Journal of Engineering Science 10(1), 2019, 113-122

JES
an international Journal

MANAGING MUNICIPAL WASTE: APPLICATION OF SPATIAL TOOLS AND TECHNIQUES

Showmitra Kumar Sarkar* **and Md. Esraz-Ul-Zannat**

Department of Urban and Regional Planning, Khulna University of Engineering & Technology, Bangladesh

Received: 08 January 2019 Accepted: 20 June 2019

ABSTRACT

Municipal waste management is one of the major challenges for every municipal authority in Bangladesh. The objective of the research was to investigate the existing condition of the municipal waste management system and prepare a GIS-based plan for Natore Municipality in northern Bangladesh. The research used spatial and non-spatial secondary data and the result was validated through ground truth and stakeholder interviews. Ward wise population was projected for the year 2021 and Spatio-Temporal building wise population was also estimation. Building wise waste generation was estimated and proposed dustbin locations were identified. Suitability analysis and service area analysis were conducted for justifying the suitable location of dustbin and landfill sites. According to the result, permanent resident of the municipality would be 91571 in 2021 and total waste generated 39372.95 kg per day. Finally, the suitable location of 45 mini dustbins and 3 landfill sites were identified for effective waste management. The research would help the authority to take initiatives to increase the efficiency of Municipal Waste Management system of Natore Municipality.

Keywords: *Municipal solid wastes, Waste collection points, Disposal sites, ArcGIS, Suitability Analysis*

1. INTRODUCTION

Bangladesh experiences numerous environmental problems associated with the poor management of municipal waste (Hasnat *et al.*, 2019). Like other Asian developing countries, rapid urbanization and lack of coordination among proper plan, skilled manpower, and public awareness are the major challenges for managing the waste in Bangladesh. Lack of technical experiences and financial resources exacerbates this situation for the capital to small towns, which are resulting in various problems such as inadequate service coverage, operational ineffectiveness, and inadequate landfill sites. To sum up, A poor waste management system is responsible for several environmental problems (i.e., unpleasant odor, air pollution, and groundwater contamination) and the risk of human health, which leads to the disruption of normal life. In this context, there is a pressing need to call for a waste management system that will be sustainable.

Studies revealed that about 4.9 million tons of wastes were produced per year in the urban areas of Bangladesh. It is projected that the contemplated amount would grow up to 47,000 tons/day and close to 17.2 million tons per year by 2025, due to the rapid growth both in population and the increase in per capita waste generation (Khandker and Hossain, 2017). In 518 urban areas of Bangladesh (i.e., 10 city corporations, 298 municipalities, and 210 other urban centers) around half of the household waste dumped in inappropriate areas (i.e., roadside, low lying areas, water reservoir, and canal). So, municipal waste management has become one of the major challenges for the municipal authorities.

Natore municipality is one of the influential urban areas in northern Bangladesh and connecting hub of central and southwest parts. It is district headquarter which located near two historical sites (i.e., Rani Bhabani Rajbari and Uttara Gano Bhaban) and the largest beel in Bangladesh (i.e., Chalan Beel). People are migrating in these core urban areas from other sub-districts especially from the rural areas and putting pressure on the population. The amount of domestic waste generated within the municipality is huge and increasing day by day. This makes the municipal authority overburden to manage the domestic waste properly due to having different constraints like faulty management, lack of an appropriate plan and its implementation, expertise and cutting-edge technology and most importantly financial constraints. It is an urgent need to find out the exact gaps, which are the hurdles to handle the existing solid waste management system effectively with the available strengths of the municipality. The major objectives of the research were to investigate the existing condition of the municipal waste management system to find out the gaps and weakness and propose a plan for Natore Municipality with the help of using spatial tools and techniques. The study would help the authority to take initiatives reducing the impact of poor waste management as well as to increase the efficiency of Municipal Waste Management system.

2. LITERATURE REVIEW

Municipal waste (MSW) is a type of waste that consists of typical, everyday items that are thrown away by the public. Municipal waste is typically called garbage or trash in the U.S. and refuses or rubbish in the U.K. (Kumar

* Corresponding Author: mail4dhrubo@gmail.com

et al., 2016). It varies from country to country depending on what systems are available with regard to recycling and how waste is disposed. In a developed country with good recycling systems, municipal waste will mainly include items that cannot be recycled. These items that are not able to be recycled are disposed in a landfill (Glanville and Chang, 2015).

There exist many ways to manage the municipal waste such as Landfills, Incineration/Combustion, Recovery and Recycling, Plasma gasification, Composting, Avoidance/Waste Minimization and Waste to Energy (Recover Energy), etc. (Ministry of the Environment, 2015). Moreover, in recent year spatial tools and techniques such as GIS and Remote Sensing become more popular in waste disposal monitoring and mapping which improve the accuracy and efficiency of municipal waste management process (Karsauliya, 2013). Research shows that by choosing suitable site and best collection and distribution route through GIS technique can reduce environmental pollution and can save money by minimizing travel cost and time (Kallel *et al.*, 2016).

