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Analysis and forecasting of municipal solid waste in Nankana City using geo-spatial techniques

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Abstract The objective of this study was to analyze and forecast municipal solid waste (MSW) in Nankana City (NC), District Nankana, Province of Punjab, Pakistan. The study is based on primary data acquired through a questionnaire, Global Positioning System (GPS), and direct waste sampling and analysis. Inverse distance weighting (IDW) technique was applied to geo-visualize the spatial trend of MSW generation. Analysis revealed that the total MSW generated was 12,419,636 kg/annum (12,419.64 t) or 34,026.4 kg/day (34.03 t), or 0.46 kg/capita/day (kg/cap/day). The average wastes generated per day by studied households, clinics, hospitals, and hotels were 3, 7.5, 20, and 15 kg, respectively. The residential sector was the top producer with 95.5% (32,511 kg/day) followed by commercial sector 1.9% (665 kg/day). On average, high-income and low-income households were generating waste of 4.2 kg/household/day (kg/hh/day) and 1.7 kg/hh/day, respectively. Similarly, large-size families were generating more (4.4 kg/hh/day) waste than small-size families (1.8 kg/hh/day). The physical constituents of MSW generated in the study area with a population of about 70,000 included paper (7%); compostable matter (61%); plastics (9%); fine earth, ashes, ceramics, and stones (20.4%); and others (2.6%).The spatial trend of MSW generation varies; city center has a high rate of generation and towards periphery generation lowers. Based on the current population growth and MSW generation rate, NC is expected to generate 2.8 times more waste by the year 2050.This is imperative to develop a proper solid waste management plan to reduce the risk of environmental degradation and protect human health. This study provides insights into MSW generation rate, physical composition, and forecasting which are vital in its management strategies.

Keywords Municipal solid waste · Generation · Population · Forecasting · Geo-visualization · GIS

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Introduction

Municipal solid waste (MSW) is a burning environmental problem particularly in developing countries (Alam et al. 2002; Chen et al. 2005; Sujauddin et al. 2008; Zhang et al. 2010). The MSW is non-liquid waste material arising from domestic, commercial, industrial, agricultural and mining and construction activities, and from the public services (Ashalakshmi and Arunachalam 2010; Okot-Okumu and Nyenje 2011; Karak et al. 2012). The quantity of MSW is directly proportional to population growth (Delgado et al. 2007; Muttalib and Mohammed Mozaffar Hossain 2016). Similarly, improved living standards have accelerated the rate of MSW generation (Erkut et al. 2008). Modern urban living style has aggravated the problem of waste generation because of super packing and use of fast food products that have changed waste composition (Guerrero et al. 2013; Bufoni et al. 2015). Urbanization also directly contributes to waste generation, and cities are facing problems of environmental deterioration and public health issues (Singh et al. 2011; Muttalib and Mohammed Mozaffar Hossain 2016). Wastes generated by urban societies comprise of garbage, rubbish, construction and demolition material, leaf litter, and other constituents in a fraction (Zhang et al. 2010). The physical composition of MSW is food waste, yard waste, wood, plastics, papers, metals, leather, rubbers, inert materials, batteries, paint containers, textiles, construction and demolishing materials, and many others (Valkenburg et al. 2008).Various studies indicate that in developing countries, 55–80% of the MSW is generated by households followed by commercial activities with heterogeneous nature and quantity (Nabegu 2010; Nagabooshnam 2011; Miezah et al. 2015). The main determinants of MSW are geographical, climatic, socio-economic, demographic, and cultural (Buenrostro and Bocco 2003).

Solid wastes have been categorized into six classes (Sharma 2012; Vij 2012). *Urban solid waste* (wastes from slaughter houses and canning and freezing industries); *rubbish* including *combustible* (paper, wood, cloth, rubber, and garden wastes), *non-combustible* (metals, glass, ceramics, stones, dirt, paints, and some chemical), *ashes*, *and residues* (cinders and fly ash of combustion solid fuels for heating and cooking or from incineration of solid wastes by municipal and apartment house incinerators); *large wastes*; *demolition and construction rubble* (pipes, lumber, masonry, brick, plastic, roofing and insulating materials, automobiles, furniture, refrigerators and other home appliances, tiles); *dead animals* (household pets, birds, rodents, zoo animals, and also anatomical and pathological wastes from hospitals); and *sewage treatment process solids* (screenings, settled solids, sludge).

