DEVELOPMENT OF A FUZZY BASED MODEL FOR SELECTING APPROPRIATE LANDFILL SITE FOR MUNICIPAL SOLID WASTE DISPOSAL

A Thesis Is Submitted For The Partial Fulfillment Of The Continuous Assessment Of The Course Of Master Of Civil Engineering Of Jadavpur University For The Session 2015-2016

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DECLARATION

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ABSTRACT

A fuzzy based model was developed in the proposed work to evaluate the suitability of landfill sites for disposing municipal solid waste considering 32 attributes as proposed by Central Pollution Control Board (CPCB) in their publication ***CPCB (2003)***. The work is demonstrated with reference to Asansol Municipal Corporation (AMC) area in West Bengal, India, as a case study. The attributes include both quantitative and qualitative variables. These attributes were assessed qualitatively by the experts related to solid waste management. The weightage of each attributes and sensitivity index of each attributes related to proposed sites were defined in the form of triangular fuzzy membership functions based on the intuitions and data related to available literatures. The fuzzy decisions provided by the experts were then defuzzified by Yager's unit interval method to get the crisp weightage corresponding to each attribute and sensitivity index for attributes corresponding to each proposed sites. At a time the experts were to evaluate one attribute for both weightage and sensitivity index calculation.

The performance of the model was checked by determining relative percentage error considering the model obtained weightage and ***CPCB (2003)*** mentioned weightage. From the results it was clear that for most of the attributes the weightage obtained by the two methods were more or less same except for the attributes distance from collection area, distance to nearest drinking water source, public acceptability, distance to nearest surface water, depth of ground water and job opportunities. Which implies that, during decision making experts provide more emphasize to economic viability and social acceptability of the sites along with environmental sustainability. From the results of sensitivity index calculation also it was clear that the attributes, type of road, population within 500 meters, use of the site by nearby residents, land use/ zoning, decrease in property value with respect to distance, public utility facility within 2 km, public acceptability, health, odour, vision, climatic features contributing to air pollution, susceptibility to erosion and run off and seismicity obtained more sensitivity index than ***CPCB (2003)*** for the two sites considered by ***CPCB (2003)*** in their Site Sensitivity Index (SSI) study. The attributes are mainly qualitative attributes describing socio-economic conditions hence fuzzy interpretation of those attributes can capture the ambiguity in the meaning of the attributes and overcome the imprecision and uncertainty of the related data more effectively.

Finally, the model was applied for AMC area for selecting best landfill sites from the two landfill sites that were identified best on primary survey. It was found landfill site 2 is the best suitable site for landfilling since total score 400.054 is less than 427.734 for the site 1. As per classification proposed by ***CPCB (2003)*** the proposed site 2 may be classified under moderately suitable site. The proposed model can be effectively used for any landfill sites if data regarding proposed sites are available.

Keyword: Landfill site selection, fuzzy logic based model, attributes, model performance, weightage, sensitivity index, Asansol Municipal Corporation.

1. Introduction

1.1. General

Global population increase and urbanization are challenging municipal authorities to manage solid waste (SW). Solid waste management (SWM) has now become an important issue worldwide. For the developed countries, the quantity and kind of solid wastes, and the lack of disposal sites have caused a greater concern for SWM. For the developing nations, the growth in both size and concentration of the population, combined with a lack of public awareness has made the problem of SW a critical public issue.

Dumping and burying the municipal solid waste (MSW) in as many years has been the most common method for the disposal ***(Charnpratheep et al., 2002)***. Despite the use of recyclable materials worldwide, waste disposal to landfill remains the most common practice for waste management because it is simple and relatively inexpensive ***(Kim and Owens, 2010)***.

Landfill selection is an important municipal planning process which affects different regions in the economic, the ecological, and the environmental health sectors ***(Barlaz et al., 2003; Kouznetsova et al., 2007; Goorah et al., 2009)***. The location must comply with the requirements of the existing government regulations and at the same time must minimize economic, environmental, health, and social costs ***(Siddiqui, 1996)***.

Limited space availability for landfill disposal and growing negative public opinion towards landfills and its operations are continuously increasing, the " not in my backyard" (NIMBY) and not in anyone's backyard (NIABY) phenomena is becoming more popular nowadays creating tremendous pressure on the decision makers involved in the selection of a landfill site.

Inefficient selection causes several problems, such as social opposition, environmental problems, cost increases etc. The determination and evaluation of positive and negative characteristics of one location relative to others is a difficult task and can be seen as a multi criteria decision (MCD) making problem.

1.2. Methods of Landfilling

Final destiny of Solid Waste is reached by its disposal on land, deep below earth's surface, or ocean bottom. For techno-economic reasons, landfilling or dumping on land is the most suitable option. Solid waste disposal in landfill is the most widely used method for disposing of waste and about 80% of the wastes go to landfill ***(Singh and Dubey, 2012)***.

The primary methods used for landfill ***(CPHEEO, 2000)*** are:

- Area Landfill
- Trench Landfill
- Slope Landfill
- Valley Landfill

1. **Area landfill (above ground):** The area landfill is used when the terrain is unsuitable for the excavation of trenches in which to place the solid waste. High groundwater conditions necessitate the use of area-type landfills. Site preparation includes the installation of a liner and leachate control system. Cover material must be hauled in by truck or earthmoving equipment from adjacent land or from borrow-pit areas.

2. **Trench Landfill (below ground):** The trench method of landfilling is ideally suited to areas where an adequate depth of cover material is available at the site and where the water table is not near the surface. Typically, solid wastes are placed in trenches excavated in the soil. The soil excavated from the site is used for daily and final cover. The excavated trenches are lined with low permeability liners to limit the movement of both landfill gases and leachate. Trenches vary from 100 to 300 m in length, 1 to 3 m in depth, and 5 to 15 m in width with side slopes of 2:1.

3. **Slope Landfill:** In hilly regions it is usually not possible to find flat ground for landfilling. Slope landfills and valley landfills have to be adopted. In a slope landfill waste is placed along the sides of existing hill slope. Control of inflowing water from hillside slopes is a critical factor in design of such landfills.

4. **Valley Landfill:** Depressions, low-lying areas, valleys, canyons, ravines, dry borrow pits etc. have been used for landfills. The techniques to place and compact solid wastes in such landfills vary with the geometry of the site, the characteristics of the available cover material, the hydrology and geology of the site, the type of leachate and gas control facilities to be used, and the access to the site. Control of surface drainage is often a critical factor in the development of canyon/depression sites. It is recommended that the landfill section be arrived at keeping in view the topography, depth to water table and availability of daily cover material.

1.3. Landfill Site Selection

Many methods are developed from time to time to propose best landfill site among the available alternatives. Methods based on geographic information system (GIS), analytical network process (ANP), analytical hierarchy process (AHP), ordered weighted average (OWA), boolean logic (BL), fuzzy logic (FL), delphi technique (DT), site sensitivity index etc had been used either alone (with various modifications) or in combination of two or more for selecting landfill site. Most of site selection methods lack practical applications. This is due to the number of variables and complexity of the mathematical models which include the factors and constraints required in decision making ***(Shukla et al., 2012)***.

1.4. Landfill Disposal and Siting for Indian Conditions

More than 90% of MSW generated in India is directly disposed on land in an unsatisfactory manner ***(Sharholy el al., 2008)***. The disposal sites in India are located without consciousness about the environmental and public health hazards arising from disposing of waste in improper location. Uncontrolled dumping of wastes on the outskirts of town and cities has created overflowing landfills, which have environmental impacts in the form of pollution to soil, groundwater, and air, and also contribute to global warming ***(Chattopadhyay et al., 2009)***. Most of the landfilling sites are low-lying areas which are prone to flood.

Currently, in India the waste is not treated in systematic and scientific manner. As a result the whole area in and around the disposal site has become unhygienic and posing serious threat to the public health. There is no monitoring facility at the disposal sites, neither there is any provision of fencing/ boundary wall, there is no arrangement for protective measures like impervious lining materials cover material etc to protect the canal/ river from contamination. No consideration has been given to pollution control.

The selection of appropriate landfill site is one of the key elements of municipal solid waste management system. Due to rapid rise in environmental awareness among the public and reduction of availability of urban land, the problem of selecting appropriate waste disposal sites is becoming challenging and complex.

Selection of a new landfill site requires the evaluation of many attributes related to environmental, social and economic conditions. Such a large range of information comprises not only quantitative, but also qualitative attributes which consists a number of uncertainties that are not well considered in the traditional way of selection process of landfilling. This may result in misleading outputs. To deal with the uncertainties arising during the evaluation process, fuzzy set theory appears to be a good complimentary approach due to its ability to deal with linguistic variables and most of human reasoning.

1.5. Objective

The objective of this research work is the development of a fuzzy based model for selecting appropriate landfill site for municipal solid waste disposal. Asansol Municipal Corporation (AMC) was considered as case study to check the suitability of the model.

1.6. Scope

1. To study the present SWM scenario of the study area.
2. To characterise the SW of the study area to determine the disposable fraction of SW.
3. To calculate the required area for disposing disposable component of SW with respect to time (in years).
4. To identify the attributes for landfill site selection.
5. To collect data regarding the selected attributes.

6. To develop a Fuzzy based model for landfill site selection. It includes the calculation of **weightage (W)** for each attribute and **sensitivity index (SI)** for each attribute of each proposed landfill site, the calculation of **attribute score (AS)** for each attribute of each alternative site and finally calculation of **total score** (**TS**) of each alternative site. Which requires
   a. Fuzzification of weightage and sensitivity index of each attributes
   b. Formation of expert panel
   c. Preparation of questionnaire to collect data regarding attributes.
   d. Collection of expert opinion regarding the attributes
   e. Calculation of weightage based on expert opinion
   f. Defuzzification of weightage
   g. Normalization of weightage
   h. Sensitivity index calculation for each attribute of each landfill site
   i. Defuzzification of sensitivity index
   j. Calculation of attribute score for each attribute of each alternative site
   k. Calculation of total score of each alternative site
7. To validate model considering the data of two landfill sites mentioned in ***CPCB (2003)***
8. To evaluate model performance by calculating relative percentage error for the weightage of each attribute.
9. To apply the model in the study area to find a suitable landfill site.

2. Literature Review

2.1. Solid Waste (SW)

Solid wastes are all wastes arising from human and animal activity that are normally solid and that are discarded as useless or unwanted. ***(Peavy et al., 1985)***

MSW is normally comprised of food wastes, rubbish, demolition and construction wastes, street sweepings, garden wastes, abandoned vehicles and appliances, and treatment plant residues etc.

2.2. Solid waste Management (SWM)

SWM may be defined as a discipline associated with control of generation, storage, collection, transfer, processing and disposal of solid waste in an environmentally friendly and cost effective manner creating least public opposition.

Municipal solid waste management (MSWM) is an integrated and complex system which often involves sophisticated interactions and multiple feedbacks associated with environmental effects, economic development patterns, population, etc. It is becoming an exceedingly complex activity due to increasing environmental regulations that continue to impose stricter MSWM requirements.

The relation between public health and improper storage, collection, and disposal of solid wastes is quite clear. Public health authorities have shown that rats, flies, and other disease vectors breed in open dumps, as well as in poorly constructed.

Solid waste Handling and Management rule for India was first developed in the year 2000 and then reaffirmed in 2013 and 2015.

2.2.1. Objective of SWM

- To remove discarded materials from inhabited places in a timely manner to prevent the spread of disease to minimise the likelihood of fires and to reduce the aesthetic insults arising from putrefying organic matter.
- To dispose of the discarded materials in an environmentally acceptable manner.

2.2.2. Functional Elements in SWM

The functional elements in SWM are:

- Solid Waste Generation
- Storage and Handling at Generation point
- Collection
- Transfer or Transport
- Processing
- Disposal

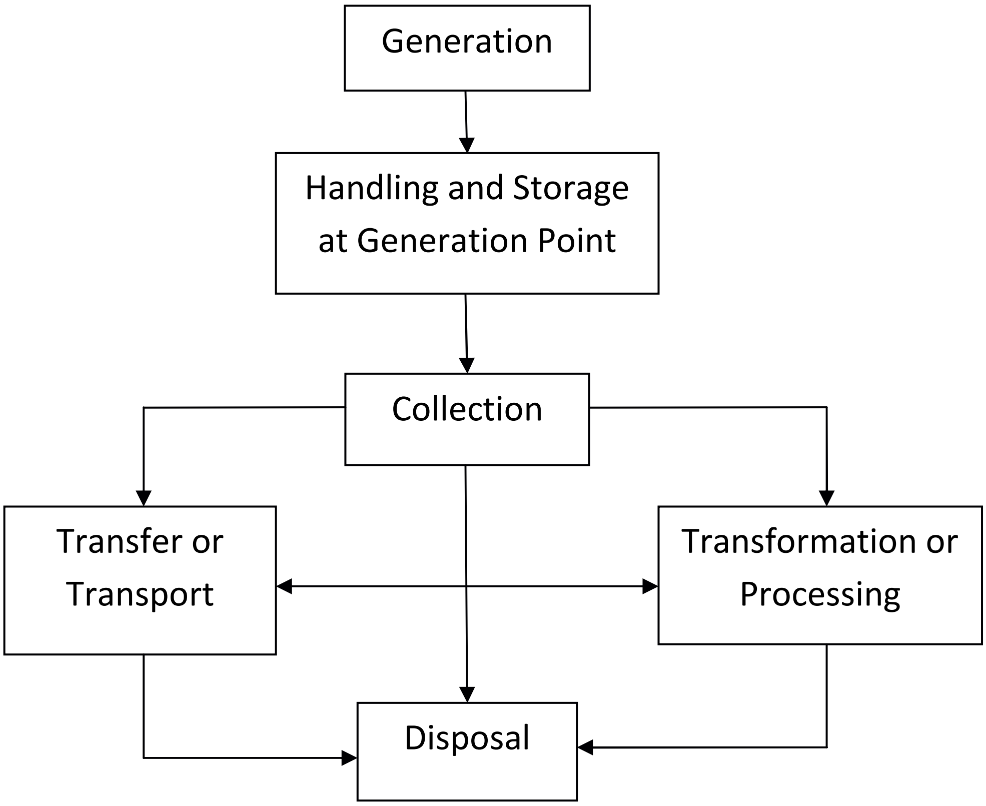

Figure 1: Functional Elements of SWM

Source: ***(Peavy et al., 1985)***

1. **Solid Waste Generation:** Those activities in which materials are identified as no longer being of value and are either thrown away or gathered together for disposal.

2. **Storage and Handling at Generation:** Those activities associated with the handling, storage, and processing of solid wastes at or near the point of generation.

3. **Collection:** Those activities associated with the gathering of solid wastes from the generators.

4. **Transfer or Transport:** Those activates associated with
    a. The transfer of wastes from the smaller collection vehicle to the larger transport equipment and
    b. The subsequent transport of the wastes, usually over long distance to the disposal site.

5. **Processing:** Those techniques, equipment and facilities are used to improve the efficiency of the other functional elements and to recover usable materials, conversion products, or energy from solid wastes.

6. **Disposal:** Those activities associated with ultimate disposal of solid wastes including those wastes collected and transported directly to a landfill site, semisolid wastes (sludge) from wastewater treatment plants incinerator residue compost, or other substances from the wires solid waste processing plants that are of no further use.

2.3. SWM in Developing Countries

Urban solid waste management is considered as one of the most immediate and serious environmental problems confronting municipal authorities in India The most common problems associated with inadequate sanitation of solid waste include diseases transmission, odour nuisance, atmospheric and water pollution, and economic losses.

The estimated solid waste generation ranges from 100 grams per capita per day in small towns, 300 - 400 grams per capita per day in medium size cities and about 500 grams per capita per day in large cities ***(Singh and Dubey, 2012)***. As per the available trend, the amount of waste generated per capita is estimated to increase at a rate of 1% – 1.33% annually in India ***(Singh and Dubey, 2012)***.

Management including collection, transportation and disposal of municipal solid waste is mostly unscientific in India which demands immediate attention.

Under Swachh Bharat Abhiyan an initiative had been taken by government of India, to make India clean by 2nd October 2019. Special emphasis on promoting segregation of waste at source, door to door collection of waste, night sweeping for large cities etc. Composting for smaller town, cluster management for solid waste processing for medium towns etc.., individual house hold latrines, community and public toilets creation, identification of brand ambassadors and running awareness campaigns, executing theme based fortnightly sanitation drives like for mandis, schools etc are being given.

2.4. Methods of Landfill Siting

Selection of suitable land for municipal landfill is the most important factor for municipal solid waste (MSW) management. The location must comply with the requirements of the existing government regulations and at the same time must minimize economic, environmental, health, and social costs.

In the process of selection of the best place for landfill there might be several alternate sites available which can make it difficult to select the best option and decision making process. The increasing environmental pollution and rising costs, political and social situations, public health in the region affects landfill site selection.

The determination and evaluation of positive and negative characteristics of one location relative to others is a difficult task as it involves too many attributes and their complex relationships. Several techniques have been proposed by different researchers. The techniques mainly used are:-

1. **Geographical Information System (GIS):** Geographic information system (GIS) is a digital database management system designed to manage large volumes of spatially

distributed data from a variety of sources. They are ideal for advanced site-selection studies because they efficiently store, retrieve, analyze, and display information according to user-defined specifications.

Geographic Information Systems (GIS) approaches are popular for planning and management because of their interdisciplinary character and they link different backgrounds and disciplines.

Paul et al. (2014) used GIS to select appropriate landfill site for Kolkata based on the site sensitivity index methodology proposed by ***CPCB (2003)***

Geneletti (2010) taken inputs based on stakeholder's analysis and spatial multi criteria technique for selecting landfill site of Saraca's Plain, Italy. Visibility, accessibility and air pollution constraint are considered for appropriate site selection. Result shows that application of different factors in various stages of modeling gives better results. ***Moeinaddini et al. (2010)***, ***Eskandari et al. (2012)***, ***Gorsevskiet et al. (2012)*** also used GIS for selection of landfill site considering different attributes.

2. **Analytical Network Process (ANP):** The ANP process in the most comprehensive framework for the analysis of public, governmental and corporate decisions. It allows the decision maker to include all the factors and tangible or intangible criteria that have a significant effect on making a best decision.

   The ANP allows both interaction and feedback within clusters of element (inner dependence) and between clusters (outer dependence). Such feedback best captures the complex effects in interplay in human society, especially when risk and uncertainty are involved.

   Tukkaya et al. (2007) address the problem of undesirable facility location selection using ANP process. ***Beltran et al. (2009)*** and ***Khandivi and Ghomi (2012)*** also proposed siting of solid waste facilities using this process.

3. **Analytical Hierarchy Process (AHP):** The AHP method breaks down a complex multi criteria decision problem into a hierarchy and is based on a pair-wise comparision of the importance of different criteria and sub-criteria.

   The AHP process is developed into three principle steps. The first step establishes a hierarchical structure. The second step computes the element weights of various hierarchies and the third step computes the entire hierarchical weights.

   Tavares et al. (2011) used the approach along with GIS and concluded the methodology to be applicable to any region provided that specific local conditions are taken into account. ***Feo and Gisi (2010)*** applied this method for Campania Region, in Southern Italy and found that both technical and nontechnical decision-makers showed the same behavior in (indirectly) selecting the best site.

4. **Ordered Weighted Average (OWA):** The OWA operator ***(Yager, 1988)*** is a technique for ranking criteria and addressing the uncertainity from their interaction. The robustness of the OWA approach is that it yields continuous scaling scenarios between the intersection (risk adverse) and the union (risk taking) operators. This continuous scaling is accomplished by global and local weights.

The global weights are assigned first based on decision- makers judgements or through a pairwise comparison for controlling the level of criteria trade-off to other criteria while the local weights are incrementally added and removed from the criteria and provide leverage for controlling the level of uncertainty and risk taking.

Gorsevski et al. (2012) sitted a landfill using AHP /OWA aggregation procedure incorporating uncertainty through a fuzzy membership function and expert opinions.

5. **Boolean Logic Model (BL):** In this model, equal weight is given to all factors i.e., all attributes are considered to be equally relevant for selecting landfill site.

   Delgado et al. (2008) used GIS based model along with Boolian logic, binary evidence and overlapping for data analysis to site inter-municipal landfill for Cuitzeo Lake Basin, in Mexico.

6. **Fuzzy Logic Model (FL):** Fuzzy logic ***(Zadeh, 1965)*** provides a framework whereby basic notions such as similarity, uncertainty and preference can be modelled effectively.

   It was designed to supplement the interpretation in linguistic or measured uncertainties for real-world uncertain phenomena. Fuzzy linguistic models permit the translation of verbal expressions into numerical ones, thereby dealing quantitavely with imprecision in the expression of the criterion.

   Singh and Dubey (2012) used fuzzy logic to develop a fuzzy utility model considering some of the attributes that were proposed by ***CPCB (2003)***.

   Al- Jarrah and Abu-Qdais (2006) proposed the siting of a new landfill site using fuzzy set. ***Onut and Soner (2008)*** proposed a fuzzy TOPSIS based methodology to identify the landfill site selection for Istanbul, Turkey.

7. **Delphi Technique (DT):** It is a structured group communication process that allows a group of experts to deal with complex problems. Delphi is assumes that opinions of experts are justified as inputs to decision-making where absolute answers are unknown, and that a consensus of experts will provide a more accurate outcome than a single expert.

   Delphi is an iterative process that begins with generating many initial unevaluated ideas (i.e., species). It presents these unevaluated ideas in a questionnaire to experts, who respond anonymously. The evaluated, revised, and returned to the experts, with commentary, for further evaluation. This process is repeated until a final opinion is reached.

   Delphi can accommodate large groups and remote input from distant locations.

   Pandiyan et al. (2010) applied this method for three-landfill site at Melakottaiyur, Pachaiyankuppam and Gummidipoondi in Tamil Nadu.

8. **Site Sensitivity Index (SSI):** Central Pollution Control Board (CPCB) under the Ministry of Environment and Forest (MOEF) with National Environmental Engineering Research Institute (NEERI), Nagpur, India has developed a technique to quantify the suitability of site for sanitary landfilling on a comparative scale in terms of the Site Sensitivity Index (SSI) ***(CPCB, 2003)***.

The SSI is an increasing scale index, wherein a lower value indicates that site has less sensitivity to the impacts (preferable) and higher value indicates that the site has high sensitivity to the impacts (undesirable). The SSI has many possible applications including ranking of potential landfill sites, prioritization of management plan initiatives and public information.

Babu and Ramakrishna (2003) applied three mathematical models as linear interpolation, overall linear distribution and polynomial equations to differentiating the attribute significance with regard to SSI as linear and non-linear. ***Ohri and Singh (2011)*** founds that if data of few factors are incomplete or unavailable this method fails to select the landfill site.

2.5. Critical Literature Review

Thus the literature review clearly suggests that siting of a landfilling site is a multi criteria decision making problem in which both crisp and linguistic variables are involved.It is very difficult to develop a selection criterion that can precisely describe the preference of one site over another. Many precision based methods for site selection in waste management have been investigated. Most of these methods have been developed based on the concepts of accurate measurements and crisp evaluation. In Indian condition due to lack of proper management the crisp data are difficult to obtain. However, most of the selection parameters cannot be given precisely. The evaluation data of solid waste facility location suitability for various subjective criteria and the weights of the criteria are usually expressed in linguistic terms. This makes fuzzy logic a more natural approach to this kind of problem.

To deal with the indicators' uncertainties arising during the evaluation process, fuzzy set theory appears to be a good complimentary approach. Once the indicators are represented by fuzzy sets, there are several fuzzy techniques that can be used to facilitate formulation and calculations of uncertainties associated with these fuzzy indicators. The fuzzy approach in ranking of suitable landfill sites is still having a lot of potential to apply wherein all important criteria such as environmental and hydrological conditions, accessibility, ecological and societal effects etc. can be incorporated in a more effective manner.

2.6. Guidelines for Landfill Site Selection

2.6.1. Ministry of Environment and Forest Guidelines

Table 1 includes the various factors that should be kept into mind before selecting a landfill site for an area as proposed in Municipal Solid Waste (Management and Handling) Rules, 2000; 2013 and 2015.