3. METHODS AND MATERIALS

3.1 Study Area

Natore Municipality under Natore District is one of the most important urban areas in Northern Bangladesh. Three reasons (i.e., being a historical site, rapid population growth, and poor waste management system) were behind selecting as a study site. The area under Natore Municipality is 14.80 Square Kilometer including nine administrative wards and 33 mahallahs. According to (BBS, 2011), the total permanent population was 81203. Natore is considered as the gateway for connecting divisional headquarters Rajshahi to Capital City Dhaka as well as Rangpur Division and Khulna Division.

According to the Natore Municipality Development Plan (2010-2030), the total household waste production in Natore Municipality was 33.25 ton/day (i.e., 0.34 kg/person/day) in 2010. The amount of household waste has been increasing rapidly due to a change in lifestyle and food habits. Increasing use of packing items (i.e., plastics, cans, aluminum foils, etc.) changed the composition of household waste cause incalculable harm to the environment. The existing waste management system covered only 40% of the total municipality area and private low lying areas was used for disposal of collected waste.

3.2 Materials and Tools

The research was conducted using spatial and non-spatial secondary data from relevant organizations such as shape files of existing features (i.e. boundary, roads, structures, river, etc.) from Natore Municipality, population data from Bangladesh Bureau of Statistics and satellite images from Google Earth. The generated result was validated through ground truth and stakeholder (i.e., 9 key people of municipal authority and people living or working in the study area) interviews. 5 Focus Group Discussions (FGDs) (i.e., 1 with the only female, 1 with the only male, and 3 with both male and female) were also conducted for investigating the existing condition of household waste management. Spatial analysis technology (i.e., ArcGIS 10.5) was used for data preparation, analysis, and visualization.

3.3 Population Projection for 2021

The research used previous population data of 2001 and 2011 from Bangladesh Bureau of Statistics. The annual percentage growth rate was calculated for every nine wards of the municipality by using the following equation.

$$Annual\ Growt\ Rate\ (\%) = \frac{\frac{(Population\ 2011 - Populatio\ \ 2001)}{Population\ 2001}}{(2011 - 2001)} * 100$$

The research was based on the projected population for 2021 due to fulfilling the goal of Vision 2021 (i.e., Digital Bangladesh) of Bangladesh Government. Ward wise future population was projected for 2021 using calculated growth rates and base population (i.e., the population in 2011) by the following equation.

$$Populationin\ 2021 = Population\ 2011 * (1 + \frac{2021 - 2011}{100} * Annual\ Growt\ Rate)$$

3.4 Spatio-Temporal Building Population Estimation

In most of the urban areas of Bangladesh, building wise population was not estimated by the municipal authority. The projected population of 2021 was distributed according to the residential buildings. For population distribution among the buildings, two parameters (i.e., number of floors and footprint area of buildings) were

used. According to (Lwin and Murayama, 2009), following mathematical expressions of the volumetric method was used in this research.

$$BP_i = \left(\frac{CP}{\sum_{k=1}^{n} BA_k . \mathrm{BF}_k}\right) * BA_i . \mathrm{BF}_i$$

Where: BP_i = the population of building i, CP = the census tract population, BA_i = the footprint area of building i, BF_i = the number of floors of building i.

Root mean square error (RMSE) was also calculated for randomly selected buildings using the following formula. And finally, the estimated population was represented in the map for showing spatial distribution.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Actual - Estimated)^2}{n}}$$

3.5 Household Waste Generation

Building wise daily waste generation was calculated by multiplying estimated building population and the World Bank standard of per capita waste generation in the municipal area of Bangladesh. Ward wise total amount of household waste was calculated and volume was calculated using Bulk Density of average generated waste in Bangladesh from the secondary source. According to the existing practice of the municipality and availability of land beside the road, the research proposed 4 cubic meters (6.5ft * 5.5ft * 4ft) dustbin in the study area. Finally, the required number of dustbin for managing the daily generated waste in each ward was calculated. Here, waste was calculated on a daily basis instated of a cumulated waste generation because this research recommended that daily waste should be cleaned on that day.

$$Waste\ Generated\ in\ Ward = \sum(Building\ Population * Per\ Capilat\ Waste\ Generation)$$

$$Volume\ of\ Waste\ (m) = \ Generated\ Waste\ (kg)/Bulk\ Density\ (kg/m^3)$$

3.6 Distribution of Proposed Dustbin (Theoretical Basis)

Hotspots analysis was conducted for identifying the distribution of waste generation within the municipality. Each ward was divided into a number of zones according to the calculated required number of dustbins. Locations of dustbins were identified by considering the density of population and residential buildings.

3.7 Suitability Analysis for Dustbin (Logical Basis)

A suitability analysis was conducted for justifying the theory based locations of the dustbin. This suitability was based on seven different criteria selected from different study and finalized by field observations, FGDs, and Key Informant Interviews. Weights of each criterion were finalized according to the mean of feedback from FGDs and Key Informant Interviews. Finally, priority level was divided into five classes (Minimum to Superior) for each criterion. GIS-based raster analysis was conducted using the following table and suitable locations were justified according to result.

