ECOLOGICAL FOOTPRINT ANALYSIS FOR A SUSTAINABLE SOLID WASTE MANAGEMENT IN KOCHI CITY, KERALA

A THESIS

submitted by

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for the award of the degree

of

DOCTOR OF PHILOSOPHY

CIVIL ENGINEERING DIVISION
SCHOOL OF ENGINEERING
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY, KOCHI

SEPTEMBER 2017

Dedicated to my parents, my mentors, my husband and our dear daughter………………………..

CERTIFICATE

This is to certify that the thesis entitled **ECOLOGICAL FOOTPRINT ANALYSIS FOR A SUSTAINABLE SOLID WASTE MANAGEMENT IN KOCHI CITY, KERALA** submitted by **Athira Ravi** to the Cochin University of Science and Technology, Kochi for the award of degree of Doctor of Philosophy is a bonafide record of research work carried out by her under my supervision and guidance at the Division of Civil Engineering, School of Engineering, Cochin University of Science and Technology. The contents of this thesis, in full or in parts, have not been submitted to any other University or Institute for the award of any degree or diploma.

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Date: 28.09.2017

DECLARATION

I hereby declare that the work presented in the thesis entitled **ECOLOGICAL FOOTPRINT ANALYSIS FOR A SUSTAINABLE SOLID WASTE MANAGEMENT IN KOCHI CITY, KERALA** is based on the original research work carried out by me under the supervision and guidance of Dr. Subha V, Associate Professor in Civil Engineering, School of Engineering, Cochin University of Science and Technology, Kochi, for the award of degree of Doctor of Philosophy with Cochin University of Science and Technology. I further declare that the contents of this thesis in full or in parts have not been submitted to any other University or Institute for the award of any degree or diploma.

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Athira Ravi

ACKNOWLEDGEMENTS

I am grateful to the God-almighty, who has given me opportunities at the right time in my life and has given strength and blessings to make this research work a reality. I started my research work when I was a teacher and a daughter, and the journey passed through various stages of my life as a wife, daughter in law, mother and a government servant. A lot of hurdles paved my way, as I entered a new stage of life and as a working mother. It's been a long road, but here I am at the end, but there are so many people to whom I should extend my thanks. With great pleasure and gratitude, I extend my sincere thanks for each one of them, who have been helpful and influential in the realization of this precious goal.

First and foremost, I would like to express my intense gratitude to Dr. Subha V, my research guide, for her priceless guidance, encouragement, untiring help, and unending patience throughout the period of this research. She has been a positive influence on my professional and personal development, and I consider myself extremely fortunate to be associated with her and her family. I always received warm welcome to her home without any hesitation for the completion of the thesis. The hospitality I received from each one of the family members made me nostalgic in every manner, especially the food they served with love. The moment I reach 'TATTVA', her home, I used to gain a positive energy, peacefulness and confidence in my mind to write my thesis more effectively. Without her willingness to give her valuable time so generously for correcting all documents I wrote during the course of work, this work would not have been this much beautiful. I would possibly not have completed this research without her support and encouraging messages she has sent to me during the difficult times of my life. Simple words of gratitude may not be enough to acknowledge her sincerity, support and deep commitment to this thesis work and her profession as a teacher.

My heartfelt thanks to Prof. Dr. Benny Mathews Abraham, the Doctoral committee member, for the timely support, both academic and personal; valuable suggestions; care and blessings he has given me throughout my research period.

Special thanks to Prof. Dr. G. Madhu and Dr. George Mathew who supported me in the initial stages of my work; Dr. Deepa G Nair and Dr. Bindu C.S, for their support in my work in the absence of my guide. I also express my gratitude to the Head of the Department and all the faculty members of the Civil Engineering Division for the help and support they offered during the course of study.

I take this opportunity to thank Dr.Sreejith P.S, Dean, Faculty of Engineering and Dr. M. R. Radhakrishna Panicker, Principal, School of Engineering, CUSAT for their support given to me during the period of this research. I express my gratitude to the panel of examiners who helped me with valuable suggestions and critical comments to make significant improvements in this research.

I am deeply indebted to all my friends, students, relatives, colleagues and the staffs and waste management workers of the Kochi Corporation, who have given me timely help, support and encouragement for the survey work carried out for this research. The help and assistance rendered by Mr. Ajith Kumar, for the statistical analysis of survey data is gratefully acknowledged. I also thank my colleagues in the Town and Country Planning Department, Government of Kerala especially in the District Offices of Thiruvananthapuram, Ernakulam, Kozhikode and Malappuram, for their support to complete this work.

I take this moment to thank all my dear teachers who have showered their blessings and prayers in all my endeavours of life. Special thanks to my teachers in the Department of Architecture, College of Engineering, Thiruvananthapuram, especially Ar. Shailaja Nair, Dr. Binumol Tom, Prof. Baby K Paul, Prof. Neena Thomas and Prof. Shaji T.L for their encouragement for selecting this topic during my post graduate course which extended to this present form of research. Special thanks to Shri. Jacob Easow, former Additional Chief Town Planner; Dr. May Mathew, Senior Town Planner, GCDA for their valuable suggestions on this topic.

To my family, thank you for encouraging me in all of my pursuits and inspiring me to follow my dreams. Very special and sincere thanks to my parents' in-laws Jayachandran and Reetha for their patience, consideration and support during this research period and for taking care of my baby. I also extend my thanks to my dear brother, Ajay Ravi and his family for their timely support and prayers. Words are not enough, to extend my thanks to our dear daughter Paarvathi, the best daughter I could ever have, for the understanding and patience she has shown to me, in my busy schedule even in her childhood stage. Her cute smiles and little words have helped me to overcome the difficulties encountered in my journey.

Words are getting stuck to express my eternal gratitude to my parents Raveendran and Prabha, for their love and support throughout my life. They are my real treasures, who have raised me to this level of achievements without expecting any compliments or rewards. I am indebted to my parents for implanting in me the dedication and discipline to do well, whatever I undertake. Dear father and mother, this PhD is a tribute to your faith in me, I hope I have made you proud.

Last, but not least, I would like to thank my husband Rijesh, who with limitless patience offered me his help, care and support throughout this work. Words cannot express my gratitude for everything you have done. You have given me the strength to reach the stars and chase my dreams one by one. Thank you for accompanying me in this adventure. I look forward to our next one!!

Once again, I thank God, for letting me to achieve this goal through all the difficulties and for experiencing his guidance day by day. I will keep on trusting you for my future. I bow my head for the blessings of my grandparents and my dear uncles Sasidharababu and Shadananan for their blessings from heaven……..

Athira Ravi

ABSTRACT

KEYWORDS: Ecological footprint analysis, Kochi city, Waste footprint, Sustainable domestic organic waste management, Conceptual framework

In the past, natural resources were surplus than the requirements of the people. At present, the situation is rapidly reversing especially in urban areas. Almost all the urban area faces the major challenge of finding a way to balance human consumption/impacts and nature's limited productivity, in order to ensure that the communities are sustainable locally, regionally and globally. The environment management tools should focus on sustainable development practices and shall provide a means for measuring and communicating human induced environmental impacts upon the planet. This will be more effective, if a physical accounting of these human impacts in terms of land area, which is understandable to a common man, is carried out in any management system. These aspects can be achieved by the environmental management tool ecological footprint analysis (EFA).

Kochi, the commercial capital of Kerala, South India and the second most important city next to Mumbai on the Western coast, is a land having a wide variety of residential environments. Due to rapid population growth, changing lifestyles, food habits and living standards, the present pattern of the city 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. Of this, solid waste management is the most threatening one. Therefore, the research aims to study and explore the tool EFA and to suggest a solution to the solid waste management issues in the residential areas of Kochi city through EFA. To attain this aim, research objectives were formulated and research questions were framed. The research is carried out in three phases.

The *first phase* of the research, gives a thorough literature review of EFA and its applications (Chapter 2 and 3). The ecological footprint of Kochi city is calculated and analysed over the three consecutive years 2007-2009, sustainability issues of the city were identified and measures to reduce the ecological footprint of the city were also discussed in this phase (Chapter 4).

Finding that the solid waste management (SWM) is one of the major sustainability issue in the city, the *second phase* of the research concentrates in the detailed study of

solid waste management sector of Kochi city and the key issues of SWM are identified (Chapter 5). The concept of waste footprint, which is a subset of ecological footprint, is used to assess the impact of waste generation in the residential areas of the city, since the residential areas are generating the lion's share of solid wastes. Participatory research was carried out over the four consecutive years (2010-2013) to study and calculate the waste footprint of the city (Chapter 6), and is statistically analysed (Chapter 7). The findings of the waste foot print study are then consolidated (Chapter 8). In addition, various sustainable options for waste footprint reduction in the city were also analysed in this chapter.

Understanding that a high sustainability dilemma exists in the solid waste management in the residential areas of Kochi city, especially in the case of organic waste and plastic waste, the *third phase* of the research, puts forward a conceptual framework, which can evaluate the sustainability of domestic organic waste management practises (Chapter 9). For this the sustainable domestic organic waste management is defined (SDOWM) and aspects of SDOWM were identified. The framework developed from these aspects, can be used to evaluate sustainability of domestic organic waste management systems, not only in Kerala but also elsewhere in the world with similar situations. Then, the existing domestic organic waste management technique practised in the city - the biogas production technology is evaluated using the framework (Chapter 10). In addition, the research highlights the various quantity reduction and recycling options for the sustainable management of recyclable wastes (Chapter 11). This phase then put forward the strategies for sustainable solid waste management in the residential areas of Kochi city (Chapter 12). And finally, a waste footprint model for Kochi city was developed based on the waste foot print calculations in Kochi city (Chapter 13). This model can be used as an awareness raising tool for waste footprint reduction, at the same time as an economic instrument for the implementation of government policies. By considering the relevant parameters, similar waste footprint models for cities can be developed elsewhere in the world.

Chapter 14 put forth the conclusions of the research and recommends that EFA can be used as an effective environmental management tool to assess the sustainability issues of urban areas and the findings of this research focuses on the societal need to keep the cities liveable and sustainable.

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CHAPTER 1
INTRODUCTION

1.1 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. The situation will be more serious in the cities, since they are the 'engines of economic growth'.

According to UN projections (2008), 70% of the total world population will live in urban areas by 2050, as compared to 50% in 2010. The percentage of urban population to total population in United States, Europe and China is 83%, 73% and 47%, respectively, which is much higher compared to India (32%). World Bank studies (2011) project that, India, along with China, Indonesia, Nigeria and the United States, will lead the world's urban population surge by 2050. The urban population in India grew to 377 million, showing a growth rate of 2.76% per annum, during 2001-2011. The level of urbanisation in the country as a whole increased from 27.7% in 2001 to 31.1% in 2011, indicating an increase of 3.3 percentage points during 2001-2011 compared to an increase of 2.1 percentage points during 1991-2001 (Census, 2011). Among the states in India, a very high urban population growth has occurred in Kerala and Andhra Pradesh. Urban population growth rates have increased to 6.5% per annum in Kerala and 3% per annum in Andhra Pradesh during 2001-11, compared to just about 1% per annum during 1991-2001. Though the population growth rate is in a decreasing mode, Kerala have 82% as the decadal rate of urbanisation (2001-2011) and has been positioned in the ninth rank in the level of urbanisation (Census 2011). In the state of Kerala, Ernakulam is the most urbanized district, and Kochi city is the commercial capital of the state. Kochi city is in Ernakulam district, which is one among the two agglomerations in the state, with population more than 20 lakhs.

Kochi has been pushing its borders over the last decade relentlessly throwing to wind all cautioning by planners, that a city without a plan, without public spaces and without respect for its fragile ecological conditions, can prosper only at a high cost. Rampant shortage of drinking water, the condition of the roads, traffic congestions on arterial roads, little space for pedestrians and cyclists, rising levels of noise and air pollution, solid waste management nuisance are some of the issues that the city is facing today. Among this, solid waste management is the most threatening one. 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. 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 condition of the city is very pathetic in the present stage of unplanned manner and would wonder what will happen in the future. As planners and engineers, we know we are away from sustainability but do not know how far we are. If we cannot measure, we will not be able to manage. To have a better living condition for us and our future generations, we must know where we are now and how far we need to go. We, including a single human being, must calculate how much nature we use and compare it to how much nature is available to us. This can be achieved by applying the concept of ecological footprint analysis. The specialty of the tool, which it highlights from other tools, is that, a single human being even if a new born, an adult or old aged can measure their impact on earth. Whatever the activity, whether it is occupying a shelter, using a transport system, generation of waste etc., the impact will be displayed in mathematical figures. These figures can be compared with our bio capacity and also gives a guide line for sustainability in the proper path. The ecological footprint of waste generation can assess the type of disposal, method of disposal, appropriate recycling method specific to an area depending on the bio capacity to assimilate waste.

This research, aimed to study and explore the environment management tool, Ecological Footprint Analysis (EFA) and to suggest a solution to the solid waste management issues in the residential areas of Kochi city, the commercial capital of Kerala, South India, through Ecological Footprint Analysis.

1.2 RESEARCH SIGNIFICANCE

As the ecological footprint analysis can give a quantified impact compared with the bio capacity of an area, many ecological footprint studies are initiated in different countries, as a sustainability option. The ecological footprint of waste generation has been done in Khulna City Corporation of Bangladesh and Digos city in Philippines. In India, the ecological footprint study of the first of its kind has been done in Manali, Himachal Pradesh in 1999. A city level study, measuring the impact of a city's residential population has been done by Ravi (2007) in Kochi city, Kerala, South India. So far, a city level waste footprint study has not been carried out elsewhere in

India. Hence, an attempt is made to conduct a city level waste management study using the tool ecological footprint analysis in Kochi.

1.3 RESEARCH OBJECTIVES

The main research objectives are:

1. To study and explore the tool ecological footprint analysis (EFA) and its application in analyzing civil engineering and urban planning problems.
2. To study the ecological footprint of Kochi city and to identify the major issues in the city.
3. To investigate the solid waste management issues in Kochi city using the tool ecological footprint analysis and to develop a model for calculating the waste footprint of the residential areas of the city.
4. To formulate a conceptual framework for evaluation of sustainable waste management technologies and to develop policies, strategies and implementation options to reduce the ecological footprint, especially the waste footprint and waste management issues in Kochi city.