Table 1: MOEF Guidelines for Landfill Site Selection

Category	Municipal Solid Wastes (Management and Handling) Rules, 2000.	Municipal Solid Waste (Management and Handling) Rules, 2013	Solid Waste Management Rules, 2015
Responsibility for identification of site	In areas falling under the jurisdiction of 'Development Authorities' it shall be the responsibility of such Development Authorities to identify the landfill sites and hand over the sites to the concerned municipal authority for development, operation and maintenance. Elsewhere, this responsibility shall lie with the concerned municipal authority.	In areas falling under the jurisdiction .of 'Development Authorities' it shall be the responsibility of such Development Authorities to identify the landfill sites and hand over the sites to the concerned municipal authority for development, operation and maintenance. Elsewhere, this responsibility shall lie with the concerned municipal authority.	In areas falling under the jurisdiction of 'Development Authorities' it shall be the responsibility of such Development Authorities to identify the landfill sites and hand over the sites to the concerned municipal authority for development, operation and maintenance. Elsewhere, this responsibility shall lie with the concerned municipal authority.
Selection criteria	Selection of landfill sites shall be based on examination of environmental issues. The Department of Urban Development of the State or the Union territory shall co-ordinate with the concerned organisations for obtaining the necessary approvals and clearances.	Selection of landfill sites shall take into consideration the relevant environmental issue.	Selection of landfill sites shall take into consideration the relevant environmental issues.
Planning and design	The landfill site shall be planned and designed with proper documentation of a phased construction plan as well as a	The landfill site shall be planned and designed with proper documentation of a phased construction plan as well as a	The landfill site shall be planned, and designed and developed with proper documentation of construction plan as well as a closure plan in a phased manner. In

Category	Municipal Solid Wastes (Management and Handling) Rules, 2000.	Municipal Solid Waste (Management and Handling) Rules, 2013	Solid Waste Management Rules, 2015
	closure plan.	closure plan. In case a new landfill facility is created adjoining an existing landfill site, the closure plan of existing landfill should form a part of the proposal of such new landfill.	case of creation of a new landfill facility is created adjoining an existing landfill site, the closure plan of existing landfill should form a part of the proposal of such new landfill.
Processing facility	The landfill sites shall be selected to make use of nearby wastes processing facility. Otherwise, wastes processing facility shall be planned as an integral part of the landfill site.	The landfill sites shall be selected to make use of nearby wastes processing facility. Otherwise, wastes processing facility shall be planned as an integral part of the landfill site.	The landfill sites shall be selected to make use of nearby wastes processing facilities. Otherwise, wastes processing facility shall be planned as an integral part of the landfill site.
Set up guidelines		Landfill sites shall be set up as per the guidance notes formulated by the Ministry of Urban Development, Government of India.	Landfill sites shall be set up as per the guidance notes or guidelines formulated by the Ministry of Urban Development, Government of India.
Improvement in existing landfill site	The existing landfill sites which continue to be used for more than five years shall be improved in accordance of the specifications given in this Schedule.	The existing landfill sites which are in use for more than five years shall be improved in accordance of the specifications given in this Schedule.	The existing landfill sites which are in use for more than five years shall be improved in accordance of with the specifications given in this Schedule.
Bio medical	Biomedical wastes shall be disposed off in accordance with the Bio-medical	Biomedical waste shall be disposed of in accordance with the Bio-medical Waste	The biomedical waste shall be disposed of in accordance with the Bio-medical Waste (Management

Category	Municipal Solid Wastes (Management and Handling) Rules, 2000.	Municipal Solid Waste (Management and Handling) Rules, 2013	Solid Waste Management Rules, 2015
waste	Wastes (Management and Handling) Rules, 1998 and hazardous wastes shall be managed in accordance with the Hazardous Wastes (Management and Handling) Rules, 1989, as amended from time to time.	(Management and Handling) Rules, 199B, as amended. The hazardous waste shall be managed in accordance with the Hazardous Waste (Management, Handling and Trans-boundary Movement) Rules, 200B, as amended, from time to time. The E-waste shall be managed in accordance with the e-Waste (Management and Handling) Rules, 2011.	and Handling) Rules, 1998, as amended. The hazardous waste shall be managed in accordance with the Hazardous Waste (Management, Handling and Trans-boundary Movement) Rules, 2008, as amended, from time to time. The E-waste shall be managed in accordance with the e-Waste (Management and Handling) Rules, 2011.
Life span	The landfill site shall be large enough to last for 20-25 years.	The landfill site shall be large enough to last for at least 20-25 years.	The landfill site shall be large enough to last for at least 20-25 years and shall develop 'landfill cells' in a phased manner to avoid water logging and misuse.
Critical areas	The landfill site shall be away from habitation clusters, forest areas, water bodies monuments, National Parks, Wetlands and places of important cultural, historical or religious interest.	The landfill site shall be away from habitation clusters, forest areas, water bodies monuments, National Parks, Wetlands and places of important cultural, historical or religious interest and the distance to be maintained, as prescribed by the State Environment Impact Assessment Authority (SEIAA) on a case to case basis.	The landfill site shall be away from habitation clusters, forest areas, water bodies, monuments, National Parks, Wetlands and places of important cultural, historical or religious interest and the distance to be maintained, as prescribed by the State Environment Impact Assessment Authority (SEIAA) or the state pollution control board or pollution control committee on the case to case basis for management of solid waste management plan or 100 meter away from river, 200

Category	Municipal Solid Wastes (Management and Handling) Rules, 2000.	Municipal Solid Waste (Management and Handling) Rules, 2013	Solid Waste Management Rules, 2015
			meter from a pond, 500 meter from Highways, Habitations, Public Parks and water supply wells and 20 km away from Airports or Airbase. However in a special case, landfill site may be set up within a distance of 10 and 20 km away from the Airport/Airbase after obtaining no objection certificate from the civil aviation authority/ Air force as the case may be. The Landfill site shall not be permitted within the zone of coastal regulation, wetland, Critical habitat areas, sensitive eco-fragile areas and flood plains as recorded for the last 100 years.
Buffer zone	A buffer zone of no-development shall be maintained around landfill site and shall be incorporated in the Town Planning Department's land-use plans.	A buffer zone of no development shall be maintained around landfill sites and sites for processing and disposal of municipal solid waste. The sites for landfill, and processing and disposal of municipal solid waste shall be incorporated in the Town Planning Department's land-use plans. The buffer zone shall be prescribed by the State Environment Impact Assessment Authority (SEIAA), on a case to case	A buffer zone of no development shall be maintained around landfill sites and sites for processing and disposal of solid waste. The sites for landfill, and processing and disposal of solid waste shall be incorporated in the Town Planning Department's land-use plans. The buffer zone shall be prescribed by the State Environment Impact Assessment Authority (SEIAA) or State Pollution Control Board or Pollution Control Committee, on the case to case basis. The site, as approved by the State Environment Impact

Category	Municipal Solid Wastes (Management and Handling) Rules, 2000.	Municipal Solid Waste (Management and Handling) Rules, 2013	Solid Waste Management Rules, 2015
		basis. The site, as approved by the State Environment Impact Assessment Authority shall be notified by the concerned Local Government.	Assessment Authority shall be notified by the concerned Local Government.
Airport	Landfill site shall be away from airport including airbase. Necessary approval of airport or airbase authorities prior to the setting up of the landfill site shall be obtained in cases where the site is to be located within 20 km of an airport or airbase.	Landfill site shall be away from airport including airbase. Necessary approval of airport or airbase authorities prior to the setting up of the landfill site shall be obtained in cases where the site is to be located within 20 km of an airport or airbase.	
Temporary storage			Facilities to be created for 'temporary storage' of solid waste in each landfill sites for incoming wastes in case of shutting down of waste processing plants; which shall be taken again for further processing. The landfill site shall have provisions for using as temporary storage during emergency or natural calamities.

2.6.2. Central Public Health and Environmental Engineering Organisation (CPHEEO) Guidelines

Norms for Landfill Site Selection (***CPHEEO, 2000)***

1. **Lake or Pond:** No landfill should be constructed within 200 m of any lake or pond. Because of concerns regarding runoff of waste water contact, a surface water monitoring program should be established if a landfill is sited less than 200m from a lake or pond.
2. **River:** No landfill should be constructed within 100 m of a navigable river or stream. The distance may be reduced in some instances for non meandering rivers but a minimum of 30 m should be maintained in all cases.
3. **Flood Plain:** No landfill should be constructed within a 100 year flood plain. A landfill may be built within the flood plains of secondary streams if an embankment is built along the stream side to avoid flooding of the area. However, landfills must not be built within the flood plains of major rivers unless properly designed protection embankments are constructed around the landfills.
4. **Highway:** No landfill should be constructed within 200 m of the right of way of any state or national highway. This restriction is mainly for aesthetic reasons. A landfill may be built within the restricted distance, but no closer than 50 m, if trees and berms are used to screen the landfill site.
5. **Habitation:** A landfill site should be at least 500 m from a notified habituated area. A zone of 500 m around a landfill boundary should be declared a No-Development Buffer Zone after the landfill location is finalised.
6. **Public parks:** No landfill should be constructed within 300 m of a public park. A landfill may be constructed within the restricted distance if some kind of screening is used with a high fence around the landfill and a secured gate.
7. **Critical Habitat Area:** No landfill should be constructed within critical habitat areas. A critical habitat area is defined as the area in which one or more endangered species live. It is sometimes difficult to define a critical habitat area. If there is any doubt then the regulatory agency should be contacted.
8. **Wetlands:** No landfill should be constructed within wetlands. It is often difficult to define a wetland area. Maps may be available for some wetlands, but in many cases such maps are absent or are incorrect. If there is any doubt, then the regulatory agency should be contacted.

9. **Ground Water Table**: A landfill should not be constructed in areas where water table is less than 2m below ground surface. Special design measures be adopted, if this cannot be adhered to.
10. **Airports:** No landfill should be constructed within the limits prescribed by regulatory agencies (MOEF/ CPCB/ Aviation Authorities) from time to time.
11. **Water Supply Well:** No landfill should be constructed within 500 m of any water supply well. It is strongly suggested that this locational restriction be abided by at least for down gradient wells. Permission from the regulatory agency may be needed if a landfill is to be sited within the restricted area.
12. **Coastal Regulation Zone:** A landfill should not be sited in a coastal regulation zone.
13. **Unstable Zone:** A landfill should not be located in potentially unstable zones such as landslide prone areas, fault zone etc.
14. **Buffer Zone:** A landfill should have a buffer zone around it, up to a distance prescribed by regulatory agencies.
15. **Other criteria** may be decided by the planners.

3. Methodology

3.1. SWM Scenario in the Study Area

The proposed landfill siting is being done for Asansol Municipal Corporation (AMC) area. Asansol is an industrial cum mining town in the Burdwan district of West Bengal, India. Asansol have geographical position longitude 87° E and latitude 23°40$'$N and lies between river Ajay in the north and river Damodar in the south. The total area of AMC is 127.23 sq km with a generally flat terrain. With its mineral rich resources and heavy industrial development Asansol is a fast growing town. Though there exists vast area of agriculture lands, due to rocky soil and low rainfall, the inhabitants have to harvest their crops once a year, mainly in rainy seasons. As per census 2011 the population of Asansol declared to be 563,917 and total number of households are 113739. There are total 50 wards and 56 Mouzas under AMC.

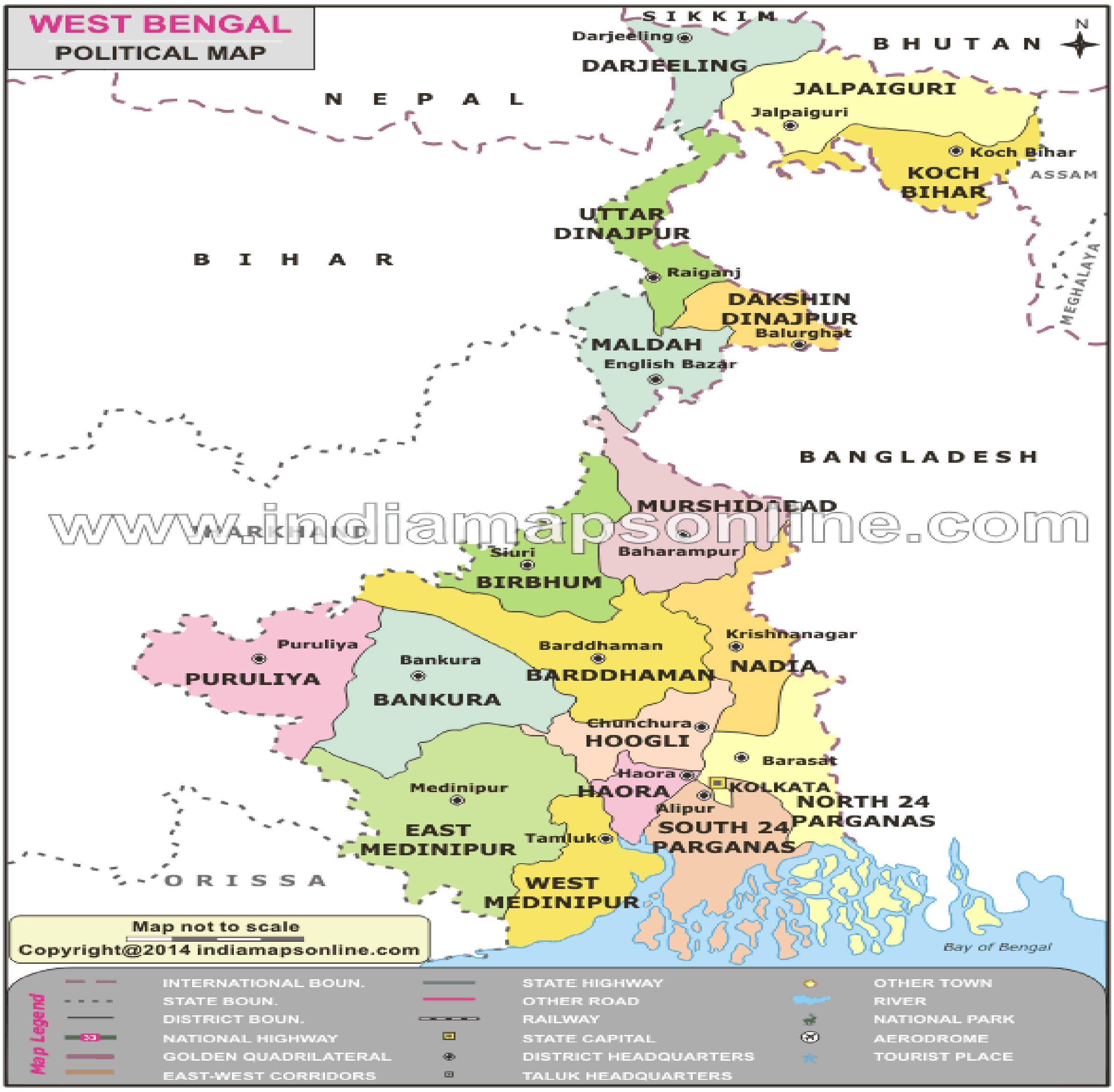

Figure 2: Map of West Bengal Showing Different Districts

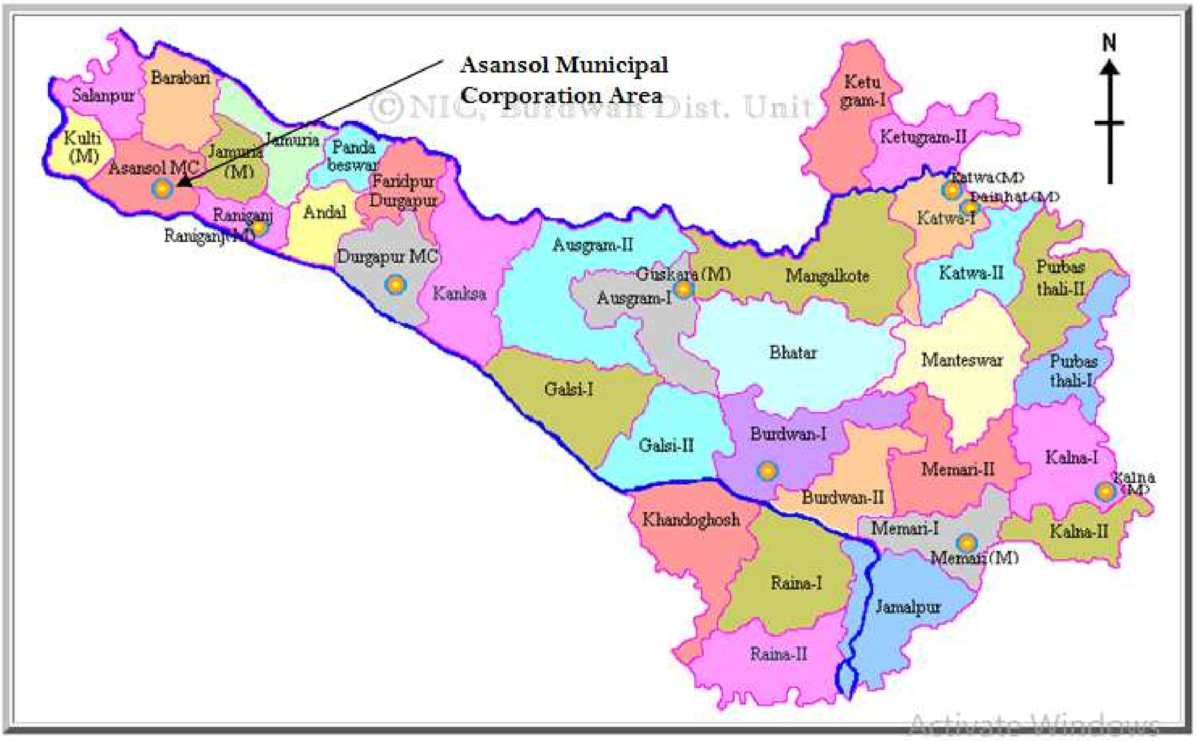

Figure 3: Map of Burdwan District Showing Different Administrative Units

3.1.2. SWM in AMC Area

The AMC is responsible for collection, transportation, management and disposal of the SW generated within the city limits. With the growing population and living standards of residents quantity of waste generating is increasing day by day making it difficult to manage and dispose total waste. Presently solid waste management system is quite unscientific, unsatisfactory and unhygienic thus causing considerable part of population to serious health risk. For SWM system public private partnership (PPP) model is followed in AMC. Everyday Municipal Corporation manages 220 MT of solid waste.

Functional elements of solid waste management in AMC are:-

1. Primary storage: Primary storage is the storage practised at source by the generators. Waste generated from domestic activities are the major contributor of solid waste, out of the total residential solid waste 60% are stored by the householders for regulated daily collection and rest 40% are thrown in open areas or roadside bins, 10 litres bins had been distributed by AMC to houses. Some citizens segregate the valuable things like plastic, glass, iron, aluminium, etc and sell them to the scrap dealers. Waste generated from shops, offices and other commercial institutions are either thrown directly in the roadside or in the nearby bins or containers without any segregation. Silt from open drains are disposed at the roadside collection points or kept alongside the drains by the sewer cleaning workers.

2. Primary collection and street sweeping: Primary collection means collecting, lifting and removal of solid waste from source of its generation including households, shops, offices and any other non-residential premises or from any collection points or any other location specified by the urban local body. Primary collection is practised in all the 50 wards by either corporation employee or private workers in the form of door to door collection. The collection is on a daily basis except Sundays and gazetted holidays. Primary collection of solid waste is being done using rickshaw van and handcarts. For the collection service provided, the citizens are charged Rs 15 to 20 per house on a monthly basis. The workers perform their duty in three shift, morning shift (6.00 AM to 11AM), day shift (11AM to 2 PM) and evening shift (2 PM to 5 PM). For Asansol market area special timing exists at night which is from 8.30 PM to 1 AM. Waste collected are transferred to the community bins or directly loaded to the vehicles going to the disposal site ***(Sarbeswar, 2015).*** Collection is done using rickshaw vans and hand cart. Figure 4 and 5 shows hand cart and rickshaw van used for collection of solid waste.

Figure 4: Hand Cart used for Solid Waste Collection

Figure 5: Rickshaw Van Used for Solid Waste Collection

Total stretch of road in AMC is 1023 km. Road swept had been classified into three categories depending on the frequency of sweeping done and its importance as presented in Table 2. Major roads are those roads that are in the high population density and important areas like market place, commercial areas etc, intermediate road are in medium population density areas like small market, housing colony etc and minor road are in low population density areas.

Table 2: Road Category based on Sweeping Frequency

Road Type	Frequency of Sweeping (days per week)
Major	7
Intermediate	2
Minor	1

Both private and municipal corporation workers are engaged in road sweeping activity. Sweeping is mainly done in the early morning when the traffic is minimal.
Brooms are used for sweeping and the wastes are collected in hand cart and rickshaw van. Collected wastes are transferred to open points or container bins.

3. Secondary storage: Secondary storage means the temporary containment of solid waste at a public place in a covered bin or container in a manner so as to prevent littering, vectors, stray animals and odour; Presently there are 1350 masonry dustbins and numerous open disposal points throughout AMC which are used for secondary storage from where wastes are transported to disposal sites on a regular basis. Segregation is not practised at any secondary storage points. Almost there are no rag pickers engaged anywhere. Total process of secondary collection is done manually and in very unhygienic manner. Open disposal points are seen with waste littered all around and are prone to health hazard. There is not sufficient bin/vat available as per the demand and CPHEEO norms. Wrong placement of bins/vats under the pressure of political leaders have caused further problem resulting in its poor utility.

4. **Transportation:** Solid wastes stored at vats/bins are transported to disposal sites with the help of heavy vehicles like dumper placer (8 nos.) and light vehicles like tractors (40 nos.) and trucks. All corporation owned vehicles are used for transportation.
Dumper placer lifts the container from commercial and residential areas and empties them in the disposal sites and place them back to their original position. Loading of waste in tractor is done in most unhygienic and unacceptable manner and needs immediate attention. After daily transportation these vehicles are parked in the water tank premises as there are no garage facility. Most of the vehicles used are in the last phase of life span and immediate investment in buying new vehicles or engaging private vehicles are required.

5. **Treatment and processing:** Presently there is no provision of treatment and processing of SW. There was a treatment plant managed under Asansol Durgapur Development Authority (ADDA) which was used to do segregation and made compressed plastic balls, the plant operated for approximately 2 years and was closed. New segregation cum compost plant has been proposed, data collection regarding the compost plant already have done. Compost site is located in southwest of the city nearly 5 to 7 km off the highway in Mohishila/Kotaldihi Ward. Total area for the site is over 100 acres. Proposed treatment facility is to be developed under Public Private Partnership (PPP), under a 'Build Operate and Transfer' arrangement. The agency will be responsible for the design, engineering, financing, procuring, construction, operation and maintenance of the facilities and transfer the same at the end of post closure period. Windrow type composting method will be used.

6. **Disposal:** Finally all transported mixed waste are brought to the disposal site and disposed. At present there are two waste disposal sites under the AMC which are open dumping type and located in the outskirts of the city. These sites are not engineered and without any boundary wall and are far from the city causing additional time and cost of transportation. There is no systematic segregation of waste at the disposal site. Dumping is being done without any provision of daily cover. There is no weighing bridge at the disposal site so the actual amount of solid waste dumped each day cannot be estimated. Rough estimation is being made depending upon the capacities of vehicles and number to trips made daily.
One of the sites is located at Kalipahari which is the major disposal site covering an area around 10 acres and another is located at Samdihi, Burnpur covering an area around 03 acres.

Figure 6: Satellite view of Kalipahari dumping site in AMC

3.2. Solid Waste Characteristics

At present in AMC area per capita solid waste generation per day is 320gms and the total generation of solid waste per day is 220 metric tons (MT), among which mixed waste is 175 MT and building debris is 45 MT ***(Asansol Municipal Corporation Website, Jan 2016),*** but the data may not be reliable as there is no facility of weighing of solid waste going for disposal.

Table 3: Category wise MSW Generation of AMC

Waste Generation By Category:	**Percentage**
Residential	68
Commercial	14
Halls, Schools, Institutions	16
Industrial	2

Source: Asansol Municipal Corporation Website (2016)

Information about the physical and chemical composition of solid wastes of AMC is essential for evaluation, processing and recovery. Besides it helps in adopting and utilizing proper equipment and techniques for collection and transportation. The main physical and chemical composition of solid waste is given in Table 4 and 5.

Table 4: Physical Composition of MSW in AMC

Components	% Composition
Total compostable	50.33
Paper	10.66
Plastic	2.78
Glass	0.77
Metal	0
Inert	25.49
Rubber and leather	0.48
Rags	3.05
Wooden matter	3.00
Coconut	2.49
Bones	0.95

Source: ***CPCB (2000)***

Table 5: Chemical Characteristics of MSW in AMC

Components	Value
Moisture	54.48%
pH	6.44-8.22
Volatile matter	17.13%
C	10.07%
N	0.79%
P as P_2O_5	0.76%
K as K_2O	0.54%
C/N ratio	14.08
Calorific value	1156.07 (Kcal/kg)

Source: ***Akolkar (2005)***

3.3. Landfill Area Calculation

One of the primary objectives of the landfill site selection is to calculate the required landfill area to accommodate the SW for the design period. To make the designed site economically viable the design period was assumed 30 years. To calculate the required area it is required to collect data regarding

- fixed and or floating population of the study area(both present data and decadal or yearly growth)
- solid waste generation rates of the fixed and floating population and decadal and annual growth of production

For simplification of the project work it is assumed that the characteristics of the solid wastes remained same for the designed period.

In Table 6 census data regarding population of AMC area from 1951-2011 along with decadal growth (in %) and annual increase (in %) are presented.

Table 6: Population Trends of AMC

Year	Population	Decadal Growth (in %)	Annual Increase (in %)
1951	76277	-	-
1961	103405	35.6	4
1971	155968	50.8	5
1981	183375	17.6	2
1991	262188	43.0	4
2000	475439	81.3	8
2011	563917	18.6	2

From the above data it is seen that the annual increase in population varies from 2 to 8%. For area calculation worst case is assumed i.e. 10% annual increase in population.

The other factors for area calculation which are assumed are:

- Per capita solid waste generation is 0.41 kg (as per Asansol Durgapur Development Authority (ADDA) report, 2006).
- Disposable SW fraction is 40% (worst case) of the total SW generation based on the physical characterization report.
- Density of SW after compaction in the landfill site is 1000 kg/m^3 ***(CPHEEO, 2000)***
- Maximum height is 20m (Manual on Solid Waste Management by ***(CPHEEO, 2000)***
- Area required is 1.2 times area calculated ***(CPHEEO, 2000)***

Calculations:

$$Annual\ SW (in\ MT) = \frac{\left(0.41 \frac{kg}{capita \times day}\right) \times Population \times (365\ day)}{1000} \ldots\ldots\ldots\ldots\ldots (1)$$

$$Disposable\ SW\ (in\ MT) = 0.40 \times Annual\ SW (in\ MT) \ldots\ldots\ldots\ldots\ldots (2)$$

$$Volume\ (in\ m^3) = \frac{Disposable\ SW\ (in\ MT) \times 1000}{1000 \frac{kg}{m^3}} \ldots\ldots\ldots\ldots\ldots (3)$$

$$Area\ calculated\ (in\ m^2) = \frac{Volume\ (in\ m^3)}{20\ m} \ldots\ldots\ldots\ldots\ldots (4)$$

$$Area\ reqd\ (in\ m^2) = 1.2 \times Area\ calculated\ (in\ m^2) \ldots\ldots\ldots\ldots\ldots (5)$$

Table 7: Estimation of Landfill Area Required with respect to Time (in years)

Year	Population	Annual SW (in MT)	Disposable SW(in MT)	Volume (in m3)	Area (in m2)	Area Reqd. (in m2)	Area Reqd.(in ha)	Total area reqd. (in ha)
2016	908194	135911	54364	54364	2718	3262	0.33	0.33
2017	999013	149502	59801	59801	2990	3588	0.36	0.68
2018	1098915	164453	65781	65781	3289	3947	0.39	1.08
2019	1208806	180898	72359	72359	3618	4342	0.43	1.51
2020	1329687	198988	79595	79595	3980	4776	0.48	1.99
2021	1462655	218886	87555	87555	4378	5253	0.53	2.52
2022	1608921	240775	96310	96310	4816	5779	0.58	3.09
2023	1769813	264853	105941	105941	5297	6356	0.64	3.73
2024	1946794	291338	116535	116535	5827	6992	0.70	4.43
2025	2141474	320472	128189	128189	6409	7691	0.77	5.20
2026	2355621	352519	141007	141007	7050	8460	0.85	6.04
2027	2591183	387771	155108	155108	7755	9306	0.93	6.98
2028	2850302	426548	170619	170619	8531	10237	1.02	8.00
2029	3135332	469202	187681	187681	9384	11261	1.13	9.13
2030	3448865	516123	206449	206449	10322	12387	1.24	10.36
2031	3793752	567735	227094	227094	11355	13626	1.36	11.73
2032	4173127	624508	249803	249803	12490	14988	1.50	13.23
2033	4590439	686959	274784	274784	13739	16487	1.65	14.87
2034	5049483	755655	302262	302262	15113	18136	1.81	16.69
2035	5554432	831221	332488	332488	16624	19949	1.99	18.68
2036	6109875	914343	365737	365737	18287	21944	2.19	20.88
2037	6720862	1005777	402311	402311	20116	24139	2.41	23.29

Year	Population	Annual SW (in MT)	Disposable SW(in MT)	Volume (in m3)	Area (in m2)	Area Reqd. (in m2)	Area Reqd.(in ha)	Total area reqd. (in ha)
2038	7392949	1106355	442542	442542	22127	26553	2.66	25.95
2039	8132243	1216990	486796	486796	24340	29208	2.92	28.87
2040	8945468	1338689	535476	535476	26774	32129	3.21	32.08
2041	9840015	1472558	589023	589023	29451	35341	3.53	35.61
2042	10824016	1619814	647926	647926	32396	38876	3.89	39.50
2043	11906418	1781795	712718	712718	35636	42763	4.28	43.78
2044	13097059	1959975	783990	783990	39199	47039	4.70	48.48
2045	14406765	2155972	862389	862389	43119	51743	5.17	53.66

In AMC area for the design period the total land requirement for disposing disposable solid waste is 53.66 Ha.

