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DEMARCATING BOUNDARIES OF SOLID WASTE DISPOSAL SITES USING GIS AND AHP: A CASE STUDY OF PATNA CITY

Subha Sinha[1], Pallav Kumar[2*] and Shivangi Mishra[3]

[1]Assistant Professor, Department of Civil Engineering, Bakhtiyarpur College of Engineering, Bakhtiyarpur, under Department of Science, Technology and Technical Education, Govt. of Bihar, India

[2,*]Assistant Professor, Department of Civil Engineering, Muzaffarpur Institute of Technology, Muzaffarpur, under Department of Science, Technology and Technical Education, Govt. of Bihar, India

[3]Assistant Town Planning Supervisor, Urban Development and Housing Department, Patna, Govt. of Bihar, India

[1]starsubha@gmail.com, [2]pallav318@gmail.com and [3]shivangicivil0038@gmail.com

ABSTRACT

Due to rising complexity of waste management in urban areas, the selection of the appropriate solid waste dumping site requires consideration of multiple parameters and evaluation criteria. In this study, suitable solid waste disposal sites for the Patna city, India is determined by integrating geographic information systems (GIS) and multi-criteria evaluation (MCE) analysis. To determine the most suitable solid waste disposal site, one of the MCE techniques, called analytical hierarchy process (AHP), is combined with GIS. To identify appropriate solid waste disposal sites, different input map layers including proximity to agricultural lands, cantonment, airport, commercial areas and industrial areas, railway lines are used in the constraint mapping. Moreover, distance from roads network, drainage networks, land slope, settlements, open spaces, public utility areas and soil classes are used in factor mapping. Initially, separate maps are developed for different constraints and factors. Further, combined constraint map is developed using Boolean Operation. Final factor map is developed using integration of GIS with AHP through iterative process. The outcome of this study is a final map of the greater Patna city region showing suitability for the location of the solid waste dumping sites by overlapping constraint map and factor map. Results revealed four different suitable areas for the location of solid waste dumping site based on suitability index, which shows most suitable and least suitable locations. The methodology used in the present study can be useful for demarcating solid waste disposal sites in similar type of cities in India.

Keywords: Solid waste dumping sites, AHP, GIS

1. INTRODUCTION

Almost every city in the world is facing the problem of managing solid waste, which comes out as resultant of daily activities of human beings. One of the prominent causes of increase in the amount of solid waste is exponential increase in urban population of the developing countries during past decades. The increasing population accelerated the urbanization and living standards of human, India being no exception. Therefore, the problem of solid waste generation from the households in India is unavoidable and requires efficient solution. The appropriate selection of site for waste disposal is a complicated process and it must combine social, environmental and topographical factors. Geographic Information system (GIS) can be very useful tool to find solid waste dumping sites, which are environmentally safe to people.

Geographic Information system is a computer-based tool for spatial operations such as entering, storing, manipulating, displaying geo-referenced data. As they manage large volumes of spatial information from various resources, GIS are ideal for site selection studies.

In addition to the GIS applications, MCE methods are integrated to achieve an optimal result for site selection. GIS provide efficient manipulation and presentation of the data and MCE supplies consistent ranking of the potential landfill areas based on a variety of criteria. Among the MCE techniques, AHP has been widely used in selecting sites for solid waste disposal in recent years. Javaheri et al. (2006) explained the importance of Analytical Hierarchy Process and use of GIS as a means of selecting appropriate site for solid waste disposal. Nas et al. (2010) determined an appropriate landfill area in Cumra County of Konya City using the integration of

Geographic Information Systems and Multi- Criteria Evaluation (MCE). Al-Ansari et al. (2013) conducted a study on municipal solid waste landfill site selection with GIS and AHP in Iraq. For landfill site evaluation, various studies (Sener et al., 2006; Higgs, 2006; Geneletti, 2010) were carried out using GIS and multicriteria decision analysis. Some other researchers used GIS and fuzzy system for identification of landfill sites (Gemitzi et. al., 2007; Lofti et. al, 2007; Singh and Vidyarthi, 2008) and others (Konos et. al., 2003; Zamorano et. al., 2008)) used GIS based integrated methods for similar purpose. Santhosh and Babu (2018) derived a method based on reliability concept using DRASTIC method and AHP integrated with GIS and the case study was conducted in Bengaluru city. Spigon et. al., (2018) identified landfill sites using optimization, multiple decision analysis and GIS analysis. Wang et. al. (2018) studied municipal solid waste landfill sites with a purpose to reduce the environmental health risk, which may be caused due to inappropriate solid waste disposal sites. There are other researchers (Bathrellos et. al, 2017; Colomer et. al., 2017; Rahmat et. al., 2017; Guler and Yomralioglu, 2017; Dhing et. al, 2018; Chen et. al., 2018; Sun et. al., 2018), who also worked with similar goal of improving the existing landfill sites or identifying the appropriate location of landfill sites. To achieve this objective, different multicriteria techniques were used in the mentioned research works.

It is inferred based on review of literatures that several studies have been carried out in the past, which used integration of GIS and AHP for identification of suitable location in different cities for solid waste disposal sites and landfill sites. Considering the credibility of this technique, the present study also attempted to exploit this technique for Patna city, which is developing at a rapid rate.

The objective of the present research is to find out most appropriate solid waste disposal sites for Patna city, India, taking into consideration the growth of city into greater Patna region by 2030. The technique to be adopted in the present study for finding out the most appropriate solid waste disposal sites will consider integration of GIS with AHP.

2. STUDY AREA

Patna is the capital city of Bihar State, situated 15 km along the confluence of the River Ganges. Here, the Patna Urban Agglomeration (PUA) or Greater Patna (being developed under the Master Plan for Patna – 2031) is selected for present study context. Proposed Patna region has an area of 1,144.92 sq.km which is approximately 1.15% of the total area of Bihar state. The study area is shown in Figure 1. It is spread across thirteen Community Development Blocks (C.D. Blocks) of Patna Districts. Patna Planning Area (PPA) has total population of 28.74 lakh as per 2001 census. Patna Urban Agglomeration, which includes Patna Municipal Corporation (PMC) and 4 census towns, contributing 61.4% of the total population in PPA (url: bih.nic.in/PMP-2031.htm).

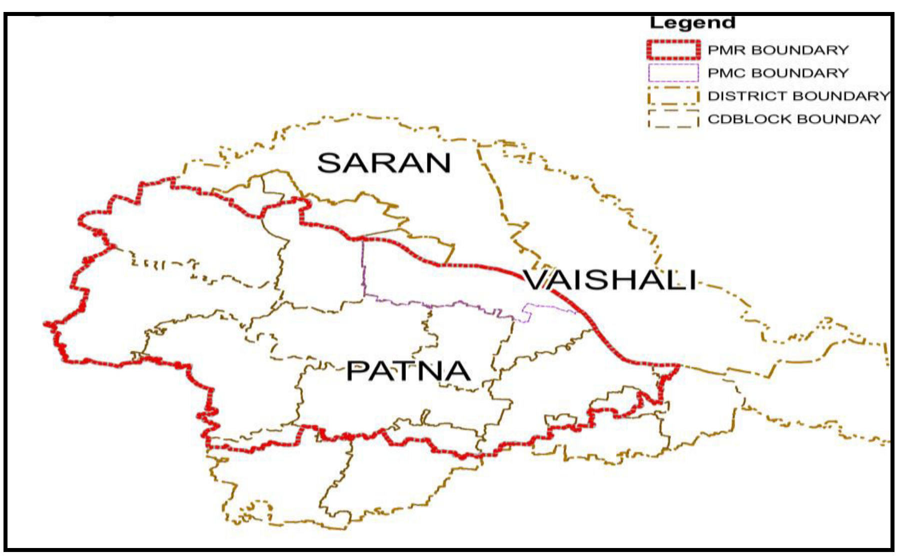


Figure 1 Study Area shown in Red Boundary

3. METHODOLOGY

The flow chart of the entire methodology is shown in Figure 2. For selection of solid waste disposal sites, six constraints and seven factors are considered. The list of constraints and factors selected in Figure 2 is based on the locations and facilities which needs utmost importance while selecting waste disposal sites, considering the entire Patna region with various land use and land cover. For selection of suitable sites for solid waste disposal, there are six constrains used such as; industrial areas, airport, railway lines, commercial areas, agricultural land and cantonment and seven factors used such as; public utility areas, settlements, road networks, water bodies, drainage network, degree of slope and soil type. These constraints and factors were used for development of combined constraint maps and combined factor maps separately. Finally, they were superimposed to obtain the suitable sites for the solid waste disposal.

