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Sustainable Options for Reducing the Waste Footprint in Urban Residential Areas

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Abstract- Due to rapid urbanization and industrialization, urban areas all over the world, are subjected to various problems like rampant drinking water shortage, traffic congestions, rising level of noise and air pollution, solid waste management issues etc. Among this, solid waste management is the most threatening one. The residential wastes constitute the lion's share of urban solid waste. Changing lifestyles will pose special waste management challenges, as waste management systems in the urban areas of developing countries are incapable of frequent adjustment to match these lifestyle changes. The difficulty has been aggravated by lack of effective legislation, inadequate funds and services, and inability of municipal authorities to provide the services cost-efficiently. This paper attempts to figure out various sustainable options to reduce the waste management issues in the urban residential areas through the waste footprint concept, which is a subset of ecological footprint in the environment management tool- ecological footprint analysis.

Index Terms- Sustainable options, solid waste management, ecological footprint analysis, waste footprint, urban residential areas, Kochi city.

I. Introduction

Everybody, who consumes the products and services of nature, makes an impact on the earth. According to the Living Planet Report 2012, during the last thirty years, consumption of natural resources has increased 40%, while earth's natural wealth in biodiversity has decreased 30%. In the next decade, we will be living in a riskier world with more people, more consumption, more waste and more poverty, but with less forest area, less available fresh water, less soil and less stratospheric ozone layer (Ravi and Subha, 2011). The situation will be more serious in the cities, since they are the 'engines of economic growth' (Vliet, 2002).

Increasing population levels, booming economy, rapid urbanization and the rise in community standards have greatly accelerated the municipal waste generation rate in developing countries (Minghua et al., 2009). Due to rapid population growth, changing lifestyles, food habits and living standards, the present pattern of the almost all the urban areas can be classified as that of haphazard growth with typical problems of unplanned urban development like water pollution, improper solid waste management, traffic congestion, slum development etc (Ravi and Subha, 2013). Of this, solid waste management is the most threatening one.

When solid waste is disposed off on land in open dumps or in improperly designed landfills (e.g. in low lying areas), it causes the impact on the environment like ground water contamination by the leachate generated by the waste dump; surface water contamination by the run-off from the waste dump; bad odour, pests, rodents and wind-blown litter in and around the waste dump; generation of inflammable gas (e.g. methane) within the waste dump; bird menace above the waste dump which affects flight of aircraft; fires within the waste dump; erosion and stability problems relating to slopes of the waste dump; epidemics through stray animals; acidity to surrounding soil and release of greenhouse gas etc (Malik and Grohmann, 2011). Hence, solid waste management (SWM) is one of the basic essential services to be provided by municipal authorities.

Management of solid waste is associated with the control of generation, storage, collection, transfer and transport, processing, and disposal of solid wastes in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations (Siddiqui et.al, 2013). Municipalities, usually responsible for waste management in the cities, have the challenge to provide an effective and efficient system to the inhabitants (Vij, 2012). However, they often face problems beyond the ability of the municipal authority to tackle (Sujauddin et al., 2008) mainly due to lack of organization, financial resources, complexity and system multi dimensionality (Burntley, 2007).

This paper analyses the various options for sustainable solid waste management in the urban residential areas through the waste footprint case study in the residential areas of Kochi city, Kerala, India.

II. Concept of waste footprint

In earlier days, municipal wastes, comprised mainly of biodegradable matter which was either recycled/reused directly as manure or was within the assimilative capacity of the local environment (Puthillath & Sasikumar, 2015). Hence solid waste management was not a major issue in the past. The biodegradable wastes of the urban centres were accepted by the suburban rural areas for bio composting in the agricultural areas. With increasing content of plastics and non-biodegradable packaging materials, municipal wastes became increasingly offensive to the farmers and cultivators. As a result, the excessive accumulation of solid wastes in the urban environment poses serious threat not only to the urban areas but also to the rural areas (Kadam et. al, 2014).