1.4 RESEARCH QUESTIONS

In order to attain the research objectives, the following research questions are framed.

1. How can the tool ecological footprint analysis be explored and its application can be analyzed?
2. How the ecological footprint studies of Kochi city can be carried out to identify the major issues in the city?
3. How ecological footprint analysis can be applied to solid waste management issues in Kochi and a sustainable model can be developed to calculate the waste footprint of the city?

4. How the conceptual framework can be framed and what policies and strategies to be formulated to reduce the waste footprint and waste management issues in the Kochi city?

1.5 STRUCTURE OF THESIS AND METHODOLOGY ADOPTED

A detailed literature review of the tool ecological footprint analysis (EFA) has been carried out and the scope of the EFA as an impact assessment tool for India has been analysed by comparing it with the existing impact assessment tool in India, the Environmental Impact Assessment (EIA) *(Chapter 2)*. The engineering applications of EFA were reviewed *(Chapter 3)* to study how the tool has been used to analyse public and environmental problems. A brief literature review of three case studies of EFA was done in: town level – Manali, India; city level – Liverpool, UK; and country level – Scotland, UK (*Chapter 3*). And then, the ecological footprint of the study area - Kochi city was carried out *(Chapter 4)*. From the lessons learned from the literature, case studies and the footprint studies in the study area, the research focused on the solid waste management issues in Kochi city. A detailed literature review of solid waste management and its problems were studied *(Chapter 5)*. The tool EFA was used to analyse the waste footprint in the residential areas in Kochi city *(Chapter 6)*. The statistical analysis of the waste footprint of the city was carried out (*Chapter 7)*. The findings of the waste footprint study of Kochi city was consolidated and the sustainable options to reduce the waste footprint of the city were also analysed *(Chapter 8)*. A conceptual framework was developed for evaluating the sustainability of domestic organic waste management techniques *(Chapter 9)*. The analysis and findings of the evaluation study using the conceptual framework, carried out to assess the sustainability of the existing domestic organic waste management technique practiced in Kochi city, is also presented and discussed (*Chapter 10).* Then, the sustainable waste management options of the recyclable wastes were analysed *(Chapter 11).* Objectives, targets and strategies were formulated for residential waste management plan for Kochi city for reducing the waste footprint of the city *(Chapter 12)*. Finally, a model for calculating the waste footprint of the city was developed *(Chapter 13)*, so that the residents can easily assess their waste impact and can adopt or change their waste generation/disposal method, thereby creating sustainability awareness. *Chapter 14* summarizes the preceding chapters and explains how each objectives of the research was attained. In addition, the scope for further research was also discussed.

The methodology of the thesis is structured in three phases. Schematic representation of the methodology adopted is shown in Figure 1.1.

1. *Phase 1* - The tool ecological footprint analysis (EFA) was studied and explored. And then the ecological footprint (EF) of the residential areas of Kochi city was studied and analysed in detail (Chapter 2-4).
2. *Phase 2* - Since the solid waste disposal was identified as the second major issue in the city, this phase concentrates in the waste footprint of the city (Chapter 5-8).
3. *Phase 3* - Understanding that a high sustainability dilemma exists in the solid waste management in the residential areas of Kochi city, especially in the case of organic waste and plastic waste, this part of the research:
   - puts forward a conceptual framework for evaluating the sustainability of existing domestic organic waste management techniques practiced in Kerala (Chapter 9 -10).
   - formulates policies and strategies for a sustainable waste management in Kochi city (Chapter 11 -12).
   - develops a model for calculating the waste footprint in the residential areas of Kochi city (Chapter 13).

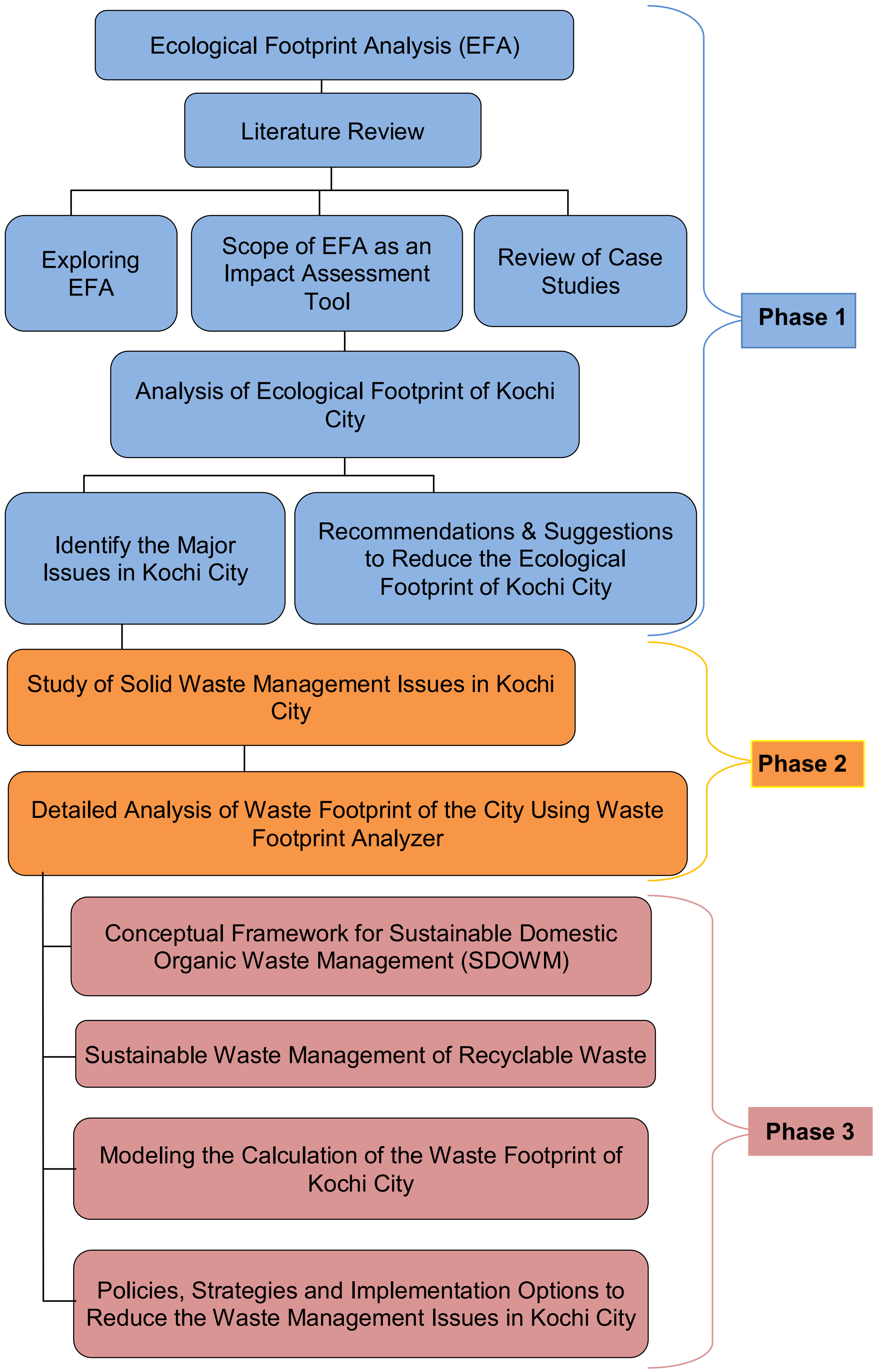

Fig. 1.1 Schematic Representation of the Methodology Adopted for the Research

CHAPTER 2
ECOLOGICAL FOOTPRINT ANALYSIS

The first part of the first research question is answered in this chapter. The environmental management tool – ecological footprint analysis (EFA) is studied and explored in general and its scope as an impact assessment tool has been analysed in the context of India. In addition, the global footprint calculator to calculate the ecological footprint is also reviewed in this chapter.

2.1 NEED FOR EFA IN ENVIRONMENTAL MONITORING AND ASSESSMENT

The material well-being of our societies builds on the biosphere's natural capital including the richness of the species that inhabit the planet (Galli et al., 2014; Mora et al., 2011). Several studies have consistently reported that biodiversity is declining at an unprecedented rate and human pressure on ecosystems is among the contributors to this decline (Weinzettal et al., 2013; Lenzen et al., 2012; Butchart et al., 2010; Ellis et al., 2010). The accumulation of human pressure is fundamental to many environmental issues and because of such increased human pressure; mankind is likely to be already beyond safe operating limits in key planetary systems (Galli, 2014; Bauler, 2012; Moldan et al., 2012; Heink and Kowarik, 2010; Rockstrom et al., 2009). Efforts to conserve biodiversity have been historically directed towards the protection of habitats and species. However, although fundamental in conservation efforts (Butchart et al., 2010) and potentially capable to supply more regulating services than threatened habitats (Maes et al., 2012), protected areas may no longer be sufficient in reducing the risk of species' extinction given how fast human pressure is growing. As human demands upon the earth's ecosystems rapidly increase (Rockstrom et al., 2009; Haberl, 2006; Nelson et al., 2006; Goudie, 1981), the future ability of the biosphere to provide for humanity and the many other species is being degraded. Barnosky et al. (2012) have argued that, a planetary-scale critical transition is approaching because of the many human pressures, and that tools are needed to detect early warning signs and forecast the consequences of such pressures on ecosystems. By measuring the footprint of a population, an individual, city, business, nation, or all of humanity, we can assess our pressure on the planet, which helps us manage our ecological assets more wisely and take personal and collective action in support of a world where humanity lives within the earth's bounds.

Ecological footprint analysis, provides an accounting system that tracks how much of the planet's regenerative capacity humans demand, to produce the resources and ecological services for their daily lives and compares that to how much regenerative capacity they have available from existing ecological assets (Galli et al., 2014). This accounting tool gives insight on the above by means of two indicators:

- On the demand side, the ecological footprint (EF) measures the biologically productive land and sea area – the ecological assets – that a population requires to produce the renewable resources and ecological services it uses.
- On the supply side, bio capacity tracks the ecological assets available in countries, regions or at the global level and their capacity to produce renewable resources and ecological services.

2.2 TERMINOLOGY RELATED TO EFA

Literature review regarding the ecological footprint analysis was an integral part of this thesis as EFA was a new environmental management tool in India , the present being the environmental impact assessment (EIA). Global Footrprint Network (GFN) is the organization headed by the authors of the ecological footprint concept and which gives the basic ecological footprint terminologies. Hence the basic literatures review about the EFA is based on GFN 2010, 2012.

Conceived in 1990 by Mathis Wackernagel and William Rees (Wackernagel and Rees,1996,1997; Rees and Wackernagel, 1996; Rees, 1992, 1996, 2001) the ecological footprint is now in wide use by scientists, businesses, governments, agencies, individuals, and institutions working to monitor ecological resource use and advance sustainable development (GFN, 2010). Ecological footprint analysis is used as an indicator for measuring environmental sustainability (Cucek, 2012) that measures how much bioproductive land and sea is available on earth, and how much of this area is appropriated for human use (Kitzes et al., 2007). The roots of EFA lie in search for an indicator that can show what part of the globe's biocapacity has been used (Hoekstra, 2009).

2.2.1 Ecological Footprint (EF)

The most widely used footprint definition is that the ecological footprint is the amount of biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the wastes it generates, using the prevailing technology and resource management practices (Galli et al., 2012; GFN, 2010; Simone et al., 2010; Wackernagel and Rees, 1996; Hoekstra, 2008). The footprint is the area, expressed in global hectare (gha) (Hoekstra, 2008) and in global area units per person (Ewing et al., 2010), needed to keep producing the food and fibre we use, absorb our wastes, generate the amount of energy we consume and provide the space for the roads, buildings and other infrastructure we rely on.

2.2.2 Biocapacity and Bioproductive Land

The area of land or sea, which is biologically productive, is called biocapacity. It represents the biosphere's ability to meet human demand for biological resources' consumption and CO_2 sequestration. Biocapacity is usually expressed in global hectares . Bioproductive land is the land and water (both marine and inland) area, that supports significant photosynthetic activity and biomass accumulation, which can be used by humans; and non-productive and marginal areas such as arid regions, open oceans, the cryosphere, and other low productive surfaces are not included.

2.2.3 Global Hectares (gha)

Average bioproductivity differs between various land use types, as well as between countries for any given land use type. For comparability across countries and land use types, ecological footprint and human demand and biocapacity are measured and expressed in units of world average bio productive area, i.e. global hectares which implies an area normalized to all average productivity of all bioproductive hectares on earth (Monfreda et al., 2004; Galli et al., 2007). One global hectare is defined as a hectare, which has the world average productivity of biologically productive land and water in a given year.

2.2.4 Equivalence Factors and Yield Factors

Equivalence factors and yield factors are used to convert actual areas in hectares of different land types into their equivalent numbers of global hectares. Equivalence factors translate a specific land type (i.e. cropland, pasture, forest, fishing ground) into a universal unit of biologically productive area, a global hectare. Equivalence factors are calculated on a yearly basis. Yield factors account for the difference in production of a given land type across different nations. Each country for each year has its own set of yield factors. National yield factors are calculated as the ratio of a country's yield to world-average yield.

2.2.5 Ecological Deficit, Ecological Reserve, Ecological Debt and Ecological Overshoot

An *ecological deficit* represents the amount by which the ecological footprint of a population exceeds the available biocapacity of that population's territory in a given year. A national ecological deficit measures, the amount by which a country's footprint exceeds its biocapacity.

Population, with an ecological footprint, smaller than their available biocapacity, runs an *ecological reserve*, the opposite of an ecological deficit.

Ecological debt is the sum of annual ecological deficits that have accumulated over a period of time. The current global ecological debt can be expressed as the number of 'planet-years' of ecological deficit the planet accrued since humanity entered into overshoot in the 1980s. One planet-year equals the total productivity of useful biological materials by the earth in a given year.