3.4. Attributes Used in Siting of Landfill

Total 32 attributes (under 7 classifications) are considered for landfill site selection based on the CPCB publication ***CPCB (2003)***

List of Classifications and related attributes are as follows:-

- Accessibility
  - Type of road
  - Distance from collection area
- Receptor
  - Population within 500 meters
  - Distance to nearest drinking water source
  - Use of the site by nearby residents
  - Distance to nearest building
  - Land use/ Zoning
  - Decrease in property value wrt distance
  - Public utility facility within 2 km
  - Public acceptability
- Environmental
  - Critical environments
  - Distance to nearest surface water
  - Depth of ground water
  - Contamination
  - Water quality

    - Air quality
    - Soil quality
- Socio economic
    - Health
    - Job opportunities
    - Odour
    - Vision
- Waste management practice
    - Waste quantity/day
    - Life of site
- Climatological
    - Precipitation effectiveness index
    - Climatic features contributing to air pollution
- Geological
    - Soil permeability
    - Depth to bedrock
    - Susceptibility to erosion and run off
    - Physical characteristic of rock
    - Depth of soil layer
    - Slope pattern
    - Seismicity

1. **Type of road:** Transportation of waste is done through roadways using medium and heavy sized vehicles. Proximity to Road is an important factor so as to decide the accessibility of the site. Landfill site near the road is highly suitable than that away from it. Landfill site that are placed far away from existing road networks increase the costs associated with construction of new access roads.

Guidelines by ***CPHEEO (2000)***

- Collection of data on existing traffic - daily traffic volume and peak hour traffic volume for six months.
- Road condition survey for existing road with suggestions for strengthening/widening should also be done before landfill site selection.
- Landfill cannot be constructed within 200 m of a state or national highway.

Guidelines by Ministry of Urban Development ***(MOUD, 2014)***

- Connection to highways and
- Conditions of the access roads should be identified.

Data considered for sensitivity calculation for the attribute in the proposed work of landfill site selection for AMC are:-

- Classification of road
    - National Highway

- State Highway
- Major District Road
- Other District Road
- Village Road

- Distance from the road

Table 8 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute type of road.

Table 8: **Weightage and Sensitivity Index Values Suggested by CPCB (2003) for Attribute "Type of Road"**

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Type of road	25	**Description →**	National highway	State highway	Local road	No road

2. **Distance from collection area:** Transportation of the solid waste to the disposal site from the source of its generation and/or secondary storage points is an important factor as it helps in deciding the most economical site. Greater the distance between source and disposal area greater its transportation cost and less suitable the selected site.
Population grows around a commercial area and spreads radially outwards with decreasing density. Substantial evidence shows that waste generation also decreases as one move away from the most commercial zone of the area.

Data considered for sensitivity calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Distance of the landfill site from an important administrative building located in the most important commercial part of the study area.

Table 9 presents the CPCB proposed weightage and sensitivity index for the attribute distance from collection area. Figure 7 presents graphically the relation between sensitivity and distance from collection area as proposed by CPCB (2003).

Table 9: Weightage and Sensitivity Index Values Suggested by CPCB (2003) for Attribute "Distance from Collection Area"

Attribute	**Weightage**	**Sensitivity index→**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Distance from collection area	35	**Description →**	< 10 km	10-20 km	20-25 km	> 25 km

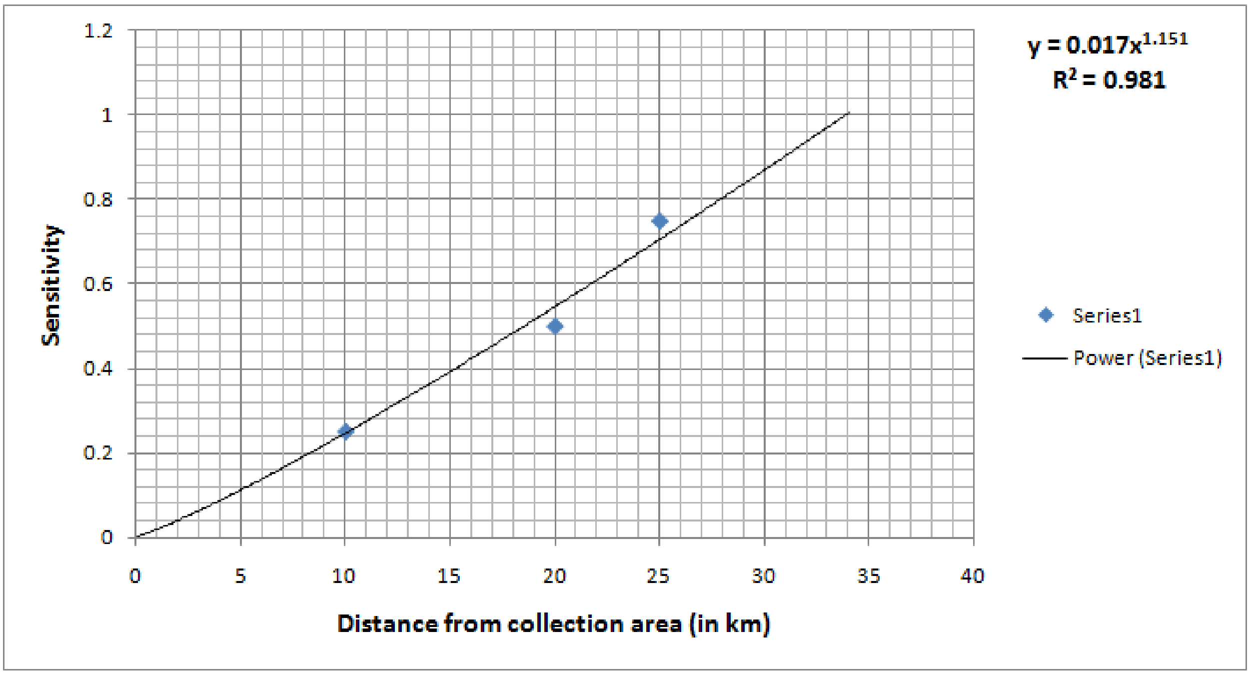

Figure 7: Sensitivity index Vs Distance from collection area

3. **Population within 500 meters:** Human population residing near a landfill site are adversely affected in many ways. It is highly recommended that there should be least habitation nearby a landfill site so as to prevent any adverse impact on them. Landfill site with least population within 500 m from its periphery will be most suitable.

As per ***MOUD (2014)***, buffer zone of 500 m for facilities dealing with 100 TPD or more of MSW; 400 m for facilities for dealing with more than 75 or less than 100 TPD; 300 m for facilities dealing with 50-75 TPD of MSW; 200 m for facilities dealing with less than 50 TPD MSW. For decentralized plants handling less than 1 TPD MSW no buffer zone is required; however adequate environmental controls are required. Practically for ideal condition there should not be any habitation within 500 m.

Data considered for sensitivity calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Number of people residing within 500 m.

Table 10 presents the CPCB proposed weightage and sensitivity index for the attribute population within 500 meters. Figure 8 presents graphically the relation between sensitivity index and population within 500 meters as proposed by CPCB (2003).

Table 10: Weightage and Sensitivity Index Values Suggested by CPCB (2003) for Attribute "Population within 500 meters"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Population within 500 meters	50	**Description →**	0 to 100	100 to 200	250 to 1000	> 1000

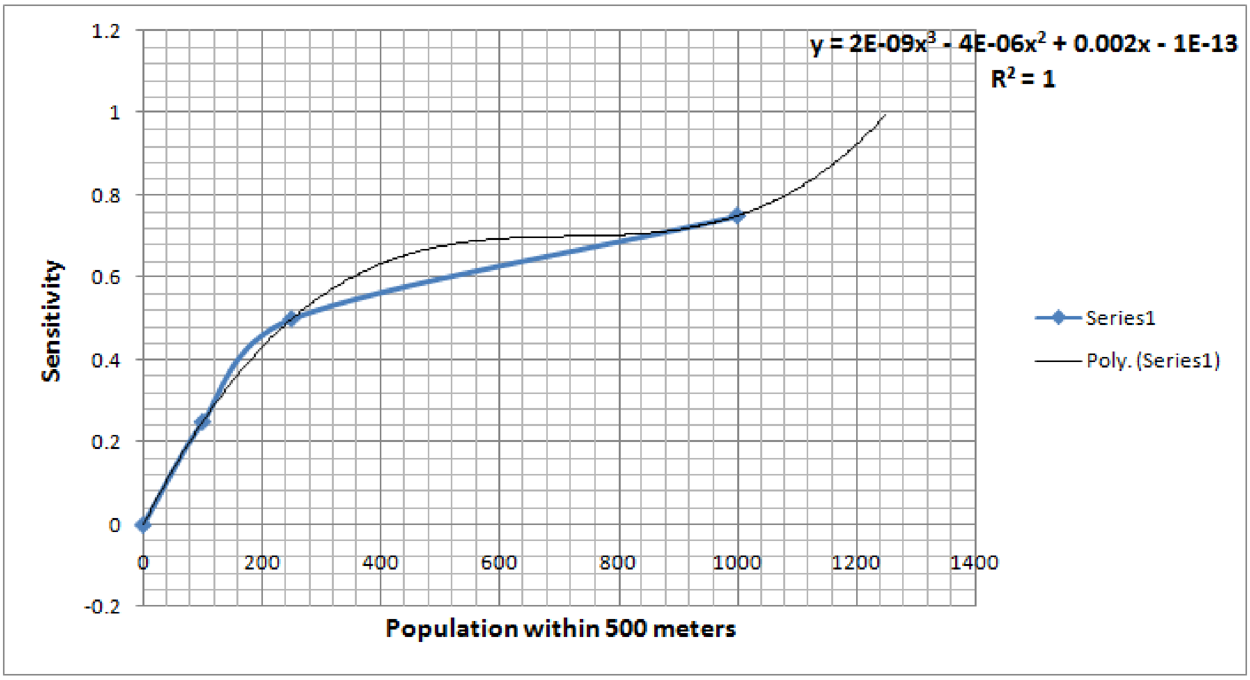

Figure 8: Sensitivity index Vs Population within 500 meters

4. **Distance to nearest drinking water source:** Contamination of drinking water source with highly toxic elements like mercury, arsenic, potassium, silica etc are common findings near a landfill site. Poisonous leachate generated from landfill site often find their way to the nearest drinking water source and contaminating them with metals, minerals, organic chemicals, bacteria, viruses, explosives, flammables, and other toxic materials. Habitants consuming the contaminated water are prone to serious disease. To avoid contamination drinking water source should be located as far as possible from the landfill site. Landfill site having maximum distance from the drinking water source will be most suitable.

As per ***CPHEEO (2000)***

- No landfill should be constructed within 500 m of any water supply well.

As per ***MOUD (2014)***

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Distance to nearest drinking water source.

Table 11 presents the CPCB proposed weightage and sensitivity index for the attribute distance to nearest drinking water source. Figure 9 presents graphically the relation between sensitivity index and distance to nearest drinking water source as proposed by CPCB (2003).

Table 11: Weightage and Sensitivity Index Values Suggested by CPCB (2003) for Attribute "Distance to nearest drinking water source"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Distance to nearest drinking water source	55	**Description →**	>5000 m	2500 to 5000 m	1000 to 2500 m	< 1000 m

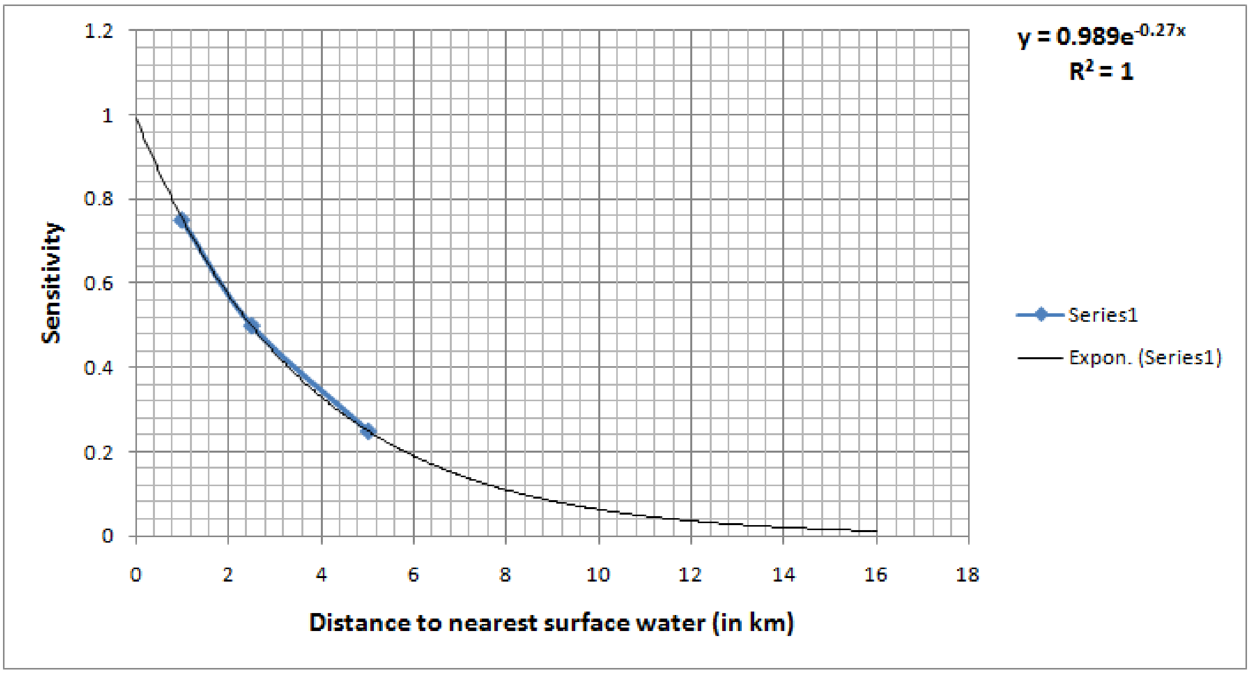

Figure 9: **Sensitivity index Vs Distance to nearest drinking water source**

5. **Use of the site by nearby residents:** This attribute gives insight about how often the site is being used by the nearby residents or others for some purpose. The purpose for which the site is being used sure to be affected if landfill site be constructed. Therefore, to avoid objections from the residents the municipal authority should provide alternative area to fulfil the requirements of the residents. Proposed landfill site with minimum usage in terms of months will be considered most favourable.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC are:-

- Not used
- Occasional
- Moderate
- Regular

Table 12: Classification of Land Use with respect to months of use

Category	Months
Not used	0-1
Occasional	1-3
Moderate	3-6
Regular	6-12

Table 13 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute Use of the site by nearby residents.

Table 13: Weightage and Sensitivity Index Values Suggested by CPCB (2003) for Attribute "Use of the site by nearby residents"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Use of site by nearby residents	25	**Description →**	Not used	Occasional	Moderate	Regular

6. **Distance to nearest building:** Methane gas generated from the decomposition process of solid waste may migrate in the nearby areas. Migrating gas can accumulate in enclosed spaces in nearby buildings. Receptors in an enclosed area like building are prone to high risk from the methane gas. For receptor safety, this attribute is important. So it is considered as an attribute in landfill site selection. As per this attribute, landfill site with maximum distance to the nearest building from its periphery will be most suitable.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Distance to the nearest building from the proposed landfill site.

Table 14 presents the CPCB proposed weightage and sensitivity index for the attribute distance to nearest building. Figure 10 presents graphically the relation between sensitivity index and distance to nearest building as proposed by CPCB (2003).

Table 14: Weightage and Sensitivity Index Values Suggested by CPCB (2003) for Attribute "Distance to nearest building"

Attribute	Weightage	Sensitivity index →	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Distance to nearest building	15	Description →	> 3000 m	1500 to 3000 m	500 to 1500 m	< 500 m

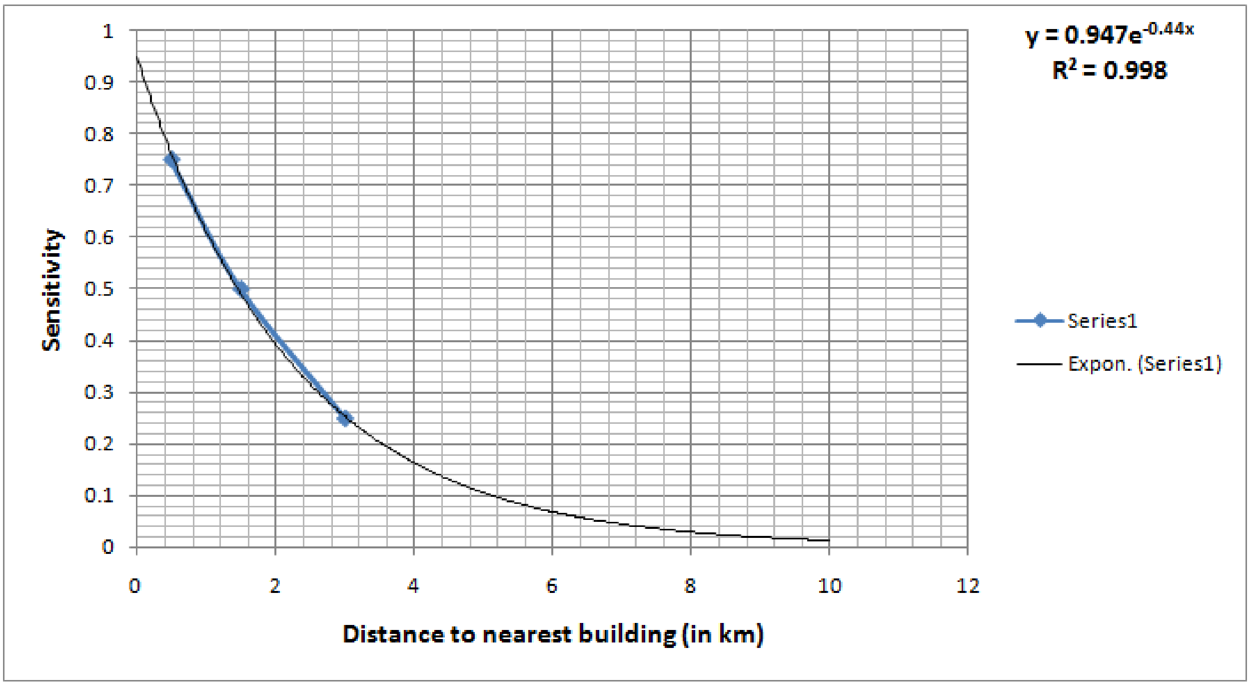

Figure 10: **Sensitivity index Vs Distance to nearest building**

7. Land use/ Zoning: Land use gives information about the category in which the proposed land belongs as ranked by the government urban planning authority. Considering the category in which a land falls, one can decide the relative utility and most probable usage of the land. For example residential land will be considered more valuable than agricultural land. Minimum utility of the land will be considered most favourable.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Land category in which the selected land fall into

Table 15 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute land use/ zoning.

Table 15: **Weightage and Sensitivity Index Values Suggested by CPCB (2003) for Attribute "Land use/ Zoning"**

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Land use/Zoning	35	**Description →**	Completely remote (zoning not applicable)	Agricultural	Commercial or Industrial	Residentia l

8. **Decrease in property value wrt distance:** Proximate of landfill site decreases nearby property values. Once a landfill site is announced at a particular location there are high chances that property value in the nearby areas will decrease considerably, especially if it is a residential area. Many a time reduction in property value is of great concern to the area residents than the fear of groundwater contamination. Proposed landfill site with maximum distance from where property values get affected will be most suitable.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Distance from where property value starts decreasing

Table 16 presents the CPCB proposed weightage and sensitivity index for the attribute decrease in property value wrt distance. Figure 11 presents graphically the relation between sensitivity index and decrease in property value wrt distance as proposed by ***CPCB (2003)***.

Table 16: **Weightage and Sensitivity Index Values Suggested by CPCB (2003) for Attribute "Decrease in property value wrt distance"**

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Decrease in property value with respect to distance	15	**Description →**	> 5000 m	2500 to 5000 m	1000 to 2500 m	< 1000 m

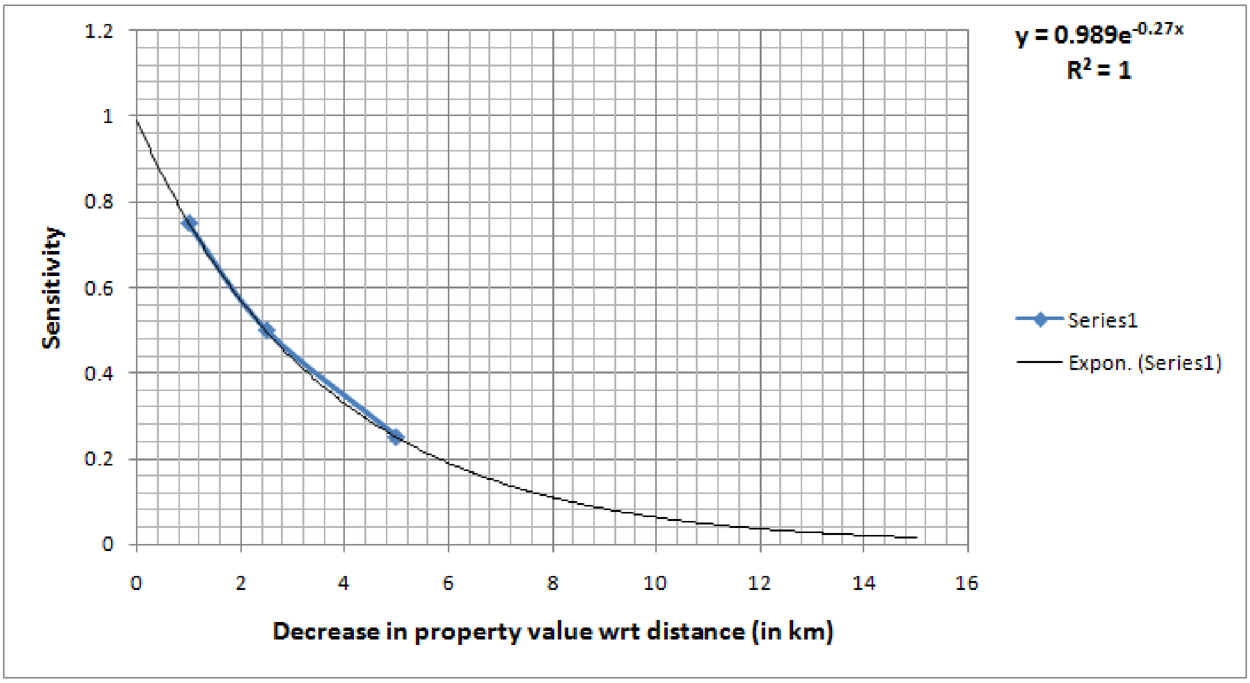

Figure 11: **Sensitivity index Vs Decrease in property value wrt distance**

9. **Public utility facility within 2 km:** Public utility facility refers to the important infrastructure facilities which are of great civilization importance and which if affected by any hazard can have severe impact on the society. Therefore for any proposed landfill site it is important to identify such facilities which are somehow in the range of getting affected by landfill site. Proposed landfill site having least important public utility facility will be considered most suitable.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- All Important public utility infrastructures (example: industry, hospital, museum etc) within 2 km and their distance from the proposed landfill site.

Table 17 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute public utility facility within 2 km.

Table 17: **Weightage and Sensitivity Index Values Suggested by CPCB (2003) for Attribute "Public utility facility within 2 km"**

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Public utility facility within 2 km	25	**Description →**	Commercial and industrial area	National heritage	Hospital	Airport

10. **Public acceptability:** Landfill site have many negative impact on the nearby residents so it is heavily opposed by local people. There are numerous examples where landfill site had been cancelled due to this particular problem only even though all other environmental and other clearance were conducted and approved. Public response after the announcement of siting of landfill site must be recorded while deciding the suitability of landfill site. Early assessment regarding how strong the "Not in my Backyard" NIMBY sentiment is, can significantly reduce the time and money spent on planning for a landfill site which may not materialise. Public reaction is less hostile if landfilling is done in an area already degraded by earlier municipal waste dumps or other activities such as quarrying, ash disposal etc. Proposed landfill site having maximum acceptability will be considered most suitable.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC are as follows:-

Data are collected by approaching local habitants within 500 m to 1000 m of the proposed site and recording their view by asking them to choose any one of the following options:-

- Fully accepted
- Acceptance with suggestions
- Acceptance with major changes
- Non acceptance

Worst maximum choice will we considered for the proposed work.

Table 18 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute public acceptability.