The wastes are mostly perceived to be of negative value and pose a serious problem of collection, transportation, and ultimate disposal (Pires et al. 2011; Lino and Ismail 2012). The declining disposal site capacity, ever increasing generation of wastes to be disposed of, and environmental problems at many existing solid waste disposal facilities create multitude of problems for management authorities. Municipal authorities are facing problems in provision of water supply, sanitation and above all collection, and disposal of MSW to the desired level because of population growth (Rao and Shantaram 1995). Open dumping of solid waste is common on public places, and polluted sites are rampant across many cities in developing countries resulting in environmental deterioration and public health problems (Mbuligwe 2002). Decomposition of solid waste leaches chemicals to underground water, and uncontrolled leachate influx is a potential source of ground water contamination. Proper solid waste management requires the collaboration between different stakeholders that include both citizens and the local authorities (Fiorucci et al. 2003; Hazra and Goel 2009; Guerrero et al. 2013). Sujauddin et al. (2008) conducted study in Chittagong, Bangladesh, and calculated the amount of generated waste. Household solid waste (HSW) was found to be 1.3 kg/hh/day and 0.25 kg/cap/day. The compostable waste was being the largest component with 62%. Tarmudi et al. (2009) found that average MSW generation in Malaysia was 0.8 kg/cap/day. Batool and Chuadhry (2009a) carried out research work in Lahore, Pakistan, and calculated the total waste generated was 500,000 t/year or 0.84 kg/cap/day. Miezah et al. (2015) found that the rate of waste generation in Ghana was 0.47 kg/cap/day. Trang et al. (2017) estimated average solid waste generation rate of 0.76 kg/hh/day by the residents of Thu Dau Mot, Vietnam, with organic waste making 67% of this waste. MSW management needs accurate forecasting (Bruvoll and Ibenholt 1997; Christiansen and Fischer 1999; Chiemchaisri et al. 2007; Intharathirat et al. 2015) that is difficult in developing countries because of insufficient historical data (Yousuf and Rahman 2007; Rimaitytė et al. 2012) and existing models (Batinić et al. 2011; Younes et al. 2015).

The focus of this research work is the analysis and forecasting of waste generation by residential, commercial, medical, and educational activities of Nankana City (NC) Punjab, Pakistan. The current and future trends of MSW generation rates of NC have been quantified and mapped because quantification, forecasting, and mapping are vital for designing management strategies. The study is important in contrast to other studies because it focuses on solid waste generation activities and spatial visualization of waste trends. Nankana Sahib is a religious center of *Sikhs*, and each year, they visit the city in large numbers from within Pakistan and other countries to offer pilgrimage, and this tradition is centuries old.

Study area

NC is located in district Nankana Sahib, Province of Punjab. It is named after the first G*uru Nanak* of *Sikhs*, and has high historic and religious value for *Sikhism*, the pilgrimage site for *Sikhs* from all over the world. Thousands of *Sikhs* not only from within Pakistan but also from other countries visit the study area each year promoting an international activity. NC is about 75 km west of Lahore City (Fig. 1). Formerly, it was a tehsil of district Sheikhupura and then became a district in 2005. Administratively, the study area is divided into 68 union councils (UC; the smallest electoral unit), out of which 11 are urban with 14.6% population. According to Nankana Municipal Corporation (NMC), the total number of households in NC was 10,837 with about population of 70,440 in 2015 and population density of 468 persons/km^2. Nankana Sahib has a population growth rate of 2.35% according to the census of 1998, which is a bit equivalent to the provincial average population. Due to its population size, it lies under the category of "small city" having population less than 0.5 million (Douglas and James 2015).

The existing Solid Waste Management System comprised of four tractor trolleys, about 20 hand trolleys and 40 workers. This system is not sufficient and performing poorly. Current daily production of municipal solid waste is about 39.97 t and is estimated to have a volume of 14,589 tons/year. In Pakistan, MSW generation ranges between 0.283 to 0.612 kg/capita/day; therefore, for study area, it is assumed around 0.457 kg/capita/day (PMDFC 2013). Climate of the study area is subject to variations with summer and winter seasons, and the annual rainfall is about 635 mm. Monsoon is the main source of summer rain. From December to March, the temperature remains low and then rises from April