Table 1: Criteria for Site Suitability of Dustbin Location

Criteria	Weight	Classify/Priority Level				
		1	2	3	4	5
		Minimum	Overall	Normal	Maximum	Superior
Density of Waste Generation (per Sq. Km)	30	0-1000	1000-2000	2000-3000	3000-4000	More than 4000
Distance from Residential Area (m)	15	120-150	90-120	60-90	30-60	0-30
Distance from Existing Roads (m)	25	80-100	60-80	40-60	20-40	0-20
Distance from Drainage Network (m)	5	0-10	10--20	20-30	30-40	More than 40
Distance from Water bodies (m)	10	0-20	20-40	40-60	60-80	80-100
Distance from Agricultural Land (m)	5	0-30	30-60	60-90	90-120	More than 120
Distance from Stream Network of Natural Flow (m)	10	0-20	20-40	40-60	60-80	More than 80
Total	100					

3.8 Service Area Identification (Logical Basis)

GIS-based service area analysis was conducted to investigate the service area of each dustbin. The research used 500 meters maximum distance of a dustbin's service area according to the existing road network. The output raster of the service area was overlapped by building footprints to investigate the served buildings.

3.9 Suitability Analysis for Landfill Sites

A suitability analysis was conducted to identify the location of landfill sites where municipal authority can dump the collected waste. Similarly, seven criteria were selected, divided according to the priority level and given weight according to field observations, FGDs, and Key Informant Interviews. This time GIS-based raster analysis was conducted for identifying suitable location landfill sites. Finally, landfill sites were finalized based on site visit and observation.

Table 2: Criteria for Site Suitability of Landfill Sites

		Classify/Priority Level				
		1	2	3	4	5
Criteria	Weight	Minimum	Overall	Normal	Maximum	Superior
Ground Elevation (m)	35	0-12	12--13	13-14	14-15	More than 15
Distance from Residential Area (m)	10	0-300	300-600	600-900	900-1200	More than 1200
Distance from Existing Roads (m)	20	More than 80	60-80	40-60	20-40	0-20
Distance from Drainage Network (m)	10	0-200	200-400	400-600	600-800	More than 800
Distance from Water bodies (m)	10	0-200	200-400	400-600	600-800	More than 800
Distance from Agricultural Land (m)	5	More than 800	600-800	400-600	200-400	0-200
Distance from Stream Network of Natural Flow (m)	10	0-200	200-400	400-600	600-800	More than 800
Total	100					

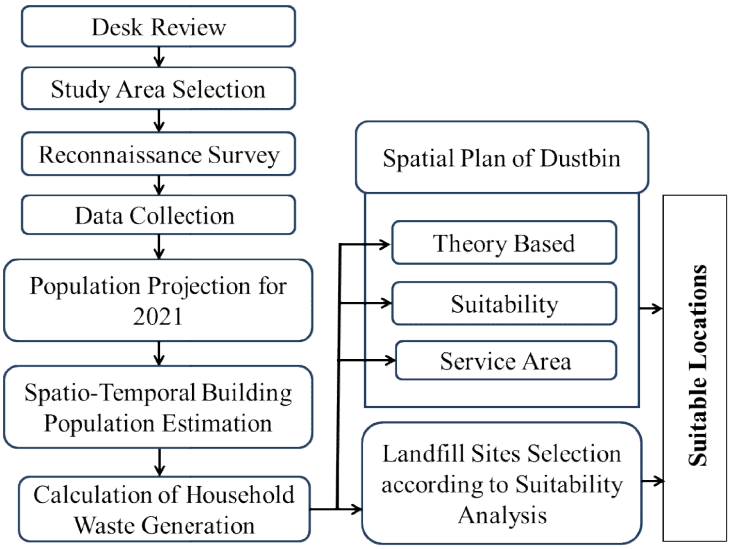

Figure 1: Methodological Flow Chart of the Research

4. ANALYSIS AND DISCUSSIONS

4.1 Population Projection for 2021

In 2001, permanent resident of Natore Municipality area was 70835 eventually distributed in nine wards. The ward 07 contained minimum population in 2001 (i.e., 6875) and field visit (including discussion with local people) identified the huge amount of agricultural land as the main reason for low population density in this wards. According to officials of municipality, wards having a larger area (i.e., ward 01, ward 03, ward 07 and ward 09) were mostly enclosed by agricultural lands during the early 21st century. A huge area under ward 01 covered by the historical site (i.e., Rani Bhabani Rajbari) and field observations identified it as another reason of low population density in this ward. 10368 permanent residents of Natore Municipality increased in ten years (from 2001 to 2011). Except ward 06, all ward showed a positive trend of population growth. According to field observation, ward 06 was the central business district of Natore Municipality and that can be the main reason behind limiting residential population. On the other hand ward 03 showed maximum population growth rate (i.e., 3.13% per year) and focus group discussion identified some major reasons (i.e., low land price compared to other wards, connected to Natore- Bogra highway, proximity to most of the government office, good living environment, etc.). In this ward, the huge number of resident came from nearby Upazila (i.e., Singra Upazila) for the purpose of business, employment and education during those ten years (from 2001 to 2011). The calculated average yearly population growth rate of Natore Municipality (i.e., 1.18%) was higher than the national population growth rate of Bangladesh in 2011 (i.e., 1.16%) as well as in 2018 (i.e., 1.03%) (Worldometers, 2018). According to population projection for 2021, total permanent resident of Natore Municipality will be 91571 but according to discussion with municipality officials, the population will be 20-25% additional due to the temporary living people.