Table 18: **Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Public acceptability"**

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Public acceptability	30	**Description →**	Fully accepted	Acceptance with suggestions	Acceptance with major changes	Non acceptance

11. **Critical environments:** Critical environment are fragile areas and needs special attention. Damage or disturbance to the critical environment can result in irrevocable change in the ecosystem and disturb the total balance of life on planet earth. Landfill site selected in areas in the vicinity of critical environment highly sensitive and less suitable.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Type of critical environment selected area fall into

Table 19 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute critical environments.

Table 19: **Weightage and Sensitivity Index Values Suggested by CPCB (2003) for Attribute "Critical environments"**

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Critical environment	45	**Description →**	Not a critical environment	Pristine natural areas	Wetlands, flood plains, and preserved areas	Major habitat of endangered or threatened species

12. **Distance to nearest surface water:** Early Civilization flourished around surface water bodies clearly establishes the vital relationship between human civilization and surface water bodies. Highly cautious measures are required to protect surface water bodies.
In India as almost 70 per cent of its surface water resources are contaminated and not fit for human consumption as well as due to different activities, such as irrigation and industrial needs. Contaminated water adds to the water scarcity already prevailing in the world.
Leachate generated from landfill contains very high BOD, Total Dissolved Solids (TDS), hardness, toxic and pathogenic parameters. It can find its way to the surface water and decrease the dissolved oxygen level in the water body which can kill the aquatic life. Toxicity of leachate can also adversely affect aquatic environment. Therefore, landfill site far from surface water bodies are more suitable.

As per ***CPHEEO (2000)***

- No landfill should be constructed within 200 m of any lake or pond. Because of concerns regarding runoff of waste water contact, a surface water monitoring program should be established if a landfill is sited less than 200m from a lake or pond.
- No landfill should be constructed within 100 m of a navigable river or stream. The distance may be reduced in some instances for non- meandering rivers but a minimum of 30 m should be maintained in all cases.
- No landfill should be constructed within 500 m of any water supply well. It is strongly suggested that this locational restriction be abided by at least for down gradient wells. Permission from the regulatory agency may be needed if a landfill is to be sited within the restricted area.

As per ***MOEF (2000)***

- Arrangement shall be made to prevent runoff water from landfill area entering any drain, stream, river, lake or pond shall be made.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC are:-

- Type of surface water surrounding the proposed landfill site
    - Flowing
    - Stagnant
- Distance of surface water source from the proposed landfill site

Table 20 presents the CPCB proposed weightage and sensitivity index for the attribute distance to nearest surface water. Figure 12 presents graphically the relation between sensitivity index and distance to nearest surface water as proposed by CPCB (2003).

Table 20: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Distance to nearest surface water"

Attribute	Weightage	Sensitivity index →	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Distance to nearest surface water	55	**Description →**	> 8000 m	1500 to 8000 m	500 to 1500 m	< 500 m

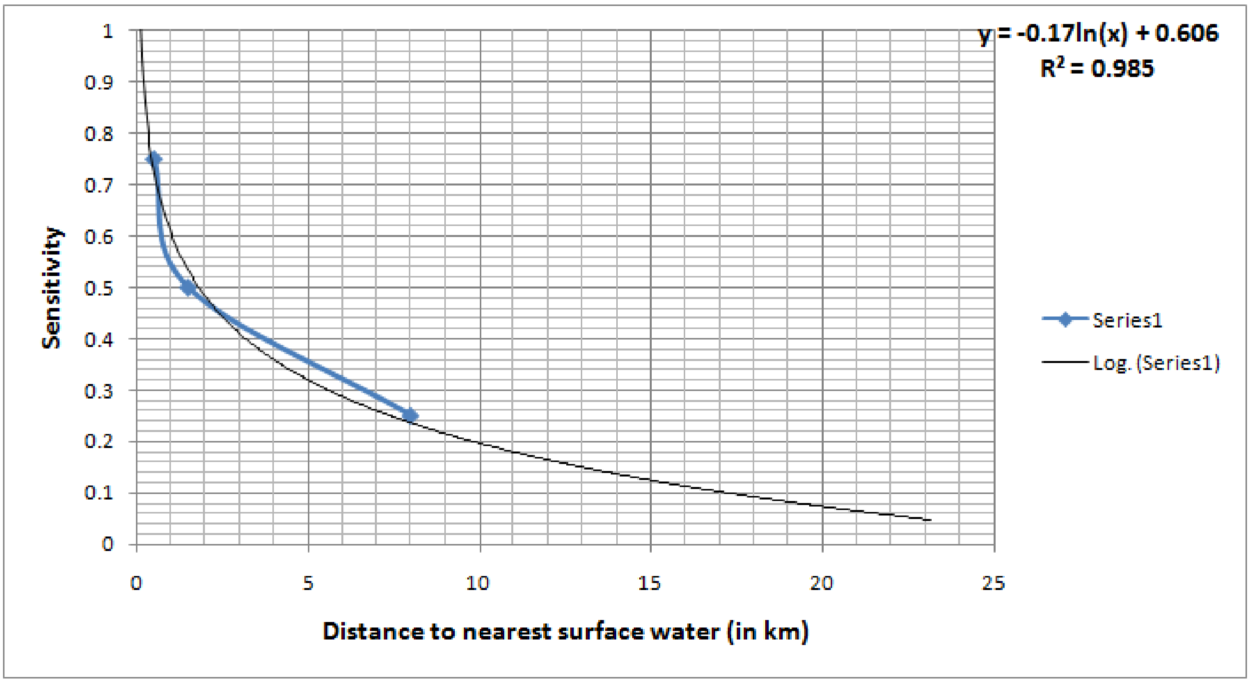

Figure 12: Sensitivity index Vs Distance to nearest surface water

13. **Depth of ground water:** Ground water is one of the fresh water source on which human rely for their various activities. Contamination of ground water with nitrates, heavy metals and other chemicals from the percolation of leachate are observed in many landfill sites. One of major concerns in a landfill is leaching of toxics into the ground water. Protection of ground water can be assured if the depth of ground water very high. Therefore landfill site having maximum depth of ground water table will be considered most suitable.

As per ***MOEF (2000)***

- The highest level of water table shall be at least two meter below the base of clay or amended soil barrier layer provided at the bottom of landfills.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- The minimum depth of underlying water table below ground surface (or nearby area if data in close proximity is not available)

Table 21 presents the CPCB proposed weightage and sensitivity index for the attribute depth of ground water. Figure 13 presents graphically the relation between sensitivity index and depth of ground water as proposed by CPCB (2003).

Table 21: **Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Depth of ground water"**

Attribute	Weightage	Sensitivity index →	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Depth to ground water	65	**Description →**	> 30 m	15 to 30 m	5 to 15 m	< 5 m

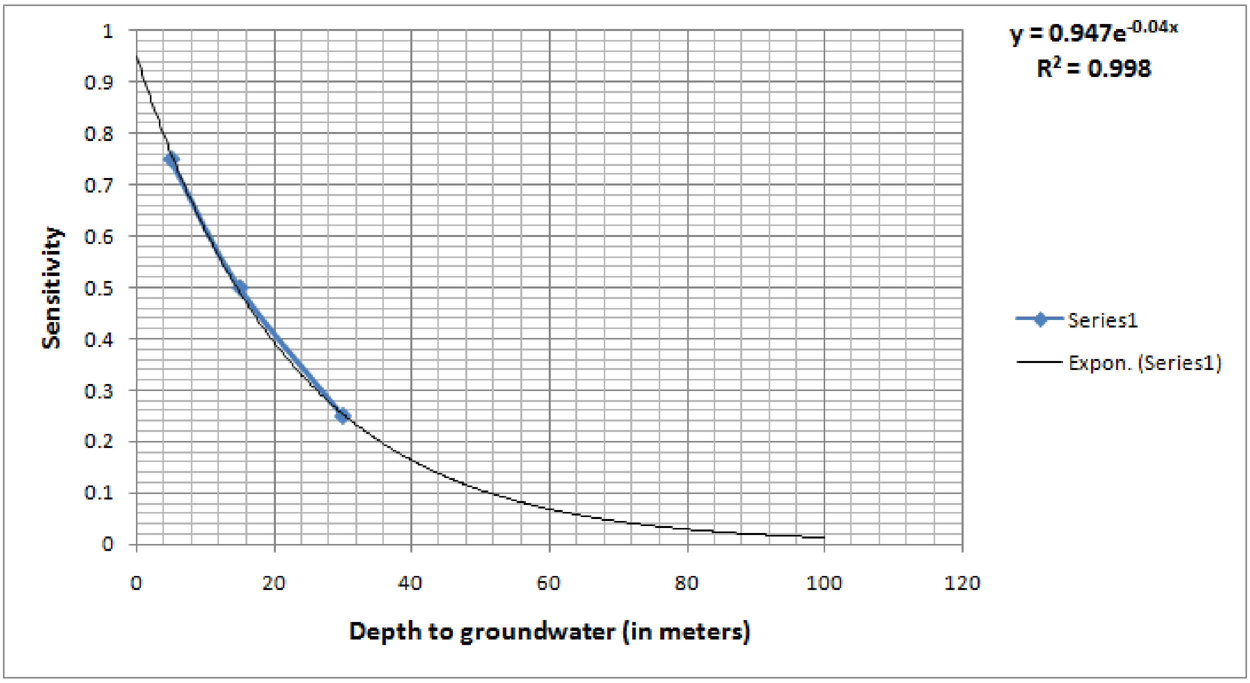

Figure 13: **Sensitivity index Vs Depth of ground water**

14. **Contamination:** Already contaminated area is less sensitive to be further contaminated due to landfilling operation may be considered as ideal landfill site.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Environmental element/s already contaminated.

Table 22 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute contamination.

Table 22: **Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Contamination"**

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Contamination	35	**Description →**	Air, water or food contamination	Biota contamination	Soil contamination only	No contamination

15. **Water quality:** Ground water is one of the most sensitive and easy target of being contaminated by the leachate generated due to landfilling action. Recent development of scientific measures like leachate collection and treatment system and liner protection has reduced the probability of ground water contamination. To check the water quality adjacent to the landfill site, drinking water standard as recommended by IS 10500 2012 has been taken as base line. The water quality parameters within the limits specified in IS standard for drinking water (IS 10500:2012) will be considered more suitable.

As per **MOEF (2000)**

- Before establishing any landfill site, baseline data of ground water quality in the area shall be collected and kept in record for future reference. The ground water quality within 50 metres of the periphery of the landfill site shall be periodically monitored to ensure that the ground water is not contaminated beyond acceptable limit as decided by the Ground Water board or the State board or the Committee. Such monitoring shall be carried out to cover different seasons in a year that is, summer, monsoon and post-monsoon period.
- Usage of groundwater in and around landfill sites for any purpose (including drinking and irrigation) is to be considered after ensuring its quality. The specifications for drinking water that should be used for monitoring of ground water quality are presented in Table 23.

Table 23: Drinking Water Specification as per IS 10500: 2012

Sl. No.	Parameters	IS 10500: 2012 desirable Limit (mg/l except for pH
1	Arsenic	0.05
2	Cadmium	0.01
3	Chromium	0.05
4	Copper	0.05
5	Cyanide	0.05
6	Lead	0.05
7	Mercury	0.001
8	Nickel	-
9	Nitrate as NO_3	45.0
10	pH	6.5-8.5
11	Iron	0.3
12	Total hardness (as $CaCO_3$)	300.0
13	Chlorides	250
14	Dissolved Solids	500
15	Phenolic Compounds as (C_6H_5OH)	0.001
16	Zinc	5.0
17	Sulphate (as SO_4)	200

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC are:-

- Fluoride
- Arsenic

Table 24 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute water quality.

Table 24: **Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Water quality"**

Attribute	Weightage	Sensitivity index →	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Water quality	40	**Description →**	Highly polluted	Polluted	Potable	Confirmed to standard

16. **Air quality:** Landfilling operation without proper precautions will not only contaminate adjacent water sources but also degrade the air quality of the neighbouring areas through emission of landfill gas, odour and dust. Therefore, landfilling operation is not acceptable if it degrade the air quality of the adjacent area.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Air quality index as per CPCB National Ambient Air Quality Status and Trends in India-2010 (2012) guidelines.

Table 25: Categories of Air Quality based on SO_2, NO_2 and RSPM as per CPCB (2012)

Pollution Level	Mean Annual Concentration Range ($\frac{\mu g}{m^3}$) Industrial, Residential, rural and Other Areas		
	SO2	NO2	RSPM
Low	0-25	0-20	0-30
Moderate	26-50	21-40	31-60
High	51-75	41-60	61-90
Critical	>75	>60	>90

Table 26 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute air quality.

Table 26: **Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Air quality"**

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Air quality	35	**Data →**	Highly polluted	Polluted	Confirmed to industrial standards	Confirmed to residential standards

17. **Soil quality:** Landfilling operation consumes huge amount of area and also degrade the soil quality of the adjacent area. For India, destruction of agricultural land causes lots of losses since economy of India is mainly agriculture dependent. Therefore, site having better soil quality area should be given least preference as far as landfill site is concerned. Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC are:-

- Soil Fertility
    - Organic carbon
    - Phosphate as P_2O_5
    - Potash as K_2O
- pH

Table 27: **Soil Fertility Level with respect to Percentage Carbon as per NBSS and LUP, ICAR (Publ. 94, 2002)**

Fertility Level	Organic carbon (%)
Very High	>1
High	1-0.8
Medium	0.8-0.6
Medium-Low	0.0.6-0.4
Low	<0.4
Very Low	-

Table 28: Soil Fertility Level with respect to Available Phosphate as per NBSS and LUP, ICAR (Publ. 94, 2002)

Fertility Level	Available P_2O_5 (kg/ha)
Very High	>115
High	115-92
Medium	92-70
Medium-Low	70-45
Low	45-22
Very Low	<22

Table 29: Soil Fertility Level with respect to Available Potash as per NBSS and LUP, ICAR (Publ. 94, 2002)

Fertility Level	Available K_2O (kg/ha)
Very High	>360
High	360-300
Medium	300-240
Medium-Low	240-180
Low	<180
Very Low	-

Table 30: Category of Soil with respect to pH value as per NBSS and LUP, ICAR (Publ. 94, 2002)

Reaction Class	pH value
Moderately Acidic	4.5-5.5
Slightly Acidic	5.5-6.5
Neutral	6.5-7.5
Slightly Alkaline	7.5-8.5

Table 31 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute soil quality.

Table 31: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Soil quality"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Soil quality	30	**Description →**	Highly contaminated	Contaminated	Average	No contamination

18. **Health:** Human health survey is an important concern during landfill site selection process. Health sensitive areas i.e. areas where considerable people are suffering from some particular health ailment must be avoided as landfill may cause synergistic effect and increase the health risk factor making the habitants more prone to disease.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Disease trend in the local areas

Table 32 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute health.

Table 32: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Health"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Health	40	**Description →**	No problem	Moderate	High	Severe

19. **Job opportunities:** Landfill establishment in an area may create some job opportunities for the nearby residents. This may be seen as a beneficial factor for the local

people. Job creation can be in the form of skilled and unskilled labour requirement for temporary and permanent basis. Rag picking may also be considered as job opportunity if done following government safety norms.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Expected job generation as number of workers.

Table 33 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute job opportunities.

Table 33: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Job opportunities"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Job opportunitie s	20	**Description →**	High	Moderate	Low	Very low

20. **Odour:** Odour problem is one of the predominant problem due to landfill site which results in strong public resistance during landfill site selection. Odour nuisance generally occurs in the downwind direction so landfill site having nearby habitation in the downwind direction will be considered as least preferable.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Distance to nearest habitation.

Table 34 presents the CPCB proposed weightage and sensitivity index for the attribute odour.

Table 34: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Odour"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Odour	30	**Description →**	No odour	Moderate odour	High odour	Intensive foul odour

21. **Vision:** Landfill site are aesthetically not pleasant to see. Landfill site selection should be made keeping in mind that site is least visible to population nearby.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Percentage visible from nearest human habitation.

Table 35 presents the ***CPCB (2003)*** proposed weightage and sensitivity index for the attribute vision.

Table 35: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Vision"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Vision	20	**Description →**	Site not seen	Site partially seen (25%)	Site partially seen (75%)	Site fully seen

22. **Waste quantity/day:** Increase quantity of solid waste will demand increase capacities of solid waste management facilities. It not only create extra burden to direct cost to the management authorities but also cause environmental loads. Therefore, landfill site that should be used to dispose huge amount of solid waste should be designed carefully so that it should be economically viable, socially acceptable and environmentally sustainable.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Total inert waste generated per day in the municipal area under consideration.

Table 36 presents the CPCB proposed weightage and sensitivity index for the attribute waste quantity/day. Figure 14 presents graphically the relation between sensitivity index and waste quantity/day as proposed by CPCB (2003).

Table 36: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Waste quantity/day"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Waste quantity/day	45	**Description →**	< 250 tonnes	250 to 1000 tonnes	1000 to 2000 tonnes	> 2000 tonnes

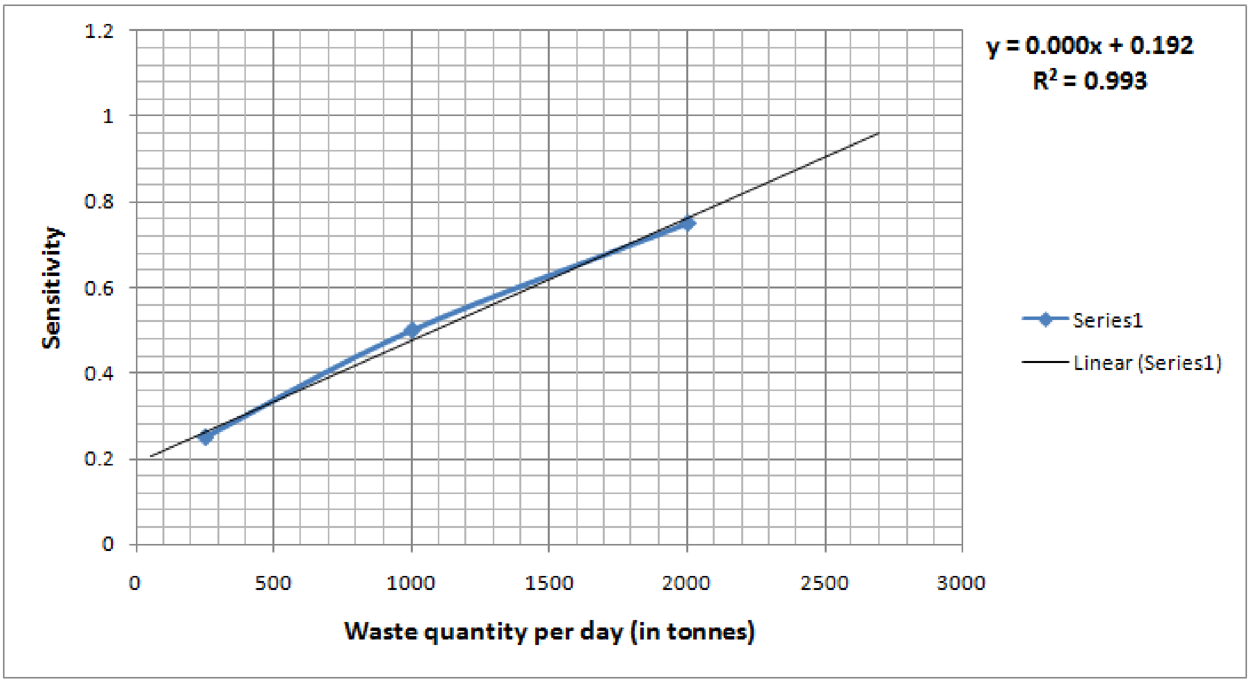

Figure 14: Sensitivity index Vs Waste quantity/day

23. **Life of site:** Life of the site is the active period for which the site can be used for solid waste disposal before being exhausted. Life of landfill site at least more than 5 years may be considered cost effective.

As per CPHEEO

- The 'active' period may typically range from 10 to25 years depending on the availability of land area.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Life of the site before complete exhaustion.

Table 37 presents the CPCB proposed weightage and sensitivity index for the attribute life of site. Figure 15 presents graphically the relation between sensitivity index and life of site as proposed by CPCB (2003).

Table 37: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Life of site"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Life of site	40	**Description →**	> 20 years	10-20 years	2-10 years	< 2 years

Figure 15: Sensitivity index Vs Life of site

24. **Precipitation effectiveness index:** Precipitation effectiveness index (P-E index) is a tool proposed by Thornthwaite's to classify climatic condition based on precipitation to evaporation ratio of a place. The term effectiveness denotes degree of utility or efficiency of the rainfall with respect to the aridity of the place. Precipitation Effectiveness Index can mathematically be represented as per the formulae below.

$$PE = \sum_{n=1}^{12} 115(\frac{P}{T-10})^{10/9} \dots\dots\dots\dots\dots\dots (6)$$

Where,

PE = precipitation effectiveness index,

$P = monthly\ precipitation\ (in\ inches)$,

$T = monthly\ temperature\ (\ in\ °F)$

The value of the index is used to classify the regions into Wet (greater than 127), Humid (63 to 127), Sub-humid (31 to 63), Semiarid (16 to 31) and arid (less than 16) ***(Babu and Ramakrishna, 2000).*** Higher value of PE index implies more sensitive landfill site.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- PE value

Table 38 presents the CPCB proposed weightage and sensitivity index for the attribute precipitation effectiveness index. Figure 16 presents graphically the relation between sensitivity index and precipitation effectiveness index as proposed by CPCB (2003).

Table 38: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Precipitation effectiveness index"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Precipitation effectiveness index	25	**Description →**	< 31	31 to 63	63 to 127	>127

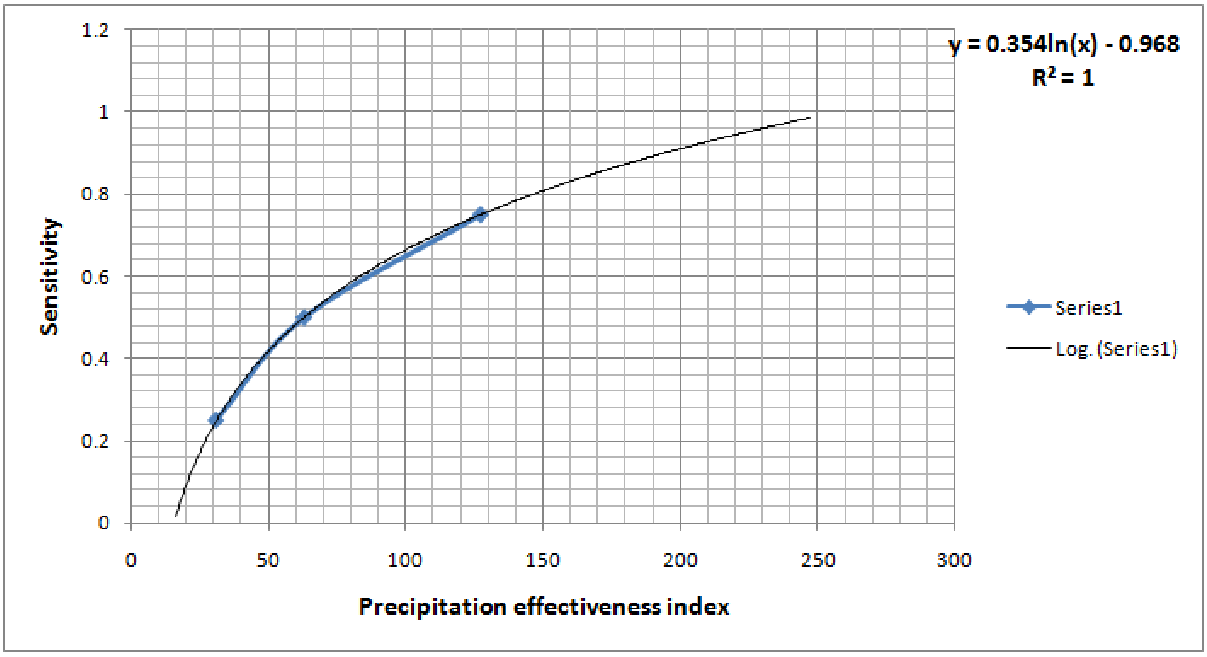

Figure 16: Sensitivity index Vs Precipitation effectiveness index

25. **Climate features contributing to Air pollution:** Generally, the degree of air pollutants discharge from various sources, and concentration in a particular area depends on climatic features. To decrease its harmful effect on the environment it is preferable that the pollutant be dispersed in a large mass of air. Dispersion of air pollutant is high if wind speed and temperature are high ***(Verma and Desai, 2008)*** which can be considered as most favourable situation.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Temperature Inversion

Table 39 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute climate features contributing to air pollution.

Table 39: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Climate features contributing to Air pollution"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Climatic features contributing to Air pollution	15	**Description →**	No problem	Moderate	High	Severe

26. **Soil permeability:** Soil permeability is a measure of the capacity of a liquid to move through the pores of a solid. Low permeable soil ensures more resistance to the flow of liquid through it thus ensuring more safety to the water source from being contaminated by leachate. Landfill sites should be located on the areas that have low permeable soil. ***(Moeinaddini et al., 2010)***.

Babu and Ramakrishna (2000) assigned sensitivity index to soil depending on the presence of clay (in %) in soil as presented in Table 40.

Table 40: Clay Percentage and Sensitivity index Relationship

% Clay	**Sensitivity index**
>50	0.0-0.25
50 to 30	0.25-0.5
30 to 15	0.5-0.75
15 to 0	0.75-1.0

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Percentage clay

Table 41presents the CPCB proposed weightage and sensitivity index for the attribute soil permeability. Figure 17 presents graphically the relation between sensitivity index and soil permeability as proposed by ***CPCB (2003)***.

