Geo-spatial Technique Combined With AHP, SRS, and RSW Methods for Suitability Analysis of Landfill Site in Durgapur Municipal Corporation

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Research Article

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Abstract

Durgapur, an industrial city, is the second and third-largest city in West Bengal in terms of population and area respectively. The city is suffering from an enormous generation of waste and improper waste management. The wastes are dumped in an unscientific and unplanned way, negatively impacting the environment and public health. Hence, the National Green Tribunal has advised the city planners to find new landfill sites following the Central Pollution Control Board's guidance. This paper focuses on the new landfill site selection of Durgapur city using the Multi-criteria Decision Making (MCDM) methods with Geographic Information System (GIS). The methodologies used for the site selection processes are GIS (for mapping the 14 criteria and overlay analysis) and MCDM methods: Analytical Hierarchy Process, Straight Rank Sum Method, and Ratio Scale Weighting Method (to derive the weights). Finally, the five landfill sites are selected after calculating the change detection.

Keywords: Landfill, Geographic Information System, Multi-criteria Decision Making, Analytic Hierarchy Process, Straight Rank Sum, Ratio Scale Weighting

1. Introduction

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Solid waste implies the organic and the inorganic waste materials produced by various activities of the society. These are generally the thrown away materials after their first use, and also termed as “unwanted or undesired” materials. From the sources of generation, municipal solid waste may be divided into three categories: residential, commercial, and institutional. Besides, based on the content in the waste, we may get the following classes: biodegradable, recyclable, and inert waste. The rapid increase in urbanization, industrialization, and population enhances the generation rate of municipal solid waste. Hence, a proper management system is required to reduce the hazardous effect in environment and public health. Therefore, the management of Municipal Solid Waste (MSW) is an essential duty for municipal authorities, planners, engineers and decision makers (Hazra and Goel 2009). The Municipal solid waste management practice includes the entire process of dealing with municipal waste: starting from the collection at the primary source to ultimately disposing of it hygienically involving five types of activities. In Waste Management System, the dumping of waste in an unscientific manner is considered as the worst step; it is in the bottom of the hierarchy and creates a negative impact in the environment (Mahini and Gholamalifard 2006; Rahman et al. 2008; Gbanie et al. 2013). Improper dumping has the negative impact on groundwater, surface water, air, and soil (Moghaddas and Namaghi 2009). Consequently, the health of the residents in the locality is directly affected by the landfill and incinerators methods (Rushton 2003; Minichilli et al. 2005). Further research have been evidenced that the problems of the landfill are directly connected with the reproductive system and other dangerous outcomes such as low birth weight, gastrointestinal problem, skin infection, respiratory problem, the abnormal sex ratio of a newborn baby (Upton 1989; Knox 2000; Vrijheid 2000; Minichilli et al. 2006; Russi et al. 2008).

This unscientific waste management is a common problem in various developing countries like India, Pakistan, Bangladesh, due to the rapid population growth with urbanization and the lack of awareness (Hasan 2004; Gorsevski et al. 2012). There are different treatment methods, viz., landfills, recycling, biological treatment, and thermal treatment, in solid waste management system (Kontos et al. 2003; Moeinaddini et al. 2010). The landfill technique, among the aforesaid methods, is a relatively cheap and easy method for most of the developing countries after recycling of the waste (Yesilnacar et al. 2008). In many cases, the waste management system seems identical in all developing countries, i.e., huge generation of waste, inappropriate collection, improper transportation, open dumping, and burning (Troschinetz et al. 2009; Guerrero et al. 2013). Most of the Indian cities have improper management system: only landfills are available to dump the gigantic amount of waste (Dhokhikah et al. 2012). The common management system, followed by many developing countries, consists of open dumping, incineration, and composting. A proper landfill site selection for Municipal Solid Waste is an essential part of urban planning to reach the goals of sustainable development (Kharat et al. 2016). Following the opinions of environmental experts, a perfect landfill to dispose of the waste co-operates the land of low environmental impact with human welfare (Demesouka et al. 2013). Nonetheless, selection of the proper landfill sites is a difficult task because of the issues: availability of land, state and regional regulations, and environment and health consequences (Kontos et al. 2005; Chiueh et al. 2008). In India, most of the times, the mixed waste, i.e., without segregation process, is dumped in the landfill; hence, the landfill is the main focused issue discussed in this paper.

In this paper, we focus on the several issues of landfill site selection in Durgapur city. Durgapur is a Tier-II city located in the state of West Bengal, India (Census of India, 2011). Durgapur

Municipal Corporation (DMC), with an area of about 154.20 sq.km and 43 electoral wards, uses 11 acres area for open dumping of the solid waste. In recent days, this city is generating around 332 tonnes of waste per day: around 262 tonnes are residential waste, about 30 tonnes are non-residential waste, and around 40 tonnes are generated because of Construction and Demolition, drain sludge, and street sweeping (DMC 2017). Waste is generally collected through the door to door collection method (~30%) by triple van and open van, and the remaining waste (~70%) are collected from the community van, roadside collection point, and concrete/masonry bin by truck, compactor, dumper. Being more explicit, in this city, garbage are collected from 3435 storage depots and the street sweeping of 1100 km (contains both major and minor roads) road. After collection, garbage are shifted to the dumping ground by 37 vehicles. In this entire process of waste management, 2210 workers are engaged: permanent workers (149) and casual staff (2061), under West Bengal Urban Wage Employment Generation Scheme. On 2nd October 2010, DMC and Asansol Durgapur Development Authority have collaborated with the Jawaharlal Nehru National Urban Renewal Mission and established a Mechanized Compost plant at Sankarpur open dumping ground (refer Fig. 1a and Fig. 1b). Unfortunately, this compost plant becomes nonfunctional after two years as the mixed waste have been dumped without segregation or recycling process. In 2019, this composting plant has been demolished and corresponding vacant land is also used in open dumping shown in Fig. 1c. No Source segregation of waste is practiced in DMC; as a result, a large number of recyclable products are also dumped. These huge waste take lots of space in dumping ground, increase the cost of transportation, and impede the treatment facilities. Currently, DMC has no treatment facilities after closed down of the composting plant. The dumping land is unscientific, open, and creates pollution to the surrounding agricultural land as shown in Fig. 1.

Fig.1: Image (a) shows the compost plant. Image (b) is foundation stone of the aforesaid compost plant. Image (c) is the demolished part the compost plant. Dumping of mixed waste is shown in Image (d); (e) Stray Dogs and birds roaming in dumping site; (f) Gas emissions from the burning of waste; (g) Poor condition of fencing and gates; (h). Surrounded agricultural land are pollute from leaching and movement of garbage (plastics, paper, etc) from the dumping ground; (i). Field visit by the author.

The National Green Tribunal in 2018 has encountered the problems, i.e., open dumping, no source segregation of waste, no transfer stations, and improper landfill sites, of DMC waste management system, and charged the municipality some fine for not following the Solid Waste Management Rules 2016. Furthermore, National Green Tribunal has given deadlines to develop a proper infrastructure to incorporate with Solid Waste Management Rules 2016. Although there are several serious issues to be resolved, in this paper, we restrict ourselves on the question: *Which areas are suitable in the city for landfill?* It is difficult to find a proper disposing land within the city boundary because of the dense population, heavy concentration of industries, and commercial areas. In order to incorporate the environment, geology, hydrology, and socio-economic factors, we extend the city boundary by 1 km on all sides. Also, we mention that a suitable selection of site must obey the instructions of the Government of India (CPCB, CPHEEO, and SWM 2016).

2. Methodology

2.1. Geographic Information System (GIS)

The geospatial technique is associated with advanced Remote Sensing and GIS. This technique helps to select the landfill site more accuracy and conveniently, and it is more frisk in the recent waste management system (Kontos et al. 2003; Chiueh et al. 2008; Zamorano et al. 2008). In recent days, the GIS techniques are more representing and operating tools for the suitability analysis. GIS is a high-performance tool to handle a large volume of spatial data from different sources. GIS use as better data management, enhance accuracy and efficiency, best quality analysis and saves time and cost (Akbari et al. 2008). Many of the key planning decisions in solid waste management systems such as to find out the shortest route for transporting the waste, location for the transfer station and landfill site selection, and monitoring the sites can be ascertained by the GIS. It is a time-saving and capital-saving digital database which provides a long term monitoring facility of any landfill (Yagoub et al. 2008, Ersoy H et al. 2009). GIS has been used in many previous works in the literature, and support that this tool is capable to handle large volume spatial data for landfill site selection (Ghose et al. 2006, Chang et al. 2008, Chen et al. 2008, Zamorono et al. 2008, Nishanth et al. 2010, Sener et al. 2011, Kanchanabhan et al. 2011, Katpatal et al. 2011, Pandey et al. 2012, Paul 2012, Yesilanacar et al. 2015).