Table 3: Ward wise Population Projection of Natore Municipality

Ward No.	Area (Acres)	Population (2001)	Population (2011)	Growth Rate (%)	Population (2021)
Ward 01	688.13	7956	8688	0.842541	9420
Ward 02	286.56	8374	8991	0.686242	9608
Ward 03	823.74	7920	11536	3.134535	15152
Ward 04	140.65	7470	7879	0.519101	8288
Ward 05	298.4	8461	9740	1.313142	11019
Ward 06	174.15	8396	7979	-0.52262	7562
Ward 07	509.62	6875	8209	1.625046	9543
Ward 08	209.38	7727	9214	1.613848	10701
Ward 09	540	7656	8967	1.462027	10278
				(Average)	
Total	3670.63	70835	81203	1.185984	91571

4.2 Spatio-Temporal Building Population Estimation

Building wise population information is one of the important components for urban planning (i.e., public facility planning and environmental planning) (Lwin and Murayama, 2009). The research identified 11669 residential buildings in Natore Municipality area from structure footprint data of the municipality. Spatio-Temporal distributions of the population were population based on a number of floors, footprint area of buildings. According to spatio-temporal relationship minimum population was 2 and maximum population in a building was 170. Mean population in residential building was around 8 and the standard deviation was 8.78. Population map of the municipality area showed that 8,163 buildings (i.e., 70% of the total building) have population 2-7, and distributed all over the study area. The socio-economic condition of a small town and the availability of lands were the main reason behind the huge number of those small single floor buildings in the study area. The research identified that the population density is higher in ward 04, ward 06, ward 08 and some part of ward 05 and ward 07. According to the field observations, the central part of the town and connection with Rajshahi-Dhaka highway were the key reasons for higher density with multistory buildings in those part of the study area. In the study area, only 0.38% of buildings have four stories or more than four stories due to socio-economic condition and availability of land. To validate the result of population distribution RMSE was calculated using estimated value and actual observation value. Total 27 observations (i.e., three in each ward) were done and the value of RMSE was calculated as 0.01586. RMSE was close to zero that represented the better distribution of population in the research area.

