Site Suitability Assessments for Waste Management Using GIS and Multi-criteria Analysis: Potentials of Waste to Energy and Urban Agriculture

May 2017

Afsana AKTHER

Site Suitability Assessments for Waste Management Using GIS and Multi-criteria Analysis: Potentials of Waste to Energy and Urban Agriculture

A Dissertation Submitted to
The Graduate School of Life and Environmental Sciences,
the University of Tsukuba
in Partial Fullfillment of the Requirements
for the Degree of Doctor of Philosophy in Agricultural Science
(Doctoral Program in Appropriate Technology & Sciences for Sustainable Development)

Afsana AKTHER

Acknowledgements

First and foremost, I would like to express my greatest gratitude to Allah, the Almighty who has given me the ability, health, and safety to finish this thesis completely and making my dream true.

This thesis would not have been completed without the help, support, guidance and efforts of many people. I wish to offer my gratitude and thanks to my academic advisor, Professor Tomohiro Takigawa for his suggestions, and inspiration at the University of Tsukuba.

I would like to express my sincere gratitude to my research supervisor Dr. Tofael Ahamed, Associate Professor, University of Tsukuba, for his guidance to complete this doctoral research. This thesis was impossible to complete without his cordial cooperation, suggestion and scholastic guidance. Thank you for the advice, support, and willingness that allowed me to pursue research on this topic for which I am truly passionate. You recognized me to work alone but also made sure to check and give the feedback so that I stayed on the right path continuously.

I wish to express my sincere gratitude to my research advisory member, Dr. Ryozo Noguchi, Associate Professor, University of Tsukuba for his valuable advice, comments, suggestion and continuous support for completion of this study. Thank you for keeping your door open and available for all the times when I needed it. I am very much grateful for your valuable academic guideline and conversations we have had during the course of study.

I would like to express my appreciation to the members of my thesis evaluation committee, Professor Tomohiro Takigawa, Dr. Tofael Ahamed, Dr. Ryozo Noguchi, and Dr. Takuma Gengawa for devoting time and efforts to evaluate the manuscript, and their helpful comments to improve the content continuously.

I would like to express my thanks to Dhaka North City Corporation, Capital Development Authority (RAJUK), Survey of Bangladesh (SoB), Dhaka Water Supply & Sewerage Authority (WASA) and all surveyors of my research and expert respondents from Government sectors, Private organization and local participants in the research area. It would be difficult for me to collect exact information and data of present waste management situation of my study area without their information.

I wish to express my thanks and gratitude's to all my lab mates who support me all the way during research periods, data analysis, and thesis preparation.

I would like to take this opportunity to dedicate all the success I have achieved in my life to my late parents and in-laws, their prayers are always with me. Finally, I would like to thank my family for their continuous encouragement and support to complete this research and submission of thesis.

Abstract

Solid waste management of urban areas becomes complex to solve. A practical macro and micro level geospatial solution is needed to solve this waste management problem in the fastest growing major cities around the world. Dhaka is one that city of Bangladesh having 16 million of population, expected to reach 20 million by 2020. Due to uncontrolled population, urbanization, industrialization and migration of people generates large amount of waste every day in the city area. Presently Dhaka city waste generation rate is 0.38 to o.40 (kg/cap/day) and total waste varied from 6000 to 7000 tons per day. It is expected that per capita waste generation rate would reach to 0.6 in 2025 and might lead severe problems of waste management. Dhaka city waste collection rate is very low due to lack of transportation to carry waste to landfills, landfill shortages and lack of bio digesters for zone wise waste management. Only 40-60% of Dhaka's waste is collected and transported to the City's two landfills. The rest amount of waste left on the waste generating sites and improper management is observed due to illegally dumped waste that causes serious environmental degradation and health hazards. At the same time, such practice emits methane (CH_4) and carbon-dioxide (CO_2). Considering the waste management problem of Dhaka North City, this research proposed a practical approach for reducing and handling solid waste generation, collection, separation and reduction at the macro and micro levels in a zone for alternate of landfills through proposing most suitable locations for sitting bio digesters and composting plants.

In this research, a GIS-based approach and multi-criteria analysis was performed to locate the most suitable sites for biogas plant installation and decentralized composting sites for reducing the zone wise unmanageable waste in a northern part of Dhaka city, specially organic waste, which was 80% of total waste. This research concentrated on site suitability analysis for installation of an anaerobic digester for waste management. Zone 2 in the northern part included 8 wards (Ward 2, 3, 4, 5, 6, 7, 8 and 15) were selected as study area for biogas plants site selection. To locate suitable sites, three sets of factors: environmental, social and safety, and economic perspectives, were considered using eleven criteria. Analysis for sitting a biogas digester plants provided some significant results of zone 2 which helped to locate the most suitable sites for plants installation. In the first step, the restriction or the constraint map were prepared and fixed the constraint sites for suitability analysis. Constraint areas were identified based on the importance to environment and government such as the national Zoo/Park, defense and industrial areas. These places were excluded from the site suitability analysis for sitting a digester plant. The rest of the areas were analyzed based on the 11 criteria's evaluation, such as, settelement or residence distance, sensitive site distance, river distance, major road distance, local road distane, agricultural land distance, slope, present land use, future urban growth, low land distance, land cost and electric pole distance. All the criteria's were considered from the research area discernment. Each criterion was evaluated using a pairwise comparison matrix. The criteria were reclassified in 5 levels (most suitable, suitable, moderately suitable, less suitable,

not suitable) using spatial analysis from ArcGIS®. The reclassified features were further analyzed using Weighted Linear combination (WLC) and Analytical Hierarchy Process (AHP). After produced the weight for each criterion obtained the next step was to produce criteria based suitable sites map. ArcGIS® spatial analysis tools were used for weighted overlayed-criteria based suitable sites map. The aggregation of excluded constraint sites and criteria based suitable sites specified the total area in five classes once again (most suitable, suitable, moderately suitable, less suitable and not suitable).

The research results indicated that 1 most suitable, 6 suitable and 3 moderately suitable sites could be used for a biogas digester plant in Zone 2 at the northern part of Dhaka City. Furthermore, the potential energy production was calculated based on per capita generated organic waste and population growth. The projected simulation results show the energy potential from 2015 to 2025 from methane (CH_4).

The proposed most suitable site at zone 2 have the potential to generate annually 26-40 MW of electricity from the generated waste. Therefore, the outcome of this research approach confirmed that the developed methodology of locating biogas digester could be implemented in the macro level of zones of the northern part of Dhaka City for handling municipal solid waste to convert energy. On the other hand, for composting plants site selection only one ward (poor waste management comparing to other wards) among 8 wards of Zone 2 were selected for this research.

Primary waste generating point, road network, sensitive location, illegal waste dumping points and waste segregation conditions were reported to select the composting location. Multi criteria analysis was applied for the identification of suitable composting points to initiate urban agriculture in the ward. A unified categorization approach for the reduction of domestic waste through the source separation and waste conversion techniques were followed to propose the optimal of waste collection bins. The spatial GIS mapping was done to locate the most uncollected points and poor roadworks, high sensitive points using standard exclusionary criteria. According to the set-up of exclusionary criteria, decision factors, standardization of factors and weighting of factors, using multi-criteria evaluation (MCE) for land suitability analysis, final suitability map was produced to identify suitable locations for composting plants.

The research results showed that 2 most suitable locations could be proposed for sitting composting plants in the ward 8 of zone 2 at the northern part of Dhaka city. This outcome revealed that the developed methodology could be used to locate most suitable points to identify composting locations for handling generated organic waste in the ward or micro levels of zones at the northern part of Dhaka City to increase urban agriculture.

This research has very significant results and proposed the practical solution to handle the large amount of generated waste in zone 2 by two ways. First, the macro level solution is to locate the

bio digester sitting location in the zone for anaerobic digestion for converting waste to energy. Second, the micro level solution for ward 8 of Zone 2, by identifying the most suitable location for sitting composting plants to increase urban agriculture. Therefore, the developed methodology can be implemented in the rest of the 9 zones of Dhaka City to find the most suitable locations for sitting bio digester and composting plants to reduce the pressure to find the landfill areas and manage the waste in the densely populated areas of Dhaka City of Bangladesh.

Keywords: Municipal Waste Management (MSWM), Geographic Information System (GIS), Analytical Hierarchy Process (AHP), Spatial Analysis, Waste to Energy, Urban Agriculture (UA), Composting and Digester Plant.

Table of Contents

Contents	*Page*
Constraint Map	
3.7 Energy Production from Biogas Digester	44
Methodology for site selection of a composting plant	48
3.8 Detailed Area Map of Research Area	48
3.9 Waste Generation Sites	49
3.10 Data integration in GIS Module	52
3.11 Spatial Multi Criteria Evaluation (SMCE) for Locating Suitable Sites	53
3.12 Site Selection and MCE	57
3.13 Reallocation of Waste Bins	58
3.14 Initiative of Urban Agriculture	59
CHAPTER 4: Results and Discussion	60
4.1 Selection of Biogas Plant's Location	60
4.1.1 Restriction Model for Constraints	61
4.1.2 Criteria Weight from Analytical Hierarchy Process	62
4.1.3 Criteria Based Suitable Sites Map	63
4.1.4 Resultant Map from the Aggregation of Constraint Map and Criteria Based Site Map	68
4.1.5 Potentials of Energy Production from Waste	71
4.2 Results for Composting Plant	72
4.2.1 Reallocation of waste collection bins	73
4.2.2 GIS Analysis for Existing Waste Collection Coverage	73
4.2.3 GIS Analysis for Road Network of Existing Waste Point	75
4.2.4 GIS Analysis for Sensitive Waste Points Location	77
4.2.5 Relocation of High Sensitive Points to Less Sensitive Points	80
4.2.6 PCSP/NGO and DCC Supports and Initiatives for Composting	83
4.2.7 GIS Analysis for Suitable Composting Point	84
CHAPTER 5: Conclusions & Recommendations	87
References	90
Appendixes (Zone 2 and Wards Map) Figure 1 to 8	94

List of Figures

List of Tables

Abbreviations (A to Z)

AHP	Analytical Hierarchy Process
ADB	Asian Development Bank
AD	Anaerobic Digester
BPDB	Bangladesh Power Development Board
BBS	Bangladesh Bureau of Statistics
CBO	Community Based Organization
CR	Consistency Ration
DTD	Door to Door
DCC	Dhaka City Corporation
DSCC	Dhaka South City Corporation
DNCC	Dhaka North City Corporation
DAP	Detailed Area Plan
DOC	Degradable Organic Carbon
DEM	Digital Elevation Map
SWM	Solid Waste Management
EPA	Environmental Protection Agency
GIS	Geographic Information System
GNI	Gross National Income
GPS	Global Positioning System
GHGs	Green House Gases
ISWA/M	Integrated Solid Waste Association/ Management
IPCC	Intergovernmental Panel on Climate Change

JICA	Japan International Cooperation Agency
JOCV	Japan Overseas Cooperation Volunteer
kWh	Kilowatt hours
LFG	Landfill Gas
MSW	Municipal Solid Waste
MIS	Management Information System
MCE	Multi Criteria Evaluation
MCF	Methane Correction Factors
MCDA	Multi Criteria Decision Analysis
MW	Megawatt
PCSP	Primary Collection Service Provider
PCS	Projected Coordinate System
RAJUK	Capital Development Authority
SoB	Survey of Bangladesh
SMCE	Spatial Multi-Criteria Evaluation
USWM	Urban Solid Waste Management
UNEP	United Nations Environment Programme
UA	Urban Agriculture
WLC	Weighted Linear Combination
WHO	World Health Organization
WtE	Waste to Energy $(m^{3)}$
WD	Waste Density (t)

Chapter 1

Introduction

1.1 Background

Population growth, economic development, and globalization have accelerated the urbanization process in developing countries. The intensity of Municipal Solid Waste (MSW) generation is directly linked with these. Growing urbanization means growing waste generation. As waste generation increases significantly, so it has a greater demand for both waste collection and innovative treatment options. Asian Development Bank (2011) reported 5.2 million tons of solid waste are generated daily worldwide, among this 3.8 million tons are generating from developing countries (ADB, 2011). Based on estimates, in Asia waste generation has reached 1 million tons per day. A World Bank study showed that urban areas in Asia spent USD 25 million per year on solid-waste management that will increase to USD 47 million per year (World Bank, 2012).

In many cases, municipal wastes are not well managed, especially in developing countries. Because cities and municipalities cannot cope with the faster growing of waste production. Developing countries in Asia have the same existing conditions. The Solid Waste generation is high, because of the population and the main component of solid waste (SW) is decomposable organic. For examples, the decomposable organic was 61.5% in Malaysia, and in Indonesia varies from 68.12% to 72.41% and Bangladesh 72% to 80 %. But only the collection problems cannot coverage the huge generated waste, and most of the developing countries are following the open dumping landfill as final disposal method. This disposal method gives environmental pollution, such as soil pollution, surface pollution and groundwater pollution which is caused by leachate and causes the GHGs emission by the waste decomposition process. (Dhokhikah et al., 2012).

Solid-waste management is a key challenge in urban areas throughout the world. Without an effective and efficient solid-waste management system, the generated waste from various human activities like industrial, commercial and domestic creates health hazards and negative impact on environment. The activities associated with solid waste management (SWM) from the generation to final disposal include generation, reduction, reuse, recycling, handling, collection, transport, transformation (e.g., recovery and treatment), and disposal. A sound waste management program needs to establish to integrate solid waste management (ISWM), legislative efforts and effective implementation are vital for the safe management and disposal of solid waste.

Municipal Solid Waste management has a significant contribution of greenhouse gases (GHGs) emission, especially the disposal of waste in landfills creates methane (CH_4) which is the causes of high global warming. Waste management disposal activities in landfills contribute 4% of GHG emissions globally (Bogner et al, 2007). In Bangladesh waste management is not managed properly, so it is also a significant contributor of GHGs emissions through the generation of methane. It is projected that by the year of 2020, waste related emissions may increase by 22%. In Dhaka, waste generation is affecting due to increased population and rapid urbanization. Other factors affecting waste generation are migration of people to city, inadequate waste management practice, and lack of awareness. The unplanned growth of Dhaka is being influenced by the factors that affected waste generation and creates the worse situation of the city.

Dhaka, the Capital of Bangladesh, is expanding rapidly and turning into a mega city with an enormous growth of population at a rate of around 6 percent a year. Dhaka City Corporation (DCC) has an area of 131 km^2 and it has more than 16 million of population. Population density exceeds 92,000 per km^2 in Dhaka. World Health Organization (2014) termed Dhaka as one of the mostly polluted cities regarding the quantity and volume of the waste; it is creating rapidly as the city population is increasing very fast. The rapid increase of solid waste in the Dhaka city becomes a serious management threat for the city authorities and at the same time for the city people. Speedy growth of industries, lack of large and available landfill sites, lack of financial resources for waste handling, poor budget for waste management, inadequate trained manpower, manual waste handling, inappropriate technology and lack of awareness of the community are the major constraints for proper solid waste management of Dhaka.

According to United Nations Environment Programme (UNEP, 2011) the organic matter in MSW streams in the South Asia region around 70%. The high volume of organic waste in South

Asia region is an important consideration for developing an appropriate management plans and treatment options easily. Most appropriate systems of collection, storage, transportation and choice of a suitable method for disposal for a sustainable management programs and proper planning entirely depends on the characteristics of municipal solid waste. Dhaka City, which has almost 16 million inhabitants, is experiencing serious difficulties in addressing the increased waste disposition burden all over the city. Organic waste represents more than 80% of solid waste throughout the year among the total generated waste (Islam et al., 2015).

Along with biogas composting from urban organic wastes can reduce the volume of waste and the need to collect and transport wastes to distant dumps. Urban agricultural (UA) policy can be an important part of a set of policies for sustainable urban environmental management. Urban agriculture has the potentials to reuse of solid waste specially the organic waste from the municipal generated waste. This reuse involves composting of organic fraction of municipal solid waste and food waste where community participation is urgent. It can comprises of two parts, one is to make compost from the organic wastes generated by the community and other part is to cultivate vegetables/fruits on the roof top garden or yard for consumption of fresh chemical free fruits and vegetables.

1.2 Problem Statement

Dhaka is the capital city of Bangladesh having 16 million of population, expected to reach 20 million by 2020. Due to uncontrolled population, urbanization, industrialization and migration of people generates large amount of waste every day in the city area. Presently Dhaka city waste generation rate is 0.38 to o.40 (kg/cap/d) and total waste is about 7000 tons per day (Hasan et al. 2009). It is expected that per capita waste generation rate would reach to 0.6 in 2025 and might lead severe problems of waste management. Crisis of land for providing the place for waste dumping is a big concern for Dhaka. Dhaka City Corporation (DCC) faces serious problems in providing a satisfactory service to the city dwellers with its land scarcity for sanitary landfilling, as it requires a very large space. In the following figure1.1 city waste management capacity is explained from the year of 2005 to now.

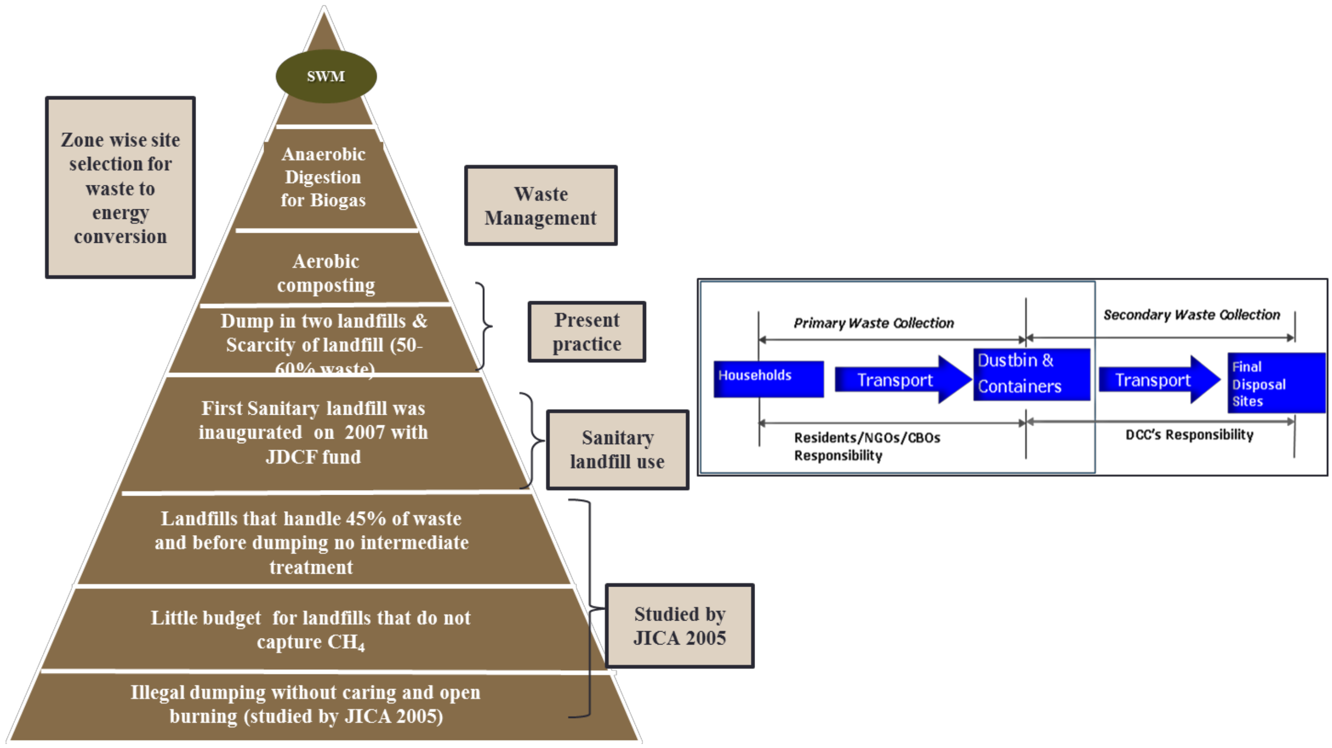


Figure 1.1: Waste Management Practice of Dhaka City (2005 to 2017)

Furthermore, Dhaka City Zone wise waste collection is not sufficient. Appropriate planning and handling of waste for ZONE (Macro Administrative Level) and WARD (Micro Administrative Unit) are lack of. Dhaka City has been divided into ten (10) Zones and Ninety (90) Wards, which could be referred as Macro level for Zone management and Micro level for Wards management is, highly required.

In addition, a significant volume of waste in Dhaka is not collected due shortage of landfills, lack of infrastructure, collection vehicles. The present disposal method also creates the soil, surface and groundwater pollutions through the leachate of wastewater and GHGs emission due to waste decomposition process. Lack of proper planning for waste disposal is the main barrier for a sustainable waste management, at the same time urban waste reduction and reuse also important. Considering the waste management problem of Dhaka City, a practical approach for reducing and handling solid waste generation, collection, separation and reduction at the macro and micro levels in a Zone and Ward is urgent. To address these urgent needs, searching of suitable lands for waste management is very important.

Nevertheless, searching of land for providing the place for waste dumping is a concern for Dhaka, it has a crisis of available large size lands, and also solid waste disposal poses a greater problem because it leads to land pollution if openly dumped, water pollution if dumped in low lands and air pollution if burnt. DCC faces serious problems in providing a satisfactory service for sanitary landfilling as it requires a very large space, and management also difficult with limited resources, budget and a poor manual management plan. But there are also some good potential for recycling of organic waste of resource recovery in a very small space and resources through zone wise management. Biogas is an environmentally friendly tool for reducing huge generated waste and reduces the greenhouse gases emissions. It is a very effective means of addressing issues like indoor air pollution, deforestation and reducing greenhouse gas emission through manure and solid waste as feedstock for biogas production (Arthur et al., 2011).

However, suitable site selection for sitting the biogas digester plant and composting plant is a major challenge for the Dhaka city. On the contrary, locating optimal sites for the biogas/composting plant has the potential to generate power or compost also involves environmental, economic, and social constraints and factors. As example, residence or the sensitive buildings like school, college, hospitals or the public places like shopping mall or commercial buildings consistently prefer that facilities such as waste handling plant or power plant should be located a certain distance from these areas. In this case, geographic information system (GIS) and muti-criteria analysis (MCA) tools are two powerful tools for land suitability assessments; it could help to locate a suitable site for the waste handling plants.

1.3 Research Objectives

This study is intended to determine solid waste generation by considering population data as well as per capita waste generation rate that can affect waste management process, and prepare a suitable solid waste management technology based on the cities demand. Using a sound methodology could reduce the environmental impact due to unmanageable waste, which usually scattered on the roadside and in open dumpsite all over the year in the city area. Suitable site selection for the biogas digester plant and composting plant can reduce the large-scale landfill site pressure around Dhaka City. Spatial multi-criteria analysis (SMCA) requires information on the value of the criteria and the geographical location of the alternatives. In addition preference can be given in a variety of constraints among criteria based on environmental, social and economic factors and out of selected criteria based on the study area preferences would be fixed and avoided those places for the selection. In this study, we proposed the use of GIS based suitable site selection for sitting a biogas plant and a composting plant for generating the energy and compost from municipal biodegradable waste.

The specific objectives of this study are as follows:

1. To select suitable sites for biogas plant installation for producing energy from waste.
2. To determine the potential of biogas production from the organic wastes.
3. To select suitable sites for composting plant installation for producing compost from waste.
4. To initiate the segregation of house hold waste for composting and the promotion of urban agriculture converting the organic waste to compost.

Chapter 2

Review of Literatures

2.1 What is Solid Waste?

Solid waste is composed of a material that is unnecessary from households, businesses, industries, agriculture and other sources of waste generation. According to Tchobanoglous et al., (1993), Comprised of all the wastes arising from human and animal activities that are generally discarded as useless or unwanted is solid waste. The Sanitation Connection (2002, online) also regarded solid waste as a material that no longer has any use or value. Solid waste also termed as “garbage”, “trash”, “refuse and “rubbish”. So any solid material that comes from domestic, commercial, industrial, agricultural and demolition activities is regarded as unwanted by those who own it, can be refer as Solid Waste.

2.2 Categorization of Waste

Solid waste is the material gathered from various human activities from different places and is normally disposed as useless and unwanted. It can be categorized based on its types, generation places, contents, materials such as plastic, paper, glass, metal, and organic waste. Categorization may also be based on it hazard potentiality to the public health or to the environment like bad liquid, radioactive, flammable, infectious, toxic, or non-toxic etc. It may also relate to the origin or sources of waste, such as household or domestic, commercial or industrial, institutional or construction and demolition, street sweeping or rubbish. Whatever the origin, content or hazard potential is, this is the reason solid waste need to be managed systematically and environment friendly to ensure sound and healthy environment. As solid waste management is a critical aspect of environmental cleanliness or hygiene and human health, it needs to be incorporated into environmental scheduling.

2.3 What is Solid Waste Management?

Britannica referred that solid-waste material that has already served its purpose regarding the collecting, treating, and disposing and discarded is no longer useful is phrases as solid waste management. Solid Waste Management is defined as the generation, storage, collection, transport, transfer, recycling or processing and disposal of the discarded materials in a way that address no harm to public health and environmental considerations. It also offers various solutions for recycling items that no more belong to the garbage or trash items. As long as people have been living in settlements and residential areas, garbage or solid waste is ongoing to generate and it is a vital issue for the day to day activities for management. Moreover, solid waste management includes the planning and legal functions in the process of reducing and solving problems that arising from waste. An inter-disciplinary relation such as public health, city and regional planning, economics, geography, sociology, political science, communication and conservation, demography, engineering and material sciences might bring the suitable solutions. A Suitable management of solid waste is necessary to reduce the adverse impact of waste on public health as well as to the environment. It also very urgent to support the economic development and improving the quality of life.

Solid waste management is a term that refers to the process of collection and treatment of wastes. Waste management is all about from the source of generation, collection and to changes or use as a usable or valuable resources. In other way we can say that solid waste management is an integral part of environmental conservation that should be observed by individuals and joint venture globally. That could keep the environment clean and reduce health impact or settlement problems.

2.4 Municipal Solid Waste Management:

MSW known as trash or garbage—consists of everyday items we use and then throw away as trash. The main sources of municipal waste generation by households, though similar wastes from sources such as commercial building, offices and public institutions are included such as schools and hospitals, shopping mall, and commercial sources such as restaurants and small businesses. Waste collection is mainly done by or on behalf of municipal authorities and disposed of through the waste management system available in the city and country. According to Environmental Protection Agency's (EPA's) definition regarding the MSW, it does not include municipal wastewater treatment sludge's, industrial process wastes, automobile bodies, combustion ash, or construction and demolition debris etc.,

2.5 Integrated Solid Waste Management (ISWM)

ISWM is an important term for waste management. Integrated Solid Waste Management (ISWM) represents a systematic approach which considered as ISWM approach. ISWM is providing the opportunity to combine a suitable approach of existing waste management practices most efficiently. Integrated solid waste management is defined as the selection and use of appropriate management of technologies, and techniques for achieving waste management goals and objectives. Integrated Solid Waste Association (ISWA) is the integration of waste source reduction, recycling and waste disposed using landfills. An efficient ISWM system considers the way of waste reducing, reusing, recycling, and managing the waste that has no harm to human health and for the environment. It involves the evaluation of local conditions and needs based on waste management. The evaluation helps for choosing, mixing and applying the most suitable solid waste management activities according to the condition.

2.6 Municipal Solid Waste Generation-A Global View

As we know that population growth, economic development, and globalization have accelerated the urbanization process in developing countries. And this are directly linked with the intensity of MSW generation. Growing urbanization means growing waste generation. Currently, more than 50% of the world's population is living the urban areas and the process of urbanization like growing population; economic development and globalization are contributing to the escalation of MSW production globally. The average solid waste generation rate in 23 developing countries is 0.77 kg/day (Troschinetz and Mihelcic, 2009) and is increasing continuously. World Bank (2012) reported that current global MSW generation are approximately 1.3 billion tons/year, which are expected to increase to approximately 2.2 billion ton/year by 2025. It is representing a very significant increase of global solid waste from 1.2 to 1.42 kg/day in the next fifteen years. Global averages are considered by region, country, city, and even within cities. The generation of fruit and vegetable waste is also very high and becoming source of concern in municipal landfills because of its high biodegradability (Bouallagui et al., 2005). The following table (Table 2.1) is shown per capita waste generation regionally.

Table 2.1: Per capita waste generation regionally

Region	Waste Generation Per Capita (kg/capita/day)		
	Lower Boundary	Upper Boundary	Average
Africa Region (AFR)	0.09	3.0	0.65
East Asia & Pacific Region (EAP)	0.44	4.3	0.95
Eastern & Central Asia (ECA)	0.29	2.1	1.1
Latin America & Carribbean (LAC)	0.11	5.5	1.1
Middle East & North Africa (MENA)	0.16	5.7	1.1
OECD	1.10	3.7	2.2
South Asia Region (SAR)	0.12	5.1	0.45

Source: World Bank (2012)

According to Globalization and Waste Management the global waste generation annually is more than 4 billion tons (municipal, industrial, hazardous). The municipal solid waste is between 1.6 to 2.0 billion tons due to the increase of population and gross national income (GNI) or capita growth in developing countries. Municipal waste is entering the waste stream every day, it is estimated that urban food waste is going to increase by 44% from 2005 to 2025. Land filled food waste is predicted to increase the global anthropogenic Greenhouse Gases emissions from 8 to 10%. ISWA also mentioned that an average 70% of the municipal waste produced worldwide is gripped into the dumpsites and sanitary landfills, 11% is treated as thermal for generating Waste to Energy (WtE) facilities and rest 19% is being recycled or treated by Biological Treatment includes composting.

ISWA showed that global facts & figures of waste management is more than 3.5 billion or more than 52% of total 2008 Earth's population (D-Waste, 2012a) which found without access to elementary waste management. Elementary waste management means sound waste collection and removal out of the residential areas, and at least controlled disposal in sanitary landfills following a systematic approach. Following graph represents the geographical distribution of population without access to Elementary Waste Management.

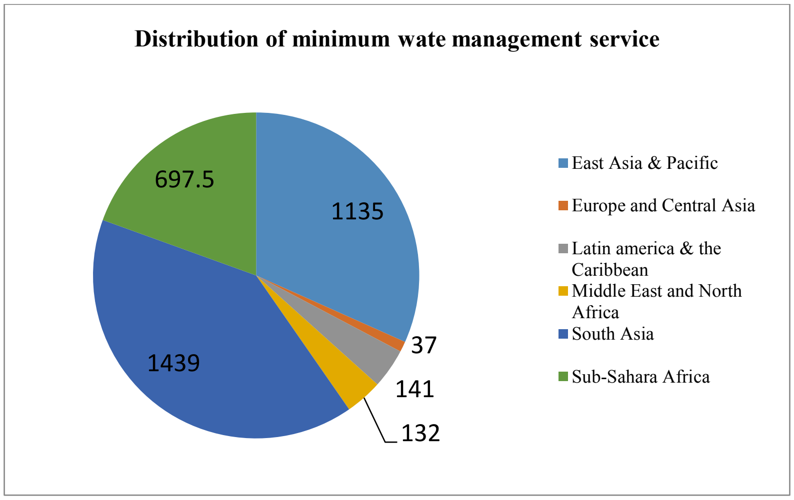


Figure 2.1: Distribution of population (2008 data) without access to Elementary WM services (D-Waste, 2012a)

Megacities (cities with a total population of 10 million people) are the results of the continuous urbanization process with a huge generation of waste. Waste management in megacities is growing very fast and it has the most important environmental challenges due to their interface with the speedy global economy; it has a global dimension too. The quality of a sound waste management services is a good indicator of a city's governance.

2.7 Generation of Solid Waste in a Megacity (Dhaka City) of Bangladesh

Dhaka is the highest growing megacity of Bangladesh. Reported estimates of solid waste generation in Dhaka city vary widely (Table 2.1), ranging from a minimum of 1,040 tons/d (BKH, 1985–86) to a maximum of 5,000 tons/day (PAS, 1997). The basis of the waste generation estimation is the assumption of city population, number of waste collection trucks availability, capacities of trucks and number of trips to landfill dumping assigned for waste transportation. BCAS (1998) figured an estimate of solid waste quantity on the basis of monitoring truck movement at the dumpsites. This estimate is based on the transported waste at dumpsites. The waste disposal at the dumpsite found a wide variation even in the same year data, like 600–800 tons/day (RSWC, 1998) and 1,199 tons/day (BCAS, 1998), presented in

(Table 2.2). The collection efficiency for all data sources has been considered to be about 50%, which appears to be a theoretical assumption. Waste density used for calculating waste quantity for all the studies also varied with a wide margin of from 0.35 ton/m3 to 0.80 ton/m3. According to Bhuiyan (1999), estimation of daily waste generation in the city area (DCC) is 3,500 tons, out of which 1,800 tons were collected and dumped at landfills, 400 tons were piled up on roadsides or open spaces, 400 tons were recycled, and the rest was illegally dumped on the way to dumpsite. It was also mentioned that the 400 tons recycled by the informal. All these studies made the prediction and some simple practical procedures which were related to waste handling, managing techniques like counting trucks for collection waste and containers for calculating waste estimates.