The suitability analysis requires spatial data with respect to sitting rules, regulations, factors, and constraints for landfill site. The Multi-criteria Decision Making (MCDM), a decision support system, calculates the relative weights from the criteria. Furthermore, the relative weights are applied on the map layer in GIS to determine the suitable area for landfill sites. The MCDM methods, combined with GIS, pave a significant path for the researcher to find out a suitable site for landfill (Malczewski 2006, Gorsevski et al. 2012). Therefore, this combination is a well-known tool in detecting suitable landfill sites (Kao et al.1996; Kontos et al. 2005; Delgado et al. 2008; Sharif et al. 2009; Nas et al. 2010; Donevska et al. 2011; Gorsevski et al. 2012; Demesouka et al. 2013; Khorram et al. 2015; Chabuk et al. 2017). Three methods of MCDM, i.e., Analytical Hierarchy Process (AHP) (Siddiqui et al. 1999; Gemitzi et al. 2007; Ersoy et al. 2009; Eskandari et al. 2012; Kara et al. 2012; Alavi et al. 2013; Uyan 2014), Ratio Scale Weighting (RSW) method (Halvadakis 1993; Sharifi et al. 2004; Sadek et al. 2006; Delgado et al. 2008; Nas et al. 2010), and Straight Rank Sum Method (SRS) with GIS have been applied in research work to obtain the landfill sites. *Therefore, in conclusion, the present study uses the GIS along with the MCDM method as tools to achieve the goals of suitability analysis for Municipal landfill site selection*. The clear methodology are shown in the flow chart in Fig.2

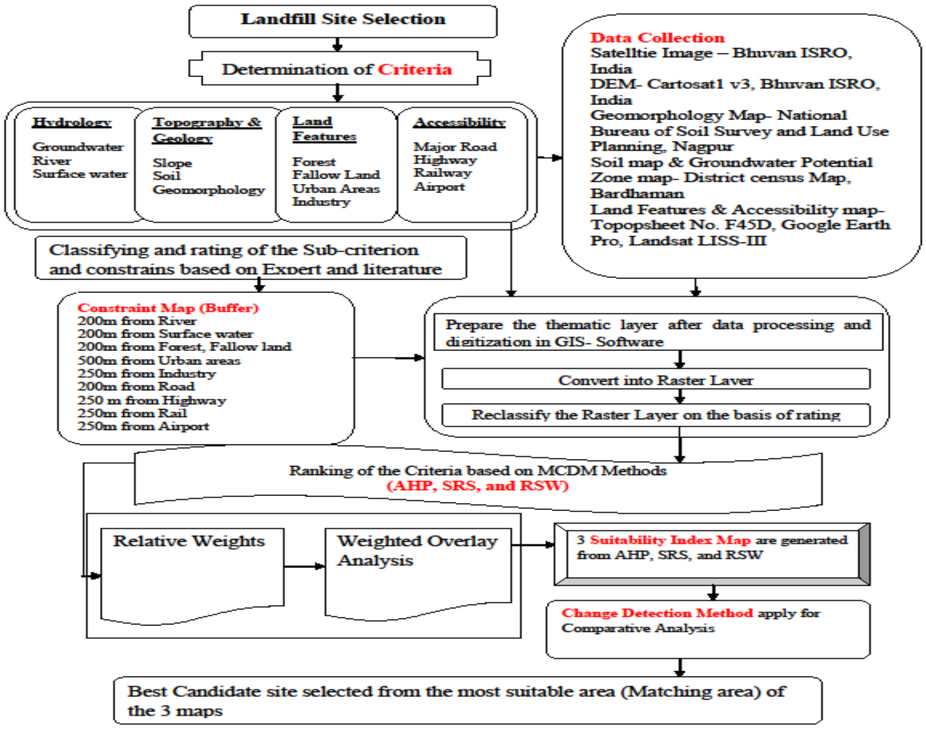

Fig.2: The Flow chart of the model for suitability analysis

2.2. Study area

Durgapur Municipal Corporation ($23^0$48'N & $87^0$32'E), with an area of about 154.20 sq.km. is located on the north bank of the Damodar River with an average elevation of 65 MSL, has undulating topography just before it enters the alluvial track of West Bengal. Two streamlets Tamla and Singaram flow through the area and falls in the Damodar river. The transitional climate between Kolkata (tropical wet and dry) and humid subtropical climate prevails here. Durgapur has average annual temperatures around 32^0C during May-June and receives about 52 inches annual rainfall.

It is the second planned city in India after Chandigarh. Geographically Durgapur is "Rurh of Bengal" because the western side of the city is full of resources (coal and iron ore); consequently, heavy industries are concentrated in its surroundings. This city is also known as the 'Industrial City' of West Bengal. The Indian Government, in 1962, has announced Durgapur as a Notified Area Authority. Later, the city has been upgraded to the Municipal Corporation in 1996 because of the huge concentration of heavy industries. In 2011, the industrial city was the 2nd (after Kolkata) and the 3rd (after Kolkata and Howrah) largest in West Bengal in terms of population (581409) and area (Census of India, 2011) respectively. The total municipal area consists of 43 wards. The increase in population from 425836 (1991) to 581409 (2011) enhances the amount of municipal solid waste. In 2019, the DMC have conducted a survey and the reported population is 656316. This huge population lead enormous amount of waste, which furthermore create problems in detecting a proper dumping ground for the Urban Local Bodies (ULBs). A 1 km buffer area from the municipal ward has been considered for new landfill site as shown in Fig. 3e.

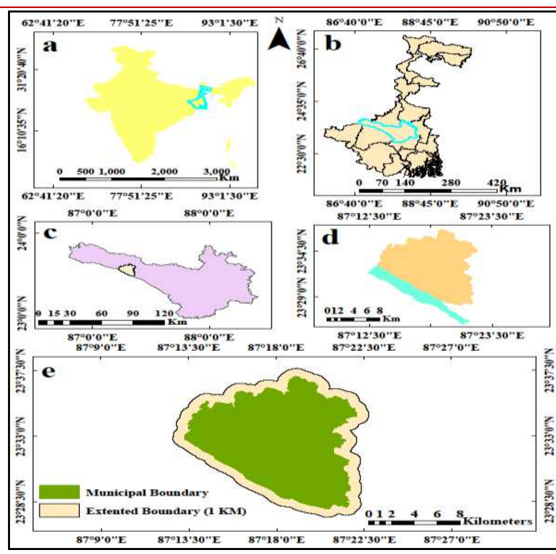

Fig.3: Study Area Map (a. India, b. West Bengal, c. Bardhaman, d. Municipal Boundary (DMC), e. Extended Boundary

2.3. Data collection

In the course of the analysis of landfill site suitability, the spatial data are collected from the different sources such as satellite image, digital elevation model (DEM), toposheet. The satellite images Landsat LISS-III are collected from Bhuvan ISRO, India (https://bhuvan.nrsc.gov.in). DEM data are extracted from CARTOSAT1, PAN (2.5/Stereo Data) Bhuvan ISRO, India (https://bhuvan.nrsc.gov.in). The Geomorphic features are collected from National Bureau of Soil Survey and Land Use Planning, Nagpur. The soil map, ground water potential zone map, river, surface water map, urban area, fallow land, forest area, accessibility map are collected from different sources like District Census Handbook of Bardhaman, Google Earth Pro, Toposheet no: F45D, and the GPS are used for coordinating the existing dumping ground.

3.Selection of criteria

In order to do suitable analysis, we need to focus on the proper selection of the criteria. The different objectives and the different geographical locations generally change the criteria selection for one study area from the others. We recall that, in Durgapur city, garbage are generally disposed unscientifically, and this process has negative impact on the adjoining environment and the public health. Hence, the multiple criteria for landfill site are an essential requirement in the present study.

In the present study, we select 14 relevant and site specific criteria based on the detailed literature survey and guidelines of Central Pollution Control Board (CPCB) to identify the suitable site for the landfill. These 14 criteria broadly come into 4 categories. In GIS, each of the

14 criteria (vector layers) is created with the help of different sources, and exported for proximate analysis to create buffer zones. Furthermore, the vector layers are converted into raster, and reclassify the buffer zones by given the rating value within the range 0 to 9. Here, 0 represents the restricted and 9 represents the most suitable site for landfill. The 14 criteria and the sub-criteria weights are explicitly discussed below:

3.1. Hydrological criteria

In this category, we focus on river, surface water (pond, well, and canal), and groundwater potential map for the analysis of the landfill suitability. Water body such as river, pond, well, canal, and Ground water are more vulnerable to contamination due to ill-suited location of landfill (Paul 2012). In order to analyze landfill site, multiple studies have been used at specific distance in hydrological criteria ranging from 100 m to 300 m (Chang et al. 2008; Gemitzi et al. 2006; Akbari et al. 2008; Gorsevski et al. 2012; Ebistu et al. 2013). The input layer of the selected criteria are prepared in GIS with the help of SOI toposheet, GPS location, Satellite Imagery, Google Earth Pro, and District Planning Map Series of Bardhaman, West Bengal. These vector layers (shape file) are exported in GIS for the proximate analysis (calculate buffer zone) shown in Fig.4 are discussed in the following paragraphs.

Table 1: Summary of the layer

No.	Criterion	Sub-Criterion	Buffer Zone	Rating	No.	Criterion	Sub-Criterion	Buffer Zone	Rating
1	Hydrology	Ground Water	1-5 5-10	7 3	**8**	Land Features	Fallow Land	<200 200-400 400-600 >600	9 9 7 4
					9		Industry	<250 250-500 >500	0 7 4
2		River	<200 200-400 400-600 >600	0 5 9 7	**10**		Urban Area	<500 500-1000 >1000	0 7 9
3		Surface Water	<200 200-400 >400	0 8 5	**11**	Accessibility	Roads	<200 200-400 400-600 >600	0 8 9 4
4	Topography & Geology	Slope	<10 10-20 20-30 30-40 >40	9 8 3 1 1	12		Highway	<250 250-500 500-750 >750	0 4 8 7
5		Soil	Older Alluvium Lateritic Red & Yellow	2 6 7	13		Railway Line	<250 250-500 500-750 >750	0 7 9 4
6		Geomorphology	Valley Bottom Upper Alluvial Plain Pediplain	2 4 7					

7	**Land Features**	Forest	<200 200-400 400-600 >600	0 4 8 5	1 4		Airport	<400 400-800 800-1200 >1200	0 5 7 3

Groundwater potential:

The input layer of the groundwater potential map is prepared through the District Planning Map Series. We obtain two zones of potential: one 1-5 yeild in litre/sec and the other one 5-10 yeild in litre/sec shown in Fig.4a. The aforesaid two zones have given rating 7 and 3 respectively. We have given the lowest (highest) yield of groundwater potential area the highest (lowest) rating. The groundwater contaminated from the pollutants of landfill depends upon the soil porosity and the permeability of the rock. Here, we only study the potential layers of groundwater.

