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GIS-BASED MULTI-CRITERIA EVALUATION TECHNIQUES FOR DEMARCATION OF SOLID WASTE DISPOSAL SITE LOCATIONS IN SOLAPUR CITY, MAHARASHTRA, INDIA

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Abstract : Environmental degradation has become one of the critical problem for the people of Solapur city, which is spreading due to urban sprawl, industrialization and overpopulation. These all factors are responsible for producing large amount of solid waste and unmanaged solid waste disposal is leading towards environmental degradation. Hence, there is a need of proper and efficient plans for management and disposal of solid waste in the Solapur city. Solid waste disposal are the most widely performed practices for dumping municipal solid waste throughout the world, including India, due to its low cost and less technical requirements. Selecting an appropriate location for the purpose of landfill is a tough process with respect to social, environmental and technical concerns. So far the scientific selection of the sites for the construction of a landfill in the urban areas is based on government Laws & regulations, depth of the groundwater table, existence of surface water bodies and the separation between roads. In the present study a scientific and GIS based technical approach based on multi-criteria decision making, Analytical Hierarchy Process (AHP) and site suitability modelling has been followed for the demarcation of suitable sites for the construction of a solid waste disposal sites in the Solapur city.

***Index Terms* –** *Solid waste disposal site selection, AHP (Analytical Hierarchy Process), GIS, Multi Criteria Decision Making (MCDA), Remote Sensing*

I. INTRODUCTION

The continuous expanding urbanization and increasing population are the major contributing factors for problems related with municipal solid waste management (Sumathi et al., 2008). The volume and production of solid waste both are increasing with accelerated rate. The phrase "solid waste" (SW) includes litter, slurry domestic solid garbage created by anthropogenic activities and other living organisms, which are often disregarded for reuse or recycling. SW covers waste generated through activities in business, industry, agriculture and society, but excluding sewage from households, silt in water, wedged solids in untreated sewage from businesses, colloidal solids in irrigation systems or any of the other countless common wastes. The solid waste is expanding day by day as the world is moving more and more towards an urban future. According to the prediction done by Hoornweg and Bhada-Tata 2012, daily waste generation will reach 1.42 kg per capita per day by 2025 which is equivalent to 2.2 billion tons per year.

The solid waste management of Solapur city is carried out by Solapur Municipal Corporation (SMC), which is the governing body of city in the Maharashtra state. SMC is led by the Municipal Commissioner and supported by 16 truck, 12 dumper, 6 compactor and 2407 tippers for collection of wet as well as solid waste from bins and street sweeping. Approximately 792.8 metric tons of solid waste and other garbage is collected on daily basis in Solapur city (City development plan 2041, Solapur). The collected solid waste and garbage is basically produced by the residential areas, streets, alleys, vacant land, building and demolition sites, parks, gardens, commercial establishments such roadside trees, hotels, stores, restaurants and markets.

The Solapur city is divided in to six zones having total 98 wards. In all the wards the practice of garbage isolation is performed, where the waste is collected in different chambers and distinguished as wet waste and dry waste. Every day only one collection per day or less is carried out for entire city. Collection of waste from home to home is not possible every day hence all the family units are required to keep their waste in selected places. Unfortunately, the solid waste from the slum areas is not collected on daily basis because of the unhygienic conditions over there. In the whole Solapur city, the solid waste management systems need proper site selection and it has become one of the most difficult part and the policymakers and officials are quite concerned about it. Number of factors including government regulation, government and municipal funding, urbanization, rising population densities, growing environmental awareness, public health, decreasing land availability for solid waste disposal site and increasing political and social opposition are responsible for the establishment of proper solid waste disposal sites in the study area.