Table 2.2: Estimate of solid waste generation of Dhaka City

Data Source	Assumed collection by DCC (%)	Volume collected by the DCC (m^3)	Assumed Solid Waste (ton/ m^3)	Quantity disposed at dump site (ton/day)	Solid waste generation (ton/day)
BKH 1985-86	50	937	0.56	520	1040
DCC 1985	50	1600	0.56	888	1776
LBI1990	50	-	-	1250	2500
Bhide 1990	50	1381	0,80	1105	2210
MMI 1991	45	1174	0,58	683	1300
PCI 1991	50	-	-	770	1540
PAS 1997	75-80	-	0.35	-	3000-5000
RSWC 1998	50	-	0.60	600-800	1200-1600
BCAS 1998	50	-	0.604	1199	2398
Bhuiyan 1999	52	-	0.689	1800	3500

Source BUET 2000*: BKH Consulting Engineer, DCC-Dhaka City Corporation, LBI-Louis Berger International, PCI- Pacific Consultants Internationals, PAS- Pan Asia Services Limited, RSWC- Roteb Solid waste Consultancy International, BCAS-Bangladesh Center for Advanced Studies*

Solid waste generation of Dhaka Metropolitan area (360 sq km) in 1998 was 3,944 tons/day (WB 1998a in BCAS, 2003). “Solid Waste Management Project” of DCC prepared by JICA and DCC experts in 2000 where showed that the metropolitan area of Dhaka city generates 4,750 tons of solid waste every day. Another report reported that waste generation of DCC was no less than 3,700 tons/day. DCC and some other reports mentioned that the waste generation of Dhaka city was about 4,000 to 5,000 tons/day. On the other hand, Japan International Cooperation Agency (JICA) team conducted survey of "Clean Dhaka Master Plan" and reported the existing solid waste generation (dry season) within Dhaka City Corporation area were 3,340 tons/day, projected to increase 4,600-5,100 tons/day by the year of 2015 (JICA, 2004). The JICA team also mentioned that the waste generation amount based on the seasons, during the summer when fruits are available in the city then the waste generation are comparatively high than other seasons. (JICA, 2004). They also reported that among the total produced waste, nearly 20% of waste is used for recycling and about 37% of municipal waste remains laying around the roadsides, open spaces or local drains. But one things need to mention here that JICA's study was limited to 131 km^2 area of the city whereas DCC's solid waste management service area is 276 km^2 (JICA, 2004). These wastes were deposited together in the same primary depots from where about 45% is finally disposed of either by the DCC or Community Based Organizations (CBOs) in the open landfill sites at Matuail near Jatrabari, Beribadh in Mirpur and in Uttara.

Hasan et al., 2009 mentioned an estimated of 7,000 t of MSW is generated daily in Dhaka City, of which only 1200–1500 tons are disposed of in landfills and the rest is left unattended, uncared and dumped locally. Dhaka city that has almost 16 million inhabitants, and this inhabitant are experienced particularly serious difficulties in dealing with increasing waste disposition burden. Composition of organic waste is more than 80% among the total waste (Islam et al., 2015). In Dhaka City the waste generation rate is approximately 1.65 million metric tons annually, per capita waste generation estimates between 0.29 to 0.60 kg/day depending on individual level of income or socio economic status (Chowdhury et al., 2014). But the growing waste still has the limitations of proper management and disposal.

The city corporation states that the collection system cannot cope with the task of handling the large volume of waste produced by the growing number of city dwellers; only 40–50 % of the produced waste is being collected. The situation is unmanaged and unsatisfactory because of large increases in population and economic development. Still Dhaka could not develop the technical approach for waste handling and remained to manual waste-handling process. Although

Dhaka North and South City Corporations handle domestic and commercial waste, because of the limitations in resources and organizational capacity it is difficult to ensure efficient waste management. The city needs major improvement in the separation of waste at source, storage, collection, transport, recycling, treatment, and disposal to reduce its adverse impact on the environment and public health.

2.8 Composition of Waste in Dhaka

The composition of municipal solid waste depends on the source of its generation. Each city has a unique combination of activities and resulting waste characteristics. Waste composition influenced by many factors, such as the economic conditions of the inhabitants, area's development situation, cultural activities, localities practice, habits and attitudes, geographical location, energy sources, and the climate of the areas. As a country urbanization and populations increasing trend is the main causes of high amount of waste generation, at the same way consumption of inorganic materials such as plastics, paper, and aluminum also the causes of increasing waste.

Experience showed that residential areas of Bangladesh generate approximately 60% of waste. In urban areas of Bangladesh solid waste has a very high organic content that varies from 72- 80% where moisture content 60-75% (Islam et al. 2015). Figure shows total waste composition and moisture content in Dhaka city every day. It shows that solid waste of Dhaka City has also similar amount of organic matters.

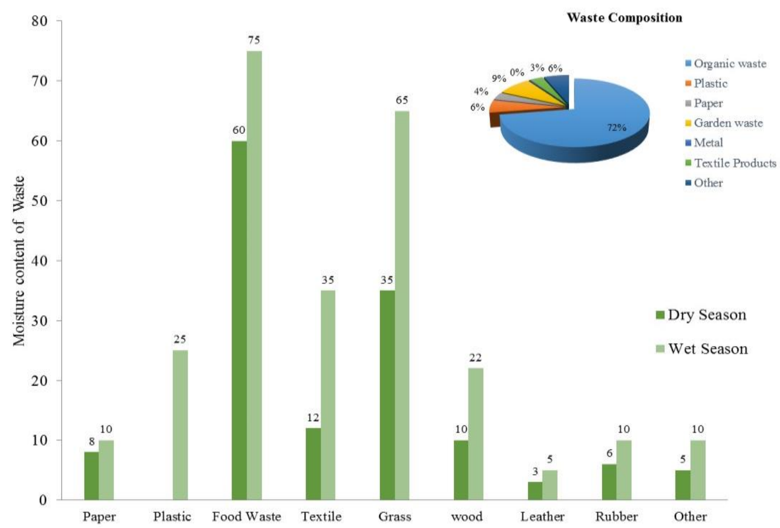


Figure 2.2: Waste composition and Moisture Content of Dhaka City Waste

Accordingly, both city corporations of Dhaka are encouraging community-based organizations and local non-governmental organizations (NGOs) called Primary Collection Service Providers (PCSPs), for providing house-to-house waste collection and transport to disposal sites. However, the efforts of PCSPs have yet not relieved city dwellers of the adverse impacts of inadequate SWM, including source separation and inefficient waste collection by the city corporation. Collection from dustbins for final disposal is not to be made efficient because of the limited numbers of sanitary landfills and scarcity of land for waste disposal. Dhaka has the severe scarcity of unused large lands that can be use as landfills. Hence, this is high time to find out an alternative, like waste to energy generation from the generated organic waste or compost production for urban agriculture from household organic waste. The shortage of manpower, logistics, and scarcity of landfill sites for disposing waste are issues of concern in the search for waste management solutions. The largest fraction by weight of mixed municipal waste consists of organic biodegradable waste, at 60–75 % (Dhaka City Corporation, 2012). Reducing the organic content, by composting or other organic waste treatment technology like biogas generation, would have a strong impact on reducing the volume of waste to be collected and disposed of. If organic waste remains unattended, it tends to decompose by natural processes, giving rise to odors, hosting and feeding a variety of insects and pests including carriers of disease, and creating severe health. The bacterial conversion of organic materials in MSW in the presence of air under hot and moist conditions is called composting (aerobic composting), and the final product obtained after bacterial activity is called compost (humus), that has very high agricultural value and can be used as fertilizer; it is non-odorous and free of pathogens. As a result of the composting process, waste is reduced by 50–85 % in volume and can be used for urban agriculture by city dwellers. Organic waste composting is effective and viable, but a sufficient market demand must be established and maintained. At the same way the conversion of waste biomass and organic substrates into energy encompasses a wide range of different types and sources of biomass conversion options, end-use applications, and infrastructure requirements (Karagiannidis et al., 2009). For energy production from waste biomass, several issues critical for all involved stakeholders, such as potential investors, involved regulators and decision makers, must be tackled (Iakovou et al., 2010). Energy production from waste biomass and urban agriculture must be synchronized together with the potential identification of composting locations and biogas to energy production and geographical factors that would be safe for the environment.

As such, suitable solid sites for disposal of waste and recycling are not match with the rapid urbanization process. In this study, we proposed the use of GIS based on multi-criteria analysis to select sites suitable for sitting a biogas and composting plant for generating the energy and compost from municipal waste. For a suitable site selection the study includes environmental factors, economical factors and social factors. To locate a best place for a rapidly developing cities consideration of all these factors are very important. Urban agricultural policy can be an integral part of a set of policies for sustainable urban environmental management using composting and a proper geographical identification of location and logistics. To obtain a long term economic solution, sustainable techniques for composting and urban agriculture, including the bioenergy perspectives of GIS-based planning, can efficiently provide spatial and nonspatial information for urban waste management.

On the other hand bio-energy generated from anaerobic digestion of biomass such as biogas, is a promising source of energy to produce heat, electricity and hydrogen for fuel cells or to be used as vehicle fuels (C. Hanping et., all 2008). Dhaka is the fast-growing developing city where economic development and prosperity speed up the consumption rate, as a result the amount of waste generation is increasing in a massive way. The increasing of waste (especially municipal waste) is the main causing of severe environmental degradation. Residence, Commercial or business, Institutions, Industrial are the main sources of solid wastes in Dhaka City. Different factors such as rising urban population, economic development, consumption mode, climate and culture and Institutional framework play a significant role in MSW generation (H.Wang et al., 2001).

Biogas plant and incineration are the most common and viable sources of energy recovery from the municipal waste in developing cities. But in Dhaka City Incineration is not viable as the composition of waste is not perfect for incineration. Dhaka city waste composition contents high moisture (72-80%) and the cost of the incineration plant is also high. However, the environment consciousness as well as financial and technical parameters is the main barrier of incineration technologies to spread out rapidly. On the other hand Anaerobic Digestion is a process of reaction and interaction of different methanogens and substances in the digester. Anaerobic digestion is a biological degradation process of organic matters which is done in the absence of oxygen. Organic digestion is very complex process and requires specific nutrients of the waste and temperature and various bacterial population (Lastella et al., 2002). Anaerobic digestion (AD), also defined as 'utilization of microorganisms, in absence of oxygenic conditions, it helps to stabilize the organic matter by transforming it into methane and other inorganic products including carbon dioxide. This could be a suitable choice for the biodegradable fraction of urban solid wastes (USW) specially for urban organic waste in developing countries.

This study using this GIS based multi-criteria approach in combination of AHP and WLC, using this approach this research will locate a place for generating the heat and gas from the municipal solid waste of Dhaka city where a digester plant and composting plant will be sitting, and converting the waste to compost and energy using those plants. This are the only option for reducing a huge amount of waste using a suitable technology for Dhaka City. As because for dumping the waste in a landfill around Dhaka city is unable to provide the land because of the scarcity of land. One of the most important benefits of biogas is energy production, including electricity, light and heat. Elimination and conversion of organic waste into useful and valuable products is another major benefit. More than 72% of municipal waste of Dhaka city is coming from the household kitchen and kitchen market. Biogas digester plant will lead to reduce this huge waste converting them into energy and also leads to most important advantage like improving hygienic conditions of the environment, reduced pathogens, and protection of air, water and vegetation in the environment. Therefore, the sitting of a solid waste facility also involve with the processing of a significant amount of spatial data, regulations and acceptance of criteria, as well as an efficient correlation in between them. Some of the promising methods for site evaluation have been discussed by Gebhardt and Jankowski (1987), Swallow et al. (1992), Chen and Kao (1997) and Sasao (2004).

A spatial multi-criteria approach was proposed for selecting a suitable sitting place for waste management. This proposed methodology will help the decision makers in the process of locating the suitable place for sitting digester plant and composting plant in every zone of Dhaka for reducing the zone wise municipal waste within a small land and as well as it can be followed in other part of Bangladesh. This study was followed AHP in combination with WLC and GIS spatial analysis tools. AHP is a decision-making technique which can be used to analyze and support decisions for multiple and competing objectives. It helps to solve a complex problem that is divided into a number of simpler problems in the form of decision hierarchy (Erkut and Moran, 1991). Siddiqui et al. (1996) were the first to combine geographic information system (GIS) and AHP procedure to aid in site selection. Similarly, Charnpratheep et al. (1997) utilized fuzzy set theory with GIS for the screening of landfill sites in Thailand (Chang et al.,2008).

2.9 Adoption of GIS in Solid Waste Management

GIS is among MIS and part of the Geo information technology, which already has been adopted to solve the solid waste management problems in many countries. Many developed countries like USA, France, Britain, etc. are using GIS method for waste management, at the same way some developing countries such as Mexico, China, Ghana, South Africa, Kenya, Nigeria; etc. also using these methods. GIS has demonstrated the strength for increasing the sustainable development in the cities. GIS technology is the combination of spatial and attributes data acquisition, storage, manipulation, analysis and visualization. It has already proved the success in assisting the planners for guiding to find out the suitable location of transfer stations for solid waste storage, designing the short paths for waste collection, creating databases for households and arranging the time tables for trucks to collect waste area to area. Previous experiences in developing countries showed that poor spatial and non-spatial data linkage is the main cause for almost all problems in solid waste management.

Undesirable facility location for MSWM has been examined extensively in many research. Since 1960s many research was developed concerning the MSWM problems. The first application referred to land use models and for optimizing the collection route and facilities for the selection of a site, focusing only on financial criteria (Truit et al., 1969). According to sustainable development approach, a waste management system has to be environmentally effective, economically affordable and socially acceptable (Bottero and Ferretti, 2011). During 1990s, MSWM models was started to consider the complexity that is intrinsic in decision problems and some MCA application were proposed for solving these problems (Caruso et al., 1993). MCA models were considered for the full range of waste streams for managing the waste management practices, this models helped to select the preferred solution on the basic of site-specific environmental and economic considerations.

Karadimas & Loumos (2008) was proposed a method for the estimation of municipal solid waste generation, optimal waste collection and calculation for counting the optimal number of waste bins and their allocation options. This method uses a spatial Geodatabase, integrated in a GIS environment and was tested in a part of the municipality of Athens, Greece. After the reallocation of the waste bins, their total number was reduced by more than 30%. This reduction had a direct positive impact on collection time and distances.

Chalkias & Lasaridi (2009) was developed a model in ArcGIS Network Analyst for improving the waste collection efficiency and transport for Nikea, Municipality of Athens, Greece. In their research they also reallocated of waste collection bins and the optimized of vehicle routing based on distance and time travelling. From their research results it was demonstrated that all the examined scenarios showed the savings in terms of collection time and travel distance for waste collection.

Apaydin & Gonullu (2006) has worked to develop an integrated system in the combination of

GIS and GPS technology for optimizing the routing of MSW collection in Trabzon city, northeast Turkey. The research results of the proposed optimized routes was savings with the existing ones and which 4–59% for distance and 14-65% in terms of time. The optimal routing was done based on population density of the area, waste generation capacity of the waste collection sites, road networking, storage bins and number of collection vehicles. The findings of the proposed technology were roughly estimated and revealed 30% cost-savings with this approach.

2.10 Previous study conducted for Municipal Solid Waste Management

Hafiz et al., 2011 worked for the waste collection efficiency through the application of GIS Techniques in Urban Solid Waste Management in a part of Dhaka City. The study conducted one survey using questionnaire and collected the Geographic Positioning system (GPS) of the existing waste bins, containers and illegal disposal sites through the GPS device. Spatial data were generated using collected GPS data and high resolution satellite images (Quickbird Image) of the study area. Researcher found that the North western part of the study area was remain uncollected by Door to door collection (DTD) regularly or twice in a week and collection bins or containers was not found for proper waste collection, The Southern Part found residential area and DTD collection service is practiced and no major illegal dumping were found it that area (Afsana et al. 2016).

Only one Mini Transfer station was found in the study area. Only one slum area was observed where densely populated and no DTD service practiced and lack of sanitation, drinking water and waste dumping containers and found unmanaged waste condition. One ward mainly mixed with residential and commercial areas was quiet clean and no major illegal dumping found in that ward. The study showed that Unclean and Untreated Solid Waste is a big concern for ensuring the public health and a progressive deterioration in health and environmental quality of the surrounding environment.

Study showed that 24 Numbers of Waste bins with the capacity of 1500 kg and 30 Waste Containers with the capacity of 5000 kg is required in the study area. The optimal location of waste bins and containers had been suggested considering present containers and bins. Current waste collecting routes and self-judgment were put into consideration in optimal route selection of waste collection using network analyst tool. A route was proposed using the Beribund highway considering the wastes collected from N-W part of the study area (Ward 46) and for disposal at Beribund site. The other routes were considered with derived results from network analysis and the routes were suggested an overall two trips for each ward of the study area (Afsana et al. 2016).

The study was done to find a solution for a sustainable urban solid waste management. It describes that strategic SWM planning in an integrated approach by the waste management authorities (DCC). (Hasan et all., 2009) assessed the landfill demand for disposal of MSW of Dhaka in the paper of Landfill demand and allocation of Municipal solid waste in Dhaka City by projecting population and waste generation for the period 2007-2025. For finding suitable landfill sites they analyzed a multi-criteria evaluation (MCE) on various raster map layers in GIS environment. Various map layers of Dhaka city (1734 km^2) was prepared using standard exclusionary criteria. All the layers were overlaid and combined using WLC method. In the suitability analysis for weighting of factors a pair-wise comparison method provided by the AHP is used which is built-in the GIS environment. In the paper it was mentioned that presently an estimated 7,000 tons of MSW is generated daily in the Dhaka City of which only 1200–1500 tons is disposed in the landfills and the rest left unattended or locally dumped. MSW is only being disposed and dumped for filling low-lying lands. The MSW is presently being disposed of mainly in Matuail, a low-lying land about three kilometer distance from the city corporation area and a number of minor sites which are operated in uncontrolled manner and without any proper earth cover and compaction. The uncollected wastes are dumped in open spaces, streets which clog drainage system creating serious environmental degradation and health risks. In order to maintain a sustained waste disposal in landfills new waste sites have to be designated as the old capacities are being filled-up. A sanitary landfill site selection involves evaluation of various criteria using national or local land-use guidelines, environmental regulations, location restrictions, and so on. Social, environmental and technical criteria should be considered for potential landfill site selection.

The specific objectives of their study were to (1) make an assessment of future demand of land for waste disposal in landfills in Dhaka city, (2) illustrate land suitability analysis method in GIS, and (3) identify qualitatively suitable locations for the landfills. At the final of this study according to the set-up of exclusionary criteria, decision factors, standardization of factors, and weighting of factors, using MCE for land suitability analysis, final suitability map is produced through WLC method. Three simulations have been run for the three scenarios and finally three suitability maps have been produced. In the final suitability maps suitable areas have been produced on a scale of suitability ranges 0 to 255. Then the best suitable areas (sites) have been identified through analysis and ranking of the sites has been done for landfill development.

In the conclusion of the study the researcher made his opinion that MCE land suitability analysis and results show that required landfill demand can be met with the available land in Dhaka city. Suitable landfill areas might be available of size less than 50 hectares as land areas less than 50 hectares have been excluded from the analysis. However, all the suitable areas found from his study can be used for landfill development, but transport cost for waste disposal from distant part of the city will be higher for waste management. Spreadsheet calculation also shows that with an increase of recycling and composting of waste significantly reduces landfill demand.

Islam. N, (2016) worked on Dhaka and Chittagong Cities Municipal Solid Waste (MSW) for the conversion of waste to energy (WtE) strategy for a sustainable MSW management. This study was conducted to estimate electricity generation potential from the two largest cities of Bangladesh assessing the feasibility of WtE strategies in terms of energy conversion and carbon reduction from the municipal solid waste of two big cities of Bangladesh. Two WtE technologies, such as mixed MSW incineration and landfill gas (LFG) recovery, are selected for the assessment of renewable energy generation and carbon reduction. He mentioned that these two options are the most preferable and mature technologies practicing in the world. MSW incineration and LFG recovery were evaluated in his study and validated the prospects of mixed MSW incineration in Bangladesh to mitigate GHGs emissions and to generate considerable revenue from electricity sales and carbon credit. Six alternative scenarios were assessed for the Dhaka and Chittagong cities waste management. The study brought its conclusion for WtE strategy based on mixed MSW incineration to generate electricity for delivering environmental benefits nationally and globally for the comprehensive development in Bangladesh.

For both of the city corporation approximately 60-70% of waste is generated from residential areas. In urban areas of Bangladesh solid waste has a very high organic content that varies from 70- 85% of total generated waste. Incineration is not viable for the composition of waste of Dhaka as the composition of Dhaka waste contents high moisture (72-80%) and the cost of the incineration plant is high. Study described that the increasing rate of the environment consciousness as well as certain financial and technical parameters have made blockage in the of incineration technologies to spread rapidly. The reality is, although WtE technologies employing MSW as their feed in materials are well developed but the disconformities of the MSW composition the complexity of the treatment facilities, and the pollutant emission still expresses considerable issues for incineration technologies (Omidreza S. 2015 WTE in Malaysia). Moreover, density of waste at the pick-up point ranges from 390 to 540-kg/m3. Composition of solid waste of Dhaka city showed that a major portion of waste is organic with high moisture content, which is suitable to produce compost fertilizer or biogas plant instead of incineration. On the other hand, Dhaka has the crisis of land for new landfill sitting in the city area. Landfill gas recovery is not suitable options for Dhaka City waste management as it requires a large land with a big manpower for waste handling, zone wise waste management using composting plant and biogas plant in a small and a suitable place can reduce the waste management and transport cost as well as cost recovery can be done through compost selling and energy distribution in the local area.

Guiqin et al., (2009) worked for the landfill site selection in Beijing city using GIS and AHP. For landfill site consideration they used multiple alternative solutions and evaluation criteria. Based on the conditions of the study area, they considered economic factors, calculated criteria weights using the analytical hierarchy process (AHP) and built a hierarchy model. According to their model landfill sites required size was >10 ha and the environmental impact on public health was considered in their research. Researchers offered AHP for weighting. In their research the economic factors were showed very important factors for developing countries and districts. The sitting process in this study found very useful for waste disposal site selection in a fast-growing region. Finally, optimal and back-up sites were selected for waste landfill candidate sites in

Beijing, China.

In their the required landfill size for this study was large and it was easy to find in Beijing as they have available land. In the case of Dhaka city nowadays it is quiet challenging to find a large landfill site considering the environmental factors following all required criteria. Zone wise plant site selection is still considerable as the required size is not large. Government can take action easily to solve zone based waste management problems.

2.11 Land Suitability Assessment for Sitting a Digester Plant

Though It is urgent to install biogas plant for reduction of MSW and energy generation as the increasing solid waste is one of the big concern for the local people, on the other hand biogas plant is an undesirable technique handling a huge waste are a big considered as NIMBY (not in my backyard)facilities. Locating optimal sites for power generation facilities is a complex task involving many environmental, economic, and social constraints and factors. For example, residence consistently prefer that facilities such as power plants be located a certain distance from residential areas. The combination of GIS and Multi Criteria Decision Analysis (MCDA) is a powerful tool for land suitability assessments will help to locate a suitable site. Using GIS based multi-criteria approaches a place were fixed for generating the heat and gas from the municipal solid waste of Dhaka city for biogas digester plant.

The digester plant land suitability assessment determined through the overlaying of thematic maps and analyzing attribute data with the support of GIS and AHP. The building of a GIS is a chain of operation that leads us from planning data observation and collection, to their storage and analysis, to the use of the derived information in some decision-making process (Chuong, 2007). This approach takes advantage of both the capability of geographical information systems (GIS) to manage and process spatial information and the flexibility of multi-criteria analysis to combine factual information (e.g. slope, infrastructure) with value based information (e.g. expert's opinion, participatory surveys) (Geneletti, 2010). On the otherhand Using Analytical Hierarchy Process is one of the popular method to obtain criteria weight in MCDM (Satty, 1977, 1980; Satty and Vargas, 1991, Wu, 1998; Ohta et al., 2007). The AHP has been employed in the

GIS based MCDM (Carver,1991; Malczewski, 1999, 2004). It calculates the needed weights associated with criterion map layers by the help of a preference matrix where all identified relevant criteria are compared against each other with preference factors. Then the weights can be aggregated with the criterion maps in a way similar to weighted combination method. GIS-based AHP is popular because of its capacity to integrate a large amount of heterogenous data and the ease in obtaining the weight of a large number of criteria, and therefore, it has been applied in tackling a wide variety of decision making problems (Tiwari et al., 1999; Nekhay et al., 2008; Hossain and Das, 2009)

2.12 Biogas Plant sitting for Energy Production

Several researches were conducted to solve the local, regional and global problems due to the improper disposal of MSW. Most of these researches showed an positive attitude on renewable energy for sustainable development, renewable energy can help to meet the daily energy needs through waste to energy routes and reduce the negative environmental and social impacts (Rao et al., 2010). There are so many definitions of sustainable development but the following is the most suitable for waste 'the development that meets present generation needs without compromising on future generation needs' (Dincer, 2000). Biogas has become an attractive alternative of energy of waste (Kothari et al., 2010). The biogas or methane yield is measured by the amount of biogas or methane that can be produced per unit of volatile solids in the feedstock after subjecting it to anaerobic digestion (Zhang et al., 2007; Moller et al., 2004).

Anaerobic digestion (AD) process has the potential to generate 367 m^3 of biogas, per dry tone waste generate about 65% methane (AD food waste report, EBMUD 2008,) with an energy content of 6.25 kWh/m^3 of biogas yielding 894TWh annually. This represents almost 5% of the global electrical energy utilization in the year of 2008. In addition, if the anaerobic digestion technology is applied, then the food waste not need to send to the landfills for disposal, that could help to reduce the transportation costs and greenhouse gas emissions. The advantage of using an anaerobic digestion in an urban environment is the suitable way to treat organic waste and produces biogas and compost. Biogas with a high percentage of methane can be used as electricity or fuel and composting process can be used as fertilizer.

2.13 Process of Biogas using Anaerobic Digestion

Biogas is an environmentally friendly tool for reducing the greenhouse gas emissions. It is very effective means of addressing issues like indoor air pollution, deforestation and reducing greenhouse gas emission through manure and solid waste as feedstock for biogas production (Arthur et al., 2011). Biomass and biogas technology has helped to improve the quality of environment by eliminating the agricultural waste, municipal wastes that could accumulate and become a major source of pollution and possible contamination.

Anaerobic Digestion (AD) is a process in which microorganism's breakdown in biodegradable material in the absence of oxygen. Anaerobic Digestion is also considered a renewable energy source for biogas production that is suitable for energy production and can replace fossil fuels. The Methane in the biogas produced from the AD can be combusted to produce both heat and electricity using internal combustion engines or micro turbines (Curry et al., 2001).

Biogas is basically referring to the gas which is produced during the breakdown of organic materials without the presence of oxygen. Biogas consist of mainly methane and carbon dioxide. This process is known as anaerobic digestion and is performed by microorganisms present in the anaerobic digester. The production of biogas has three steps; hydrolysis, acidification and methane production. In the hydrolysis steps is the polymer breakdown stage. In the second stage is the acidification stage where the acid producing bacteria convert the monomers produced in the first step to different fermentation products are mainly acids. After this step next step is acetogenesis, the different fermentation products are converted to acetic acid, which serve as one of the substrate for the methane production. In the last stage methane –producing bacteria are utilizing either acetate, or carbon dioxide and hydrogen to form methane and carbon dioxide. In the whole process, there are many factors that play a significant role in this process, like pH value, temperature, organic loading rate, retention time, C/N ratio, the amount of available nutrients and toxicity. The Anaerobic Digestion Process is shown below (Fig. 2.3);

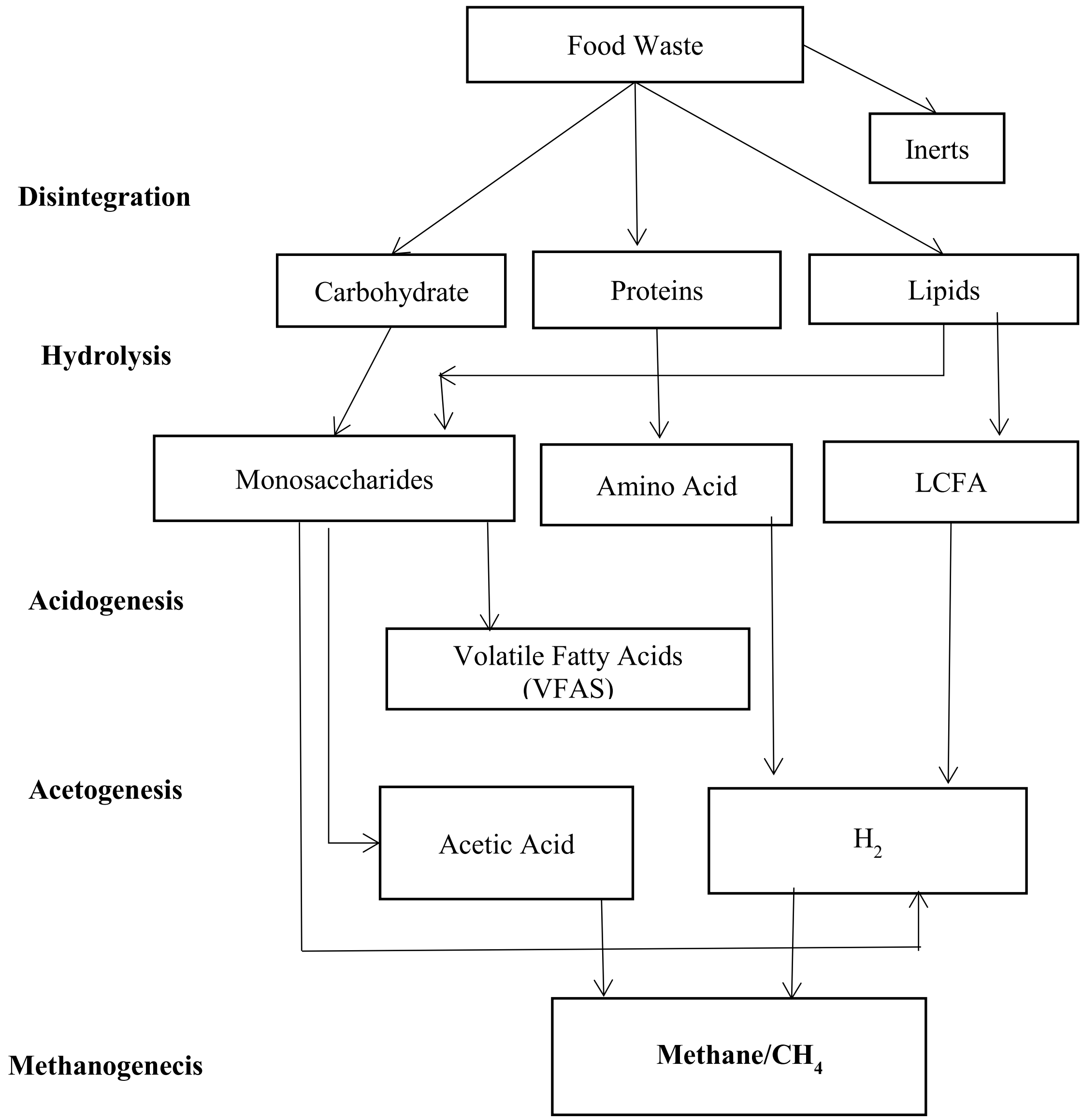


Figure 2.3: Anaerobic Digestion Process for Methane generation

Spatial multi criteria analysis requires information on the value of the criteria and the geographical location of the alternatives. This paper represents the site selection for Biogas plant for Dhaka City, after an introduction section the paper is organized as follows: a brief literature review regarding the GIS and multi criteria decision support system for the solving the solid waste management related problem, and then the study area information research purpose research methodology describing the AHP and Spatial analysis using ArcGIS 10.3 that brings to the results section where the produced map is described and finally the suitable sites map is proposed. Finally the discussion and conclusions that have been drew from the study and also highlighting the opportunities.