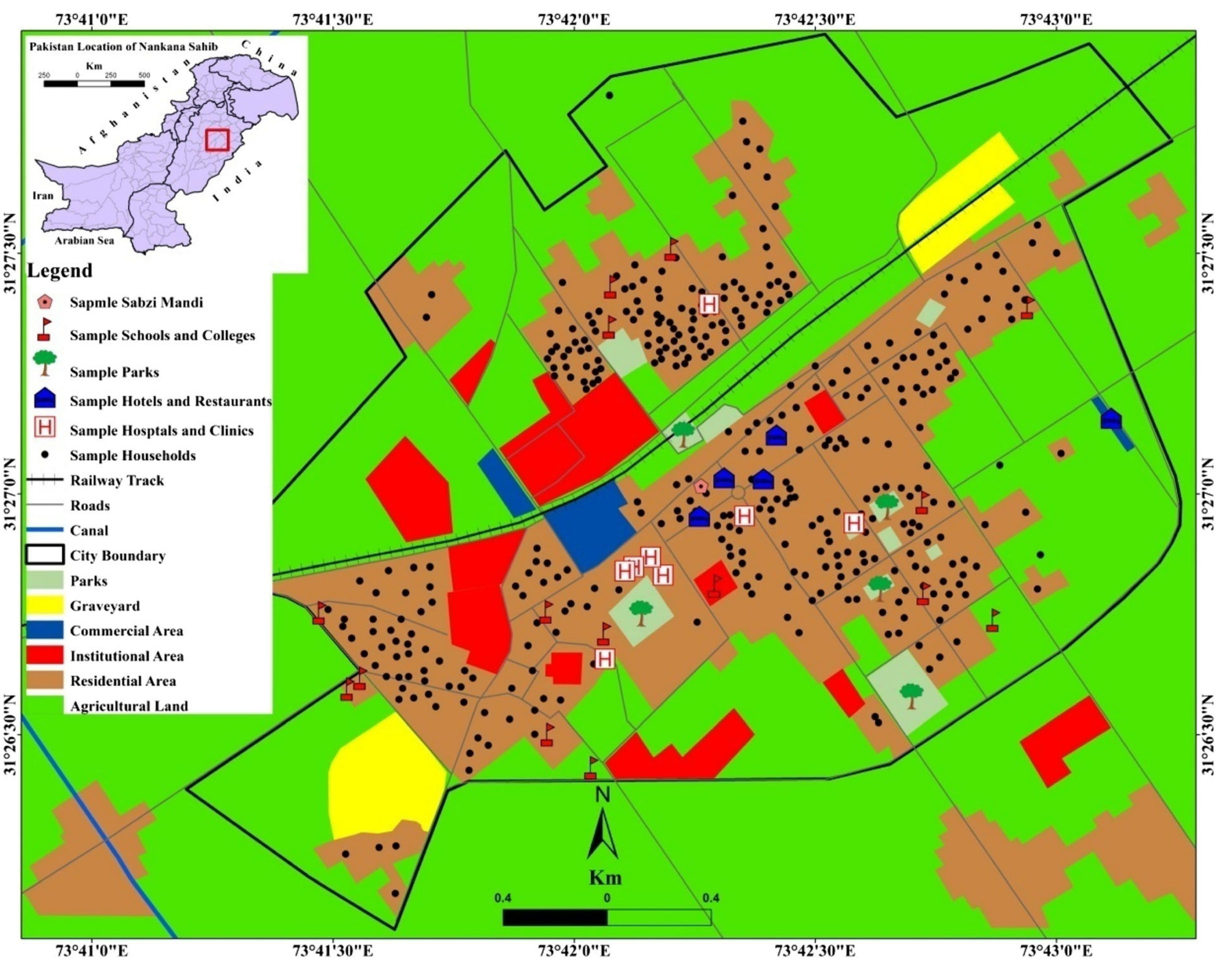

Fig. 1 Study area location, land use, and sample of interest

onward. The North West is thickly dotted with stunted trees (GoP 2000).

Methods and materials

For this study, primary data were collected through a questionnaire survey, GPS survey, and direct field measurements conducted during the year 2015. Secondary data were acquired from concerned district government departments. The methodology used is based on mathematical analysis of direct waste samples, forecasting, and spatial trend visualization using geo-spatial techniques.

In order to understand the qualitative and quantitative aspects of MSW, direct waste sampling method was adopted to weigh the waste generated at household level and determine its physical composition as used by Sha'Ato et al. (2007) and Çuci et al. (2016). Questionnaire survey was designed and conducted within the administrative boundaries of the study area. Prior to the direct waste sampling survey, a random questionnaire survey from the heads of 369 households was carried out by asking questions regarding the family size, monthly income, causes of waste dumping in public places, and its impacts on the environment. GPS survey was also conducted simultaneously to acquire the locations of the sampled households. The data were processed, and classes were made based on monthly income and family size. The monthly income of the household heads was categorized into three classes, i.e., "*low income class*" < 25,000 PKR (105 PKR = 1 US $), "*middle income class*" ranging from 25,000–50,000 PKR, and "*high income class*" > 50,000 PKR. These classes were made to determine variation in the domestic waste generation among various income groups. Similarly, family size was also divided into three categories; *small family* (< 5 persons), *medium family* (from 5 to 10 persons), and *large family* (> 10 persons).

After socio-economic survey, direct waste sampling was conducted. The number of households selected in each income class of the study area was between 30 to 45, more than their commended number of households by Gomez et al. (2008) and Miezah et al. (2015) using stratified purposive sampling where the direct sampling of waste was carried out. Similarly, 50% of the schools, colleges, hospitals, clinics, parks, hotels, restaurants, and public and private offices were surveyed randomly. The existing single fruit and vegetable market "m" was also surveyed to confirm its waste generation. Five open dumping sites were selected for weighing the domestic waste collected by sanitary workers in hand trolleys to verify the physical composition of MSW. The waste was sorted into eight categories and then spring balance was used to weigh.

Secondary data regarding the number of households and population were collected from NMC, District Nankana Sahib—Province of Punjab. The Google earth image was downloaded and used as base map to develop land use map of the study area in ArcGIS 9.3 environment. The average domestic waste generation per day for each income and family class and mentioned surveyed activities were calculated using Eq. 1:

$$C = \sum N/n \tag{1}$$

where "C" is the average waste generation per day, "N" is the numerical values of each observation, and "n" is the number of observations. Average waste generation per day was calculated for schools and colleges, hospitals and clinics, parks, hotels and restaurants, and public and private offices using Eq. 1. The average waste generation per capita/day was calculated using Eq. 2:

$$c = C/f_{(\text{average})} \tag{2}$$

where "c" is the per capita/day waste generation and "f(average)" is the family's average size. The total domestic waste generation/day was calculated by using Eq. 3:

$$\text{Total}_{(\text{domestic})} = \text{Total}_{(\text{population})} \times (c) \tag{3}$$

where "$\text{Total}_{(\text{domestic})}$" is the total domestic waste generation in kilograms per day, and "p" is the total population. Future forecasting of domestic solid waste was calculated using Eq. 6:

$$\text{Projected}_{\text{DW}} = \text{Projected}_{(\text{population})} \times (c) \tag{4}$$

and

$$\text{Projected}_{(\text{population})} = \text{Pi}\,(e^{rt}) \tag{5}$$

putting Eq. 5 in Eq. 4.

$$\text{Projected}_{\text{DW}} = \text{Pi}\,(e^{rt}) \times (c) \tag{6}$$

where "$\text{Projected}_{\text{DW}}$" is the projected domestic waste and "Pp" is the projected population after "t" years, "Pi" is the initial population, "r" is annual growth rate, and "e" is base of the natural logarithm. The projection of the population is based on exponential growth rate. The total waste generation per day for schools and colleges, hospitals and clinics, parks, hotels and restaurants, and public and private offices was calculated by using the product of the average waste generation per day and number of facilities.