Ecological overshoot occurs globally when humanity's demand on nature exceeds the biosphere's supply, or regenerative capacity. Such overshoot leads to a depletion of earth's life supporting natural capital and a build-up of waste. At the global level, ecological deficit and overshoot are the same, since there is no net import of resources to the planet. Local overshoot occurs when a local ecosystem is exploited more rapidly than it can renew itself. A global ecological deficit, however, cannot be offset through trade and inevitably leads to the depletion of ecological assets and/or the accumulation of wastes. The global ecological deficit is thus equivalent to the annual global overshoot.

2.2.6 Planet Equivalents

Every individual and country's ecological footprint has a corresponding planet equivalent, or the number of earths it would take to support humanity's footprint, if everyone lived like that individual or average citizen of a given country. It is the ratio of an individual's (or country's per capita) footprint to the per capita biological capacity available on earth.

2.3 METHODOLOGY FOR CALCULATING EF

The following sections explain the methodology for calculating the ecological footprint.

2.3.1 Land Use Types for Ecological Footprint and Biocapacity Calculations

The ecological footprint and biocapacity accounts cover six land use types (Shanthini, 2010; Kitzes and Wackernagel, 2009; GFN, 2010) as shown in Figure 2.1 and described below. The ecological footprint represents demand for ecosystem products and services in terms of these land use types, while biocapacity represents the productivity available to serve each use.

Bioproductive land:

i. Cropland – Cropland consists of the area required to grow all crop products, including livestock feeds, fish meals, oil crops and rubber. It is the most bioproductive of the land use types included in the national footprint accounts (NFA). The NFA calculate the footprint of cropland according to the production quantities of 164 different crop categories. The footprint of each crop type is calculated as the area of cropland that would be required to produce the harvested quantity at world average yields. Cropland biocapacity represents the combined productivity of all land devoted to growing crops, which the cropland footprint cannot exceed (Kitzes and Wackernagel, 2009).

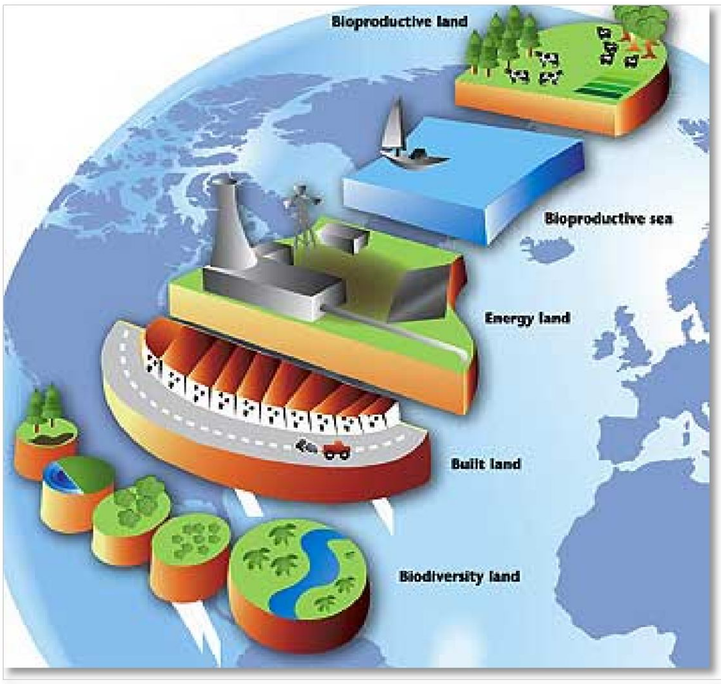

Fig. 2.1 Landuse Types for Ecological Footprint and Biocapacity Calculations
Source: GFN, 2010

ii. Grazing land – The grazing land footprint measures the area of grassland used, in addition to crop feeds to support livestock. Grazing land comprises all grasslands used to provide feed for animals, including cultivated pastures as well as wild grasslands and prairies. The total demand for pasture grass, P_{GR}, is the amount of biomass required by livestock after cropped feeds are accounted for as shown in Equation 2.1.

$$P_{GR} = TFR - F_{Mkt} - F_{Crop} - F_{Res} \tag{2.1}$$

where,

TFR	- Total feed requirement
F_{Mkt}, F_{Crop} and F_{Res}	- Amounts of feed available from general marketed crops, crops grown specifically for fodder, and crop residues, respectively.

Fishing ground – The fishing ground footprint is calculated based on the annual primary production required to sustain a harvested aquatic species. This primary production requirement (PPR) is the mass ratio of harvested fish to annual primary production needed to sustain that species, based on its average tropic level. Equation 2.2 provides the formula used to calculate PPR. It is based on the work of Pauly and Christensen (1995).

$$\mathrm{PPR} = \mathrm{CC.DR.}\frac{1}{\mathrm{TE}}^{(\mathrm{TL}-1)} \tag{2.2}$$

where,

CC - Carbon content of wet-weight fish biomass

DR - Discard rate for by catch

TE - Transfer efficiency of biomass between tropic levels

TL - Tropic level of the fish species in question.

The estimate of annually available primary production used to calculate marine yields is based on estimates of the sustainable annual harvests of 19 different aquatic species groups (Gulland, 1971). These quantities are converted to a primary production equivalents using Equation 2.3 and the sum of these is taken to be the total primary production requirement which global fisheries may sustainably harvest. Thus the total sustainably harvestable primary production requirement, PP_S, is calculated as

$$\mathrm{PP_s} = \sum(\mathrm{Q_{S.i}} \times \mathrm{PPR_i}) \tag{2.3}$$

where,

$Q_{S,i}$ - The estimated sustainable catch for species group i

PPR_i - PPR value corresponding to average tropic level of species group i.

This total harvestable primary production requirement is allocated across the continental shelf areas of the world to produce biocapacity estimates. Thus the world average marine yield (Y_M), in terms of PPR, is given by Equation 2.4.

$$Y_M = \frac{PP_S}{A_{CS}} \tag{2.4}$$

where,

PP_S - The global sustainable harvest from Equation 2.3.

A_{CS} - The global total continental shelf area.

The fishing ground calculation is one of the most complexes in the national footprint accounts and significant improvements have taken place over the past seven years; including revision of many fish extraction rates, inclusion of aquaculture production, and inclusion of crops used in aqua feeds (Ewing et al., 2010a).

Forest land – The forest land footprint measures the annual harvests of fuel wood and timber to supply forest products. As per FAO (2004), worldwide there were 3.94 billion hectares of forest land area available. The yield used in the forest land footprint is the net annual increment of merchantable timber per hectare. Timber productivity data from the forest resource assessment (FAO, 2000) and the global fibre supply (FAO, 1998) are utilized to calculate the world average yield of 1.81 m^3 of harvestable wood per hectare per year.

Built up land – The built up land footprint is calculated based on the area of land covered by human infrastructure: transportation, housing, industrial structures and reservoirs for hydroelectric power generation. As per GFN (2010), the built up land area of the world was 169.59 million hectares in 2007. The national footprint account 2010 assumes that built up land occupies what would have been previously cropland.

This assumption is based on the observation that human settlements are generally situated in fertile areas with the potential for supporting high yielding cropland.

Carbon uptake land – The uptake land to accommodate the carbon footprint is the only land use type included in the ecological footprint which is exclusively dedicated to tracking the waste product, carbon dioxide. In addition, it is the only land use type for which biocapacity is not explicitly defined. CO_2 is released into the atmosphere from a variety of sources, including human activities such as burning fossil fuels and certain land use practices; as well as natural events such as forest fires, volcanoes, and respiration by animals and microbes.

Many different ecosystem types have the capacity for long term storage of CO_2, including the land use types considered in the national footprint accounts such as cropland or grassland. However, since most terrestrial carbon uptake in the biosphere occurs in forests, and to avoid over estimations, carbon uptake land is assumed to be the forest land by the ecological footprint methodology. For this reason, it is considered to be a subcategory of forest land. Carbon uptake land is the largest contributor to humanity's current total ecological footprint and increased more than tenfold from 1961 to 2007 (GFN, 2010). However, in developing countries, the carbon footprint is often not the dominant contributor to the overall ecological footprint. The formula for the carbon footprint EF_c is

$$EF_C = \frac{P_C \cdot (1 - S_{Ocean})}{Y_C} * EQF \quad (2.5)$$

where,

P_C - The annual emissions (production) of carbon dioxide
S_{Ocean} - The fraction of anthropogenic emissions sequestered by oceans in a given year

Y_C - The annual rate of carbon uptake per hectare of forest land at world average yield

EQF - Equivalence factor for the carbon up take land of forest land.

2.3.2 Equivalence Factors and Yield Factors

The rationale behind *equivalence factors'* calculation is to weight different land areas in terms of their capacity to produce resources useful for humans. The weighting criterion is therefore, not just the quantity of biomass produced, but also the quality of such biomass, meaning how valuable this biomass is for humans. Equivalence factors are currently calculated using suitability indexes from the Global Agro Ecological Zones (GAEZ) model, combined with data on the actual areas of cropland, forest land, and grazing land area from FAOSTAT (IIASA/FAO, 2012). The GAEZ model divides all land globally into five categories, based on calculated potential crop productivity. All land is assigned a quantitative suitability index from among the following:

- Very suitable (VS) – 0.9
- Suitable (S) – 0.7
- Moderately suitable (MS) – 0.5
- Marginally suitable (mS) – 0.3
- Not suitable (NS) – 0.1

The calculation of the equivalence factors assumes that within each country the most suitable land available will be planted to cropland, after which the most suitable remaining land will be under forest land, and the least suitable land will be devoted to grazing land. The equivalence factors are calculated as the ratio of the world average suitability index for a given land use type to the average suitability index for all land use types. Figure 2.2 shows a schematic representation of this calculation.

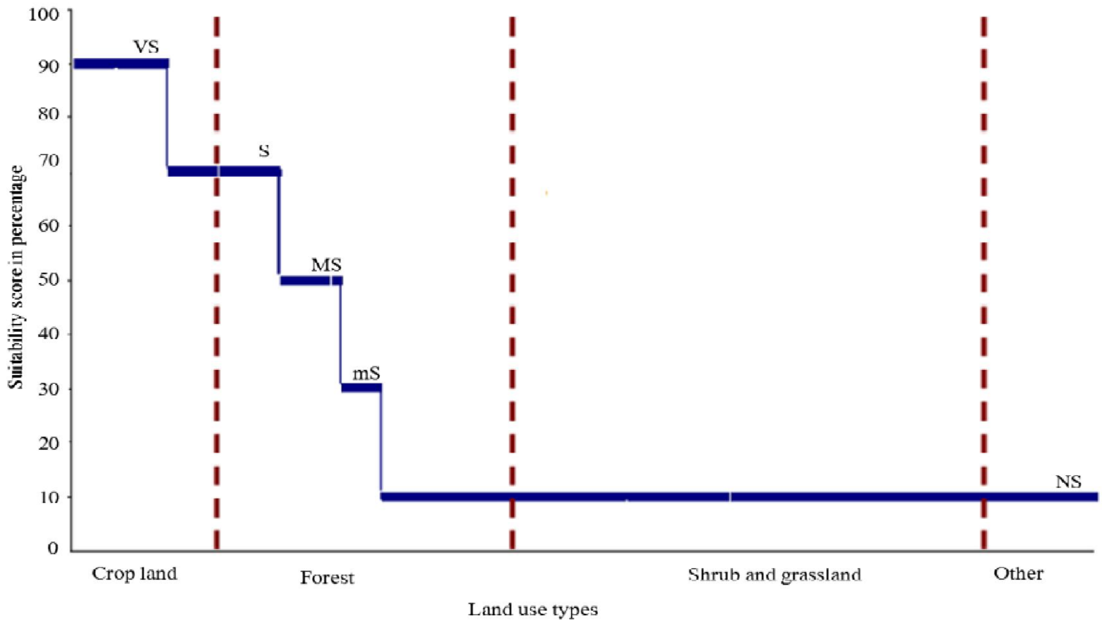

Fig. 2.2 Schematic Representation of Equivalence Factor Calculations for Different Landuse Types
Source: GFN, 2010

In the Figure 2.2, the total number of bio productive land hectares is shown by the length of the horizontal axis. The total land area is divided into the three terrestrial land use types (cropland, forest, and grazing land), for which equivalence factors are calculated using the vertical dashed lines. The length of each horizontal bar shows the total amount of land available with each suitability index. The vertical location of each bar reflects the suitability score for that suitability index, between 10 and 90. The equivalence factor for built up land is set equal to that for cropland, while that of carbon uptake land is set equal to that of forest land. The equivalence factor for hydroelectric reservoir area is set equal to one, reflecting the assumption that hydroelectric reservoirs flood world average land. The equivalence factor for marine area is calculated such that a single global hectare of pasture will produce an amount of calories of beef equal to the amount of calories of salmon that can be produced by a single global hectare of marine area. The equivalence factor for inland water is set equal to the equivalence factor for marine area. Table 2.1 shows the equivalence factors for the land use types in the 2010 national footprint accounts. The data was taken in the year 2007.

Table 2.1 Equivalence Factors for Footprint Calculations (2007)

Area type	Equivalence factor (global hectares per hectare)
Crop land	2.51
Forest	1.26
Grazing land	0.46
Marine & Inland water	0.37
Built up land	2.51

Source: GFN, 2010

Cropland's equivalence factor of 2.51 indicates that, world average cropland productivity was more than double the average productivity for all land combined. This same year (2007), grazing land had an equivalence factor of 0.46, showing that grazing land was, on average, 46 per cent as productive as the world average bio productive hectare.