River:

The Damodar river flows in the southern part of the Durgapur city boundary, whereas two rivulets (Tamala and Singaram) flow in the city. The Damodar river is the main source of water in the entire city. In order to protect the river from contamination, the landfill site should not locate within the buffer distance on both sides of the river. Following the guidelines of CPCB, the aforesaid buffer distance is taken as 200 m. The remaining buffer zones 200-400 m, 400-600 m, and<600 m are reclassified after raster conversion of the layers to provide the rating 5, 9, and 7 respectively shown in Fig.4b.

Surface water:

The contaminated run-off from the landfill site ought not to be in the surrounding area of pond, well, and canal. The surface water layer is created with the help of SOI Toposheet, GPS, and Google Earth Pro. The vector layers exported in GIS for proximate analysis with 200m interval, and further developed three buffer zones: <200 m, 200-400 m, and >400 m. The <200 m interval is the restricted area for landfill according to the guidelines of pollution control board. The remaining sub-criteria 200-400 m and >400 m of the layers are converted into raster and reclassified the zones after giving the rating 8 and 5 respectively shown in Fig.4c.

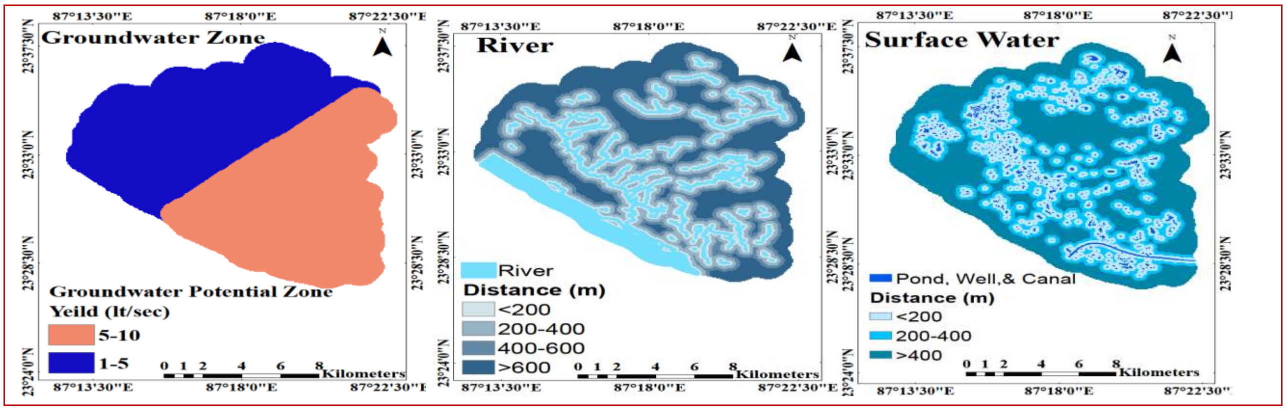

Fig.4: Selected map of Hydrological criteria: a. Ground water potential zone; b. River; c. Surface water

3.2. Criteria for topography and geology

The topography and geology are considered as the essential appraisals to control leachate, percolation or infiltration of toxic materials from the landfill site (Al-Yaqout et al. 2003; Yesilnacar et al. 2008; Ebistu et al. 2013). In this category we produce 3 criteria, viz., slope, soil, and Geomorphic features.

Slope:

The slope is defined as the rate of change of elevation in land surface, and it is one of the basic criteria to find the proper sitting of landfill. In the present study, the landfill sitting are selected on the basis of economic view and environmental perspectives. There is an inverse relationship between slopes with landfill sitting, i.e., the lowest degree of the slope has the highest suitability for landfill (Kontos et al. 2005). If the slope is greater than 25^0, the landfill is not possible (Guler et al. 2017) and is suitable where the slope is less than 10^0 (Leao et al. 2001; Nas et al. 2010). The slope layer is developed from DEM in GIS environment, and classified into five zones: $<10^0$, 10^0-20^0, 20^0-30^0, 30^0-40^0, and $>40^0$ shown in Fig.5. This raster layer is reclassified into five zones with score values 9, 8, 3, 1, and 1 respectively; the corresponding ratings are given with the help of the literature survey. The ranges $<10^0$ and 10^0-20^0 are highly preferred than the land with high elevation and steep slope for landfill due to less runoff of pollutants and less excavation cost (Kao et al. 1999; Guiqin et al. 2009).

Geomorphic Features:

The geomorphic units of the study area are digitized with the help of GIS from the source map of National Bureau of Soil Survey and Land Use Planning, Nagpur. Three Geomorphic features are found in DMC, i.e., Valley Bottom (Deposition zone of alluvium), Upper alluvial plain, and pediplain. The valley bottom and alluvial plain are less suitable for sitting the landfill, but the pediplain area is highly suitable for landfilling. This vector layer is converted into raster and further reclassifies the three features after giving the rating 2, 4, and 7 respectively.

Soil:

The type and nature of the soils reveal the permeability and porosity which control the groundwater contamination from the landfill. Therefore, locations of the landfill are unsuitable in permeable soil. There are three types of soil in DMC: Older Alluvium, Lateritic, and red & yellow soil, are digitized with the help of District Planning Map Series, Bardhaman in GIS (Fig. 5c). Laterite and red & yellow soil give highest rating than older alluvium soil due to the reasons of fertility (refer Table 1).

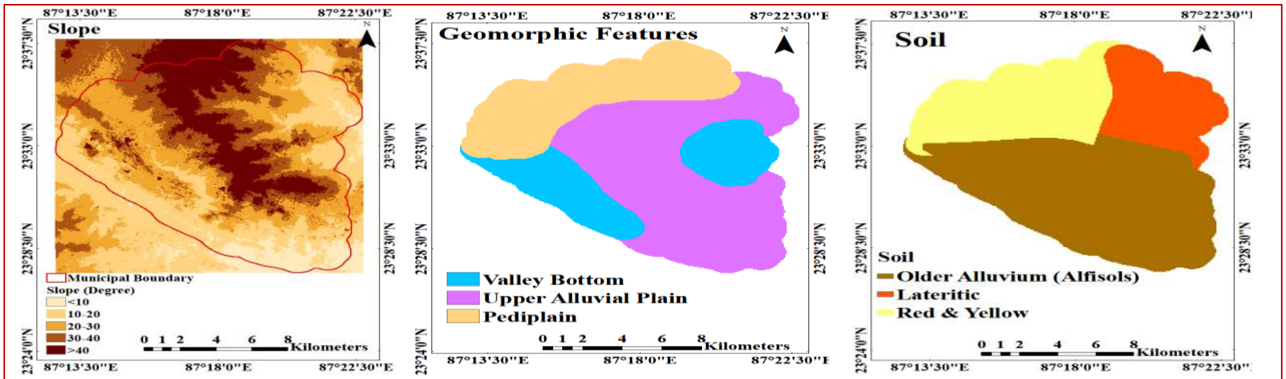

Fig.5: Selected map of Topography and Geology: a. Slope, b. Geomorphic Features, c. Soil

3.3. Criteria for Accessibility

Accessibility or transportation, an indicator of the development in any area, also an important part of the waste management system. The landfill site should not be located near to the road, highway, railway line, and airport as per Central Pollution Control Board (CPCB) Guidance and CPHEEO 2000 Manual. In this category, we study highway, road, railway line, and airport. From economic point of view, higher suitability ratings have been assigned if the landfills are closer to highway, road, railway line, and airport (Guiqin et al. 2009; Gorsevski et al. 2012; Das et al. 2015; Guler et al. 2017). On the contrary, from the environmental perspectives, we may assign lower suitability rating if the landfills are closer to transportation network (Bhambulkar 2011; Rafee et al. 2011; Jaybhaye et al. 2014). The current study has given priority to the environmental perspective. The input layers are prepared through the satellite image, Google earth pro and SOI toposheet in GIS. The vector layers are exported for proximate analysis with 200 m interval for road, 250 m interval for highway, 250 m interval for railway line, and 400 m interval for airport, and then converted into Raster layer (Fig 6). According to CPHEEO 2000, landfills cannot be suitable within 200m buffer zone on both sides of road and railway network.

The four layers (highway, major road, railway, and airport) are reclassified in GIS and the corresponding rating of the buffer zones are given in Table 1.

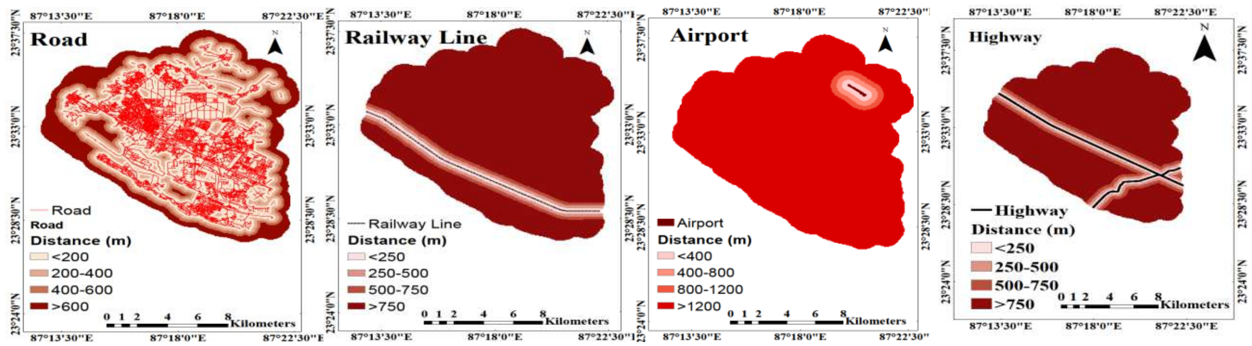

Fig. 6: Criteria for Accessibility a. Road, b. Railway, c. Airport, d. Highway

3.4. Criteria for Land features

It is an important category for landfill site selection. The different features on land surface such as urban area, industry, fallow land, and forest cover are taken into consideration before selecting any portion of municipal area are shown in Fig.7. The nearness to urban area, industry, and forest are not suitable for landfill to protect public health and environment (Gorsevski et al. 2012; Jaybhaye et al. 2014; Guler et al. 2017), and fallow lands are suitable for landfill site. The vector layers (shapefile) are prepared with the help of SOI toposheet, satellite image, and Google earth pro.