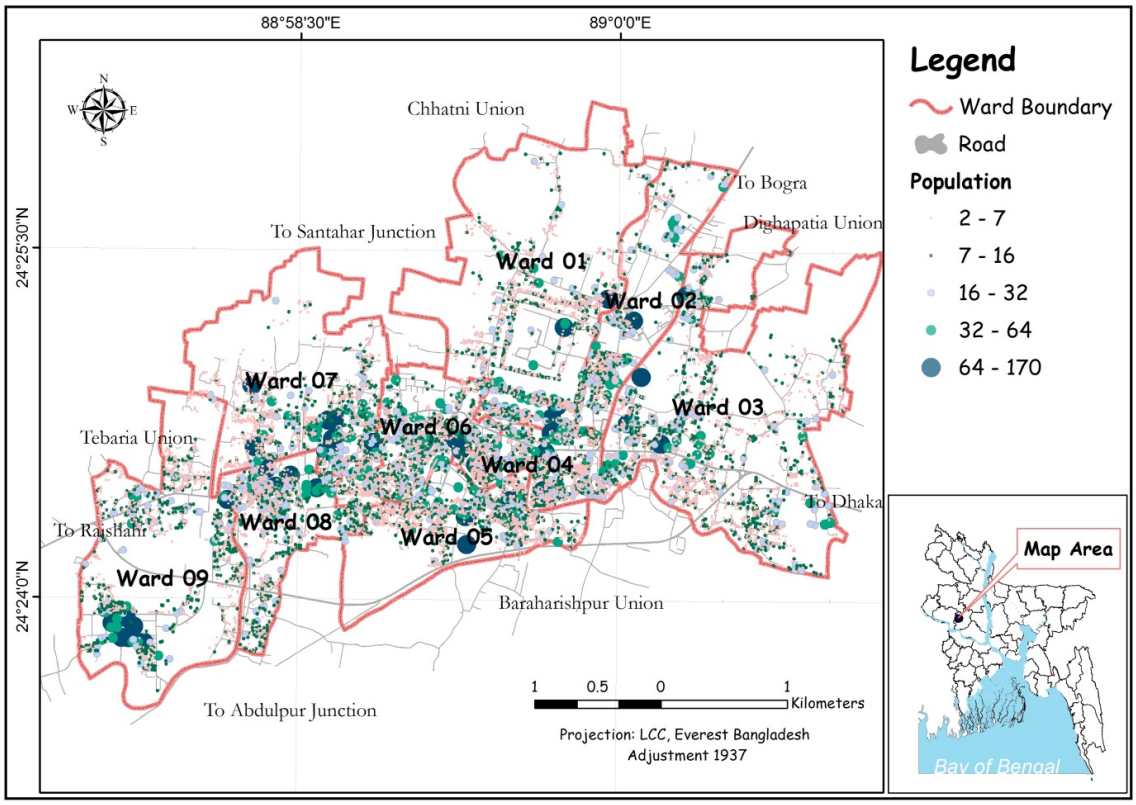

Figure 2: Spatio-Temporal Building Population Estimation of Natore Municipality

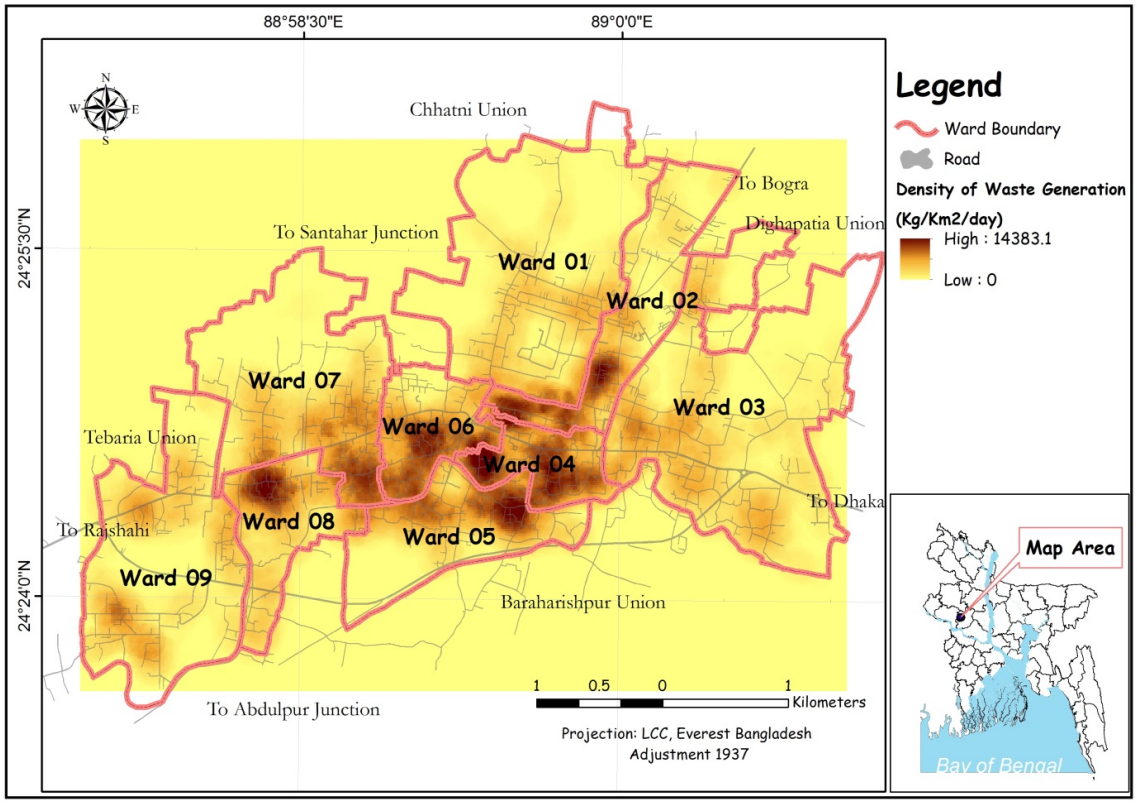

Figure 3: Spatial Distribution of Waste Generation in Natore Municipality

4.3 Waste Generation in Study Area (Household Based)

Ensuring smart waste management system, municipal waste generation needs to calculate (Shubho *et al.*, 2013). Building wise estimated population was multiplied by the country-specific standard of municipal waste generation per capita in Bangladesh (i.e., 0.43 kg/ capita/ day) (The World Bank, 2012). The result of this process was household wise waste generation per day and finally ward wise total waste generation was calculated. In accordance with the result, 39373 kg household wastes were generated in 9 wards (i.e., 11669 households) of Natore Municipality. Being the largest ward according to the area, the height amount of waste was generated in ward 03 of the study area. The research used bulk density as 213.19 kg/m^3, which is the average of bulk density for domestic waste in two seasons (i.e., dry and wet season) (JICA, 2005). Total 184.69 m^3 waste generated per day in the study area. This research proposed 45 small dustbins (i.e., 4 m^3 volume for each) with consulting with municipality officials. According to waste generation map, waste generation density was higher in ward 04, ward 06 and some part of ward 02 and ward 05. Field visit and discussion with residents identified that those parts of the municipality were densely populated with multistory buildings.

Table 4: Ward wise Waste Generation in Natore Municipality

Ward No	No of Household	Total Generated Waste (kg)	Bulk Density (kg/m^3)	Volume of Dustbin (m^3)	Number of Dustbins
Ward 01	1262	3559.11	213.19	16.69	4
Ward 02	990	3809.80	213.19	17.87	4
Ward 03	1999	6297.35	213.19	29.54	7
Ward 04	1289	4579.07	213.19	21.48	5
Ward 05	1365	4437.60	213.19	20.82	5
Ward 06	1041	3879.89	213.19	18.20	5
Ward 07	1490	4884.37	213.19	22.91	6
Ward 08	1033	3805.50	213.19	17.85	4
Ward 09	1200	4120.26	213.19	19.33	5
Total	11669	39372.95	-	184.69	45

