

Keywords*— Remote Sensing and GIS, Site Suitability, Solid Waste, Multi Criterion Layers, Pairwise Comparison and AHP.

I. INTRODUCTION

In last few decades there has been a significant increase in municipal solid waste generation particularly in developing countries. This is largely because of rapid population growth and industrialisation in India. The per capita of Municipal solid waste generated daily, in India ranges from 100 g in small towns as witnesses to 500 g in large towns (Singhal, Shaleen et al., 2006). At present in India, about 125 million tonnes of municipal solid waste (MSW) is being generated annually and it is estimated to increase at a rate of 1% to 1.33% per annum. (CPCB report 2004). The traditional method for solid waste management i.e. land filling of waste without applying any specific techniques is still in vogue in most of the developing countries. In fact, landfill is an essential part of any waste management system and is a widely used method. (Kumar, S. et al 2012).

Lucknow, the capital city of Uttar Pradesh, India, is the largest producer of solid waste in the state. The city generates about 1500 metric tonnes of solid waste per day and Lucknow Municipal corporation has no any solid disposal site and all the urban area wastes is dumped in open low lying areas without any form of cover. Among all processes involved in solid waste management including collection, transportation, processing, recycling and landfilling and disposal of wastes in suitable site is the most crucial issue because it is a serious threat to environment and mankind. Accordingly it is essential that integrated systems of waste management be considered within the path towards achieving sustainable development. Such system generally emphasize on functional elements of waste minimization (reduction), reuse, recycle and finally placing the remained material in landfills (Leao et al, 2004). As sanitary land filling is an inevitable part of MSW (Municipal Solid Waste) management system (Tchobanoglous et al; 1993). 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). Appropriate site selection of landfills may play a key role in reducing the environment contamination. Landfill has become more difficult to implement, residents opposition and environmental contamination. Land is among invaluable and finite resources that must be used shrewdly. This implies that the selection process of a suitable site for solid waste disposal must take into account various spatial, economic and social parameters, which one crucial in isolating the site. To hold and manipulate such large quantity of data, an appropriate technology is required. In this context, satellite remote sensing data and Geographical Information system (GIS), is a vital tool for processing and analyzing and handling large volume of spatial and non-spatial data in short duration. In complex decision making processes involving multi thematic layers and their pairwise comparison, Analytic Hierarchy process (AHP) has proved to be a very useful decision making tool. Most of the studies on the selection of suitable sites, therefore, are based on GIS and AHP (Guiquin et al, 2009; Akbari et al, 2008, Chang et al, 2008). Using Remote Sensing, GIS and AHP, the present study is an endeavour to select the most suitable site for solid waste disposal study area.

Study Area

The study area covers an area of about 270 sq. km. in south-eastern part of Lucknow city falling in survey of India topographical map sheet no.63B/12, 63B/13 & 63F/1 on 1:50,000 scales ***(Fig.1)***, which lies between $26^0$55'11.12"N latitude and $80^0$59'55.55"E longitudes. The state of Uttar Pradesh is the biggest populated state in India. Lucknow, being the capital city of U.P. is situated on the banks of river Gomati that divides the city into two equal halves. The main urban area of city is in south-eastern part of Gomati river and trans-Gomati area is an sub city of Lucknow. The city is well connected with state and national highways and three main railway lines from Lucknow to Jammu Tawi, Chandigarh and Dehradun via Laksar, Lucknow-Delhi, Lucknow- Howrah-Calcutta and North East Sections of Guwahati-Dibrugarh-Tinsukia and in western part it is connected from Mumbai. The total geographical area of the City is 415 Sq. Km. with 28.81 Lacs of urban population and 1456 persons per sq. km^2 urban population density as per Census of India, 2011.

The terrain is almost flat with a depression in north-eastern part and almost area of study is under gentle slope it ranges from 0-5%. It is from north and north-west to south and south-east. The highest elevation is 123.5 m. from mean sea level and lowest part in the east is floodplain of river Gomti, which flows in the heart of city from North West to south east direction.

Data used and Methodology

To meet the set objectives of the study, Survey of India topographical (SOI) Map sheet no. 63B/12, 63B/13 and 63F/1 surveyed between 1973-76, on 1:50,000 scale and satellite imageries of IRS-1C/1D LISS-III 23.5 m resolution data on 1:50,000 scale acquired in 2001-02 and IKONOS satellite's 1m. resolution data of 2011 downloaded from internet, SRTM/Cartosat-1+LISS-IV merged images has been used for preparation of multi criterion layers i.e. landuse/landcover, geomorphology, soil texture, surface water bodies, habitation, road/transport-network and slope respectively and ground water table data was collected from state/Central Ground Water Department and the data related to solid waste generation in city was collected from Lucknow municipal corporation (MCL). The data procured/collected from various departments were digitized and converted into digital format in Arc GIS software 10.0 V. for spatial analysis.

Analytical Hierarchy Process (AHP) technique was applied for pairwise comparison and Multi Criterion Decision Making (MCDM) for selection criteria and alternative recorded and criterion maps to identifying and ranking of most suitable sites. It is used to calculate the weight of each alternative with respect to each criterion under the consideration of goal of the study. Analytical Hierarchy Process (AHP) model developed by T. L Satty (1980) is structured and popular approach in multi criteria decision making. The AHP model suffer from two main drawbacks, the first relates to the fact that in some cases ranking regularities can occur when AHP or some of its variants are used, the present study, however does not suffers from this limitation the second limitation, which pertains to the use of an arbitrarily determined weightage on 9 point scale, therefore becomes important. Sometimes, the decision maker might find it difficult to distinguish among them. The present study is also based on a 9 point scale (Table-1), and assignment of weightages to various criteria is arbitrary and based on intuitive understandings of researchers regarding the relative importance of selected parameters in the context of solid waste disposal sites.