The selection of an appropriate solid waste disposal site is crucial thing and failing to do that may cause a number of negative effects, including the risk to the public health caused by unsuitable landfills sites which can pollute the soil cover, air and surface as well as subsurface water resources. The scientific method for selection of proper land fill sites can be done based on analysis of the most effective approach by taking environmental, ecological, legal, and economic factors into account. The detection of proper and suitable sites for solid waste management can be carried out using GIS techniques. GIS is an effective tool for managing and analyzing large amounts of spatially distributed data from many sources, making it a key component in the solid waste disposal site selection process. GIS allows management of enormous amounts of spatial data from several sources (Siddiqui et al. 1996) at a time with greater accuracy. Multi criteria decision analysis is an appropriate method is getting utilized by the decision-makers. In multi-criteria analyses, weights are evaluated in a variety of methods, including rating, ranking and the AHP. The weights of the criteria can be determined using the pairwise comparison method in AHP. In the present study the Weighted Linear Combination (WLC) is followed which is a technique for combining criteria into a single composite index. The final site has been identifies based on the outcomes of AHP and combined field inspections at the shortlisted locations and validation of their viability for construction point of view.

II. STUDY AREA

Solapur city of Maharashtra state (Figure 1) has been selected for identification of suitable sites for solid waste management. The city is located close to the Karnataka border at south-east region of Maharashtra state. Solapur city is facing rapid rate of population growth, economic growth, urbanization and industrialization since long time. All together are resulting in to the solid waste generation at an accelerated rate. The waste produced in all 98 wards includes all kinds of waste including biodegradable, non-biodegradable, construction, metal, plastic and some other kinds of waste material in the form of garbage.

Study area is located in the state of Maharashtra and spread over an area of 179 km^2. The population of Solapur was 1041886 in 2021, compared with 951,558 in 2011. It indicates tremendous increase during a decade and this is a key contributor to increasing Municipal Solid Waste (MSW) in Solapur. Inappropriate management of solid waste in Solapur city is making the region prone to the potential risks to the environment and public health and the solid waste management (SWM) has occurred as one of the biggest challenges for Solapur city. Previous studies show that the unsafe disposal of waste generates dangerous gases and leachates (Chavan and Zhambre 2013). Therefore, it is overbearing that the 420 Metric Ton of waste generated per day in Solapur should be properly disposed in accordance with the 'Solid Waste Management Rules 2016' and in the appropriate solid waste disposal sites.