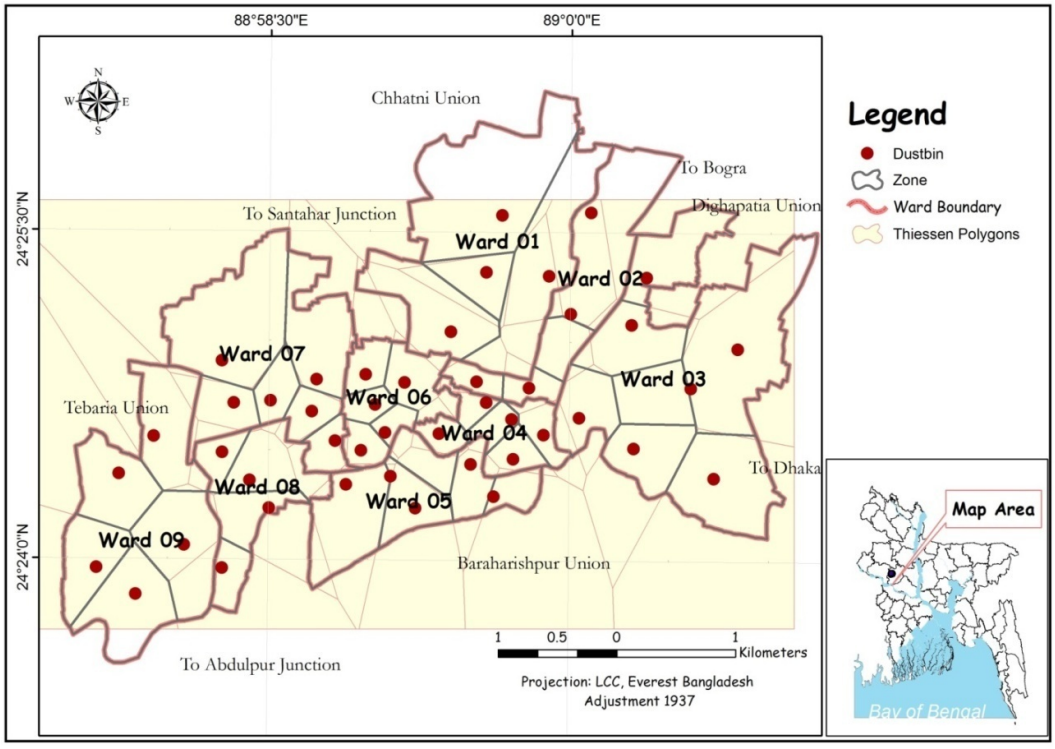

Figure 4: Proposed Dustbin Locations of Natore Municipality

4.4 Distribution of Proposed Dustbin (Theoretical Basis)

Required numbers of dustbin were distributed in each ward. According to the dustbin distribution map, dustbins zone were small in ward 04, ward 06 and some part of ward 02 and ward 05. Field visit and discussion with residents identified that those parts of the municipality were densely populated as well as generating a larger amount of household waste. On the other hands, outer parts (including fringe area) of the city have lower population density with a huge amount of agricultural lands. Households in those areas used perishable waste for domestic animals (i.e., cow, goat) and organic fertilizer. According to the field visit, large zones for one dustbin were suitable for those areas because of low building/ population density, road connectivity, and socio-economic condition.

4.5 Suitability Analysis for Dustbin (Logical Basis) Plan for Effective Waste Management Facilities

Following map showing the total of 45 dustbin locations with site suitability result. 42 dustbins were located in the superior and maximum suitable area. Three dustbins (i.e., the outer part of ward 01, ward 02, and ward 03) were located in normal suitable areas. As per as field visit, the population density was low in those three areas. According to discussion with the residents of those areas and officials of municipality, those locations will serve more people effectively than nearby superior and maximum suitable areas.