Yield factors account for countries' differing levels of productivity for particular land use types. Yield factors are country specific and vary by land use type and year. They may reflect natural factors such as differences in precipitation or soil quality, as well as anthropogenic induced differences such as management practices. The yield factor is the ratio of national average to world average yields. It is calculated in terms of the annual availability of usable products. For any land use type L, a country's yield factor YF_L is given by

$$YF_L = \frac{\sum_{i \in U} A_{W,i}}{\sum_{i \in U} A_{N.i}} \tag{2.6}$$

where,

U - Set of all usable primary products that a given land use type yield

$A_{W,i}$, $A_{N,i}$ - Areas necessary to furnish that country's annually available amount of product i at world and national yields, respectively.

$$A_{N,i} = \frac{P_i}{Y_N} \tag{2.7}$$

$$A_{W,i} = \frac{P_i}{Y_w} \tag{2.8}$$

where,

P_i - Total national annual growth of product i

Y_N and Y_W - National and world yields, respectively

Thus, $A_{N,i}$ is always the area that produces 'i' within a given country, while $A_{W,i}$ gives the equivalent area of world average land yielding 'i'. With the exception of cropland, all other land use types included in the NFA provide only a single primary product, such as wood from forest land or grass from grazing land. For these land use types, the equation for the yield factor simplifies to

$$YF_L = \frac{Y_N}{Y_W} \tag{2.9}$$

Due to the difficulty of assigning a yield to built-up land, the yield factor for this land use type is assumed to be the same as that for cropland (in other words urban areas are assumed to be built on or near productive agricultural lands). For lack of detailed global datasets, areas inundated by hydroelectric reservoirs are presumed to have previously had world average productivity. The yield factor for carbon uptake land is assumed to be the same as that for forest land, due to limited data availability regarding the carbon uptake of other land use types. All inland waters are assigned yield factors of one, due to the lack of a comprehensive global dataset on freshwater ecosystem productivities. Table 2.2 shows the sample yield factors for selected countries for the data year 2007.

Table 2.2 Yield Factors of Various Landuse Types for Selected Countries (2007)

Yield factor	Cropland	Forest	Grazing land	Fishing grounds
World average	1.0	1.0	1.0	1.0
Algeria	0.3	0.4	0.7	0.9
Germany	2.2	4.1	2.2	3.0
Hungary	1.1	2.6	1.9	0.0
Japan	1.3	1.4	2.2	0.8
Jordan	1.1	1.5	0.4	0.7
New Zealand	0.7	2.0	2.5	1.0
Zambia	0.2	0.2	1.5	0.0

Source: GFN, 2010

2.3.3 Footprint and Biocapacity Calculations

The ecological footprint of a product is defined as the sum of the footprints of all activities required to create, use and/or dispose of that product during its life cycle.

$$\mathrm{EF}_{\mathrm{product}} = \sum_{i=1}^{6}\sum_{j=1}^{n} \mathrm{EQF}_i * \mathrm{EF}_{i,j} \tag{2.10}$$

where,

i - Land type (crop land, grazing land, fishing grounds, forest, built-up land and energy land)

j - Production inputs

EQF_i - Equivalence factor of the ith land

Biocapacity (BC) is assessed by multiplying the land area available annually for production (A) of each type of land ‘i’, by the appropriate yield factor (YF) and equivalence factors (EQF).

$$\mathrm{BC} = \sum_{i=1}^{6} \mathrm{A}_i * \mathrm{YF}_i * \mathrm{EQF}_i \tag{2.11}$$

2.4 ECOLOGICAL FOOTPRINT AND SUSTAINABILITY

The ecological footprint value can be used as a sustainability measure. Ecological bottom lines or ecological quotient denoted by EQ, which is the ratio of total ecological footprint and the own share of supply limits of natural capital, is an indicator of sustainability.

$$\mathrm{EQ} = \frac{\text{Total Ecological Footprint}}{\text{Own Share of Supply Limits of Natural Capital}} \tag{2.12}$$

EQ <1 is sustainable

EQ >1 is unsustainable

If EQ is less than one, we can say the system is sustainable. On the other hand, the value of EQ greater than one indicates that the total ecological footprint exceeds the share of supply limits of nature, the unsustainability issue occurs.

2.5 SCOPE OF EFA AS AN IMPACT ASSESSMENT TOOL FOR INDIA

In 1950, environmental impact assessment (EIA) was developed as a consequence of increased public awareness of the harmful environment and social effects of development in USA. By 1970, EIA was made mandatory for major development projects. In India, EIA came into existence through EIA notification of 1994. Under this notification, government clearance is required for 29 categories of projects such as hydroelectric projects, watershed management projects, large scale industries etc. The project proponent is required to submit Environmental Impact Statement (EIS) & Environmental Management Plan (EMP). Expert committees evaluate the impacts and reports. Technical staff at Ministry of Environment and Forest (MoEF) scrutinizes the proposal before placing it to the expert committee. For site specific projects, site clearance and environmental clearance is needed. The scope of EFA as an impact assessment tool for India was analysed by comparing EFA with Environmental Impact Assessment (EIA), the existing widely accepted impact assessment tool in India. Table 2.3 shows the comparison of EIA with EFA.

Table 2.3 Comparison of EIA with EFA *(Ravi, 2007 thereafter)*

EFA	EIA
Impact of a single man can be measured. Considering our present situation, each and every impact including human impacts should be studied to have a sustainable living.	*Impact of a single man can be measured. But done mostly for large projects.* EIA is mostly done for macro level projects which have regional implications resulting in the fact that the local environmental issues are often neglected.
Energy consumption is given due consideration.	*Did not have an analysis on the energy consumption.* This is a major drawback in the impact assessment mechanism which is very essential in the present days of energy depletion.
Quick and easy There are many software developed for the quantification of the impacts and with these technologies the analysis can be made quick and easy.	*Time consuming* Since the preparation of the environmental statement is done by the members of the expert committee, the difference in their views will lead to cost and delays consequent on preparation of impact statements.
Impacts are quantified and compared with the capacity. Both environmental and social impacts are quantified and compared with capacity.	*Impacts are quantified to an extend only.* Impacts are quantified with respect to the effect on the environment only.
Can accurately measure how far we are away from sustainability.	*Tries to keep a balance only in the environmental aspects.*
Whoever assesses the impact, the result will be the same.	*Changes will depend on the views of the expert committee.*
Criteria for assessment vary depending on the region and depending on the time when it is assessed. Each country can use the methodology in the assessment but the criteria can be changed with respect to their locality.	*Criterion for assessment is purely developed by foreign agencies.* Most of the developing countries are adopting the same criteria for impact assessment, developed by the foreign agencies, which may not be applicable to their region.

It shows that, EFA can be done for an individual, where impacts are quantified and compared with bio capacity. It is quick and easy and energy consumption is given due consideration. EFA can accurately measure how far we are away from sustainability and whoever assesses the impact the result will be same. The criteria for assessment vary year wise and location wise.

2.6 GLOBAL FOOTPRINT CALCULATOR

This section gives an overview of the global footprint calculator based on which the ecological footprint of study area is calculated.

Global footprint calculator (GFC) is a footprint calculator, developed by Redefining Progress (RP) and Earth Day Network (EDN) in the year 1993, for calculating the region specific personal ecological footprint. It is an online calculator, which is available in the website, my footprint. Redefining Progress is a non-profit, nonpartisan public policy organization based in Oakland, California. They create and advocate policies to encourage accurate market prices, protect our common assets, and foster a sustainable world. Through research, writing, education, and advocacy, Redefining Progress aims to change how policymakers, opinion leaders, and the general public think about progress-so that they work together to build a better future for all. Earth Day Network is the non-profit coordinating body of worldwide earth day activities. The goal is to promote a healthy environment and a peaceful, just, sustainable world by spreading environmental awareness through educational materials and publications, and by organizing events, activities, and annual campaigns. The network includes more than 5,000 organizations in 184 countries. The network is based in Seattle, Washington, USA (GFN, 2010).

2.6.1 Ecological Footprint Calculations in Global Footprint Calculator

Major components for footprint calculation in GFC are food, mobility, shelter and goods and services. It is mainly based on national consumption averages and is meant to give us an idea of our ecological footprint relative to other people in the country we live in and is getting updated based on researches in this field. Footprints are calculated using a methodology that includes the following steps:

- Identify and add up the amount of biocapacity in a country or the world; i.e., how many hectares (or acres) of land are dedicated to crop production, pasture land, forests, fishing, carbon storage areas, and built space.
- Use equivalence factors to normalize all biocapacity categories into global hectares; i.e., making crop land, grasslands, and forest comparable using a common denominator such as net primary productivity or agricultural potential.
- Subtract bio-capacity for the needs of non-human life.
- Determine the average yield factors for a hectare of biocapacity; e.g., how many tonnes of beans per hectare of crop land are produced.
- Use the biocapacity and yield factors to measure the area of biocapacity a population's consumption and waste output requires over the course of a year; e.g., one tonne of beans might require half global hectare to grow, and thus the footprint of two tonnes of bean consumption is one global hectare.
- For a country level footprint, an additional step is taken to add in imports and subtract exports in the final tally.

2.6.2 Parameters for Footprint Calculations in Global Footprint Calculator

i. *Parameters for food footprint*

   - Dependence on animal based products and its frequency
     - Because of the large area of land or sea needed to raise livestock and catch fish, eating less meat and fish could reduce the food footprint by up to 40%.

- Dependence on processed, packaged & imported food materials
    - Buying more organic food can reduce the food footprint by around 15%.
    - Buying more locally grown food can reduce the food footprint by about 10%.

ii. *Parameters for goods footprint*

- Amount of waste generation
- Dependence on size of house
- Food consumption
- Mobility footprint

iii. *Parameters for housing footprint*

- Number of people in the house
- Size and type of home
- Dependence on energy efficient electricity use in the house

iv. *Parameters for mobility footprint*

- Dependence on public transportation facilities
- Dependence on two wheelers and four wheelers
- Dependence on walking habits & using bicycle
- Dependence on air travel
- Consumption of fuel for vehicles
- Vehicular pooling

2.6.3 Display of Results in the Global Footprint Calculator

On a global level, the results are biocapacity (supply) estimates for crop land, pasture land, forest, fisheries, and carbon storage areas. We compare that to the footprint (demand) for food, forest, and other resource consumption categories, as well as carbon emissions. The calculator results are in the following manner.

- Food, housing, mobility and goods and services footprint in global hectares

- Comparison with national and world averages
- Calculating number of earths needed if we are following the current life style

2.7 SUMMARY OF THE CHAPTER

This chapter answers the first part of the first research question. The tool ecological footprint analysis was reviewed in detail, exploring the need for EFA in environmental monitoring and assessment, various terminologies related to EFA, methodology for calculating EFA, relation between EFA and sustainability. The scope of EFA as an impact assessment tool has been analysed and the global footprint calculator which was used to calculate the ecological footprint was studied in detail.

The review of the ecological footprint analysis showed that the ecological footprint can track humanity's demands on the biosphere, by comparing the renewable resources people are consuming against the earth's regenerative capacity (biocapacity) which is the area of land actually available to produce renewable resources and absorb CO_2 emissions.

Compared with the existing impact assessment tool in India - Environmental impact assessment (EIA), the impact assessment through EFA is easy, quick, highly quantifiable, unique and consistent. The comparison of EFA with EIA showed that EFA can be used as an impact assessment tool for India.

Studies on global footprint calculator revealed that the size of a person's ecological footprint depends on development level and wealth, and in part on the choices individuals make on what they eat, what products they purchase and how they travel. The global footprint calculator can give the footprint values in our finger tips, which we can compare with national and world averages. The calculator helps the individual to realise and quantify the impact caused by the lifestyle and consumption pattern on the planet.

Thus, it is concluded that, EFA can be used as an impact assessment tool for India and the global footprint calculator can be used to assess the impact of a single individual which in turn helps to assess the sustainability issues of a region. With this, the research focuses to the second part of the first research question, about the various applications and case studies of EFA to assess the sustainability issues and to arrive at solutions, in the following chapter.

CHAPTER 3

APPLICATIONS AND SELECTED CASE STUDIES OF EFA

Answering the first part of the first research question in the previous chapter, the second part of the first research question is answered in this chapter. For this, the chapter analyses the various applications of EFA in different fields like urban planning with special reference to transportation and housing; public policy; awareness raising; sustainability assessment etc. In addition, the chapter analyses case studies of EFA conducted at town level, city level and country level in India and elsewhere in the world.

3.1 APPLICATIONS OF EFA

The ecological footprint can be applied at all scales, ranging from single products to humanity as a whole. It is a useful tool to help budget limited natural capital (Wackernagel et al., 2006). There have been footprint applications on every continent. Global and national accounts have been reported in headlines worldwide, and over 100 cities or regions have assessed their ecological footprint. The most wide-ranging ecological footprint analyses are the 'Footprint of Nations' series undertaken by Wackernagel and his team (Wackernagel et al., 2002). Published in 2002 in summary form by World Wide Fund for nature International (WWF) these cover one fifty two countries and are necessarily based on international datasets. The organization uses the ecological footprint in its communication and policy work for advancing conservation and sustainability. Government agencies, particularly in Europe, have studied the implications of ecological footprint results, and have re-examined the significance of carrying capacity. These showed that ecological footprint can serve as a screening indicator for environmental performance (Huijbregts et al., 2008). The ecological footprint can also been commonly used to assess human pressure in geographical context, for instance on the level of nations, regions or cities (Folke et al., 1997; Wackernagel et al., 2002; Nijkamp et al., 2004).

Ecological footprint (EF) balance sheets which describes how much nature we use and how much is available have been calculated for the planet (Wackernagel et al., 2002), for nations (Wackernagel et al., 2002; Haberl et al., 2001; Monfreda et al., 2004; Moran et al., 2008), for cities and regions (Wackernagel et al., 2006; Kissinger and Haim, 2008; Scotti et al., 2009). Few studies have also calculated the EF of organizations, universities like University of Redlands, University of Toronto and activities such as specific industrial production and supply like wood and non wood pulp production in Canadian prairies, textile sectors etc. (Venetoulis, 2001; Kissinger and Rees, 2007; Conway et al., 2008; Herva et al., 2008).