Now, dealing with waste, is a major challenge in many of the local bodies or government. There are two aspects to the challenge, the social mind set and technology application (Varma, 2007). The social mind set is a very important aspect to be considered in this challenge. People are not aware of the quantity of waste generation from their own houses and work places, nor do they realize that the residential wastes are a major threat to waste management in the city. They believe that waste disposal is the responsibility of the government. But, the actual problem settles or comes under control when we consider how wastes are generated and how they are disposed. This requires awareness among the public about the waste generation and disposal methods. To provide a qualitative environment and atmosphere and to maintain the aesthetics and heritage of urban areas, a quantitative approach for waste management is to be applied. The amount of waste generation and their impact on the environment shall be calculated by individuals, households, enterprises etc. This shall be compared with the biocapacity of the area in which we lives to assimilate the per capita waste generation. The waste foot printing technique is such a quantitative tool which can assess the individual impact of earth due to the waste generation.

Ecological footprint of waste generation or waste footprint means the measurement of biologically productive land (fossil, energy land, forest land, pasture land, built up area etc.) to assimilate the generated waste (Wackernagel et al., 2006). The ecological footprint of waste generation provides per capita land requirements for waste generation. By calculating the waste footprint, the local authorities can determine the land required to assimilate the waste generated in present and future, selection of disposal site and disposal site characteristics, the land fill site design and the importance of recycling of different waste categories in order to reduce the footprint (Salequzzaman et al., 2006).

III. The Study Area – Kochi city

The study area – Kochi city (formerly known as Cochin), lies between 9°48’ and 10°50’ latitude and 76°5’ and 76°58’E longitude, Kerala, South India. It is the commercial capital of Kerala, ‘The God’s Own Country’ and is in the Ernakulam district of Kerala. The Kochi Municipal Corporation extends to an area of 94.88 sq.km. As per census of India 2001, the population of Kochi Corporation is 5,95,575 and as per census 2011 the population is 6,01,574. The density of the city is 6,340 persons per sq. km against a density of 819 persons per sq. km in Kerala, 382 persons per sq. km in India and a world average of 46 persons per sq. km in 2011 (Census, 2011). The city is known as the ‘Queen of Arabian Sea’ which has attracted many voyagers and traders over the centuries especially the Greeks, Romans, Arabs, Chinese etc. Portuguese, Dutch and English came here and established colonies in the city which assimilated the cultures of many communities from all over the globe.

Kochi city region (KCR), constitutes an area of 366.91sq.km, it includes Kochi Corporation (Kochi city) and 9 municipalities 14 panchayats and parts of 4 panchayats. The region produces about 670 tons of solid waste per day. The contribution of Kochi city to the KCR alone is nearly 300T (CoK, 2010). The solid waste in Kochi Corporation is generated from a variety of sources, ranging from residential, to commercial establishments, public and institutional areas (CoK, 2010). 66% of the wastes are generated by the households in the city, 21% of waste by the commercial establishments, 4% by road sweeping, 3 % by institutions, and the rest 2% each by drain sweeping, clinical and construction and demolition wastes. This shows that the residential areas of the city are contributing the lion's share of Kochi’s solid waste. As per the solid waste generation studies (KSUDP, 2007), the physical composition of municipal solid waste in Kochi city shows that organic wastes contribute to the maximum (79.78%) followed by paper (4.87%) and plastic wastes (4.83%). The composition of metal waste is comparatively low (0.35%).

The main issues identified in Kochi city related to solid waste management are poor level of waste collection; no segregation at source; no planned recycle/reuse; poor frequency of waste collection; inefficient collection and disposal at temporary transfer locations; obsolete waste handling and transportation system; inadequate street cleaning arrangement; water logging due to choking of drains with waste; mosquito menace due to stagnation of water in drains; filling environment not congenial to a tourists destination; misery to the poor who are the worst affected due to poor waste management; no shared vision for solid waste management etc.