2.14 Urban Agriculture

Urban agriculture is an important source for environmental and production efficiency benefits. It could bring multiple benefits in health, social, economic and ecological issues. In a city urban agriculture enhances urban food security and nutrition, local economic development, poverty alleviation and social inclusion of disadvantaged groups and sustainable environmental management (Cohen et al., 2012). Since MSW contains high amounts of organic matter, composting this matter and use it in urban agriculture might be a solution for the growing waste problem in metropolitan regions (Sharma, 2003).

Waste is found as problem when it is the question for where to dispose of, but it seems as resource for sustainable development. The use of fertilizer has been implemented in urban agriculture at both the household and community level. A household with a rooftop garden or a backyard can contributes in reusing organic waste as compost from the segregated household waste. Urban farms, that can be animal production, vegetable production or other purpose, is able to collect and process as much of urban waste as possible (Smit and Nasr, 1992).

2.15 Decentralized Composting in Bangladesh and Financial Feasibility

Zurbr ¨ ugg et al. (2005) has described the experiences of Waste Concern, Bnagladesh. Waste Concern is a research based Non-Governmental Organisation, of Bangladesh initiated one community-based decentralized composting project in Mirpur, Dhaka, Bangladesh. This is the project where organic waste is being using for composting with the aim of developing a low-cost technique for conversion the organic waste to compost of municipal solid waste. The developed techniques of Waste Concern found a well-suited techniques for the conversion of organic waste to compost. This project was considered the waste stream of Dhaka, climate conditions, socio-economic conditions along with the development of public–private–community partnerships in solid waste management. The project was followed an approach that comprised a technical and scientific evaluation of the composting process and also the an analysis of the compost marketing.

Waste Concern did a financial assessment of the project and showed that a scheme with a capacity of 3 tons of waste per day can be viable when given an initial support by municipalities or other donors. Land acquisition in urban areas is always one financial key obstacle for initiating a composting plant. For the Mirpur composting plant project of Waste Concern, rough estimates of the project shows that the municipal waste transportation and landfill costs can be reduced by US$ 18,500 per year (based on full capacity of the plant). This estimate takes into account that decentralized composting reduces the amount of generated municipal waste that needs to be transported by municipal trucks and manpower as well as the reduction of municipal expenses for final disposal of the waste. Of the 3 tons collected daily by Waste Concern, 2.52 tons are either composted or sold as recyclables. Thus based on a reduction of solid waste of 2.52 tons daily and estimated solid waste collection and transportation costs of the Dhaka City Corporation of US$ 16.4 per ton (World Bank, 1996), the composting scheme of Mirpur reduces the cost for the municipality in terms of collection and transportation by US$ 15,085 per year. In addition, final disposal costs were estimated based on the price of landfill surface area (US$ 24.5/m^2) and a factor converting waste weight to final landfill surface area required. This conversion factor was determined by assuming a waste density of 1.1 ton/m3 and a dumpsite waste height of 6m (e.g. 6m^3 waste per square meter surface area). Again based on a reduction of solid waste of 2.52 tons daily this amounts to cost savings in landfill disposal of US$ 3414 per year.

The case of Waste Concern in Dhaka is one example of a viable small scale and decentralized composting plant. Using an appropriate composting technology in combination with a separate suitable place, sound financial management, as well as an appropriate marketing strategy ensures high quality compost and constant sales throughout the year. This decentralized composting plant is being done by the non-governmental organization which is based on donor fund or project fund. To give a permanent shape of this technology Government involvement is urgent.

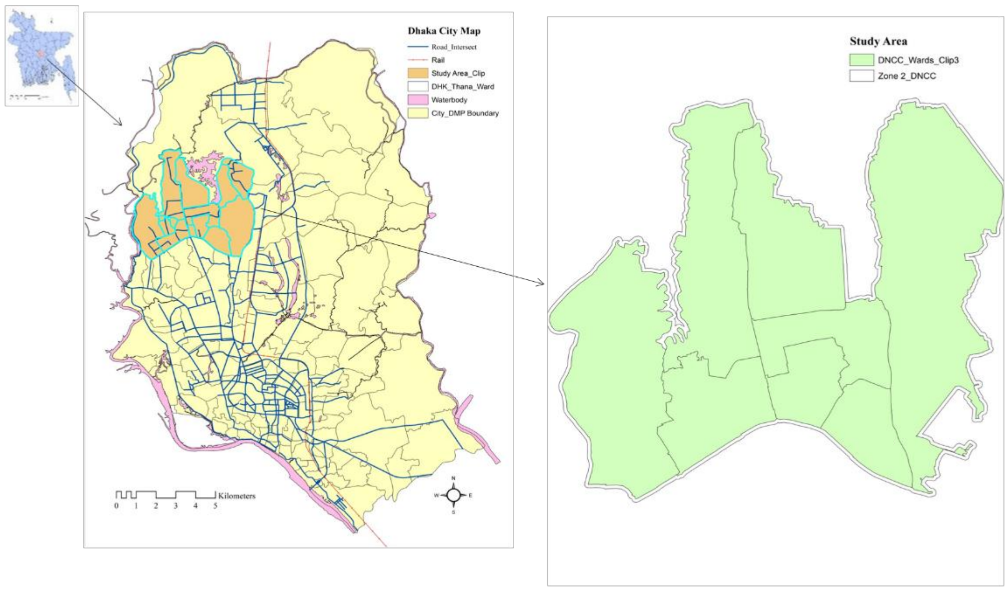
Chapter 3

Methodology

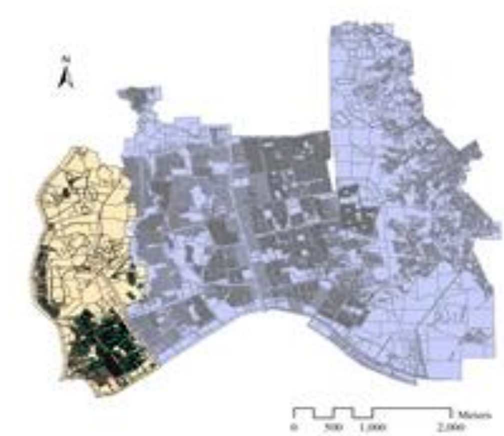
3.1 Geographical Extent

This study describes the site suitability analysis for sitting two plants composting and biogas digester for waste management as a potentially effective option to produce compost and energy from organic waste in Dhaka City. To conduct the research one of the zone (Zone 2) of Dhaka North City Corporation was selected for research. Dhaka North City Corporation (DNCC) is an autonomous body of the Bangladesh Government that consists of 36 northern wards distributed in 5 zones (Zones 1, 2, 3, 4, and 5) of Dhaka. Prior to its establishment in 2011, DNCC was governed by the Dhaka City Corporation. The study area was Zone 2 of DNCC (Fig. 5), which consists of 8 wards (Wards 2, 3, 4, 5, 6, 7, 8 and 15). Zone 2 is located in the northern part of Dhaka, at 23.44° to 23.54°N 90.20°-90.28°E, and has a total area of 22.7 km^2 (Figure 5)The Bangladesh National Zoo and Dhaka Cantonment (Headquarters of the Bangladesh Army, Navy and Air Force) are located in this zone. The total population of this zone is 1,002,501 (BBS, 2011). This zone encompasses a total of 17 hospitals, 29 clinics, 208 schools, 54 colleges, 3 universities, 194 mosques, 2 parks and 5 playgrounds. Zone 2 of DNCC (previously zone 8 of DCC) is one of the highest waste-generating areas of Dhaka (JICA, 2005) and has a high population. Some of the areas of this zone have shortages of gas and electricity facilities.

The biogas digester plant will be handling by the city authority under their regular cleaning activities from their selected waste point. The plant will be controlled and managed by the government for reducing the cleaning and maintenance cost as well as reduced the huge waste pressure from limited landfill sites. For this digester plant the total zone (wards 2,3,4,5,6,7,8 & 15) was covered for site selection analysis (Fig. 3.1). This study was also examined the potential to provide biogas energy converted to electricity and gas for this area.



(a) (b)



(c)

(a) Dhaka City (b) Zone 2, North of Dhaka Biogas Plant Site Selection (c) Highlighted ward for Composting Point Site

Figure 3.1: Geographical extent for biogas plant and composting plant of the study at Zone 2 of Dhaka

On the other hand the composting plant will be handled by the local people who could segregate their organic waste in the household level. The separated waste will be given local NGO's who are responsible for door to door waste collection and they will convert the organic waste to compost. The conversion of compost will be done in a separate place and the site selection for this will be analyzed in this research. The converted compost will be distributed among those localities who segregated their waste at household and they will use this compost for their rooftop or in-house gardening. For composting plant one ward of zone 2 was selected for intensive observation of local people interest regarding urban agriculture through a household survey. Among 8 wards of zone 2 ward 8 generated the highest amount of waste, the reason of high waste generation at ward 8 was investigated. All the waste points of ward 8 was observed and city corporation activities and their waste management techniques also analyzed. Ward 8 was taken as study area for composting point site selection.

3.2 Land use Map

In the time intervals of 1960-2000, 2000-2014 and 1960-2014, built-up areas of Dhaka increased by 114.80%, 44.49%, and 210.37%, respectively (Uddin et. al., 2014). By contrast, cultivated land, vegetation, water bodies and low land areas have decreased. Urban areas have expanded to the north, northwest and west of Dhaka. Consequently, the area of cultivated land and water bodies decreased during 1960-2000 (Islam et al., 2009). The land use map for Zone 2 was collected from RAJUK 2010 and 2015, and some areas documented as low land or water bodies were determined to be flat land during field work. According to JICA, the 2005 land use map showed that the study area was 22.7 km2. Of this area, settlements comprising housing occupied 10.9 km^2 (48%), commercial and public facilities occupied 1.5 km2 (7%), industries occupied 0.2 km^2 (1%), roads and railways occupied 1.0 km^2 (4%), parks, urban green areas, brick fields and restricted areas occupied 0.7 km^2 (3%), cultivated land, forest, and open spaces occupied 3.6 km^2 (16%), and water bodies and swamps occupied 4.9 km^2 (21%). The population density in Zone 2 is the highest among all the zones of Dhaka. Accordingly, the waste generation rate is very high. The total waste generation from 8 wards of this zone was 516 tons/day. Among this waste, only 50-60% was collected daily dumping at a landfill site, and the rest was unmanaged and uncollected. The total area of the eight administrative wards is 22.7 km^2, of which only 3.6 km^2 remains available for development (Fig. 3.2).

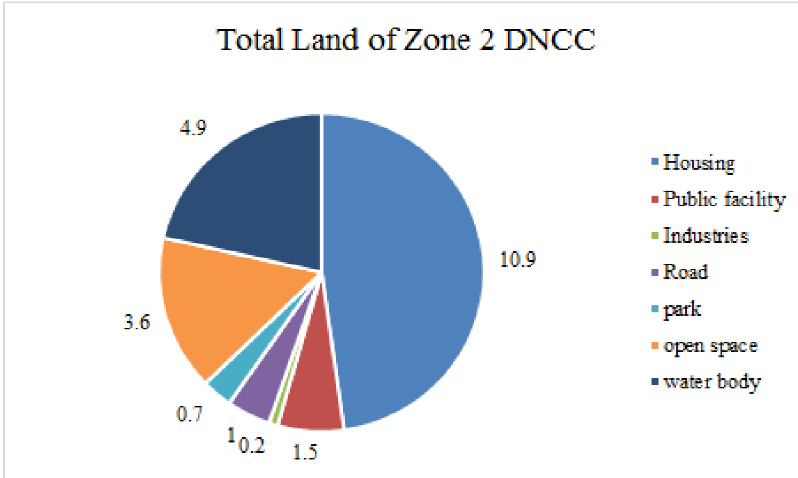


Figure 3.2: Land distribution of Zone 2 (study area), DNCC (Source; JICA, 2005)

3.3 Methodology for site selection of a biogas digester plant

For selection of digester plant site and composting plant site two different conceptual frameworks were used. According to research area size and the management of plants will be different. The sites will be acquired by the Dhaka city authority but the management will be different in the initial stage. Like the biogas plant will control the total zone waste and the regular waste handling capacity at least 600 tons/ day, whereas composting plant would be handle by the local people and PCSP who will use the converted compost to reduce the waste of illegal waste points and enhance the urban agriculture of that wards. Site selection for two plants (Biogas and Composting) has been described separately. Site selection for biogas plants in urban areas requires an extensive evaluation process. The location must comply with government regulations while minimizing economic, environmental, health and social costs (Siddique et al., 1996).

As the area size is small for composting plant and plant will be controlled by the local NGO's and local inhabitants based on their waste management practice and area condition like the waste points location, waste collection condition by the DCC authority, road network for of waste point, sensitive and high risk waste points, vacant land availability all the things were considered dor methodology development.

The conceptual framework for site selection for a biogas digester plant is shown in (Fig. 7). For the analysis, population data were obtained from the Bangladesh Bureau of Statistics (BBS). A digital topographic map and digital geospatial data from Zone 2 were collected from the Survey of Bangladesh (SoB) and Capital Development Authority (RAJUK). The Projected Coordinate System (PCS) for the topographic map was WGS_1984_UTM_Zone_46N (meters, scale, 1:20000). The raster resolution was 10 m. The digital elevation map was defined as the map slope and contour lines of the area. In urban areas, a biogas digester plant must be constructed in an area without important or ecological value but of sufficient size capacity (1 hectare or 10,000 m^2 in the context of Dhaka City) for use in waste conversion for biogas energy production, for site selection the size of the land will be fixed based on the land availability . For the location of waste management facilities, the plant requires stepped procedures that can be described as follows (Fig. 3.3).

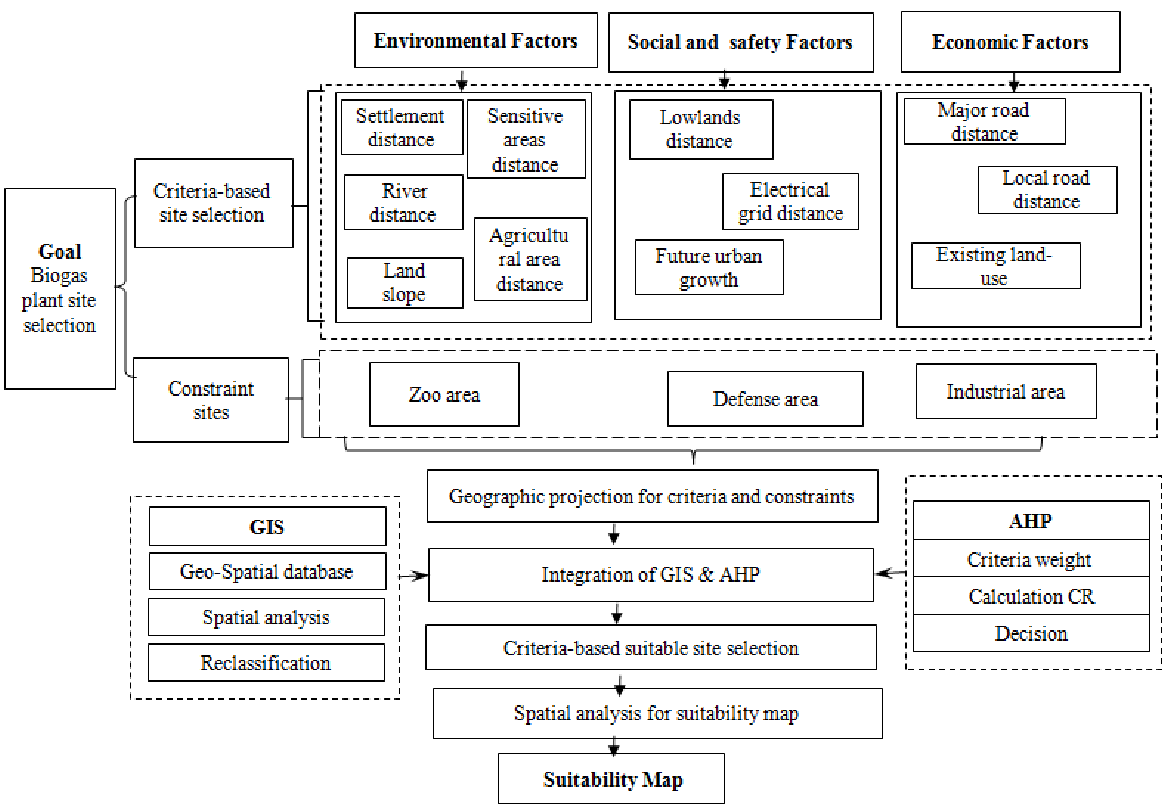


Figure 3.3: Conceptual framework for site suitability assessments for sitting bio digester

3.4 Analytical Hierarchy Process (AHP)

To produce the final suitable site for digester plant actual rating for the parameter or criteria related to this study was required. This was determined based on the AHP analysis. AHP is a widely used method was introduced by Saaty, 1977. AHP is a decision support tool, which can be used to solve complex decision problems. AHP can serve as powerful tool to consider complicated problems that involved several interrelated objectives (Chuang 2001). The priority of each factors criteria were analyzed based on the Expert's opinion. The first step of this analysis was designing a questionnaire to obtain expert opinions to determine the importance of the involved criteria and factors based on the AHP rating scale (Fig. 3.4).

The AHP techniques were followed according to the four steps shown below. Eleven criteria were selected to evaluate the alternatives. Seven experts were selected from government and private organizations to determine the importance of the criteria using the AHP evaluation scale. The relative importance of the criteria for the factors was established using a pairwise comparison matrix. The values were obtained based on the integer values from 1 (equal value) to 9 (extremely different), with higher numbers indicating that the chosen criteria were considered more important.

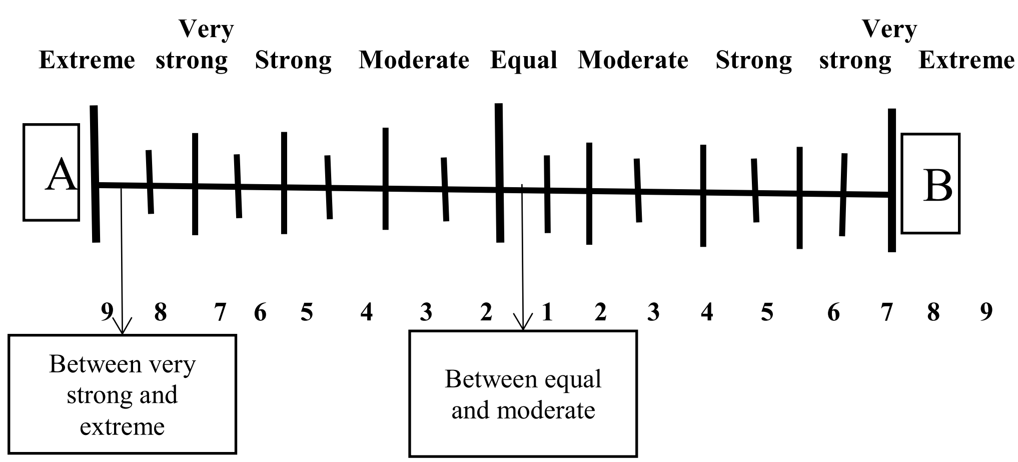


Figure. 3.4: Rating scale for the pair-wise comparison in AHP

than other criteria. Pair wise comparison was done in between the eleven (11) criterions. A comparison matrix among the matrix was developed. The principal eigenvalue and the corresponding normalized right eigenvector of the comparison matrix gave the relative importance of the criteria being compared. The consistency of the matrix was then evaluated. If CR is smaller than 0.10, then the degree of consistency is fairly acceptable. But if it is larger than 0.10, then there are inconsistencies in the evaluation process which was subsequently used to compute the Eigen vector and represented the ranking of criteria. Each criterion is explained in detail below. These explanations include selection of the criteria and how each was evaluated and weighted using the AHP criteria weight. Related figures and tables is also provided.

In the AHP process, the consistency vector, consistency measure, and Eigenvalue (λmx) of the criteria can be expressed as follows:

$$\begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix} + \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix} = \begin{bmatrix} Cv_{11} \\ Cv_{21} \\ Cv_{31} \end{bmatrix} \quad (1)$$

$$Cv_{11} = \frac{1}{W_{11}}[C_{11}W_{11} + C_{12}W_{21} + C_{13}W_{31}]$$
$$Cv_{21} = \frac{1}{W_{11}}[C_{21}W_{11} + C_{22}W_{21} + C_{23}W_{31}] \quad (2)$$

$$Cv_{31} = \frac{1}{W_{11}}[C_{31}W_{11} + C_{32}W_{21} + C_{33}W_{31}]$$
$$\lambda_{max} = \sum_i^n CV_{ij} \quad (3)$$

The approximations of the Consistency index (CI) and Consistency Ratio (CR) can be expressed as:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$
$$CR = \frac{CI}{RI} \quad (5)$$

If $CR < 0.1$, then the judgements are consistent; if $CR > 0.10$ then the judgments are inconsistent

3.5 Criteria Selection

Eleven criteria were selected under three factors, which were defined and classified by the experts and from literature reviews (Table 3). The three identified factors were environmental, social and safety, and economic factors, and the criteria were distance from residence or settlement, low land distance, land slope, sensitive area, river distance, agricultural area distance, major road distance, local road distance, electrical grid distance, existing land, and future urban growth plan. A biogas plant should be situated as far as possible from water and other biophysical elements of ecological and environmental value. The selection of criteria under environmental factors was given the highest priority to avoid residences and sensitive locations due to odor, nuisance and public sentiment. A large amount of waste can be generated in front of a digester plant, which could generate leachet and negatively affects natural resources. The second factor type considered for environmental safety issues was social and safety factors. These factors are important due to the city structure of Dhaka. Third, economic factors are related to financial restrictions and included a consideration of the existing land distribution for land price, distance from major roads and distance from local roads.

Distance from settlement

The biogas digester plant located near to the settlement area introduces various environmental problems. In general waste handling plant should be located at a significant distance away from settlement due to public concerns, such as aesthetics, odor (Tagaries et al., 2003) and health concerns. Biogas digester plant will generate the energy from a fixed place and a sealed digester plant. However, Dhaka is densely populated, and free/open space is limited. Considering these issues, the reclassifications were performed for the criteria in 5 steps. Among the distance steps, a 0-30 m distance from a residence was considered restricted (0), whereas greater than 150 m was considered best (5).

Distance from the sensitive points

Sensitive points mean the building or constructions which were public facility related to health, education like school, college, hospital, clinics and commercial/ official building like office and shopping mall. Zone 2 has 17 hospitals, 29 clinics, 3 universities, more than 100 schools and colleges and mosques & shopping malls. These all were taken as sensitive points for site selection and reclassifications were performed using 5 grades. <100 m distance was taken as restricted or unsuitable and > 500 m distance was graded as 5 or suitable place.

Distance from major road

The proximity to major roads is another crucial criterion that must be considered for biogas plant site selection. Plant site should not be very near to the major and not too far from the existing road network to avoid the waste carrying cost. It is suggested to use existing roads to avoid the high cost of constructing connection roads (Nas et al., 2008). For selecting a plant study analysis fixed the major road distance <150 meter as restricted and 750-1000 m was given the high score 5.

Distance from local roads

Dhaka city's area has been connected with so many local and major roads. Waste collection and transportation is very important for biogas plant, especially for carrying the waste from nearest waste point by van and small trolley local road is required for smooth transportation. NGO's or CBO's were responsible for carrying the household waste from to waste points. If the local road is available with the selected sites, the waste generation for the plant will be smooth. The less distance from the vacant sites was given the high score for ranking. Reclassifications were done following 5 grades, the low distance was given the high score and the high distance of local road from the vacant land were given low scores. <100 m distance of local road were analyzed using 5 score and >500 was scored 0 or unsuitable.

Distance from River

A biogas plant should not be located near rivers or water bodies. The generated waste from a plant digester can produce leachate and contaminate water. A national study in 2000 emphasized that efficient operation of a fixed dome biogas plant requires siting away from flood-prone zones (Biogas Audit Bangladesh, 2011-2013). Floodwater entering the digester could disrupt its operational capacity. The research area is not at high risk for floods. To avoid increases in river water during the rainy season, a 0-500 m distance from the river was considered restricted, whereas distances greater than 2500 m were given the highest rank for site selection.

Distance from low land

According to WHO guideline for biogas plant sitting at least 10 m distance is required from low land, water wells and water source which were followed for analysis (Ref; Final report biogas audit Bangladesh 2011-2013, volume 1). During the fieldwork some of the land were found low and stuck water during rainy season, however during field work some low land (DAP 2010,RAJUK) were found high which was filled with soil and doing some development work, many of low vacant lands were (found plain and perfect for plant selections. Reclassification was performed using 5 steps, a distance of <10 m was considered restricted, whereas a distance of more than 50 m was given the highest rank for the selection of suitable sites.

Slope Map

Slope of the land surface is a crucial factor for biogas plant. Slope profile appears visually attractive to observe across a wider geographical area. The complexity of the area in terms of slope is a vital factor in the suitability analysis for biogas digester plant. The slope was calculated using the pixel basis based on the digital elevation model (DEM) of the study area. Steep slope will lead to high excavation cost. The slope of the land surface is an important factor for biogas plant installation. A 5-10% slope was considered as a gentle slope and given the highest score for the selection of suitable sites.

Distance from Agricultural Land

The land use plan was given the priority for the site selection. In this study land use was divided into four types: built-up area which was covered the 50% of total area, potential built-up area, swamps and water bodies. A distance of 50 m from agricultural land was considered restricted, whereas a distance of greater than 250 m was considered best (highest suitability) for the selection of suitable land.

Proposed Urban Growth

The future/proposed urban growth map was considered as an important criterion for biogas plant site selection. The Dhaka structure plan (RAJUK, 2016-2035) was designed to review the previous structure plan and has been updated with a vision for the city up to the year 2035. GIS analysis was performed considering this future urban growth plan. A score on a suitability scale was given based on input from biogas plant experts.

Existing land use

Government land, private owners and real estate developers dominate land acquisition in Dhaka. There is no control of private land prices. Very few programs have sought to regulate land prices to ensure wider access of people to the land market. To assess land cost criteria, the available land and land types were analyzed and given a priority ranking.

Dhaka is the capital of Bangladesh; it is the focal point and center of all activities in the context of political, social and economic perspective of Bangladesh. The main stream of urbanization process is oriented towards this megacity. To cope up with the heavy pressure of urbanization, Dhaka is in vital need of accurate and systematic information about its land market. Government land, private owner and real estate developers dominate land market of Dhaka. There is no control of land market and over land price and very few programs were undertaken to regulate land price in order to ensure wider access of people land market. To assess land cost criteria, the available land and land types were analyzed and given a priority ranking.

Distance from Electric grid

Dhaka City is subject to vulnerabilities due to tangles of electrical poles and wire cables, and many vacant lands have electrical poles. For safety reasons, vacant land with electrical pole(s) was excluded. Lands that excluded poles within a safe distance were considered for suitable site selection. Electrical energy is required for the digester plant, and the plant should not be located far from an electrical pole. For a biogas plant, the electrical source distance should be minimized (Sandra, 2014). Considering these issues, low and high distances were given the highest ranking (5) for reclassification. Criteria reclassification scale table is given below (Table 3.1)

3.6 Suitable site selection

Suitable sites for a biogas digester plant were developed from the different layers described above. The features were residential areas, lowlands, major roads, local roads, agricultural areas, sensitive sites, restricted areas, slopes, zoos/parks, industrial areas, and digital elevation. The suitability of a site can be expressed as follows:

$$S = \left(\sum_{i=1}^{p} C_i w_i\right)\left(\prod_{j=1}^{q} r_j\right) \qquad (6)$$

S is a suitable site for a digester plant, *Wi* is the weight for criterion *Ci* for site selection, and *rj* is restrictions on site selection. Site selection for biogas digester plants was performed according to the steps outlined below.

3.6.1 Vacant Lands Identification

It was consider that for the suitable site for a biogas plant size of the land in a suitable place was required. A land area of at least 3000 m^2 (0.3 ha) was considered suitable as the site of a biogas plant in the context of zone 2 under north city corporation of Dhaka City. In the primary stage we collected the land use data from survey of Bangladesh (SoB) and RAJUK where we found in total 115 vacant lands those have at least minimum requirement of land 1 hectare/ 3000 m^2. These all 115 vacant lands were located during field work and observed the real present situation. Among this some lands found already covered.

with some construction and some were under construction. Some lands found with stuck water and some lands were with electric pole with transformer. These types of lands were excluded for the analysis. Finally in total 71 vacant lands were found to be suitable for locating a biogas plant with area from 0.3 ha to 3.5 ha and they were analyzed for potential sites of a biogas digester plant.

3.6.2 Constraint Sites:

Constraints, that is, non-compensatory criteria defining the characteristics of an area, should be excluded from suitability analysis. A constraint serves to limit the alternatives under consideration by classifying an area into two classes: unsuitable (value 0) and suitable (value 1) (Mahiti and Ghomalifard, 2006). Considering the location of the study area, 3 sites (zoo/park area, defense area and, ready-made cloth industries and other industries) were considered as constraints, and a constraints map was prepared.

Allowing these 3 restrictions constraints map were prepared following the steps
In the first step of analysis 3 feature files were being added for three buffer analysis and 100m buffering for zoo/park, restricted area and ready-made cloth industrial areas. In the 2nd step using the geo processing tools all the feature files were converting to raster for raster analysis and intermediate layer map were prepared for these 3 constraints and converted to Boolean raster map of each constraint, these Boolean map consider the obstacle map using unsuitable (0 value) and suitable (1value) for the constraint map and finally the using the Raster calculator the final constraint map was formed.

Table 3.1: Criteria reclassification scale rationale considered for analysis

Criteria	Reclassification	Suitability Scale	Reclassification	Suitability Scale	Reclassification Scale Rationale (Context of Dhaka, Bangladesh)
Settlement or distance of R/A	<30	0(Restricted)	91-120	3	As per other landfill site selections in Dhaka, the distance from settlements was reclassified, and a rank was given for waste management (Hasan, *et al.* 2009).
	30-60	1	121-150	4	
	61-90	2	>150	5	
Land slope	<1	1	10.1-12.5	3	The land slope parameter was reclassified using different scales, and >5-10 % was given the highest rank.
	1-2.5	2	12.6-15	2	
	2.6-5	4	>15	1	
	5.1-10	5		5	
Distance from low land	<10	0(Restricted)	31-40	3	Fieldwork revealed that most of the low lands were flat and could be used for future purposes. Due to the scarcity of available open spaces, a distance of 50 m was given the highest rank for locating suitable places.
	10-20	1	41-50	4	
	21-30	2	>50	5	
Distance from river	0-500	0	1501-2000	3	To protect water bodies in case of leachate contamination from deposited waste.
	501-1000	1	2001-2500	4	
	1001-1500	2	>2500	5	
Distance from agricultural land	<50	0(Restricted)	151-200	3	In the DMDP project, agricultural areas are protected to ensure food supply. The restricted distance from agricultural land was given consideration to avoid possible hazards (Hasan *et al.* 2009). In the analysis, a distance of greater than 250 m was given the highest rank.
	51-100	1	201-250	4	
	101-150	2	>250	5	
Distance from sensitive areas	<100	0 (Restricted)	301-400	3	Sensitive areas include hospitals, clinics, schools, colleges, and religious places. Bus stops and other public places are also considered sensitive locations.
	100-200	1	401-500	4	
	201-300	2	>500	5	
Distance from major roads	<150 m	0(Restricted)	601-750	4	The distance from major roads is important. In Dhaka City, vacant lands near major roads are not available. Biogas plant also required separate places to install. A greater distance may increase costs. Based on the city requirements, a score was given.
	150-300m	1	750-1000	5	
	301-450	2			
	451-600	3			
Distance from local roads	<100	5	301-400	2	To carry waste smoothly, Local roads should be available for van and truck movement. The proposed plant is required to handle waste from Zone 2, with vans and small trucks carrying waste to the plant instead of the nearest waste points. A closer distance to local roads was given a higher rank.
	101-200	4	401-500	1	
	201-300	3	>500	0 (Restricted)	
Distance from electrical grid	0-50	5	151-200	2	For social safety reasons, vacant lands with electrical poles were excluded from the analysis. However, a higher capacity of electrical supply is also required for the digester plant, and the distance should not be far from an electrical pole.
	51-100	4	>200	1	
	101-150	3			
Proposed urban growth	Commercial zone/			3	Open space is required for public functions and sustainable development of cities. Due to rapid urbanization, open space in Dhaka is quickly disappearing. Dhaka has many scattered open spaces, which were ranked according to RAJUK proposals for urban growth. Those places were scored as 5 for the analysis.
	Road Network/ Transport			0 (Restricted)	
	Institutional zone /Water retention area/Flood flow zone/Low land			2	
	Urban Residential Area			1	
	General Industrial zone			4	
	Open space/Overlay Zone			5	
Existing land and land cost	Restricted (Cantonment/Commercial offices/Garments industry)			0(Restricted)	The present land use map was considered important. Open land or plain land was considered as low land. Vacant land could be public or private property and thus may involve land costs and an acquisition process.
	Residential/ Recreation or Commercial activity/ Education/Research/ Agri. Area.			1	
	Park/ Play ground			2	
	Public facility			3	
	Mixed areas			4	
	Open land/ Forest/Char Island/ low land			5	

3.6.3 Criteria based Suitable Site Map Preparation using Overlay Operation

For suitability map AHP was used on each criteria layer attributes, and raster calculator tools within ArcGIS Spatial Analyst environment were utilized for evaluation. After created the constraint map, the next step was the preparation of a criteria-based suitable site map. The map of the criteria's features was first converted to raster, and criteria distances were obtained based on the Euclidean distance (output cell size was taken based on one DEM). The criteria weights were counted from the AHP scale, and all criteria with fewer than three factors were reclassified from grade 1 to 5 using spatial analysis tools. After the reclassification, weighted overlay analysis was performed with each criterion weighted based on the AHP.