In present case, AHP model has been used on eight criteria pertaining to geomorphology ***(Fig.2)***, landuse/landcover ***(Fig.3)***, accessibility of road/transport network ***(Fig.4)***, presence of surface waterbodies(river/drainage), lake/ponds, canal/distributaries) ***(Fig.5)***, soil texture ***(Fig.6)***, slope ***(Fig.7)***, habitation ***(Fig.8)***, and groundwater table ***(Fig.9)***. These multi-criterion layers have been used because they hold key place in the location of any landfill site. The pairwise comparison of related attributes was used to establish the relative importance of hierarchy elements. As can be seen in Table 6, it is near to geomorphology and landuse/landcover along with waterbodies and groundwater table and habitation residential area, road/transportation, soil texture and slope. A model provides comprehensive and lucid composition for structuring a decision problem for relating their elements to overall goals and for evaluating alternative solutions and is used in all over the world in a wide variety of decision making processes and has proved a vital tool in locating of suitable sites for various purposes. The steps involved in the process are being described below:

STEP 1

Firstly the decision problem is decomposed into a hierarchy of interrelated decisions. At the top level (level-0) of the hierarchy is the goal of the study. The elements at the lower level hierarchies include the selection criteria at level-1 and alternatives at level-2. Firstly, the selection criteria are pair-wise compared to each other with respect to the goal of the study. Similarly, at level-2, alternatives are pair-wise compared one by one with respect to the each criterion of the level-1. The numbers of comparisons are calculated by using Eq. 3.1 as follows:

$$\frac{n(n-1)}{2} \tag{3.1}$$

Where, n = number of things to compare

STEP 2

The selection criteria in level one relative to their contribution or significance to the goal of the study is made. In the present study, the pair wise comparisons have been expressed in a scale proposed by Satty (1988). This scale has been given in Table 1 Based on this scale; comparative judgments are expressed as ratios resulting in a square reciprocal matrix as follows:

$$A = \begin{pmatrix} a_{ii} & a_{ij} & \cdots & a_{in} \\ a_{ji} & a_{jj} & \cdots & a_{jn} \\ \cdots & \cdots & \cdots & \cdots \\ a_{in} & a_{jn} & \cdots & a_{nn} \end{pmatrix} \quad (3.2)$$

For all $i = 1,2,......,n$ and $j = 1,2,.....,n$

In pair wise comparison the dominant element is assigned an integer value, and the dominated element is assigned a fractional value. That is:

$$a_{ij} = \frac{1}{a_{ji}} \quad \text{(For all i and j)} \quad (3.3)$$

Hence, diagonal elements in Eq. 3.1 are always equal to 1 (when compared to itself, each element has equal importance). Also, the lower triangular elements of the matrix in Eq.3.1 are the reciprocal of the upper triangular elements as shown in Eq. 3.2. Therefore, the pair wise comparison data are required for only half of the matrix elements. For example, if element 1 is significantly more important compared to element 2, then a_{12} will have a value 9 in the upper triangle, and a_{21} will have 1/9 in the lower triangle.

STEP 3

The software known as Expert-Choice is based on multi-criteria decision making analysis which includes one of the methods is considered the most useful in the context of consistency index (CI) assessment is described and applied which consist of following steps.

1. Calculate the sum of each column of the reciprocal matrix.
2. Normalise the elements in each column by dividing by the column sum using Eq. 3.3 below. The sum of each column should be 1.

$$\overline{a_{ij}} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (3.4)$$

For all $j = 1,2,.....,n$

The normalized principal Eigen vector is also called priority vector**.** Since it is normalized, the sum of all elements in priority vector is 1. The priority vector shows relative weights among the things that we compared.

3. Calculate the average value across the row to obtain the principal Eigen vector or priority vector using Eq.3.4 below. These priority vectors show the relative weight of the decision factor.

$$W_i = \frac{\sum_{j=1}^{n} \overline{a_{ij}}}{n} \quad (3.5)$$

For all $i = 1,2,......,n$

4. Calculate the λ_{max} by the summation of products between each element of and the sum of columns of the reciprocal matrix. Even more, for consistent reciprocal matrix, the Eigen value is equal to the size of comparison matrix.
5. Calculate the Consistency Index (CI) as deviation or degree of consistency using the Eq. 3.5 below:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (3.6)$$

Where, CI = Consistency Index, λ_{max} = Eigen vector, n=size of matrix

6. Extracted the standard random consistency index (RI) value according to the size of the matrix from the Satty's random consistency index (Table-2).
7. Calculate the consistency ratio (CR) to find out the consistency of the answer by dividing the consistency index (CI) value over the random consistency index (RI), or in Eq. 3.6 below:

$$CR = \frac{CI}{RI} \quad (3.7)$$

Where, CR=Consistency Ratio I=Consistency Index, and RI= Random Consistency Index

8. Calculate the overall composite weight by normalization of linear combination of multiplication between RIWs of selection criteria and RIWs of alternatives using Eq. 3.7.

$$SI = \sum W_i X_i \quad (3.8)$$

Where, $S.I.$ = Suitability Index of each alternative W_i = RIW of particular selection criteria, X_i = RIWs of alternatives with respect to each criterion

In resulting, if the value of Consistency Ratio is ≤ 0.1 the inconsistency is acceptable. If the Consistency Ratio is > 0.1, there is a need to revise the subjective judgment until the C.I. is within the 0.1 tolerance level.