The percentage of each fractional constituent component in the sample was calculated by using Eq.7:

$$\text{Percentage}_{(FC)} = \left(W/\text{Total}_{(weight)}\right) \times 100 \quad (7)$$

where "Percentage$_{(FC)}$" is the percentage fractional constituent component of sampled waste, "*W*" is the weight of separated waste, and "Total$_{(weight)}$" is the total weight of sampled waste. Total MSW (TMSW) generated (kg/day) in the study area was calculated by using Eq. 8:

$$\begin{aligned}\text{Daily}_{(TMSW)} = {} & \text{Total}_{(domestic)} + T_{(schools\ and\ colleges)} \\ & + T_{(hospitals\ and\ clinics)} + T_{(parks)} \\ & + T_{(hotels\ and\ restaurants)} \\ & + T_{(public\ and\ private\ offices)} \\ & + T_{(fruit\ and\ vegetable\ market)} \end{aligned} \quad (8)$$

$$\text{Annual}_{(MSW)} = \left\{ \begin{aligned} & \text{Total}_{(domestic)} + T_{(schools\ and\ colleges)} \\ & + T_{(hospitals\ and\ clinics)} + T_{(parks)} \\ & + T_{(hotels\ and\ restaurants)} \\ & + T_{(public\ and\ private\ offices)} \\ & + T_{(fruit\ and\ vegetable\ market)} \end{aligned} \right\} \times \{360\} \quad (9)$$

The annual MSW generated was calculated using Eq. 9.Each household location was digitized in ArcGIS 9.3 environment, and point layer was generated. MSW data was linked to the point layer of sample locations and then IDW technique was applied as point interpolation to visualize the spatial trend of waste generated per day.

Results and discussion

Socio-economic conditions of the studied population

In the surveyed area, high-, middle-, and low-income households are distributed in such a way that no one can recognize the specific location for a certain income class except the low-income group whose concentration is increasing while moving out from the city center. The total population of surveyed households (369) was 2583 persons. Out of total surveyed households, medium-size families (5–10 persons) were 48%, while small (< 5 persons) and large-size families (> 10 persons) were 22 and 30%, respectively. Average family size of surveyed household (hh) was 7 with ± 5 *SD*. The amount of waste generated by hh differed from each other, and on average, small families were generating 1.8 kg/hh/day, medium-sized families were generating 2.8 kg/hh/day, and large families were generating 4.4 kg/hh/day (Table 1). Other studies have also found a direct relationship between waste generation and family size of a hh (Suthar and Singh 2015; Khanet al. 2016; Trang et al. 2017).

Similarly, the monthly income of the studied household heads was classified into three groups; *low-income*, *middle-income*, and *high-income* groups. About 31% of the working people in the area had monthly income less than 25,000 PKR; income of 45% of households was in the range of 25,000–50,000 PKR; and only 24% of the surveyed household heads belonged to the high-income group, > 50,000 PKR. So, majority of the population in the study area belonged to either low- or middle-income groups. Trang et al. (2017) have found that the quantity of the MSW generated is linked with economic status of the society and hh. In the current study area, on the average, low-income group was generating 1.7 kg/hh/day, the middle-income group was generating 3.1 kg/hh/day, and the high-income group was generating 4.2 kg/hh/day of MSW. The average for all income groups and family size were 3 kg/hh/day (Table 2). In a study by Jadoon et al. (2014), per capita waste generation rate of the Lahore City was found to be 0.96, 0.73, and 0.67 kg/cap/day for high-, middle-, and low-income groups, respectively, showing a positive

Table 1 Waste generation rate (WGR) of various family size groups

Family size	Percentage	WGR (kg/hh/day)
Small (< 5 persons)	22	1.8
Medium (5–10 persons)	48	2.8
Large (> 10 persons)	30	4.4
Average		3

correlation between income and waste generation with an average amount of 0.79 kg/cap/day waste generation. As the income increases, the quantity of waste generation also increases due to the greater purchasing power of the high-income group (Khan et al. 2016).

Municipal waste composition and generation

Increasing urbanization, population, and consumption patterns result in increased solid waste generation (Ogwueleka 2013). Municipal authorities have to manage the solid waste arising from residential, commercial, and institutional activities along with the waste from the street sweepings (Marshall and Farahbakhsh 2013). Normally, the municipal bodies handle all the waste deposited in the community bins located at different places in the city (Batool and Chuadhry 2009a). In the study area, municipal authority was not working properly, and the residents were also disposing the wastes directly in the streets. The main sources of MSW generation were households. The average wastes generated per day in studied households, clinics, hospitals, and hotels were 3, 7.5, 20, and 15 kg, respectively. The fruit and vegetable market was generating waste of about 500 kg/day. The total estimated MSW generated in the study area was 34,026.4 kg/day (34.03 t/day) in which residential sector was the top producer with 32,511 kg/day (95.5%) followed by commercial sector (1.9%; Annex. Table 4).