3.6.4 Suitable Sites Identified based on Constraint Map and Criteria Map

In this phase, the constraint and criteria maps were combined to identify unsuitable sites. Sites were classified as most suitable, suitable, moderately suitable, less suitable, and not suitable and located on this combined map. A spatial analysis was performed using constraint- and criteria-based maps (Fig. 3.5) used to locate the most suitable sites for biogas plant installation.

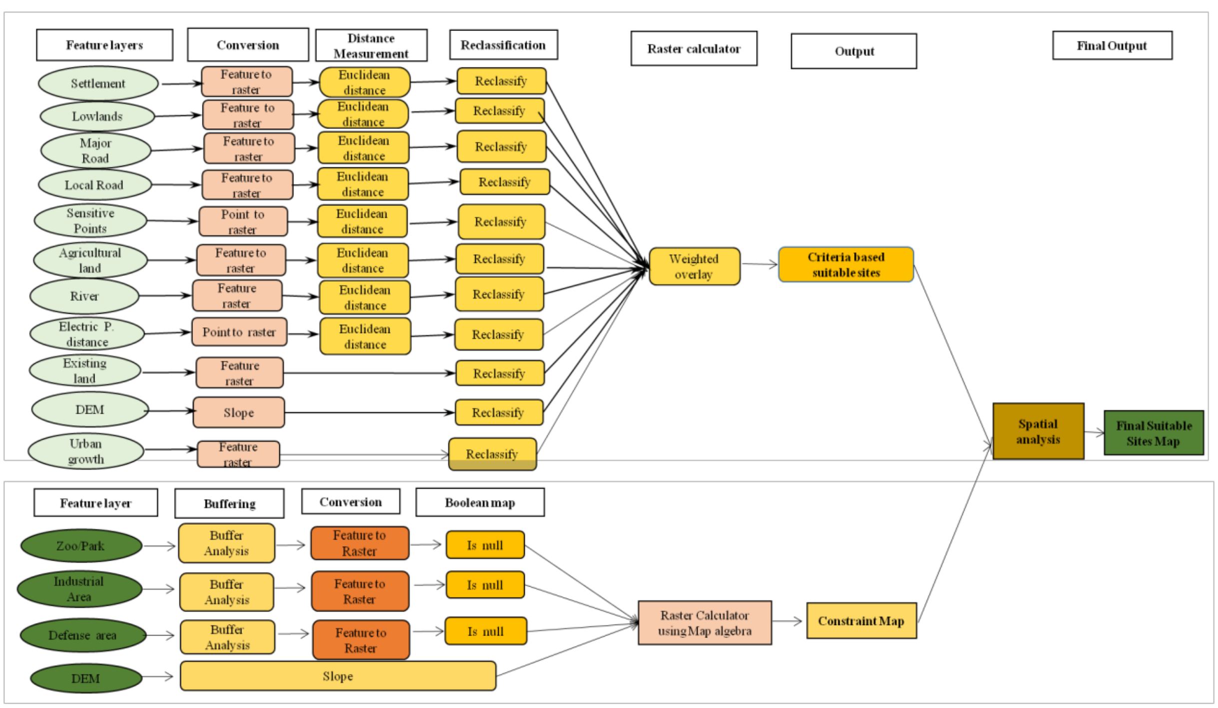


Figure 3.5: Spatial analysis for suitable site map

3.7 Energy production from Biogas Digester

There are various methods available for the treatment of organic waste but anaerobic digestion appears to be a promising approach (Lee et al., 2009). In Dhaka the Municipal solid waste are generating from residence and commercial places mainly. The following graph shows the physical composition of organic waste from the north part of Dhaka (Islam N. 2015). Waste characteristics and compositions are very important for generating the energy from waste. In Bangladesh, the municipal waste contains a big percentage of moisture (72-80%). For the incineration technology high moisture is affect greatly as because of the lower calorific value of the waste, however in the case of anaerobic digester (AD), water is generally added to the digestion process, thus, the amount of moisture in the waste will not be a problem in an AD system Boullagui et al.

In the study area, Zone 2 of DNCC is one of the most densely populated and highest waste-generating zones. In 2005, a JICA study performed in 10 zones of Dhaka indicated that zone 8 (presently Zone 2 of DNCC in the study area) generated the highest amount of waste, with a very low collection rate for dumping. This research survey (2016) showed that Zone 2 (Previous zone 8) of DNCC had the highest waste generation among all other zones, with very poor collection (Fig. 3.6). This uncollected waste could be used to generate biogas from the biodegradable waste and produce heat and electricity.

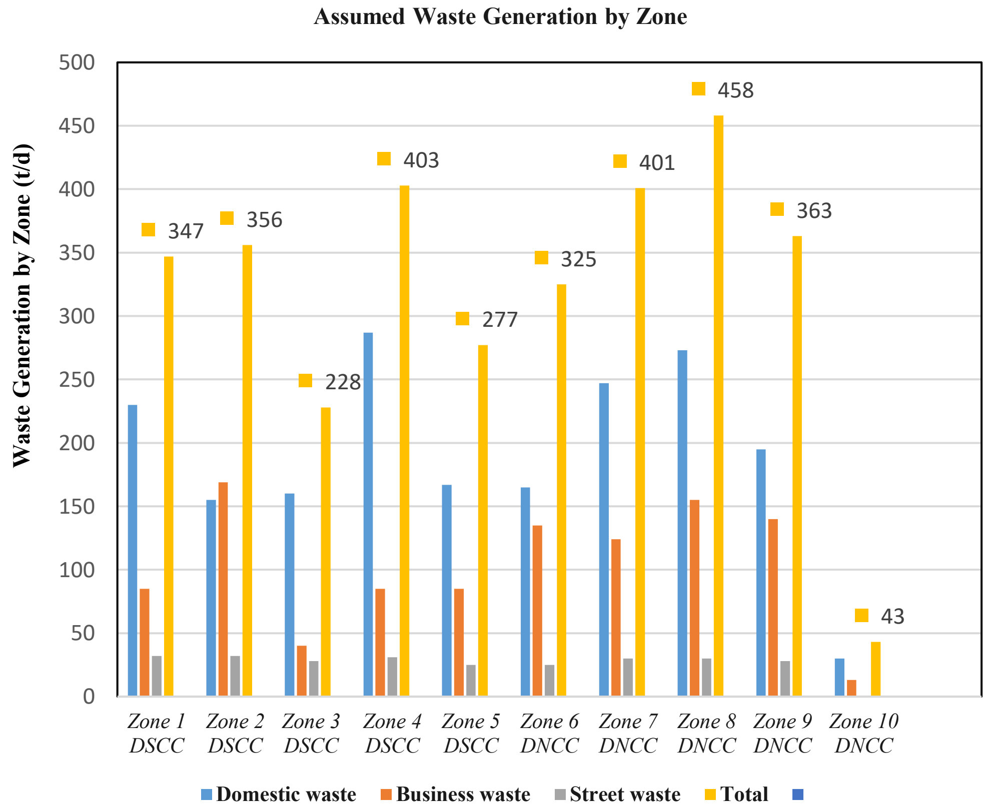


Fig 3.6: Zone wise waste management situation (JICA, 2005)

Presently Dhaka city is handling the waste using 2 landfills. The final disposal of waste is done in landfill sites. Among 2 landfills Matuail landfill is semi aerobic where the methane –dioxide, oxygen and odorous gases release through pipes, this landfill is handling Dhaka south part (total 5 zones of DSCC) wastes. On the other hand, the north part of Dhaka cities wastes was handling by Aminbazar landfill, still it was using as open dumping and going to be constructing as sanitary landfill soon. The waste handling facility of these two landfills is not enough to manage the generated waste of Dhaka (Fig. 3.7).

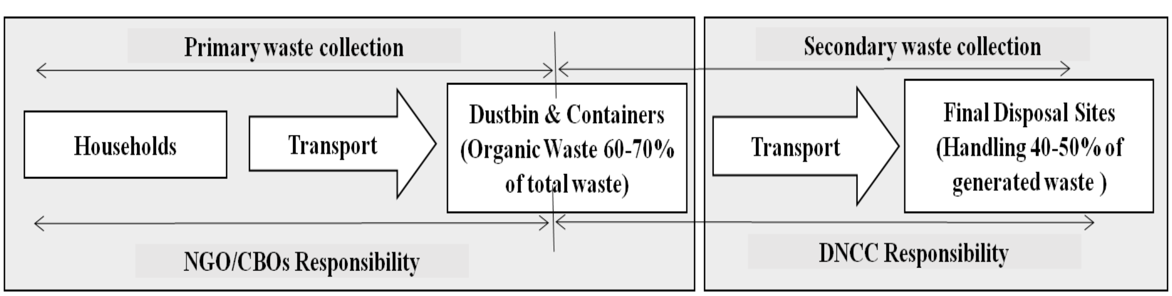


Figure 3.7: Dhaka city waste collection steps

This condition found very unfavorable for the environment and for the localities as well. The scenario of this zone showed that the uncollected waste can be generated biogas from the biodegradable waste and produce a heat and electricity. The biogas production requires energy at four stage such as collection and transportation of the substrates, operation of the biogas plant, upgrading the biogas and finally spreading at digester (Berglund and Borjesson,2016). For Dhaka City MSW was dumped in the 2 landfills where still the gases release control was not scientific. Record showed that in the month of June 2016 from the 36 wards of Dhaka North City Corporation waste generated 67,981t/m and 2251 t/d. In the study area (total 8 wards of Zone 2, DNCC) the generation was 420 t/d and 13,019 t/m. Biogas production process started from the input of various like MSW, industrial waste, sludge etc. To get the optimum biogas the composition of substrates should have specific characteristics and the absence of required nutrients in the substrates needs pretreatment. The biogas production process from MSW in Dhaka city can be following (Fig. 3.8)

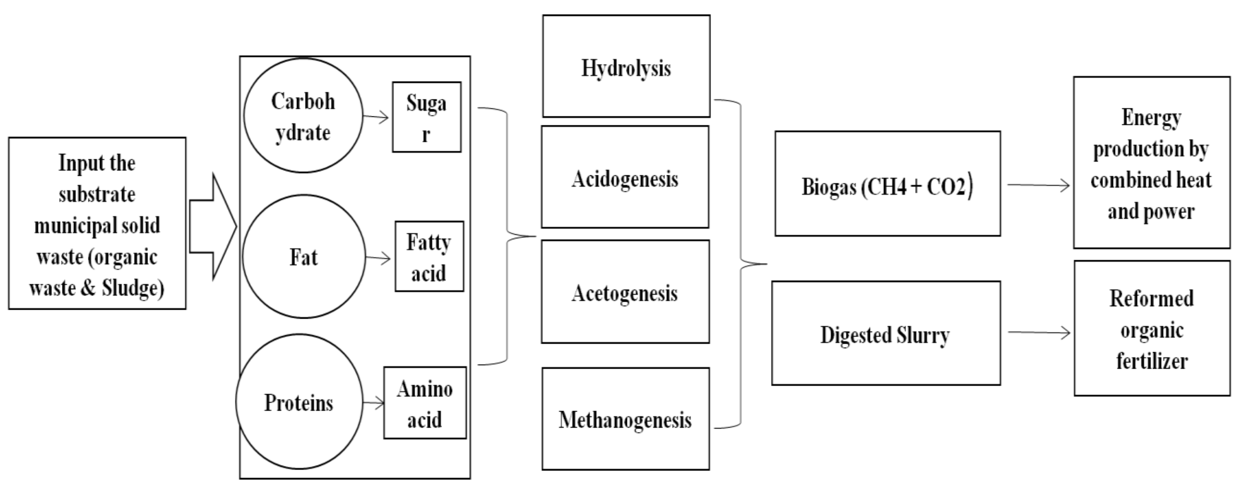


Figure 3.8: Biogas production process

In this research, the waste to energy potential of the organic waste of Zone 2 was calculated for the years 2015-2025. The forecast energy potentials from municipal solid waste generation were calculated using the following formula.

$$W_q = P_o[(1+r)^y]\times W_r\times\frac{1}{1000} \quad (7)$$

Here, Wq is total waste generation, P_0 is the initial population (BBS, 2011), r represents the percentage of the growth rate, y is the year, and Wr is the per capita waste generation.

Biogas production requires energy at four stages: the collection and transportation of the substrates, operation of the biogas plant, upgrading of the biogas, and, finally, spreading at the digester (Berglund and Borjesson, 2006). The biogas potentials from Zone 2 of DNCC were based on the IPCC framework. The biogas production process begins with the input of various substrates such as MSW, industrial waste, and sludge. To obtain optimum biogas, the composition of the substrates should have specific characteristics, and pretreatment may be required is required nutrients are absent in the substrates. The biogas production process from waste generated in zone 2 followed IPCC Guideline methods described for CH_4 emissions. The use of the IPCC default method produces good estimates of the yearly emissions; increasing the amount of waste disposal will lead to an overestimation, and decreasing the amount will result in an underestimation of yearly emissions. For this study, the IPCC default method was chosen because CH_4 will be measured under anaerobic conditions annually. CH_4 generation from Zone 2 organic waste using anaerobic digestion following the IPCC default method was calculated using the following expression:

$$CH_{4\,Emissions} = \left(MSW_T\times MSW_F\times MCF\times DOC\times DOC_F\times F\times\frac{16}{12} - R\right)\times(1-OX) \quad (8)$$

CH_4 is the emission of methane (tons/year), *MSWT* is the total MSW generated (tons/year), and MSWF is the fraction of waste disposed of in the digester. *X* is 16/12, a conversion factor for converting C to CH_4. MCF is a methane correction factor (fraction) and a coefficient for the disposal of different types of solid waste. The IPCC guidelines include *MCF* values of 1 for managed or anaerobic sites and 0.4 to 0.8 for unmanaged sites. *DOC* is the degradable organic carbon; IPCC guidelines provide one equation for DOC: *DOC* = 0.4 (*P*) x 0.17(*G*) x0.15 (*F*) x0.30 (*W*), where *P* is paper waste, *F* is food or kitchen waste, *G* is garden waste, and *W* is wood waste. *DOCF* is the Fraction *DOC* dissimilated; a default value of 0.77 was considered according to IPCC guidelines. *F* is the fraction of methane; 0.5 is the IPCC default value. *R* is the recovered CH_4 (tons/year); for Dhaka waste, *R* is 0. *OX* is the oxidation factor; for Dhaka waste, it was assumed that 1 m^3/t CH_4 generates 2 KW of electricity and that biogas contains 60% CH_4, which generates 2 kw/m^3 electricity. A CH_4 volume conversion factor of 676 m3/ton of CH_4 was used.

Methodology for Site Selection of a Composting Plant

3.8 Detailed Area Map of Research Area

For the selection of composting site in ward 8, study used the Detailed Area Plan (DAP) of RAJUK. Detailed Area Plan provides the basic infrastructure and services in the study area through systematic planning. As my research findings will provide a guideline to develop a program for public sector action aiming at the implementation of the plan and gave me the initial guideline for future infrastructure development as well. To reallocate the waste dumping point and suitable composting point Detailed Area Plan of RAJUK helped me to prepare the database in a professional manner.

This part of study focused mainly on domestic solid waste management in Ward-8, Mirpur, Zone-2 of Dhaka North City Corporation. The data used in this study were derived from Survey in the study area through the structured questionnaire for the Household owner, Primary Collection service providers and Meeting with the Dhaka City Corporation officials and the JOCV, JICA of the respective area. Qualitative and quantitative analysis were performed using weighted average to find out sensitive locations, road networks and uncollected waste as the criteria of suitable composting site selection. Moreover, suitable sites for composting were located based on land type, accessibility and environmental considerations.

Intensive observation was done of the PCSP waste collection from the household daily, Route Network, waste dumping in the DCC dumping point and DCC waste collections and transportation from the dumping sites. Collection schedule of City Corporation small waste point and illegal waste point in the area was also observed and maintained record during the survey period.

The aim of this study was to analyze the present waste management situation in the research area of Ward 8 Mirpur which is consists of 21 Mahalla and evaluate the problems that arose due to short comings of proper waste management system. Based on the analysis and related literature reviews, a model need to develop that could be able to improve the waste management situation. The revealed technology for amendments in the system through GIS based model would reduce the waste management workload to some extent and the conversion of Household Waste to Compost for the potential urban agriculture for a sustainable environment.

3.9 Waste Generation Sites

For selection the composting site this study was performed in ward 8 of Zone 2 for handling the waste of that ward using the selected composting plant. The composting plant site selection was done to develop waste management, including waste reduction and collection techniques, with geographical positions.

First, the total area waste sites location was identified as large waste sites, small waste sites, and illegal waste sites (Fig. 3.10). A total of 81 waste sites were identified in ward 8 of Zone 2, where 6 % found to be DNCC large waste sites, 13 % DNCC small waste sites, and 81 % illegal waste sites created because of the inadequate provision of bins and access to waste collection bins (Fig. 3.11), some glimpses were also given (Fig. 3.12). Technical criteria consisting of the size of the waste sites, truck parking for waste collection, access to waste disposal by PCSP, and distance from the main source of waste consumption were taken into consideration to identify very suitable, moderately suitable, or less suitable waste sites for relocation of waste sites to improve the waste management condition of ward 8. The position of waste sites is one of the important factor criteria for locating a suitable composting sites. Proximity analysis was performed with a 30 m buffer for all waste sites. Waste sites located near publicly sensitive area like sensitive buildings, according to waste sensitivity scores of 7–9, were identified, with high scores corresponding to high-sensitivity waste sites and low-scoring sites suggested for relocation (Table 3.2).

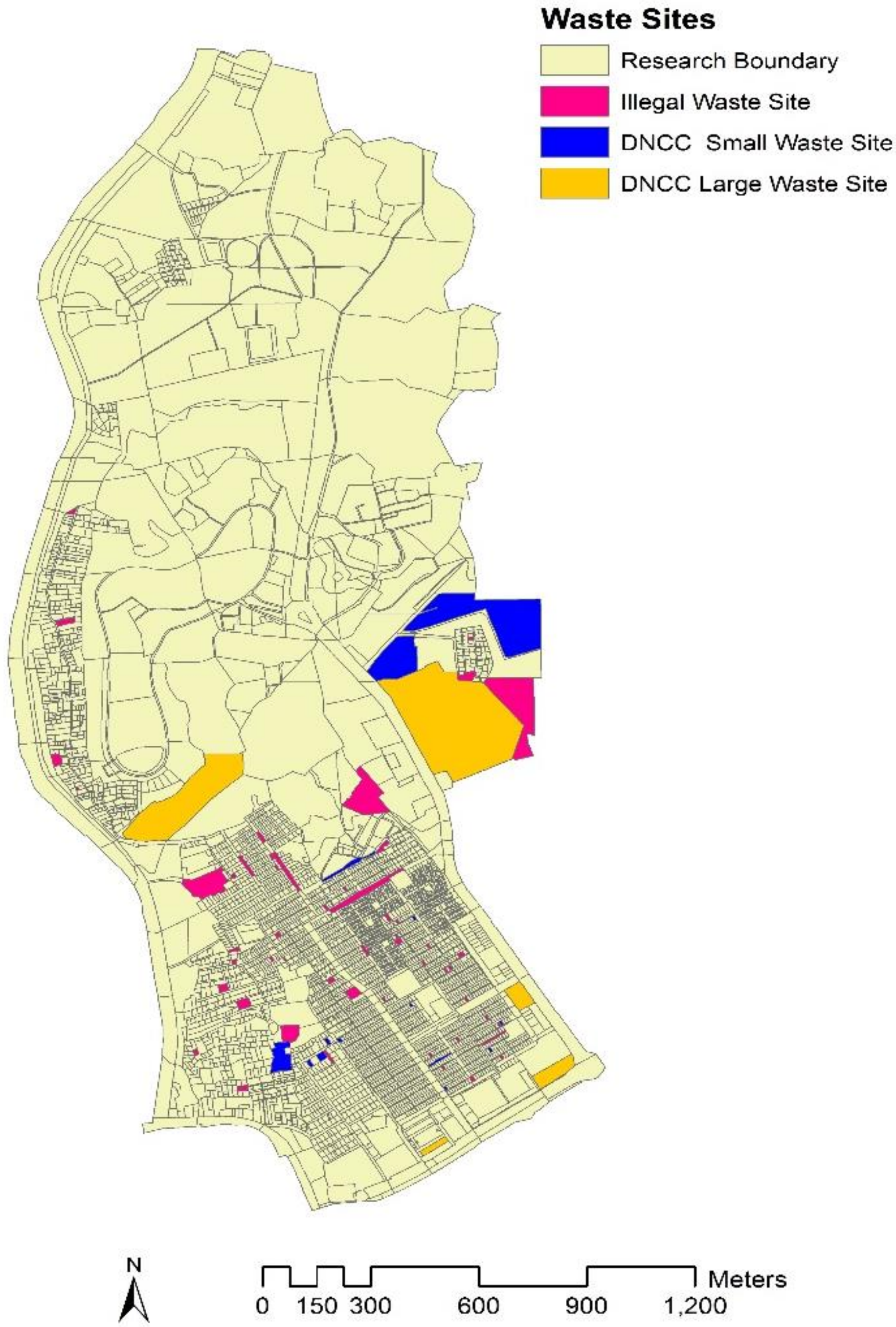


Figure 3.9: Waste sites in research area (Ward 8)

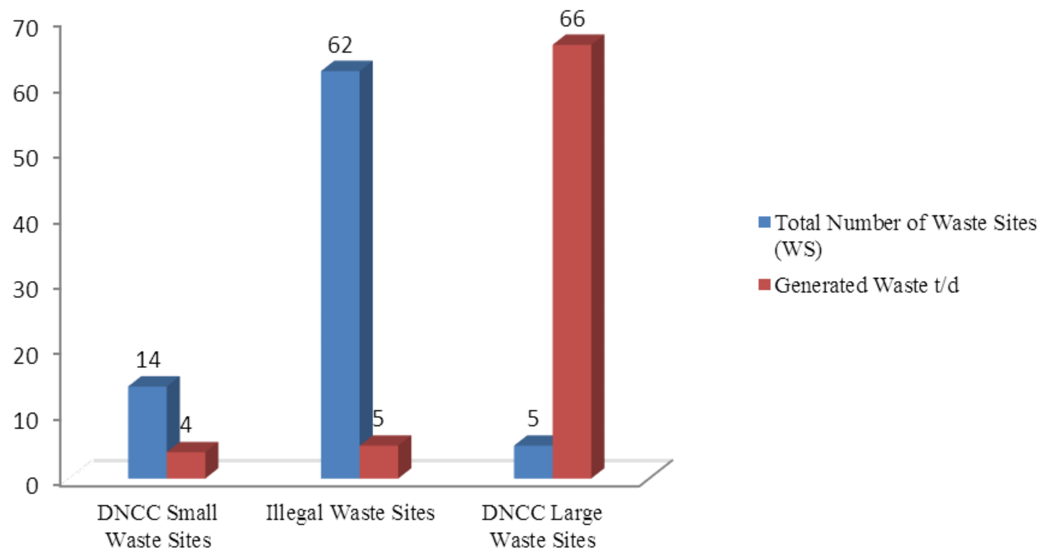


Figure 3.10: Waste sites and generated wastes at study area

a. Large Waste Point

b. Small Waste Point

c. Illegal Waste Point

Figure 3.11: Glimpses of Waste Points in Study Area (Ward 8)

Table 3.2: Waste Site Sensitivity (WSS) score

Waste sites Distance (Meter)	Waste sites Location	Score
0–500	Hospital, Mosque, Educational Institution.	9
	Road Intersection	7
	Residential Area	5
500–1,000	Residential Area	3
1,000-2,000	No sensitive site	1

3.10 Data Integration in GIS Module

This part of study was analyzed the current waste management situation in ward 8. A conceptual framework and research diagram using GIS is proposed (Fig 3.13). ESRI ArcGIS 10® was used for mapping and data analysis. At the beginning, establishment of a spatial database of waste sites, availability of waste bins, waste segregation, type of waste site, waste collection trip, PCSP records, and land use and type based on environments. Secondly, GIS analysis was performed to visualize area wise collection status of waste, and identification of sensitive waste sites. Georeferencing was performed using WGS84 and BTM projections. A Garmin® handheld GPS was used to collect positional information to sub-meter accuracy. Thirdly, attributes were selected for composting sites applicable to vacant land for initiating urban agriculture in ward 8. Fourthly, criteria and constraints were categorized to evaluate the attributes. Finally, GIS analysis was performed to find the best suitable composting site.

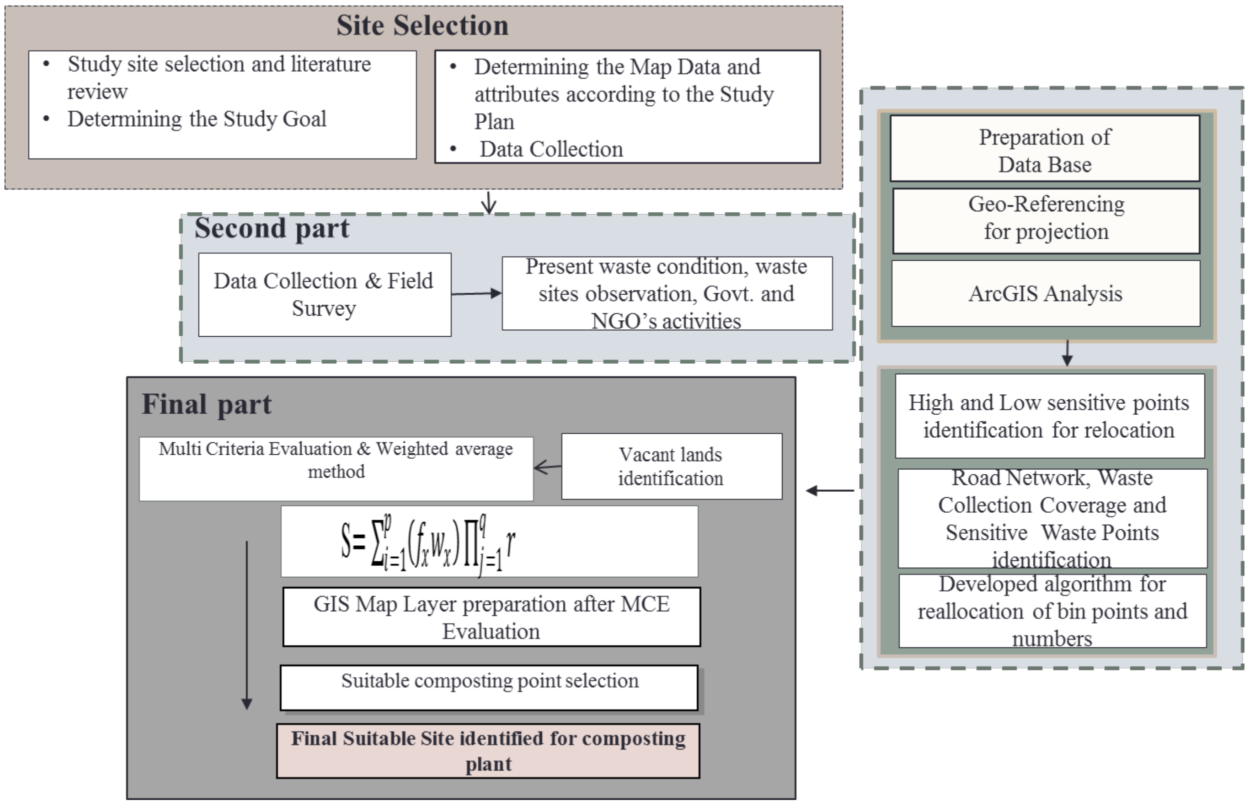


Figure 3.12: Research Conceptual Framework

3.11 Spatial Multi-Criteria Evaluation (SMCE) for Locating Suitable Sites

Multi-criteria analysis is a sequence of processes in which several decisions has to take for the problem recognition and ends with recommendations. Any sort of decision-making is depending on three basic phases (Shari and Retsios, 2004).

Searching Phase

This phase involves searching or looking for the decision of environment for analysis. The data acquisition, storage, retrieval and management functions convert the real world situation into GIS database during this phase.

Design Phase

The next phase was the design phase involves inventing and analyzing a set of possible solutions to problem identified in the intelligence phase. Design phase represented the decision situation by structuring and formalizing the available data and information about the decision problem.

Choice Phase

Decision rules for locating suitable sites for best composting point has been prepared based on multi criteria analysis process. The decision rules for site suitability for solid waste disposal. In the decision process, at this phase each alternative is evaluated and analyzed in relation to others in terms of specific decision rules. The rule is used to rank the alternatives under consideration. The ranking depends upon the decision maker is preference. In general, GIS does not provide a mechanism for representing choice and priority in context of evaluating conflicting criteria and objectives. Under these circumstances, the ultimate success of GIS in decision making depends on how well the system can succeeded as a spatial decision support system in the decision making process.

Some definitions

Alternatives: A decision is a choice between alternatives. The alternatives may represent different courses of action, different hypotheses about the character of a feature, different sets of features, and so on.

Criterion: A criterion is some basis for a decision than can be measured and evaluated. It the evidence upon which a decision is based. Criteria can be of two kinds: factors and constraints.

Factor: A Factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. It is therefore measured on a continuous scale.

Constraint: A constraint serves to limit the alternatives under consideration.

Decision Rule: Decision Rule is the procedure by which criteria are combined to arrive at a particular evaluation, and by which evaluations are compared and acted upon, is known as a decision rule.

As per my study one of the focuses is to locate one suitable composting point for converting the household organic waste to compost by the local NGO or Primary Collection Service Provider. Multi Criteria Evaluation was done according to the formula 10 where the following factors, Criterion and constraints were considered:

Factors for best point are Land ownership, Land Type and Environmental consideration based on the locality and industrial area.

Attribute of Factor are Public land, Private Land, wetlands, plains land, population density.

Criterion of Factors are Uncollected waste, Poor road network waste point and Sensitive location of waste point.

Constraints are Efficient collection service by PCSP, inappropriate odour compounds facility, Plain water contaminations.

Attribute of Constraints are continuing door to door collection, Site drainage Run on to the clean water body and leachet management.

Multi-criteria analysis is a sequence of processes in which several decisions are made for problem recognition, and recommendations are generated (Shari and Retsios, 2004). In the evaluation process of SMCE data acquisition, storage, retrieval, and management functions are performed based on the GIS database and converted to the real-world situation. The design phase involves developing and analyzing possible solutions to the problem identified in the searching phase (Fig. 3.14). The site selection process was performed on the basis of the design phase and choice phase after obtaining the decisions of criteria and factors at the evaluation phase. SMCE was applied to identify potential areas on the basis of their socioeconomic characteristics to make final recommendations for the best composting sites in the study area for reducing the waste load.