The improper solid waste management in the city is identified as the root cause of many problems like pollution, outbreak of diseases, nuisance and other urban problems in the city (CoK, 2010). Also the organic waste from residential areas constitutes the major share (79.78%) of the municipal solid waste in Kochi city. If unattended, this will be a real threat to the city which will affects the serene nature of the city, social and economic development. This focus to the waste foot print study of Kochi city.

IV. Methodology

To study the waste footprint of the city, a household survey was conducted during the period 2010-2013. Five hundred representative random samples (households) were selected from the residential areas of Kochi Corporation and outskirts, based on various criteria such as: low and high density areas within the corporation boundary and outskirts, away/near the CBD/MTN(CBD-Central Business District, MTN-Major Transportation Node), the modes of waste disposal, type of housing unit and the ownership of the buildings.

The survey was carried out with a participatory research (Pretty and Ward, 2001) using a structured questionnaire, which contains questions concerning the socio economic profile of the households, quantity of waste generation of each category of waste, type of waste disposal etc. The objective of the questionnaire was to analyze the variation in waste footprint values depending on the socio economic profile of the people, quantity of waste generation and the type of waste.

The survey was conducted in three seasons namely dry season (April, December - January), wet season (July) and festival season (August) with respect to the state of Kerala. These three seasons were selected to study and analyse the seasonal variations in the footprint values in the city. The year 2010 was taken as the base year of this study. For tracking the waste generation and the recycling methods in the residences, survey was repeated in three consecutive years 2011 to 2013, in houses selected from already surveyed houses (2010 data) based on people's whole hearted support, involvement and co-operation in the research. The households were requested to segregate the wastes generated per day and to store for one day. The wastes generated were categorized into paper, glass, plastic, metal and organic waste (mainly food waste). The amount of paper waste was indirectly taken from the data of periodicals in the houses. The amount of glass and metal waste generated in a week was taken in account. The quantity of hazardous waste and e-waste was of negligible value in the residential while the survey was conducted. So the quantity of these wastes was not taken into account during the field study.

In calculating the waste footprint, the methodology/equations to assess the household ecological footprint of waste (Wackernagel et al., 2006) were used. The methodology utilizes the waste generation categories and the land use categories for those consumption and waste generation. The land use categories considered for waste footprint equations are energy land, forest land and built up land (Salequzzaman et al., 2006). Based on the equations, the waste footprint of each component of waste and the waste footprint analysis of Kochi city is carried out to quantify the impact of solid waste generation in Kochi city.

Software in a visual basic platform was developed (based on the above said equations) for the data entry and calculations, and the footprint values are estimated. The software was named the waste footprint analyser and the analyser generates the footprint value in hectares per capita and the programme is executed to get the waste foot print of the residents of the city.

In order to statistically analyze the data regarding waste footprint calculations dependent and independent variables were identified from the survey data. The statistical analysis of the waste footprint values for the dependent variables with respect to the independent variables has been done separately for the four consecutive years (2010 – 2013). The combined analysis of variations of the dependent and independent variables over the years were also carried out. For the year wise analysis of each category of wastes and footprint values (dependent variables) with respect to independent variables, ANOVA analysis was carried out for each year (2010-2013). To analyse the variations in quantity of wastes and footprint values with respect to the independent variables over the years, homogeneity of error variance across all years were tested for significance, by doing Bartelett's chi-square test (Gomez et al., 1984) for each variable. The test results showed that, except for a very few cases the error variances were homogenous. Therefore, the pooled analysis (Gomez et al., 1984) of variance was conducted across the years, to test if the variable was significant over the years and whether the interaction between year and the variable was significant.

For arriving at the sustainable waste management options for Kochi city, the analysis based on different recycling levels, different waste generation levels and combination of different recycling level and waste generation level were studied and examined in detail. The different recycling levels taken for the study falls under the head; present recycling; targeted recycling; and projected recycling. The different waste generation levels include; present generation; targeted reduction; and projected reduction.