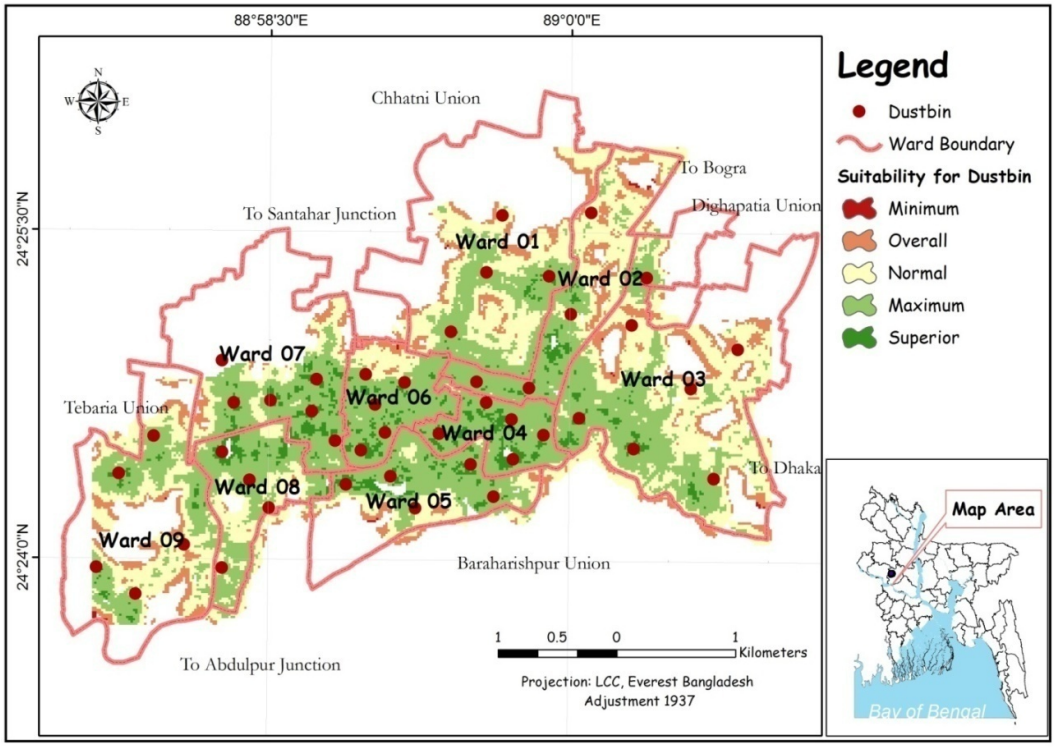

Figure 5: Suitability Analysis for Dustbin Location of Natore Municipality

4.6 Service Area Identification (Logical Basis)

This section of research identified the service area of the proposed dustbins in the study area. According to the result, most of the households were in the service coverage area in the study area. Households were scattered and roads were mud-covered in the outer part of municipality area. As a result, some households near the peripheral area were not covered by 500 meters service coverage area. According to field observation, most of the household near fringe area reuse their household waste organic fertilizer and food for a domestic animal. According to the officials of municipality, the amount of waste generated in the outer part of the city was little because of low population density and municipality can easily manage those wastes. Municipality wanted to improve roads and other facilities in the near peripheral area for future demand and expansion of the city. This research will help the municipality to find out the priority area for future development too.