Average physical constituents of MSW generated in the study area with a population of about 70,000 include paper 7%; compostable matter 61%; plastics 9%; fine earth, ashes, ceramics, and stones 20.4%; and others 2.6% (Fig. 2).Compostable matter quantity was high because of the use of fresh vegetables, fruits, other food wastes, wood, and leaves at household level. Similar results have been found by Suthar and Singh (2015).The spatial trend of MSW generation varied across the city.

Table 2 Waste generation rate of various income groups

Income groups	Percentage	WGR (kg/hh/day)
Low income (< 25,000 PKR)	31	1.7
Middle income (25,000–50,000 PKR)	45	3.1
High income (> 50,000 PKR)	24	4.2
Average		3

The city center has a high rate of waste generation, and towards peripheries, waste generation rates lowered (Fig. 3). The city center has fruit market "*Sabzi Mandi*," hotels, restaurants, hospitals, recreational parks, and residences of the high-income group. The collective waste generation of these sectors was higher than the periphery where income class low and small and medium family households were residing. Other studies from developing countries and from Pakistan have also found that the composition of municipal solid waste is dominated by organic and recyclable materials stressing the need for their source segregation for composting and recycling (Troschinetz and Mihelcic 2009; Al-Khatib et al. 2010; Jadoon et al. 2014; Trang et al. 2017). Organic waste is reported to be the major component (67.46%) in the municipal solid waste of Lahore City (Jadoon et al. 2014) as also reported in the current study for NC. In many cities of Pakistan, waste segregation is being carried out by street scavengers, and it was estimated that 525 t/month of recyclable material worth US$ 30,875/month is collected by them from a small area of Lahore City and US$ 4.5million/year from the whole city showing its greater economic potential (Asim et al. 2012; Batool et al. 2008). It was also estimated that if recycling is carried out through the formal sector in the Lahore City, it can generate revenue of US$ 8.8 million/year along with saving energy and natural resources (Batool et al. 2008).

The nature of MSW is dynamic because it varies spatio-temporally depending upon the uses, season, waste management practices, tourist season, and other socio-economic and demographic features of the area like income, education, and family size. In case of the Nankana City at the birth anniversary of *Guru Nanak*, there is a huge gathering of Sikhs coming from different parts of the world. So, due to its great religious importance, the number of visitors increase each year. This increase in population at a certain time of the year has both environmental and economic consequences. Among these environmental issues, solid waste management is the major issue. The waste generation rate increases at this time of the year due to an increased number of visitors. According to an estimation, the waste materials at the tourist sites are usually polythene bags, broken glasses, plastics and tins, and etc. (Kuniyal et al. 2003).The waste paper generated in the study area is almost the same as in Dehradun, India, where it was found to be 6% of the MSW (Table 3). Compostable matter is the major component in the municipal solid

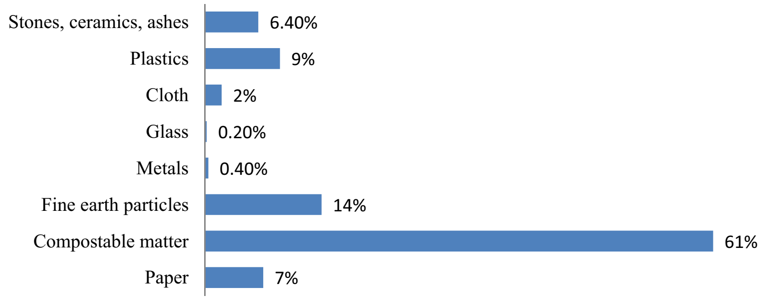

Fig. 2 Composition and quantity of physical constituents in domestic MSW in the study area

waste composition of both Pakistani and Indian cities followed by plastics and paper. In the current study area, fine earth particles were 14% because NC is a small developing urban center surrounded by agriculture land. The percentage of plastics/polythene was more than the paper items because of the increased use of single-use polythene bags and other packing materials. High-income class mostly prefers to discard material instead of repairing and reusing it, or they use such materials which cannot be reused or recycled, and this practice