The 'present recycling' meant the recycling rate that was observed during the time of primary survey conducted (2010) for the waste footprint studies in Kochi city. Since, less than 15% samples reported recycling of wastes, it is assumed that the 0% of waste is recycled. The 'present waste generation' refers to the waste generation status of each component of waste during the primary survey. During the primary survey, surveys conducted in the consecutive years (2010 -2013) and based on other secondary surveys such as interviews and discussions with local body officials, department officials, NGOs and other organizations; it was observed that many recycling initiatives are in the pipeline and at the anvil, which may get launched in the residential areas of the city and outskirts. The 'targeted recycling' values are meant in this regard. The 'targeted waste reduction' means the waste reduction level that can be attained after the targeted recycling or a shift in the waste generation habits of the people. The 'projected recycling' rate is assumed considering the maximum recycling levels practiced in other urban areas over the world, that can reduce the waste footprint to considerable levels. 'Projected waste reduction' is the maximum waste reduction that can be achieved at the optimistic level.

V. Results and Discussions

A. Waste Footprint and Land Requirements for the Assimilation of Generated Waste in the City

The waste generation in the residential areas of Kochi city as on 2013 is 0.51kg/capita/day with an average household size 3.72. Based on the trend analysis, this may be projected to 0.58kg/capita/day in 2020. On an average the organic waste constitutes about 80.1%, metal waste 10.5%, glass waste 5.1%, paper waste 2.6 % and plastic waste 1.9% of the total waste. In order to assimilate these wastes, an area of 0.013 hectare per capita is required in the dry seasons, 0.016 hectare per capita for the festival season and 0.015 hectare per capita for the wet seasons. An average of 132.04 m2 per capita of energy land, 0.08 m2 per capita of forest land and 16.47 m2 per capita of built up land is required to assimilate the waste generated by the residents of Kochi city. The temporal variations of the waste footprint of the residential areas of Kochi city shows that, the waste footprint has been increasing from 0.0129 hectares per capita in 2010 to 0.0163 hectares per capita in 2013. This accounts for 26.35% increase within 4 years. For all other wastes except for plastics and metals the percentage share of the footprint value is less than the percentage share of that waste in the total waste (Ravi and Subha,2016).

The analysis of ecological footprint of waste generation in the residential areas of Kochi city showed that, with the present trend of waste generation and a population growth rate of 4.5%, by 2051 the population will need about the full area of the city to assimilate the generated waste. This is shown in Table 5.1.

Table 5.1 Land Requirement for Waste Management of Kochi City Over the Decades

Year	Population	Waste footprint per person	Area (hectares) required for the total population
2001	595575	0.013	7674.6
2011	601574	0.013	7751.9
2021	628645	0.013	8100.7
2031	656934	0.013	8465.2
2041	686496	0.013	8846.2
2051	**717388**	0.013	**9244.3**
2061	749671	0.013	9660.3
2071	783406	0.013	10095.0
2081	818659	0.013	10549.2

Projections are made up to the year 2081 in order to show the severity of the problem, such that by 2051 the entire city land area is required for assimilation of waste.

B. Sustainable Options to Reduce the Waste Footprint in the Residential Areas of Kochi City

i. *Analysis based on different recycling levels*

The 'present recycling' level values for all categories of waste were assigned zero percentage (Column 2). By the initiatives mentioned in last paragraph of the methodology part, it is expected that 60% of paper waste, 30% of glass and metal waste, 75% of organic waste and 25% of the plastic wastes can be recycled (Column 3). At the high optimistic level, the projected recycling levels for paper, glass, metal, organic and plastic wastes are 90%, 50%, 60%, 90% and 50% respectively (Column 4). These recycling values are entered in the waste footprint output table of the waste footprint analyser for the waste footprint analysis. This will generate the waste footprint for present, targeted and projected values of each category of waste. Table 5.2 shows, how the waste categories and their recycling levels affects footprint.