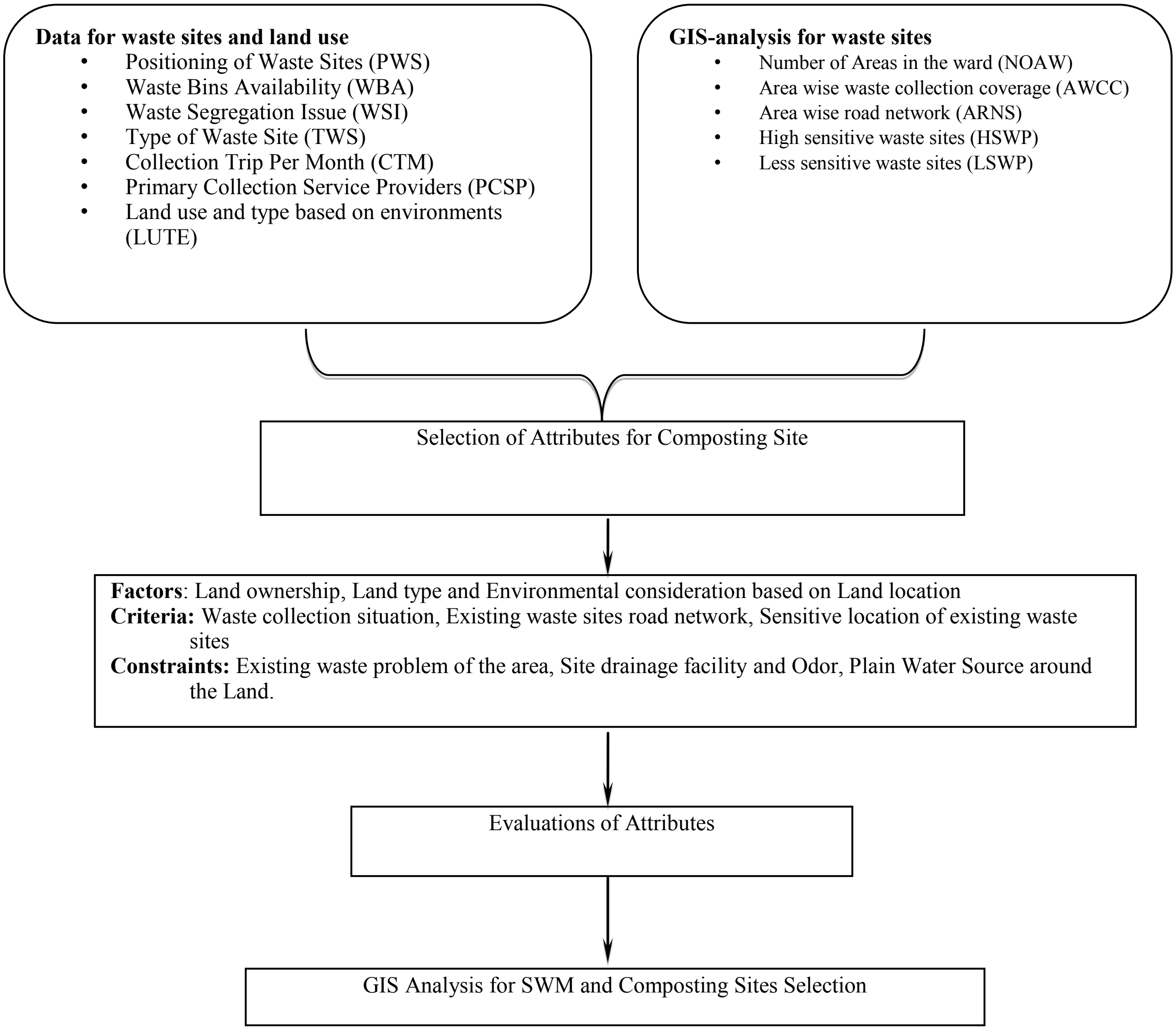


Figure 3.13: Spatial Decision Support System (SDSS) for Solid Waste Management

The evaluation criteria characteristics reflect the impact of a site on several spatial (and sometimes nonspatial) aspects. These criteria can be assessed only for a potential site. The factors, criteria are listed in the procedures of SMCE graph (Fig 3.15). In the choice phase of the site selection process, the suitability of each site identified as a potential site was assessed by multi criteria evaluation (MCE) analysis. In the study, vacant lands were identified of ward 8 for land suitability analysis. Among the sites, MCE analysis was performed considering factors of land ownership (public or private land), land type (wet or plain land), and environmental consideration based on land location, such as whether the vacant sites were within the locality or detached from the locality. These factors were scored by study criteria including waste collection conditions, road network, and sensitivity of waste site locations to these constraints or to obstacles such as poor PCSP service, unpleasant odors, and plain water source.

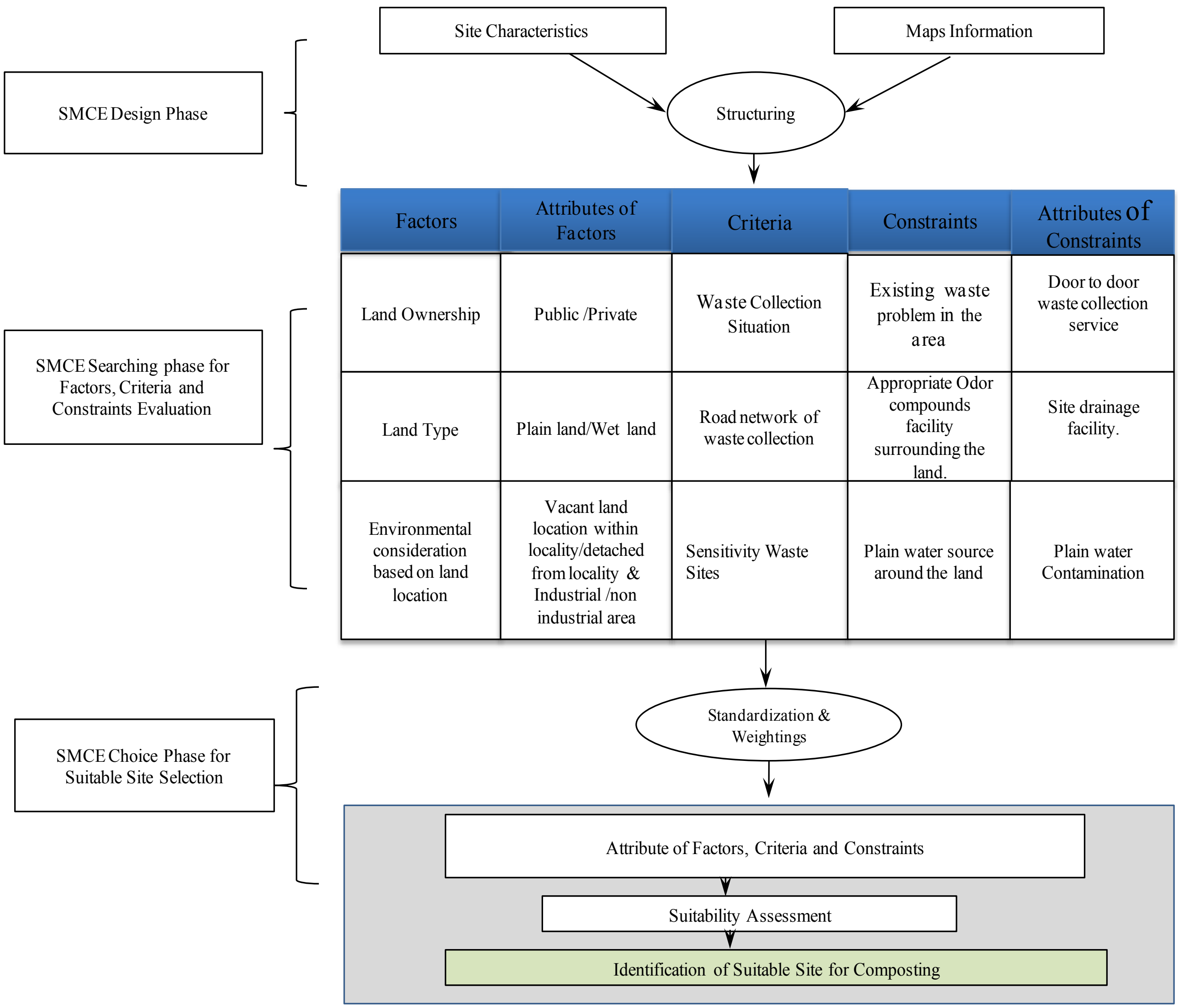


Figure. 3.14: Procedure of Spatial Multi-Criteria Evaluation (SMCE) for the Selection of Composting Site

3.12 Site Selection and MCE

By use of a weighted linear combination, factors were combined by application of a weight to each followed by summation of results to yield a suitability map. The weighted evaluation may be expressed as follows:

$$S = \sum w_i x_i \tag{9}$$

where, S is suitability, w are weights of factors, and x are criterion scores of factors. The procedure was modified by multiplication by the suitability calculated from the factors and constraints. The modified suitability can be expressed as follows:

$$S = \sum_{i=1}^{p} (f_x w_x) \prod_{j=1}^{q} r \tag{10}$$

i is the factor, p is total number of factors, and *x* is the weight of the factor. *fx* is resultant summation between the weight of the factor and the type of attribute for that factor. *wx* is the summation among the weight of criteria. *j* is the constraint and q is the total number of constraints. *r* is the product between the constraints and type of attribute for that constraints.

3.13 Reallocation of Waste Bins

As this ward was the highest waste generating ward of Zone 2 and collection rate was also poor so reallocation of waste bins was analyzed of this area on the basis of population density, waste collection equipment, waste container capacity, and daily stored waste amounts. The total number of required bins was calculated to cover the waste production of the sector for seven trips per week; we considered the collection efficiency for all data sources to be approximately 50 %, apparently a theoretical assumption. The number of required bins (N) was calculated from the following expression:

$$N = \frac{WD}{V \times \rho \times \varepsilon} \tag{11}$$

where, WD (t) is the daily waste quantity including the waste deposited outside of the bin, V (m^3/bin) is the bin capacity, ε is the coefficient of filling bin relates to waste density (0.80), ρ is the waste density and considered from 0.35 to 0.80 t/m^3. In this study ρ was assumed as 0.56 t/m^3 (Yousuf, 2007).

3.14 Initiative of Urban Agriculture

As significant portion of waste dominated by organic waste, total waste could reasonably be reduced by composting of organic waste. At present about 2–5% of total waste get composted. This amount could easily be increased by establishing community based composting plan in the locality. Proper solid waste management is difficult for the lacking of financial and institutional capability of DCC, community based initiatives can be focused on composting can reduce the haphazard waste originated at the household level and using of that compost in the Yard or Rooftop for garden. It will help to reduce the total amount of waste quite substantially. This will release the pressure on the local government for the collection and final disposal of the waste. Our baseline survey using structured questionnaire showed that more than 80% waste was organic, unsegregated, and dumped into the 81 located points. PCSP/NGOs had a significant role for waste collection nowadays, the waste management situation was better with the help of Dhaka City Corporation PCSP could collect the organic waste from the household and could stored a specific place for composting and start decentralized composting with the help of City corporation and the ready compost can be provided among the household owner for their rooftop garden or Urban agriculture. City dwellers attitude toward future initiatives for urban agriculture through the composting were found very positive during the study.

Form our survey using the structured questionnaire among household owner it was informed that they enjoy gardening and they think that their roofs are suitable for gardening and do not require any improvement work for starting the urban agriculture anytime. The results of survey regarding the urban agriculture is given in the results section.

Chapter 4

Results and Discussion

To achieve a sustainable MSWM for Dhaka city Zone wise management is required. Presently Dhaka city has 10 zones and based on the research and literature review it is found that the Zone wise management is done for primary or secondary waste collection, final disposal is done combinedly which because of the landfill scarcity of the city and lacking of waste handling technologies. These studies have revealed the zone wise final waste handling techniques specially the 70-80% organic waste generated from the zone that can be converted to energy and compost using the plants. It will help to accelerate the demand to reduce the environmental, social impact of uncared waste in the zone. Sitting a biogas plant and a composting plant in a zone is the possible long term and short term recommendation to achieve a sustainable MSWM. Firstly, long term strategic framework of municipal solid waste management of Dhaka city authority, second are about some immediate action program that could be taken by the local people and NGO's/PCSP to reduce the illegal waste points waste immediately. The results of research are given below accordingly.

4.1 Selection of Biogas Plant's Location

The study aimed to identify the most suitable sites for digester plant installation in the northern part of Dhaka City. Study observed that the energy generation from the municipal waste can make some significant changes of the study area. The municipal waste generation confirmed the potential to generate energy from a biogas digester plant. Three different factors: Environmental, social and economic factors were analyzed using selected criteria for suitability site analysis to install the biogas digester plant. Under those factors, the criteria-based and constraints maps were generated. For GIS-based analysis, two different data models were generated: vector and raster. Some files were generated as vector and some were as raster. For sitting a biogas digester plants all the vectors files were converted to raster formats. The techniques were followed like extended vicinity analysis using Euclidean distance or proximity analysis of criteria's immediate surrounding area analysis using the calculation of slope and some local analysis using reclassification map production. The results of each step are given below:

4.1.1 Restriction Model for Constraints

In the first step the restriction map or the constraint map were prepared and fixed the constraint area for suitability analysis. Constraints were identified based on the location of the area and which were not included in the criteria list (Fig. 4.1)

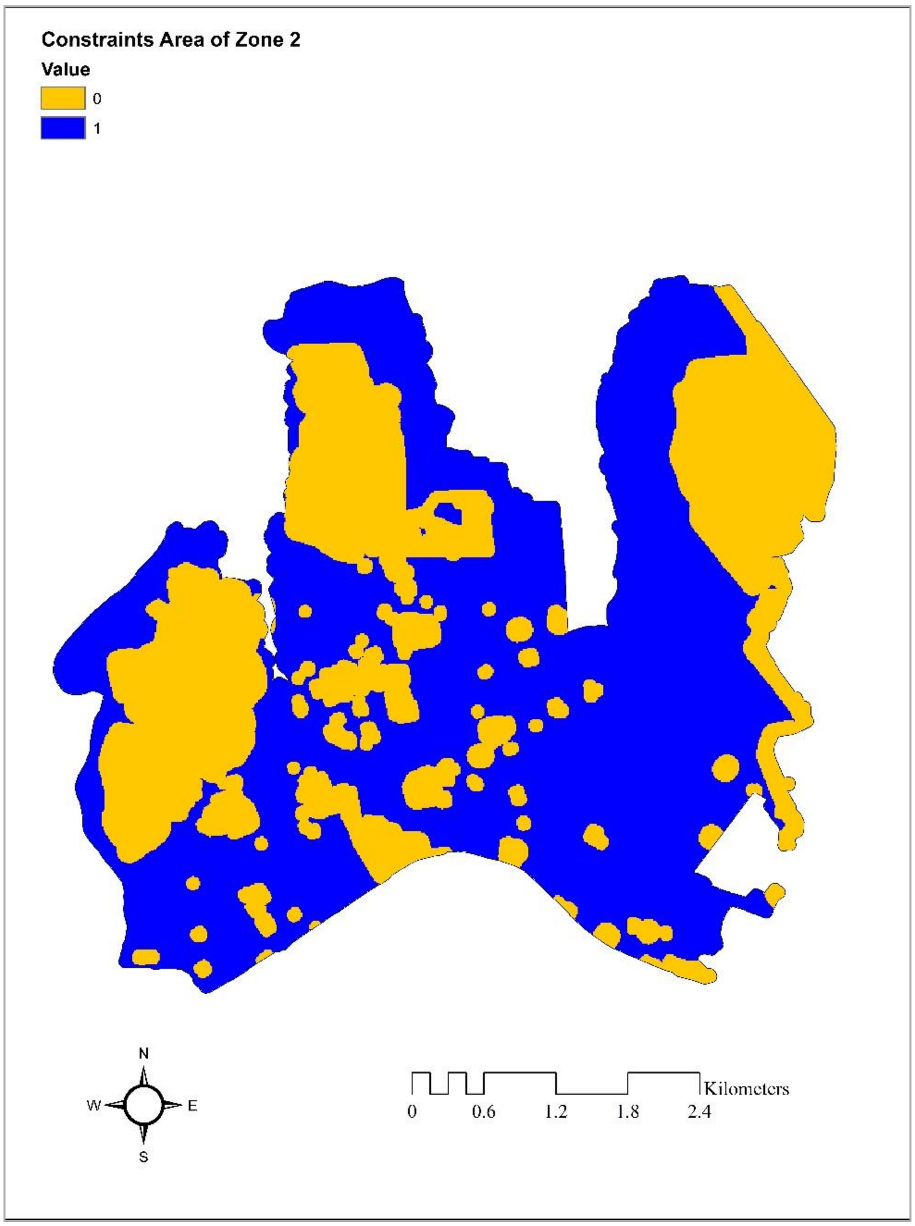


Figure 4.1: Constraint area identified in Zone 2 of Dhaka City

4.1.2 Criteria Weight from Analytical Hierarchy Process

A hierarchical process was used to select the suitable sites for installation of a biogas digester plant. The cardinal rankings for criteria were determined for each judge separately by pairwise comparison. Two alternatives and the relative importance of these two criteria were considered and output as a ranking. The comparison matrix was developed from the 11 criteria (Table 4.1). To produce the matrix, seven expert opinions were collected and analyzed to determine the final weight and ranking of criteria (Table 4.2).

Table 4.1: Pair-wise comparison among the criteria based on expert opinions

No.	Category	No.	1	2	3	4	5	6	7	8	9	10	11
1	Distance from Residence	1	1	0.50	0.50	0.14	0.11	0.14	0.12	2.00	2.00	0.11	0.11
2	Land Slope	2	2.00	1	1.00	0.14	0.12	0.14	0.14	3.00	3.00	0.12	0.14
3	Distance from Lowlands	3	2.00	1.00	1	0.14	0.11	0.14	0.11	3.00	2.00	0.12	0.11
4	Distance from River	4	7.00	7.00	7.00	1	0.50	0.50	0.11	9.00	9.00	0.33	0.50
5	Proposed urban growth	5	9.00	8.00	9.00	2.00	1	1.00	0.11	9.00	9.00	0.50	1.00
6	Distance from Agricultural land	6	7.00	7.00	7.00	2.00	1.00	1	0.11	9.00	9.00	0.50	1.00
7	Distance from Sensitive areas	7	8.00	7.00	9.00	9.00	9.00	9.00	1	9.00	9.00	1.00	6.00
8	Distance from Major Roads	8	0.50	0.33	0.33	0.11	0.11	0.11	0.33	1	1.00	0.12	0.14
9	Distance from Local roads	9	0.50	0.33	0.50	0.12	0.11	0.11	0.11	1.00	1	0.11	0.14
10	Distance from electrical grid	10	9.00	8.00	8.00	3.00	2.00	2.00	1.00	8.00	9.00	1	6.00
11	Existing land use	11	9.00	7.00	9.00	2.00	1.00	1.00	0.17	7.00	7.00	0.17	1

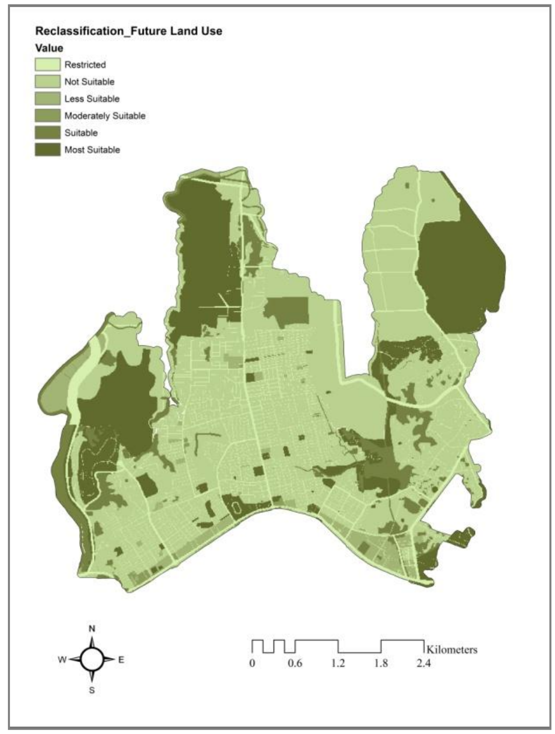
Table 4.2: Final criteria weights and ranking (aggregation of expert's scores and rank)

Criterion Names	(Criterion Weights)							Weight %	Rank
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7		
Settlement or Distance from R/A	0.023	0.085	0.016	0.068	0.064	0.168	0.11	6.91	6
Land Slope	0.026	0.082	0.02	0.025	0.045	0.025	0.025	2.83	11
Distance from Lowlands	0.034	0.08	0.144	0.05	0.234	0.043	0.086	8.16	5
Distance from River	0.066	0.022	0.018	0.08	0.13	0.029	0.026	8.67	4
Proposed/Future Urban Growth	0.107	0.062	0.058	0.088	0.034	0.089	0.063	5.73	9
Agricultural Land	0.092	0.04	0.173	0.155	0.085	0.073	0.155	11.04	3
Distance from Sensitive Areas	0.249	0.233	0.113	0.211	0.12	0.267	0.244	20.53	1
Distance from Major Roads	0.026	0.189	0.129	0.028	0.039	0.061	0.021	6.90	7
Distance from Local Roads	0.028	0.08	0.122	0.081	0.037	0.063	0.02	4.99	10
Distance from Electrical Grid	0.213	0.054	0.092	0.029	0.02	0.024	0.043	6.79	8
Existing Land Use	0.137	0.272	0.116	0.285	0.193	0.229	0.019	17.87	2

4.1.3 Criteria based suitable sites map

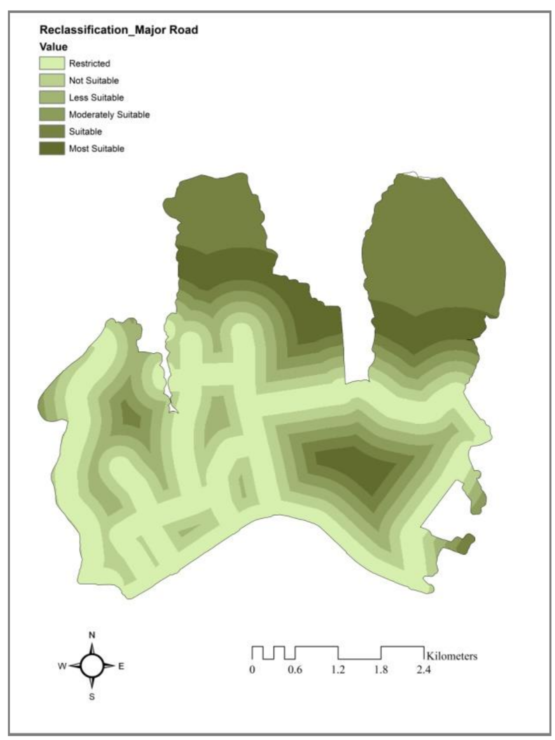
After produced the weight for each criterion obtained the next step was to produce criteria based suitable sites map using the geo formula in the GIS environment. ArcGIS spatial analysis tools were used for the resulting of criteria based suitable sites map. Before the final criteria based map Euclidean distance map reclassification maps were also produced (Fig.4.2 a-k). The proximity map was done for those criteria which were analyzed based on distance. Corresponding map of all factors criteria were reclassified from 1-5 by spatial information technologies and produced the final criteria based suitable map using weighted overlay where the criteria weight derived from AHP calculation scale were used. Finally the raster calculator produced the resultant of this step which is criteria based suitable site map (Fig. 4.3)

(a) Land Use

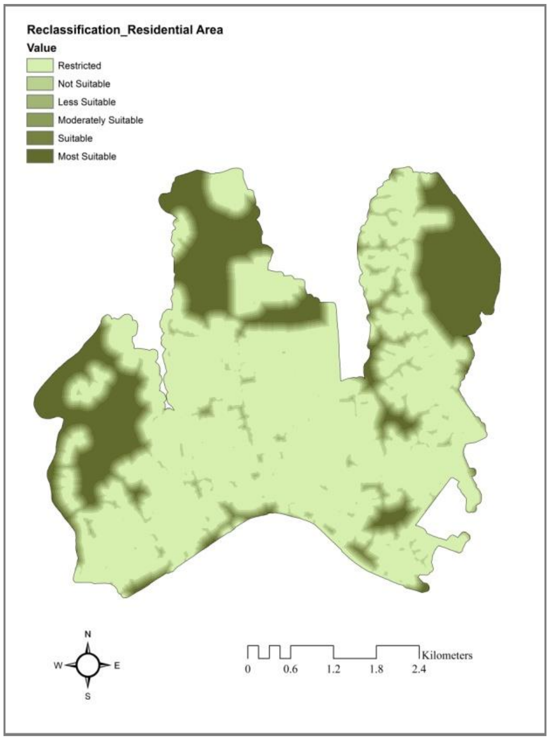


(b) Future Land Use (Unban growth)

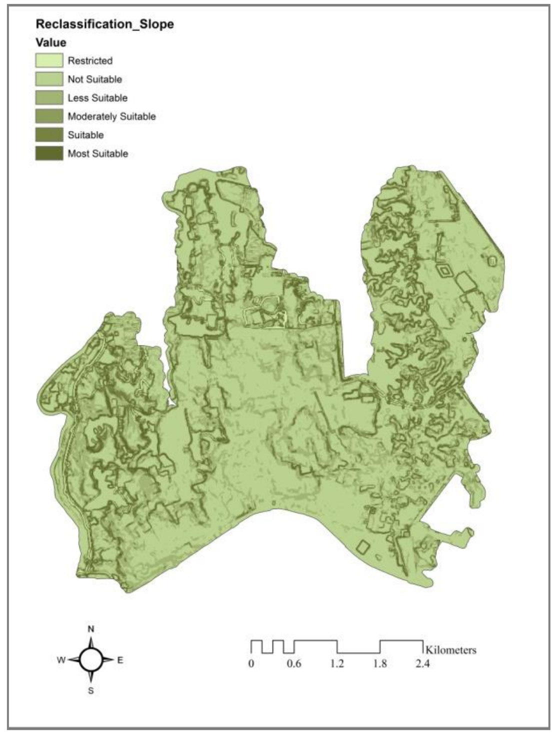
(c) Local Road Distance



(d) Major Road Distance

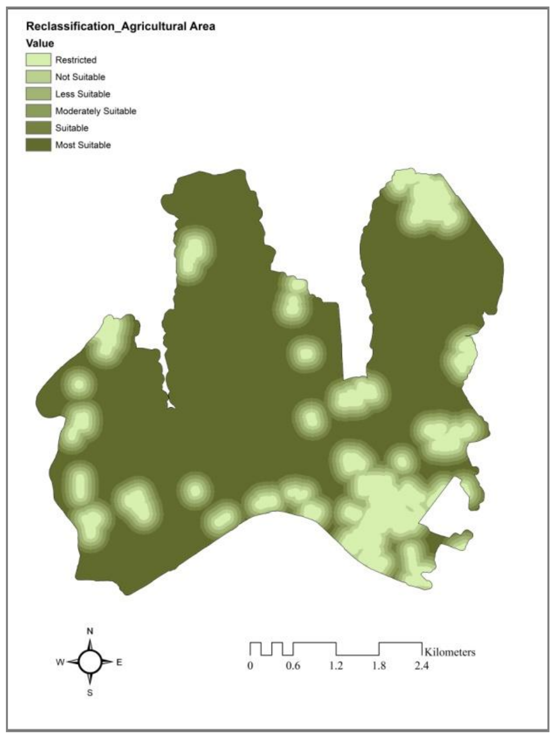


(e) Residential Area Distance



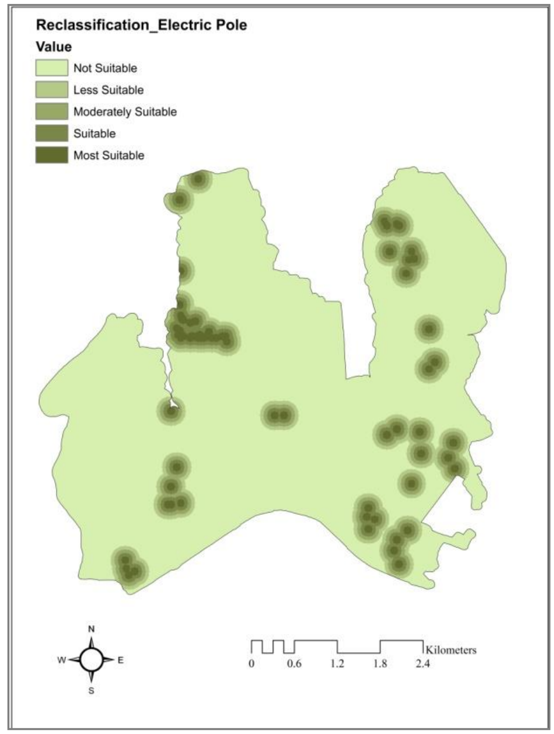
(f) Slope

(g) Sensitive Points Distance

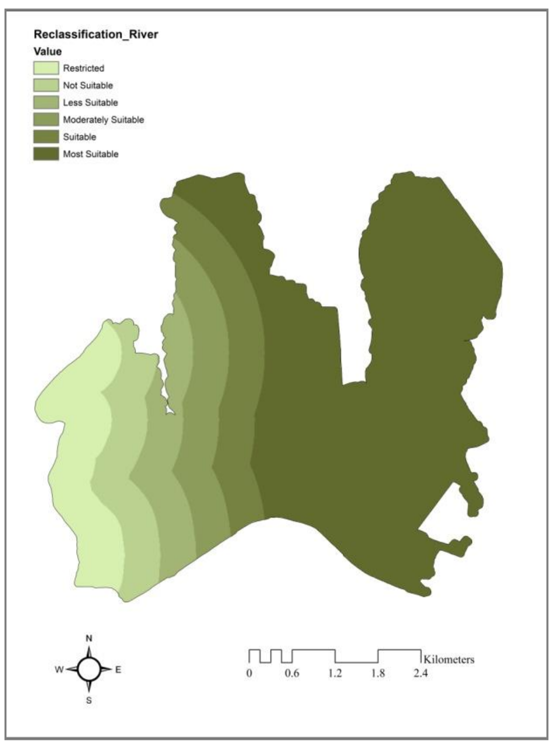


(h) Agricultural Land Distance

(i) Lowlands



(j) Electrical Pole Distance



(k) River Distance

4.2: Criteria based reclassification map (a-k)

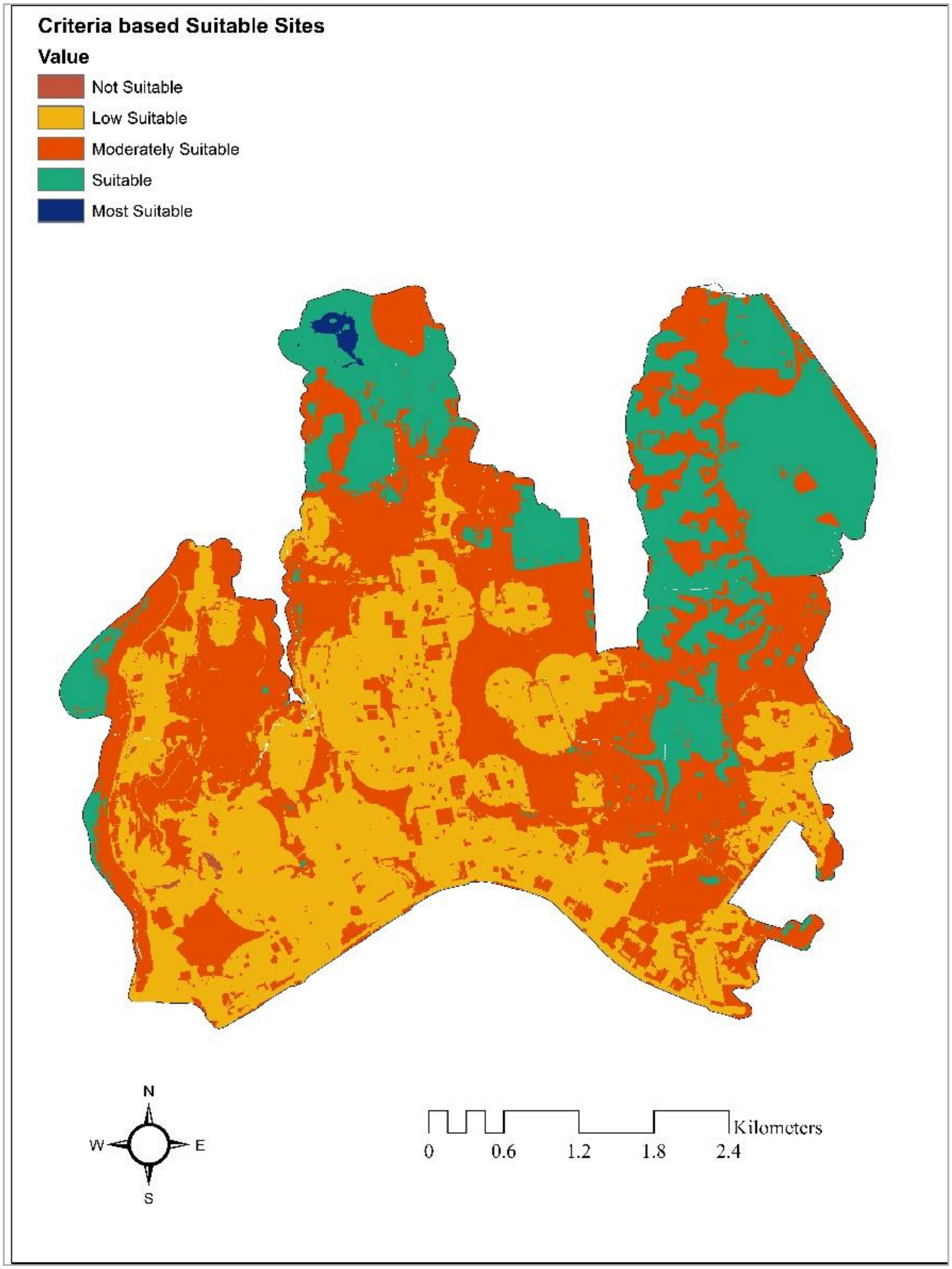


Figure 4.3: Criteria based suitable site map

4.1.4 Resultant Map from the Aggregation of Constraint Map and Criteria Based Site Map

The suitability sites for installing a biogas plant were identified from the weighted overlay of factors and constraints. The results showed that the central part of the territory was unsuitable for installation of a plant. The analysis revealed the unsuitable areas based on the constraints and restricted criteria distance (0) weight in the reclassification map. Excluding restricted areas, the total area was divided into five categories: most suitable, suitable, moderately suitable, less suitable, and not suitable. In total, 115 vacant lands were identified, of which only 71 had the minimum area required for a biogas plant digester. The remaining lands were excluded due to small area, prior settlement or construction, water inundation, or the presence of electrical poles. The final suitability map represented the suitable (red circle) or unsuitability sites for biogas plant installation (Fig. 4.4).