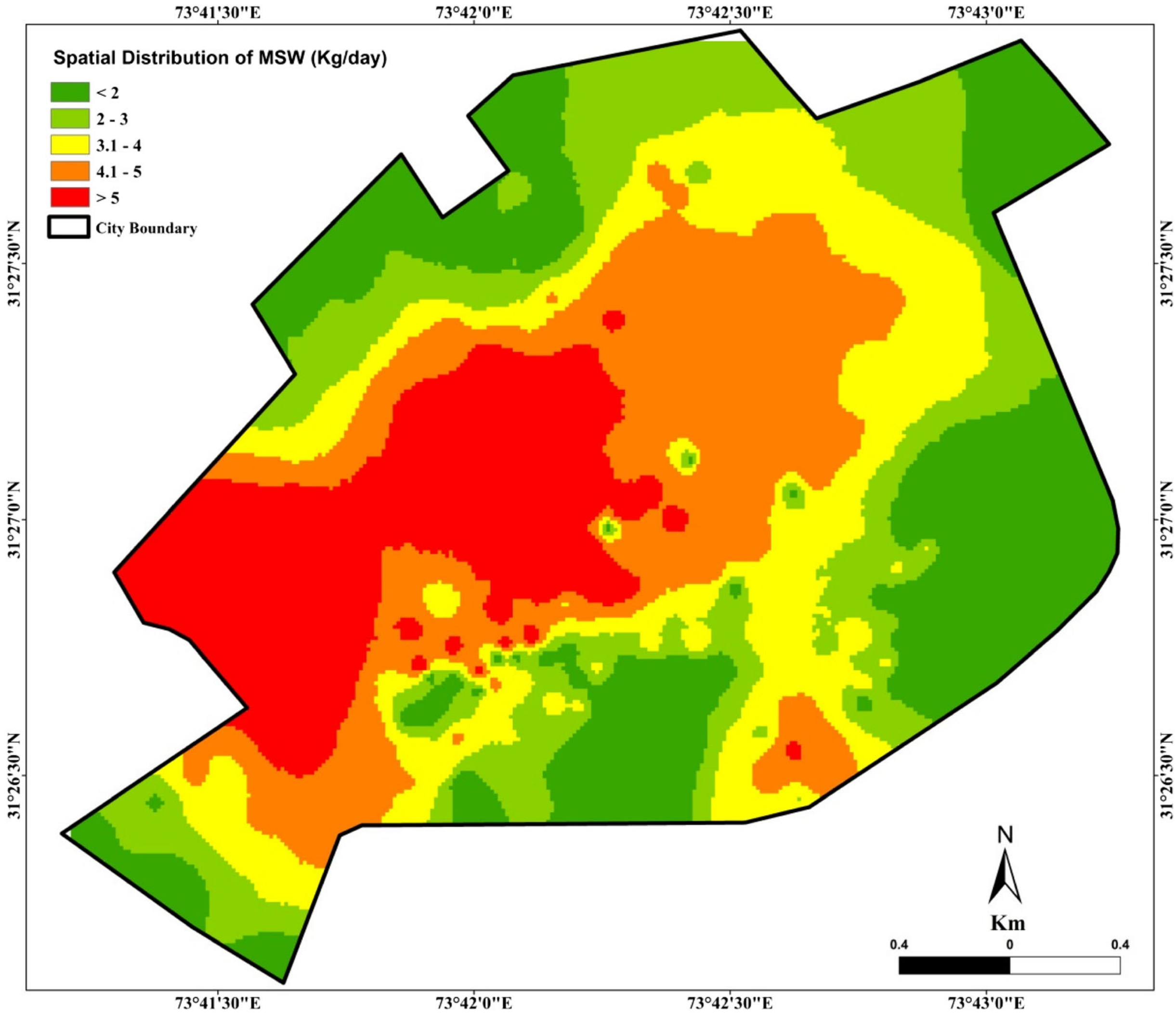

Fig. 3 Spatial visualization and trend of MSW generation (kg/day) in Nankana City. Source: Field Survey 2015

leads to the huge amounts of waste generation (Marshall and Farahbakhsh 2013). Commercial packing and carrying of about 80% of commodities are in single-use polythene bags in the study area. Another important physical constituent of the MSW of current study was paper which should be recycled instead of disposing off as such (Table 3).

Compostable waste majorly included kitchen waste, e.g., fruit and vegetable waste. A greater quantity of waste is produced by the high-income group due to their greater consumption and purchasing power (Suthar and Singh 2015). High-income families also generate more paper waste due to their high purchasing power of magazines and newspapers and etc. (Ogwueleka 2013).

On the basis of the current study results, it is forecasted that the amount of MSW will increase to about 42,000 t per annum by the year 2050 from 13.600 t in 2015 (Figure 4). Beede and Bloom (1995) estimated that globally, the solid waste production will increase from 13 billion tons to 27 billion tons by the year 2050. Suocheng et al. (2001) found that in the 1997 global generation of MSW was 0.49 billion tons with an estimated annual growth rate of 2–3% in developing nations and 3.2–4.5% in developed nations. Moghadam et al. (2009) have found a direct relationship between population increase and solid waste generation in Iran where the waste generation increased with a constant rate with the increase in the urbanization rate.

Community awareness

MSW management is one of the core areas regarding environmental protection in current and future scenarios. Community awareness regarding the negative consequences of open dumping of wastes in public places is an important factor in sustainable solid waste management. Analysis revealed that most of the residents in the study area were not aware of the negative impacts of open dumping of MSW. About 57% of the studied population responded that there is no effect of open dumping on the environment and human life. The view of remaining 43% was that wastes are polluting the environment resulting in bad odor and contaminated groundwater which causes waterborne diseases. Community perception regarding the open dumping of solid waste was also variable. About 37% of the studied population considered that TM employees are not working properly. Sanitary workers have been collecting waste from door to door but are not disposing it off properly. They have been unloading wastes from hand trolleys directly in the open spaces or vacant plots, and such places have become open dumping sites. The role of District Management Authority is also very poor because the population and the spatial extent of the city has increased, but there is no improvement in the existing MSW management system. The perception of about 57% of the studied households was that TMA and local residents are responsible for dumping (Fig. 5). In high-income countries, public awareness acts as a driver for the solid waste management. In such countries, negative impacts of the poor handling system like burning dumps and incinerators used in the past have changed the people's perception about waste management strategies (Marshall and Farahbakhsh 2013). The handling of solid waste is quite difficult after its generation, and only in some cities of Pakistan waste is properly collected and disposed of in landfill sites. While most preferable strategy is an open dump system that is majorly used in Pakistan (Ali et al. 2014), both land filling and open dumping systems face the common threat of leachate production. This leachate may contaminate the surface water by its percolation into lakes, streams, or may leach down into the groundwater. The surface water is taken by the aquatic animals causing the accumulation of hazardous metals inside the body (Budi et al. 2016), while groundwater is used as drinking water, causing diarrhea, hepatitis, abdominal pain, and vomiting (Maiti et al. 2016).