Table 5.2 Waste Categories and Different Recycling Levels Affecting Footprint

Waste Category	**Recycling (%)**			**Waste Footprint (in m^2/capita)**		
	Present	**Targeted**	**Projected**	**Present**	**Targeted**	**Projected**
1	**2**	**3**	**4**	**5**	**6**	**7**
Paper	**0**	**60**	**90**	**3.26**	**2.36**	**1.92**
Glass	**0**	**30**	**50**	**2.85**	**2.58**	**2.42**
Metal	**0**	**30**	**60**	**23.35**	**16.69**	**10.04**
Organic waste	**0**	**75**	**90**	**96.76**	**54.67**	**46.25**
Plastic	**0**	**25**	**50**	**2.64**	**2.18**	**1.72**
Total waste footprint (m^2/capita)				**128.86**	**78.48**	**62.35**

The calculations in the Table 5.2 anticipates a 39% reduction (128.86 get reduced to 78.48) in footprint value through the above said programmes, if implemented in the city and suburbs. Also a maximum of 51% (128.86 get reduced to 62.35) reduction in footprint value can be attained through the high optimistic value of recycling.

ii. *Analysis based on different waste generation levels*

An analysis of the different waste generation levels is are shown in Table 5.3. On entering the various waste reduction level values as given in the table to the waste footprint output table provided by the waste footprint analyser, the present, targeted and projected waste footprint values are obtained.

Table shows that, with present waste generation trend the footprint is 128.86 m^2 per capita which get reduced to 69.67m^2 per capita by targeted waste reduction levels (Column 3). By projected waste reduction levels (Column 4) the footprint values get reduced to 24.09 m^2 per capita. Therefore we can observe a proportional decrease in the footprint value with decrease in waste generation.

On comparing targeted and projected footprint values in Table 5.2 and 5.3, it is clear that, the source reduction proved to be the first order hierarchy, as per the waste management hierarchy theories in terms of waste footprint values. In other words, we can say that by targeted recycling levels only 39% (128.86 m^2 to 78.48 m^2) footprint reduction can be achieved whereas by targeted waste reduction levels 46% (128.86 m^2 to 69.67 m^2) reduction in footprint values can be achieved. Likewise by projected recycling levels, only 51% (128.86 m^2 to 62.35 m^2) footprint reduction is obtained whereas 81% (128.86 m^2 to 24.09 m^2) footprint reduction can be achieved by projected waste reduction levels.

Table 5.3 Different Waste Generation Levels and Footprint Values

Waste Category	Waste generation			Waste Footprint		
	Present kg/capita/day	Targeted reduction (%)	Projected reduction (%)	Present footprint	Targeted footprint	Projected footprint
1	2	3	4	5	6	7
Paper	0.01	**50**	**80**	**3.26**	**1.63**	**0.651**
Glass	0.03	**30**	**50**	**2.85**	**1.99**	**1.42**
Metal	0.05	**30**	**50**	**23.35**	**16.35**	**11.68**
Organic waste	0.42	**50**	**90**	**96.76**	**48.38**	**9.68**
Plastic	0.01	**50**	**75**	**2.64**	**1.32**	**0.66**
Total waste footprint (m^2/capita)				**128.86**	**69.67**	**24.09**

iii. Analysis Based on the Combination of Waste Reduction and Recycling

The combined analysis of a situation where there is waste reduction and appropriate recycling is given in Table 5.4. According to the analysis, with the recycling techniques proposed to launch in the city as explained earlier in the methodology part (targeted recycling Column 6) and a 50% reduction in paper, organic and plastic waste; 30% reduction in glass and metal waste generation, a reduction in the waste footprint value to 66.5% (i.e. 128.86 get reduced to 43.09 m^2 per capita) can be obtained.