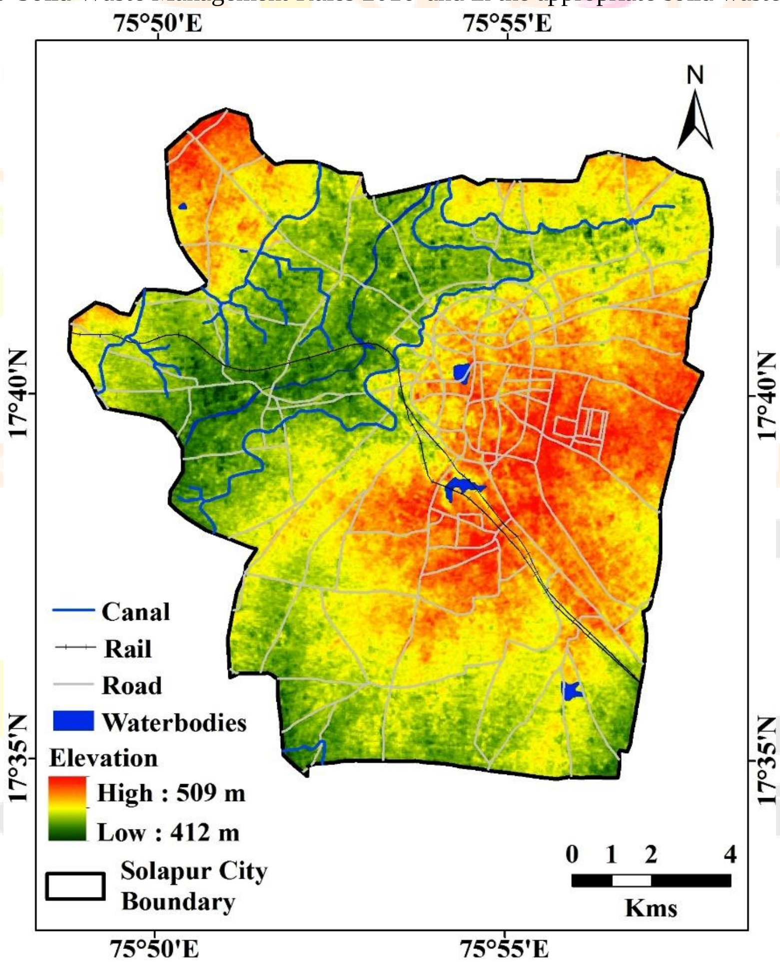

Figure 1 Location of study area

In the study area it is found that the main component of waste management is segregation of dry and wet waste. Waste segregation plays an important role in confirming proper recovery, reuse and recycling of collected waste material. In Solapur city, the Waste segregation at the source is carried out with approximately 87% of the waste generated. Active participation of citizens from Solapur city will be the key to the success of waste segregation at source. Even though people are supposed to sort the waste, around 13% of household from study area don't segregate the waste into dry and wet waste.

III. MATERIAL AND METHODOLOGY

ESRI ArcGIS 10.8 software is utilized for identification and demarcation of solid waste disposal sites in the study area. The basic use of the software contains the utilization of several tools, including buffer, clip, intersect, union, merge, dissolve, identify, weighted overlay, and erase functions. Freely downloadable Satellite data (LISS III) from government of India is used for generating Land use Land cover maps. The ancillary data is collected from Solapur Municipal Corporation this data is considered as primary data.

Secondary data is generated by processing the primary data and applying cartographic techniques. SRTM 1 Arc-Second Global satellite imagery-based DEM data, in raster format with a 30m resolution, was downloaded from USGS Earth Explorer and used for extraction of slope of the study area.

Establishing standards for selecting potential solid waste disposal site was the initial step in this work. The parameters were therefore established after reviewing previous research on solid waste disposal selection criteria. Slope, land use, water bodies, roads, settlement and the required data layers for interpretation were the criteria for the selection of suitable sites for dumping the solid waste (Table 2). Basically five parameters including road network, stream network & surface waterbody, slope of the surface, built up and land use land cover were preferred for suitability classification (Table no. 1) of the study area for the purpose of solid waste disposal sites identification.

Table 1. Suitability classification based on distance and slope

Criteria	**Distance**	**Suitability**	**Rank**
Road Network	<100m	Unsuitable	1
	100-200m	Least Unsuitable	2
	200m-300m	Most Suitable	5
	300m-400m	Suitable	4
	Above 400m	Less suitable	3
Stream Network & Surface waterbody	<100m	Unsuitable	1
	100-200m	Least Unsuitable	2
	200m-300m	Less suitable	3
	300m-400m	Suitable	4
	Above 400m	Most suitable	5
Slope (Degree)	< 4	Most suitable	5
	4-8	Suitable	3
	8-12	Least Unsuitable	2
	Above 12	Unsuitable	1
Built up area	<100m	Unsuitable	1
	100-200m	Least Unsuitable	2
	200m-300m	Less suitable	3
	300m-400m	Suitable	4
	Above 400m	Most Suitable	5
Land Use Land Cover	Water body and stream	Unsuitable	1
	Built-up	Least Unsuitable	2
	Agricultural/Forest	Suitable	3
	Wasteland	Most suitable	4

Table 2. Planning parameters and their descriptions

Sr. No	Planning Parameters	Description
1	Road accessibility	It enables the efficient conveyance of garbage to dump locations.
2	Separation from water bodies	While it serves as a source of drinking water, it constantly monitors for water pollution.
3	Slope	The slope should be designed so that leaching is discouraged.
4	Settlement	Specifications for land use should permit the development of solid waste disposal site.
5	Future growth	Future waste generation will increase together with population growth.