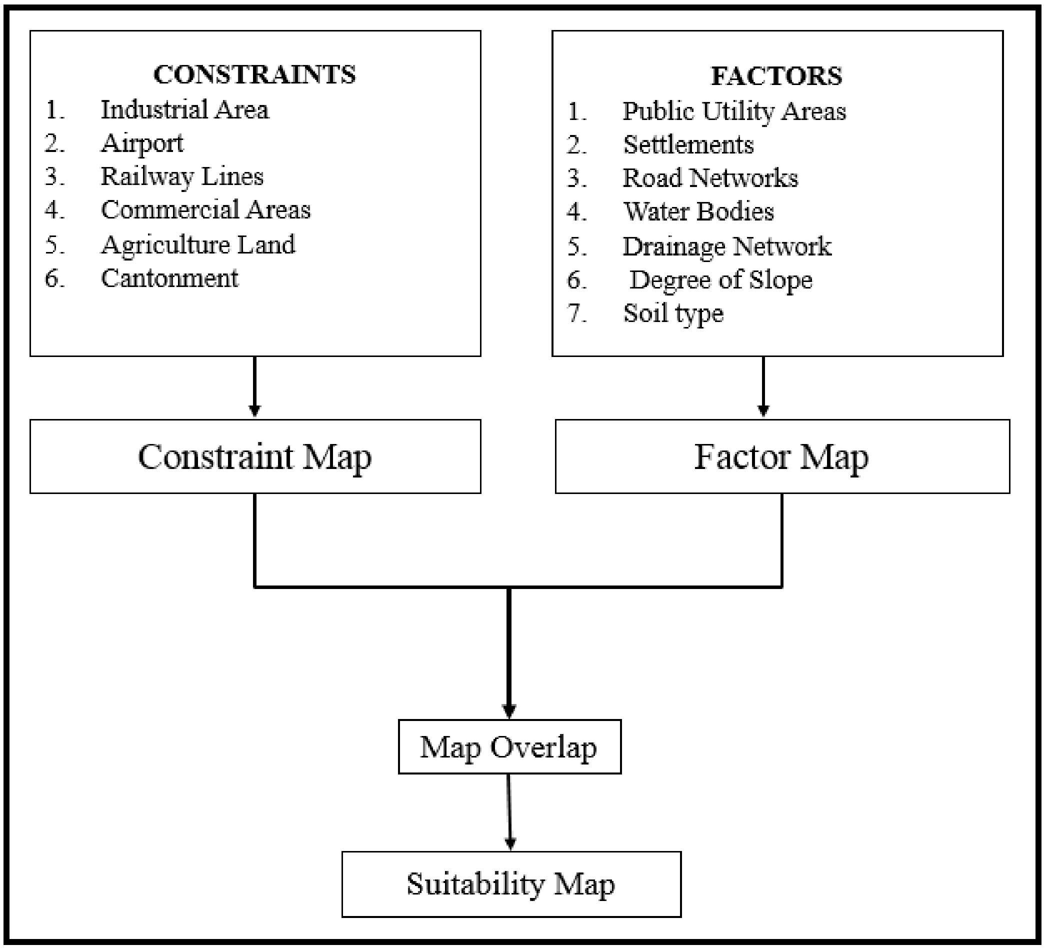


Figure 2 Methodology for attaining suitability map

4. GIS Mapping of Constraints and Factors

For constraints listed in previous section, also mentioned in Table 1(Column 1), buffer distance is created around them. The details of buffer distance for each constraint is given in Table 1(Column 2). The buffer distance was so selected such that effects of solid waste disposal sites on the constraints should be negligible. If greater Patna region is considered, settlements did not happen in a planned way, but spaces are available at different locations which may be used later on for solid waste disposal. It was thought in the present study that a safe distance of 200 m to 500 m would be sufficient as buffer, taking into consideration the future development near these constraints. The maps of constraint criterion with buffer zones are given in Figure 3 (a) through (e). In case of constraint mapping, from figure 3(a) to 3(e), the red color shows the area which are under agriculture, cantonment, commercial, industrial and railways buffer. The blue color in these figures indicate the area which are further usable. The study under present context is made for greater Patna region, therefore, the agricultural cover can be seen over longer areas along the entire region as shown in Figure 3 (a). It is evident from the Figure that a significant proportion of area is under agriculture cover for the entire greater Patna region. Figure 3(b) shows the Cantonment area which are located in Danapur area of the city. From strategic perspective, the buffer zone around this area is also very important. There are several commercial areas in the city, and buffer zone for the same is created and is shown in Figure 3(c). Patna does not have many industries located within its boundary, however, some of the area under cover are shown in Figure 3(d). There are more than 10 railway stations in Patna city (which includes halt station, junction, way-side station, terminal station), consequently rail lines can be seen passing through the city area, and map for the same is created along with the buffer in Figure 3(e).

Table 1 Buffer Zones for Constraint Criteria

Constraint (1)	**Buffer Distance (2)**
Agriculture	500 m
Airport	2000 m
Cantonment	500 m
Commercial Areas	200 m
Industrial Areas	200 m
Railway Lines	200 m