Urban Area:

The maximum portion of the study area covered with high built-up area, and the classification of urban area are considered through economic factors (transport & cost of land) as well as surrounding environment to people from the negative impacts to the landfill, i.e., disease, foul smell, and insect (Chabuk et.al, 2019). The landfill sites are always selected far away from the urban area due to public opposition (Lober 1995; Mahini et al. 2006). In GIS, the vector layer is exported in proximate analysis for buffering within 500 m interval and 3 zones are developed. Furthermore, the vector layer is converted into Rater layer and reclassify the 3 zones >500 m, 500-1000m, and <1000m with a scale value of 0, 7, and 9 respectively shown in Fig.7a. The landfill site cannot be permitted within 500m habitable zone following the guidance's of CPCB, CPHEEO, and SWM Rules 2016.

Industry:

Durgapur is an industrial city of the state West Bengal in India. Iron and steel industries have been developed in 1994. Most of the industries are concentrated in the southern portion of National Highway (DMC). Consequently, the land devoted to the industries and the corresponding surrounding areas are not suitable for landfill. Buffering within 250 m is restricted, whereas the buffer zones 250-500 m and 500 m are suitable for landfilling.

Forest:

Forest covered area are not suitable for landfill sitting. As per the government rules, buffer of 200 m are restricted for any landfill location. The reasons of restrictions are leachate and poisonous waste from the landfill destroys the habitation, soil and normal food cycle in the forest (Gworek et al. 2015; Adamcová et al. 2016).

Fallow land:

The fallow land is highly suitable for landfill in municipality area. In urban areas these lands are used for the expansion of urban area, new industry set up. These lands are easily used for landfill due to low nutritional value. In GIS the fallow land with 200 m and 200-400 m buffer area are highly suitable for landfill with rating 9 and far away from the fallow land are not suitable for landfill.

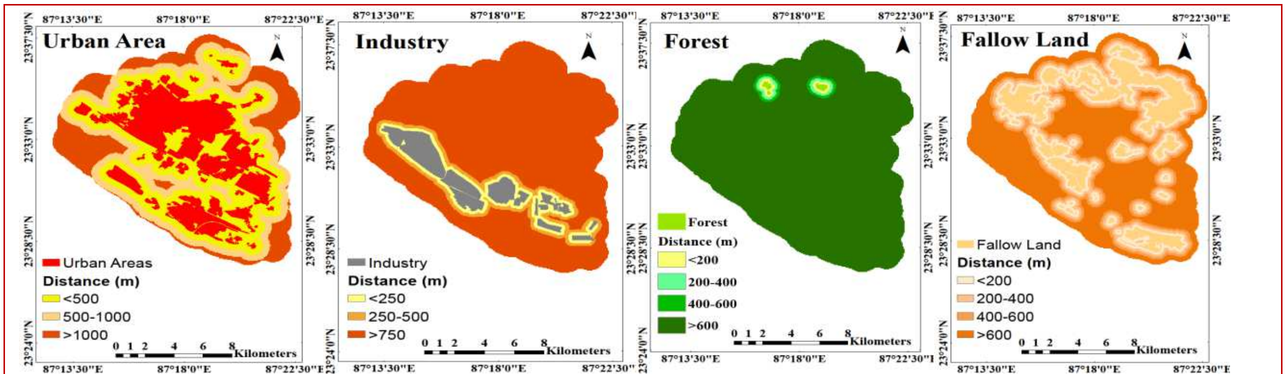

Fig.7: Criteria map for land features a. Urban Area, b. Industry, c. Forest, d. Fallow Land

4. Multi-criteria Decision Making Methods

MCDM, decision making tools, help to derive weights of each criterion, after that the weights will integrate in a logical manner for decision making segments at the end (Gorsevski PV et al. 2012). Three methods of MCDM are implemented in the study to derive the weights of the criteria. These methods are Analytical Hierarchy Process (AHP), Straight Rank Sum Method (SRS), and Ratio Scale Weighting Method (RSW).

4.1. Straight Rank Sum Method (SRS)

Malczewski, in 1999, has described the straight rank sum method. It is a simple ranking technique used to determine the weight of the criteria. The criteria are arranged by rank in order from most to least important on the basis of comparative significance given by decision makers to calculate weight of the factors using the formula $(n - r_i + 1)$, where nis the number of criteria in the selection process, and r_i is the ranking position of the criteria.

In order to calculate the relative weight RW_i in Straight Rank Sum method, we divide the weight of each criteria $(n - r_i + 1)$ by the summation of all the criteria weights$\sum$ $(n - r_j + 1)$, i.e.,

$$RW_i = \frac{(n-r_i+1)}{\sum(n-r_j+1)}. \qquad (1)$$

The calculated value of relative weights of 13 criteria are shown in Table 2

4.2. Ratio Scale Weighting Method (RSW)

The Ratio Scale Weighting Method is also applied in this study. The weights of the criteria are given directly by decision makers. The allocation of proportional ratio score values for each criterion is given between 0 and 100 based on various decision makers (Sener 2004). Here, the value 100 is assigned to imply the most important criterion (Sener 2004).

To calculate the standard weight(SW_i), the ratio scale value of each criterion is divided by the smallest value (lowest significant factor) of the criteria. After that, for the calculation of the relative weight we normalized the standard weight, i.e., divide each criterion of the standard weights(SW_i) by the sum of all the standard weights of the criteria. Mathematically we may write the following equation:

$$RW_i = \frac{SW_i}{\sum_{j=1}^{n} SW_J} \qquad (2)$$

with the help of the equation the relative value are calculated in Table2

Table2. The Criteria Weights calculate through SRS and RSW methods

MCDM methods	**SRS**		**RSW**		
Criteria	**(n-r+1)**	**Relative Weights**	**Ratio Scale Value**	**Standard weights (Swi)**	**Relative weights**
Groundwater	10	0.1695	95	17	0.1677

River	7	0.1186	70	10	0.1198
Surface water	7	0.1186	65	9.5	0.1138
Slope	3	0.0508	50	5	0.0599
Soil	2.5	0.0424	44	4	0.0479
Geomorphic Features	2	0.0339	42	4	0.0479
Urban areas	8.5	0.1441	82	12	0.1437
Industry	1.5	0.0254	10	2	0.0239
Forest	5.5	0.0932	55	9	0.1078
Fallow land	1	0.0169	5	1	0.0119
Highway	4	0.0678	52	6	0.0719
Major Road	2	0.0339	15	3	0.0359
Railway	2.5	0.0424	25	4	0.0479
Airport	2.5	0.0424	28	4	0.0479

4.3. Analytical Hierarchy Process

AHP, a theoretical analysis, was developed by Saaty in 1980 for multi-criteria decision making. This technique, also referred as Saaty method, is used in different studies to find out the weighting for any criterion. The weightage of the criteria are illustrated with the help of a comparison matrix (C). The elements of C may take any integer value within the range [1, 9], and each value expressed the relative importance between two criteria.

Table 3. The Comparison Scale (Saaty, 1980)

Intensity of Importance	**Definition**
1	Equal Importance
3	Weak Importance
5	More importance
7	Much more importance
9	Extremely importance
2,4,6,8	Intermediate

The scale of the aforesaid relative importance, shown in Table 3, implies that 9 represents the maximum preference, whereas 1 symbolizes no (or equal) preference. The numerical points are assigned in the criteria on the basis of decision makers (expert view & literature review) and produced the pair wise comparison matrix. Relative weight, derived from the pair-wise comparison matrix for each criterion, allows the decision makers to choose the best criteria. In the next paragraph, we elaborately discuss the methodology to construct the matrix C.

Let C is a matrix of dimension $m \times m$ with elementsc_{ij}, which satisfies the following condition:

$$c_{ji} = \begin{cases} 1, \text{if} i = j, \\ \frac{1}{c_{ij}}, \text{otherwise}, \end{cases} \qquad (3)$$

Where i and j respectively represent the row and column of c_{ij} with $i = 1,2,3, \cdots, m$ and $j = 1,2,3, \cdots, m$. Eq. 1 implies that C is a reciprocal matrix of order m. Furthermore, if $\lambda_i \wedge \omega_i$ are the i^{th} eigen value and eigenvector of C respectively, the consistency index (CI) is defined as:

$$CI = \frac{\lambda_{max} - m}{m - 1}. \qquad (4)$$

Here, λ_{max} is the maximum eigenvalue. Intuitively, CI implies the average deviation of the comparative elements from their true values. Finally, the consistency ratio (CR) is defined after dividing the CI by the random index values (RI). The RI values are provided by Saaty and are given in Table 4 where, upper row is the random matrix order and lower row (RI) is the corresponding index of consistency for random judgment.