Road: The selected solid waste disposal site must be within 400 meters from the road network due to high transportation costs, because the dumping sites which are far away from major roadways will be difficult to access the solid waste disposal sites. Hence those locations falling within 400 m from main roadways are considered as suitable location (Figure 2). Only around 19% of the overall land usage is contributed by the roads and transportation zone, which is sufficient by standards. According to URDPFI guidelines, a minimum of 12–14% of the land must be designated as a road and transportation zone. Solapur city has a comprehensive network of highways, including the NH-9, NH-13, SH151 and other metaled roads. The center of the city is formed by a network of roads in a ring-radial pattern. The city's residential parts are connected by recently built roads.

Water Body: A buffer zone of 500 meters was generated around each water body present in the study area and then divided the area in to 5 rank categories. Where rank 1 is assigned for an unsuitable location for the purpose of solid waste disposal sites and a rank 5 is assigned for the most suitable location (Figure 3). Based on the current land use analysis, approximately 3.77 km^2 (8.27%) of the total developed area are occupied by water bodies. Siddeshwar Lake and Shambhaji Lake are the two major lakes located in the Solapur city.

Slope: Before constructing new infrastructure, especially solid waste disposal, the examination of slope of the selected area is very important. According to the worst-to-best designs, Paul & Ghosh, (2022), has assigned values to the gradients ranging from 1 to 5. In the present study , number 1 is considered as worst location and 5 considered as excellent location. Also, authors have recommended that the slope angle between 0° and 4° are identifies as best suitable location for the purpose of solid waste disposal, whereas the slopes of the area more than 12° have been rejected (Figure 4).

Built up area: The solid waste disposal sites close to the residential areas can create very harmful effects with respect to the public health. These sites emit poisonous gases such as Hydrogen Sulphide (H_2S) and this gas has potential to severely impact the respiratory organs of human being and can cause lung cancer. Hence, in order to prevent public health issues from the solid waste disposal biohazards, the dumping site was selected far away from the residential areas. For identifying the appropriate distance between the solid waste disposal sites and residential areas, a buffer zone of 500 m was generated and the area falling within this buffer zone is avoided, on the other hand the area having more than 500 m distance from the residential zone are identifies as suitable locations for solid waste disposal sites (Figure 5).

During the field checks, it was found that slum settlements are quite dispersed throughout most of the areas in Solapur city. According to the city development plan report, during the year 2011, there are 220 slum communities in the city. Out of which 159 slum communities (72%) are authorized and 61 (28%) are unauthorized. Based on 2011 censes approximately 2.92 lakh people Solapur's population lives in slum areas. In the past record's of 2001 census, approximately 2.18 lakh of the city's population were the resident of slum area. It indicates that the city's slum population has grown by 34% over the past ten years, surpassing the city's average population growth of 9.02%. This suggests that the migration from other surrounding places is causing the population growth in the city's slum areas to rise.

Land use/Land cover: The land use land cover of the Solapur city is divided in to 4 ranks. Which includes water bodies, streams, forests, agricultural crops, wastelands and built-up area. Rank 1 was assigned to the water body and stream network, rank 2 were assigned for built up areas, agricultural sector or forest area has been ranked as 3, wastelands are given rank 4, which is the top most rank in this section (Figure 6).

In the present study the AHP technique which is a part of multi-criteria decision-making techniques is utilized to identify the suitable locations for solid waste disposal site. Saaty (1977) has developed the AHP techniques and this is a mathematical method for analyzing difficult choices including several criteria. In the Pairwise comparison in the context of the AHP technique compares the decision analysis criteria and establishes appropriate values for each of these criteria. As indicated in the below table (Table 3) the comparison matrix illustrates the significance of each assigned criterion in the left column in relation to each criterion in a right row. A scale from 1 to 9 is assigned, where 1 indicates the importance of both column and row components equally.