3.2 FOOTPRINT APPLICATIONS IN ENGINEERING AND URBAN PLANNING

The ecological footprint (EF) could play a useful role in conducting assessments about the design of a city, that will be sustainable with the consumption and life style of the inhabitants of such city or neighbourhood, by documenting some of the behaviours that are most crucial to person's total environment impact and how they are related to design and building form (Nelson and Ludin, 2013). This has been mentioned in their comparative analysis of ecological footprint of two different neighbourhoods in Minna, Nigeria. The analysis considered the building design, types, consumption pattern, life style and land use in the study regions. The study concluded that, there are different estimates of ecological footprint of different neighbourhood of a city rather than estimating the city's ecological footprint. But the difference is negligible and could be due to several factors such as consumption habit, lifestyle, household size, availability of private cars, parking, building form etc. The ecological footprint tool was deemed to have considerable promise as a neighbourhood planning tool, despite challenges associated with data assembly and conversion and limitations in its ability to deal with cause and effect processes (Nelson and Ludin, 2013).

EF has been identified as a useful method for the evaluation of sustainability of tourism activities (Hunter and Shaw, 2007); even if only few studies are specifically devoted to the evaluation of sustainability of hospitality structures (Valentina and Serenella, 2010). Ecological impact of renewable resource based energy technologies and bio fuels using EF have been analyzed by Kettl et al. (2011). The study results showed that the environmental pressure of fossil based technologies and fuels are indeed much larger than that of comparable technologies and products on the base of renewable resources.

Chambers and Lewis (2001) were the first to use the ecological footprint methodology as an aggregated ecoefficiency indicator at the corporate level. They analyzed the case studies of Anglian Water Services (the UK regulated part of the Anglian Water Group) during the years 1998/1999 and Best Foot Forward in 1999/2000 (Bagliani and Martini, 2012). Lenzen et al. (2002) introduced, for the first time, the input-output analysis to calculate the ecological footprint at the company level, focusing on the case of the Sidney water services. Some studies have adopted ecological footprints to analyse agricultural production: among the earlier ones, Thomassen and Boer (2005) and Van der Werf et al. (2007) focused on the dairy sector, Deumling et al. (2003) on the horticultural sector and Stoeglehner and Narodoslawsky (2009) on the energy crop sector. Niccolucci et al. (2008) applied the ecological footprint to compare conventional and organic wine production systems in Italy. In their study, energy and material data were sorted by four production phases (agricultural, winery, packing, distribution) considered separately.

Cerutti et al. (2010) used the ecological footprint for a detailed analysis of a commercial peach orchard. Differently from previous studies, they considered not only the one year field operations, but also the whole life time of the orchard. The calculation was conducted by studying six different orchard stages separately. A systematic approach, which is able to analyse the impacts of supply chains, has been presented by Wiedmann et al. (2009). The ecological footprint can also be used as an appropriate screening indicator for selecting municipal solid waste management hierarchies (Herva and Roca, 2013).

3.2.1 EFA in Transportation

The study conducted by Chi and Stone (2005) develops a footprint methodology for quantifying the impacts of transportation investments in a spatial scale that is compatible with local planning policy. This study also developed a framework for projecting the future land requirements needed to sustain a county level transportation system in response to ongoing trends in annual vehicle kilometres of travel and average fleet fuel efficiency. In addition to assessing the environmental impacts of development patterns, there was a critical need to model the implications of alternative development futures. Therefore, the work combines footprint analysis with GIS and simple linear regression to forecast the future land requirements of a transportation network, assuming a business as usual scenario. By reducing the various impacts of transportation to a single metric of land area, the transportation network footprint can be mapped and visually evaluated against the spatial requirements of other landuse sectors and against the total available land area.

Most important, in accounting for a broader range of environmental impacts than generally considered, such as the land area required sequestering greenhouse gas emissions from the transportation sector, the ecological footprint measure encourages communities to manage growth long before a region is fully developed (Chi and Stone, 2005). Footprint of transportation related activities includes the footprint of transportation fuel consumption and the footprint of builtup areas for transportation infrastructures. Thus all forms of public transportation such as buses, taxis, motor-cycles, private cars and freight vehicles which consume fossil fuels like CNG, LPG and petrol contribute to footprint (Agrawal et al., 2006).

In Great Britain, with regard to water, air and all transportation means such as metro, buses, cars, motorbikes and scooters, and regarding other transportation infrastructures, ecological footprint of transportation of 0.67 global hectares was calculated (Barrett et al., 2004). In York, the amount of CO_2 produced per kwh from various types of fuels used for vehicles such as private cars, buses, motorcycles and aircrafts were calculated and transportation footprints of 1.49 hectares for the city was estimated (Barrett et al., 2002). Footprint of transportation in the city of Adelaide in Australia with regard to the use of private vehicles like cars and trucks, motorcycles, buses, rail and air transport and passenger boats was calculated as 0.66 global hectares per capita (Agrawal et al.,2006).

In the city of Kermanshah in western Iran, considering the amount of diesel and gasoline consumption by public and private vehicles such as buses, mini buses and cars and motorcycles, the ecological footprint of transportation was estimated at 0.32

hectares (Gharakhluo et al., 2013). Shayesteh et al (2014) in his study concluded that, EFA concept can be a useful analytical method for estimating the total impacts of different activities such as transportation and air pollution that has resulted from vehicles traffic and gasoline has a major role in the transportation footprint of Isphahan. So a decrease in the proportion of gasoline, would lead to a decrease in ecological footprint and the total impacts of transportation on the natural environment.

3.2.2 EFA in Housing

The evaluation of the ecological footprint related to housing activities, ranging from heating to lighting system, from air conditioning to water consumption can be compared and quantified in different phases of the construction and restructuration of a building (Marco et al., 2010). By integrating a common embodied energy analysis with EFA, it is possible to assess not only energy expenses but also natural capital appropriation of buildings, adding up all inputs into a single value. This has been demonstrated in the studies of two types of houses in Italian contest. The assessment of building impact enables to find a common language between architectural and ecological disciplines and to generate useful analysis for establishing sustainability parameters for building construction and urban planning. The study showed that minor capital requirement is required in multi storied buildings, due to the more number of dwellers for each building, sharing of built up area, less requirement of bio productive land and more natural capital saving and optimization of the environmental burdens due to environmental expensive structural elements i.e. foundations. In the same study, EFA of building materials shows the importance of natural materials like wood and cork in CO_2 reduction.

Apart from the engineering and urban planning applications, other applications of EFA are discussed in the following sections.

3.3 FOOTPRINT APPLICATIONS AS A SUSTAINABILITY INDICATOR

Ecological footprint provides a conceptually simple, intuitively appealing way to incorporate sustainability goals into the planning process (Bicknell et al., 1998). By monitoring human use of renewable natural capital, ecological footprint accounts provide guidance for sustainability: a footprint smaller than the available biocapacity is a necessary condition for 'strong sustainability', a stand point which asserts that securing people's well-being necessitates maintaining natural capital (Wackernagel et al., 2006). Some people argue that 'strong sustainability' is too stringent, since technology and knowledge can compensate for lost ecological assets. While this can be debated, even managing for 'weak sustainability' requires reliable accounting of assets. Hence, by measuring the overall supply of resources, and human demand on, regenerative capacity, the ecological footprint serves as an ideal tool for tracking progress, setting targets and driving policies for sustainability.

The ecological footprint has gained popularity for its informative strength as it expresses the results of its analysis in spatial units that can be easily communicated and which allow for the comparison of human consumption directly to nature's limited productivity. Also, it is one of the few measures that aggregate a variety of human impact in consistence with thermodynamic laws and ecological principles (Holmberg et al., 1999).

Ecological footprint analysis can directly measure the impact of household consumption on environment (Zhiying and Cuiyan, 2011). It is also useful for documenting the overall human use or abuse of the potentially renewable functions and services of nature. Particularly, by aggregating in a consistent way a variety of human impacts, it can effectively identify the scale of human economy in comparison to the size of biosphere (Holmberg et al., 1999).

3.4 FOOTPRINT APPLICATIONS IN PUBLIC POLICY

Ecological footprint accounts, allow governments to track a city or region's demand on natural capital, and to compare this demand with the amount of natural capital actually available. The accounts also give governments the ability to answer more specific questions about the distribution of these demands within their economy. Ecological footprint analysis along with urban metabolism analysis provides valuable information to local government planners and policy analysts on urban energy and material flows and on cities' appropriations of the world's shrinking biocapacity (Moore et al., 2013).

It can be used as a tool to inform policy makers on the impacts of the different policy options that they are considering (Barrett et al., 2005). Again, York City Council (SEI-Y, 2000) stated that ecological footprint was very useful to gauge themselves against the average earth share of land of 1.9 global hectares, as well as gaining new insights from including such a broad range of data. They are using the footprint as part of their community plan and also use it as a monitoring tool as part of the councils environment management strategy (SEI-Y, 2000).

Barrett et al. (2004), in his study revealed that, in both the United Kingdom and elsewhere in the world, the most important perceived outcome of ecological footprint studies is the interest that it has created from local residents, environment groups and other key individuals due to its resonance. This response was supported by York City Council, who observed that the EF offers a focus for policy and action that is tangible and measurable, academically compiled and easy to understand. The University of Oslo carried out an ecological footprint for the city and reported that they were wide acceptance of the tool in media (Aall and Norland, 2002).

Municipal applications: There may well be over hundred ecological footprint studies for cities, ranging from student projects to comprehensive analyses of a metropolitan area's demand on nature. London, for instance, has already undergone three rounds. In 1995, urban sustainability specialist Herbert Girardet estimated that the United Kingdom capital's footprint was 125 times the size of the London city itself. In other words, in order to function, London required an area, almost equal to the size of the entire productive land surface in the United Kingdom to provide the resources the city used and to dispose of its pollutants and waste (Wackernagel et al., 2007).

National and regional applications: A number of national and regional footprint studies have contributed to policy discussions, some in close cooperation with government agencies. Ecological footprint calculations are also experimented on the scale of sub national populations (Chambers et al., 2002; Barrett et al., 2004). Resource and Energy Analysis Programme (REAP) aims at helping British local governments and agencies understand the footprints of residents by providing data, maps and reports on carbon and ecological footprints for local authority areas (Gondran, 2012). In March 2001, the National Assembly for Wales adopted the ecological footprint as their headline indicator for sustainability, making Wales the first nation to do so. The first report was commissioned through WWF–Cymru (the Welsh section of World-Wide Fund for Nature) and executed by Best Foot Forward

(BFF), a non governmental organisation. This report details Wales's energy, transportation and materials management (WWF, 2010). The update of the EF report was produced yearly by Stockholm Environment Institute (Dawkins et al., 2008) for formulating public policy.

EPA Victoria, the lead state agency responsible for protecting the environment, established a series of pilot projects in 2002 in partnership with a wide range of organizations and businesses, to further investigate the practical applications of the ecological footprint to promote sustainability (EPA, 2008). Under a grant from the US Environmental Protection Agency, Sustainable Sonoma County, a local NGO, used the ecological footprint as the foundation of a 2002 campaign. By inviting wide public participation and comment on the study before it was released, it was able to generate strong local buy-in. As a result, the launch of the study received countywide media coverage and built the groundwork for a subsequent campaign. The latter resulted in all municipalities in Sonoma committing simultaneously to reduce their CO_2 emissions by 20 per cent, making it the first US country to do so. To meet this commitment, they established programmes that track progress towards meeting their reduction goal (Hancock et al., 2002).

In late 2006, the EF study conducted by the Swiss government, tested to what extent the international data sources used by Global Footprint Network correspond to the statistics of the Swiss Federal Statistical Office (Von Stokar et al., 2006). They concluded that the data sets are largely consistent and also this method was used to calculate embodied energy in trade.

International applications: The European Environment Agency (EEA) is under a constitutional requirement of the European Union to produce a state of the environment report every five years. The 2005 report prominently featured Europe's ecological footprint. Preparatory discussions on the UN Convention on biodiversity have identified the ecological footprint as a key indicator for the 2010 targets (COP, 2010). Increasingly, governments are recognizing the importance of ecological assets for securing the country's future well-being. The European Parliament commissioned a comparative study on the application of ecological footprinting to sustainability, which included case studies exploring potential uses of the footprint in international legislation (Chambers, 2001). The United Nations Population Fund (UNFPA) report 'State of World Population 2001 – Footprints and Milestones: Population and Environmental Change', builds on ecological footprint concepts (UNFPA, 2001).

3.5 FOOTPRINT APPLICATIONS AS AN AWARENESS RAISING AND EDUCATION TOOL

Most of the local authorities have taken the ecological footprint calculations as a means for communication and raising awareness among the general public (Gondran, 2012). The easy to understand concept portrayed by the ecological footprint makes it a highly useful and informative tool. It depicts the impacts of our actions upon the planet in a unique and visual manner, making the concept accessible to policy makers, children, government officials and the general public alike. The often reported 'hard to understand' concept of sustainable development is combated by the ecological footprint whereby people can easily understand the impacts of their actions. It has the potential to act as a catalyst through which, it communicate the complicated notion of sustainable resource consumption and place it into the context of peoples' daily lifestyles. Through the various visual expression of the EF, people would find it easier to identify and quantify the components of their lifestyle (e.g. energy consumption in the home) which have the greatest impact, the degree to which the consequences of their lifestyle will affect them at the individual, local and ultimately global scale (Barrett et al., 2004). And again EF can be used as a tool to reduce the resource consumption of each individual.

Most local authorities who have calculated their ecological footprint have reported that the ecological footprints have spread the insight of scarce natural resources and western land appropriation (Barrett et al., 2004). The Angus Council commented that the ecological footprint project helped to raise environmental issues amongst elected members. Although they cannot be sure that policy outcomes are a direct result of the ecological footprint study, a number of important initiatives have been put into practice since the completion of the project. These include the implementation of a fair trade policy, the investigation of a green procurement policy, the setup of a group for monitoring e-waste issues, the further development of a green transport plan and the development of a state of the environment report for Angus (Vergoulas et al., 2003). The EFA as an educational tool has the potential to offer a range of strategies that aim to help students understand the linkage between behavioural choices and their impact on the ecological systems. It also enables students to think critically about the choices they make and the environmental consequences of those choices and to take the opportunities and responsibilities they have as members of a larger community for active participation and collaboration in moving toward sustainability (Gottlieb et al., 2012).