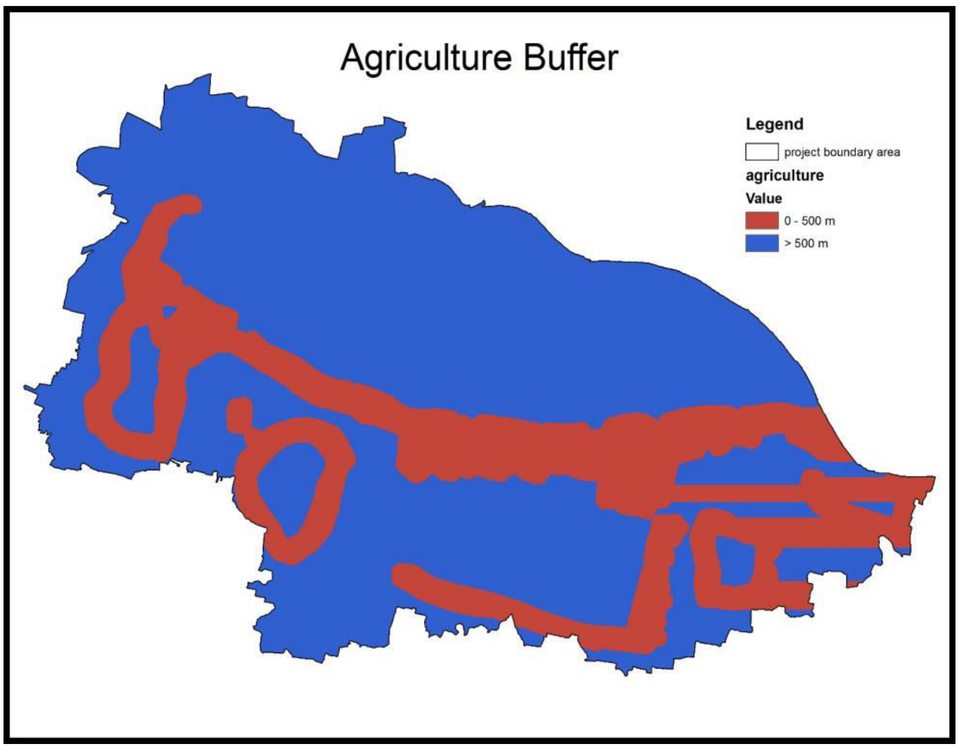


Figure 3(a) Map of Agriculture Buffer

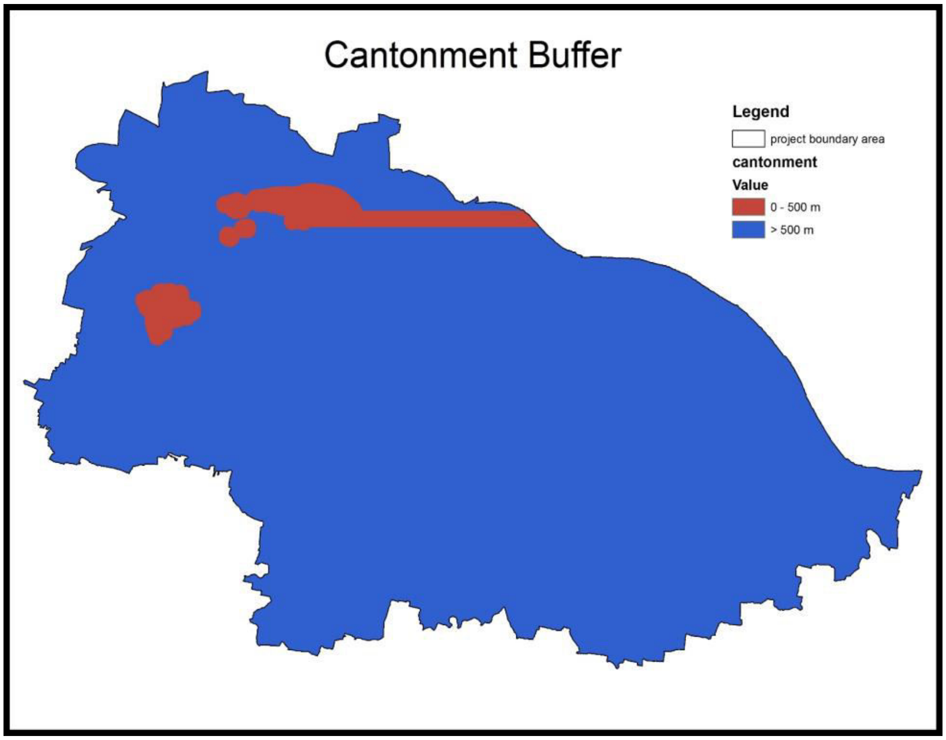
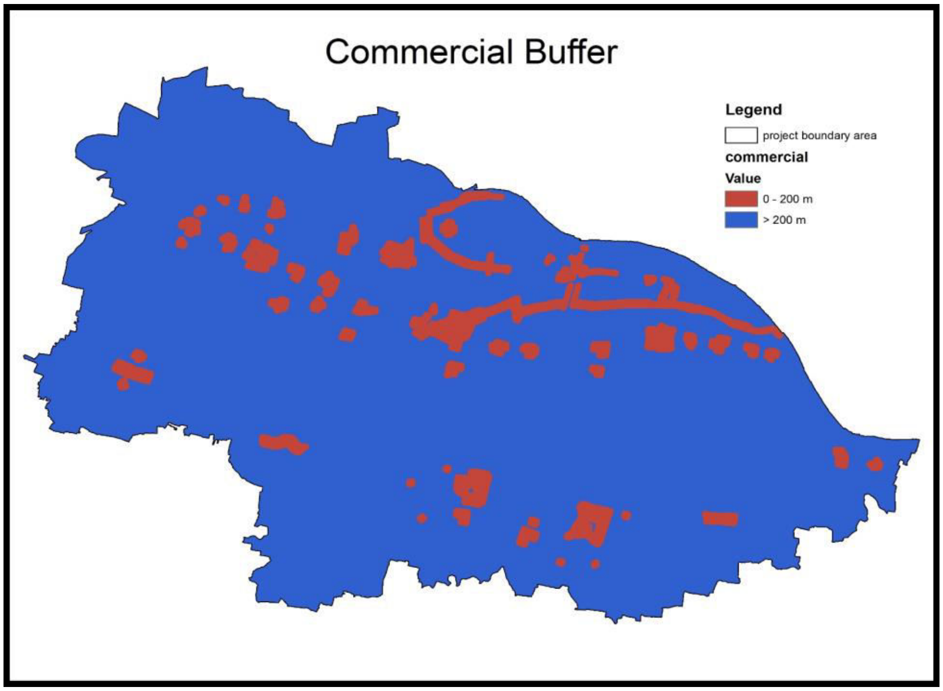