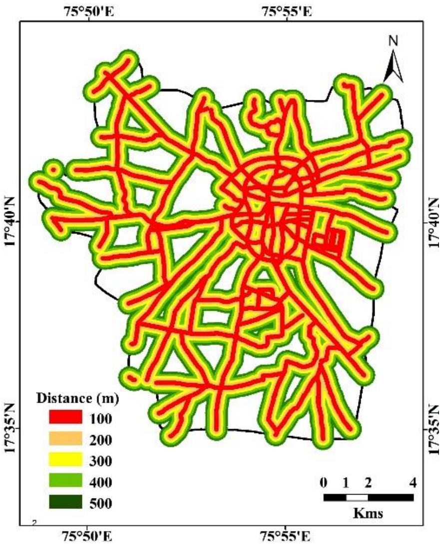

Figure 2. Buffer zone provided for road

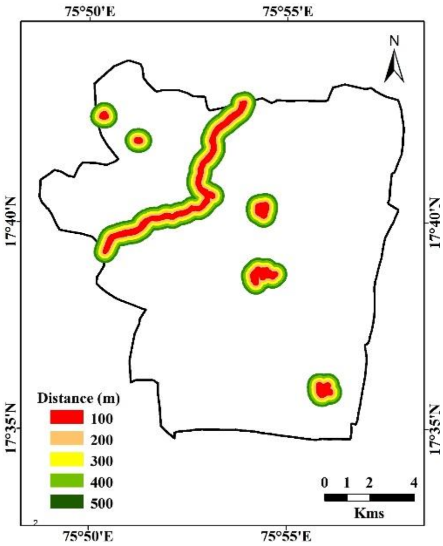

Figure 3. Buffer zone provided for waterbody and stream

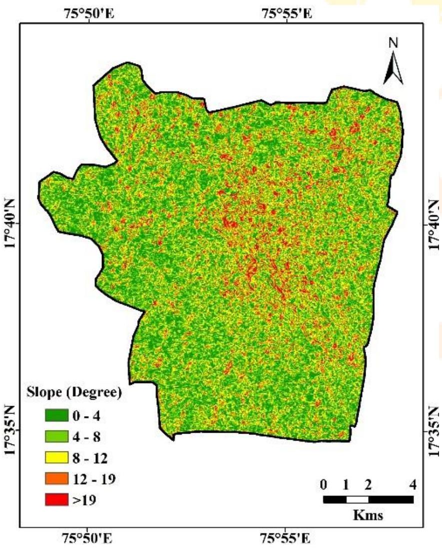

Figure 3. Slope map of Solapur city

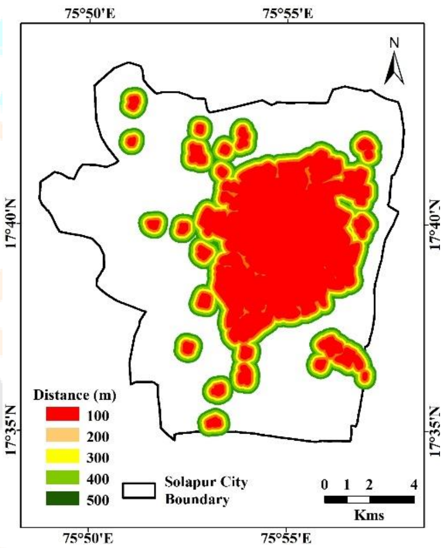

Figure 4. Buffer zone provided for settlement

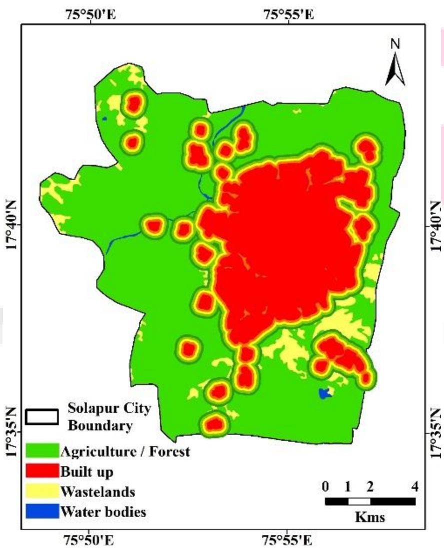

Figure 5. LULC map of Solapur city

Table 3. Rating scale of different parameters

Rating	Definition

9	Row extremely more important
8	Row very strongly to extremely more important
7	Row very strongly more important
6	Row strongly to very strongly more important
5	Row strongly more important
4	Row moderately to strongly more important
3	Row moderately more important
2	Row equally important to moderately more important
1	Row and column equally important
1/2	Column equally important to moderately more important
1/3	Column moderately more important
1/4	Column moderately to strongly more important
1/5	Column strongly more important
1/6	Column strongly to very strongly more important
1/7	Column very strongly more important
1/8	Column very strongly to extremely more important
1/9	Column extremely more important