Table 41: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Soil permeability"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Soil Permeabilit y	35	**Description →**	> 110-7cm/sec	110-5to 110-7	110-3 to 110-5	< 110-3

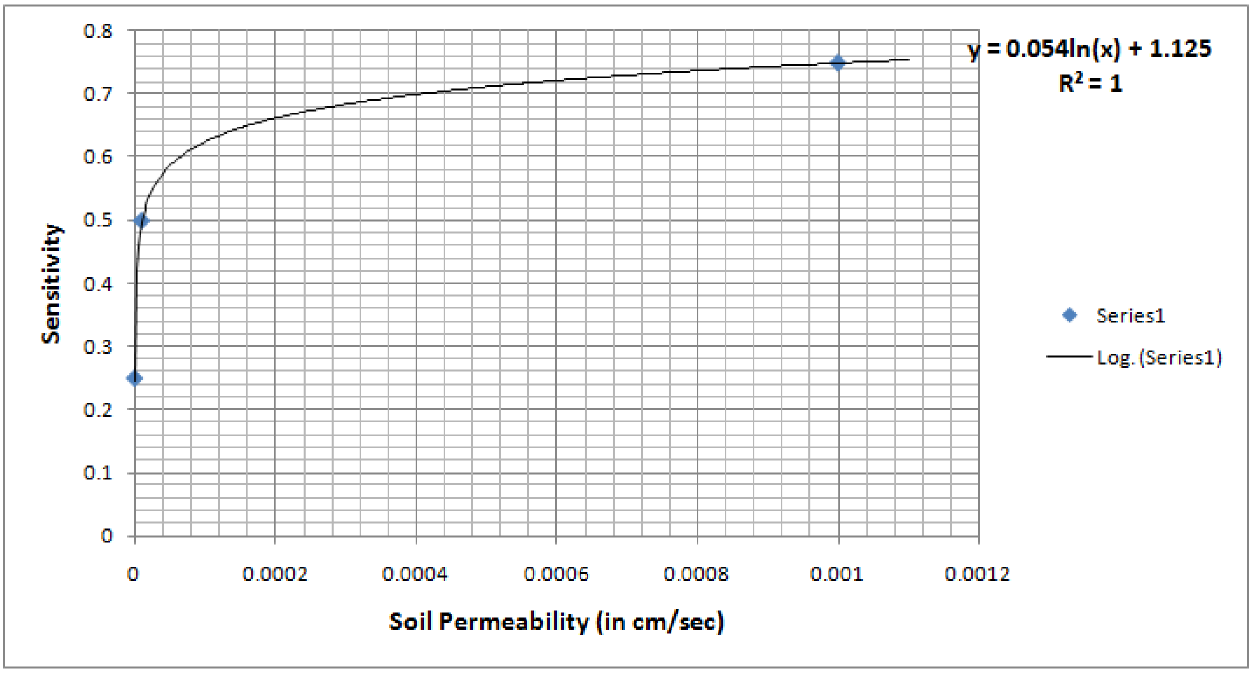

Figure 17: Sensitivity index Vs Soil permeability

27. **Depth to bedrock:** Depth of bedrock is the overall thickness of soil, weathered and semi weathered formation for a particular area. High depth to bedrock increases the suitability of a site for landfill site construction.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Depth of bedrock

Table 42 presents the CPCB proposed weightage and sensitivity index for the attribute depth to bedrock. Figure 18 presents graphically the relation between sensitivity index and depth to bedrock as proposed by CPCB (2003).

Table 42: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Depth to bedrock"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Depth to bedrock	20	**Description →**	> 20 m	10 to 20 m	3 to 10 m	< 3 m

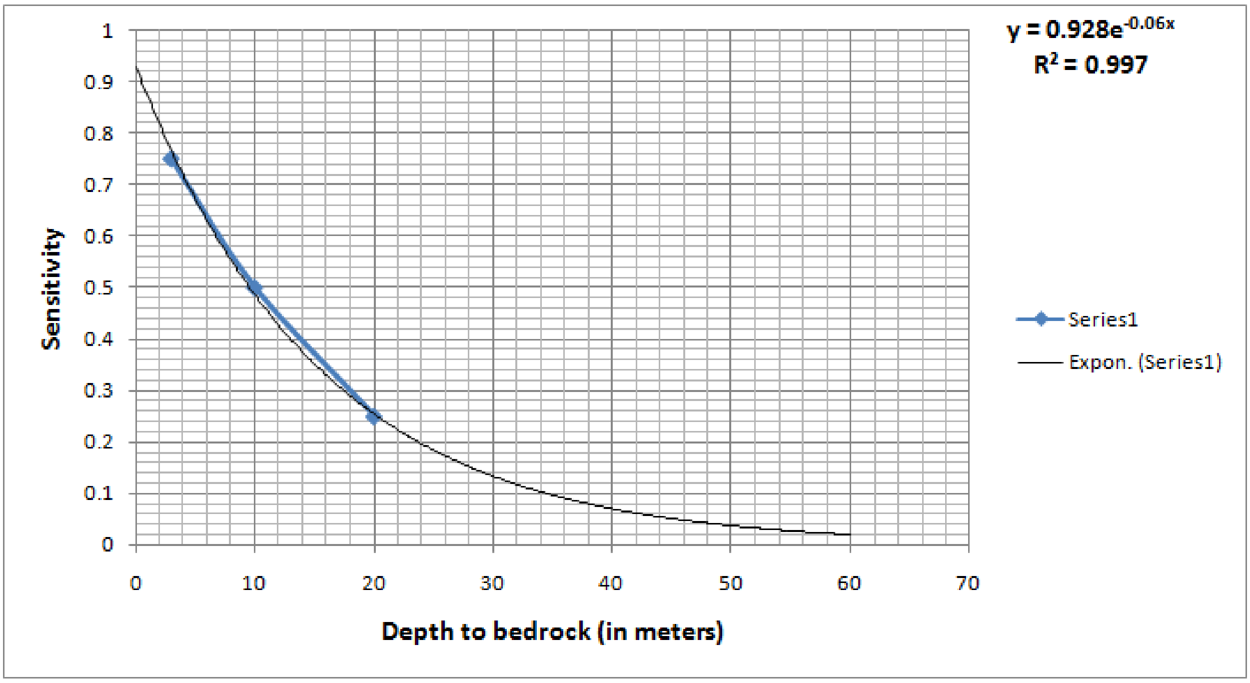

Figure 18: Sensitivity index Vs Depth to bedrock

28. **Susceptibility to erosion and run off:** Erosion and run off problem can be troublesome for the easy operation of landfill site. The magnitude of erosion problems at landfill sites is proportional to the area of soil exposed to the erosive elements and the duration of that exposure. Runoff contaminated by the landfill operation may also cause of concern.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Soil loss per year

Table 43: Classification of Amount of Soil Loss as per NBSS and LUP, ICAR (Publ. 96, 2002)

Class	Soil Loss (t $ha^{-1}yr^{-1}$)
Very Slight	<5
Slight	5-10
Moderate	10-15
Mod. Severe	15-20
Severe	20-40
Very Severe	40-80

Table 44 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute susceptibility to erosion and run off.

Table 44: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Susceptibility to erosion and run off"

Attribute	Weightage	Sensitivity index →	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Susceptibility to erosion and run-off	15	**Description →**	Not susceptible	Potential	Moderate	Severe

29. **Physical characteristics of rock:** Massive unweathered rock underlying a landfill site is to be considered favourable for landfill site construction. Hard rock without fault ensures barrier between leachate and groundwater table and safeguards the water source from contamination.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC are:-

- Massive
- Weathered
- Unweathered
- Soft
- Medium
- Hard

Table 45 presents the CPCB proposed weightage and sensitivity index for the attribute physical characteristics of rock.

Table 45: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Physical characteristics of rock"

Attribute	Weightage	Sensitivity index →	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Physical characteristics of rock	15	**Description →**	Massive	Weathered	Weathered	Highly weathered

30. **Depth of soil layer:** Huge amount of soil are required for landfill operation for providing daily cover, intermediate cover and final cover. Transportation of soil from some other location to the disposal site is not an economical option for the municipal corporation that seldom have sufficient funds for solid waste management. It is preferred to use the soil from the site itself so that the extra transportation cost may be avoided. Therefore depth of soil layer is an important criterion that is considered for landfill site selection under Indian conditions. Greater the soil depth more suitable proposed landfill site. Generally depth of soil layer in the site is observed by Electrical Resistivity test.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Depth of soil layer.

Table 46 presents the CPCB proposed weightage and sensitivity index for the attribute depth of soil layer. Figure 19 presents graphically the relation between sensitivity index and depth of soil layer as proposed by CPCB (2003).

Table 46: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Depth of soil layer"

Attribute	Weightage	Sensitivity index →	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Depth of soil layer	30	Description →	> 5 m	2-5 m	1-2 m	< 1 m

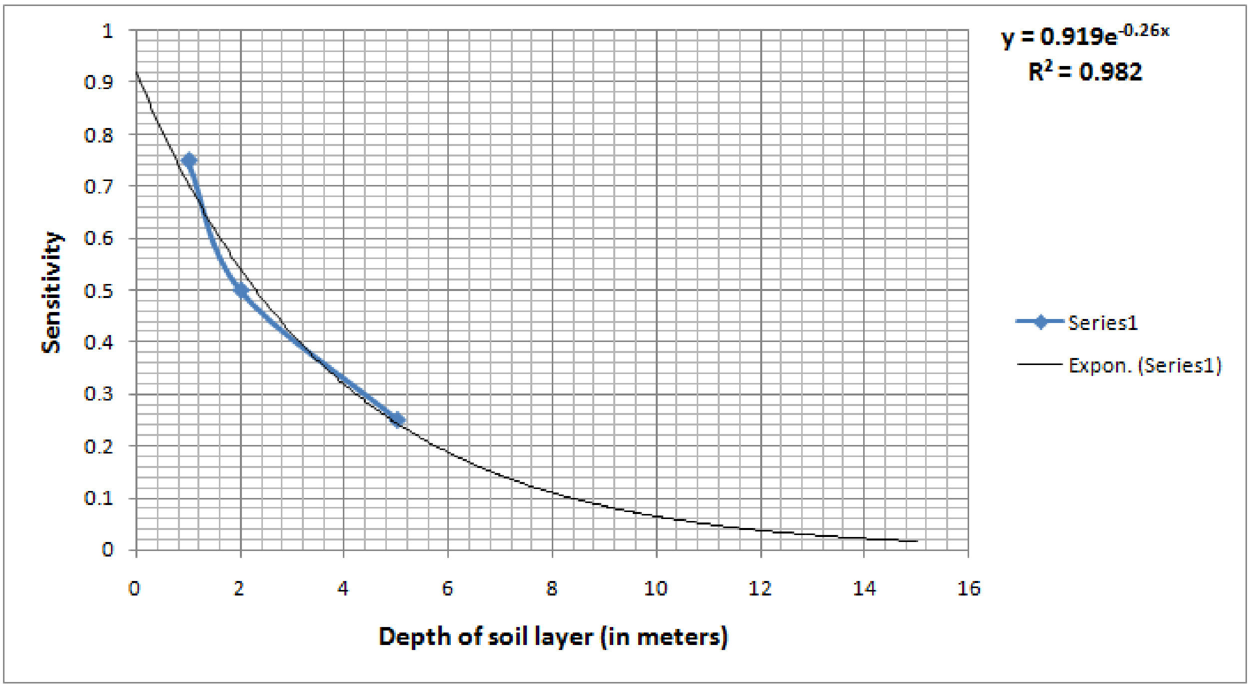

Figure 19: Sensitivity index Vs Depth of soil layer

31. **Slope pattern:** Landfill site are preferred to be constructed on flat terrain. Flat terrain will have less cut and fill cost during construction phase. Landfill site constructed on a sloping terrain may carry contaminated rainwater flowing over it in the downstream area thus contaminating all the areas coming into contact. To prevent water logging, site should not be concave i.e. the site must not be in the depression zone else it will collect all the rainwater from the catchment and such huge contaminated water will be stored and seeped and would be difficult to manage. Therefore, landfill site with least slope will be most suitable.

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Land slope in %.

Table 47 presents the CPCB proposed weightage and sensitivity index for the attribute slope pattern. Figure 20 presents graphically the relation between sensitivity index and slope pattern per day as proposed by CPCB (2003).

Table 47: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Slope pattern"

Attribute	**Weightage**	**Sensitivity index →**	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Slope pattern	15	**Description →**	< 1 %	1-2 %	2-5 %	>10%

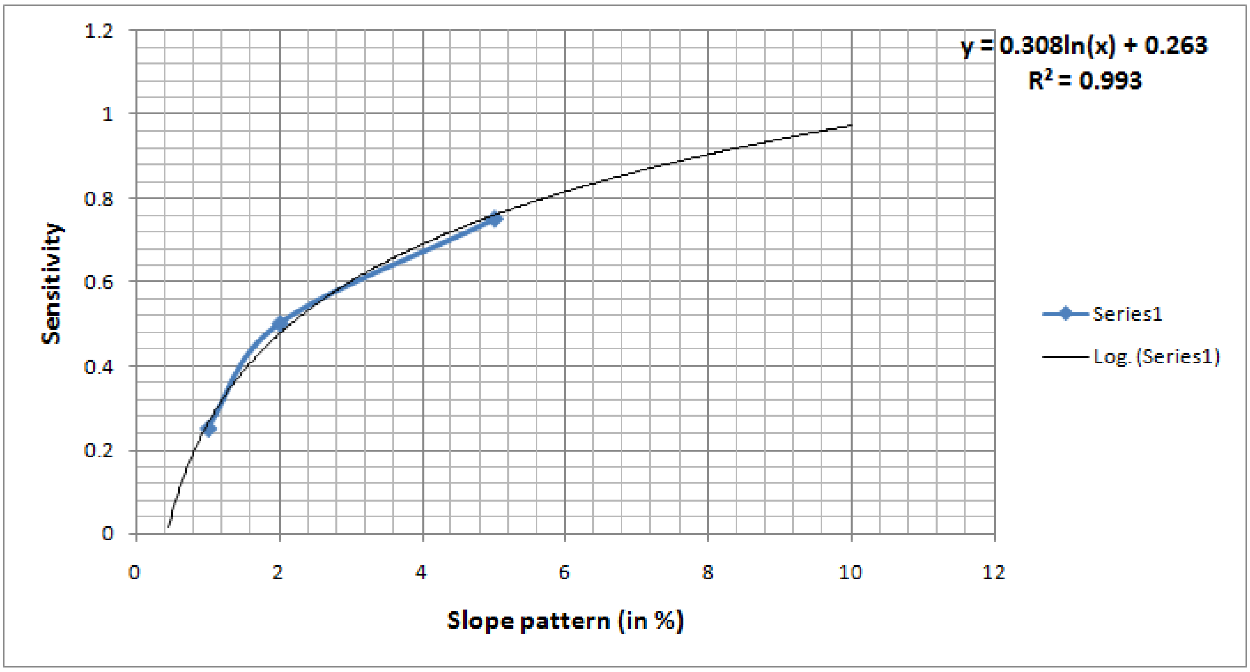

Figure 20: Sensitivity index Vs Slope pattern

32. **Seismicity:** Seismic loading may be considered important during design of landfill as it may result in some serious damages like puncturing of landfill liner due to the shearing force produced due to earth shaking and hence polluting the groundwater below it, cover cracking and dysfunctioning of gas collection system.

Bureau of Indian Standards have divided India into four seismic zones - II, III, IV and V where zone II to IV sensitivity index increases.

Landfill site constructed in zone V should be considered most sensitive.

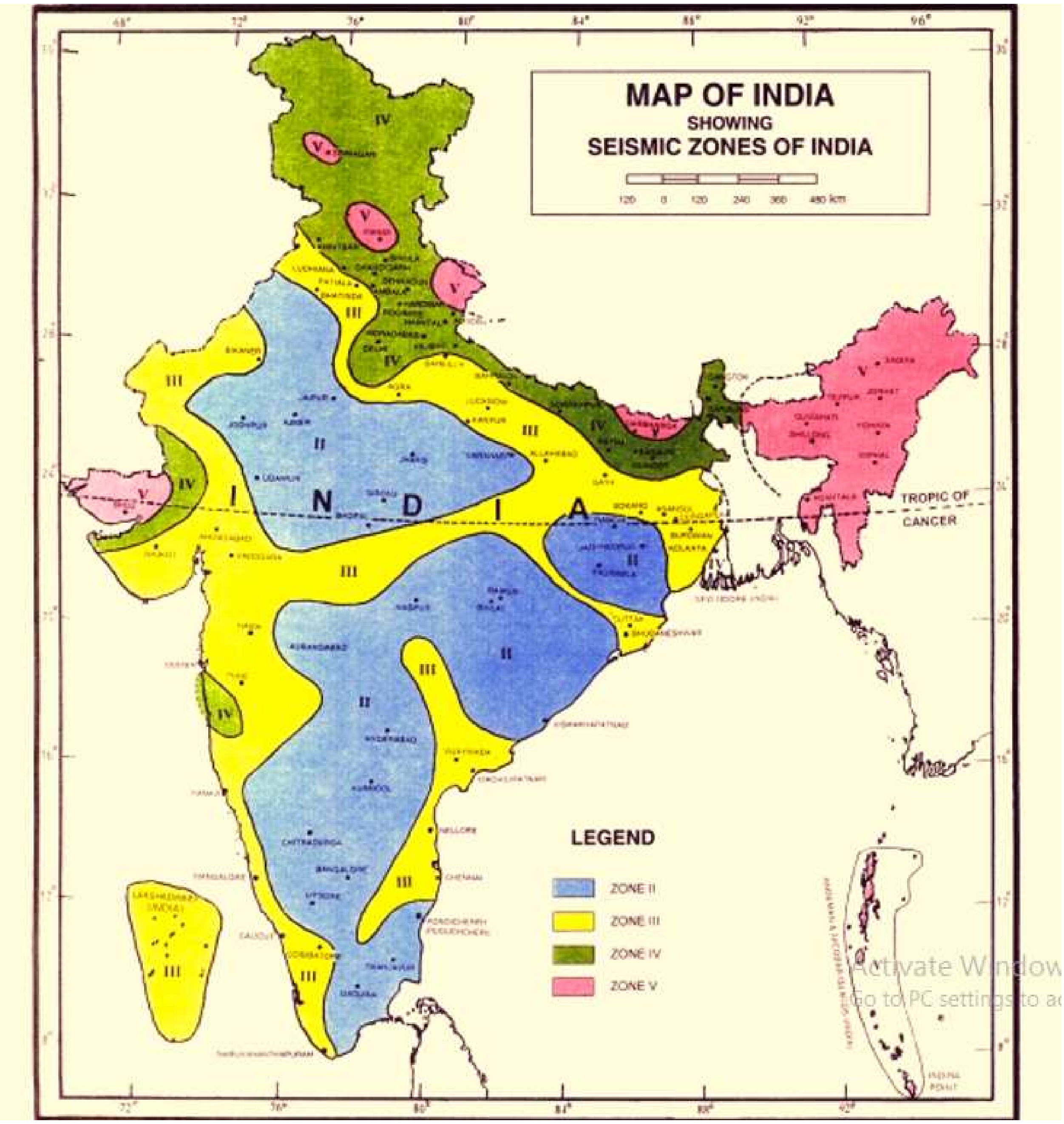

Figure 21: Map of India showing Different Seismic Zones

As per MOUD (2014)

- No landfill site should be constructed within 500m from fault line fracture

Data considered for sensitivity index calculation for the attribute in the proposed work of landfill site selection for AMC is:-

- Zone
    - Zone II
    - Zone III
    - Zone IV

- Zone V

Table 48 presents the CPCB (2003) proposed weightage and sensitivity index for the attribute seismicity.

Table 48: Weightage and Sensitivity index Values Suggested by CPCB (2003) for Attribute "Seismicity"

Attribute	Weightage	Sensitivity index →	0.0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Seismicity	20	**Description →**	Zone I	Zone II	Zone III	Zone IV and V

3.5. Data Collection

Data were collected for two purposes:

- Formulation and validation of fuzzy based model, for calculating weightage and sensitivity index for the selected attributes.
- Identification of suitable landfill site for the study area using the proposed model.

3.5.1. Data for Model Development and Validation

Data for site 1 (Kannahalli) and site 2 (Seegehalli) site in Bangalore based on the CPCB (2003) were used for formulation and validation of the model. Table 49 shows data of all the 32 attributes of the two alternative site selected by ***CPCB (2003)*.**

Table 49: Attribute Data for Proposed Landfill Site by CPCB (2003)

Sl No.	Attribute	Site 1 (Kannahalli)	Site 2 (Seegehalli)
1	Type of road	• 2.5 km • State Highway	• 1.5 • State Highway
2	Distance from collection area	25 km	24 km
3	Population within 500 meters	100	100
4	Distance to nearest drinking water source	200 m	500 m
5	Use of the site by nearby residents	Not used	Not used
6	Distance to nearest building	100	500
7	Land use/ Zoning	Completely Remote	Completely Remote
8	Decrease in property value wrt distance	No Decrease in property value	Moderate
9	Public utility facility within 2 km	No public utility	No public utility
10	Public acceptability	No complaints	No complaints
11	Critical environments	Not a critical Environment	Not a critical Environment
12	Distance to nearest surface water	1.5 km	3 km
13	Depth of ground water	5 m	20 m

Sl No.	Attribute	Site 1 (Kannahalli)	Site 2 (Seegehalli)
14	Contamination	No contamination	No contamination
15	Water quality	Potable	Potable
16	Air quality	Confirming to residential standards	Confirming to residential standards
17	Soil quality	Average	Average
18	Health	Moderate	No problem
19	Job opportunities	Low	Low
20	Odour	Moderate	Moderate
21	Vision	Site partly seen (25%)	Site not seen
22	Waste quantity/day	1197 t/d	1197 t/d
23	Life of site	21 months	2 months
24	Precipitation effectiveness index	31 to 63	31 to 63
25	Climatic features contributing to air pollution	No problem	No problem
26	Soil permeability	$1 \times 10^{-4}\ to\ 1 \times 10^{-5}$	$1 \times 10^{-4}\ to\ 1 \times 10^{-5}$
27	Depth to bedrock	10 - 40 m	9 to 27 m
28	Susceptibility to erosion and run off	Not susceptible	Moderate
29	Physical characteristic of rock	Weathered	Weathered
30	Depth of soil layer	0.3 to 3	0 to 9.5 m
31	Slope pattern	2%	$> 10\%$
32	Seismicity	ZONE I	ZONE I

3.5.2. Data for Implementation of Proposed Model in AMC

Two sites are selected near Asansol area for landfill site based upon the following factors:-

- Within 2 km from suitable main road
- Economical travel distance (30 km) from origin of waste
- Not a flood plain

Attribute related data were collected to calculate the sensitivity of the site.

Table 50 presents the sources of data regarding different attributes that have been used for model implementation in AMC for landfill site selection.

Table 50: Source of Attribute Data for Selected Landfill Sites in AMC

Attribute	Data Source	Remarks
Type of road	• Google Maps • Bhuvan/ Indian Space Research Organisation (ISRO) website	
Distance from collection area	• Google Maps • Bhuvan/ Indian Space Research Organisation (ISRO) website	
Population within 500 meters	• Google Maps • Bhuvan/ Indian Space Research	

Attribute	Data Source	Remarks
	Organisation (ISRO) website ● Site visit and Survey	
Distance to nearest drinking water source	● Google Maps ● Bhuvan/ Indian Space Research Organisation (ISRO) website ● Site visit and Survey	
Use of the site by nearby residents	● Google Maps ● Bhuvan/ Indian Space Research Organisation (ISRO) website ● Site visit and Survey	
Distance to nearest building	● Google Maps ● Bhuvan/ Indian Space Research Organisation (ISRO) website ● Site visit and Survey	
Land use/ Zoning	● Bhuvan/ Indian Space Research Organisation (ISRO) website ● Site visit and Survey	
Decrease in property value wrt distance	● Site visit and Survey	
Public utility facility within 2 km	● Google Maps ● Bhuvan/ Indian Space Research Organisation (ISRO) website ● Site visit and Survey	
Public acceptability	● Site visit and Survey	
Critical environments	● Google Maps ● Bhuvan/ Indian Space Research Organisation (ISRO) website ● Site visit and Survey	
Distance to nearest surface water	● Google Maps ● Bhuvan/ Indian Space Research Organisation (ISRO) website ● Site visit and Survey	
Depth of ground water	Central ground water Board (CGWB) website http://www.india-wris.nrsc.gov.in	
Contamination	● Public Health Engineering Department (PHED) website http://www.wbphed.gov.in ● Central Pollution Control Board (CPCB) ● National Bureau of Soil Survey and Land Use (NBSS and LUP, ICAR) paper maps and publications	

Attribute	Data Source	Remarks
Water quality	Public Health Engineering Department (PHED) website http://www.wbphed.gov.in	
Air quality	Central Pollution Control Board (CPCB)	
Soil quality	National Bureau of Soil Survey and Land Use (NBSS and LUP, ICAR) paper maps and publications	
Health	Site visit and Survey	
Job opportunities	Site visit and Survey	
Odour	• Google Maps • Bhuvan/ Indian Space Research Organisation (ISRO) website • Site visit and Survey	
Vision	Site visit and Survey	
Waste quantity/day	Asansol Municipal Corporation (AMC) website	
Life of site	Calculation	Refer Table 7
Precipitation effectiveness index	Calculation	Refer Table 51
Climatic features contributing to air pollution	Asansol Durgapur Development Authority (ADDA) report, 2006	
Soil permeability	National Bureau of Soil Survey and Land Use (NBSS and LUP, ICAR) paper maps and publications	
Depth to bedrock	Central Mine Planning and Design Institute Limited (CMPDI), Institute 1	
Susceptibility to erosion and run off	National Bureau of Soil Survey and Land Use (NBSS and LUP, ICAR) paper maps and publications	
Physical characteristic of rock	District Resource Map of Geological Survey of India (GSI)	
Depth of soil layer	National Bureau of Soil Survey and Land Use (NBSS and LUP, ICAR) paper maps and publications	
Slope pattern	Survey of India, District Planning Map Series, Barddhaman	
Seismicity	IS 1893 (Part 1) :2002	

Table 51: Precipitation Effectiveness (P-E) Index Calculation

Month (2014)	P (Rainfall in inch)	T (Temp in °F)	$\frac{P}{T-10}$	$\frac{P}{T-10}^{\frac{10}{9}}$	$115\times(\frac{P}{T-10}^{\frac{10}{9}})$
Jan	0.48	64.58	0.0088	0.005201	0.6
Feb	0.69	69.8	0.011587	0.007061	0.81
March	0.83	78.62	0.012106	0.007413	0.85
April	1.66	86.54	0.021655	0.014146	1.63
May	3.75	87.26	0.048512	0.03466	3.99
June	9.22	86.18	0.120984	0.095677	11
July	10.66	83.12	0.145807	0.117724	13.54
August	9.29	82.58	0.128015	0.101875	11.72
Sept	8.43	82.76	0.115849	0.091176	10.49
Oct	3.94	80.6	0.055877	0.040554	4.66
Nov	0.41	73.94	0.006404	0.003653	0.42
Dec	0.31	66.2	0.005464	0.003063	0.35
				PE	**60.05**

The attribute related data for the two proposed sites of AMC area are listed in Table 52

Table 52: Attribute Data for Proposed Landfill Sites in AMC

Sl No.	Attribute	LF 1	LF 2
1	Type of road	0.15, District Main Road	.850, State Highway
2	Distance from collection area	7.9	13.3
3	Population within 500 meters	0-100	0-100
4	Distance to nearest drinking water source	<1000m	<1000m
5	Use of the site by nearby residents	Not used	Moderate
6	Distance to nearest building	400 m	200 m
7	Land use/ Zoning	(Built up, Urban and Barren/Unculturable/Wastelands, Scurb Lands and Agriculture,	(Built up, Urban and Agriculture, Crop Land)

Sl No.	Attribute	LF 1	LF 2
		Crop Land)	
8	Decrease in property value wrt distance	No Decrease	1 km
9	Public utility facility within 2 km	Industry, School	Industry, Resort and Water Park, Petrol Pump and commercial shops
10	Public acceptability	Non acceptance	Acceptance with minor suggestions
11	Critical environments	Not a critical Environment	Not a critical Environment
12	Distance to nearest surface water	Stagnant, 500 m	Stagnant, 500 m
13	Depth of ground water	> 0.73	> 0.73
14	Contamination	Air	Air
15	Water quality	No Fluoride and Arsenic contamination	No Fluoride and Arsenic contamination
16	Air quality	Critical (SO2 L, NO2 C and PM10 C)	Critical (SO2 L, NO2 C and PM10 C)
17	Soil quality	Organic Carbon - Low (<0.4 %) Phosphate - Low (45-22 kg/ha) Potash Low (<180 kg/ha) pH Moderately acidic (4.5 - 5.5)	Organic Carbon - Low (<0.4 %) Phosphate - Low (45-22 kg/ha) Potash Low (<180 kg/ha) pH Moderately acidic (4.5 - 5.5)
18	Health	No Problem	No Problem
19	Job opportunities	< 100 workers	< 100 workers
20	Odour	< 600 m	< 600 m
21	Vision	50-75%	0-25%
22	Waste quantity/day	220	220
23	Life of site	5 yrs	12 yrs
24	Precipitation effectiveness index	Sub Humid (P-E = 60)	Sub Humid (P-E = 60)

Sl No.	Attribute	LF 1	LF 2
25	Climatic features contributing to air pollution	Temperature inversion during winter	Temperature inversion during winter
26	Soil permeability	Clay (0 - 20 %)	Clay (0 - 20 %)
27	Depth to bedrock	3-12 m	3-12 m
28	Susceptibility to erosion and run off	Moderate (10-15 t /ha/yr)	Moderate (10-15 t /ha/yr)
29	Physical characteristic of rock	Soft to Medium Rock	Soft to Medium Rock
30	Depth of soil layer	Shallow (25 - 50 cm)	Shallow (25 - 50 cm)
31	Slope pattern	2 to 8 %	2 to 8 %
32	Seismicity	III	III

Satellite view of the proposed landfill sites of AMC area are presented in Figure 22.
Sample of distance calculation from the proposed sites as required for attribute data are presented in Figure 23.
Area calculations of the proposed sites are presented in Figure 24 and 25.
Geomorphology around the proposed sites are presented in Figure 26 and 27.
Ground water prospects around the proposed sites are presented in Figure 28 and 29.
Land use and Land cover around of the proposed sites are presented in Figure 30 and 31.