Analysis of Data

Satellite imageries of IRS-1C/1D, IKONOS and SRTM data has been used for preparation of multi thematic map/layers includes geomorphology, soil texture, land use/land cover, transport network, surface water, ground water table, habitation and slope.

Geomorphological Map

Geomorphological map has been prepared using IRS-1C/1D data, and the three categories identified and mapped in the study area.They are alluvial plain (older), flood plain, and alluvial plain (younger) ***(Fig.2)***. It was also observed from Geomorphology map that four sites out of seven sites namely Site-2, Site-3, Site-4 and Site-6 are located in identical class (alluvial plain older), while Site-

1,Site-5 and Site-7 are located in alluvial plain younger. Site-2, Site-3, Site-4 and Site-6 are considered as suitable to siting landfill Surface deposits of alluvial plain older are characterized as consolidated alluvial deposited by river like Gomti. It comprises multiple sequence of gray sand to yellow silt and clay with intermittent calcareous which are composed of oxidized, brown and highly micaceous sand of fine medium grain, and therefore, older alluvial plains are having deep groundwater prospect and low permeability (N.R.D.M.S. Report, Lucknow, 2001,).

Soil Texture Map

The soil texture map has been prepared using IRS-1C/1D satellite data and five major categories are identified and delineated in the study area as clayey silt/sand, coarse loamy, fine loamy, fine silty and loamy as shown in ***Fig.2***. Among different classes of soil, fine grained soils seem to be more suitable for landfills than coarse grained soils. However, clay compared to soils with a silty clay texture, having low drainage, shrink/swell potential and low workability usually reduces its suitability for landfills (Oweis et al., 1998). Silt to very fine silty clay, clay, mixed soil, sandy soil, clean sand/gravel have been reported to be very high, high, moderate, low and unsuitable for landfills (Brady et al., 1996; Oweis et al., 1998). According to the suitability of soil for landfill and site location containing specific soil class, a site suitability table has been prepared for soil texture (Table-3).

Landuse/ Landcover Map

Land-use/Land-cover map has been prepared using IKONOS data. In which seven broad categories identified land use and mapped in the study area namely agriculture land, built-up land, urban/rural, wasteland Forest and water bodies, industrial area, as shown in ***(Fig. 4)***. Wastelands are degraded lands include sodic lands (salt affected land) and scrub lands, which seem to be more suitable for landfills due to lack of appropriate water and soil management or on account of natural causes. However scrub lands often appear like fallow land or which could be discriminated but in essence these are also categorize as waste land and considered as moderately suitable for solid waste disposal. Sites which are located within or adjacent to built-up area, vacant plots and other important recreational or tourism-related activities are unsuitable for disposal (Thoso, 2007). Consequently, it is noticed that Site-1, Site-4, Site-5 and Site-7 are more suitable area for disposal, while Site-2, Site-3 and Site-6 are seen to be moderately suitable.

Surface Water Body Map

Surface water bodies have been grouped and mapped into four classes as river, canal / distributaries, drainage / nala and lakes / ponds. Using ***Fig.5*** distances of all sites have been measured with respect to each surface water body in terms of its suitability.It has been considered that region within 1000 m. from river and canal (Thoso, 2007); 500 m. from drain and 200 m. from large water body are unsuitable for landfill (Rahman et al., 2007). Accordingly, it is observed that Site-1 and Site-5 are the most suitable area for waste disposal site, while Site-2 and Site-4 are found to be moderately suitable for disposal site.

Transport Network Map

The transportation network map has been prepared based on Survey of India (SOI) topographical map of study area surveyed between 1973-76 and it has been updated using IKONOS sat.1m. resolution image. The categories identified in the study area. They are railway line, national highway (NH), city major roads (CMjR) and city minor roads (CMnR) as shown in (***Fig. 6***). According to Allen (2000), distance greater than 1 km. from NH, SH and CMjR should be avoided. The landfill site should not be placed too far away from existing road networks to avoid the expensive cost of constructing connecting roads (Lin, 1999) and transportation cost of solid waste. Distance from minor roads of the city should be smaller than 30 m. (Cantwell, 1999) and between 200 m. and 1 km. of a railway line. Distances of different sites from existing transportation network have been measured for proximity of transport network with respect to each site. It is seen that Site-3, Site-4, Site-5 and Site-6 are suitable because these are near to NH, CMjR, and CMnR, whereas, Site-1, Site-2 and Site-7 are unsuitable sites having distances beyond the required distance from NH, CMjR and CMnR.

Slope Map

Slope map has been generated from Digital Elevation Model (DEM). The distribution of slope values in the study area ranges between 0^0 and 20° as shown in ***Fig.7*** (Erkut et al. (1991) state that if the slope is too steep, it is difficult and costly to construct the landfill. Slope is an important factor when siting a landfill, since higher slopes would increase runoff of pollutants from the landfill, and thereby contaminate areas further away from the landfill site (Lin et al., 1999). As a matter of fact, Lin and Kao's study (1999) suggests that a slope less than 12% would be suitable for the prevention of contaminant runoff. All Sites .i.e. Site-1, Site-2, Site-3, Site-4, Site-5, Site-6 and Site-7 are located in < 5^0 slope .Thus, it is considered that, region within 5^0 slope, region within 5^0 to 10^0 slope and region greater than 12^0 slope are taken as suitable, moderately suitable and low suitable respectively for landfill (Sener, 2004). **Table-4** shows the slope range according to their suitability for waste disposal.