Table 4. Comparison matrix

Item Description	**Land use**	**Waterbodies**	**Settlement**	**Slope**	**Road**
Land use	1.00	0.50	0.25	7.00	3.00
Waterbodies	2.00	1.00	0.50	7.00	7.00
Settlement	4.00	2.00	1.00	9.00	9.00
Slope	0.14	0.14	0.11	1.00	0.50
Road	0.33	0.14	0.11	2.00	1.00

Consistency ratio – 0.03 Reasonable consistency

In AHP estimations, a pairwise comparison produces a matrix, which is then calculated to determine the weights of the particular criteria. The consistency ratio (CR) of decisions have been determined via pairwise comparison. The random probability of values being obtained is shown by CR in a pairwise comparison matrix (Table 4). After getting values from each comparison the relative criterion has been given a particular score for estimations of weighted aggregate of 1 i.e. 100% weightage.

The Priority table, which was generated using the online AHP calculator, shows that the settlement area received the highest priority while the slope factor had the lowest priority (Table 5).

Table 5. Weightage to different parameters

Parameters	**Weight**
LULC	16.30%
Waterbodies	28.00%
Built up	46.80%
Slope	03.50%
Road	05.40%

The final suitability map was generated after assigning weights to each criterion based on the AHP approach and sub-criteria weighting. The criterion maps were then classified using ArcGIS 10.3 software after getting converted from vector format to raster format. Using the ArcMap weighted overlay tool, the analysis was further performed by multiplying each criterion by its weight in addition to a second criterion for identification of the best solid waste disposal locations. All the findings were finally categorized into four groups: including unsuitable, less-suitable, suitable, and best-suitable (Table 6).

Present study suggests that, based on the weighted overlay analysis, only 4.45% of the land is best suitable for the purpose of solid waste disposal site under the current conditions, with 64.47% of the area can be considered as suitable, whereas 32.35% can be considered to be less suitable and 0.73% area in unsuitable zone for the solid waste disposal sites (Figure 7 and Table 6).

Table 6. Selection site area coverage

Site	Area (Km.^{2})	Area (%)
Unsuitable	1.3	0.73
Less Suitable	57.9	32.35
Suitable	111.84	64.47
Best Suitable	7.96	4.45