Table4. Random Index (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

By construction, CR values lie within the range [0, 1]. The values of CR are inversely proportional to the degree of consistency of the judgments, i.e., lower values of CR are indicating more consistent judgments (Setiawan et al., 2014). In this study, adopting $RI_{14} = 1.57$, the calculated value of CR is 0.072< 0.1 = Acceptable, which further implies that there is reasonable consistency level in the pair wise comparison, and it is elaborately shown in Table 5.

Table 5: Pair wise Comparison Matrix and Relative Weights of the Criteria

Criteria	Groundwater	River	Surface water	Slope	Soil	Geomorphic features	Urban Areas	Industry	Forest	Fallow land	Highway	Major Road	Rail	Airport	Criteria Weights
Groundwater	1	2	2	2	3	4	2	5	5	8	3	7	4	4	0.1703
River	0.5	1	1	3	3	2	0.33	5	4	9	3	4	3	3	0.1032
Surface water	0.5	1	1	3	3	2	0.5	5	3	8	3	4	3	2	0.1024
Slope	0.5	0.33	0.33	1	0.5	1	0.25	2	0.5	4	2	3	3	2	0.0482
Soil	0.33	0.33	0.33	2	1	2	0.33	2	0.5	5	0.5	2	0.5	0.5	0.0399
Geomorphology	0.25	0.5	0.5	0.5	1	1	0.33	2	0.33	4	0.5	3	1	2	0.0451
Urban areas	0.5	1	2	4	3	3	1	4	2	7	2	6	3	4	0.1204
Industry	0.2	0.2	0.25	0.5	0.5	0.5	0.25	1	0.25	5	0.5	0.33	0.5	0.5	0.0226
Forest	0.2	0.25	0.2	2	3	3	0.33	4	1	7	3	4	5	4	0.0812
Fallow land	0.13	0.11	0.12	0.25	0.2	0.25	0.14	0.5	0.14	1	0.17	0.17	0.17	0.14	0.0099
Highway	0.33	0.33	0.33	2	3	2	0.5	6	0.33	5	1	4	2	5	0.0543
Major Road	0.14	0.25	0.25	0.33	0.5	0.33	0.17	3	0.25	6	0.25	1	0.5	0.33	0.0217
Railway	0.25	0.33	0.33	0.2	2	0.33	0.33	2	0.2	6	0.33	2	1	1	0.0299
Airport	0.25	0.33	0.5	0.5	2	0.5	0.25	2	0.25	7	0.5	3	1	1	0.0366
λ_{max}	15.469														
Consistency Index (CI)	0.113														
Consistency Ratio (CR)	0.072														

5. Final Landfill Map

The weighted overlay analysis is the most applied approach to solve multi-criteria problems in GIS. In order to draw the final suitable maps from the multi-criteria, we use the weighted overlay as it is one of the fruitful tools for site selection and suitability model (Ayalew 2004; Belay et.al 2015; Roslee et al. 2017). Also, this tool is useful in different fields of suitability analysis such as to find out the most suitable location for new township, ground water potential zone, ground water recharge zone, suitable crop zone, and susceptibility analysis for landslide (Belay et al. 2015; Riad et al. 2011; Kaliraj 2015; Jamil et al. 2018; Feizizadeh et al. 2013; Basharat et al. 2016).

The weight of each raster map is calculated with the help of three MCDM methods: AHP, SRS, and RSW. After deciding the weight of multi-criteria, the "Weighted Overlay" options in spatial analyst tools of GIS software are implemented to create the final raster maps of the suitability index for landfills. The weights of the criteria are analyzed using three WLC methods (Tables 4 and 5). In addition, the 14 criteria (Groundwater, River, Surface water, Slope, Soil, Geomorphic Features, Forest, Fallow land, urban areas, Industry, Highway, Major Road, Railway, and Airport) overlay in spatial analysis tool of GIS. Finally, using the "weighted Overlay" option, we create the site suitable map. These weighted overlays are done three times for three weighted methods: AHP, SRS, and RSW. The Weighted Overlay can be expressed as:

$$S_i = \sum_{k=1}^{n} RW_k \times SC_{ki}$$

(5)

Where S_i is the suitability index of the area i; n is the criteria number; RW_k is the relative weight of each criteria; SC_{ki} is the rating of the sub-criteria under criterion k. The three final raster maps for suitable landfill site are prepared and shown in Fig. 8.

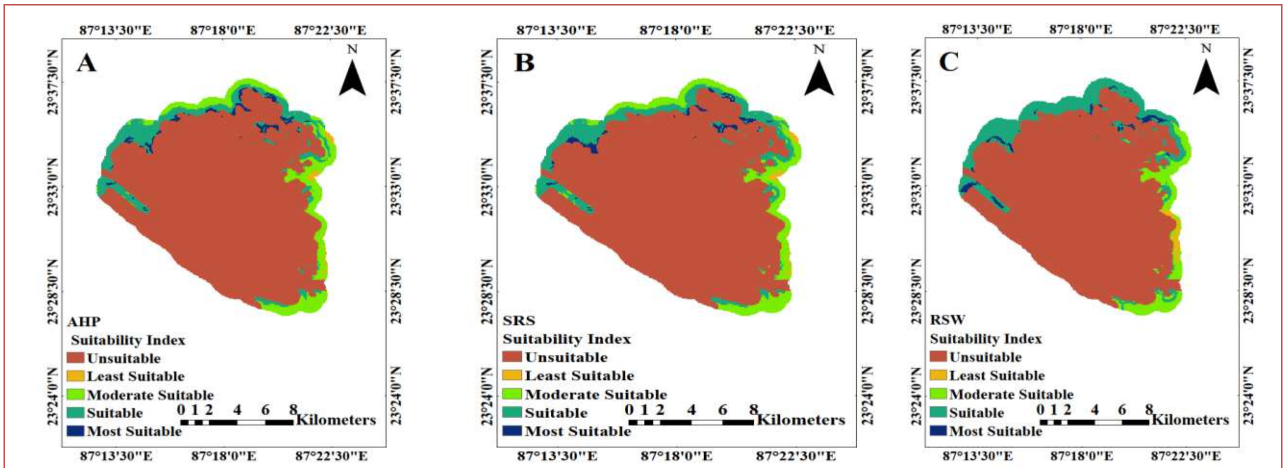

Fig.8: Final map of Landfill Site Suitability using method: a. AHP, b. RSW, c. SRS

6. Result and Discussion:

The present study focuses on the analysis of the suitable site to concern the environmental and public health in Durgapur Municipal Corporation for dumping the garbage, which are generated on daily basis. In the course of our study, in search of new landfill we formulate 14 criteria layer in GIS environment. To derive the weights of these 14 criteria, we adopt the three discussed methods: AHP, SRS, and RSW. Then overlay the each criterion weight in GIS to prepare the three final maps. In each method, the suitability index value is categorized into five classifications of suitability areas. The corresponding categories are unsuitable, least suitable, moderate suitable, suitable, and most suitable, and we summarize the number of pixel and the area of each category for landfill sitting in Table 6.

Table 6: Area with percentage of the final map in every suitability category in three 3 MCDM methods

MCDM Methods	Suitability Index	Unsuitable	Least Suitable	Moderate Suitable	Suitable	Most Suitable
AHP	Count	37155	336	2575	5597	547
	Area (sq.km)	173	1	18	20	3
	Percentage	80.46	0.47	8.37	9.3	1.4

	(%)					
SRS	Count	37119	229	3866	4387	546
	Area (sq.km)	173	1	19	19	3
	Percentage (%)	80.46	0.47	8.84	8.84	1.39
RSW	Count	37155	421	2875	5597	547
	Area (sq.km)	173	2	17	20	3
	Percentage (%)	80.46	0.93	7.91	9.30	1.39

The areas of every index categories to each method are slightly different from the others. The differences are checked with the help of change detection method developed by U.S. National Land Cover Database (NLCD) (Jin et al. 2013). The change detection method is calculated by comparing the pixel value of 3 final suitability raster maps. After comparing we can easily detect the matching pixel and non-matching pixel from all the categories. In this paper, we calculate the change detection from the 3 final raster maps in GIS environment, the “Map Algebra” option from spatial analyst tool using the formula:

$$CD_{RM} = AHP_{RM} + SRS_{RM} - 2RSW_{RM} \quad (6)$$

Where, CD_{RM} is the change detection of the raster map; AHP_{RM} is the final raster map of Analytical Hierarchy Process; SRS_{RM} is the final raster map of Straight Rank Sum Method; RSW_{RM} is the final raster map of Ratio Scale Weighting Method. From the change detection calculation, it is clearly shown that around 95% area are matching, while non-matching area comprises only 5% (refer Fig. 9). The landfill sites are always selected from the most suitable and the suitable areas in the matching pixel regions. All the methods are overlaid to determine the intersecting area within the map (Fig. 10a). From the final overlay map of all MCDM methods and the comparison map, we select the candidate site for new landfill.

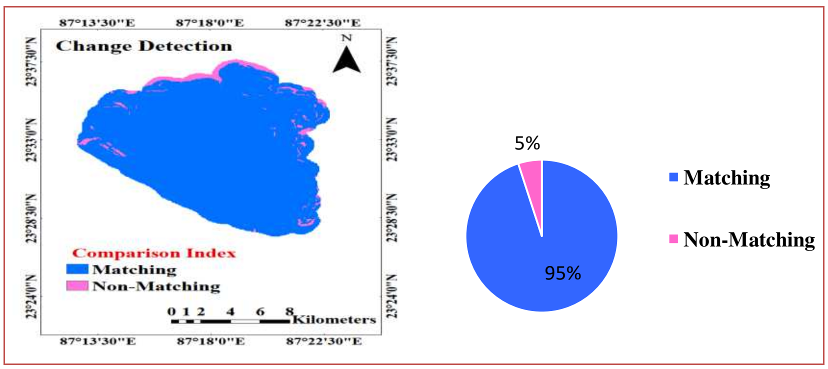

Fig.9: Comparison Map

Hence, in DMC, six landfill sites are selected in the most suitable and the suitable areas from the intersection map generated using the three methods (AHP, SRS, and RSW).