In Pakistan, the waste collection efficiency is very poor, and it ranges from 51 to 69% of the total waste generated, while the remaining waste (31%–49%) remains on the roads, open spaces, and streets causing pollution in the environment (Mahar et al. 2007). A recent study of Pakistan's second largest city, Lahore, has shown collection coverage of only 68%. There is no official recycling facility in the city, only approximately 27% (by weight) of waste is reported to be recycled, and that too is through the informal sector (Masood et al. 2014). A composting facility is now generating 47,230 t/year of compost in Lahore but only few larger cities are the focus of these improved waste management facilities, and the medium and small cities are still being badly ignored. Giving contracts to Turkish companies in Lahore City has improved the situation of MSW management. Solid waste collection was also reported to improve by 30% in 6 years after the involvement of private companies in waste collection in Tanzania (Kaseva and Mbuligwe 2005). Altaf and Deshazo

Table 3. Comparison of wastes in Indian and Pakistani cities

S. number	Type of wastes	India	Pakistani	
		Dehradun[1]	Lahore[2]	Nankana[3]
1	Paper	8†	5.04	7
2	Compostable waste	80	67.02	61
3	Plastics	7	12.77	9
4	Glass	1*	2.19	0.2
5	Metals	4	0.02	0.4
6	Cloth		1	2
7	Fine earth particles		6.19	14
8	Stones, ceramics, ashes		5.77	6.4
Total		100	100	100

Sources: [1]Tahir et al. 2015; [2]Batool and Chuadhry 2009b; [3]Current Study

(1996) have shown that in spite of the lack of awareness, less education, and low income, people are reported to give priority to solid waste management in Pakistan as compared to other urban services, and they are willing to pay for its proper disposal. The government should also focus on improving solid waste collection and disposal facilities for people.

Compostable matter comprised of about 61% of the total waste of NC and it represents a best energy source that can be converted into methane (Gunaseelan 2004). An average of 27.2 MJ/m^3 of energy content (biogas) is estimated from food waste containing 73% of methane content (Zhang et al. 2007). The power plants for waste to energy play a vital role in reducing the environmental impacts, demands in fossil fuels and other health-related issues. Pakistan is currently facing severe electricity shortfall with an average of around 5000 MW that varies during high (summer) and low (winter) demand periods of the year. So, this organic waste if collected properly can be used for energy generation. MSW generated in Pakistan has a potential to produce 50.35 million m^3/year energy by biochemical and 265 million m^3/year by thermo-chemical processes, with a potential contribution of about 0.07 and 0.34%, respectively, in the total primary energy supply of the country (Korai et al. 2017). Lahore Waste Management Company (LWMC) has developed a system of gas collection at the first sanitary landfill site in Pakistan at Lakhodair (LWMC 2014). Moreover, LWMC is also installing a 35-MW waste to energy power plant based on controlled combustion of MSW. Incineration and anaerobic digestion are reported to be economically and environmentally more superior technology choices for electricity generation than landfill gas recovery system (Tan et al. 2015; Fernández-González et al. 2017). A recent study in Hyderabad, city of Pakistan, has revealed a power generation potential of anaerobic digestion (biochemical) in the range of 5.9–11.3 kW/t/day (Korai et al. 2016).

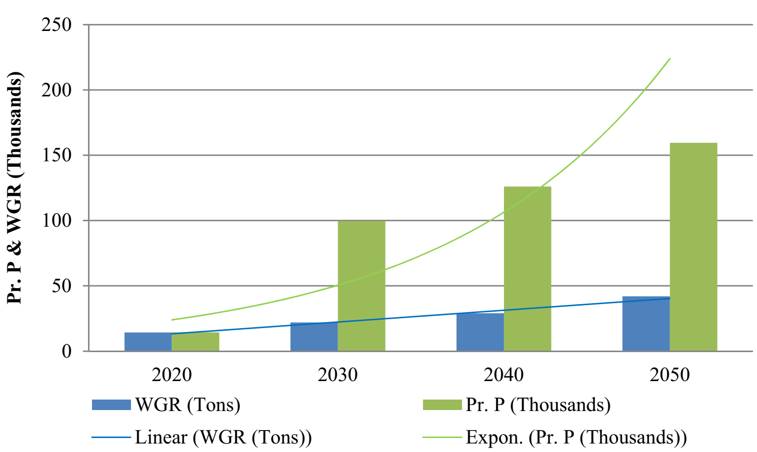

Fig. 4 Projected population (Pr.P) and waste generation rate (WGR)