3.6 SELECTED CASE STUDIES OF EFA

Case study through literature was conducted in different places where EFA was used as a sustainability indicator. Analysis has been done to examine how the parameters and methods for the analysis of ecological footprint were selected specific to a region.

The study was conducted in town level- Manali in India, city level- Liverpool in UK and country level - Scotland in UK. Criteria for the selection of case studies were done based on the similarity of the location with Kochi city, the study area of the thesis. Kochi city is a port city with development oriented in tourism and IT development. In this regard the tourist centre Manali, port city Liverpool and IT based development in Scotland were taken in account.

3.6.1 Case Study in Town Level– Manali, India

Manali, a town situated in the Kullu District of Himachal Pradesh, North India, is a major tourist destination in North India. Manali continued to function as a small, relatively unknown service centre until 1958, when independent India's first Prime Minister, Jawaharlal Nehru, visited the region. He was overwhelmed by the beauty and serenity of Manali and declared his full support in developing the area's tourist potential. The Himachal government capitalized on the media publicity and began its own program to develop tourism infrastructure in the region. This development proceeded at a steady, albeit slow pace, until the late 1970's. From that point forward, major changes in the shape and size of Manali began to take place. Small, orchard based guest houses began to be replaced by a myriad of hotels ranging from economy to luxury accommodations; the Himachal Pradesh Tourist Development Corporation (HPTDC) established four of its own hotel operations in Manali; and HPTDC, along with other tour operators began to develop and market package tours to the Manali area to domestic and foreign tourists. By 1981, the village had been declared a town and became one of only three urban centres in the Kullu Valley. The ecological footprint studies of Manali were conducted prior to the town becoming a major tourist destination (1971) and after its change as a tourist destination (1995). The estimate of the national ecological footprint per capita was the starting point for assessing Manali's ecological footprint (Cole and John, 2002). The ecological footprint of the average Indian was estimated to be approximately 1.3 hectares in 1995 and 0.97 hectares in 1971. This equates to a 34 % increase in the per capita footprint in India over the 24 year period. The bulk of this increase is due to an increase in the per capita energy consumption between 1971 and 1995. In terms of Manali, the ecological footprint created by the permanent population, based on national data, has increased from 1737 hectares (17.37 sq.km) in 1971 to 3331 hectares (33.31 sq.km) in 1995. This is almost a doubling (or 100 percent increase) in the town's ecological footprint over the 24 year period, despite the fact that the resident population has only risen by 45%. To put these values into perspective it is important to remember that the size of Manali was approximately 1.8 square kilometers (180 hectares) in 1971 and 3 sq.km (300 hectares) in 1995. This means that the ecological footprint of Manali's residents were over 9 times the actual area of Manali in both 1971 and 1995. Figure 3.1 shows the changes in Manali's ecological footprint in 1971 & 1995. Results for the monthly ecological footprints of Manali indicate that the largest ecological footprints occur in the months of May and June, those months when tourist arrivals are at their highest.

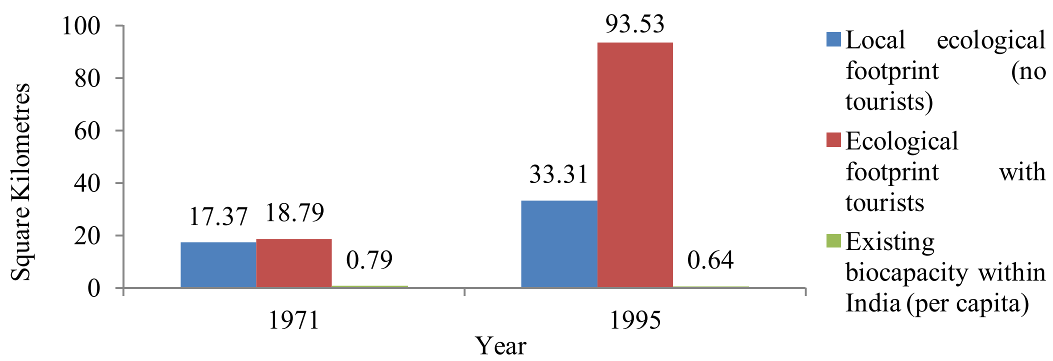

Fig. 3.1 Changes in Manali's Ecological Footprint – 1971 &1995
Source: Cole and John, 2002

3.6.2 Case Study in City Level – Liverpool, UK

The development of Liverpool as a major city in United Kingdom truly began in the seventeenth century when its port became the main connection between England and Ireland. Further expansion occurred with the onset of industrialization when the city was pivotal for colonial trade and central to the slave trade with Africa, Europe and North America. To hasten the processes of trade, the River Mersey and associated docks were strategically linked with the manufacturing regions of Lancashire and Yorkshire via the Manchester and Leeds shipping canals (Barrett and Scott, 2001). As a result, Liverpool rapidly became the second busiest port in the world. By 1914, one third of all UK exports and 25% of all imports, were dealt with by the port. According to the studies conducted by John Barrett in 2001, Liverpool has a total ecological footprint of 4.15 hectares. This means that the average Liverpool resident requires just over 4 hectares of land to supply them with all their necessary resources, the transportation and use of those resources and the disposal of those resources. If everyone in the world lived a similar lifestyle to the average Liverpool resident, then we would require a total of 2.5 planet earths to supply all the necessary resources. Figure 3.2 gives the ecological footprint of Liverpool by activities. Waste has the highest ecological impact, followed by the provision of bio-resources, then transport (both passenger and freight), utilities, biodiversity protection and finally buildings and land.

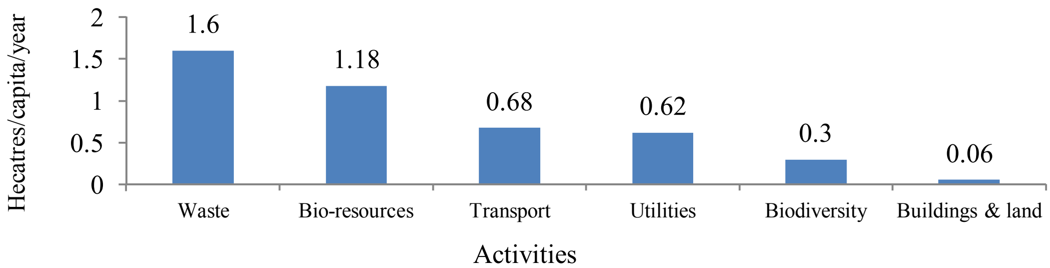

Fig. 3.2 Ecological Footprint of Liverpool by Different Activities
Source: Barrett and Scott, 2001

3.6.3 Case Study in Country Level – Scotland, UK

Scotland is one of three countries in Great Britain, covering an area of 78,722 sq.km, with a coastline of over 9,000 kilometres. Most people live in and around the two largest cities - Glasgow and Edinburgh. In 2000, Scotland contributed 8.3% (almost €30 billion) to the UK's total revenue (Chambers et al., 2004) The largest contributing sectors to the Scotland's gross domestic product are manufacturing and financial and real estate business services. The majority work in the service sector, with the second largest number of employees working in manufacturing. The predominant forms of employment in the service sector are tourism, customer service centres (call centres) and IT/technology support. Scotland's history and beauty attracts over 19 million tourists a year, with the majority travelling from within the UK. Edinburgh Castle, the Highlands and Ben Nevis - Britain's highest mountain - are among some most notable attraction of the country. The country's natural heritage is one of its strongest assets, with almost 100,000 kilometres of rivers and canals, 316 freshwater lochs (of which Loch Ness is the deepest and most famous), 790 islands and 284 munros (mountains over 3,000 feet). Land designated as Sites of Special Scientific Interest (SSSIs) covers almost 13% of Scotland's total land area. Amongst a variety of other areas of interest, the country also has 73 National Nature Reserves, 40 National Scenic Areas and 5 world heritage sites.

Table 3.1 shows the ecological footprint of Scotland's residents, by component, in 2001 as per the ecological footprint studies, conducted by Best Foot Forward Ltd. in 2004. The ecological footprint of Scotland's residents can be broken down into direct energy, materials and waste, food, personal transport, water and built land. In 2001, Scotland's residents' ecological footprint was 27,082,915 gha (global hectares) or 5.35 gha per capita. That is, the average Scotland resident would require an area of more than 5 hectares, with world average biocapacity, to sustainably support them. Direct energy which includes domestic and service energy constituted 18% of the total ecological footprint of the Scotland's residents. Domestic energy use was responsible for 68% of the direct energy ecological footprint, of which electricity was the biggest (Chambers et al., 2004). As a fuel type, electricity was the largest contributor to the direct energy ecological footprint, at 33%. At 26%, 'natural gas & LPG' (liquid propane gas) made the second largest fuel type contribution to the direct energy ecological footprint. The ecological footprint for materials and waste in 2001 was 10,164,881 gha (2.01 gha per capita). It accounts for 38% of the total Scotland residents' ecological footprint.

Table 3.1 Component Wise Ecological Footprint of Scotland's Residents (2001)

Component	Ecological footprint (gha)	Per capita ecological footprint (gha)	% of total ecological footprint
Direct energy*	4,902,562	0.97	18%
Materials & waste	10,164,881	2.01	38%
Food	7,834,524	1.55	29%
Personal transport	3,038,280	0.60	11%
Water	98,767	0.02	0.4%
Built land	1,043,902	0.21	4%
Total EF	27,082,915	5.35	100%

* Includes domestic and services energy
Source: Chambers et al., 2004

The ecological footprint for food consumed by Scotland's residents in 2001 was 7,834,524 gha (1.55 gha per capita). It accounted for 29% of a Scotland resident's total ecological footprint. Animal-based food products were responsible for 77% of the food ecological footprint. Of this, meat had the largest ecological footprint (2,738,787gha), accounting for 45% of animal-based products. Beef & veal accounted for 69% of the meat ecological footprint. The plant-based food type with the largest ecological footprint was bread' (379,928 gha), responsible for just under 5% of the food ecological footprint. The personal transport ecological footprint of Scotland's residents in 2001 was 3,038,280 gha (0.6 gha per capita), and accounted for 11% of the total ecological footprint. The largest component was car travel, which accounted for 2,361,043 gha (78%) of the personal transport ecological footprint. Air travel was the second largest component, which accounted for 436,755 gha (14%).

The ecological footprint of water consumed by Scotland's residents was 98,767 gha (0.02 gha per capita). Leakage accounted for 36% (162,540 megalitres) of domestic water supplied and has an ecological footprint of 16,149 gha (0.003 gha per capita).The built land ecological footprint for Scotland in 2001 was 1,043,902 gha (0.21 gha per capita). This accounted for 4% of a Scotland resident's ecological footprint. The built land type with the largest ecological footprint was commercial/ industrial with 0.09 gha per capita.

3.7 ANALYSIS OF THE CASE STUDIES

Tables 3.2 – 3.5 show the general analysis of the case studies; analysis of the assumptions made; analysis of the parameters selected in the case studies; and analysis of the identified problems respectively.

Table 3.2 General Characteristics of the Case Study Areas of EFA

	Manali	Liverpool	Scotland
Status	Town	City	Country
Topography	Hilly	Flat terrain	Mountainous highlands
Extent of the area	3.5 km^2	111.84 km^2	78722 km^2
Population	3000	468000	Above 5 million
Population density	10-15/ km^2	4,001 / km^2	955/ km^2
Developing sector	Tourism	Sea port	Tourism & IT development
Method of analysis	Component	Component	Component & compounding

The details in Table 3.2 show that the developing sectors in the case studies selected were mainly tourism, IT and port development. Both component method and compounding method were used. Analysis of the assumptions (Table 3.3) made shows that the assumptions made were mainly region specific and based on the availability of national data.

Table 3.3 Analysis of the Assumptions Made in the Case Study Areas of EFA

Manali	Liverpool	Scotland
• Inclusion of only biologically productive land • Consumption items- restricted to major categories • Current industrial harvest practices are sustainable • Ecological aspects excluded are -soil contamination and other forms of pollution, such as ozone depletion, and waste absorption	• The waste footprint is based on the loss of embodied energy through its disposal • To calculate transport footprint CO_2 emissions from fuel consumptions, maintenance and manufacture is used. • The ecological footprint of water and water treatment- considering the energy required to supply the water. • The built land includes the city of Liverpool, the land occupied by rail, unproductive land and road space.	• The ecological footprint is normalised by applying equivalence factors. • Biocapacity of an area is normalised using locally derived yield factors. • All energy data was converted to a standard unit of GigaWatt hours • Built land is not included in the materials & waste component • A number of proxy methods were used • Only passenger transport data accounted for in the personal transport component.

Table 3.4 Analysis of the Parameters Selected in the Case Study Areas of EFA

Manali	Liverpool	Scotland
Biotic resources like food and other crops timber & energy	Transport Waste materials(food, paper & timber) Water Housing stock and built land Energy use Biodiversity protection	Direct energy Materials and waste Food Personal transport Water Built land

The parameters included for the study of Manali's footprint were only biotic resources and energy. But the Liverpool and Scotland case studies included wide variety of parameters like transport, waste, water, energy, built land etc. The availability of national data is a great factor while selecting the parameter to be studied.

Table 3.5 Analysis of the Identified Problem Area in the Case Studies

Manali	Liverpool	Scotland
Resource consumption Energy consumption Tourist inflow	Waste issues – especially the impact of domestic waste, followed by commercial waste; Resources issues – supplying Liverpool with all its food, wood and other bio-resources; Passenger transport – both car and air transport have a significant footprints; Electricity – especially commercial electricity use, however domestic use is still an important factor	Materials & waste Food

Table 3.5 shows that Manali, being a tourist place, resource consumption, energy consumption and tourist flow were the identified problem areas. In Liverpool and Scotland, waste was the main issue and resource consumption was the second issue. Passenger transport and electricity also added problems to the Liverpool area.