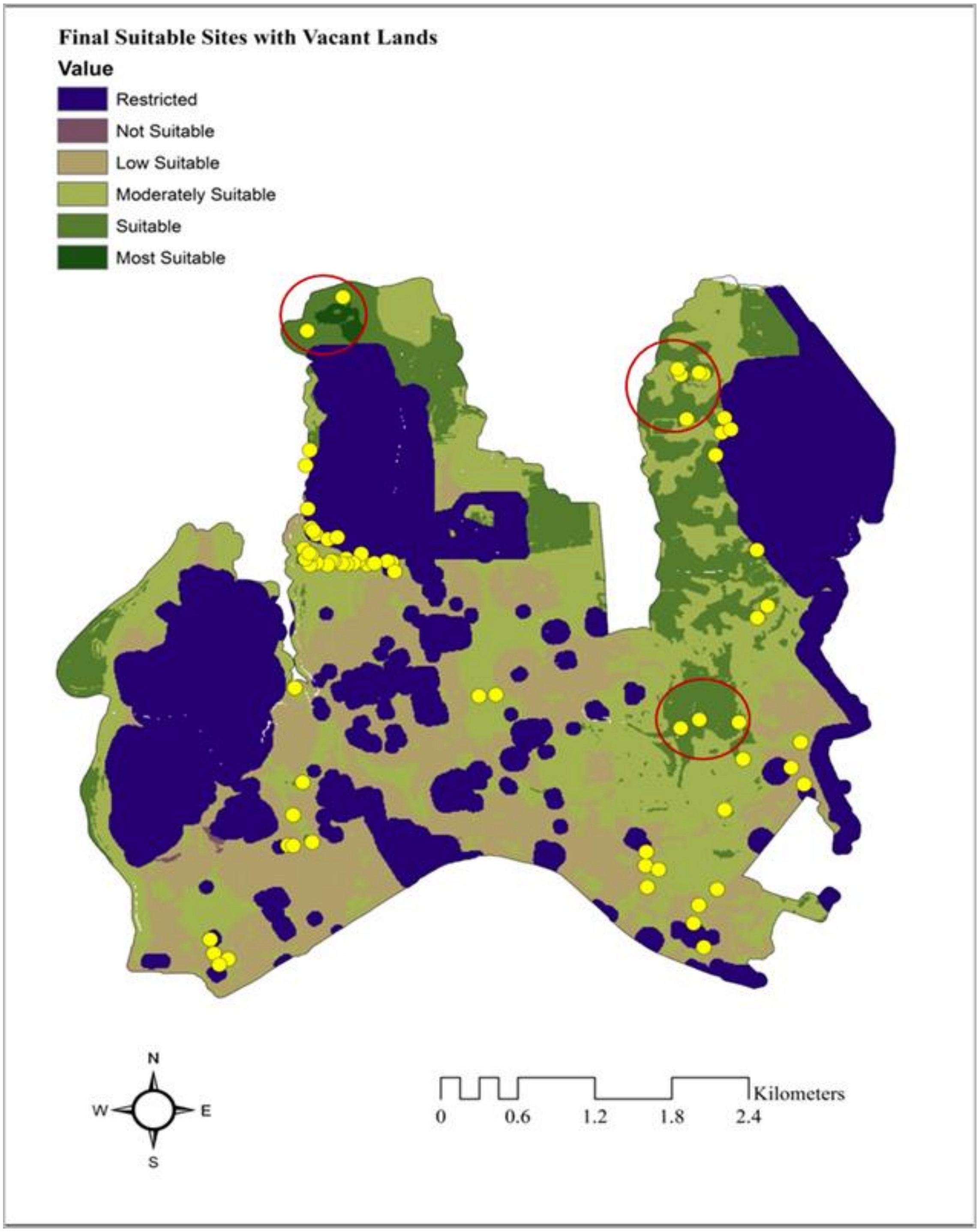


Figure 4.4: Suitable site for a biogas plant

The aggregated map identified the sites of suitable and unsuitable. The vacant land will focus further which would be realistic more for digester plant based on the size and sewerage line distance is one of the big factors for digester plant. Finally, the aggregated map was generated based on the biogas plant suitability index (Fig 4.5), which reflected three factors following eleven criteria. One (1) most suitable (Ranked 1) site was identified, and six (6) suitable sites were located (Ranked 2). Three (3) sites were identified as moderately suitable (Ranked 3), and the rest of the sites were less and not suitable (Table 4.3).

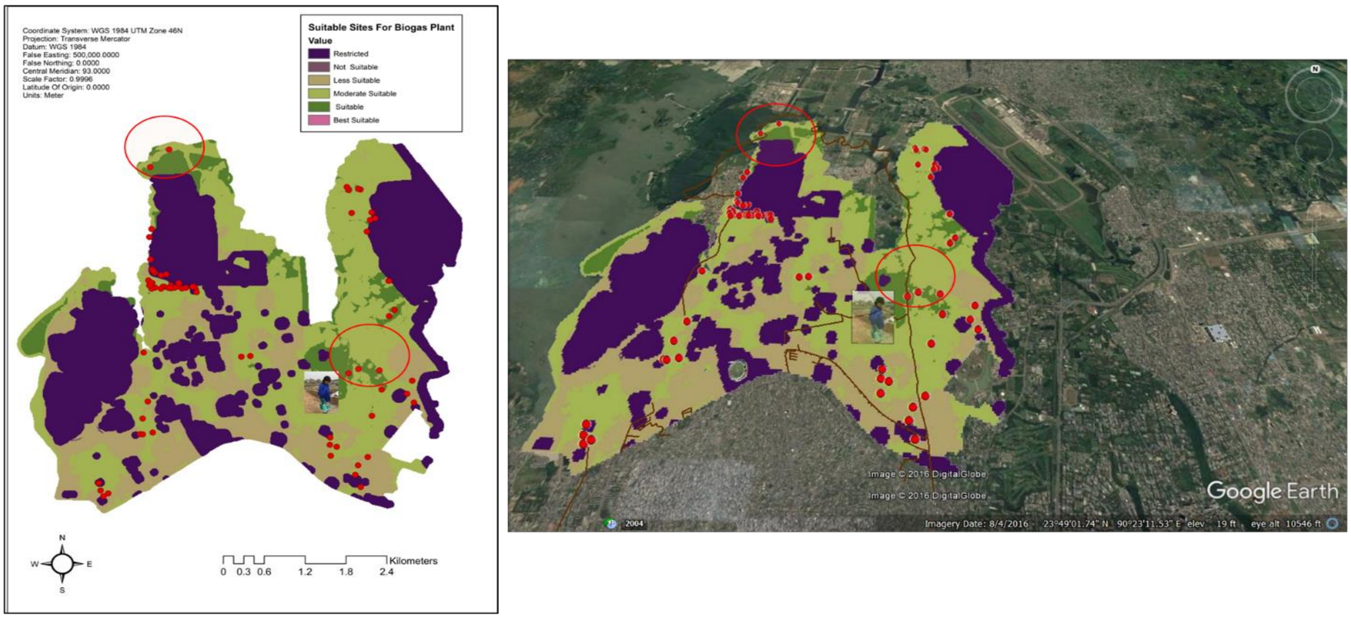


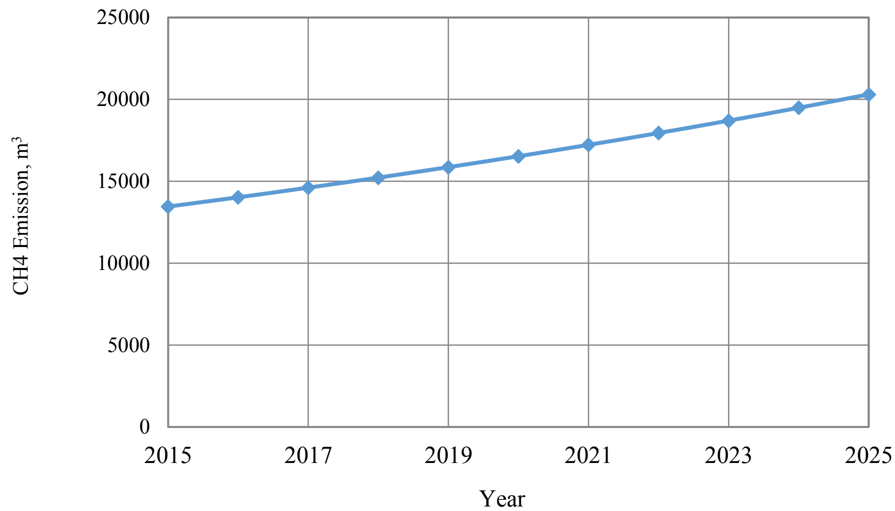
Figure 4.5: Suitable biogas sites showed in Google Map

Table 4.3: Suitability of vacant lands/sites and their area

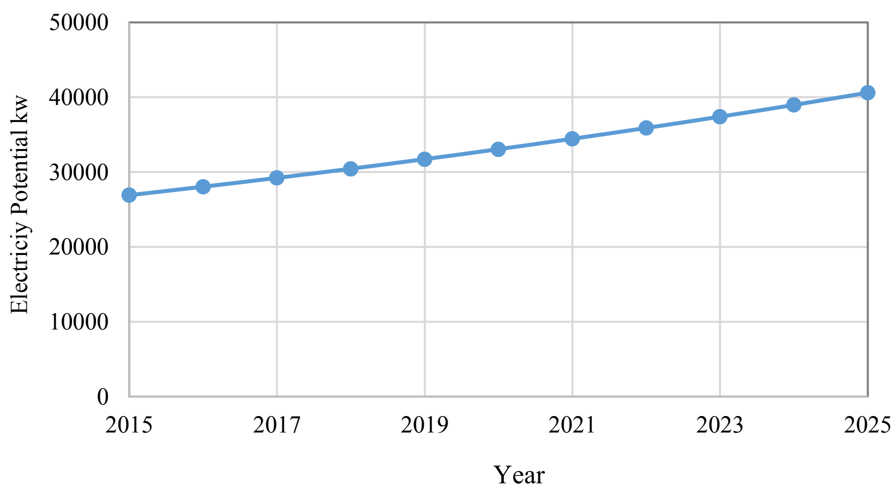
Vacant land/site	Suitability Class	Site Area (km^2)
1	Most Suitable	10216
2	Suitable	5663
3	Suitable	4595
4	Suitable	5083
5	Suitable	6180
6	Suitable	4063
7	Suitable	5308
8	Moderately Suitable	5848
9	Moderately Suitable	7057
10	Moderately Suitable	6097

4.1.5 Potentials of Energy Production from Waste

Natural gas is the main source of energy (81.43%, BPDB 2014-2015) in Bangladesh. The increasing population size has increased the use of natural gas and decreased the reserve of gas over time. In Zone 2, biogas potential was calculated following IPCC default methods, and CH_4 generation was projected from 2015 to 2025. The estimated energy potentials were approximately 26,912 KW in the initial year and 40,610 KW by the year 2025 (Fig. 4.6), corresponding to an electricity production of approximately 26 MW in the initial year and 40 MW by the year 2025.



(a) Methane generation



(b) Electricity potential

Figure 4.6: Projected Methane generation and electricity potential from waste in Zone 2 of Dhaka City

4.2 Results for Sitting of a Composting Plant

Figure 4.7: Illegal dumping, traffic and road congestion

The above picture (Figure 4.7) was taken during the survey of ward 8. This type of illegal points of city corporation generates huge waste with a very poor collection, only once in a month. There are several problems which arise due to this present waste situation. There is only very few number of bins in the selected place of the area which found not enough for the local people. Due to this there is direct disposal of waste to the dumping grounds without segregation. The accumulation of waste around the bins was the basic problem faced wherever there was an uncovered bin and there is no proper base platform for bins. Also, there was a lack of waste handling awareness amongst the citizens. Due to all these reasons, an unpleasant situation always exist around the bin. This accumulated and uncovered garbage becomes an invitation for several problems in the locality. Bad odour was created around the waste bins area, which makes unpleasant environment. This also affects the economic factor, market value of the area decreases if there is a badly maintained waste area nearby as it poses a bad aesthetics. The accumulated waste becomes a breeding ground for insects, flies, different bacteria, and micro-organisms this could create health problems.

The situation became worse during the rainy season. As the waste bins were open from both top and bottom the waste was directly exposed to the rain. The water makes the waste wet and it even drains out of the bin from the bottom, thus polluting the streets. The poor management of waste contributes serious health hazards for city dwellers.

4.2.1 Reallocation of Waste Collection Bins

Urban solid waste management is considered as one of the most serious environmental

Table 4.4: DCC waste dumping points and over stored waste (tons/day)

Area	Number of waste container	Capacity of bin (m^3/bin)	Waste stored (ton/day)	Over Carrying Waste (ton/day)	Reallocation of Bins (Required)
Eidgah Field	3	5	18	3	6
Rainkhola Bazar	4	3	15	3	8
Beribadh	1	3	5	2	1
Sony Cinema Hall	1	3	3	0	0
Muktijoddha Market	4	5	25	5	13
CC small & Unwanted WP	0	0	6	6	1
	13		72	19	29
Instead of 13 bins 29 Bins was needed to be reallocate for different points with the present situation					

problems confronting municipal authorities in developing countries. One of these impacts is due to location of dumping site in unsuitable areas. One of the focus of this Research was to determine of suitable sites for the disposal of urban solid waste generated from Ward -8, Mirpur of Dhaka City and surrounding areas using GIS techniques. The generated waste of ward was dumped to 81 points of ward 8, among these 81 points only 5 points were handled by the city authority using 13 containers, which found not enough to handle the waste. It was observed that all the waste points stored over waste and made the area uncleaned. Reallocation of the waste collection bins was analyzed and calculated the number of waste bins for total generated waste in the designated 5 large waste points of DCC authority. In the following table (Table 4.4) it was found that the storing wastes only the City Corporation big dumping point is over from the Container capacity and required more Container and Dumping site.

4.2.2 GIS Analysis for Existing Waste Collection Coverage

The digitized map of the study area is shown (Fig. 4.8) with the collection condition of research area. A total of 81 waste generation points were identified during the survey area including 14 were city corporation small waste point, 62 were illegal waste points and 5 were city corporation big waste dumping point. All together generate around 70-75 tons waste per day in ward 8 of

Zone 2. It is illustrated that around 35% area is remain 100% uncollection of waste, during the survey it was found that the area which is covered by PCSP van service is 100% (no waste found) collection for 28% area and around 50% waste found uncollected in the illegal waste point and areas which is not covered by van service according to the survey result it was 37% (Fig. 4.9).

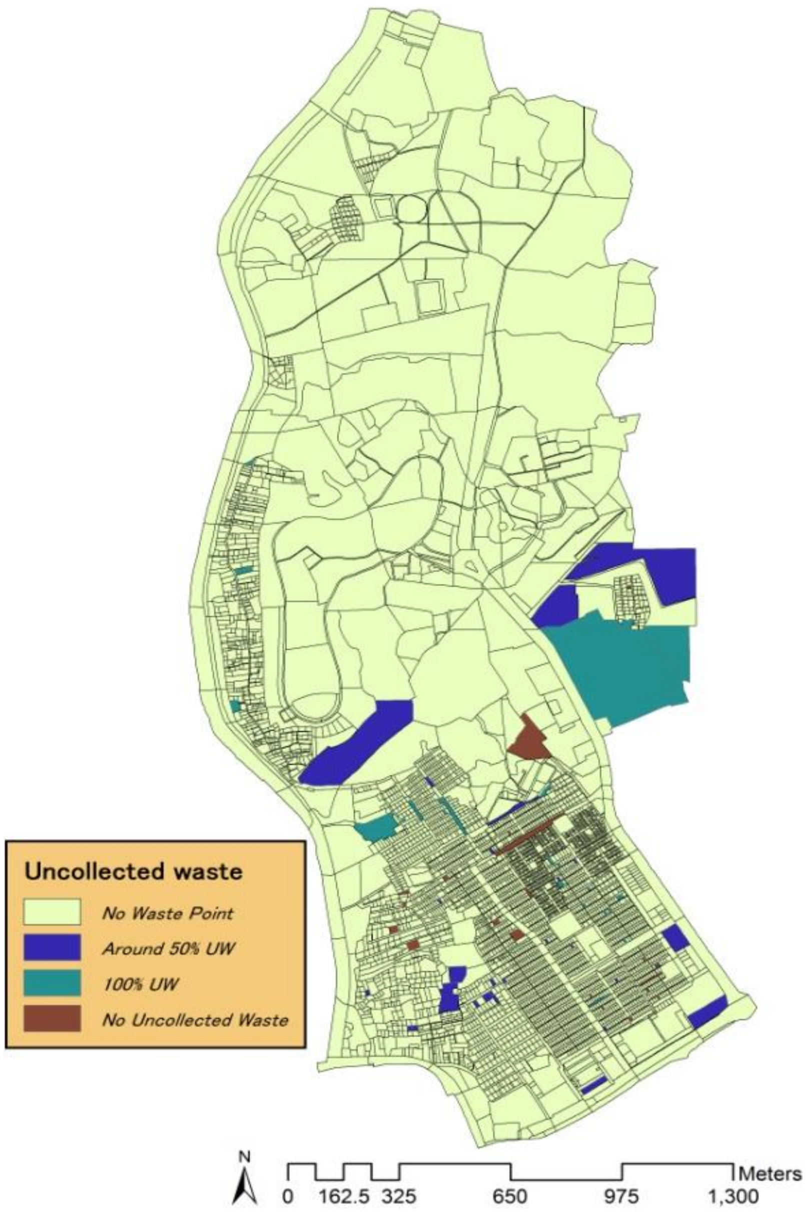


Figure 4.8: Uncollected waste in the study area

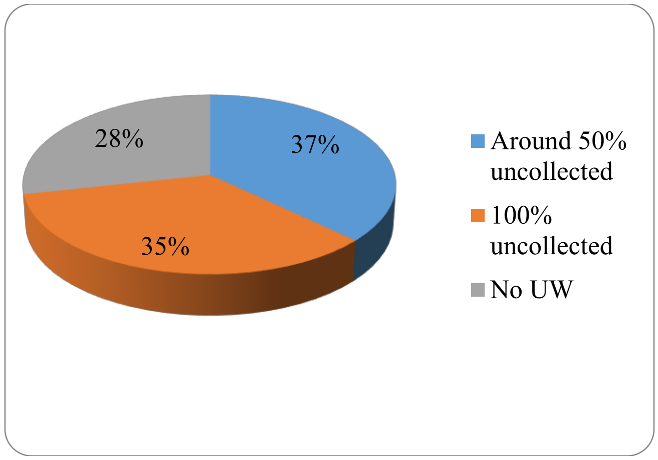


Figure 4.9: Uncollected waste (%) in the study area

4.2.3 GIS Analysis for Road Network of Existing Waste Point

Solid Waste Management refers to the collection, storage, transportation and final disposal of waste in an environmentally friendly manner. It includes all activities that seek to minimize the health, environmental and aesthetic impacts of over generated solid wastes. Solid waste management has become an essential aspect of health delivery also. This research attempted to optimize the route for collection and transportation of municipal solid waste of the city using geo-informatics technique. Initially all ancillary data have been collected from various sources. Using hand held GPS, the position of the entire dust bin in the area were collected and the data are converted into shape file. According to the road condition based on access of the transport to the dumping point for waste storing, collection and transportation the weight was given and from the shape file of existing dustbin point road network, network database for the entire road are prepared using Arc-GIS 9.3 (Figure 4.10).

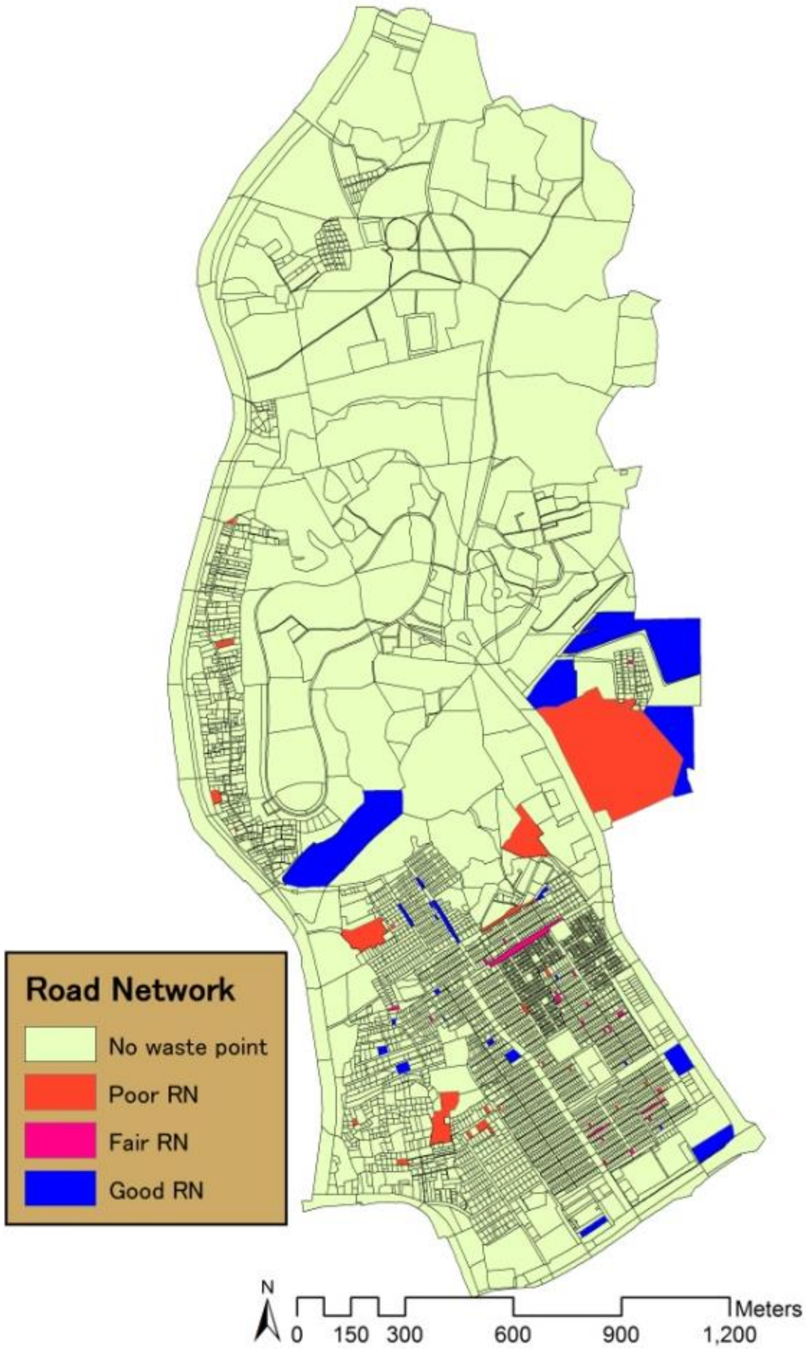


Figure 4.10 : Road network for existing waste points in the study area.

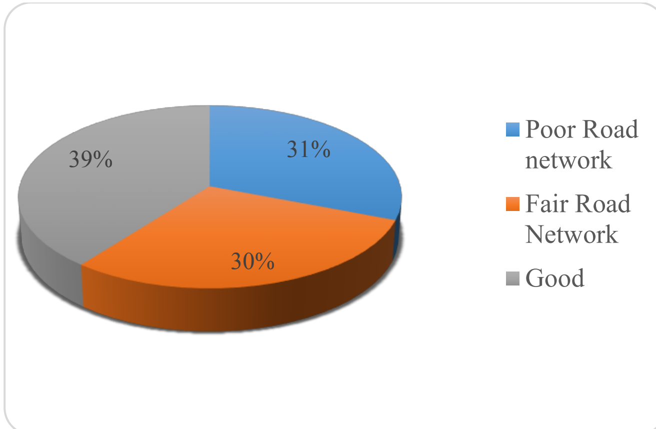


Figure 4.11: Existing Bin Point's Road Network (%) in the Study Area

It shows that (Fig. 4.11) among the 81 waste points, 31% were situated where the road network found very poor, 30% waste points located in a fair road network and 39% were located in a very good road network. Most of the illegal waste points were located in a very poor congested and unsuitable place. Vehicle entrance was not possible in those points; some points are just located in a very narrow road where the primary waste collection van also cannot access to provide the waste collection service.

4.2.4 GIS Analysis for Sensitive Waste Points Location

This study was conducted based on 81waste points recorded with a handheld GPS unit and additional survey was conducted. ArcGIS analysis was carried over for the road network analysis and sensitive location of waste bins in the study area, It was found that 21% of the existing waste collection points were located where the road networks are good but the locations are very sensitive, Like some of them were located just beside of educational institutes, hospitals, road intersection and market places (Figure 4.12 and Figure 4.13).

These sensitive points are very crowded and people are suffering problem due to huge waste. Also there was no consideration for road types, different size of containers, and the accessibility of different type of waste collection vehicles. Waste collection issues consideration was inadequate and sometimes a large percentage about 50% waste remains or leftover longer time in the collection points because shortage of transport or collections vehicle. Waste occupied huge spaces of streets caused traffic congestion and environmental degradation at the intersection points and other sensitive points.

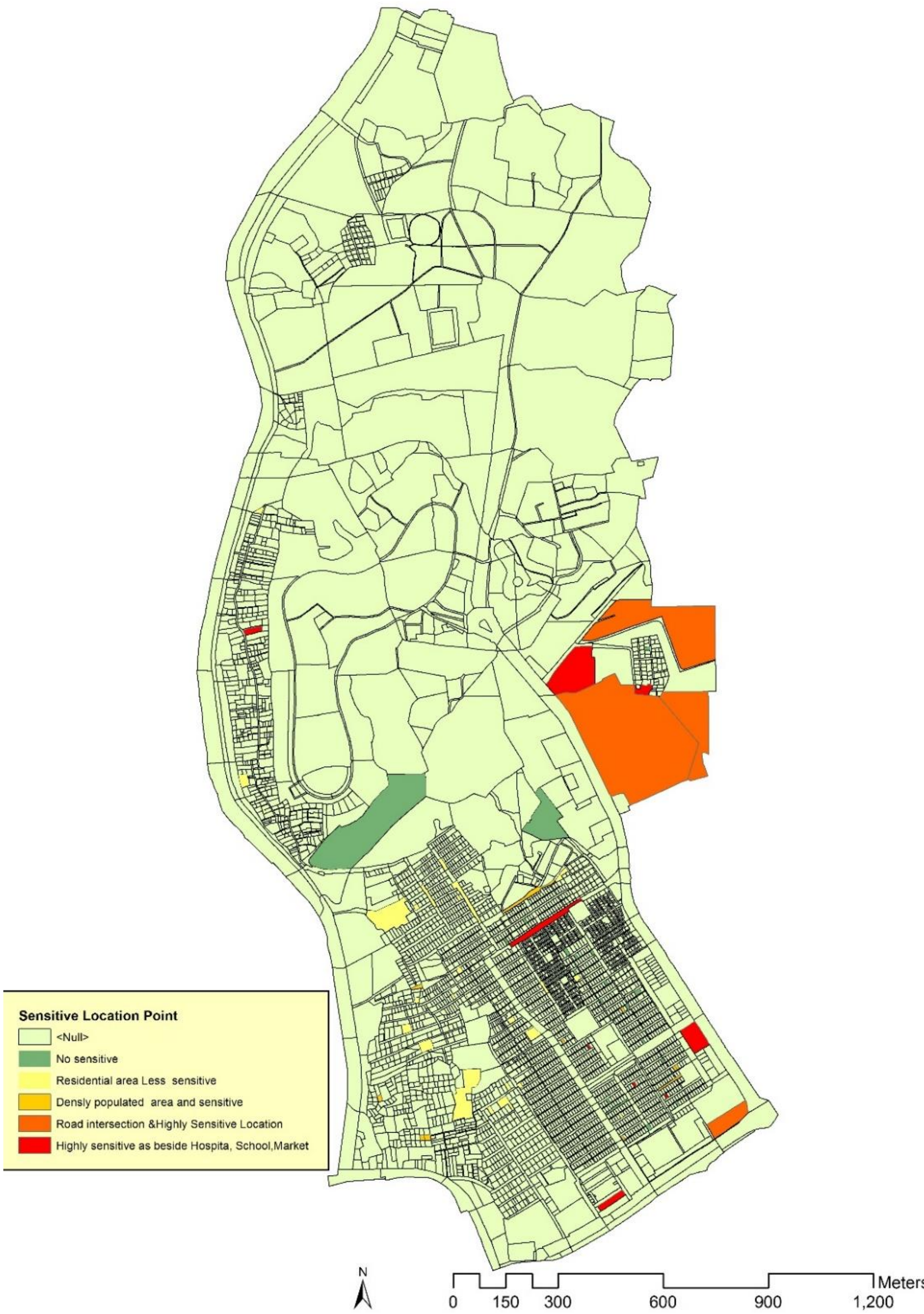


Figure 4.12: Sensitive Waste Bin Locations in the Study Area

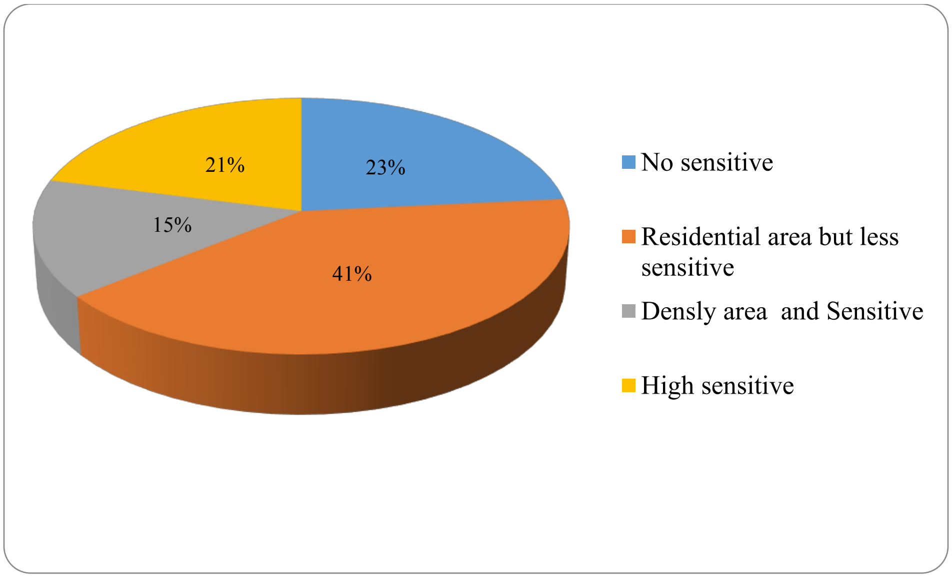


Figure 4.13: Sensitive Waste Bin Locations (%) in Study Area

Sensibility scores was given of waste dumping points based on the nearest sensitive building or organization, road type, distance, container placement, containers size, waste collection vehicle size and stop over time for waste collection and peoples movement around the waste point location. Sensibility score of waste point in study area is shown (Table 4.5).