Table 5.4 Combined Analysis of Waste Reduction and Recycling

Waste Category	Present			Targeted (%)			Projected (%)		
	Generation (kg)	Recycling	Footprint	Reduction in Generation	Recycling	Footprint	Reduction in Generation	Recycling	Footprint
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Paper	0.01	**0**	**3.26**	**50**	**60**	**1.18**	**80**	**90**	**0.38**
Glass	0.03	**0**	**2.85**	**30**	**30**	**1.81**	**50**	**50**	**1.21**
Metal	0.05	**0**	**23.35**	**30**	**30**	**11.68**	**50**	**60**	**5.02**
Organic	0.42	**0**	**96.76**	**50**	**75**	**27.33**	**90**	**90**	**4.62**
Plastic	0.01	**0**	**2.64**	**50**	**25**	**1.09**	**75**	**50**	**0.43**
Total waste footprint (m^2/capita)			**128.86**	**43.09**			**11.66**		

In the maximum optimistic level (i.e. 80% reduction in paper waste generation and 90% recycling of paper; 50% reduction in glass waste generation and with 50% recycling; 50% reduction in metal waste generation and with 60% recycling; 90% organic waste reduction and 90% recycling; 75% reduction in plastic waste and 50% recycling), 91% (i.e. 128.86 get reduced to 11.66 m^2 per capita) reduction of the present waste footprint of the city can be achieved.

iv. Projected Land Requirement for Waste Management of the City

The land required for waste management for the total population of the city over the years based on the present, targeted and projected waste footprint values per person is shown in Table 5.5. It shows that, with the present trend of waste generation and a population growth rate of 4.5% (Census, 2011), by 2051, the population will need about the full area of the city (9244.3 hectares) to assimilate the generated waste.

Table 5.5 Projected Land Requirements for the Waste Management of the City with respect to Waste Footprint Values

Year	Population	Waste footprint / person (hectares per capita)			Land area in hectares required for the waste management of the total population based on		
		Present	Targeted	Projected	Present footprint	Targeted footprint	Projected footprint
2001	595575	0.0129	0.0043	0.0012	7674.6	2566.3	694.4
2011	601574	0.0129	0.0043	0.0012	7751.9	2592.2	701.4
2021	628645	0.0129	0.0043	0.0012	8100.7	2708.8	733.0
2031	656934	0.0129	0.0043	0.0012	8465.2	2830.7	766.0
2041	686496	0.0129	0.0043	0.0012	8846.2	2958.1	800.5
2051	**717388**	**0.0129**	**0.0043**	**0.0012**	**9244.3**	**3091.2**	**836.5**
2061	749671	0.0129	0.0043	0.0012	9660.3	3230.3	874.1
2071	783406	0.0129	0.0043	0.0012	10095.0	3375.7	913.5
2081	818659	0.0129	0.0043	0.0012	10549.2	3527.6	954.6

The analysis also shows that by the targeted value of footprint (43.09 m^2 per capita in Table 5.5), only 33% of the total area (3091.2 hectares) of the city is required for waste assimilation by 2051. Whereas by the projected value (11.66 m^2 per capita in Table 5.5) only 9% area of the city (836.5 hectares) is required for waste assimilation by 2051.

VI. Conclusion

The paper analyzed various sustainable options for reducing the waste footprint values of Kochi city through different waste reduction and recycling levels and a combination of the both. The different levels were present, targeted and projected. The present levels were the recycling and waste generation levels observed during the primary survey. The targeted levels were finalized based on various recycling and waste reduction initiatives which are in the pipeline and going to implemented in the residential areas of the city and outskirts. The projected levels were fixed considering the maximum recycling levels practiced in other urban areas over the world that can reduce the waste footprint to considerable levels and the maximum waste reduction that can be achieved at the optimistic level.

The analysis of different recycling levels anticipates a reduction of footprint values from 39% to 51%. About 46% to 81% reduction in footprint values is observed through different waste generation levels. Through the analysis of combination of different waste reduction and recycling levels, the footprint values showed reduction from 66.5% to 91%. Therefore the analysis of various sustainable options for reducing the waste footprint of Kochi city proved that source reduction especially that of organic and plastic waste, along with recycling of all the wastes will reduce the waste footprint effectively in the urban residential areas.

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