Habitation Map

Habitation map of study area has been prepared using IKONOS satellite's 1m. resolution data. In which two broad categories are identified and interpreted, they are built-up (urban) and built up (rural) as shown in (***Fig.8***). According to Rahman (2007), the distance from urban built-up area should be at least 1 km and from isolated houses, it should be 500 m to locate a landfill site. For towns and villages having a population greater than 500, distance of 500 m is considered suitable. Siddiqui (1996) suggests that no new landfill site should be located closer than 0.4 km (0.25 m) from a collection of ten or more houses. On the other hand, the landfill site should be located within 10 km of an urban area due to the economic considerations.

Accordingly, it has been observed that, Site-4 and Site-1 are considered as most suitable areas because these are located at adequate distances from urban and rural built-up land. Site-5 and site-6 are considered as moderately suitable and Site-2, Site-3 and Site-7 are considered as least suitable due to inadequate distance from urban built-up land.

Calculation of Relative Weights for Alternatives

Following the procedure laid down in relative weights (RW), each alternative with respect to each selection criteria was calculated including geomorphology, soil texture, land-use/land-cover, transport network, ground water table, surface water, habitation and slope. The relative weights of Site-2, Site-3, Site-4 and Site-6 are contributing identical value (0.200) with respect to geomorphology which shows that the priorities of Site-2, Site-3, Site-4 and Site-6 are equally important with respect to geomorphology. Site-1, Site-5, Site-7 is found to have very low priority as (0.067) in comparison to Site-2, Site-3, Site-4 and Site-6.

Site-2, Site-3, Site-4, Site-5, Site-6 and Site-7 are equally important with respect to soil texture because these are found to have equal relative weights as (0.091). Site-1 is found to be very high importance with high relative weight as (0.455).

Site-1, Site-4, Site-5 and Site-7 are found to have identical relative weight (0.200) with respect to land-use/land-cover. Site-2, Site-3 and Site-6 are found to have relative weight (0.067). It has been seen that Site-1, Site-4, Site-5 and Site-7 are equally important with respect to land-use/land-cover, while, Site-2, Site-3 and Site-6 have very poor alternatives in comparison to Site-1, Site-4, Site-5 and Site-7.

Relative weights with respect to transportation network shows that Site-5 is resulting into highest relative weight as 0.307, thus considered as most dominant alternative. Site-6, having RW 0.213, is found to be comparatively better than Site-1, Site-2, Site-3, Site-4 and Site-7. Site-1, Site-2 and Site-7 are having low relative weights as 0.047, 0.095 and 0.087 respectively. However, Site-3 and Site-4 are fairly better than Site-1, Site-2 and Site-7.

According to relative weights of alternatives with respect to ground water table, Site-5 and Site-6 are found to have highest relative weight as 0.314 that shows Site-5 and Site-6 are most prior alternative followed by other. Site-1, Site-3 and Site-2, Site-4 are found to be identical as 0.092 and 0.042 respectively. However, Site-7 has relative weight of 0.103 which is higher than Site-1, Site-3 and Site-2, Site-4.

It has been observed that Site-1 is the best alternative contributing highest RW (0.351), followed by Site-5, which is contributing little lesser RW (0.229). Site-3, Site-6 and Site-7 are seen to have low relative weights as 0.062, 0.065 and 0.048 respectively thus considered as low priority with respect to surface water. While site-2 and Site-4 are moderate alternative having moderate relative values 0.126 and 0.119 respectively while talking the priorities of alternatives with respect to surface water bodies.

According to pairwise comparison of alternatives with respect to habitation, Site-4 is found to be best alternative having highest relative weight as (0.326), followed by Site-1, which is having little lesser RW (0.251) with respect to habitation. Site-5 and Site-6 are seen to be resulting into moderate equal relative weights as (0.138). However, Site-2, Site-3 and Site-7 are seen to have low relative weights as 0.031, 0.043 and 0.071 respectively thus considered as low priority with respect to habitation.

In pairwise comparison with respect to slope, it is seen that, Site-1, Site-2, Site-3, Site-4, Site-5, Site-6 and Site-7 are contributing identical relative weight (0.143) with respect to slope showing that the priorities of these sites are equally important with respect to slope.

Calculation of Maximal Eigen value, Consistency Index and Consistency Ratio for Alternatives

Maximal Eigen value ($\lambda_{\max}$), consistency index (CI) and consistency ratio (CR) for alternatives with respect to each selection criterion have been calculated using the equations as discussed earlier and tabulated in Table-5.

Calculation of Relative Weights for Selection Criteria

Amongst various relative weights for the selection criteria, Road/transport network has the results into highest value of relative weight (0.222) followed by others, which seems to be the most dominant criteria. Road is seen to be considerably more important than SWB (0.193) and moderately more important than Soil (0.108), Landuse/Landcover (0.121), GWT (0.104), Habitation (0.080) and Slope (0.118). Geom and Habitation results into lowest values of relative weights as 0.055 and 0.080 respectively, indicates that these criteria have least significance.

Calculation of Overall Composite Weight

The overall composite weight is calculated by combined the relative weights of alternatives along with the relative weights of the selection criteria followed by a summation of a results to yield a suitability index (Eastman, 2001) using Eq.3.8 as shown below.

$$SI = \sum W_i X_i$$

Where, $S.I. =$ Suitability Index of each alternative

W_i = RW of particular selection criteria

X_i = RWs of alternatives with respect to each criterion

Table-6 shows the suitability index of alternatives for landfill with respect to each selection criteria.