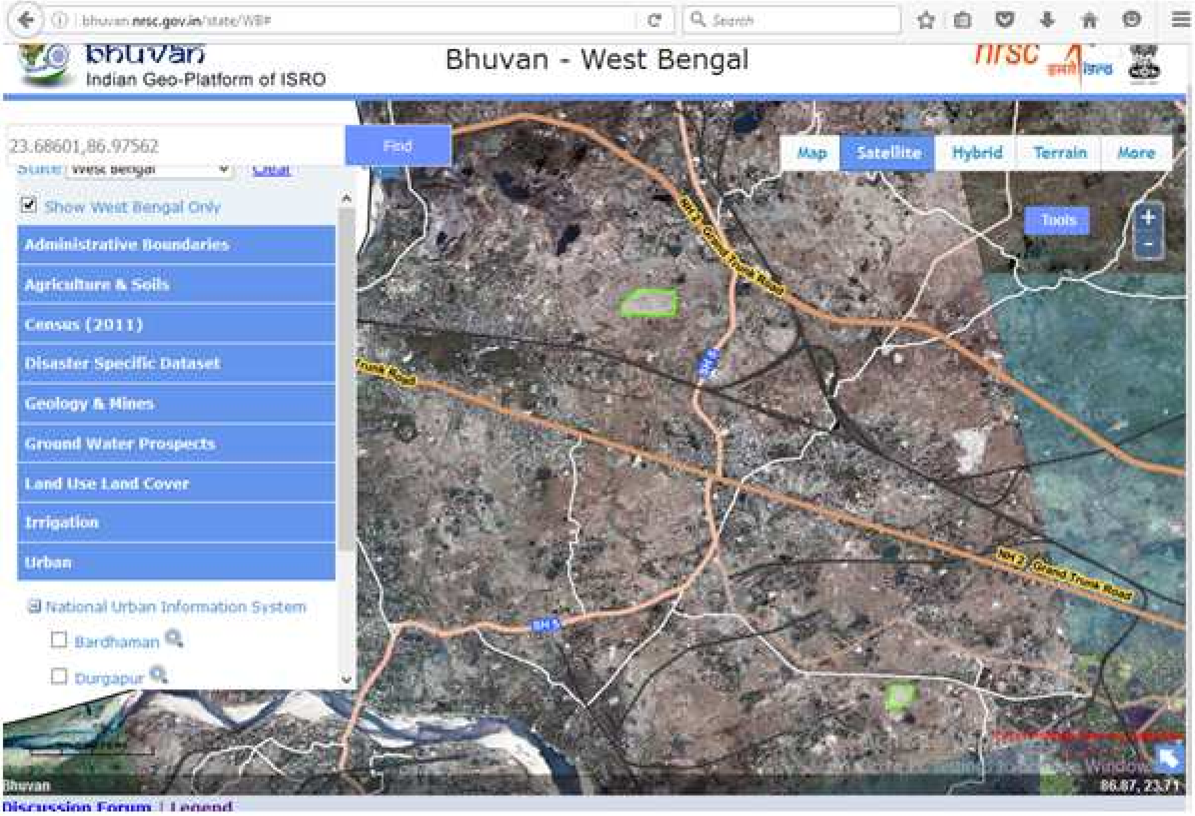

Figure 22: Satellite View of Proposed Landfill Sites

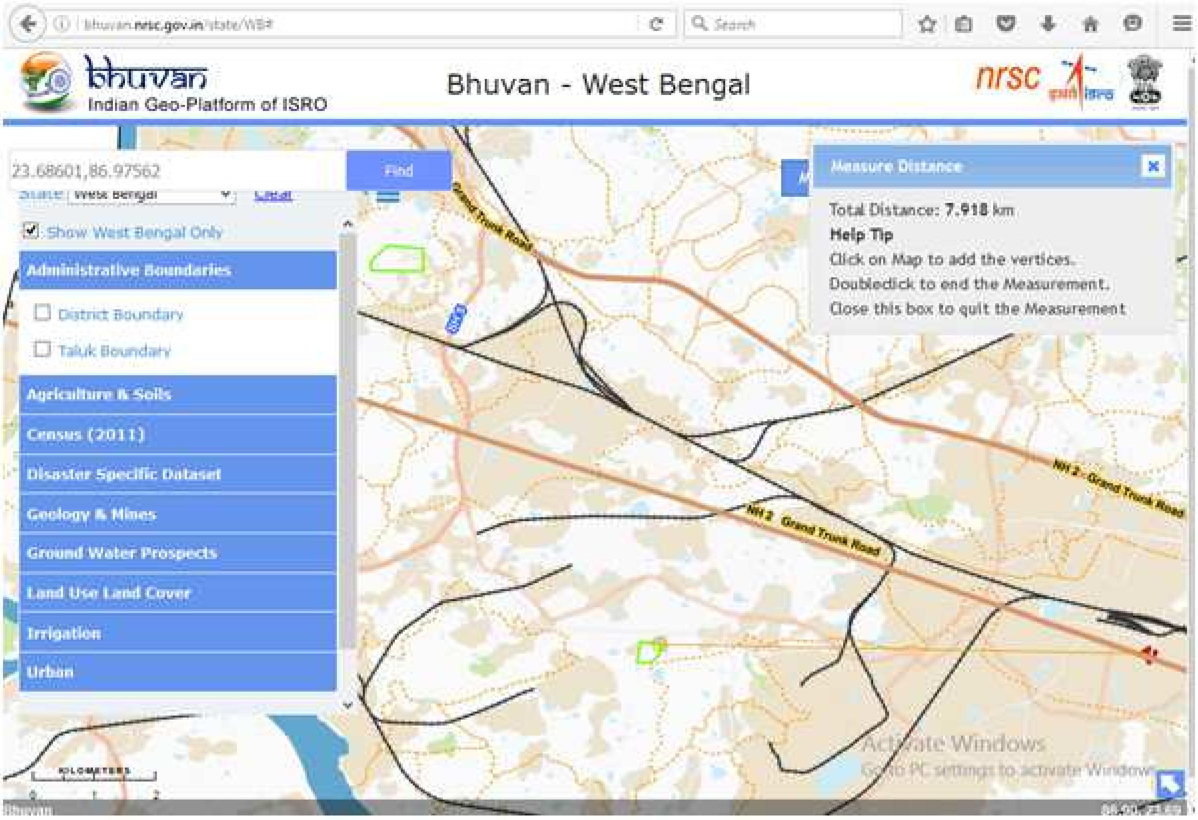

Figure 23: Sample Distance Calculation for Selected Landfill Site

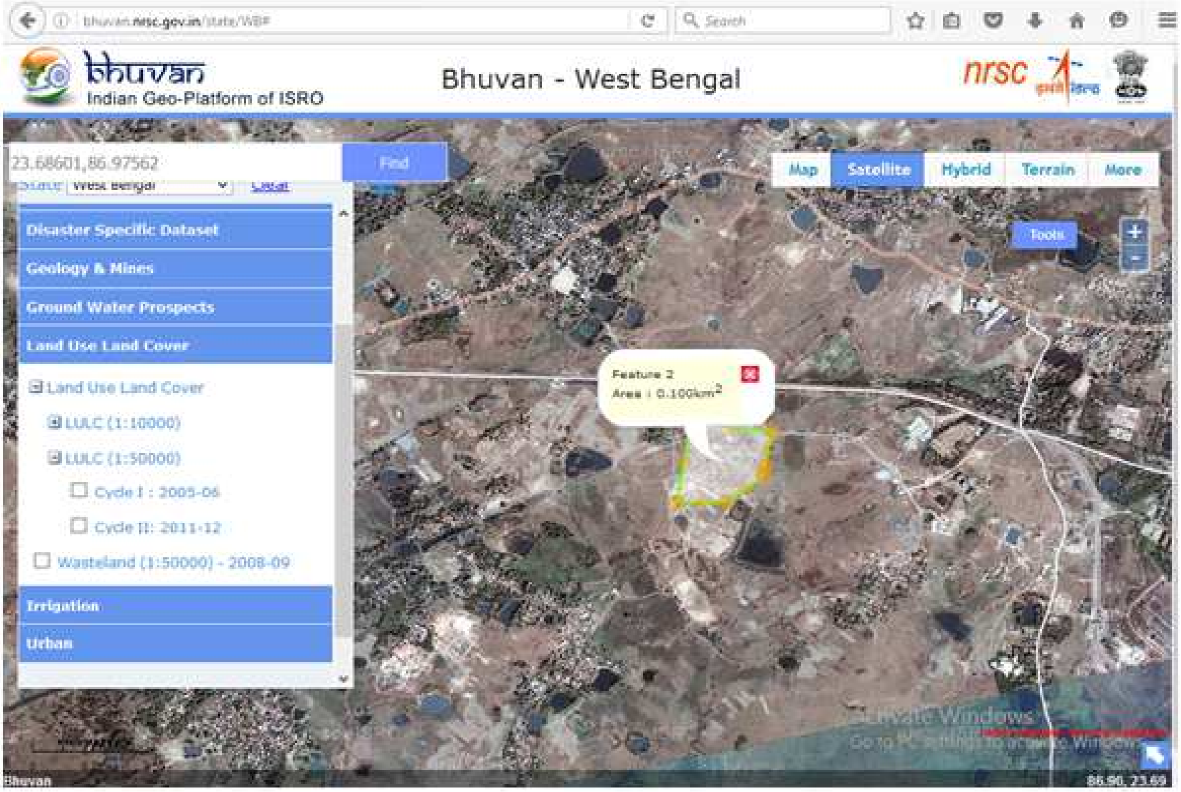

Figure 24: Area Calculation of Landfill Site 1

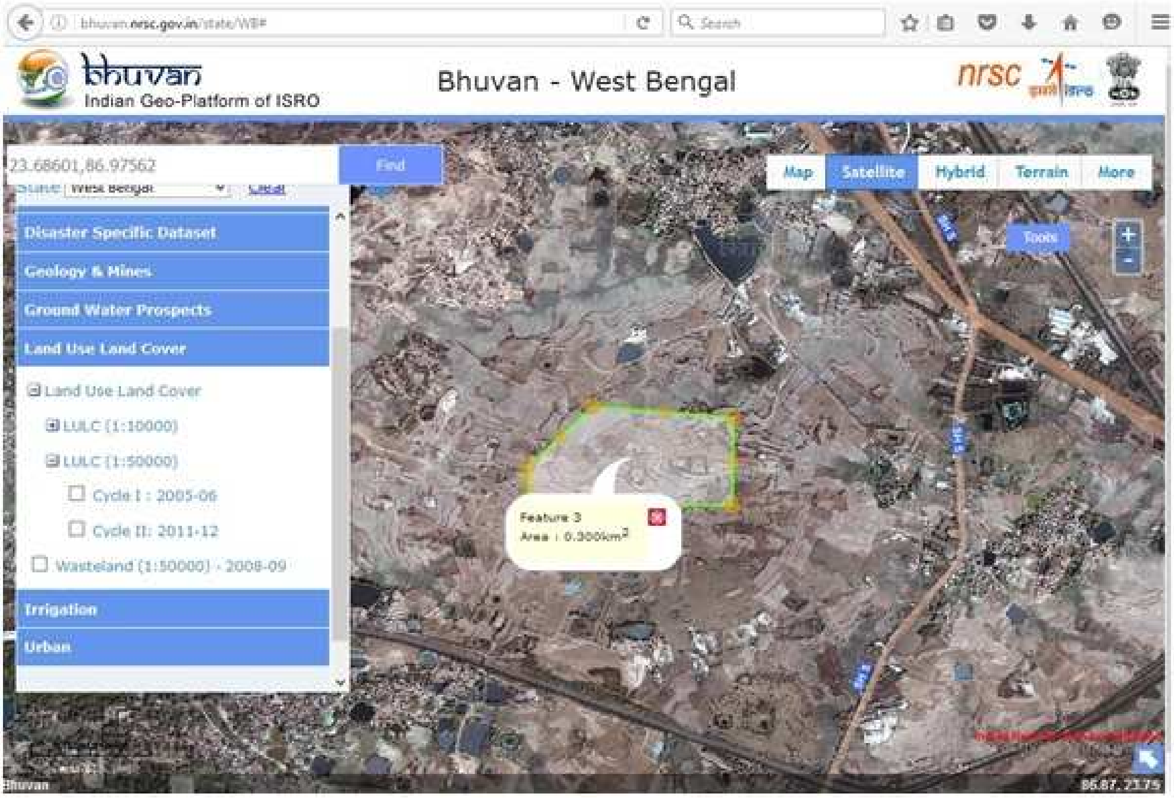

Figure 25: Area Calculation of Landfill Site 2

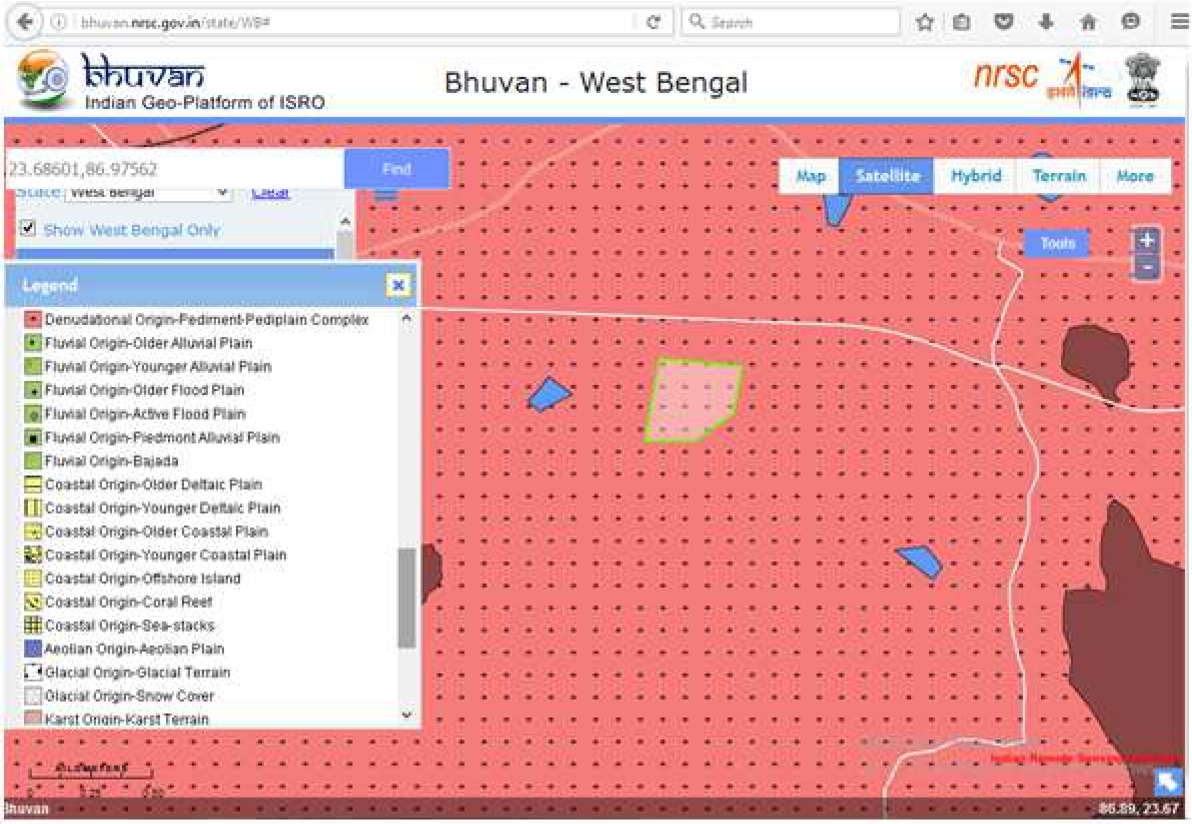

Figure 26: Geomorphology around Landfill Site 1

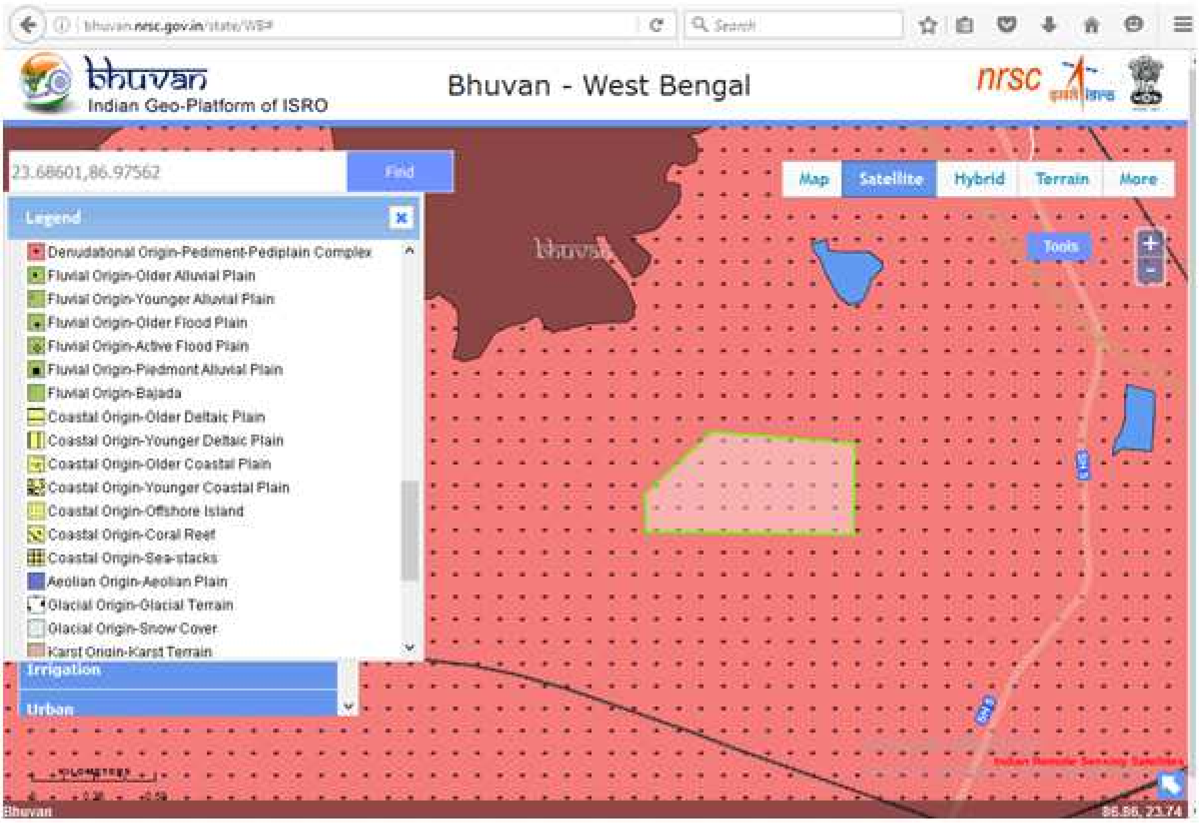

Figure 27: Geomorphology around Landfill Site 2

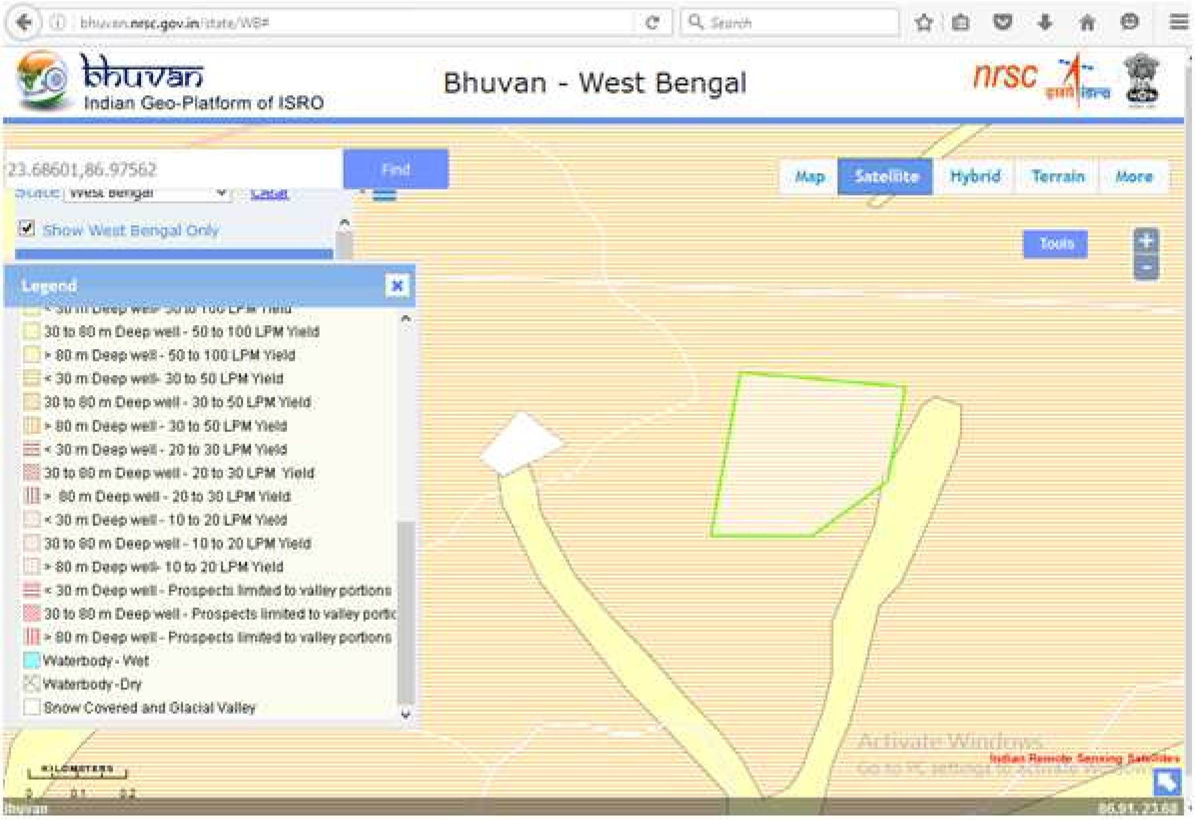

Figure 28: Ground Water Prospects around Landfill Site 1

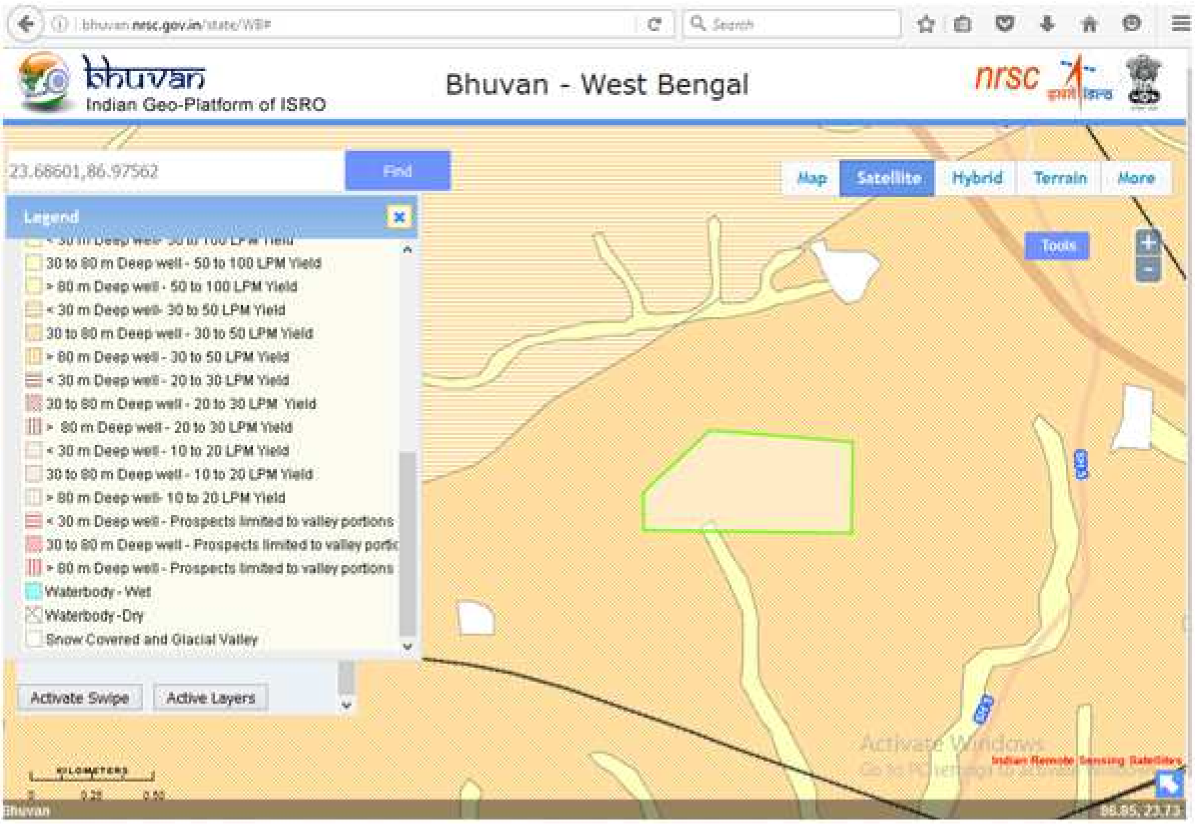

Figure 29: Ground Water Prospects around Landfill Site 2

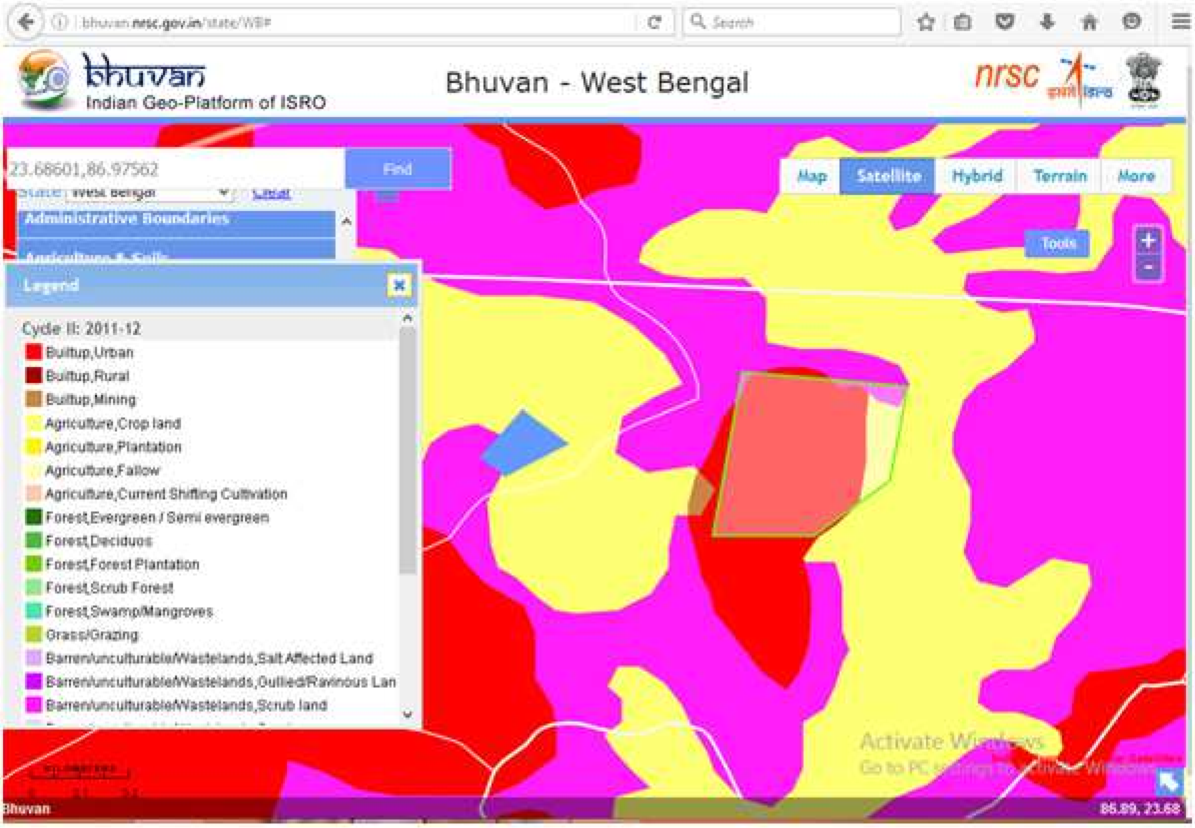

Figure 30: Land Use and Land Cover around Site 1

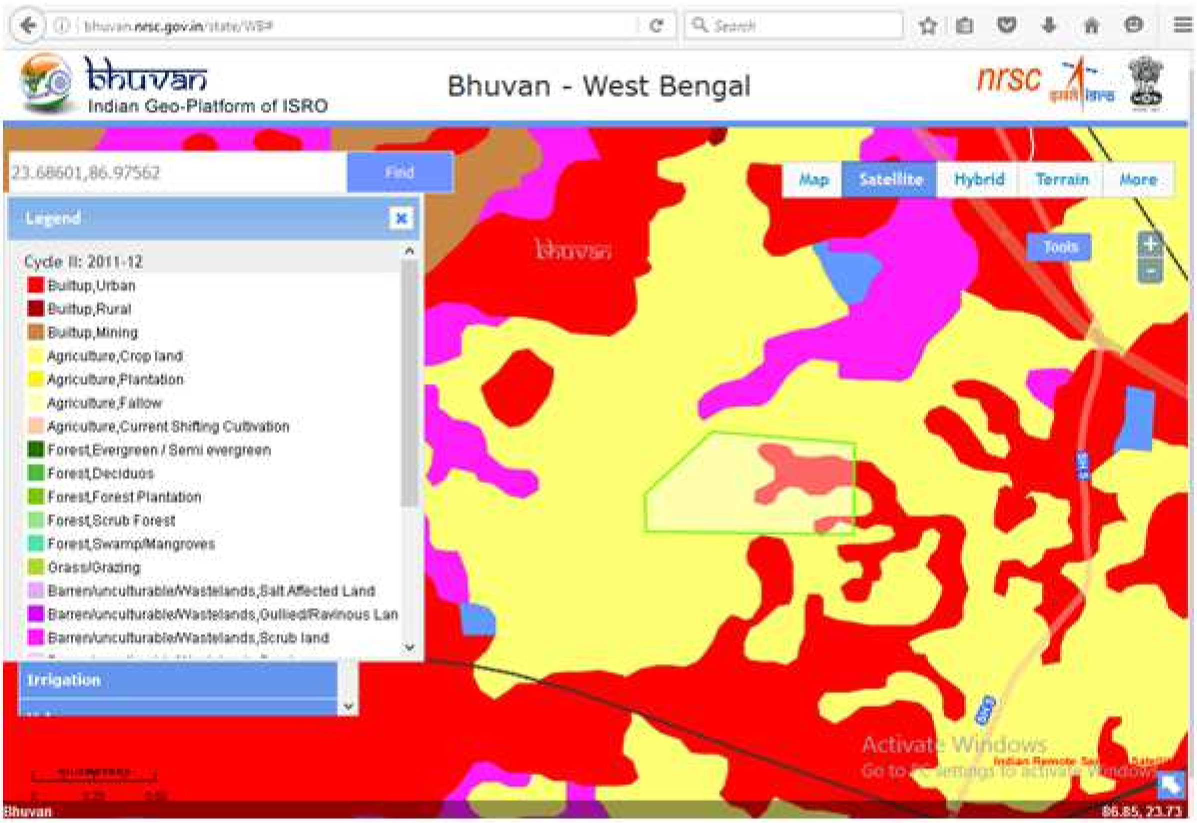

Figure 31: Land Use and Land Cover around Site 2

3.6. Model Development

A fuzzy based model was developed to integrate various attributes with respect to each available alternative site for landfilling operation. After identifying the attributes and possible landfill sites, the weightages and sensitivity index of each attributes were calculated based on expert opinions. All the attributes were assigned linguistic term and were expressed as triangular membership function. The formulation of the proposed model in presented schematically in Figure 32.

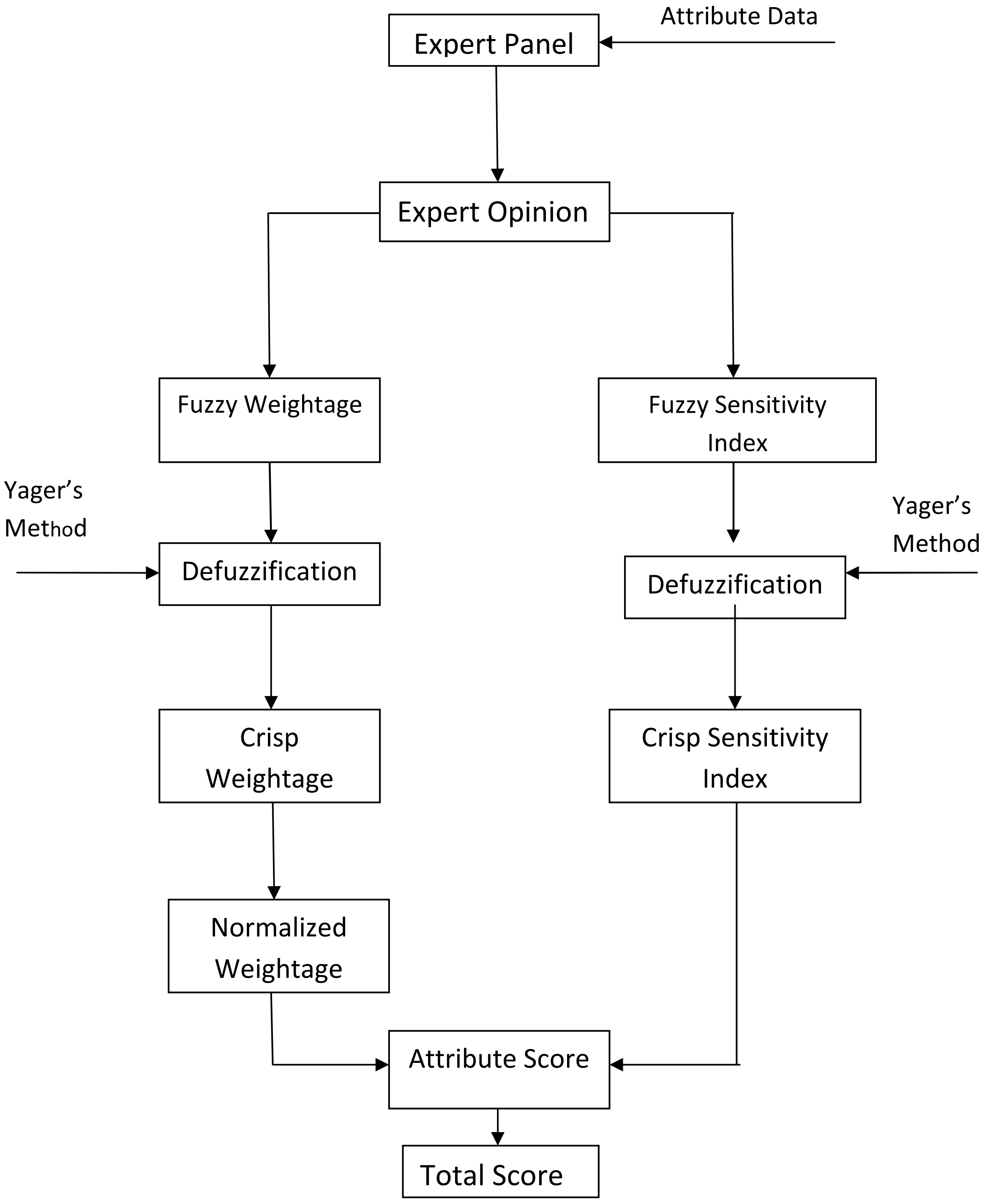

Figure 32: Flow chart of Proposed Model

3.6.1. Fuzzification

Weightage and sensitivity index of each attribute have been defined in the form of triangular membership functions (a, μ(a)), (b, μ(b)), (c, μ(c)) as shown figure 33, where μ(x) is the membership value for any input variable x.

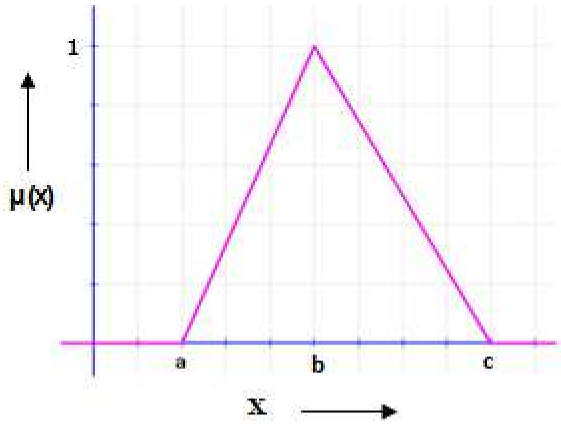

Figure 33: Triangular membership function

The membership functions for the triangular fuzzy numbers were calculated based on the equations7

$$\mu(x) = \begin{cases} 0, & for\ x < a \\ \frac{x-a}{b-a} & for\ a \le x \le b \\ \frac{c-x}{c-b} & for\ b \le x \le c \\ 0, & for\ x > c \end{cases} \quad \dots\dots\dots\dots\dots\dots (7)$$

Table 53 and 54 present the triangular fuzzy numbers and corresponding membership functions for weightage and sensitivity index respectively. For weightage calculations, each attributes were divided into seven groups while for sensitivity index calculation each attributes were divided into five groups. The fuzzy values and corresponding membership functions for the attributes for calculating weightages and sensitivity index were assigned intuitionally based on the related works obtained in published literatures. Figure 34 and Figure 35 presents the triangular membership functions of weightage and sensitivity index respectively for each attribute.

Table 53: Membership Functions for Weightages

Linguistic descriptions of the attributes	Fuzzy values and Corresponding Membership functions for Weightages
Very Very Low (VVL)	(0,0) (0.05,1) (0.1,0)
Very Low (VL)	(0.05,0) (0.1,1) (0.3.0)
Low (L)	(0.1,0) (0.3,1) (0.5,0)
Medium (M)	(0.3,0) (0.5,1) (0.7,0)
High (H)	(0.5,0) (0.7,1) (0.9,0)
Very High (VH)	(0.7,0) (0.9,1) (0.95,0)
Very Very High (VVH)	(0.9,0) (0.95,1) (1,0)

Table 54: Membership Functions for Sensitivity Index

Linguistic descriptions of the attributes	Fuzzy values and corresponding Membership functions for Sensitivity index
Very Good (VG)	(0,0) (0.1,1) (0.3.0)
Good (G)	(0.1,0) (0.3,1) (0.5,0)
Fair (F)	(0.3,0) (0.5,1) (0.7,0)
Poor (P)	(0.5,0) (0.7,1) (0.9,0)
Very Poor (VP)	(0.7,0) (0.9,1) (1,0)

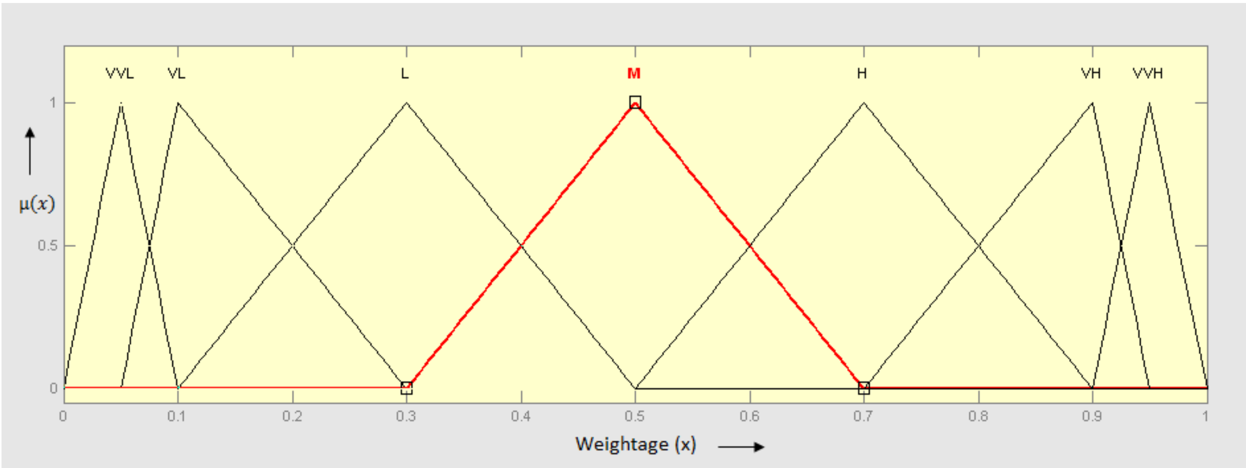

Figure 34: Different membership functions for weightage

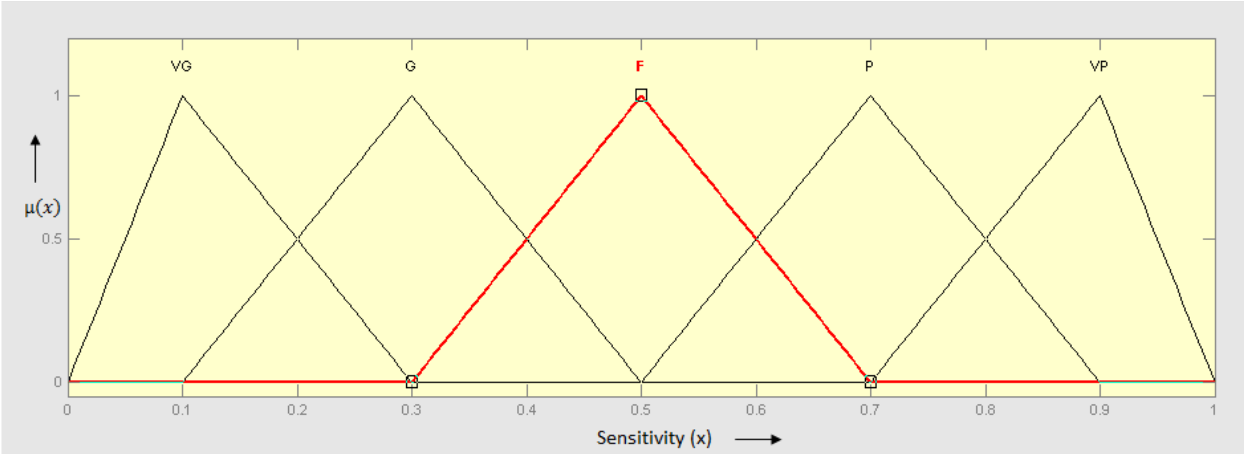

Figure 35: Different membership functions for sensitivity index

3.6.2. Collection of Expert Opinion

A questionnaire was prepared to collect data regarding expert opinion for each attributes and alternative sites regarding their weightages and sensitivity index. The attributes were expressed linguistically to the experts. A sample questionnaire is presented in Appendix 1

A group of four experts (E_1, E_2, E_3, E_4) were decided based on their experiences and expertise in the relevant fields. Expert opinions corresponding to importance of each attributes and sensitivity of each attribute of each alternative site were collected by face to face questionnaire survey. To make data more reliable Delphi Method were adopted.

$$Let\ A_i(i = 1,2, \dots \dots \dots m)\ represents\ the\ i^{th}\ attribute$$
$$E_j(j = 1,2,3,4 \dots, n) represents\ the\ j^{th}\ expert$$

3.6.3. Weightage Calculation

Let w_i^j represents the individual weightage assigned for i^{th} attribute by j^{th} expert
$\widetilde{w}_i$ represent net weightage for i^{th} attribute