Figure 3 (b) Map of Cantonment Buffer



3(c) Map of Commercial Buffer

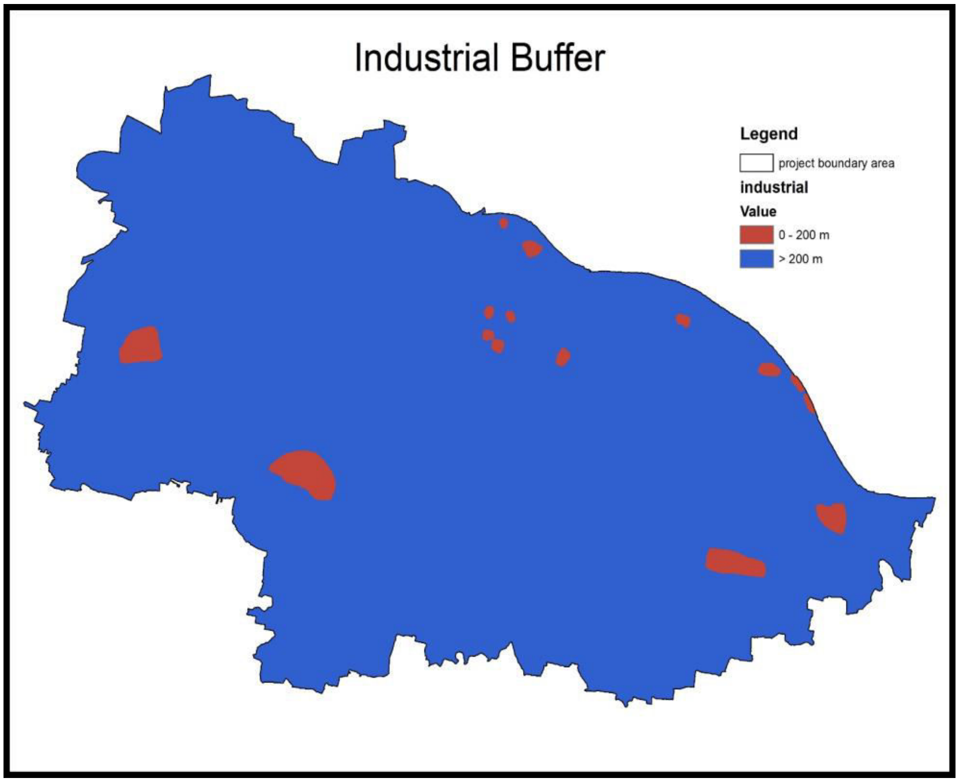


Figure 3(d) Map of Industrial Buffer

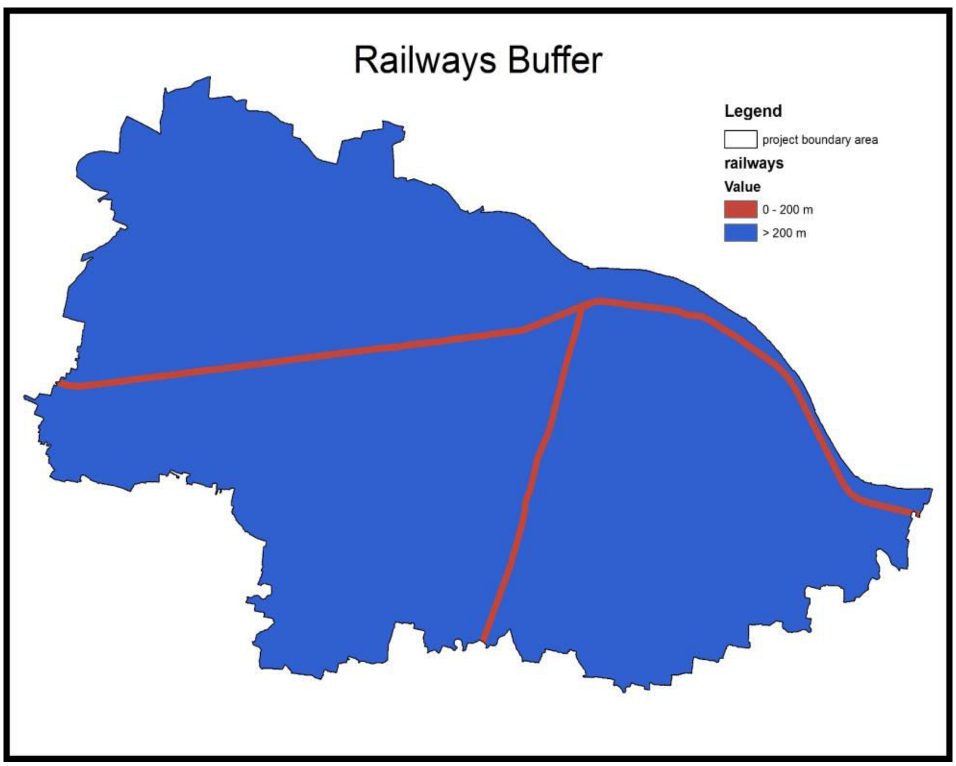


Figure 3(e) Maps of Railway Buffer

For factors listed in previous section in flow chart, mapping is done after classification of distance-based classes for each factor. The weights for each are given in Table 2. Table 2 (Column 1) shows different factors, Table 2(Column 2) shows the distance range and Table 2(Column 3) shows the suitability weights assigned to each class.

Table 2 Classes divided for Factor Map along with their respective weights

Factor (1)	Class (2)	Weight (3)
Public Utility Areas	< 200 m	0
	200 m – 500 m	5
	500 m <	10
Roads	< 500 m	0
	500 m – 1000 m	7
	1000 m <	10
Settlements	0 – 200 m	0
	200 m – 500 m	3
	500 m – 1000 m	7
	1000 m <	10
Slope	0 – 3°	10
	3° - 6°	8
	6° - 10°	4
	10° <	0
Drainage Network	< 500 m	0
	200 m – 500 m	3
	500 m – 1000 m	8
	1000 m <	10
Waterbodies	< 500 m	0
	200 m – 500 m	2
	500 m – 1000 m	6
	1000 m <	10
Soil	Soil Type J	0
	Soil Types B, C, D	2
	Soil Type G	9
	Soil Types A, E, F, H, I	10

Once the constraint areas are defined using GIS mapping, the next step in the process is creating factor map of the area. The maps of factors with distance classes are given in Figure 4 (a) to 4(g).

The factor map shall consider the suitability of areas for GIS mapping. The process will define the extent to which a given area is suitable for disposal sites. For a given factor, say public utility areas (in Figure 4(a)), the area around it is provided with three different distance ranges, 0 to 200 m is represented with red colour showing it least suitable for disposal sites, 200 to 500 m is shown with white color making it moderately suitable and more than 500 m is shown with blue color, making it highly suitable areas. On similar lines, the factor mapping was done for other factors such as; road classes, settlement classes, slope classes, water bodies, stream classes and soil map. In Figure 4(b), the area within 0 to 500 m of roads are marked as red and is not suitable for disposal sites, 500m to 1000m is moderately suitable and more than 1000 m are highly suitable areas for disposal sites, while considering roads. In Figure 4(c), it can be observed that settlement in Patna city has happened in most haphazard way, red color (0 to 200m) areas are the areas with maximum settlement whereas the lighter red colored area (200to 500m) shows the area with lesser density of settlements. Further, grey colored area (500 to 1000m) are the areas with no settlement, and may be considered suitable for disposal sites. However, blue color area can be considered most suitable, while considering settlement. Figure 4(d) shows the slope of Patna city, the higher the slope more are the chances of movement of leachate (which is a very dangerous liquid generating from solid wastes). Therefore, areas with gentler slope (0 to 3° and 3 to 6°) are more preferred as disposal sites when compared with areas with higher slopes (6 to 10° and >10°). Water bodies such as rivers, lakes, ponds etc. within the city limits are marked in the Figure 4(e). Red color around water bodies area (0 to 200m) represent the areas least suitable for solid waste disposal, followed by light red color area (200to 500m). However grey color area (500 to 1000 m) and blue color area (>1000m) shows the area with suitability and high suitability for solid waste disposal. In Figure 4(f), streams classes show the area with continuous and steady movement of water; these areas are also important because they finally put the water into water bodies and may serve as carrier of leachate. Classification of suitability of disposal sites are made in a similar way for both water bodies and stream as just-mentioned. In Figure 4(g), various soil types are shown. These soil types are defined into following classes:

A – Stony surface phase

B – Moderately well drained phase (Class 3 drainage)

C – Consolidated bedrock phase (50 to 100 cm depth)

D – *Unconsolidated bedrock phase (50 to 100 cm depth)

E – Cobbly or stony subsoil phase

F – Peaty surface phase

G – Ortstein phase

I – Coarse or moderately coarse texture (20 to 50 cm depth)

J – Medium to moderately fine texture (20 to 50 cm depth)

These soil type and their inherent behavior can be the reason that sometimes the water table may be affected due to leachate from the solid waste. If soil is pervious in nature, then disposal of solid waste at such locations will not be justified. It is because the leachate may affect the water table at such locations and the water properties of such locations may not be good. Hence, to avoid such scenarios, the present study also took care of the soil type before finalizing the suitable locations for soil waste disposal sites. Soil types; A, E, F, I, are recommended as most suitable for disposal sites. Moreover, effect on water table due to waste disposal sites will be interesting to study and is planned in the future scope of this work.