All the possible selected sites of the study area are ranked according to their suitability for landfill. The suitability index varies from 0.210 for Site-5 (Near Mohan Ganj) to 0.201 for Site-1 (Near Mastemau Village). Site-6 (Near Sahu Village) and Site-4 (Near Kunwar Bahadur Khera) are having moderate value of sensitivity index as 0.149 and 0.148 respectively. Thus, Site-5 (Near Mohan Ganj) and Site-1 (Near Mastemau Village) having higher suitability index are identified as potential landfill sites in the study area (Malczewski, 1999; Eastman, 1999; Mahini, et al., 2006; Sener, 2005). Site-4 and site-6 are found to have moderately suitable.

Results and Discussion

During field verification, Site-1 and site-5 are found to be most suitable sites for landfill in terms of criteria used in the analysis. However, Site-1 is found not suitable. For instance Site-1 has insufficient distance from NH and RL but it is seen to be possible to transport the waste to disposal site (Site-1) by passing through the CMjR and CMnR of the city. The current land-use/ land-cover for Site-1 and Site-5 are found to be open scrub with having the ground water table as 50 to 60 feet & 100 feet respectively which is found to be most appropriate condition for landfill because scrub land (degraded lands) are more convenient to landfill which are characterized by waste lands due to improper soil and water management results in degraded land formation.

Site-4 & Site-6 are also observed as moderately suitable in comparison to Site-2, sie-3 and Site-7 because geomorphology, soil texture, slope, transportation and ground water table are found to be convenient to landfill for Site-3. However, during field verification, Site-4 & Site-6 are found to have some no suitability in terms of surface water body because it has not considerable distance from canal which is found to be undesirable condition because landfills create noxious gases and leakage that make them unsuitable to be in proximity to surface waters (Erkut et al., 1991; Bagchi, 1994; Dorhofer et al., 1998).
The current land-use/ land-cover for Site-4 is open scrub while for site-6 is fallow land.

Site-2, Site-3 and Site-7 are found to have many faults in terms of criteria used in the analysis. Site-2 is found to be not suitable for landfill because, the distance from urban built up area is found to be really insufficient as the Site -2 is adjacent to the habitation. Siddiqui (1996) suggests that no new landfill site should be located closer than 0.4 km from a collection of ten or more houses has been considered. On the other hand, the landfill site should be located within 10 km of an urban area due to the economic considerations (Serwan et al., 1998). For Site-3 & Site-7 during field verification it is found that Site-3 and Site-7 has not considerable distance from canal as described above in terms of surface water. This is found to be in undesirable condition. The distance from urban built-up area and rural built up area is found to be not at considerable distance from site-3.

After doing pair wise comparison analysis Site-2, Site-3 & Site-7 are not determined as suitable for landfill due to their overall performance because the model gives some lower scores for these sites but all of them should have to be field verified as even the lowest score whereas site-5 and site-1 is determined respectively the most suitable sites in the study area due to more priority value among these sites and considered as being useful for the proposed waste disposal site by the Lucknow Municipal Development Corporation.

Conclusion

The study demonstrates the capability of Remote Sensing data for preparation of multi-criterion layers or thematic maps and their spatial analysis in Geographical Information System (GIS) environment and Analytical Hierarchy Process (AHP) model's applicability for assignment of weightage, pairwise comparison, multi criterion decision making analysis (MCDM) and calculation of vector for identification and selection of most suitable sites for landfill in the study area.

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Table-1: The Saaty's Rating Scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

Table-2: Saaty's Random Consistency Indices

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Where, n = size of the comparison matrix,
RI = Random Consistency Index

Table-3: Site Number/ Soil Texture and Landfill Suitability

S. No.	Site number/ Soil Texture	Suitability
1	Site-1/ Fine silty	High
2	Site-2/ Fine Loamy	Moderate
3	Site-3/ Fine Loamy	Moderate
4	Site-4/ Loamy	Moderate
5	Site-5/Clayey Silt/Sand	Moderate
6	Site-6/ Loamy	Moderate
7	Site-7/Fine Loamy	Moderate

Table-4: Slope Ranges According to their Suitability for Landfill

Slope Range	Suitability	Sites
$< 5^0$	High	Site-1,Site-3, Site-2, Site-4, Site-5, Site-6, Site-7
6^0 to10^0	Moderate	
11^0 to15^0	Low	-
$>15^0$	Unsuitable	-

Table-5: Calculation of Maximal Eigen value, Consistency Index and Consistency Ratio for Alternatives

S. No.	Pair-Wise Comparison for Alternatives with respect to each Selection Criterion	λ_{max}	CI	RI	CR
1	Geomorphology	7.01	0.00	1.32	0.00
2	Soil Texture	7.00	0.00	1.32	0.00
3	Land-Use/ Land-Cover	7.01	0.00	1.32	0.00
4	Transport Network	7.78	0.13	1.32	0.09
5	Ground Water Table	7.24	0.04	1.32	0.03
6	Surface Water	7.54	0.09	1.32	0.06
7	Habitation	7.61	0.10	1.32	0.08
8	Slope	7.00	0.00	1.32	0.00

Table-6: Calculated Relative Weights of Selection Criteria and Alternatives

GOAL	CRITERIA (*Wi*)	ALTERNATIVES (*Xi*)	
LANDFILL SITE SELECTION (1.000)	GEOMORPHOLOGY (0.055)	SITE-1	0.067
		SITE-2	0.200
		SITE-3	0.200
		SITE-4	0.200
		SITE-5	0.067
		SITE-6	0.200
		SITE-7	0.067
	SOIL TEXTURE (0.108)	SITE-1	0.455
		SITE-2	0.091
		SITE-3	0.091
		SITE-4	0.091
		SITE-5	0.091
		SITE-6	0.091
		SITE-7	0.091
	LAND-USE/LAND-COVER (0.121)	SITE-1	0.200
		SITE-2	0.067
		SITE-3	0.067
		SITE-4	0.200
		SITE-5	0.200
		SITE-6	0.067
		SITE-7	0.200
	TRANSPORT NETWORK (0.222)	SITE-1	0.047
		SITE-2	0.095
		SITE-3	0.106
		SITE-4	0.145
		SITE-5	0.307
		SITE-6	0.231
		SITE-7	0.087
	GROUND WATER TABLE (0.104)	SITE-1	0.092
		SITE-2	0.042
		SITE-3	0.092
		SITE-4	0.042
		SITE-5	0.314
		SITE-6	0.314