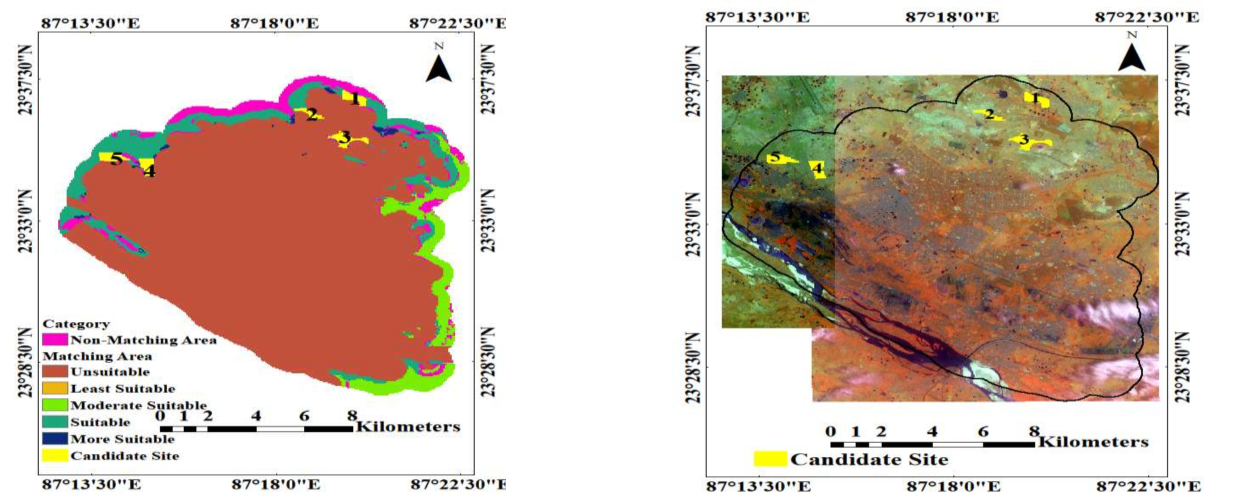

Fig.10: a. Candidate Site selected from the Suitable and the most suitable zone of the Overlay Map, b. Candidate site also view in the Satellite Image.

7. Conclusion

In conclusion, this paper aims to find out a dumpsite for sustainable waste disposal in DMC. Currently, the Durgapur city is suffering from the inappropriate waste management system, and the open dumping is one of the serious issues. The unscientific open dumping has serious negative impact on environment and public health. This city generates enormous amount of waste, and the waste amount is increasing with the increase in population. Hence, the ULBs pay greater attention to find out the suitable landfill sites, which fulfill all the essential requirements. In search of the proper selection process for sustainable waste disposal in DMC, we have adopted the GIS and the MCDM techniques. The 14 different criteria (Groundwater, River, Surface water, Slope, Soil, Geomorphic Features, Forest, Fallow land, urban areas, Industry, Highway, Major Road, Railway, and Airport) have been used in these processes to determine the suitable candidate site for landfill. The criteria are incorporated into GIS for decision making process.

The three MCDM methods like: AHP, SRS, and RSW have been used to derive the weights of the criteria which are entered in GIS. Three output maps are generated with the help of weighted overlay analysis in GIS. After that, the percentage of matching pixel and non-matching pixel are 95% and 5% respectively calculated by comparing the final raster map of AHP, SRS, and RSW using spatial analyst tool "Map Algebra" in GIS. The final raster map is developed by intersecting the three final maps, where most suitable category from the matching area is the appropriate area for landfill sites. Finally, five candidate sites have been selected from the final maps.

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Figures

Figure 1

Image (a) shows the compost plant. Image (b) is foundation stone of the aforesaid compost plant. Image (c) is the demolished part the compost plant. Dumping of mixed waste is shown in Image (d); (e) Stray Dogs and birds roaming in dumping site; (f) Gas emissions from the burning of waste; (g) Poor condition of fencing and gates; (h). Surrounded agricultural land are pollute from leaching and movement of garbage (plastics, paper, etc) from the dumping ground; (i). Field visit by the author.