Table 4.5: Waste point sensibility score

Waste point Distance (m)	Waste point Location Besides	Sensibility Score
0-500	Hospital, Mosque, Educational Institution.	9
	Road Intersection	7
	Residential Area	5
500-1000	Residential Area	3
1000-2000	No sensitive point	1

4.2.5 Relocation of High Sensitive Points to Less Sensitive Points

Figure 4.7 shows the identified high-sensitivity waste sites. Proximity analysis was performed with 30 m buffering, and 14 waste generation sites were found to be located in close proximity to sensitive buildings. These sites were considered high-sensitivity waste sites and suggested for relocation. The high-sensitivity waste sites (Fig. 4.14) were located near educational institutions, hospitals, or shopping malls, or in industrial, and high-traffic areas. At the same time, another analysis was performed to identify low-sensitivity waste sites for the relocation of high sensitive sites.

To identify low-sensitivity waste sites, analysis was performed, and relocation sites were identified (Fig. 4.15) to which high-sensitivity waste sites could be relocated. A 30 m buffer was established for all waste sites for choosing the best suitable waste collecting sites. Also to choose the best location the attribute expression was sensitive location point rank <= 3 which indicates no sensitive points and the road network >=3 which indicates fair or good road network for waste collection, and the possible relocating places has been pointed out in the map where high sensitive points can move (A total of 19 sites were identified as low-sensitivity waste sites. Environmentally lower-sensitivity and convenience proximity distance can be given priority for continuing the waste collection of door-to-door service by PCSP and DNCC.

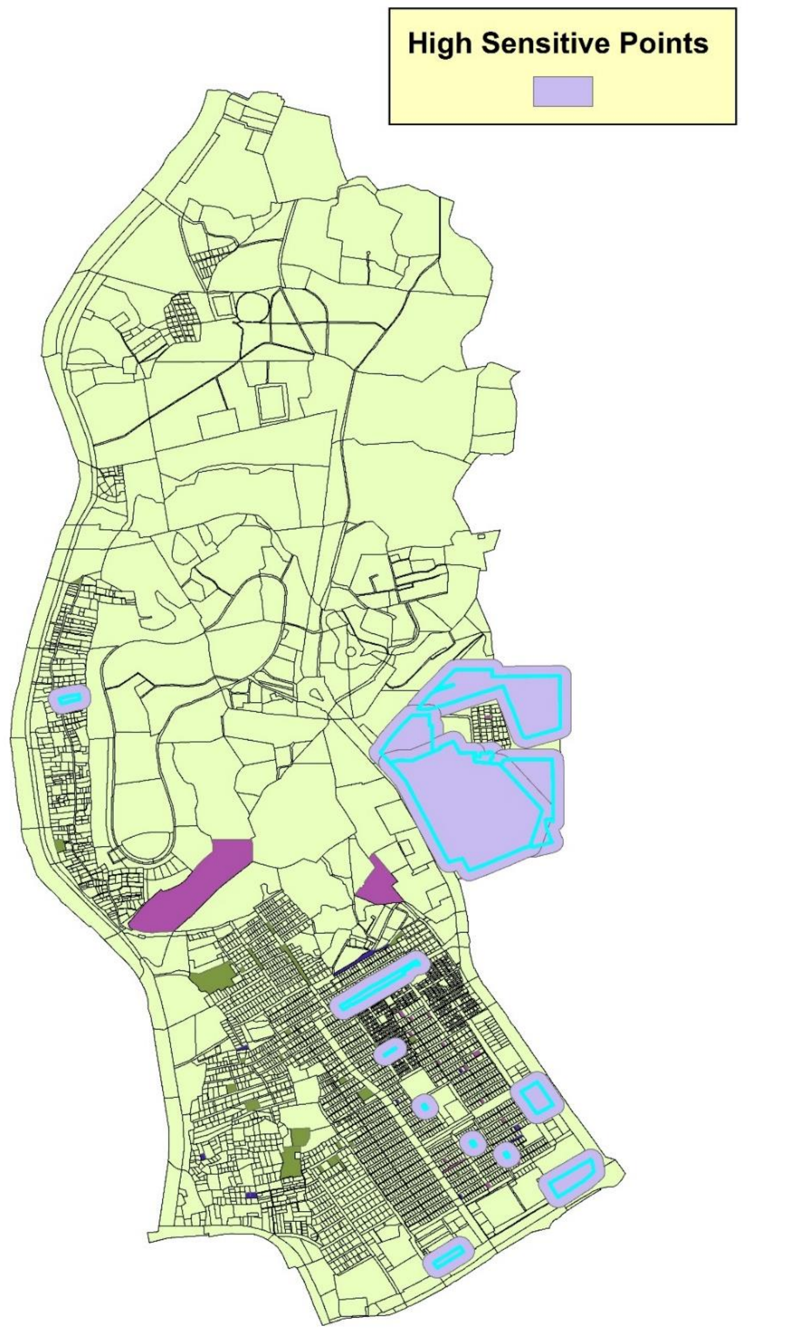


Figure 4.14: High Sensitive Waste Points

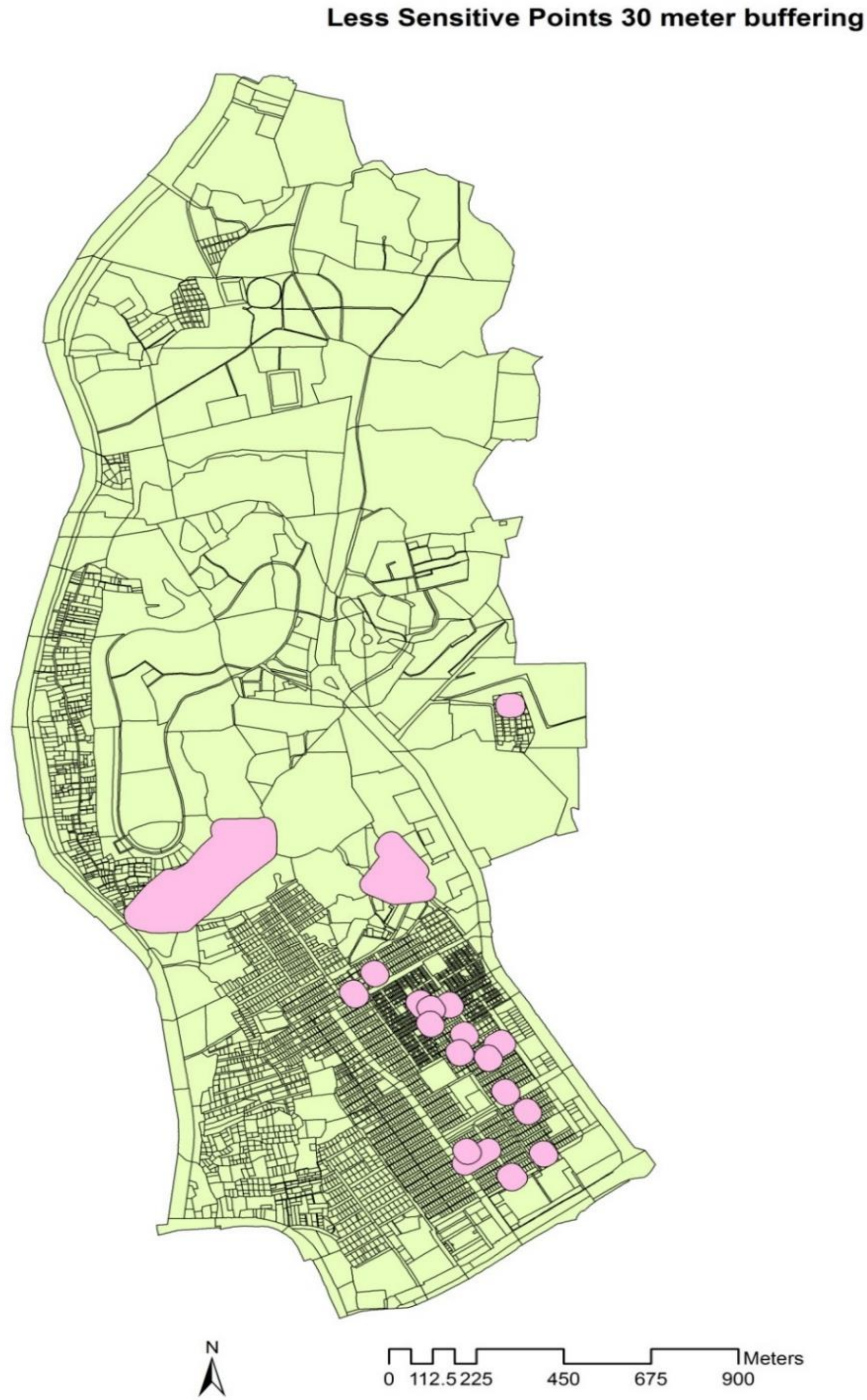


Figure 4.15: Less Sensitive Points for Relocation of High sensitive waste points

4.2.6 PCSP/NGO and DCC Supports and Initiatives for Composting

PCSP/NGOs had a significant role for waste collection nowadays, the waste management situation was better with the help of Dhaka City Corporation PCSP could collect the organic waste from the household and could stored a specific place for composting and start decentralized composting with the help of City corporation and the ready compost can be provided among the household owner for their rooftop garden or Urban agriculture. City dwellers attitude toward future initiatives for urban agriculture through the composting were found very positive during the study.

The result of survey of household owners is shown in (Fig.4.16). The owners were interested in gardening on their rooftops, as there were no vacant spaces around their homes. The survey also showed that the 37% household owners were well informed about urban agriculture. However, 63 % of the respondents were not well informed about sustainable urban agriculture at the household level. The questionnaire was extended further and it was observed that 89 % household owners were interested in composting with the support of the local government or nonprofit organization. The owners were interested in segregating organic waste at home, if the local government took steps toward composting. We noted that 90 % of household owners agreed that conversion of organic waste to compost would be one of the best ways for reducing waste volume and ensuring the cleanliness of the area.

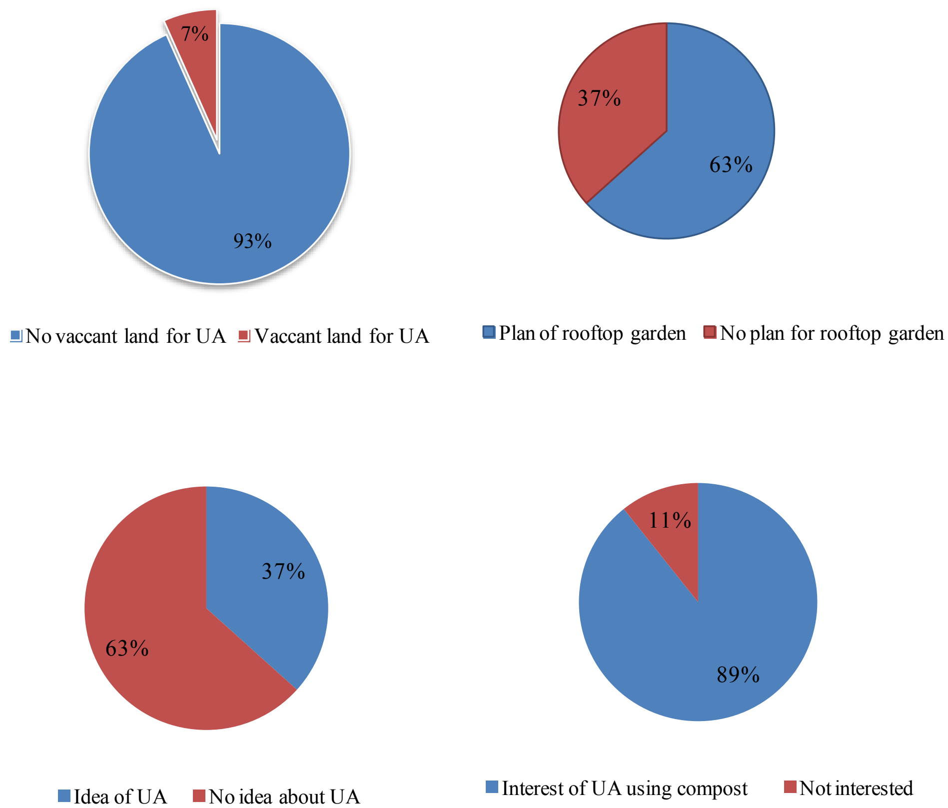


Figure 4.16: Household survey for the initiative of urban agriculture

Urban agricultural policy can be an integral part of a set of policies for sustainable urban environmental management. The exploration of organic waste conversion might promote the hinder urban agriculture to implement policies that effectively integrate agriculture into the urban environment.

4.2.7 GIS Analysis for Suitable Composting Point

There are some suitable sites pointed out in (Fig. 4.17) which are located as suitable composting point. With the 100 meter buffering analysis two best suitable vacant points have been located, these two points considering some nearest vacant land that meet the required land space for composting point.

Some sites were selected as suitable composting sites by the SMCE analysis as shown in methodology part. In total, 455 vacant land sites were used for land suitability analysis, among them suitable composting sites were identified. Two areas, Al-Kamal Housing and Uttar Bishil, were identified as the two suitable composting sites among the 455 vacant lands. Furthermore, a proximity analysis was done to get the information of nearest features for these two areas. In case of Uttar Bishil, one of the main roads passed through this area, which made it as a potential business area. The proximity analysis also extended for Al Kamal Housing site, which was found as protected area and had less influence of nearest features. Therefore, Al-Kamal Housing site was ranked highest and recommended as the best composting site as it was matched within the required land space and less influence of nearest features.

Finally in my analysis through the ArcGIS the suitable composting location were identified, where segregated organic waste could be stored for preparing compost to distribute to the residents through NGOs/PCSP .

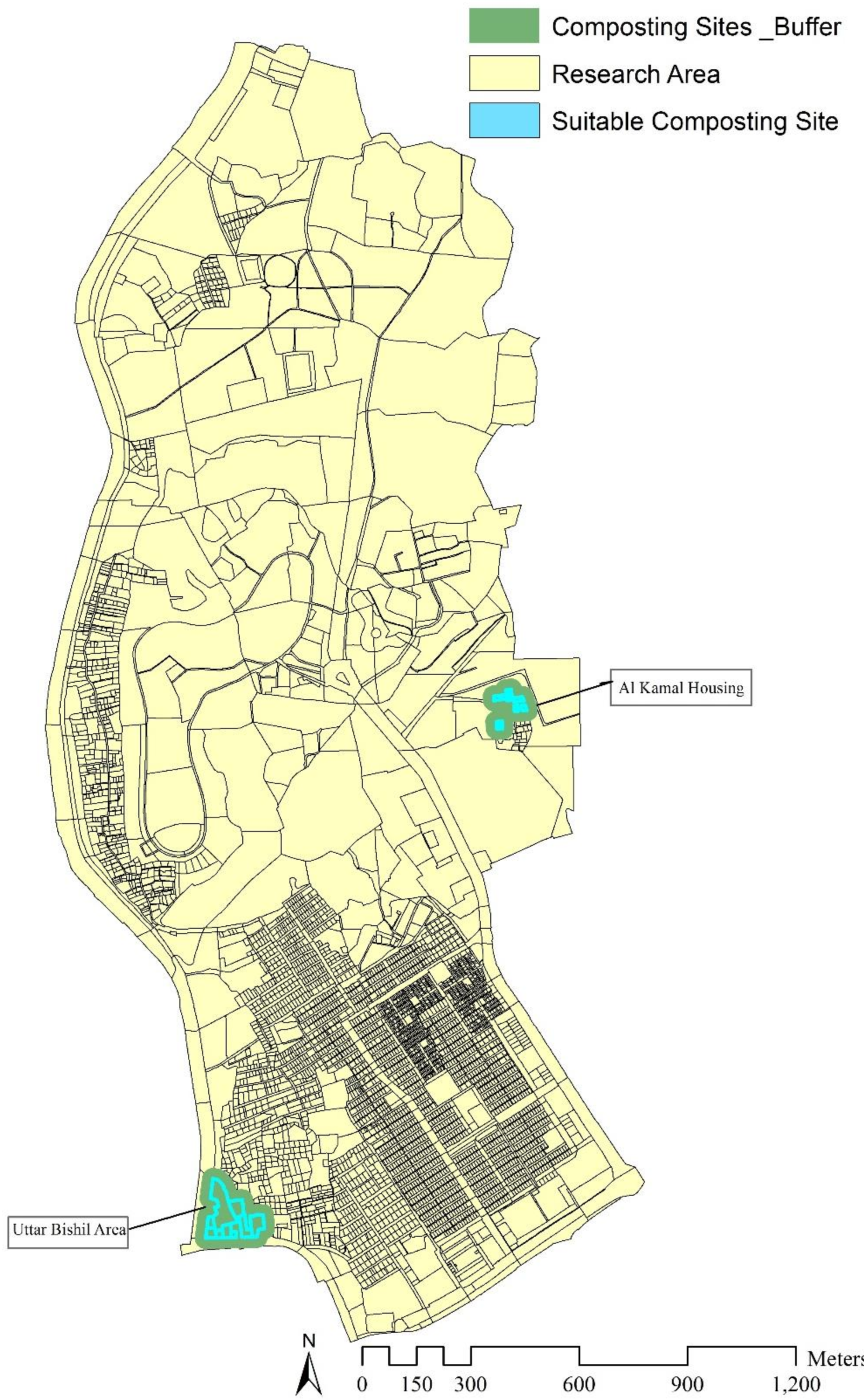


Fig. 4.17: Identified composting sites for initiating urban agriculture through the conversion of organic waste

CHAPTER 5

Conclusions and Recommendations

Most of the developing countries like Bangladesh has lack access to advanced technologies. However, technologies must be sustainable in the long term. Therefore, the selection of sustainable waste strategies is very important for the urban development. This study has proposed the practical solution to handle the zone wise large amount of generated waste through the site selection of a biogas plant and a composting plant. Two levels of solutions were proposed for waste management.

- Macro level solution was proposed for most suitable locations to install biodigester plants (Zone 2) for anaerobic digestion to convert waste to energy.
- Micro level solution was proposed to reallocate waste sites and bins for managing generated waste and most suitable locations for composting plants (Ward 8, Zone 2) to increase urban agriculture initiatives.

The biogas plant site plant would offer to generate the methane gas from the organic waste and converted to electricity and gas, and composting plant will produce the compost for the promotion of urban agriculture through the localities. To select the suitable sites for these plants site suitability analysis was done using GIS and MCE. This study was the combination of GIS and Multi Criteria Analysis (AHP and WLC) for the site selection, which found much capable to handle the environmental, economic and social criteria for selection of the sites. The priority sites were identified and finally associated maps were overlaid to fine the most suitable site for biogas plant and composting plant-using ArcGIS.

For municipal waste biogas is the suitable option for Dhaka city waste and it also requires less time and investment compare to land filling. It is a potential source of electricity by adopting the active biogas from the municipal organic waste. Moreover, it can reduce the pressure of locating a big site for landfill and managing cost for waste management.

Another issue pertaining solid waste management there is high operational cost in solid waste collection and the limitations of sanitary Landfill site. As the sanitary landfill is also in a limited number and scarcity of land for sanitary landfill, it is the high time to find out one alternative like energy generates and urban agriculture through the composting which can be converted from 70-80% organic waste was also focused in this research.

Dhaka where the waste generation rate varies from 0.44 t-0.60 per/kg/d and the city is unable to accommodate the waste dumping landfill areas, biogas is only the viable option for reducing the volume of waste as well as the conversion the waste to energy for electricity and gas consumption. The result showed that a relevant part of the territory is unsuitable for sitting a plant and this is the central part of the area and the constraint area is also focused the unsuitable sites. The suitability map also showed the condition of the study that represents the suitability or unsuitability of a certain place, some places were located best suitable but only one or two criteria shows the less or moderate suitable in analysis.

For the composting point sites selection, an intensive focus was given for the highest waste generating ward of the same zone, all the waste points were surveyed and found that most of the existing waste points were located without the proper estimation of population density, amount of waste generation rate, area boundary map, existing road network map and high sensitive point location. Analysis revealed the high sensitive waste points and find out the less sensitive points based on sensitivity and road network rank. Suggested relocating waste bins were considered due to the bin proximity of sensitive building and proximity of environmentally sensitive area (like water stream or industry zone). Some more factors were also considered in the process of allocation like routing for collection system, number and type of bin locations, collection vehicle, consider to public convenience and some other technical factors which was not under the consideration of study and these matters can be done by the Dhaka City Corporation authority before relocating the high sensitive points to those located less sensitive points.

This study located the relocating waste point based on the poor read network and high sensitive waste point and finally located the relocation places for suitable waste points using GIS analysis.

In connection, all these, the study this study suggested the urban agriculture which can be an effective method in ensuring food supply and satisfying nutritional needs of the inhabitants. From the research survey, it was also ensured that community participation could be the strength for the promotion of urban agriculture.

However, for sustainable urban solid waste management, strategic SWM planning should be incorporated in an integrated approach by the waste management authorities of Dhaka City Corporation (DCC). Number of container and location of DCC big waste point should be increased instead of small and illegal waste point. Furthermore, immediate action is needed to stop or minimize the illegal waste dumping points, which found fully uncollected for the long time during the study. The GIS technique can be used as a decision support tool by Dhaka City Corporation authority for their efficient management of the daily operations considering the waste container distribution and transporting routine to the disposal sites.

DCC is running their activities manually, which was found unplanned and irregular, making the terrible waste condition day by day. Dhaka City Corporation required the skilled persons initially to perform this optimization task and assigned the routes to the concerned vehicles. Dhaka City Corporation (DCC) is also unable to offer the desired level of services with the existing capacity and trend of waste management. Projection of future generation rate indicates that by the year 2020 it may exceed 30 thousand tons/day, which in turn will require over 200 acres/yr of landfill area. Study showed that 80% of the city corporation waste is organic. Government steps for the conversion of organic waste to energy and compost will enhance to encourage the reduction of organic waste dumping in the waste points which could bring an essential change for the reduction of waste of city authority into their landfill, also helps to reduce the Greenhouse Gas (GHG) emissions and especially the disposal of waste in open landfills generates methane (CH_4) that has high global warming potential.

References

ADB, (2001), Toward sustainable municipal organic waste management in South Asia. Australian Government, Aid Program.

Afsana A., Tofael A., Tomohiro T., Ryozo N. (2016). GIS-based Multi-criteria Analysis for Urban Waste Management, Journal of Japan Institute of Energy, 95, 457-467.

Berglund, M. & Borjesson, P. (2006). Assessment of energy performance in the life-cycle of biogas production. Biomass and bioenergy, 30, 254-266.

Bouallagui, H., Touhami, Y., Cheikh, R.B., Hamdi, M., (2005), Bioreactor performance in anaerobic digestionof fruit and vegetable wastes. Process Biochem. 40, 989-995

Bottero, M., & Ferretti, V., (2011). An analytic network process (ANP) based approach for location problems: the case of a new waste incineration plant in the province of Torino (Italy). Journal of Multi-criteria Decision Analysis, 17, 63-84.

Bogner, J., M. Abdelrafie Ahmed, C. Diaz, A. Faaij, Q. Gao, S. Hashimoto, K. Mareckova, R. Pipatti, T. Zhang (2007), Waste Management, In Climate Change: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

BUET (2000). Characterization of municipal solid waste and preliminary environmental impact assessment of collection and disposal works in Dhaka city'. Department of Civil Engineering, Bangladesh University of Engineering and Technology, BRTC, DCC.

Chuang, P.T., (2001). Combining the analytic hierarchy process and quality function deployment for a location decision from a requirement perspective, International Journal of Advanced Manufacturing Technology 18, 842-849.

C. Hanping. L. Bin, Y. Haiping, Y. Guolai, Z. Shihong, (2008). Experimental investigation of biomass gasification in a fludized bed reactor, Energy & Fuels. 22, 3493-3498.

Chuong, M., (2007). Multi-criteria land suitability evaluation for selected fruit crops in Hilly Region of central Vietnam. Humbolt University of Berlin.

Chen, W.Y., Kao, J.J., (1997).Fuzzy drastic for landfill sitting. In: proceedings of the 13th International Conference on Solid Waste Technology and Management, Philadelphia, PA, USA.

Charnpartheep, K.m Zhou, Q., Garner, B., (1997). Preliminary landfill site screening using fuzzy geographical information systems, Waste Manage. Res. 15, 197-215.

Chang, Ni-Bin, Parvathinathan, G., Breeden, J.B., (2008). Combining GIS with fuzzy multicriteria decision-making for landfill sitting in a fast-growing urban region. J. Environ. Manage.87 (1), 139-153.

Carver SJ. (1991), Integrating multi-vriteria evaluation with geographical information systems. Int J Geogr Inf Syst ,5 (3); 321-39

Charles, W., Walker, L., Cord-Ruwisch, R, (2009). Effect of pre-aeration and inoculums on the start-up of batch thermophilic anaerobic digestion of municipal solid waste. Bio resource. Technol. 100, 2329-2335

Chowdhury et al., (2014). Developing 3Rs strategy for waste management in the urban areas of Bangladesh. Journal of Environmental Science, Volume 8 Issue 5, 9-18.

Cohen B., (2006), Urbanization in Developing Countries. Current Trends, Future Projections, and Key Challenges for Sustainability. Technology in Society 28 (1-2), pp. 63-80.

Concern, W., (2005a). Community based composting, Slum based waste management and composting pilot program: Urban slum and suburb project. Waste Concern Dhaka.

Dey, P.K., & Ramcharan, E.K., (2008). Analytic hierarchy process helps select site for limestore quarry expansion in Barbados. Journal of Environmental Management, 88 (4), 1384-1395.

Donevska KR, Gorsevski PV, Jovanovski M, Pesevski, (2012). Regional non-hazardous landfill site selection by integrating fuzzy logic. AHP and gepgraphic information systems, Environ Earth Sci 67: 121-131.

D. Hoornweg and P. Bhada., World bank (2012), What A Waste, A Global Review of Solid Waste Management, No. 15.

D.AHC, N. M, M.RUH, D.TH, IORS, (2014). Developing 3Rs strategy for waste management in the urban areas of Bangladesh; Socioeconomic and climate adoption mitigation option.

Dhaka Draft Structure Plan 2016-2035 by RAJUK

D-WASTE (2012a), “Waste management for everyone”, available at www.d-waste.com

Erkut, E., Moran, S.R, (1991). Locating obnoxious facilities in the public sector: an application of the hierarchy process to municipal landfill sitting decisions. Socio, Econ.Plan. Sci. 25, 89-102.

Eurostat, (2012e), 'Reference Metadata in Euro SDMX Metadata Structure (ESMS)', (http://epp.eurostat. ec.europa.eu/cache/ITY_SDDS/EN/env_wasmun_ esms.htm)

Final Report Biogas Audit Bangladesh 2011-2013, Volume 1, NDBMP-IDCOL Dhaka, Bangladesh

Geneletti, D., (2010). Combining stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites. Waste Management, 30(2), 328-337.

Gebhardt, K., Jankowski, J., (1987). Preliminary landfill sitting and related analysis using simple modeling techniques. Journal of Engineering Geology 23, 291-306.

Islam, M.S., Ahmed, R. Shahabuddin, M.R., and sheikh, A.H., (2009). Pattern of Land use change and its dynamic of urban expansion in Dhaka City, Journal of Geo-Environment, Vol. 9, 107-120.

International Solid Waste Association (ISWA) (2012), Globalization and Waste Management.

Jankowski P. 1995, Integrating geographical information systems and multiple criteria decision making methods. Int J Geogr in Sys, 9 (3) 251-73

JICA. (2005), The study on solid waste management in Dhaka city. Clean Dhaka Master Plan, Final Report, Japan International Cooperation Agency, Pacific Consultants International, Yachiyo Engineering Co., Ltd.

Khan, S., & Faisal, M.N. (2008). An analytic network process model for municipal solid waste disposal options. Waste Management, 28(9), 1500-1508.

Khalil, W., Goonetilleke, A., Kokot, S., & Carroll, S. (2004). Use of chemo metrics methods and multui-criteria decision-making for site selection for sustainable onsite sewage effluent disposal. Analytica Chimita Acta, 506 (1), 41-56.

Lastella, G., Testa, C., Cornacchia, G., Notorincola, M., Voltasio, F. & Sharma, V.K. (2002). Anaerobic digestion of semi-solid organic waste: biogas production and its purification. Energy conversion and Management, 43, 63-75.

Lee, M., Hidaka, T., Hagiwara, W., Tsuno, H., (2009). Comparative performance and microbial diversity of hyper thermophilic and thermophilic co-digestion of kitchen garbage and excess sludge, Bio resource. Technol. 100, 578-585.

Lesteur, M., Bellon-Maurel, V., Gonzalez, C., Latrille, E., roger, J.M., Junqua, G., Steyer, J.P., (2010). Alternative methods for determining anaerobic biodegradability: a review. Process Biochem. 45, 431-440.

Mohammed A. Shari, Vasilios Retsios (2004) Site selection for waste disposa through spatial multiple criteria decision analysis Published on Journal of Telecommunication and Information Technology.

M.K. Ghose, "A GIS based transportation model for solid waste disposal – A case study on Asansol municipality" science direct (2005), pp 1287-1293.

M.S.Islam, A. Sultana, M.Rasheduzzaman, G.K.Kundu, A.K.I.Kamal, M.K.Uddin, J. Sci. Res. 7(3), 129-137(2015), Assessment of the present state economical propect of solid waste at Amin Bazar waste dumping site, Bangladesh

M. R. Hasan, K. Tetsuo, S.A. Islam, (2009). Landfill demand and allocation for municipal solid waste disposal in Dhaka City, Journal of Civil Engineering (IEB), 37 (2) 133-149

Malczewski ,2006 Review article GIS-based multicriteria decision analysis: a survey of the literature. Int J Geogr Inf Sci , 20 (7); 703-26

M.N.Uddin, M.F.Anwar, M.T.Rahman, M.N.Mobin, (2014), an Investigation on the pattern of land use change in Dhaka city using remote sensing and GIS application, j.Environ.Sci. & Natural Resources, 7(2): 105-109.

Matluba K.,(2014). Study of open space in the context of Dhaka city for sustainable use, International Journal of Engineering and Technology, Vol. 6, No. 3

Omidreza S., Alireza F., Marjan B., nor A. C.S., (2015), an overview of Waste-to Energy in Malaysia, Applied Mechanics and Materials Vol. 695, pp 792-796

Queiruga, D., Walther, G., Gonzalez-Benito, J., & Spengler, T. (2008). Evaluation of sites for the location of WEEE recycling plants in Spain. Waste Management, 28, 181-190.

Rao, M., S., Singh, A.K. & Sodha, M.S. (2000). Bioenergy conversion studies of the organic fraction of MSW: assessment of ultimate bioenergy production potential of municipal garbage. Applied Energy, 66, 75-87.

Rao, P.V., Baral, S.S., Dey, R. & Mutnuri, S. (2010). Biogas generation potential by anaerobic digestion for sustainable energy development in India. Renewable and Sustainable Energy Reviews, 14, 2086-2094.

SenerB, Suzen MI, DoyuranV, Landfill site selection by using geographic information systems, Environ Geol 2006; 49 (3) 376-88

Siddiqui, M., Everett, J.M., Vieux, B.E., (1996). Landfill sitting using geographical information systems: a demonstration. J.Environ.Eng. 122, 515-523.

Sasao, T., (2004). An estimation of the social costs of landfill sitting using a choice experiment. Waste Management 24, 753-762.

Swallow, S.K., Opaluch, J.J., Weaver, T. F., (1992). Sitting noxious facilities: an approach that integrates technical, economics, and political consideration. Land Economics 68 (3), 283-301.

Siddiqui, M., Everett, J.M., Vieux, B.E., (1996), Landfill sitting using geographical information systems: a demonstration. Journal of Environmental Engineering 122, 515-523.

Satty 1980

Sandra S., Luis A. A., Luis C. D. (2014). Biogas plants site selection integrating Multicriteria Decision aid methods and GIS techniques: A case study in Portugal city, Journal of Biomass & Bioenergy 71(2014) 58-68.

Salman. M, A. Golamalifard M., (2006). Sitting MSW Landfills with weighted linear combination methodology in a GIS environment. Int. J. Environ. Sci. Technol. 3 (4). 435-445.

Syed Hafizur Rahman,2011 Application of GIS Techniques in Urban Solid Waste Management. Dhaka published Jul-Sep (2011) Journal of Sustainable Development and Environmental Protection Vol.1 No.2.

Tchobanglous, G.Theisen, H. and Vigil, S. (1993). Integrated solid waste management, Engineering principls and Management Issues, New York, NY.