		SITE-7	0.103
	SURFACE WATER (0.193)	SITE-1	0.351
		SITE-2	0.126
		SITE-3	0.062
		SITE-4	0.119
		SITE-5	0.229
		SITE-6	0.065
		SITE-7	0.048
	HABITATION (0.080)	SITE-1	0.251
		SITE-2	0.031
		SITE-3	0.043
		SITE-4	0.326
		SITE-5	0.138
		SITE-6	0.138
		SITE-7	0.071
	SLOPE (0.118)	SITE-1	0.143
		SITE-2	0.143
		SITE-3	0.143
		SITE-4	0.143
		SITE-5	0.143
		SITE-6	0.143
		SITE-7	0.143

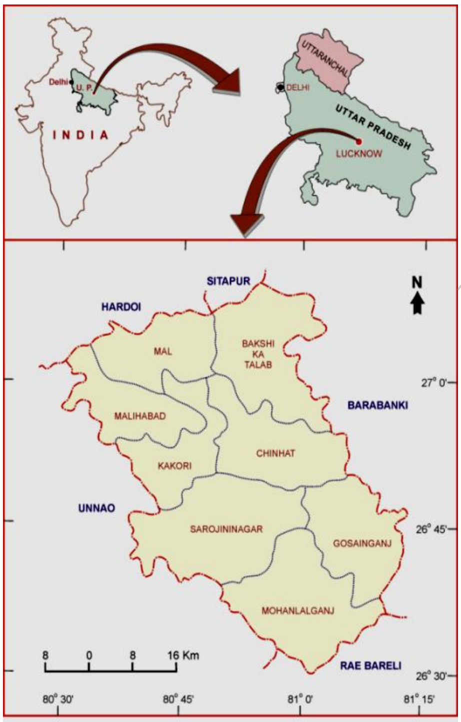