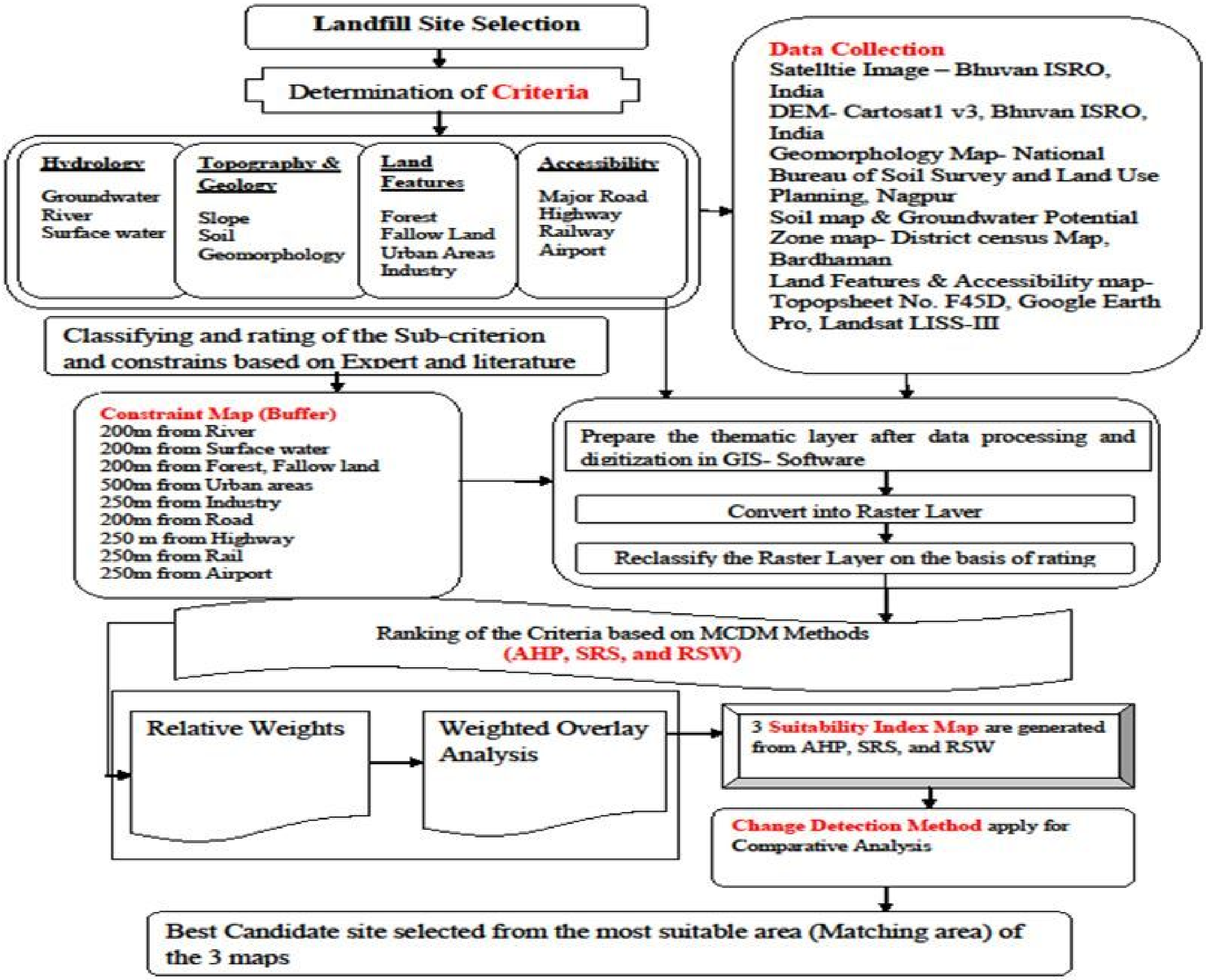

Figure 2

The Flow chart of the model for suitability analysis

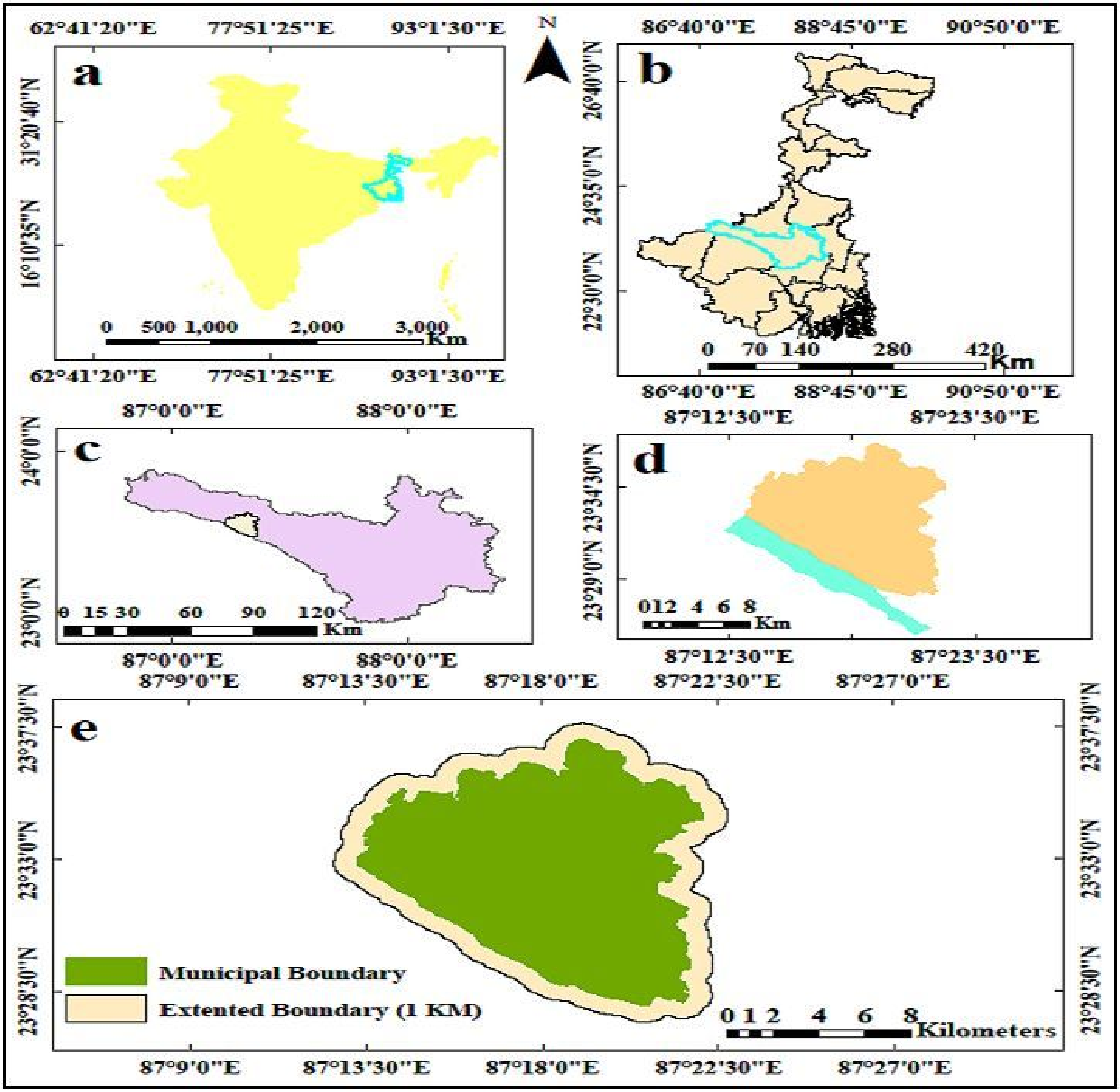

Figure 3

Study Area Map (a. India, b. West Bengal, c. Bardhaman, d. Municipal Boundary (DMC), e. Extended Boundary

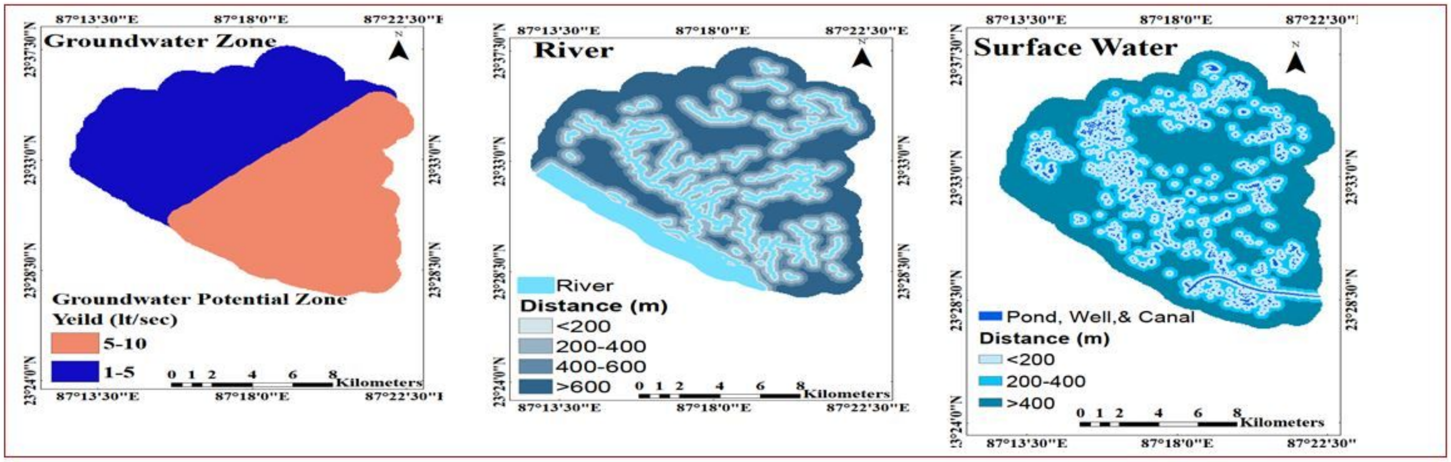

Figure 4

Selected map of Hydrological criteria: a. Ground water potential zone; b. River; c. Surface water

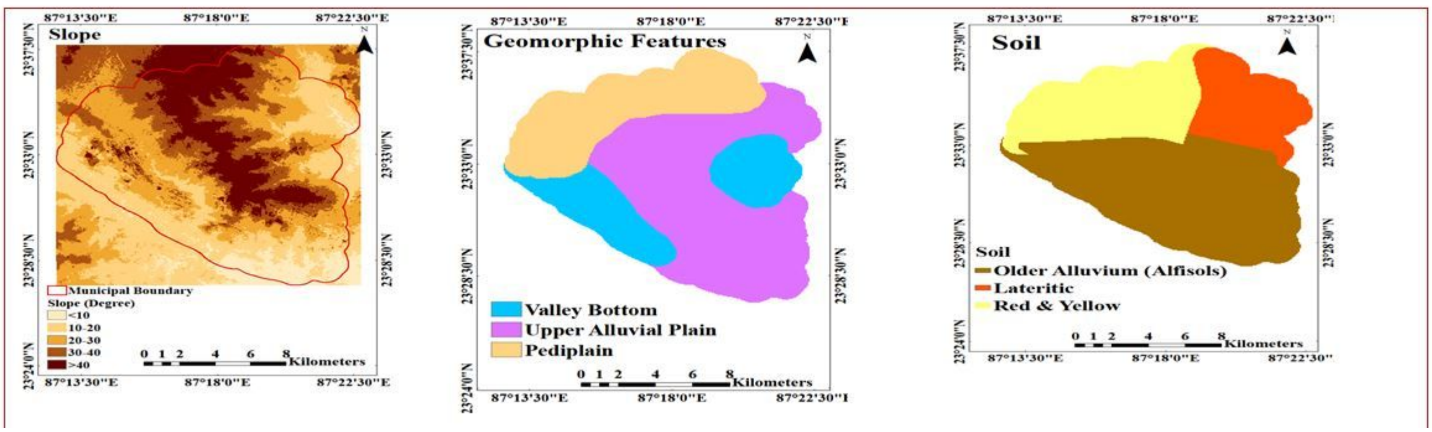

Figure 5

Selected map of Topography and Geology: a. Slope, b. Geomorphic Features, c. Soil

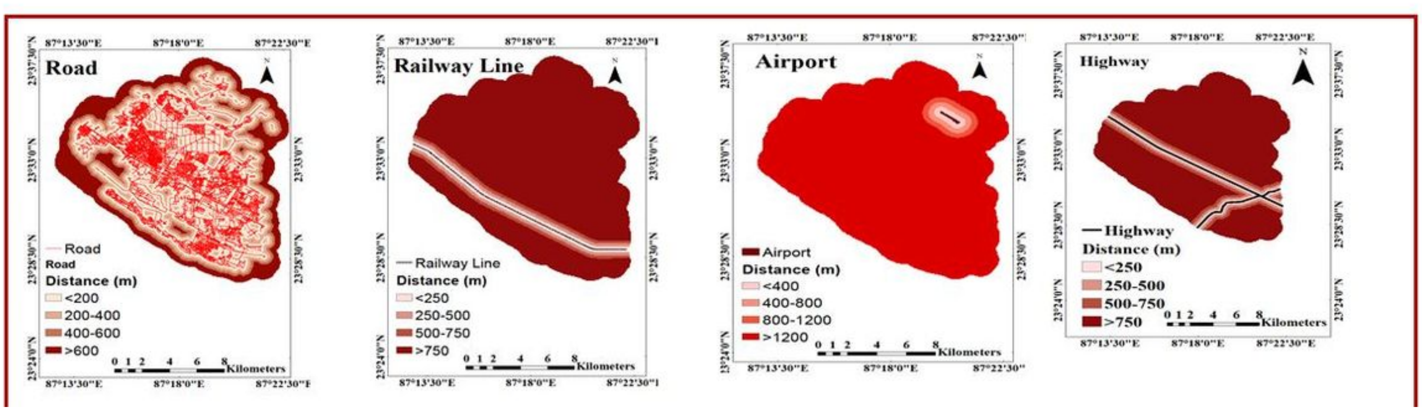

Figure 6

Criteria for Accessibility a. Road, b. Railway, c. Airport, d. Highway

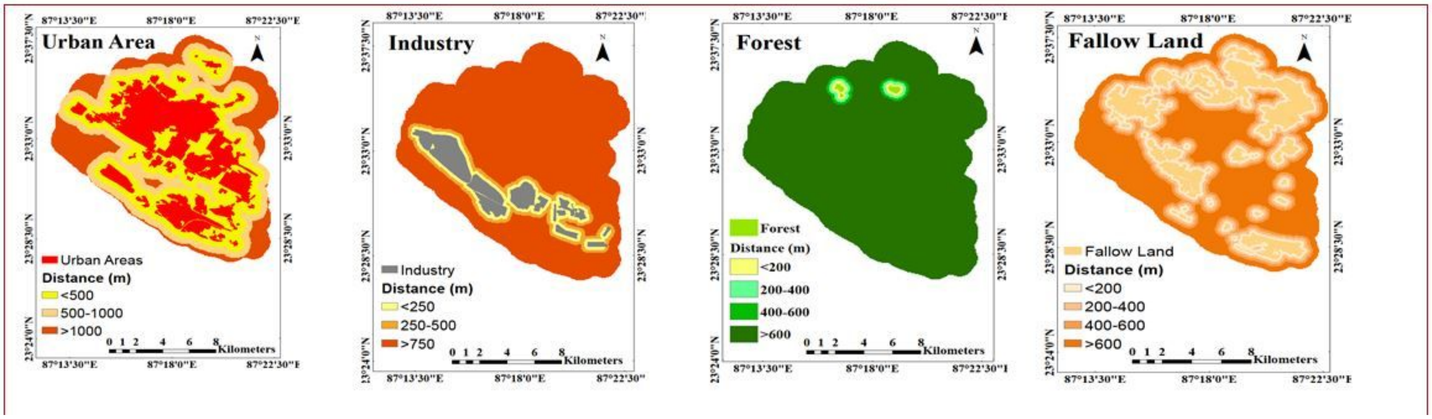

Figure 7

Criteria map for land features a. Urban Area, b. Industry, c. Forest, d. Fallow Land