$\widetilde{w}_i$ is in the form triangle written as $\widetilde{w}_i = (a, b, c)$
Where a, b and c are calculated using following formulae

$$\widetilde{w}_i = \frac{\sum_{j=1}^{n} w_i^j}{n} \dots \dots \dots \dots \dots \dots (8)$$

Example:

For example, for the attribute related to health, the opinions by different experts are H, VH, H and H, which corresponds to triangular fuzzy membership values of importance as (0.5,0.7,0.9),(0.7,0.9,0.95),(0.5,0.7,0.9) and (0.5,0.7,0.9) respectively. Therefore the net fuzzy weight can be calculated as

$$\widetilde{w}_i = \frac{\sum_{j=1}^{4} w_i^j}{4}$$

$$\widetilde{w}_i = \frac{w_i^1 + w_i^2 + w_i^3 + w_i^4}{4}$$

$$\widetilde{w}_{18} = \frac{0.5+0.7+0.5+0.5}{4}, \frac{0.7+0.9+0.7+0.7}{4}, \frac{0.9+0.95+0.9+0.9}{4}$$
$$\widetilde{w}_{18} = 0.55, 0.75, 0.9125$$

3.6.4. Defuzzification of Weightage

After getting the weightages in the form of triangular fuzzy numbers, deffuzification was done to get the corresponding crisp value using Yager's unit Interval method as per the equation 9.

$$\text{Crisp weightage, } \overline{\overline{w}}_i = \int_0^1 \frac{{a_\alpha}^L + {a_\alpha}^U}{2} d\alpha \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where,

$${a_\alpha}^L = (b-a)\alpha + a$$
$${a_\alpha}^U = c - (c-b)\alpha$$

Example:

For the weight calculation for the attribute health, defuzzified value is

$$\overline{\overline{w}}_{18} = \int_0^1 \frac{(.2\alpha + .55) + (.9125 - .1625\alpha)}{2} d\alpha$$
$$i.e.\ \overline{\overline{w}}_{18} = 0.740625$$

3.6.5. Normalization of Weightage

After getting the crisp weights corresponding to each attributes, normalization is done to convert the crisp weightage with respect to 1000 so as to compare with the results of ***CPCB (2003)***.

Normalization of crisp weightage is done using following formulae

$$W_i = \frac{\overline{\overline{w}}_i}{\sum_{i=1}^{m} \overline{\overline{w}}_i} \times 1000 \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Example:

$$W_i = \frac{\overline{\overline{w}}_i}{\sum_{i=1}^{32} \overline{\overline{w}}_i} \times 1000$$

$$W_{18} = \frac{0.74065}{18.225} \times 1000$$
$$Gives, W_{18} = 40.6379$$

3.6.6. Sensitivity Index Calculation

s_{ki}^{j} represents the individual sensitivity as triangles assigned for i^{th} attribute of k^{th}alternative by j^{th}site expert

$\tilde{s}_i$ represent net sensitivity for i^{th} attribute

$\tilde{s}_i$ is in the form of triangle written as $\widetilde{w}_i = (a, b, c)$

Where a, b and c are calculated using following formulae

$$\tilde{s}_{ki} = \frac{\sum_{j=1}^{n} s_{ki}^{j}}{n} \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

i.e.

$$\tilde{s}_{ki} = \frac{\sum_{j=1}^{4} s_{ki}^{j}}{4}$$

$$\Rightarrow \tilde{s}_{ki} = \frac{s_{ki}^{1} + s_{ki}^{2} + s_{ki}^{3} + s_{ki}^{4}}{4}$$

For example, for a particular alternative site for the attribute health, if the opinion by four experts are F, G, F and P respectively while their corresponding triangular fuzzy values are (0.3,0.5,0.7),(0.1,0.3,0.5),(0.3,0.5,0.7and) and (0.5,0.7,0.9) respectively. Therefore, the net fuzzy sensitivity index can be calculated as below

$$\tilde{s}_{118} = \frac{0.3 + 0.1 + 0.3 + 0.5}{4}, \frac{0.5 + 0.3 + 0.5 + 0.7}{4}, \frac{0.7 + 0.5 + 0.7 + 0.9}{4}$$

$$\tilde{s}_{118} = 0.3,0.5,0.7$$

3.6.7. Defuzzification of Sensitivity Index

After obtaining the triangular fuzzy values of sensitivity related to each attributes, Defuzzification was done using Yager's unit Interval method as per the equation 12.

$$\text{Crisp weightage}, \bar{\bar{s}}_{ki} = \int_0^1 \frac{a_\alpha{}^L + a_\alpha{}^U}{2} d\alpha \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Where,

$$a_\alpha{}^L = (b - a)\alpha + a$$
$$a_\alpha{}^L = c - (c - b)\alpha$$

Example:

For the attribute health of alternative 1,

,

$$\bar{\bar{s}}_{118} = \int_0^1 \frac{(.2\alpha + .3) + (.7 - .2\alpha)}{2} d\alpha$$
$$\bar{\bar{s}}_{118} = 0.5$$

3.6.8. Attribute Score Calculation

Attribute score (AS) is calculated using equation 13

$$AS_{ki} = W_i \times \bar{\bar{s}}_{ki} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (13)$$

Example:

For the attribute health related to the alternative 1,

$$AS_{118} = W_{18} \times \bar{\bar{s}}_{118}$$
$$AS_{118} = 40.6379 \times 0.5$$

$$AS_{118} = 20.31893$$

3.6.9. Total Score Calculation

The weighted linear sum aggregated function was used to calculate total score for a particular site by using equation 14

$$Total\ score\ for\ a\ particular\ site = \sum_{i}^{n} W_i \bar{\bar{\boldsymbol{s}}}_{\boldsymbol{ki}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (14)$$

Where W_i is the weight of the particular attribute and $\bar{\bar{\boldsymbol{s}}}_{\boldsymbol{ki}}$ is the sensitivity of the particular attribute for the corresponding alternative site.