3.8 SUMMARY OF THE CHAPTER

The chapter analysed various application of ecological footprint analysis (EFA) and case studies in town level, city level and country level. From the studies, it is clear that the EFA can be applied as a tool to assess region specific sustainability issues. The literature show that the main purposes for undertaking ecological footprint studies in many regions were to use within the community plan factors which can help to analyse potential scenarios to determine targets and predict footprint reductions; to assist in sustainable development and environmental strategy formation; to provide baseline data set from which future projects could be performed; to provide useful information to undertake public awareness and education campaigns; to use the ecological footprint as a key performance indicator etc. The footprint accounts also give government the ability to answer more specific questions about the distribution of these demands within their economy.

Thus the last part of the first research question is answered and it can be concluded that ecological footprint indicator will give a clear picture of where we are and where we need to be. Ecological examinations can give direction for local, national and global efforts to close the sustainability gap. Then they become an effective planning tool and a guide post for a more secure, equitable and sustainable future.

From the lessons learned from Chapter 2 and Chapter 3, the following chapter focuses on the application of the EFA to the study area - the Kochi city.

CHAPTER 4

ECOLOGICAL FOOTPRINT ANALYSIS OF THE STUDY AREA - KOCHI CITY

Highlighting the tool ecological footprint analysis, its need, applications and case studies from elsewhere in the world in the previous chapter, the second research question is dealt in this chapter. The chapter examines the scope of ecological footprint applications for the sustainability issues of the study area – the Kochi City, Kerala, South India. For this, the chapter overviews the study area in general, calculate its ecological footprint and analyses the significance of EFA of Kochi city.

4.1 OVERVIEW OF THE STUDY AREA

The study area – Kochi city (formerly known as Cochin), lies between $9^{\circ}48'$ and $10^{\circ}50'$ latitude and $76^{\circ}5'$ and $76^{\circ}58'$E longitude, Kerala, South India. It is the commercial capital of Kerala 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 /sq.km against a density of 819 persons/ sq. km in Kerala, 382 persons per sq. km in India and a world average of 46 persons/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.

Physical, social, political and economic factors have played their decisive role in the formation of land use pattern in Kochi city. Constraints of landforms and lagoon system contributed to the concentration of economic activities to the water front areas.

The temperature of the Kochi city varies between 20.6°C to 33.2°C. The average annual rainfall exceeds 3,000 mm (CoK, 2010). The city is a commercial centre and connected to all parts of the world, as it has one of the major sea port, busiest airport, well connected rail and road network.

The economy of the city can be categorized as a business economy with emphasis on the service sector. Major business sectors include construction, manufacturing, ship building, transportation/shipping, seafood and spices exports, chemical industries, information technology (IT), tourism, health services, and banking. A larger hi-tech business campus, the Smart City Special Economic Zone (SEZ), is expected start construction works. The state government has given priority to the establishment of IT and BPO enterprises to exploit the opportunities that have arisen in the field. These all will contribute to higher rate of urbanization. Figure 4.1 shows the location and a view of Kochi city.

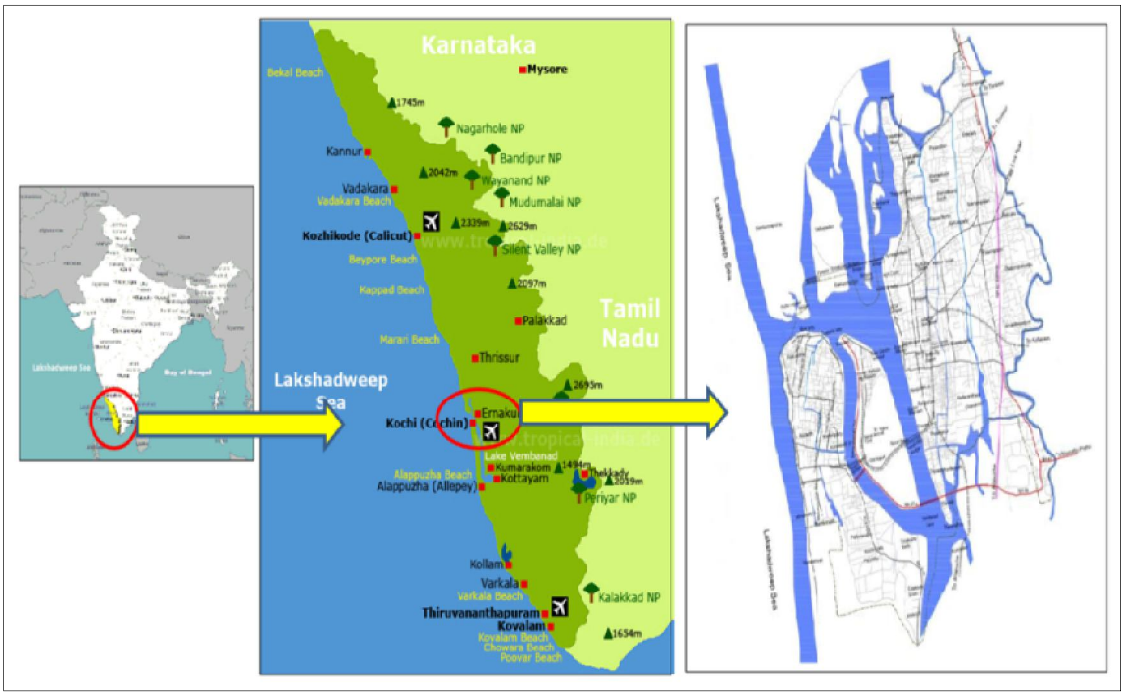

Fig. 4.1 Location of the Study Area – Kochi City
Source: CoK, 2010

The existing land use pattern has resulted from the complex interactions of varied factors in the urban structures. The characteristic feature of the central city is the predominance of the area under water. The water sheet consists of backwaters, rivers, canals, tanks and ponds and altogether it forms 23.4% of the green land of the city (CoK, 2010). The net dry land available for urban use amounts to 71.86% of the gross land i.e. 68.18 sq.km. Kochi is having a tropical climate with intense solar radiation and abundant precipitation. Figure 4.2 shows the land use profile of the city, which depicts that 78.04% of the city land falls under residential category and the next high share (9.99%) goes to traffic and transportation.

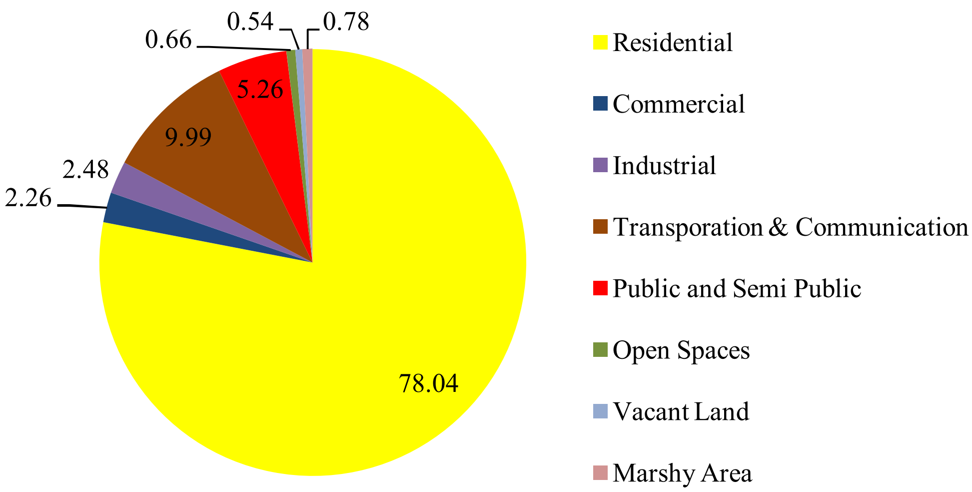

Fig 4.2 Land Use Breakup of Kochi City
Source: CoK, 2010

4.2 ECOLOGICAL FOOTPRINT OF KOCHI CITY

The ecological footprint analysis of Kochi city was calculated by Ravi (2007) using the global footprint calculator (GFC). Components for footprint calculation considered were food, mobility choices, shelter and goods and services. The study showed that the ecological footprint of Kochi city was 2.19 global hectares (gha) per person, which is much greater than the national average of 0.8 global hectares and exceeds the available biocapacity of the world (1.18 global hectares). This shows that the city is unsustainable in terms of consumption of natural resources and waste assimilation. Keeping this as the baseline study, the research focused the in depth study of EFA of the city. Thus EFA of the city is calculated by taking representative samples from the administrative wards within the Corporation boundary. The trend analysis of EFA was carried in three consecutive years, 2007 - 2009. Methodology and findings of the study is detailed in the following sections.

4.2.1 Selection of Sample and Technique of Survey

Ecological footprint study of Kochi city was carried out for components such as food, mobility, shelter and, goods and services. A questionnaire survey was carried out in representative random samples from the city population. The minimum sample size has been arrived using the equation given below

The sample size has been determined by the equation

$$N = \frac{z^2 P(1-P)}{d^2} \tag{4.1}$$

Where N – Minimum sample size required for the conduction of the survey

z – Z score which is 1.96 for 90% confidence interval

P – Prior judgement based on past surveys. Since no surveys have been conducted in the past P value is assumed as 0.5 (50%) since the standard error formula will be largest when P is 0.5.

d – margin of error which is taken as 5%

The N value equates to be 384 samples. Therefore 500 samples (houses) were taken for the survey.

Trend analysis was carried out by selecting representative samples from the samples considered for the base study (100 houses). The questions in the questionnaire were framed in such a way that they match the corresponding questions in the global footprint calculator.

The criteria for selection of sample for the study was based on the density of population (as per Census, 2001), concentration of high rise buildings and location. Administrative wards having density of population above 175 PPH (average density) were categorized as high density wards and others as low density wards. Wards were also categorized according to the concentration of high rise buildings (above and below the average number of high rise buildings) and based on their distance from the central business district (CBD) and major transportation nodes (MTN). Then the different combinations of these criteria were grouped and selected one ward from each combination. Table 4.1 shows the selection of wards from each combination selected for survey. For example, the third row of the table indicates the combination high density-more concentration of high rise buildings- location near to CBD & MTN. None of the administrative wards of the city comes under this combination.

Table 4.1 Selection of Wards for the Ecological Footprint Study of Kochi City

Density		High rise buildings concentration (Nos.)*		Location (w.r.t to CBD & MTN)		Administrative Ward No.	Ward Name
High	Low	>14	<14	Near	Away		
●		●		●		---	
●		●			●	---	
●			●	●		50	PanampillyNagar
●			●		●	7	Pandykudi
	●	●		●		58	Ernakulam North
	●	●			●	20	Mundamveli
	●		●	●		53	Thevara
	●		●		●	31	Ponnekara

*The figure 14 indicates the average number of high rise buildings in an administrative ward of Kochi Corporation in 2007 as per the Occupancy register of the Corporation.

Again, no administrative ward of the city comes under the combination 'high density-high concentration of high rise -location away from CBD& MTN (Row 4). The fifth row of the table shows the combination 'high density-low concentration of high rise -location near to CBD & MTN in which the administrative ward no. 50 (Panampilly Nagar) falls. Therefore the ward Panampilly Nagar in the city was selected for the study. Sixth row shows the combination 'high density-low concentration of high rise -location away from CBD& MTN in which the ward no. 7 falls. Likewise wards pertaining to other combinations were identified and selected for primary study. As per this, survey was carried out in six administrative wards in the Kochi Corporation namely Ward No. 7-Pandykudi, Ward No. 20 -Mundamveli, Ward No. 31-Ponnekara, Ward No. 50-Panampilly Nagar, Ward No. 53-Thevara and Ward No. 58-Ernakulam North (Table 4.1).

4.2.2 Calculation of Ecological Footprint of Kochi City

The ecological footprint of the Kochi City is calculated for four components (food, mobility, shelter and goods and services) in 500 houses selected at random from the six administrative wards of Kochi Corporation. To calculate the ecological footprint of the city population as a whole the following steps are taken.

1. Ecological footprint of all the four components for 500 houses in the six administrative wards of the city was calculated separately.
2. The average of the footprint values of each component in the houses of a ward was calculated as the average footprint value of the respective components of that ward.
3. Therefore ward wise, component wise footprint values were arrived for the city.

4. The ecological footprint value of the city for each component is taken as the average values of the respective components of the six administrative wards of the city. Thus the food footprint, mobility footprint, shelter footprint and goods and services footprint of the city is calculated.
5. And finally the total footprint of the city (EFA of Kochi city) is calculated as the sum of average of all the components of the footprint of all wards.

For example, the first house in the first ward is taken. The food footprint, mobility footprint, shelter footprint, goods and services footprint of the inhabitants of that house is calculated. Then the calculation is repeated for the selected number of houses in that ward. The average of the food footprint of the selected number of houses gives the food footprint of the first ward. Likewise the other components are also calculated. Similarly the calculation is carried out for all the six wards. Then the food footprint of the city is calculated as the average of the food foot print of all the six wards. By doing similar calculations for the other components, the shelter, mobility and goods & services footprint of the city is calculated. Then the ecological footprint of the city is calculated as the sum of the food footprint, shelter footprint, mobility footprint and goods & services footprint of the city.

Based on the footprint study of the city, carried out in three consecutive years (2007 to 2009), it was found that the average footprint (2.25) in the city area, in global hectares (gha), is much above the national average (0.8). The variation over the years is shown in Figure 4.3. The footprint values of the city are increasing from 2.19 in 2007 to 2.24 in 2008 and 2.35 in 2009. For all wards, as shown in Figure 4.4, the shelter footprint shows the maximum value of 1.21 gha followed by goods and services footprint (0.7 gha), food footprint (0.45 gha) and mobility footprint (0.26 gha).