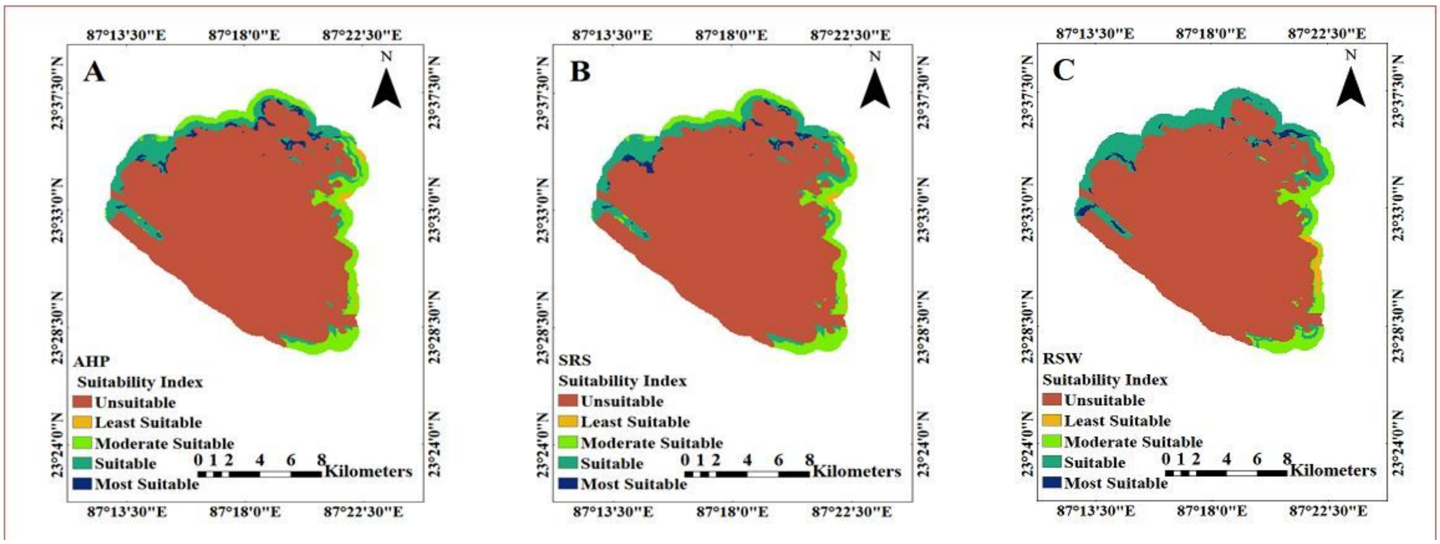

Figure 8

Final map of Landfill Site Suitability using method: a. AHP, b. RSW, c. SRS

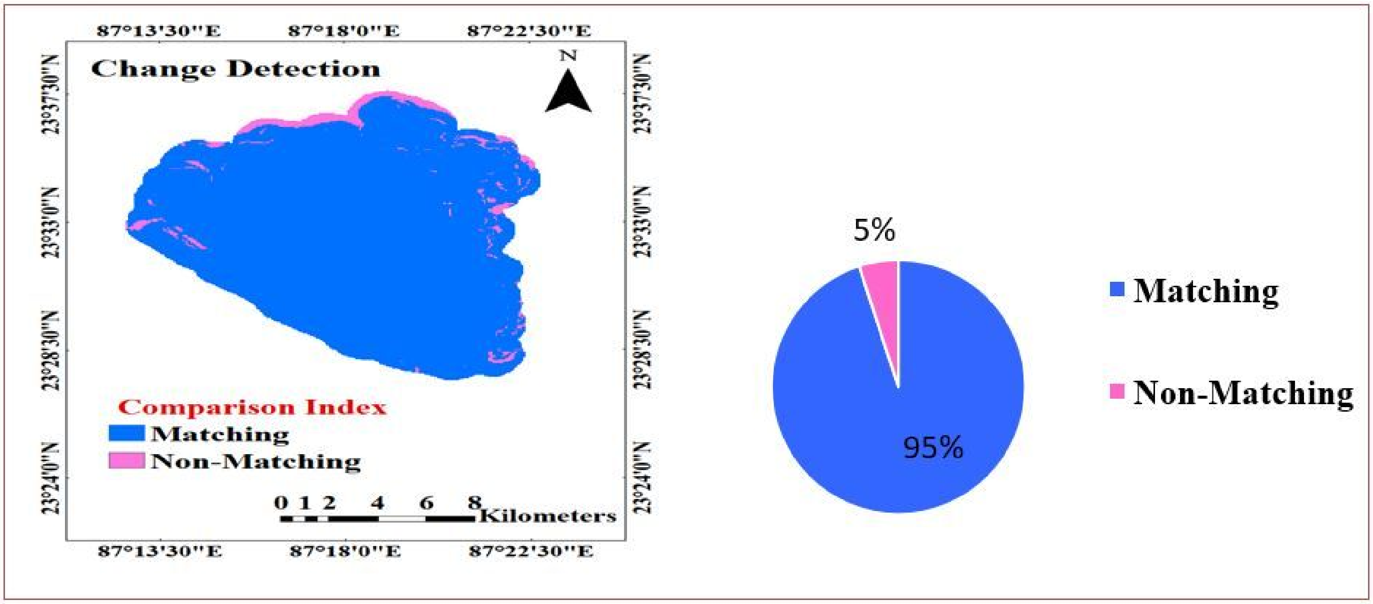

Figure 9

Comparison Map

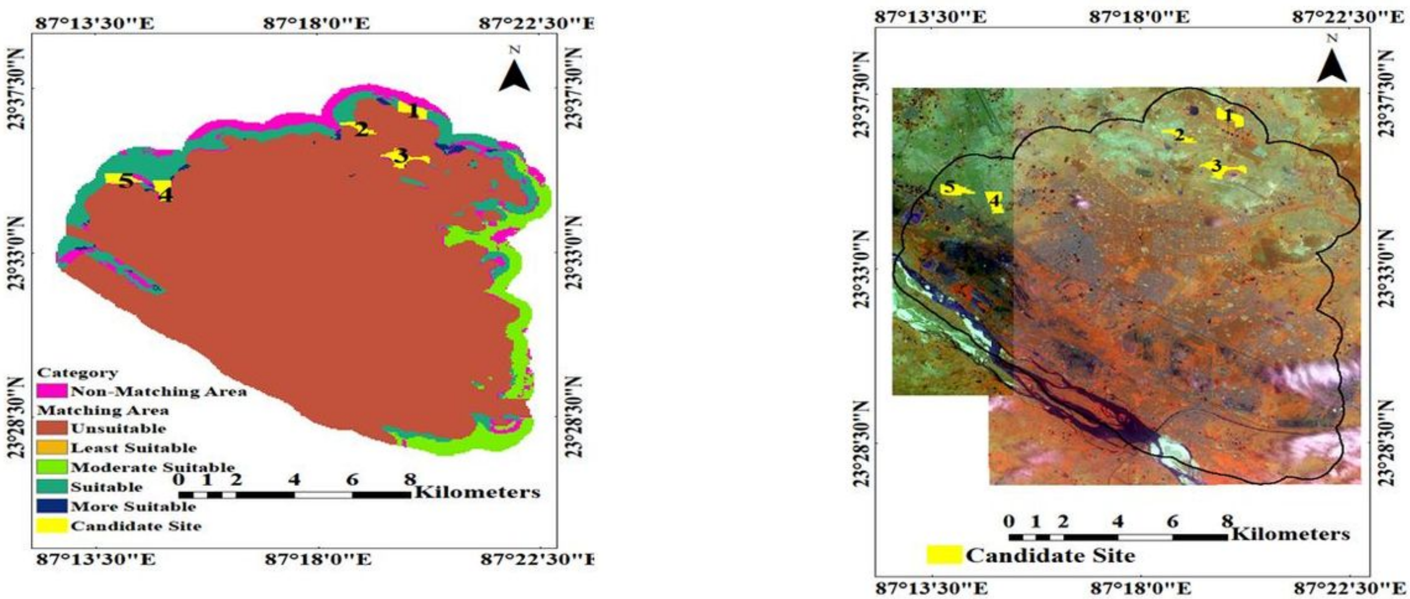

Figure 10

a. Candidate Site selected from the Suitable and the most suitable zone of the Overlay Map, b. Candidate site also view in the Satellite Image.