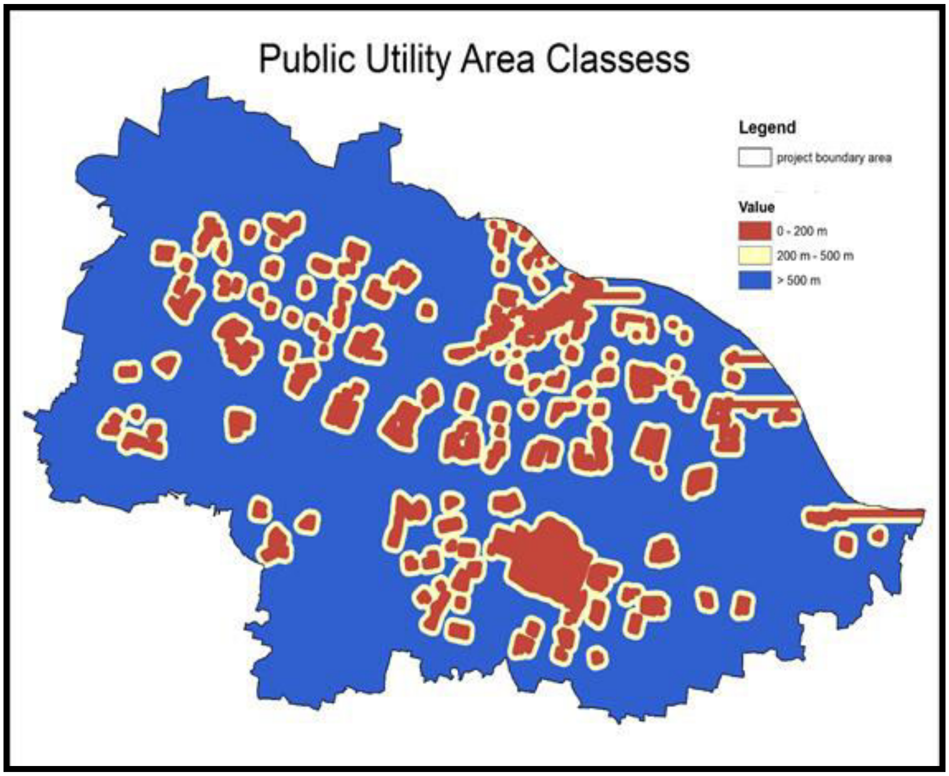


Figure 4(a) Map of Public Utility Area

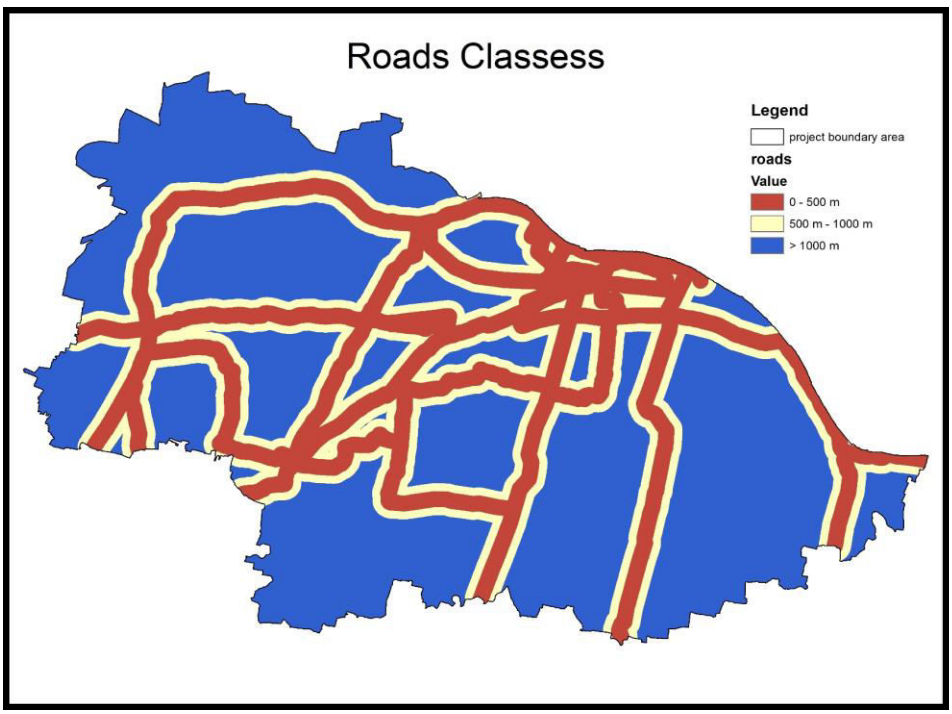


Figure 4(b) Map of Road Network

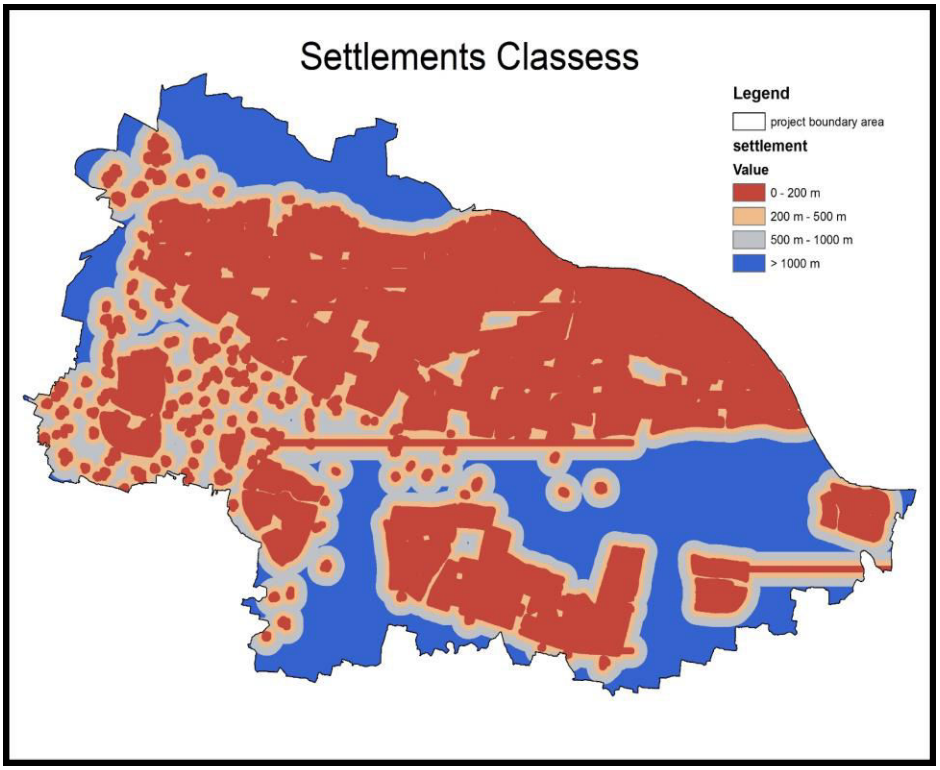


Figure 4 (c) Map of Settlement Classes

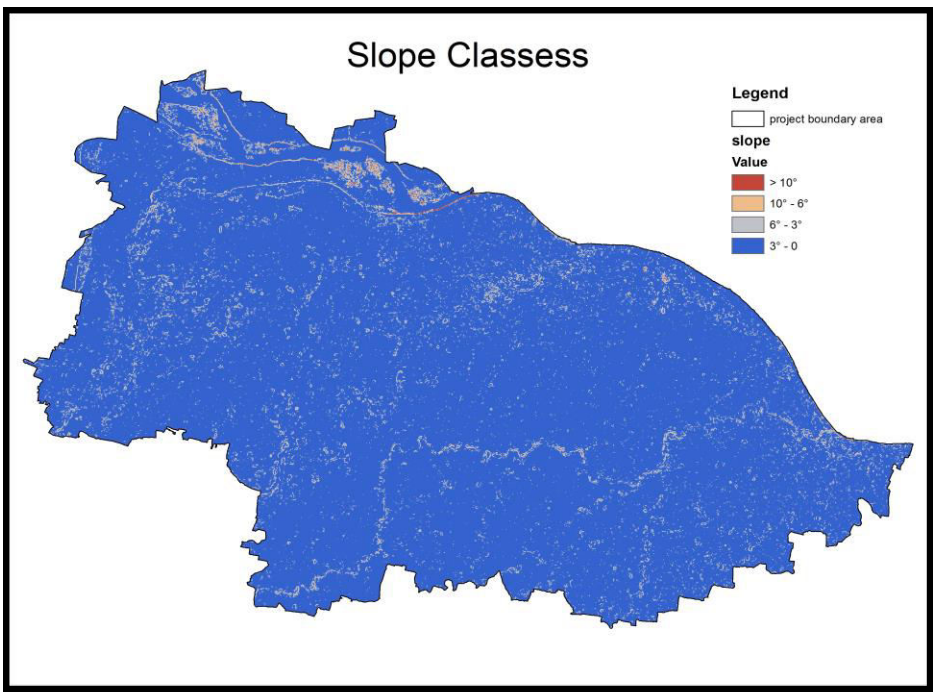


Figure 4(d) Map of Slope

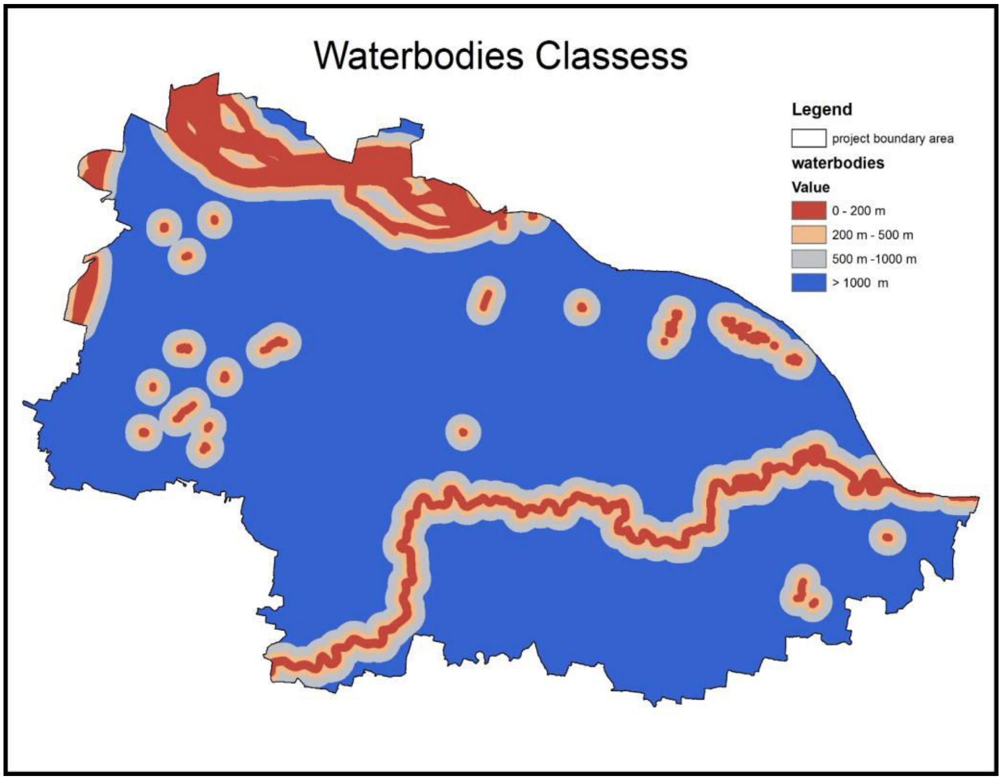
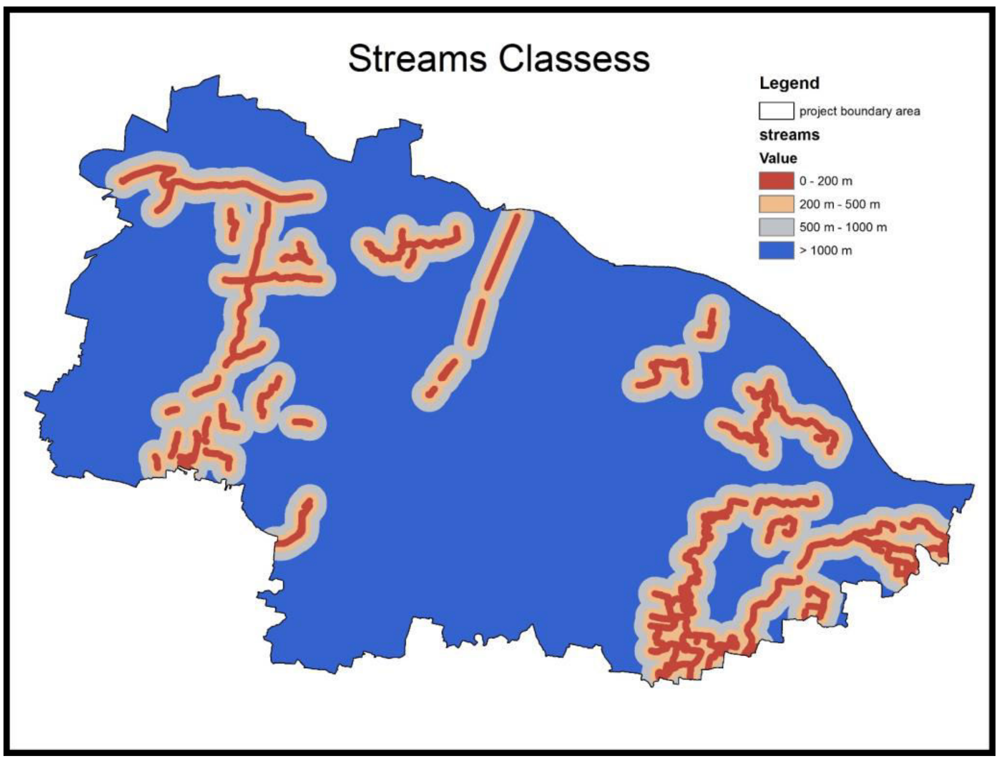


Figure 4(e) Map of Water Bodies



4(f) Map of drainage network in the area

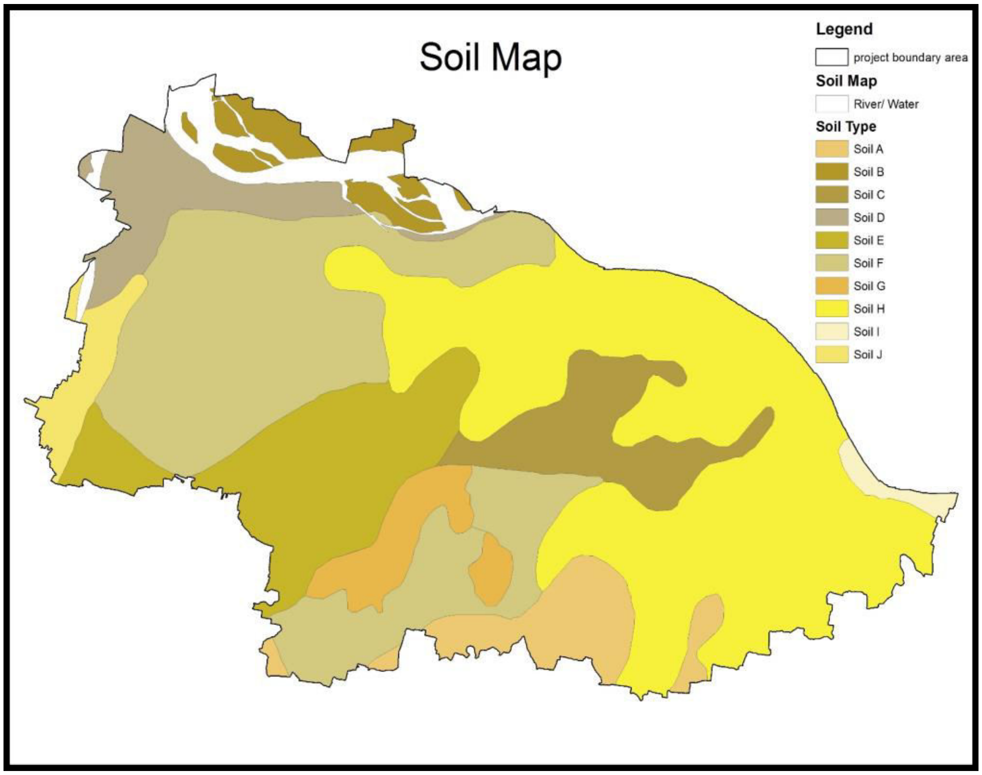


Figure 4(g) Map of various soil type in the entire area

5. Final GIS map after overlapping Constraints and Factors

The mapping made in previous section for individual constraint and factor are combined at aggregate level to obtain final map for suitable sites for solid waste disposal. This helped in identification of dumping sites after considering the various constraints and factors. In the subsections below, final constraint map and final factor map are explained. To obtain final constraints and final factors, certain mathematical operations are used.