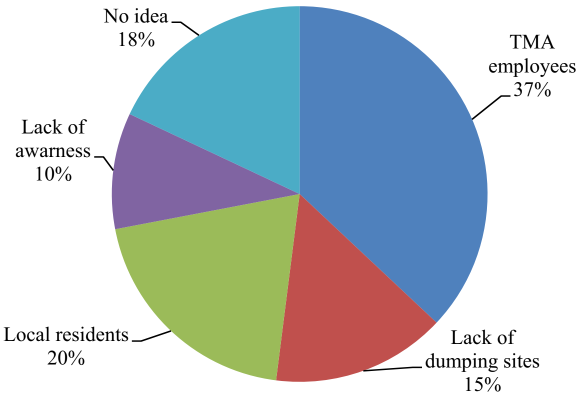

Fig. 5 Community perception regarding dumping of MSW

Proper waste disposal can help to reduce dependence on fossil fuels and greenhouse gas emissions and can prevent the environment from air pollution (Chen and Lo 2016). Electricity generation from MSW has an estimated potential of reducing 0.5% of annual GHG emissions of Iran, and thus can be promising in meeting international GHG reduction commitments of other developing countries as well (Rajaeifar et al. 2017). Biofuel production-related climate benefits are greater especially for the developing countries with current negligible land filling as compared to landfill-dominant countries as the impact of landfills on climate decreases in the long term (Aracil et al. 2017).

Plastic waste constituted about 9% of the total waste, and it can be reused or recycled. Sometimes, plastic items are disposed of after a single use, so it is preferable to reuse such items as their reuse requires fewer resources with less energy. For example, in the UK, about three quarter of PET bottles are used to manufacture apparel, carpet fibers, and bottles (Al-Salem et al. 2009). In South Africa, a legislation was made to reduce plastic bag usage comprising price-based tools and standards in order to decrease public demand for plastic shopping bags. The results have shown positive impact of legislation by reducing plastic waste (Hasson et al. 2007). So, legislation can play an important role to restrict the plastic usage. Prohibition of non-degradable plastic product (manufacturing, sale, and usage) regulations came into force in 2013 in the capital city (Islamabad) of Pakistan. The purpose of this was to especially prohibit the manufacturing, sale, and usage of non-degradable plastic bags in Islamabad City but since then no such legislation is being made for any other city of Pakistan.

Recyclables (paper, glass, and metals) were among the other important waste types in the MSW of NC. These wastes can be reused and recycled, and their percentage recovery varies according to waste collection system. A study by Batool et al. (2008) has shown that only 21.2% of all recyclable waste is recycled in Lahore and that is mainly through informal sector, i.e., through scavengers. Furthermore, it was suggested that if recycling is formally adopted, a revenue of 530 million PKR (US$ 8.8million) per year can be generated along with saving huge amounts of energy and natural resources. Proper recycling of the waste has greater GHG mitigation potential. A study by Chen (2016) in Taiwan has reported that recycling of metals reduce on average of 1.83 × 106 kg CO_2-eq/year, and recycling paper reduces on average 7.38 × 105 kg CO_2-eq/year. The energy savings were found to be 1.33×10^{10} kW h by recycling paper and 1.26×10^{10} kW h by plastics. For the continuation of all these operations (reuse and recycling), it is mandatory to segregate waste at its source to enhance segregation efficiency. Current study emphasizes the need of proper waste collection, disposal, and management system in NC to yield greater economic, social, and environmental benefits.

Conclusion

The study concludes that the components of sampled waste included paper; compostable matter; fine earth particles; metals; cloths; plastics; and stones, ceramics, and ashes. About 97% of the MSW is generated by domestic activities, and the waste mostly comprised of compostable matter, plastics, and paper. It is forecasted that by the year 2050, waste generation of Nankana City will be raised from 13,600 to 42,000 t in 2015.

The study further concludes that with ever increasing population, unplanned urbanization and economic development coupled with improved life style, the MSW generation will elevate. Municipality has failed to manage it properly because of limited existing infrastructure, logistic support, and manpower. Dumping near roads, railways, parks, and schools is very common, and most of the communities are unaware of its negative consequences on environment and human health. Hazardous environmental and health impacts might be the fate of NC, if the issue is not managed properly. It is imperative to develop proper solid waste management plan to prevent environmental degradation and protect human health.

Annex

Table 4 Municipal solid wastes generation rate by various surveyed sectors

S. number	Sources	Waste generation (kg/day)	Total MSW (kg/day)	Total
Residential sector				
i	Households	3	3 × 10,,837 = 32,511	32,511
Commercial sector				
ii	Hotels and restaurants	15	15 × 11 = 165	665
iii	Fruit market	500	1 × 500 = 500	
Medical sector				
iv	Hospitals	20	2 × 20 = 40	115
v	Clinics	7.5	7.5 × 10 = 75	
Educational sector				
vi	Private schools	13	13 × 10 = 130	366
vii	Govt. schools	7	7 × 25 = 175	
viii	Private colleges	14	2 × 14 = 28	
ix	Govt. colleges	11	3 × 11 = 33	
x	Parks and grounds	21	21 × 11 = 231	231
Offices				138.4
xi	Govt. offices	2	2 × 25 = 50	
xii	Private offices	1.7	1.7 × 52 = 88.4	
Total			34,026.4	

Source: Field survey 2015

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