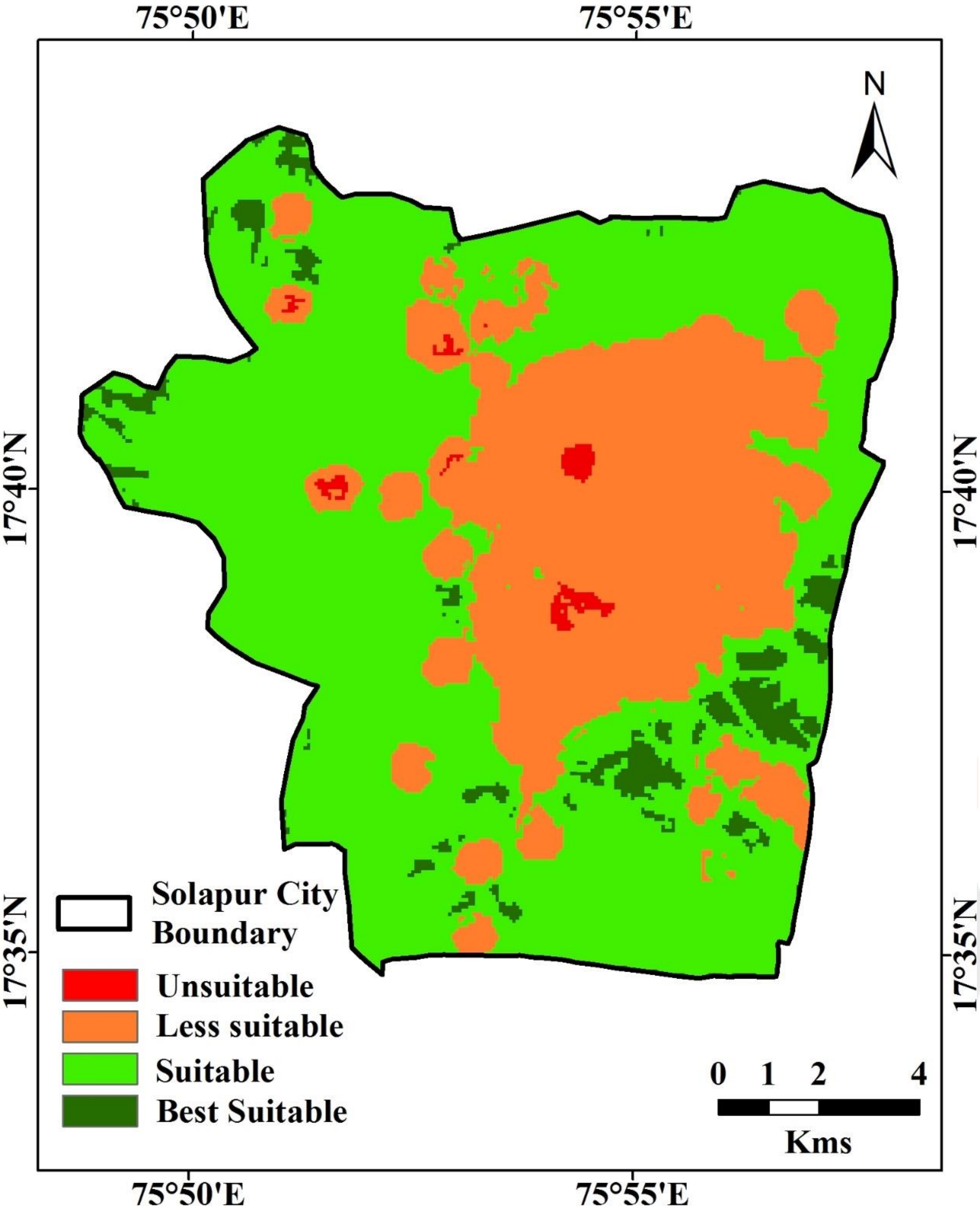

Figure 6. Solid waste disposal suitability map of Solapur city

It is crucial to remember that the multiple factors considered here are case-specific and may vary from region to region depending on the population.

IV. CONCLUSIONS

Since last few decades Solapur is witnessing tremendous rise in urbanization. Hence, the future garbage production will likely to be exceeding the capacity of the existing disposal methods as well as the dumping sites with respect to size and locations, making them outdated as well. In the present study, GIS techniques were utilized in conjunction with AHP-MCDA methods for the identification of best suitable sites for the disposal of solid waste in the city of Solapur. The study area has few important factors which are highly influencing the presence of solid waste disposal site near by them and hence the selection of best suitable waste disposal sites in such area is challenging. Fortunately, after applying AHP techniques, the identification of such suitable location has become easier. These influencing factors are land use, proximity to the road system, water bodies and settlement. In the study area each factor which can affect the selection of sites have been assigned with appropriate weights. The AHP method has provided a simpler way to rank and balance the various factors those were considered during the investigation. Based on the outcomes of the present study and the identified location in the study area, owing to the accelerated rate of urban expansion and industrialization, it is observed that only 4.45% of the total area is best suitable for the purpose of selection of solid waste disposal sites, whereas 0.73% of the area is unsuitable followed by 32.35% area is less suitable and 64.47% of the area is suitable for the purpose of dumping the solid waste from entire Solapur city. Hence, present study proves that the geospatial technology can be applied to effectively managing the municipal solid waste, leading to the major relief for city officials.

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