Table 55 presents the decision criteria for landfill site selection based on total score obtained by equation 14.

Table 55: Decision Criteria for landfill site selection

Total Score	Site Description
<300	Less sensitive to the impacts (Preferable)
300 to 750	Moderate
>750	Highly sensitive to the impacts (Undesirable)

Source: ***CPCB (2003)***

4. Results and Discussions

The expert opinion obtained for weightage calculation for each attribute is presented in Table 56.

Table 56: Linguistic Weightage of Each Attribute

Sl NO.	Attribute	E_1	E_2	E_3	E_4
1	Type of road	M	M	M	M
2	Distance from collection area	H	VH	H	VH
3	Population within 500 meters	VH	VH	VH	VH
4	Distance to nearest drinking water source	VH	VH	VH	VH
5	Use of the site by nearby residents	M	L	M	M
6	Distance to nearest building	VL	L	L	L
7	Land use/ Zoning	H	M	H	H
8	Decrease in property value wrt distance	VL	L	L	L
9	Public utility facility within 2 km	M	L	M	M
10	Public acceptability	H	VH	VH	VH
11	Critical environments	VH	VH	H	VH
12	Distance to nearest surface water	VH	VH	VH	VH
13	Depth of ground water	VH	VH	VH	VH
14	Contamination	H	H	H	H
15	Water quality	H	VH	H	H
16	Air quality	H	H	H	H
17	Soil quality	M	H	M	H
18	Health	H	VH	H	H
19	Job opportunities	VL	L	L	VL
20	Odour	M	M	H	M
21	Vision	M	M	L	L
22	Waste quantity/day	VH	VH	H	H
23	Life of site	VH	H	H	H
24	Precipitation effectiveness index	M	M	M	M
25	Climatic features contributing to air pollution	L	L	L	L
26	Soil permeability	H	H	H	H

Sl NO.	Attribute	E_1	E_2	E_3	E_4
27	Depth to bedrock	L	L	M	L
28	Susceptibility to erosion and run off	L	L	L	L
29	Physical characteristic of rock	L	L	L	L
30	Depth of soil layer	H	M	M	M
31	Slope pattern	L	VL	L	L
32	Seismicity	L	L	L	M

The weightages are calculated from the triangle values by applying the formulae presented in equation 8. After getting the fuzzy weightage the crisp weights are calculated applying Yager's Defuzzification method using equation 9. All the weightages are normalized by using equation 10. Weightage of each attribute, their normalized weightage and CPCB weights of each attribute along with % relative error are presented in Table 57.

Table 57: Crisp and Normalized Weightage of Each Attribute

Sl No	Attribute	Fuzzy Weights			Crisp Weightage	Normalized Weightage	CPCB Weightage	% Relative Error
		a	b	c				
1	Type of Road	0.300	0.500	0.700	0.500	27	25	10
2	Distance from collection area	0.600	0.800	0.925	0.781	43	35	22
3	Population within 500 meters	0.700	0.900	0.950	0.863	47	50	-5
4	Distance to nearest drinking water source	0.700	0.900	0.950	0.863	47	55	-14
5	Use of the site by nearby residents	0.250	0.450	0.650	0.450	25	25	-1
6	Distance to nearest building	0.088	0.250	0.450	0.259	14	15	-5
7	Land use/ Zoning	0.450	0.650	0.850	0.650	36	35	2
8	Decrease in property value wrt distance	0.088	0.250	0.450	0.259	14	15	-5
9	Public utility facility within 2 km	0.250	0.450	0.650	0.450	25	25	-1
10	Public acceptability	0.650	0.850	0.938	0.822	45	30	50
11	Critical environments	0.650	0.850	0.938	0.822	45	45	0
12	Distance to nearest surface water	0.700	0.900	0.950	0.863	47	55	-14

13	Depth of ground water	0.700	0.900	0.950	0.863	47	65	-27
14	Contamination	0.500	0.700	0.900	0.700	38	35	10
15	Water quality	0.550	0.750	0.913	0.741	41	40	2
16	Air quality	0.500	0.700	0.900	0.700	38	35	10
17	Soil quality	0.400	0.600	0.800	0.600	33	30	10
18	Health	0.550	0.750	0.913	0.741	41	40	2
19	Job opportunities	0.075	0.200	0.400	0.219	12	20	-40
20	Odour	0.350	0.550	0.750	0.550	30	30	1
21	Vision	0.200	0.400	0.600	0.400	22	20	10
22	Waste quantity/day	0.600	0.800	0.925	0.781	43	45	-5
23	Life of site	0.550	0.750	0.913	0.741	41	40	2
24	Precipitation effectiveness index	0.300	0.500	0.700	0.500	27	25	10
25	Climatic features contributing to air pollution	0.100	0.300	0.500	0.300	16	15	10
26	Soil permeability	0.500	0.700	0.900	0.700	38	35	10
27	Depth to bedrock	0.150	0.350	0.550	0.350	19	20	-4
28	Susceptibility to erosion and run off	0.100	0.300	0.500	0.300	16	15	10
29	Physical characteristic of rock	0.100	0.300	0.500	0.300	16	15	10
30	Depth of soil layer	0.350	0.550	0.750	0.550	30	30	1
31	Slope pattern	0.088	0.250	0.450	0.259	14	15	-5
32	Seismicity	0.150	0.350	0.550	0.350	19	20	-4

From Table 57 it is clear that the weights for different attributes obtained from the proposed model and weights obtained from ***CPCB (2003)*** proposed Site Sensitivity Index (SSI) method are more or less same except for the attributes:

- Distance from collection area (weightage from this work is 43 which is more than the ***CPCB (2003)*** value of 35, probable reason can be the more importance of economic consideration in Indian conditions.)
- Distance to nearest drinking water source (weightage form this work is 47 which is much less than ***CPCB (2003)*** value of 55, probable reason may be the usage of liner in engineered landfill which blocks the leachate from contaminating drinking water

source and the disposal of only inert solid waste in the landfill site which generates very less leachate.)

- Public acceptability (weightage from this work is 45 which is much more than ***CPCB (Feb 2003)*** value of 30, probable reason can be due to the strong opposition of local people for landfill site due to their bad experiences and knowledge of unscientific dumping sites conditions which prevail throughout the country.)
- Distance to nearest surface water (weightage from this work is 47 which is much less than ***CPCB (Feb 2003)*** value of 55, probable reason may be same as explained for the attribute "Distance to nearest drinking water source")
- Depth of ground water (weightage for from this work is 47 which is much less than ***CPCB (2003)*** value of 65, probable reason may be same as explained for the attribute "Distance to nearest drinking water source")
- Job opportunities (weightage from this work is 12 which is much less than ***CPCB (2003)*** value of 20, probable reason may be due to the less quantity and quality (unskilled) of job creation people are less interested in this factor and this attribute has still lesser significance in Indian conditions)

In SSI method proposed by ***CPCB (2003)***, the weights were assigned by the experts by pairwise comparison method. The distance from collection area, from nearest drinking water source, nearest surface water, and depth of ground water are quantitative attributes while public acceptability and job opportunities are qualitative attributes. SSI technique may tend to be less effective in dealing with the imprecise or vague nature of the linguistic attributes and at the same time not deal with human reasoning for both qualitative and quantitative attributes as mentioned above. Therefore, a great variation may be observed in the weights of the mostly popular used attributes. In the proposed method, the attributes were presented to the experts as ordered linguistic terms, the meaning of each term is given by a fuzzy set defined on the variable domain is more close to human reasoning. Since in this method, an expert is judging one attribute at a time therefore, the proposed method is flexible enough so that some partial conclusion can be made. At the same time, it is clear that experts gave more weights to the attributes distance from collection area and public acceptability. That means experts were concerned not only about environmental sustainability of the sites but they gave more importance to economic viability and social acceptability of the sites.

To validate the proposed model the sensitivity are calculated considering ***CPCB (2003)*** mentioned sites Data related to each attribute mentioned by ***CPCB (2003)*** are provided to the experts to obtain their opinion related to sensitivity of each attribute of each alternative site and are presented in Table 58

The crisp value obtained for the sensitivity is presented in the Table 58

Site sensitivity Index calculated for the two mentioned sites by CPCB are provided in the Table 59.

Table 58: Crisp Sensitivity Index of Attributes

Sl No.	Attribute	Site 1 (Kannahalli)					Site 2 (Seegehalli)				
		E_1	E_2	E_3	E_4	Crisp Sensitivity Index	E_1	E_2	E_3	E_4	Crisp Sensitivity Index
1	Type of Road	F	VP	G	P	0.594	G	F	VG	F	0.356
2	Distance from collection area	VG	P	F	F	0.456	VG	P	F	F	0.456
3	Population within 500 meters	G	G	F	G	0.350	G	G	F	G	0.350
4	Distance to nearest drinking water source	P	VP	F	P	0.694	G	G	G	VG	0.256
5	Use of the site by nearby residents	VG	VG	VG	VG	0.125	VG	VG	VG	VG	0.125
6	Distance to nearest building	P	P	F	P	0.650	F	VG	G	VG	0.263
7	Land use/ Zoning	VG	VG	VG	VG	0.125	VG	VG	VG	VG	0.125
8	Decrease in property value wrt distance	VG	VG	VG	VG	0.125	G	F	G	F	0.400
9	Public utility facility within 2 km	VG	VG	VG	VG	0.125	VG	VG	VG	VG	0.125
10	Public acceptability	G	VG	F	G	0.306	G	VG	F	G	0.306
11	Critical environments	VG	VG	VG	G	0.169	VG	VG	VG	G	0.169
12	Distance to nearest surface water	G	G	F	VG	0.306	VG	VG	G	VG	0.169
13	Depth of ground water	F	VP	F	G	0.544	VG	P	VG	VG	0.269
14	Contamination	VP	VP	VP	P	0.831	VP	VP	VP	P	0.831
15	Water quality	P	F	G	P	0.550	P	F	F	P	0.600
16	Air quality	P	P	P	VP	0.744	P	P	P	VP	0.744

Sl No.	Attribute	Site 1 (Kannahalli)					Site 2 (Seegehalli)				
		E_1	E_2	E_3	E_4	Crisp Sensitivity Index	E_1	E_2	E_3	E_4	Crisp Sensitivity Index
17	Soil quality	F	F	F	G	0.450	G	F	G	G	0.350
18	Health	F	F	P	P	0.600	G	VG	F	G	0.306
19	Job opportunities	VP	P	F	VP	0.738	VP	P	F	VP	0.738
20	Odour	F	G	G	F	0.400	F	G	G	F	0.400
21	Vision	F	G	F	P	0.500	VG	VG	VG	G	0.169
22	Waste quantity/day	F	G	G	F	0.400	F	G	G	F	0.400
23	Life of site	P	P	P	P	0.700	VP	VP	VP	VP	0.875
24	Precipitation effectiveness index	F	G	F	F	0.450	F	G	F	F	0.450
25	Climatic features contributing to air pollution	G	G	G	G	0.300	G	G	G	G	0.300
26	Soil permeability	P	P	F	G	0.550	P	P	F	G	0.550
27	Depth to bedrock	G	F	VG	G	0.306	G	P	G	G	0.400
28	Susceptibility to erosion and run off	G	G	VG	G	0.256	P	P	G	P	0.600
29	Physical characteristic of rock	P	F	G	G	0.450	P	F	G	G	0.450
30	Depth of soil layer	P	F	F	F	0.550	F	G	G	F	0.400
31	Slope pattern	G	G	G	G	0.300	P	P	F	P	0.650
32	Seismicity	VG	VG	VG	G	0.169	VG	VG	VG	G	0.169

Table 59: Obtained Attribute Score and CBCB (2003) Attribute Score

Sl No.	Attribute	Normalized weightage	Site 1 (Kannahalli)			Site 2 (Seegehalli)		
			Crisp Sensitivity Index	Attribute Score (AS)	Attribute Score from CPCB	Crisp Sensitivity Index	Attribute Score (AS)	Attribute Score from CPCB
1	Type of Road	27	0.594	16.289	8.75	0.356	9.774	8.75
2	Distance from collection area	43	0.456	19.558	26.25	0.456	19.558	21
3	Population within 500 meters	47	0.350	16.564	12.5	0.350	16.564	12.5
4	Distance to nearest drinking water source	47	0.694	32.832	55	0.256	12.127	44
5	Use of the site by nearby residents	25	0.125	3.086	0	0.125	3.086	0
6	Distance to nearest building	14	0.650	9.251	15	0.263	3.736	11.25
7	Land use/ Zoning	36	0.125	4.458	0	0.125	4.458	0
8	Decrease in property value wrt distance	14	0.125	1.779	0	0.400	5.693	3.75
9	Public utility facility within 2 km	25	0.125	3.086	0	0.125	3.086	0
10	Public acceptability	45	0.306	13.811	4.5	0.306	13.811	4.5
11	Critical environments	45	0.169	7.610	6.75	0.169	7.610	6.75
12	Distance to nearest surface water	47	0.306	14.493	27.5	0.169	7.986	16.5
13	Depth of ground water	47	0.544	25.733	48.75	0.269	12.719	16.25
14	Contamination	38	0.831	31.927	35	0.831	31.927	35
15	Water quality	41	0.550	22.351	30	0.600	24.383	30

16	Air quality	38	0.744	28.567	35	0.744	28.567	35
17	Soil quality	33	0.450	14.815	22.5	0.350	11.523	22.5
18	Health	41	0.600	24.383	10	0.306	12.445	6
19	Job opportunities	12	0.738	8.852	10	0.738	8.852	10
20	Odour	30	0.400	12.071	10.5	0.400	12.071	10.5
21	Vision	22	0.500	10.974	6	0.169	3.704	0
22	Waste quantity/day	43	0.400	17.147	27	0.400	17.147	27
23	Life of site	41	0.700	28.447	32	0.875	35.558	40
24	Precipitation effectiveness index	27	0.450	12.346	12.5	0.450	12.346	12.5
25	Climatic features contributing to air pollution	16	0.300	4.938	0	0.300	4.938	0
26	Soil permeability	38	0.550	21.125	17.5	0.550	21.125	17.5
27	Depth to bedrock	19	0.306	5.881	6	0.400	7.682	12
28	Susceptibility to erosion and run off	16	0.256	4.218	0	0.600	9.877	11.25
29	Physical characteristic of rock	16	0.450	7.407	4.5	0.450	7.407	11.25
30	Depth of soil layer	30	0.550	16.598	22.5	0.400	12.071	22.5
31	Slope pattern	14	0.300	4.270	3.75	0.650	9.251	15
32	Seismicity	19	0.169	3.241	0	0.169	3.241	0
Total Score (TS)				**448.107**	**489.75**		**394.321**	**463.25**

5. Model Evaluation

Model evaluation is done by finding the relative percentage error of weightage considering ***CPCB (2003)*** value to be base value, which is presented in Table 57. Almost all the obtained weightage values are close to CPCB ***(2003)*** weightages. In all for 26 attributes relative percentage error is less than equal to 10%. Major deviation are seen for 6 attributes where for 2 attributes (distance from the collection area and public acceptability) values are more and for 4 attributes (distance to nearest drinking water source, distance to nearest surface water, depth of ground water and job opportunities) values are less than that on CPCB results.

6. Application of the Model to Identify Suitable landfill Site in AMC

The data related to attribute corresponding to the proposed sites are already presented in Table 52. These data were presented to the experts to obtain the sensitivity related to each data.

The calculated sensitivity index of the attributes related to each alternative sites proposed for AMC calculated by using equations 11 and 12 are presented in Table 60.

From the Table 61 it is clear that the TS for site 1 is 427.734 and site 2 is 400.054. Therefore site 2 is less sensitive than site 1 and is the best suitable site for AMC. As per ***CPCB (2003)*** classification, the site is moderately suitable site for landfilling operation.

Table 60: Crisp Sensitivity Index of Attributes

Sl No.	Attribute	Site 1					Site 2				
		E_1	E_2	E_3	E_4	Crisp Sensitivity Index	E_1	E_2	E_3	E_4	Crisp Sensitivity Index
1	Type of Road	G	G	VG	VP	0.400	G	G	VG	G	0.256
2	Distance from collection area	VG	VG	VG	VG	0.125	VG	G	VG	F	0.263
3	Population within 500 meters	G	G	F	G	0.350	G	G	F	G	0.350
4	Distance to nearest drinking water source	G	G	G	G	0.300	G	G	G	G	0.300
5	Use of the site by nearby residents	VG	VG	VG	VG	0.125	F	F	VG	F	0.406
6	Distance to nearest building	F	G	G	F	0.400	VP	P	F	P	0.694
7	Land use/ Zoning	G	G	G	G	0.300	G	G	G	G	0.300
8	Decrease in property value wrt distance	VG	VG	VG	G	0.169	VG	VG	VG	G	0.169
9	Public utility facility within 2 km	F	F	P	G	0.500	F	F	P	G	0.500
10	Public acceptability	VP	VP	VP	VP	0.875	G	G	VG	G	0.256
11	Critical environments	VG	VG	VG	G	0.169	VG	VG	VG	G	0.169
12	Distance to nearest surface water	P	F	P	G	0.550	P	F	P	G	0.550
13	Depth of ground water	VP	VP	VP	VP	0.875	VP	VP	VP	VP	0.875
14	Contamination	F	G	G	G	0.350	F	G	G	G	0.350
15	Water quality	P	F	F	P	0.600	P	F	F	P	0.600
16	Air quality	VG	VG	VG	G	0.169	VG	VG	VG	G	0.169

Sl No.	Attribute	Site 1					Site 2				
		E_1	E_2	E_3	E_4	Crisp Sensitivity Index	E_1	E_2	E_3	E_4	Crisp Sensitivity Index
17	Soil quality	G	G	G	G	0.300	G	G	G	G	0.300
18	Health	G	VG	F	G	0.306	G	VG	F	G	0.306
19	Job opportunities	VP	P	F	F	0.644	VP	P	F	F	0.644
20	Odour	F	VG	VG	G	0.263	F	VG	VG	G	0.263
21	Vision	P	P	P	F	0.650	F	G	F	G	0.400
22	Waste quantity/day	VG	VG	VG	G	0.169	VG	VG	VG	G	0.169
23	Life of site	G	G	G	F	0.350	VG	VG	VG	G	0.169
24	Precipitation effectiveness index	F	G	F	G	0.400	F	G	F	G	0.400
25	Climatic features contributing to air pollution	VP	P	P	P	0.744	VP	P	P	P	0.744
26	Soil permeability	P	P	F	P	0.650	P	P	F	P	0.650
27	Depth to bedrock	F	VP	F	F	0.594	F	VP	F	F	0.594
28	Susceptibility to erosion and run off	P	P	G	F	0.550	P	P	G	F	0.550
29	Physical characteristic of rock	F	F	F	F	0.500	F	F	F	F	0.500
30	Depth of soil layer	P	F	F	F	0.550	P	F	F	F	0.550
31	Slope pattern	F	F	F	F	0.500	F	F	F	F	0.500
32	Seismicity	VP	P	P	F	0.694	VP	P	P	F	0.694

Table 61: Obtained Attribute Score of Alternative Sites in AMC Area

Sl No.	Attribute	Weightage	SITE 1		SITE 2	
			Crisp Sensitivity Index	Attribute Score	Crisp Sensitivity Index	Attribute Score
1	Type of Road	27	0.400	10.974	0.256	7.030
2	Distance from collection area	43	0.125	5.358	0.263	11.253
3	Population within 500 meters	47	0.350	16.564	0.350	16.564
4	Distance to nearest drinking water source	47	0.300	14.198	0.300	14.198
5	Use of the site by nearby residents	25	0.125	3.086	0.406	10.031
6	Distance to nearest building	14	0.400	5.693	0.694	9.873
7	Land use/ Zoning	36	0.300	10.700	0.300	10.700
8	Decrease in property value wrt distance	14	0.169	2.402	0.169	2.402
9	Public utility facility within 2 km	25	0.500	12.346	0.500	12.346
10	Public acceptability	45	0.875	39.459	0.256	11.556
11	Critical environments	45	0.169	7.610	0.169	7.610
12	Distance to nearest surface water	47	0.550	26.029	0.550	26.029
13	Depth of ground water	47	0.875	41.409	0.875	41.409
14	Contamination	38	0.350	13.443	0.350	13.443
15	Water quality	41	0.600	24.383	0.600	24.383
16	Air quality	38	0.169	6.481	0.169	6.481
17	Soil quality	33	0.300	9.877	0.300	9.877
18	Health	41	0.306	12.445	0.306	12.445

Sl No.	Attribute	Weightage	SITE 1		SITE 2	
			Crisp Sensitivity Index	Attribute Score	Crisp Sensitivity Index	Attribute Score
19	Job opportunities	12	0.644	7.727	0.644	7.727
20	Odour	30	0.263	7.922	0.263	7.922
21	Vision	22	0.650	14.266	0.400	8.779
22	Waste quantity/day	43	0.169	7.234	0.169	7.234
23	Life of site	41	0.350	14.223	0.169	6.858
24	Precipitation effectiveness index	27	0.400	10.974	0.400	10.974
25	Climatic features contributing to air pollution	16	0.744	12.243	0.744	12.243
26	Soil permeability	38	0.650	24.966	0.650	24.966
27	Depth to bedrock	19	0.594	11.403	0.594	11.403
28	Susceptibility to erosion and run off	16	0.550	9.053	0.550	9.053
29	Physical characteristic of rock	16	0.500	8.230	0.500	8.230
30	Depth of soil layer	30	0.550	16.598	0.550	16.598
31	Slope pattern	14	0.500	7.116	0.500	7.116
32	Seismicity	19	0.694	13.323	0.694	13.323
TS			**427.734**		**400.054**	

7. Conclusion

7.1. Conclusion

Landfill site selection is very important for developing country as there is scarcity of land nearby the urban areas from where majority of solid waste is generated. Selected landfill site must be economically viable, socially acceptable and environmentally sustainable. Several methods are already used for landfill site selection but those methods have limitations in their usage as it is a multicriterion decision making process and involves crisp as well as linguistic variables as input in decision making. Not well established relationship between attribute data and sensitivity index further adds degradation to the performance of those methods. Therefore in this study a fuzzy based model was developed to identify a suitable landfill site to incorporate uncertainty associated in specifying various attributes which are often imprecisely defined to the decision makers by the data handler. Sensitivity of the proposed model was validated by the data provided by ***CPCB (2003)*** and from the error analysis it was found that the model was good fit. The proposed model was also applied to select suitable landfill site for Asansol Municipal Corporation (AMC). Two sites were first selected based on the preliminary constraints like within 2 km from suitable main road, economical travel distance (30 km) from origin of waste and not a flood plain. Applying the proposed model, site 2 was found to be most suitable with total score 400.054 and falling under the category moderately sensitive as labelled by ***CPCB (2003)***.

Though context specific, but the proposed model can be easily used as a tool by planners and decision makers in the process of initial screening to select a suitable landfill site.

7.2. Future Scope of the Work

The present work can be extended to include the following modifications:-

- In the present work the data related to Solid Waste generation obtained from literature were used to calculate the projected SW generation to estimate the required landfill area for the design period. The generation rate was considered fixed. But in reality SW generation depends on time and socioeconomic criteria of generators. Therefore, the variation of SW generation with time and socioeconomic characteristics of generators may be considered during area calculations for landfilling.
- During opinion collection, only four experts were chosen mainly from academic institutions. Experts from different fields like waste manager, decision maker, political persons and common people can be included in the expert panel to get more generalized results.
- During model development all the attributes were assigned with triangular membership function based on intuition. Different membership function along with different fuzzification methods should be implemented and compared to determine the best fitted membership function.
- In the proposed method, only 32 attributes as proposed by ***CPCB (2003)*** in SSI method were used. But from the results, it was obtained that the selection was mainly

based on socio-economic attributes. Therefore, increasing or decreasing the number of attributes based on the local conditions may be done to make the model more flexible.

- A full economic viability study and including of direct attributes related to economy may give more insight into the expenditure which in developing countries like India are of much more important as the responsible authorities have limited funds.
- During model development a detailed behavioural study should be made so as to derive more accurate public view regarding the acceptability of landfill site, which was not done in this work due to time and resource constraints.

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Annexure 1

Sample questionnaire prepared to collect expert opinion

- For Weightage

Sl No.	Attribute	Weightage
1	Type of road	
2	Distance from collection area	
3	Population within 500 meters	
4	Distance to nearest drinking water source	
5	Use of the site by nearby residents	
6	Distance to nearest building	
7	Land use/ Zoning	
8	Decrease in property value wrt distance	
9	Public utility facility within 2 km	
10	Public acceptability	
11	Critical environments	
12	Distance to nearest surface water	
13	Depth of ground water	
14	Contamination	
15	Water quality	
16	Air quality	
17	Soil quality	
18	Health	
19	Job opportunities	
20	Odour	
21	Vision	
22	Waste quantity/day	
23	Life of site	
24	Precipitation effectiveness index	
25	Climatic features contributing to air pollution	
26	Soil permeability	
27	Depth to bedrock	
28	Susceptibility to erosion and run off	
29	Physical characteristic of rock	
30	Depth of soil layer	
31	Slope pattern	
32	Seismicity	

- For Sensitivity Index

Sl No.	Attribute	Site 1 (Kannahali)	Site 2 (Seegehalli)
1	Type of road		
2	Distance from collection area		
3	Population within 500 meters		
4	Distance to nearest drinking water source		
5	Use of the site by nearby residents		
6	Distance to nearest building		
7	Land use/ Zoning		
8	Decrease in property value wrt distance		
9	Public utility facility within 2 km		
10	Public acceptability		
11	Critical environments		
12	Distance to nearest surface water		
13	Depth of ground water		
14	Contamination		
15	Water quality		
16	Air quality		
17	Soil quality		
18	Health		
19	Job opportunities		
20	Odour		
21	Vision		
22	Waste quantity/day		
23	Life of site		
24	Precipitation effectiveness index		
25	Climatic features contributing to air pollution		
26	Soil permeability		
27	Depth to bedrock		
28	Susceptibility to erosion and run off		
29	Physical characteristic of rock		
30	Depth of soil layer		
31	Slope pattern		
32	Seismicity		

Sample questionnaire prepared to collect data for "public acceptability"

Person	Fully accepted	Acceptance with suggestions	Acceptance with major changes	Non acceptance
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				