Fig.1 Location Map of Study Area

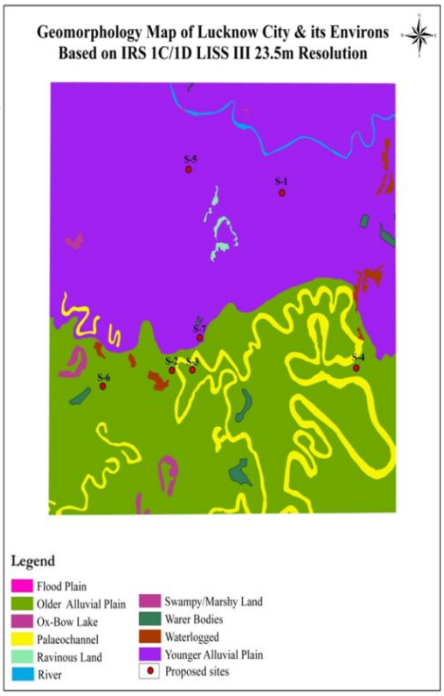

Fig.2 Geomorphology Map

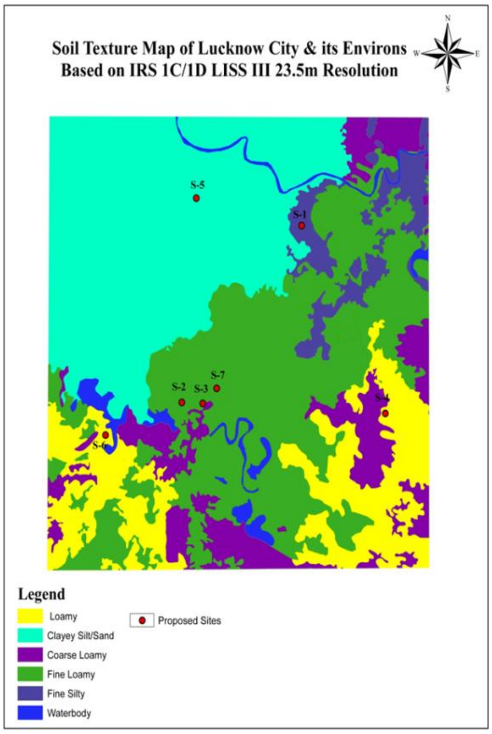

Fig.3 SoilTextureMap

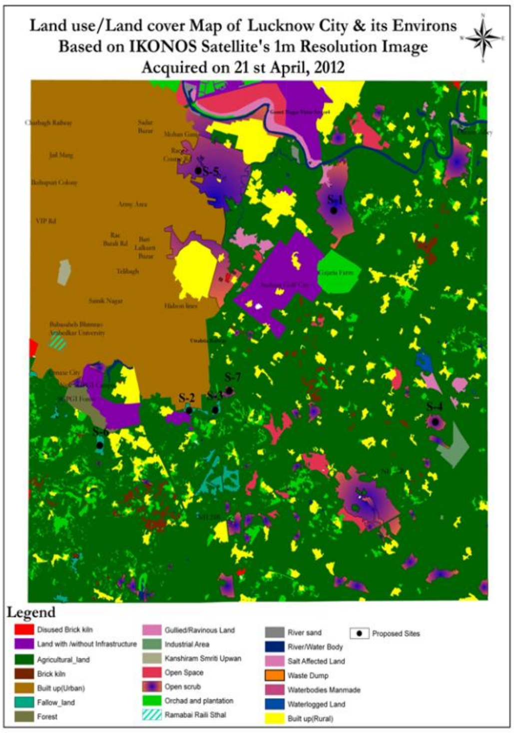

Fig.4 Landuse/Landcover Map

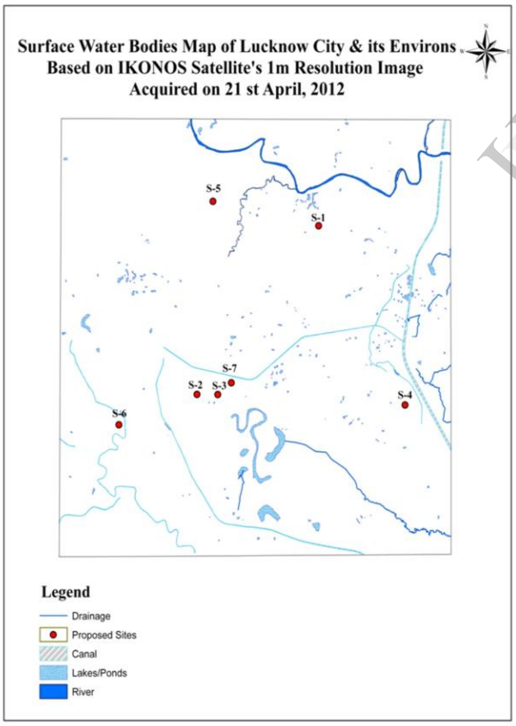

Fig.5 Surface Waterbodies Map

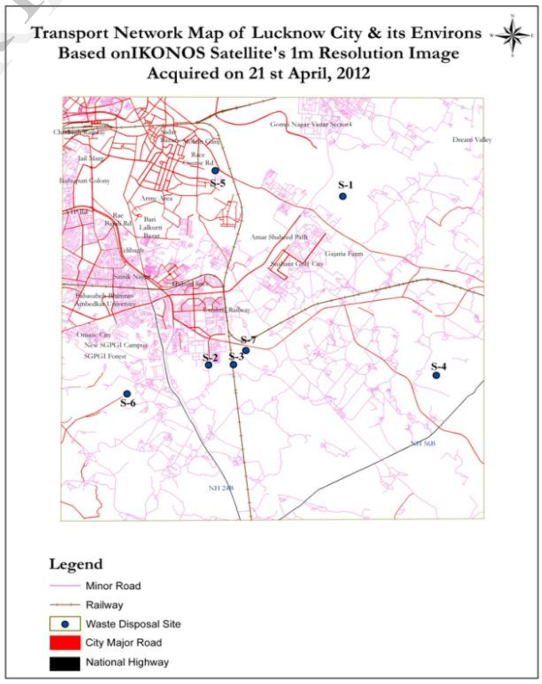

Fig.6 Transport Network Map

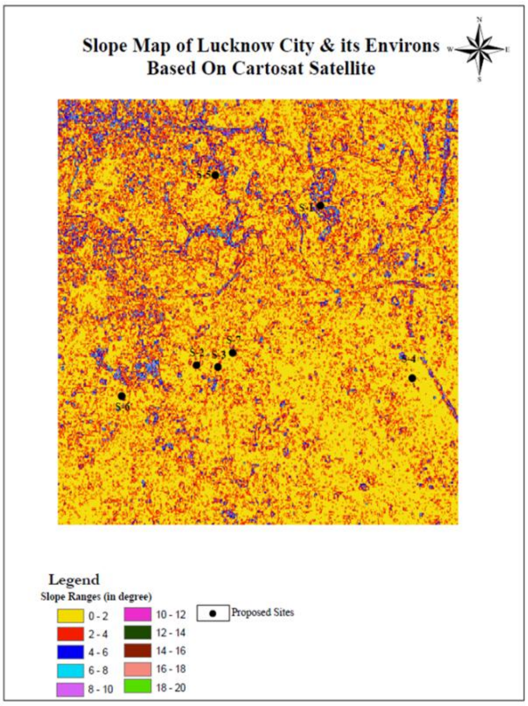