5.1 Final Constraint Mapping

To proceed with constraint mapping, all the unsuitable or restricted areas being considered as constraints need to be identified. The identification of such areas was performed using Boolean "AND" operation. To create aggregated constraint areas, the operation used is shown below in Equation 1. The operation includes constraints along-with the buffer distance.

Constraint map = (constraint1 & constraint2 & constraint3&…) (1)

The resultant is a map of study area showing restricted areas and suitable areas for solid waste disposal. This is done using Raster calculator Tool in Spatial Analyst, ArcMap. The resultant obtained is shown in the form of constraint map in Figure 5.

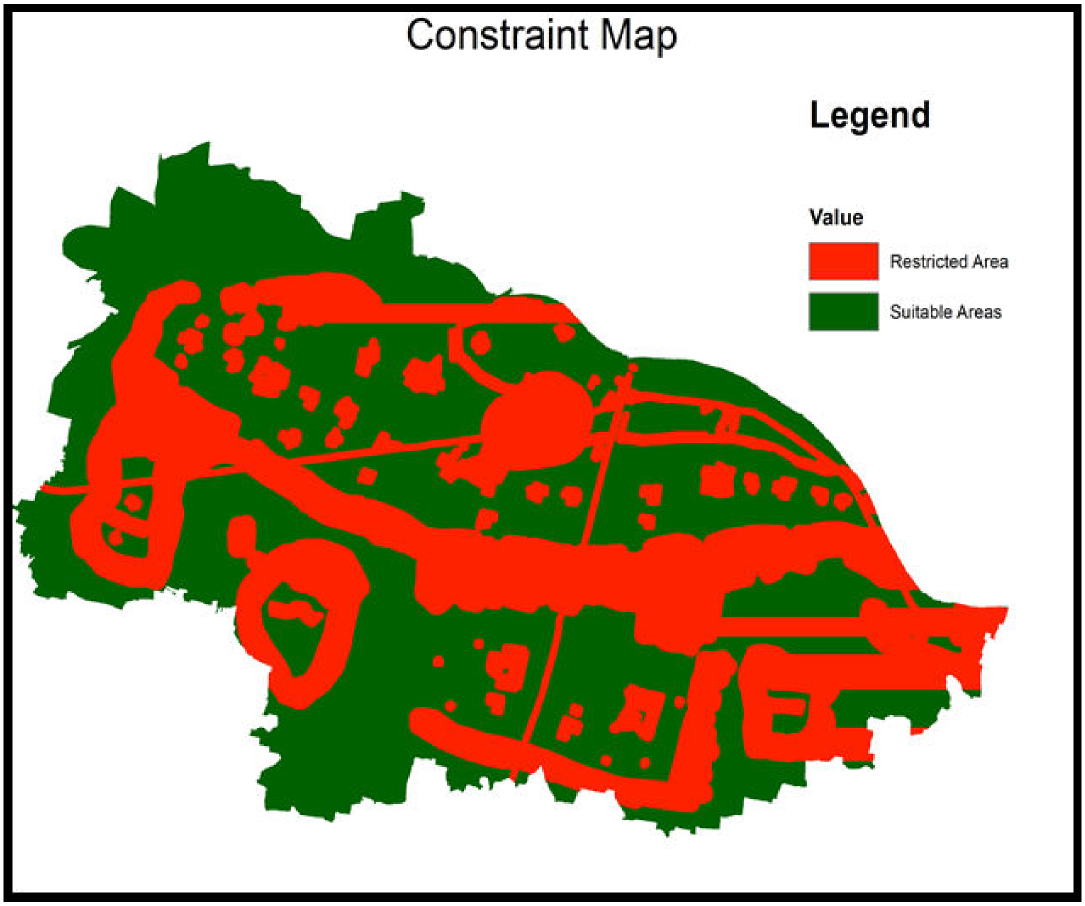


Figure 5 Final Constraint and Factor Maps

5.2 FINAL FACTOR MAPPING

In factor mapping, overlapping of various maps of classes of factor criteria is done to find a suitability index, which shows the suitability of a given pixel based on the factors. For all the factors except slope and soil type, different class weights are assigned based on the distance from a factor. The farther the distance, higher the values of weights. Similarly, in case of slope, greater degree of slope entices greater weights. In case of soil type, it is based on inherent properties of soil. These weights assigned here are based on rating provided by experts in the field of solid waste management using Saaty's scale (Saaty, 1980) given in Table 3 using nine-point pair-wise comparison rating. Three experts who are specialized in this area were asked to rate the factor criteria in Table 4 for pair wise comparison. Further, principle eigenvalue and normalize right eigenvectors are computed, which give the relative importance of corresponding factor layers correctly through iterative process.

The consistency of pair-wise comparisons is calculated by computing the Consistency Index (CI) and then Consistency Ratio (CR) is calculated with help of CI and Random Consistency Index (RI). If the Consistency Ratio exceeds 0.1, then the pair-wise comparison is revised. This is done repeatedly until CR reaches below 0.1. The combined factor map is shown in Figure 6. The CI and CR are calculated as given in Equation (2) and Equation (3):

$$CI = (\lambda_{max} - n) / (n - 1) \quad (2)$$

$$CR = CI / RI \quad (3)$$

where n= dimension of the matrix

λ_{max}= principal eigen value

Table 3 Saaty's Scale for analytical hierarchy process (AHP)

Intensity of importance	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

Table 4 Importance of Different Factor Criteria

	Public Utility Areas	Roads	Settlements	Slope	Soil	Streams	Waterbodies
Public Utility Areas	1	3	0.2	2	3	0.333	0.333
Roads	0.333	1	0.333	0.5	1	0.2	0.2
Settlements	5	3	1	5	7	3	3
Slope	0.5	2	0.2	1	2	0.25	0.25
Soil	0.333	1	0.143	0.5	1	0.2	0.2
Streams	3	5	0.333	4	5	1	1
Waterbodies	3	5	0.333	4	5	1	1

Weights of different factor criteria are listed in Table 5. Based on Table 5, it is inferred that settlement is having maximum weightage, followed by streams and waterbodies, thereafter, public utility areas and roads, and lastly, soil type. The importance of these factors and their weightage is obtained through two-step process; first comparison of two factors at a time for all the factors, second defining weights of different factors based on comparison with respect to other factors using AHP.

Table 5 Weights of Different Factor Criteria

	Public Utility Areas	Roads	Settlements	Slope	Soil	Streams	Waterbodies	Weights
Public Utility Areas	0.076	0.150	0.079	0.118	0.125	0.056	0.056	**0.094**
Roads	0.025	0.050	0.131	0.029	0.042	0.033	0.033	**0.049**
Settlements	0.380	0.150	0.393	0.294	0.292	0.501	0.501	**0.359**
Slope	0.038	0.100	0.079	0.059	0.083	0.042	0.042	**0.063**
Soil	0.025	0.050	0.056	0.029	0.042	0.033	0.033	**0.038**
Streams	0.228	0.250	0.131	0.235	0.208	0.167	0.167	**0.198**
Waterbodies	0.228	0.250	0.131	0.235	0.208	0.167	0.167	**0.198**
checksum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

After defining importance of alternatives of different factors, evaluation of landfill sites is the next step. The evaluation of weights of each factor layer are obtained from a consistent matrix, a factor map is prepared using Raster calculator Tool in Spatial Analyst, ArcMap. This is done by weighted sum method using Equation (4):

Suitability of Factor Map = factor1*w1 + factor2*w2 + factor3*w3 (4)

The results in the form of factor map showing suitability of each pixel, as shown in Figure 5. The qualitative rating of areas is made as; least suitable, less suitable, suitable and most suitable. The suitability of areas varies based on relative weights assigned using AHP for comparison of areas. The rating of various areas based on different factors are shown with the help of different colors; deep red. light red, light green, deep green. Deep red color represents least suitable areas and deep green represents most suitable areas.