Troschintez, A.M., Mihelcic, J.R., (2009). Sustainable recycling of municipal solid waste in developing countries. Waste management.Vol-29,915-923

Truitt, m., Liebnman, J., kruse, C. (1969). Simulation model of urban refuse collection. Journal of the Sanitary Engineering Division, April, 289-298.

Tariq, B. Y., & Mostafizur R., (2007). Monitoring quantity and characteristics of municipal solid waste in Dhaka City

Yu, H., Huang, G.H., (2009). Effects of sodium as a PH control amendment on the composting of food waste. Bio resource. Technol. 100, 2005-2011.

R. Vijay, "Estimation and allocation of solid waste to bin through geographical information systems". Journal of Environmental Engineering and Science, Volume 7, Number 1, 1 January (2008) , pp. 39-43

S. Upasna & M. S. Natwat. (2003). Selection of potential waste disposing sites around Ranchi Urban Complex using Remote Sensing and GIS techniques. In: Map India 2003.

Nishanth.T , Prakash M.N , Vijith.H. (2010), Suitable site determination for urban solid waste disposal using GIS and Remote sensing techniques in Kottayam Municipality, India Published International Journal of Geomatics and Geosciences Volume 1, No 2, 2010

E. Tinmaz & I. Demir, (2005) Research on solid waste management systems: To improve existing situation in Corlu Town of Turkey. In: Science Direct,

Urban Development & Local Government, World Bank (2012), What a Waste: A global review of Solid Waste Management.

Y. Dhokhikah, Y. Trihadiningrum (2012) Solid waste management in Asian Developing Countries: challenges and opportunities.

Zurbrügg, C., Drescher, S., Rytz, I., Sinha, A.H.M.M., Enayetullah, I., (2005). Decentralized composting in Bangladesh, a win-win situation for all stakeholders. Resources, Conservation and Recycling 43, 281-292.

Appendixes

Research Area Map

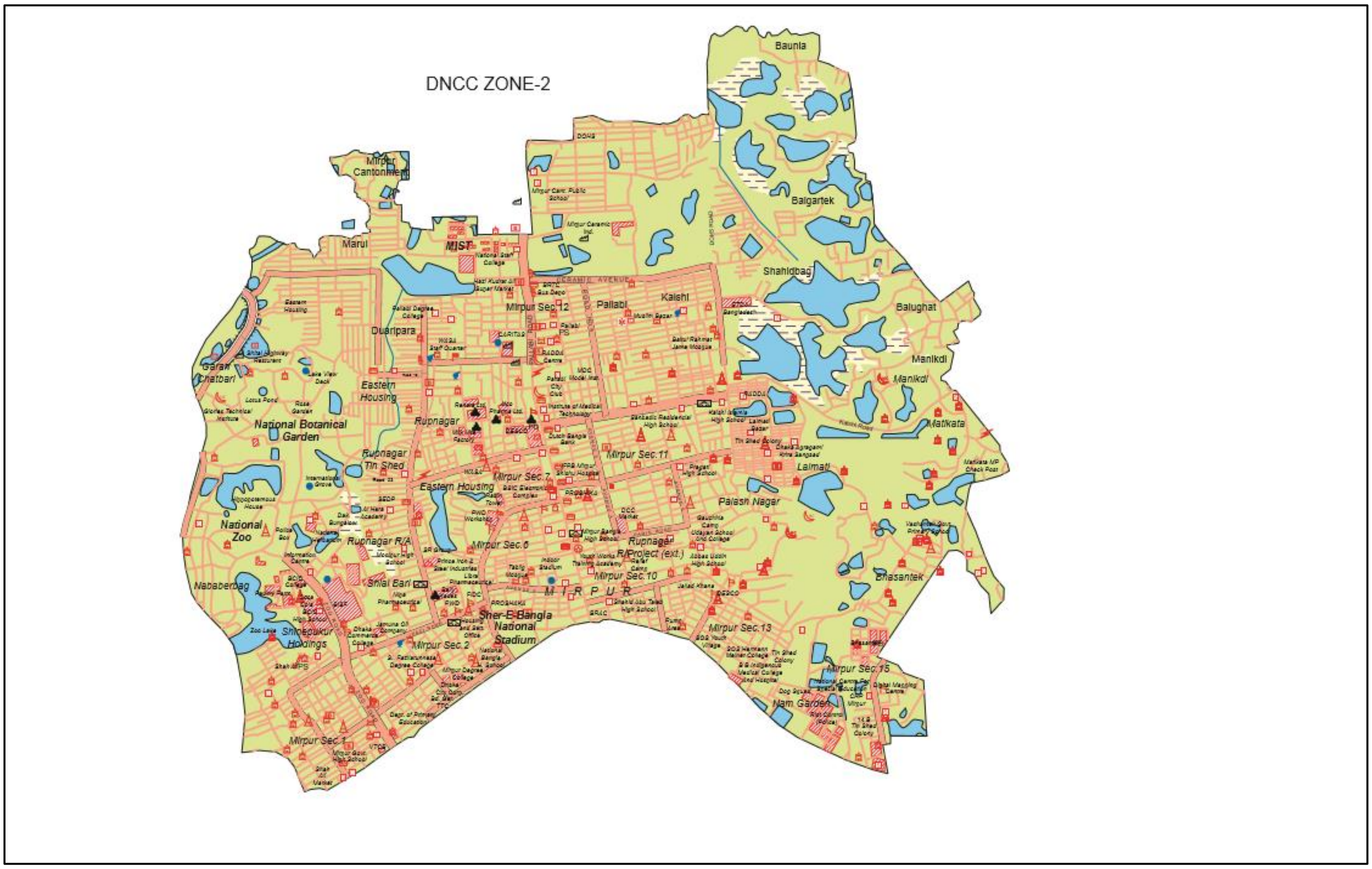


Fig. 1: Research Area Zone 2 of Dhaka North City Corporation

Ward No 2

Fig. 2: Ward 2 Map of Zone 2, Dhaka North City Corporation

Ward No 3

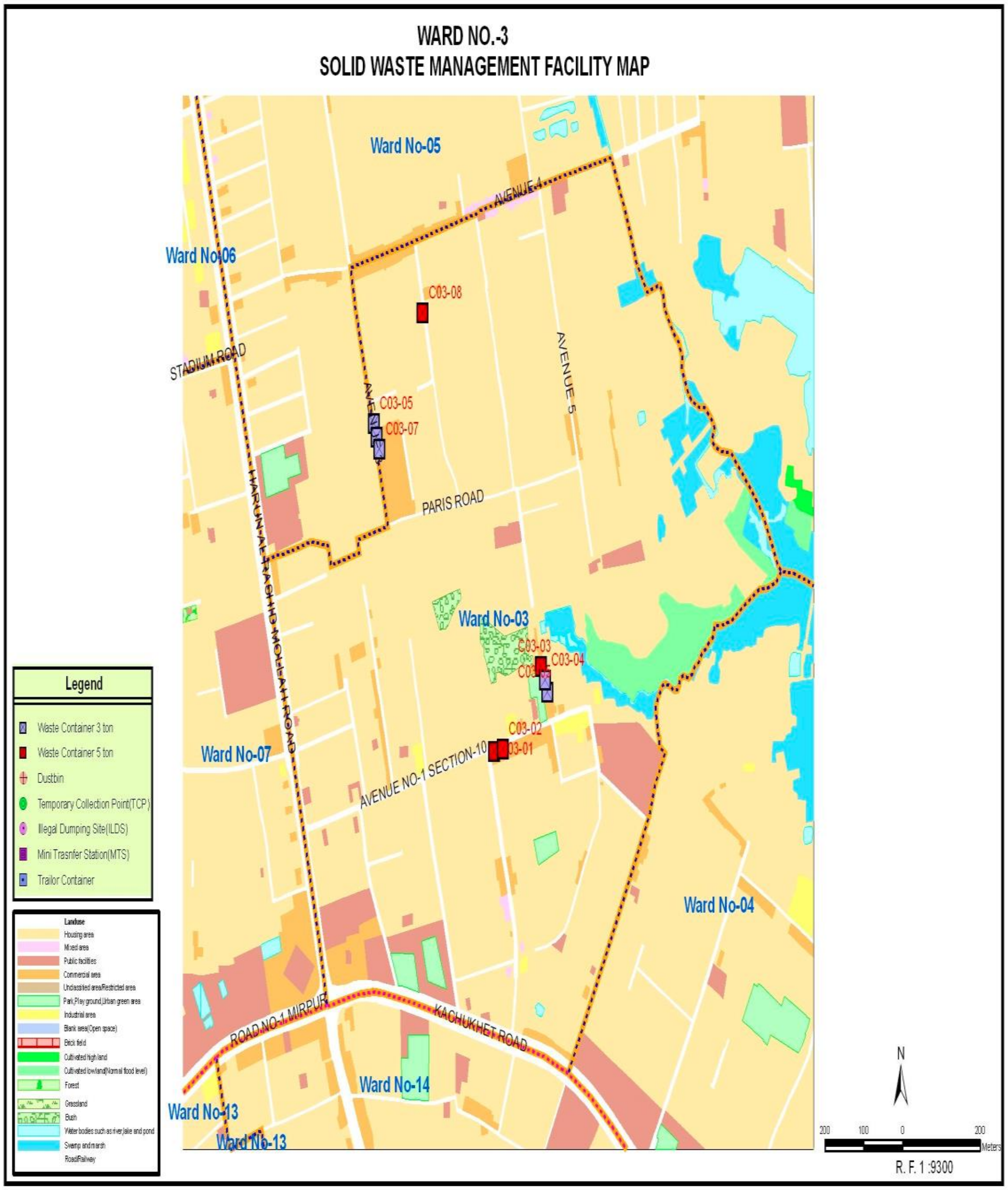


Fig. 3: Ward 3 Map of Zone 2, Dhaka North City Corporation

Ward No 4

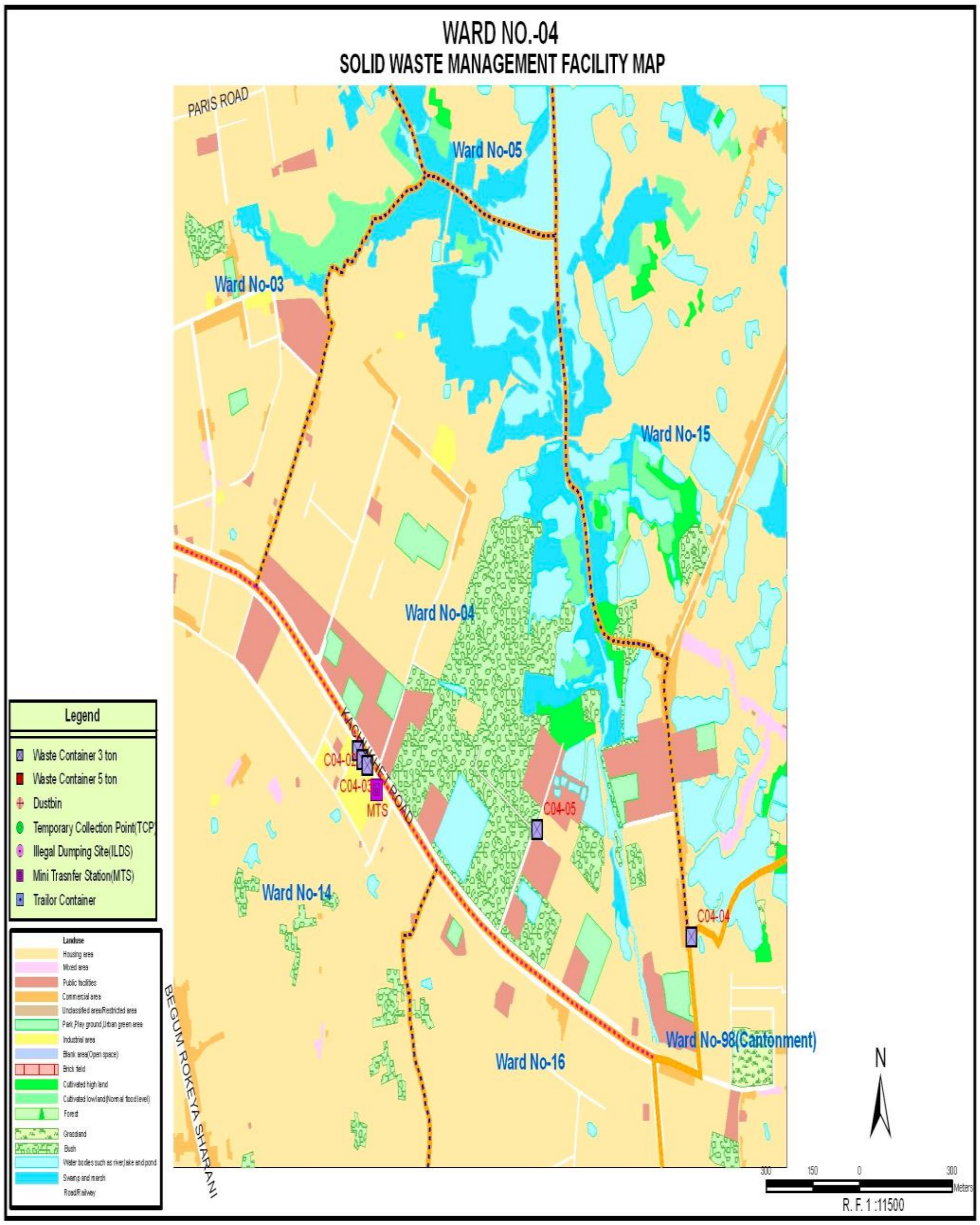


Fig. 4: Ward 4 Map of Zone 2, Dhaka North City Corporation

Ward No 5

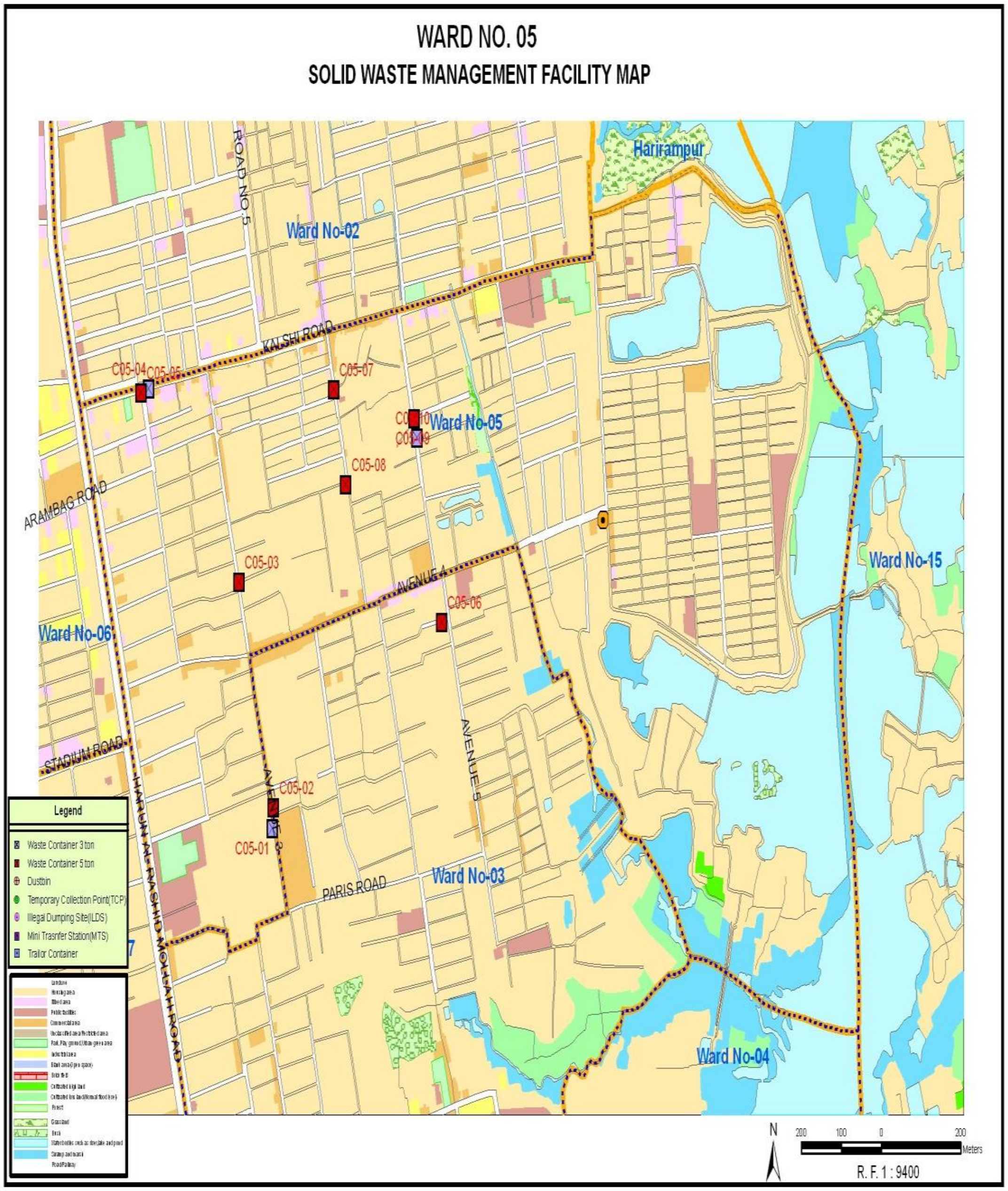


Fig. 5: Ward 5 Map of Zone 2, Dhaka North City Corporation

Ward No 6

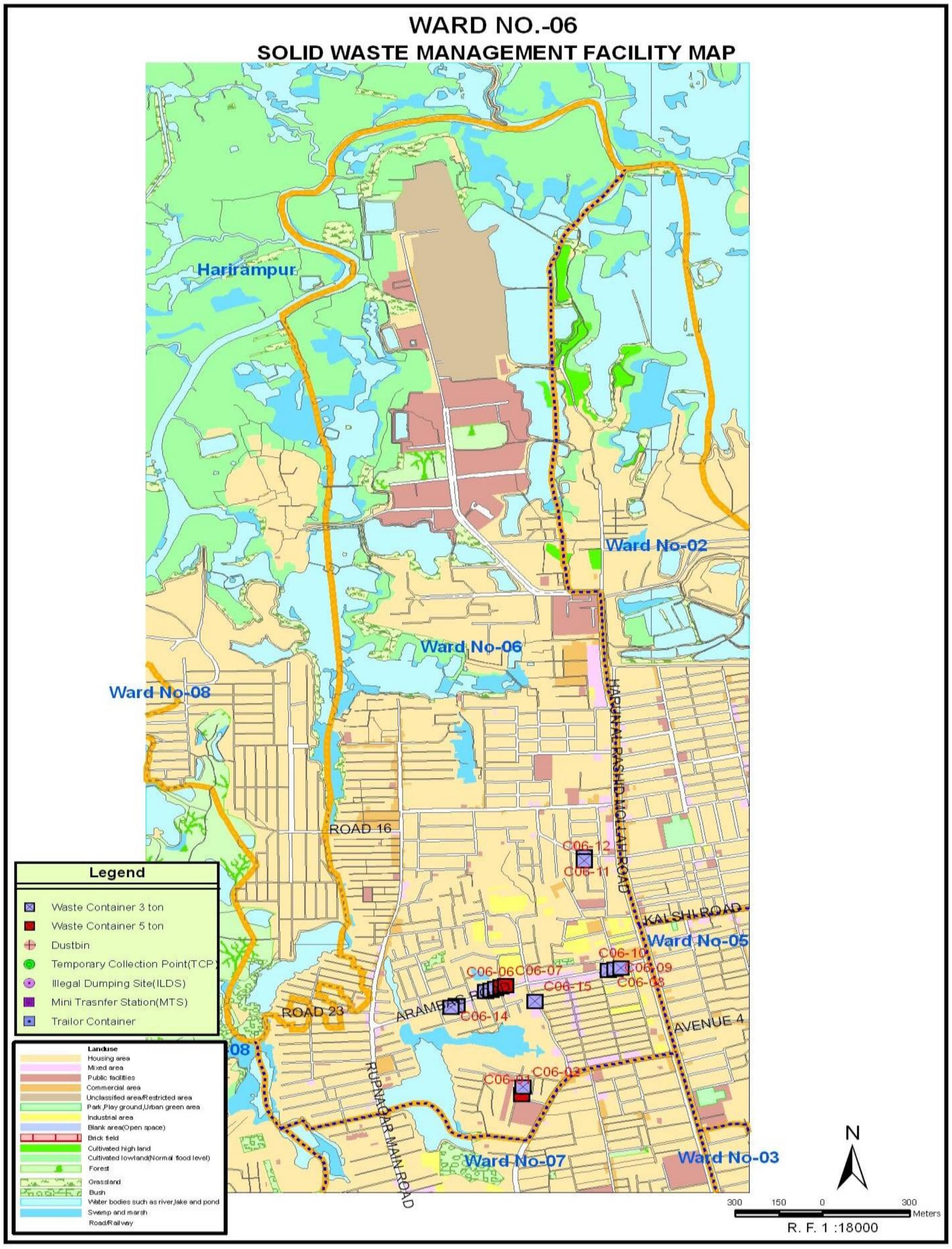


Fig. 6: Ward 6 Map of Zone 2, Dhaka North City Corporation

Ward No 7

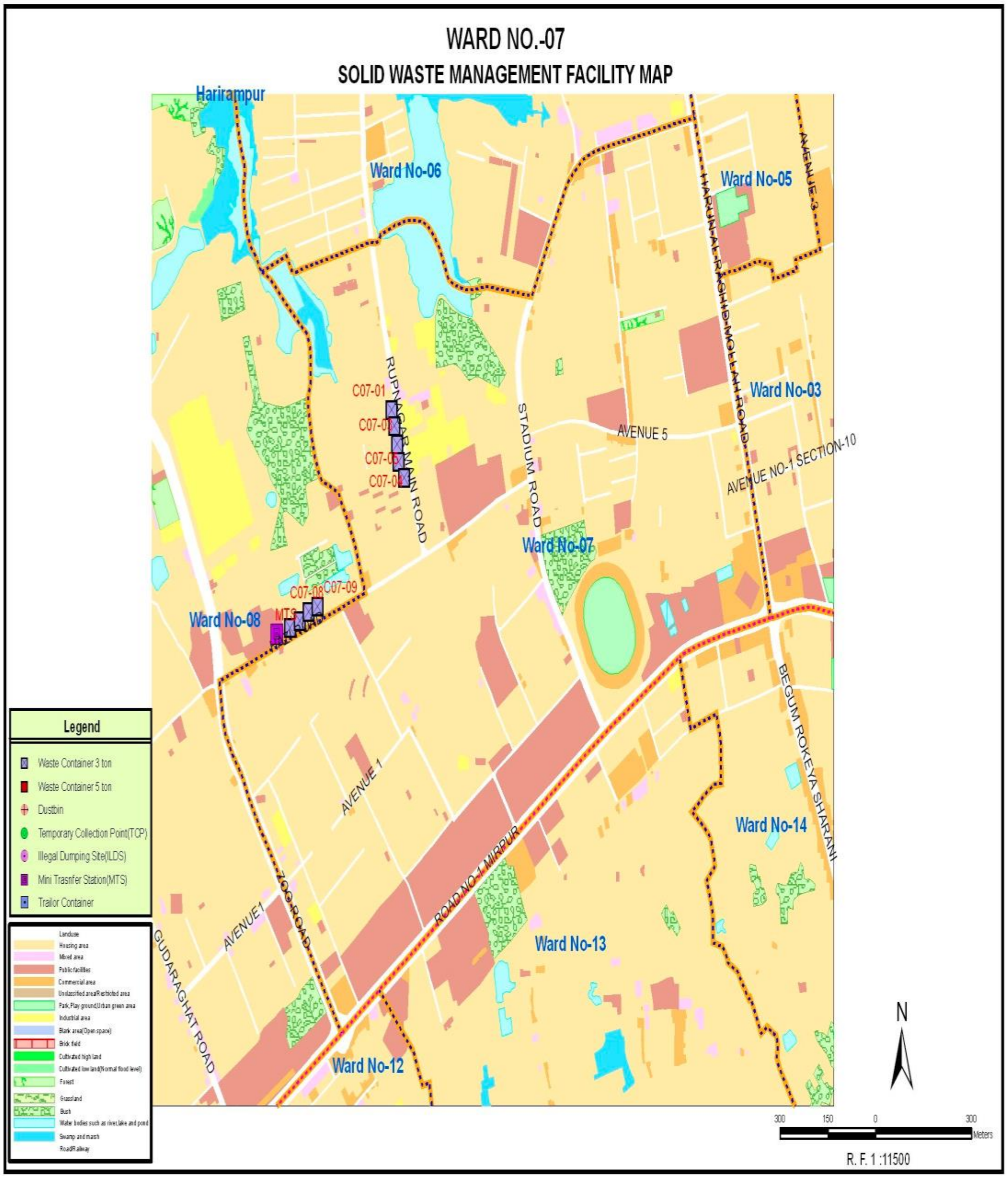


Fig. 7: Ward 7 Map of Zone 2, Dhaka North City Corporation

Ward No 8

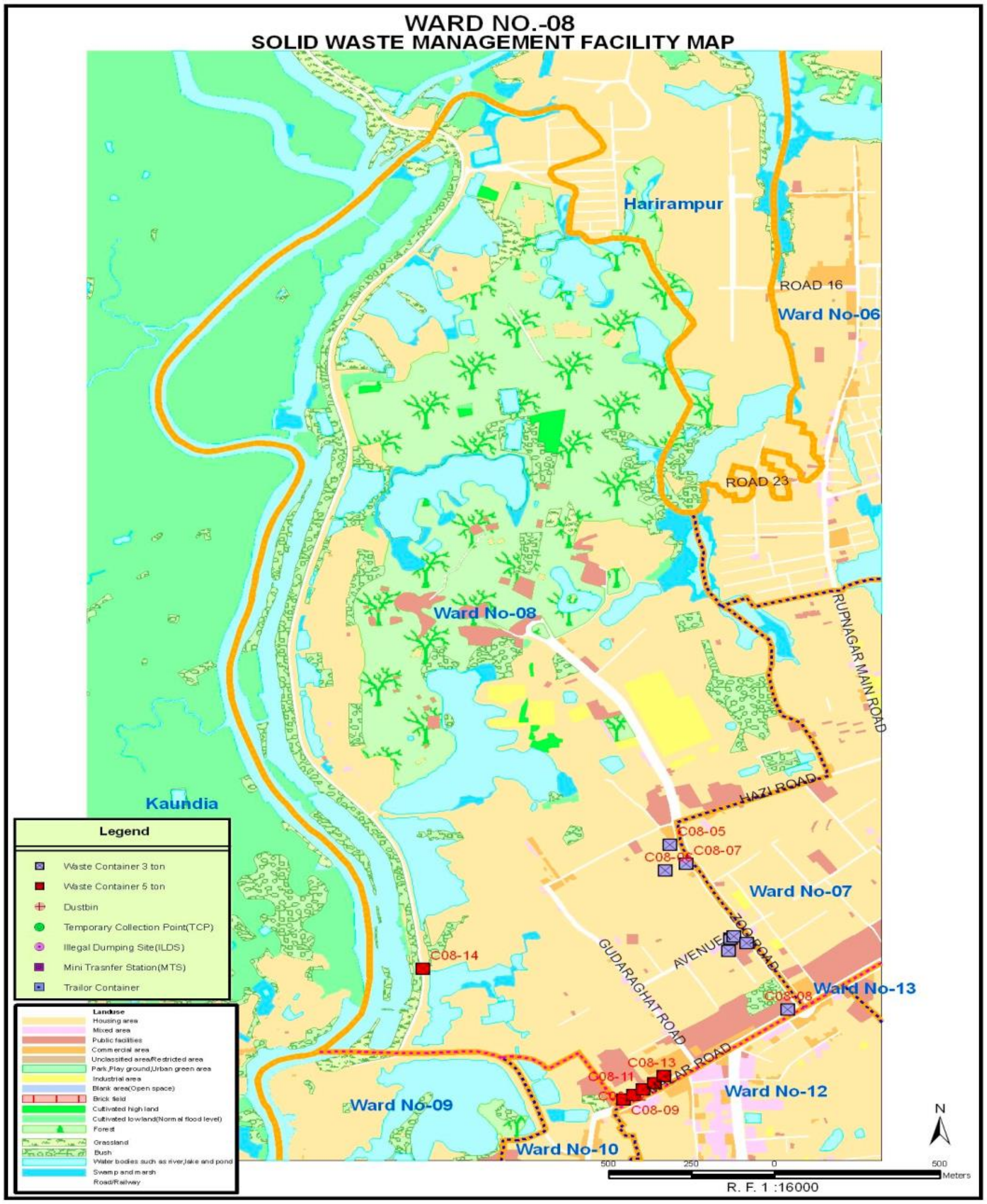


Fig. 8: Ward 8 Map of Zone 2, Dhaka North City Corporation

Ward No 15

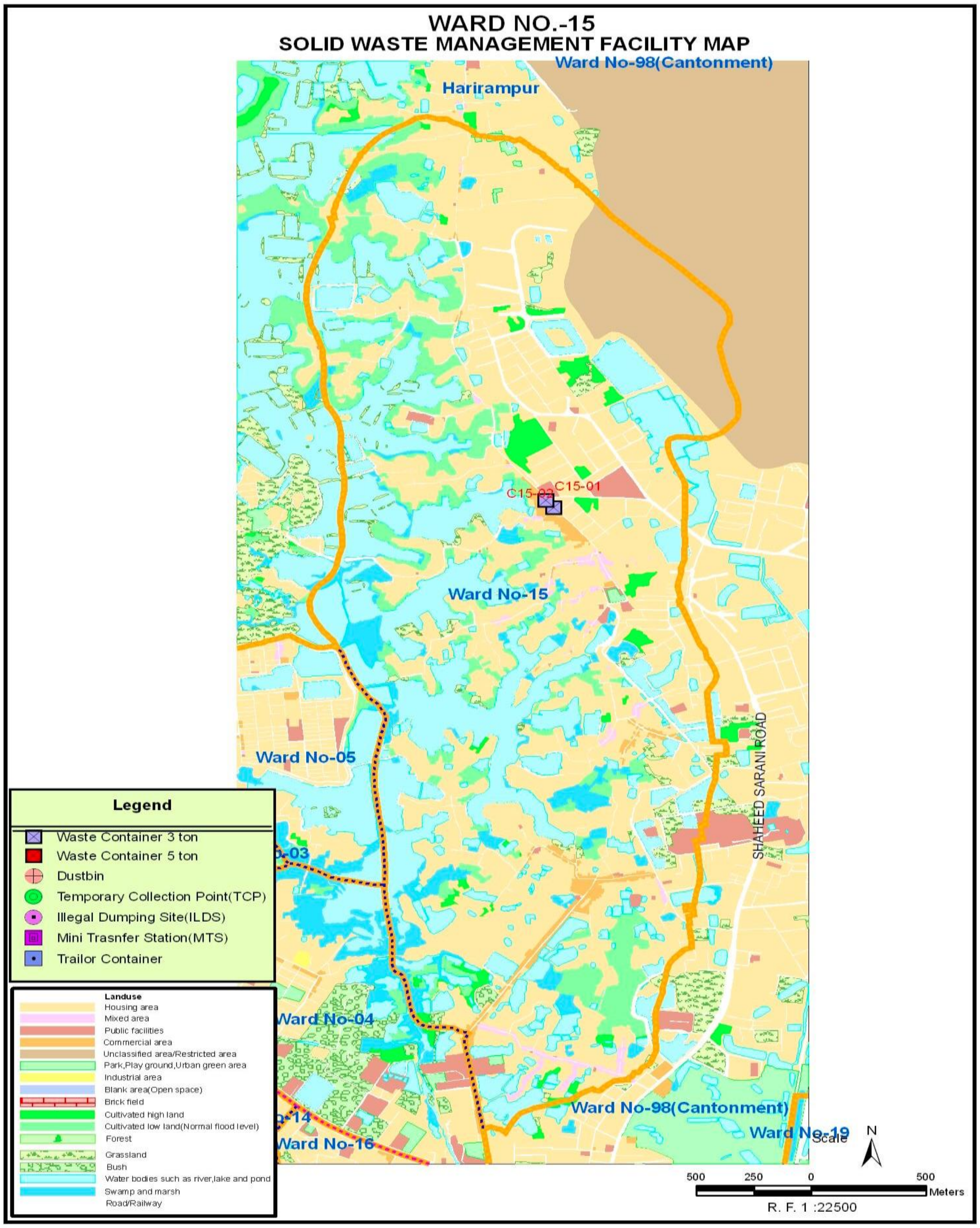


Fig. 9: Ward 15 Map of Zone 2, Dhaka North City Corporation