Fig.7 Slope Map

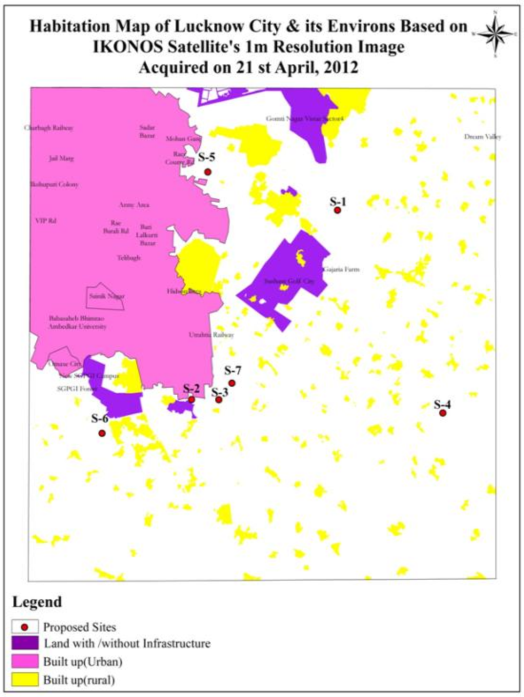

Fig.8 Habitation Map

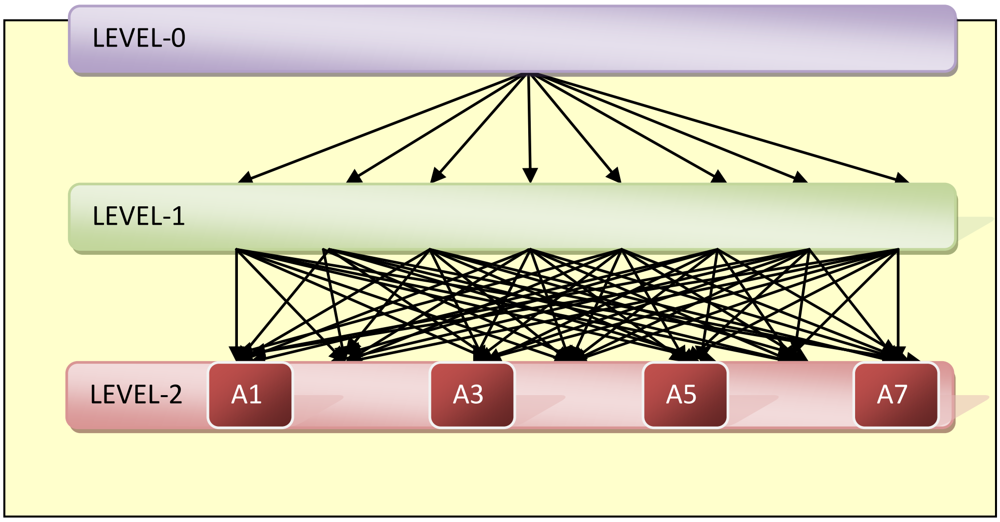

Fig. 9: Decision Hierarchy for Landfill Site Selection

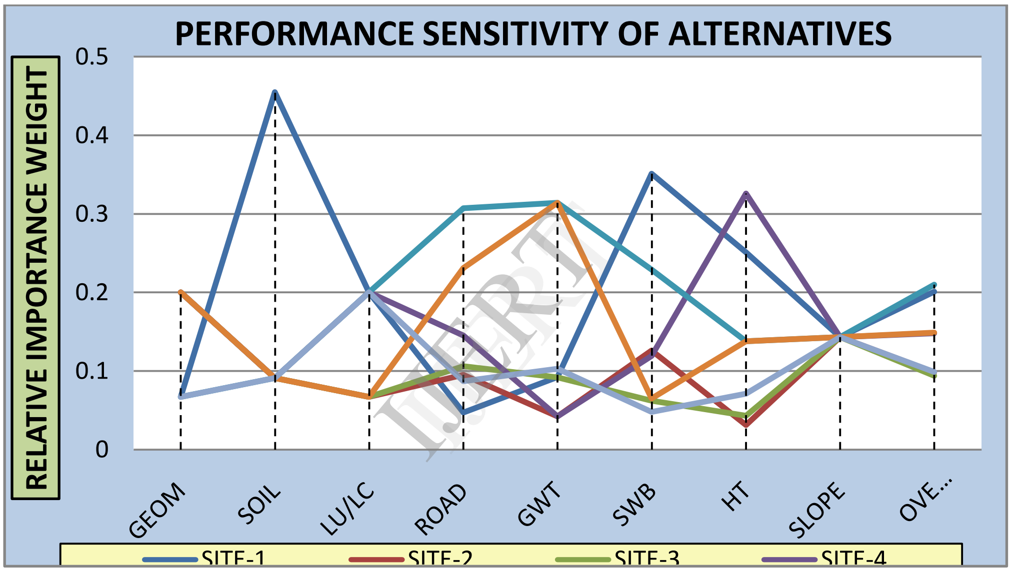

Fig. 10: Performance Sensitivity of Alternatives with respect to each Selection Criteria

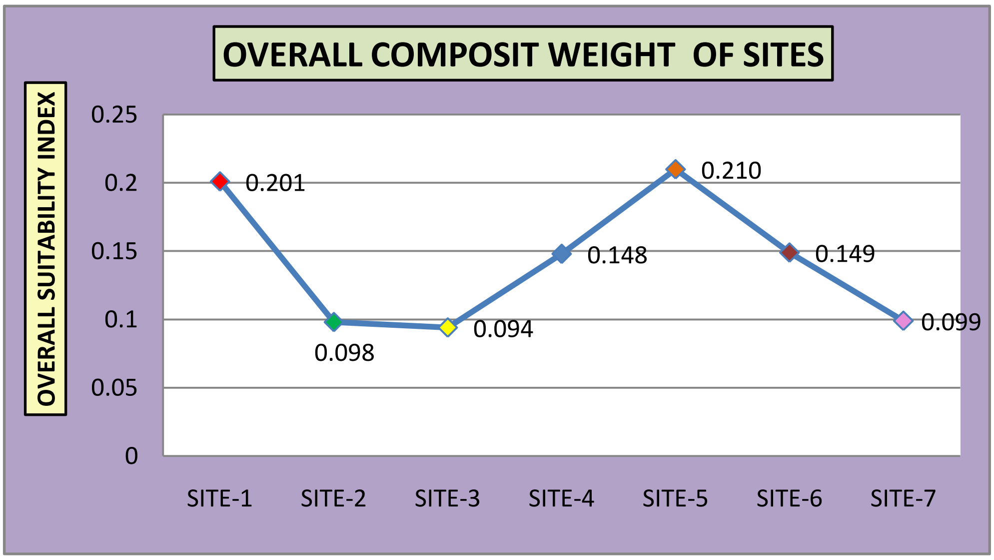

Fig. 11: Overall Composite Weight of Site