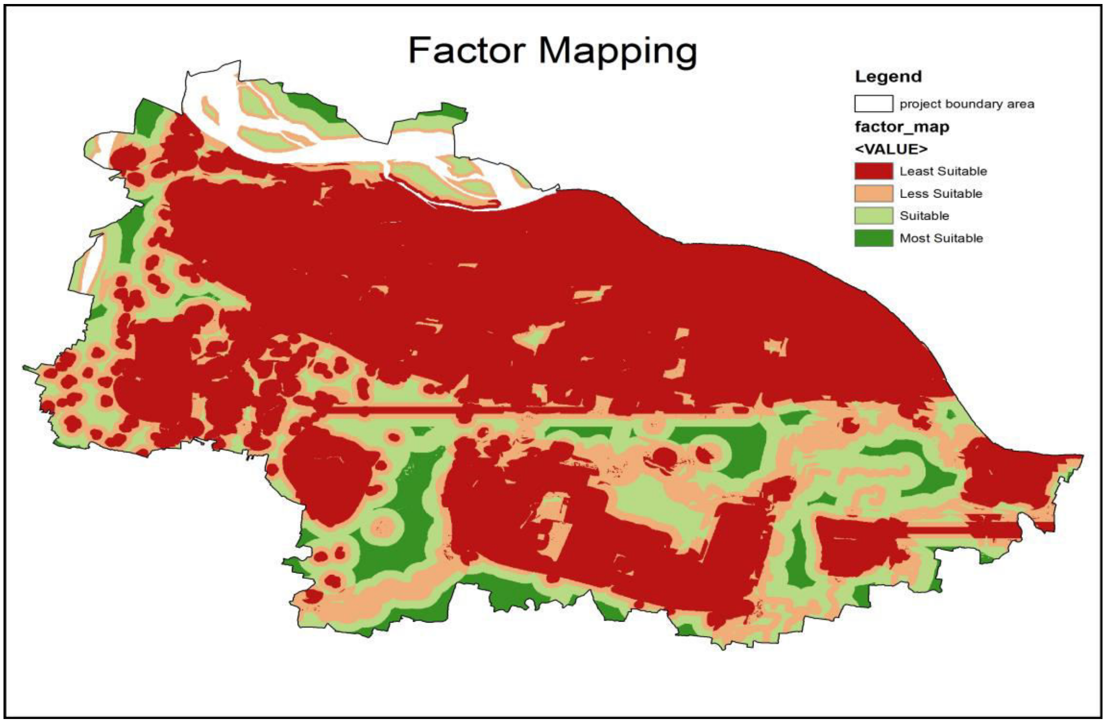


Figure 6 Final Factor Map

5.3 FINAL SUITABILITY MAPPING

After the overlap of factor map and constraint maps are prepared, the final suitability map is developed using algebraic multiplication of the two maps. The final suitability map is derived based on the Equation (5) given below:

Final Suitability Map = Constraint Map*Factor Map (5)

The final suitability map is shown in Figure 7. The resultant is a map of study area identifying restricted areas and Suitable areas. The respective suitability index varies from 0 to 10, which are classified in to five separate suitability classes- Not Suitable from 0 to 4, Least Suitable from 4 to 6.5, Less Suitable from 6.5 to 8.5, Suitable from 8.5 to 9.5 and then, Most Suitable from 9.5 to 10. The values can be well interpreted through the legends provide in Figure 6.

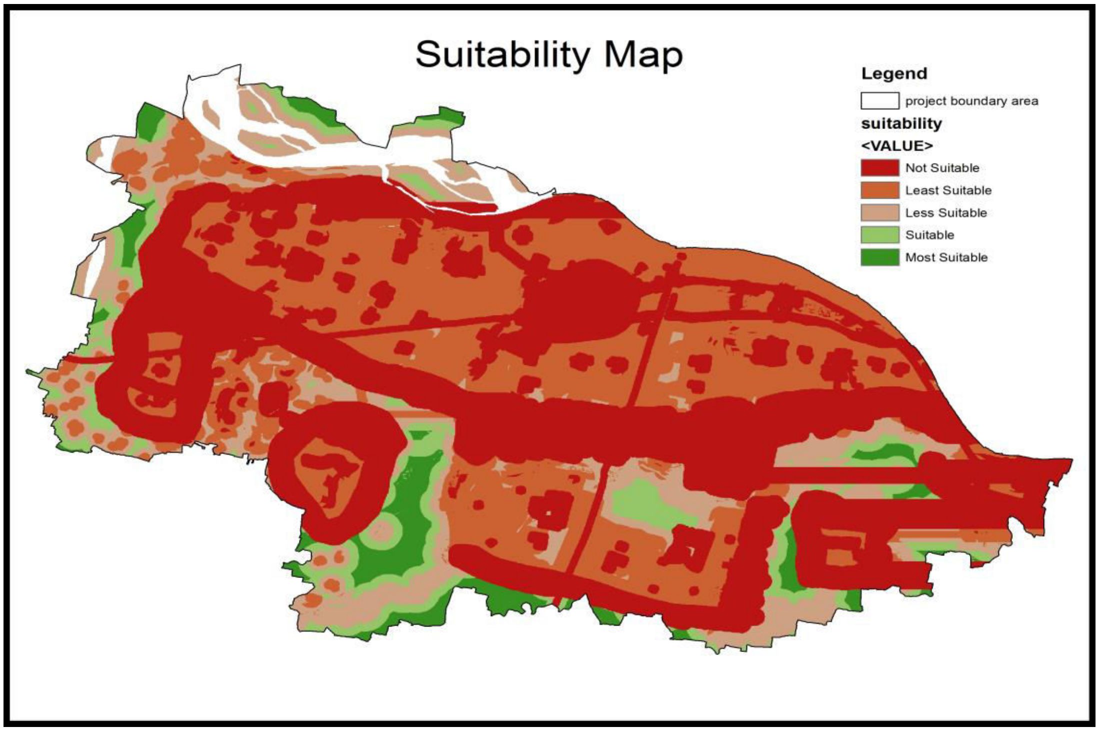


Figure 7 Final Suitability Map

6. CONCLUSION AND FINDINGS

The present research is an attempt to find out most suitable locations for solid waste disposal sites for Patna City. For identification of such locations, several constraints and factors were considered. At first, the locations were kept away from the constraints; hence, safe buffer distance is created around them. Further, factors were chosen to demarcate the areas with different level of suitability for solid waste disposal sites. A large part of study area comes under unsuitable or the least suitable categories due to extensive settlements. Suitability index is also calculated having values ranging from 0 to 10, where 0 represents least suitable and 10 represents most suitable locations. Some of the key findings from the present study are:

- Integration of AHP with GIS is found to be an effective tool for identification of solid waste disposal sites.
- Separation of factors and constraints made it possible to study these parameters at individual level accurately. Further, the overlap or superimposition of these map served in creation of suitability index, based on factor mapping for qualitative interpretation of suitability of a given area for dumping solid wastes.
- The most suitable areas have been identified in largely four locations based on geographical area of the Patna city. First region is sandwiched between Naubatpur region and the Punpun River, second is to the south-west of Punpun settlements and South-east of Punpun River, the third and the fourth ones are relatively small stretches east of Punpun, south of Punpun River and west of Fatuha.
- Other relatively lesser suitable areas are around the most suitable areas and some lie on the far western edge of the study area. Moreover, these far western suitable stretches are dotted by pockets showing relatively lesser suitable areas.
- The map developed through the present study will be useful in effective solid waste management for Patna city. Further, the steps and methodology provided here will be also useful in identification of solid waste disposal sites for cities or town of similar type, where settlements are unplanned and excessive.

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