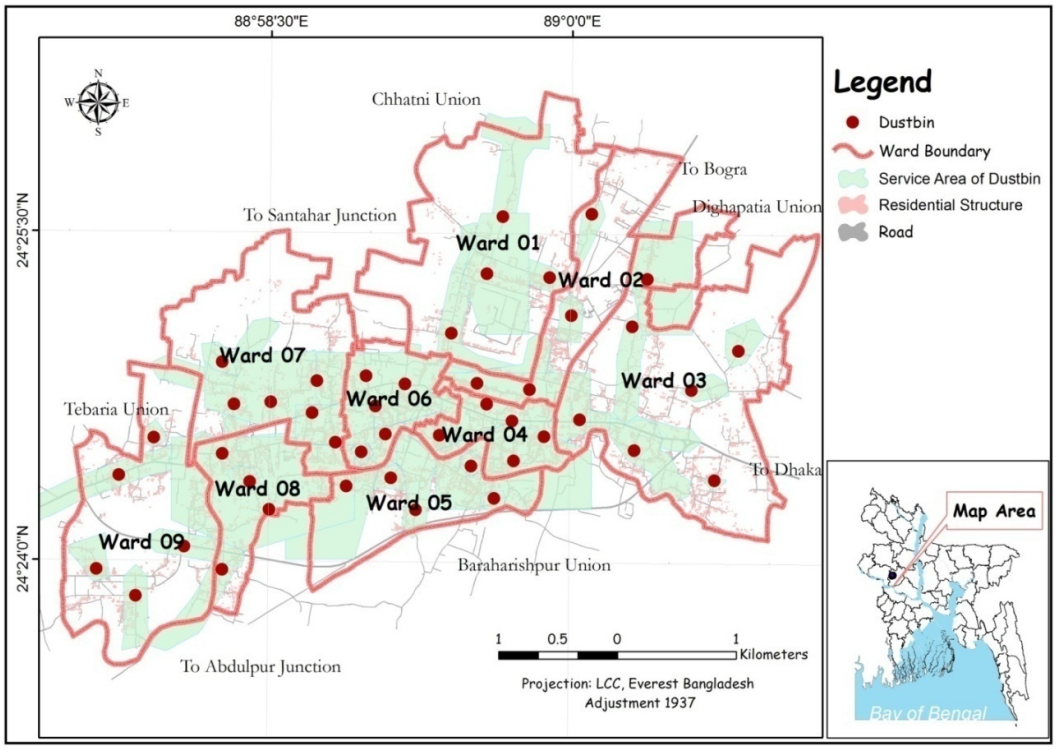

Figure 6: Service Area Analysis for Dustbin Location of Natore Municipality

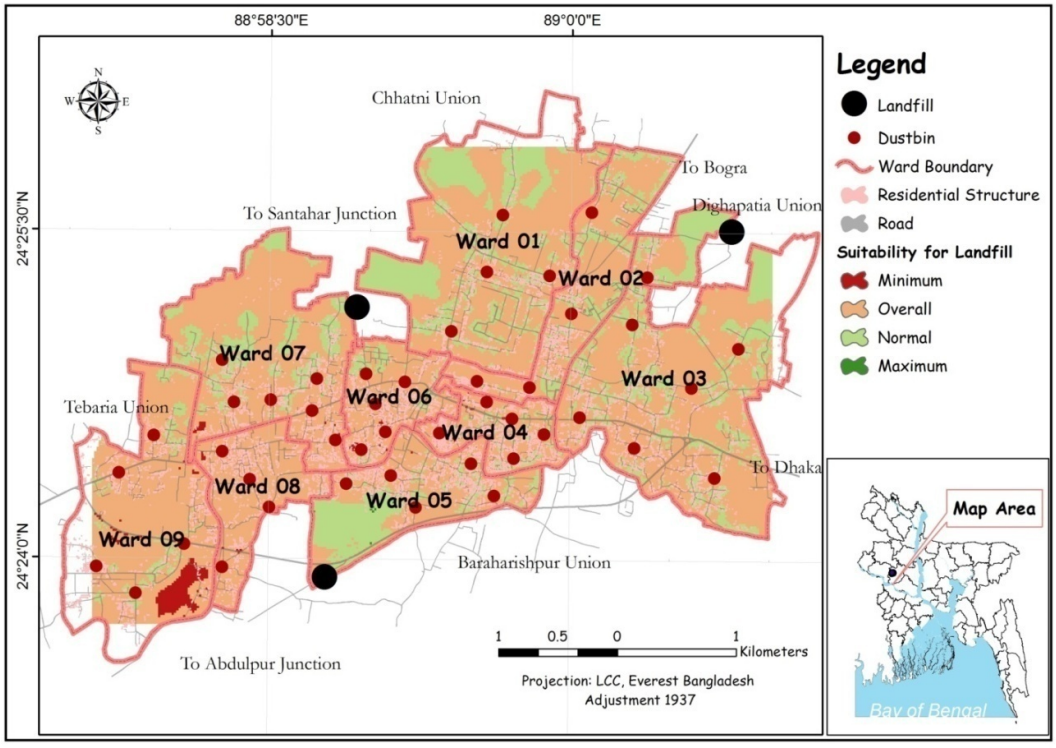

Figure 7: Suitability Analysis for Landfill Sites of Natore Municipality

4.7 Identifying Landfill Sites for the Collected Waste

According to suitability analysis, most of the suitable areas for landfill sites were located in the peripheral area of the municipality. People of the municipality wanted landfill sites away from their house. The municipal authority also wanted those sites out of municipal boundary. According to officials of municipality, they suggested some low lying areas located in peripheral zones that may help for future development and city expansion. On the

other hand, those locations will minimize environmental degradation due to household waste. The research suggests specific landfill site for specific wards (i.e., site 01 for ward 02, 03, 04; site 02 for ward 01, 06, 07 and site 03 for ward 05, 08, 09). According to field observation, connectivity between landfill sites and dustbins locations was accessible. According to the municipality, three landfill sites will help to manage household waste in a proper schedule.

5. CONCLUSIONS

The research investigated the existing condition of the waste generation scenario in Natore Municipality area with identifying the required number of household dustbins and landfill site locations regarding of the total projected populations using spatial tools and techniques. This study revealed the relationship between the populations and their subsequent waste generations, how the wastes would have been collected from the household through placing the suitable bins in the suitable locations and disposed of those wastes in the suitable landfill sites. The local government body like the municipal authority could adopt the findings of the research to overcome the hurdles in managing the solid waste management with having a myriad of constraints, which would reduce the impact of the existing waste management as well as to increase the efficiency of municipal waste management system of Natore Municipality.

REFERENCES

Bangladesh Bureau of Statisties, 2014. *Bangladesh Population and Housing Census 2011: Urban Area Report.* Dhaka: Bangladesh Bureau of Statisties, Statistics and Informatics Division, Ministry of Planning.

Glanville , K., and Chang H. C., 2015. Remote Sensing Analysis Techniques and Sensor Requirements to Support the Mapping of Illegal Domestic Waste Disposal Sites in Queensland, Australia. Remote Sens., 13053-13069.

Hasnat, G. T., Kabir M. A., and Hossain M. A., 2019. Major environmental issues and problems of South Asia, Particularly Bangladesh. Handbook of Environmental Materials Management, 109-148.

JICA., 2005. *The Study on Solid Waste Management in Dhaka City.* Yachiyo: Japan International Cooperation Agency, Pacific Consultants International Yachiyo.

Kallel, A., Serbaji M. M., and Zairi M., 2016. Using GIS-Based Tools for the Optimization of Solid Waste Collection and Transport: Case Study of Sfax City, Tunisia.

Karsauliya, S., 2013. Application of Remote Sensing and GIS in Solid Waste Management: A Case Study of Surroundings of River Yamuna, India. *International Journal of Environmental Engineering and Management.*, 593-604.

Khandker, S., and Hossain M., 2017. *Solid Waste: Emerging Threat to Gazipur City Dwellers*. Retrieved September 26, 2018, from daily-sun Web site: http://www.daily-sun.com

Kumar, S., Dhar H., Nair V. V., Bhattacharyy J., Vaidya A., and Akolkar A., 2016. Characterization of municipal solid waste in high-altitude sub-tropical regions. *Environmental Technology*, 2627-2637.

Lwin, K., and Murayama Y., 2009. A GIS Approach to Estimation of Building Population for Micro-spatial Analysis. *Transactions in GIS*, 401–414.

Ministry of the Environment, 2015. *Solid Waste Management and Recycling Technology of Japan.* Japan: Ministry of the Environment.

Shubho, M., Hassan M., Hossain M., and Neema M., 2013. Quantitative Analysis of Spatial Pattern of Dustbins and its Pollution in Dhaka City--A GIS Based Approach . *Asian Transactions on Engineering*.

The World Bank, 2012. *What a Waste: A Global Review of Solid Waste Management.* Washington, DC: Urban Development & Local Government Unit, World Bank.

Worldometers, 2018. Bangladesh Population Live: Worldometers. Retrieved September 29, 2018, from Worldometers Web site: http://www.worldometers.info