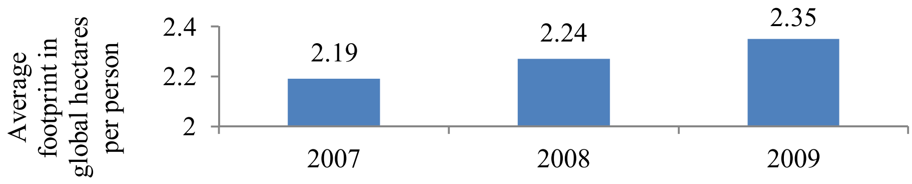

Fig. 4.3 Ecological Footprint of Kochi City in Three Consecutive Years (2007-2009)

On average, the shelter footprint constitutes about 46.37% of the footprint. Average house area usage is 400.45 sqft/person. This contributes to the high shelter footprint. Average shelter footprint for high rise building units were 0.21, for row housing units 0.57 and for independent units 0.77 to 1.21 gha. The low land area occupancy and the sharing of the built up area with more people, when compared to other units reduces the average shelter footprint of high rise buildings. The mobility footprint of the population in the wards near to the CBD and major transportation nodes is low because of their dependence on public transportation facilities when compared to the other wards. Average dependence on public transportation facilities in the city is about 36.4%. Improper waste disposal at the source (house) is contributing to high waste footprint, which in turn raises the goods and services footprint of the population.

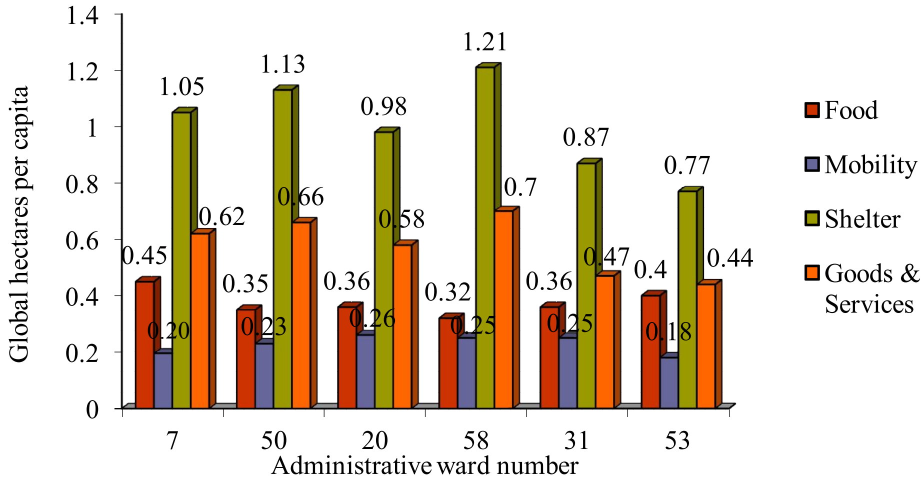

Fig. 4.4 Comparison of Footprint Components in Administrative Wards of Kochi City

The average footprint is highest in administrative ward no.58 (2.52 gha) because of the high shelter footprint (1.21 gha) because of high house area usage. The lowest ecological footprint is in ward no. 53 (1.79gha) (Figure 4.5). The reason can be attributed to the low house area usage in that ward.

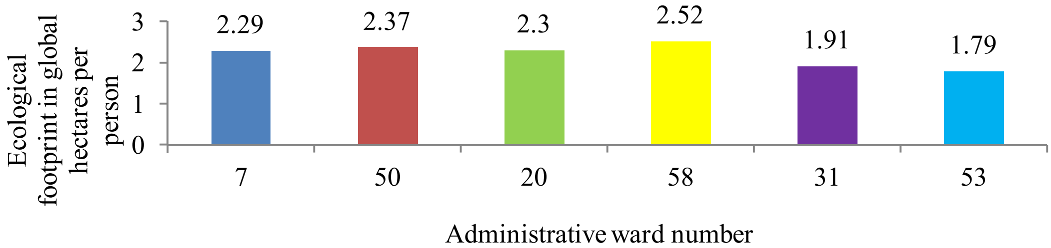

Fig. 4.5 Average Footprint in the Administrative Wards of Kochi City

The average male footprint (2.43) is greater than the female footprint (1.96) because the male mobility footprint is more than that of female. The analysis of family structure and footprint shows that the average footprint of nuclear family (2.42) is more than that of joint family (1.92). The high house area usage per person for nuclear family is the reason behind the high nuclear family footprint. The age and footprint comparison showed vague results. Families in the income group less than Rupees 5K (1K=Rs. 1000/-) showed low footprint values in most of the wards as shown in Figure 4.6.

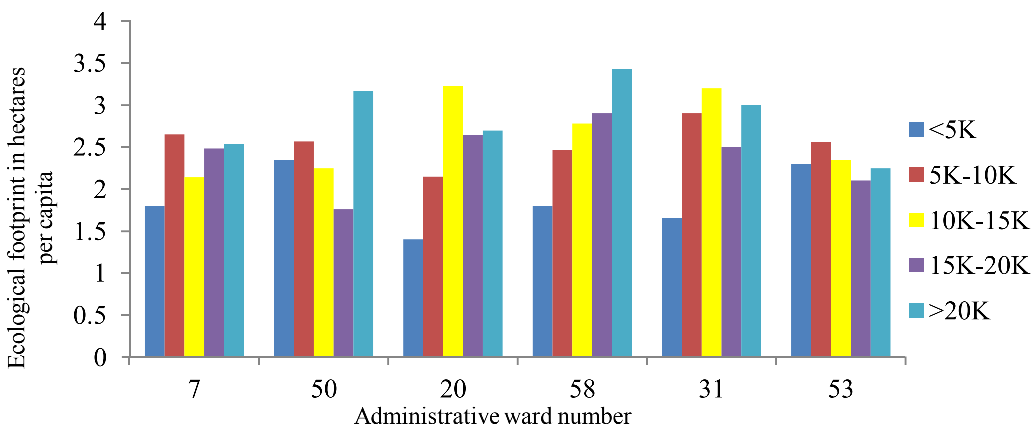

Fig. 4.6 Variation of Ecological Footprint with respect to Household Income in Administrative Wards of Kochi City

The low house area usage and dependence on public transport facilities and the low goods and services footprint are the factors identified for their low footprint values. The mobility footprint was directly proportional to the distance to the place of work or education in most of the wards (Figure 4.7). The usage of resources (fuel for travel and land area to absorb the CO_2 emitted) for high distance of travel may be reason behind.

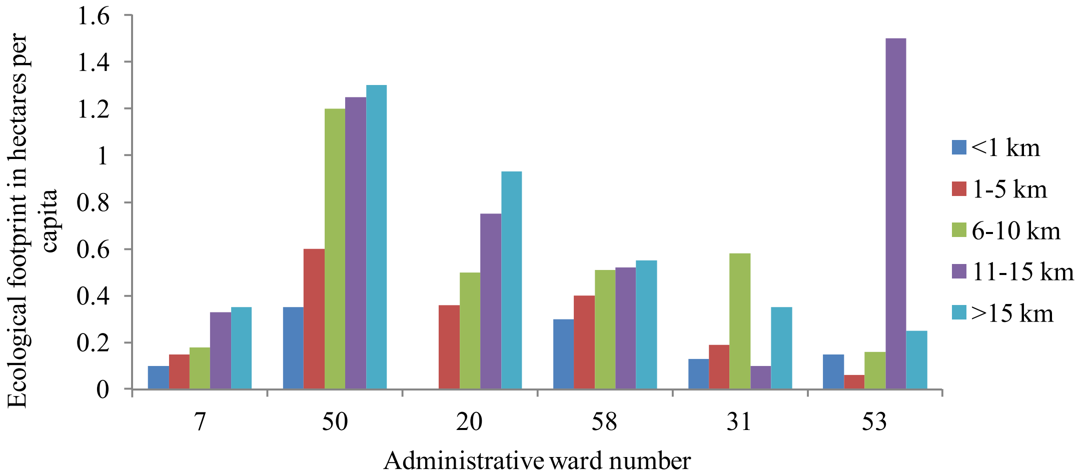

Fig. 4.7 Variation of Mobility Footprint with respect to Distance of Place of Work in Administrative Wards of Kochi City

Mobility footprint is maximum for 35-50 age groups keeping all other factors same, since they are the working group in the population. Increase in the mobility footprint increases the goods and services footprint also. The mobility footprint of females is only 32% of male mobility footprint. Variation in mobility footprint may be due to the factors such as 48-56% male working compared to 40-52% female working group; 17.4% of the male population conducts more than three hours air travel; only 17.4% of the males are depending on public transportation compared to 45% of the females and; dependence on motorbike is 2% for female compared to 26% of the males. The component wise break up over the years is shown in the Figure 4.8.

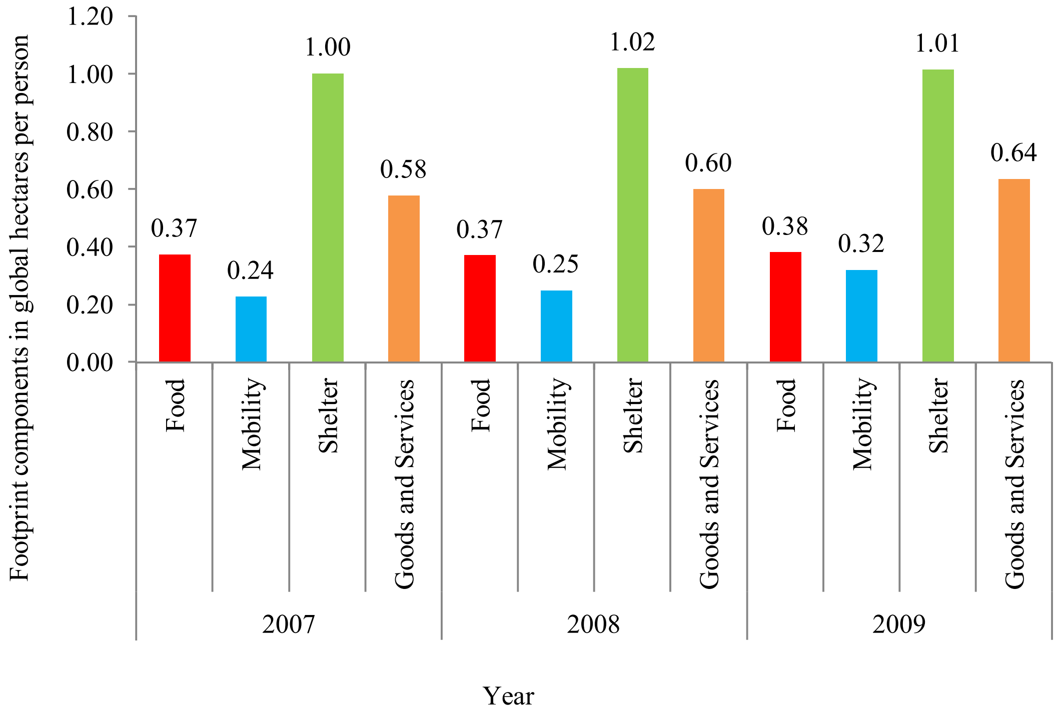

Fig. 4.8 Variation of Ecological Footprint Components (2007-2009)

The percentage variation in the footprint components over the years are given in Figure 4.9. The shelter and food footprint showed slight increase in values. Mobility footprint shows an increase of 4.17 percentage in 2008 to 33.33 percentage in 2009. The ecological footprint of the Kochi city was calculated by selecting 500 houses randomly from the six administrative wards of the city in 2007. In the year 2008 and 2009 the survey was repeated in 100 houses in order to do a trend analysis of the ecological footprint of the city from the already surveyed 500 houses (every 5th house). The mobility footprint in the selected 100 houses had parameters for high mobility footprint values in the year 2008. There were no special policy changes or other infrastructural developments in the city during the year 2008. Hence the high deviation in mobility footprint values may be attributed to the error in the randomly selected 100 houses. The goods and services footprint shows an increase of 3.45 percentage in 2008 to 10.34 percentage in 2009. Food footprint shows low increase when compared to mobility and goods and services footprint but shows an increase of

2.7% in 2009. Shelter footprint shows an increase of 2% in 2008 and remains the same.

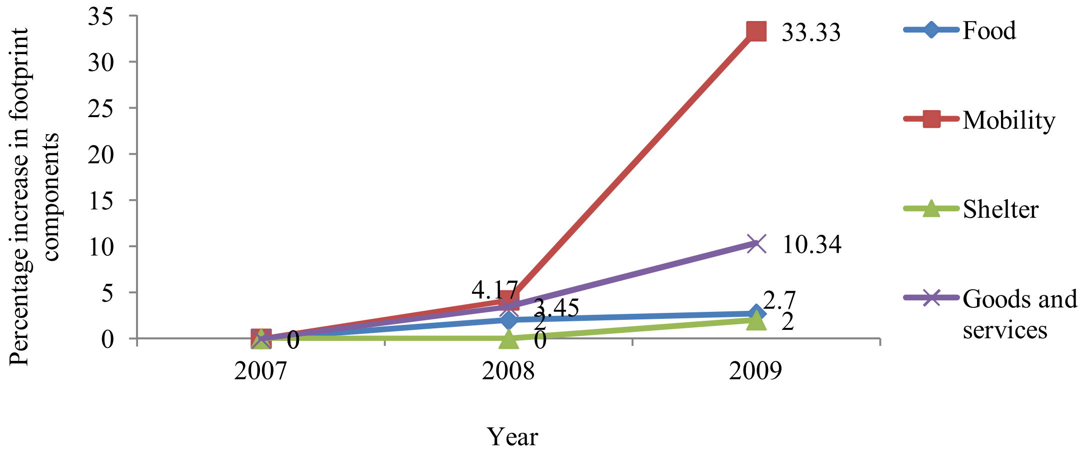

Fig. 4.9 Percentage Increase in Ecological Footprint Components over the Years (2007-2009)

The increased employment opportunities, easiness to purchase and hire vehicles and the less dependency on public transportation facilities are the factors identified for the annual increase in mobility footprint. The food habits of the residents remain more or less same as depicted in the food footprint values. But the wastage of food and over consumption is also observed during the study. The shelter footprint shows an increase in value due to the import of non-vernacular materials and less energy efficient materials. Also the building materials are transported through very large distances. The main factor reasoned for the hike in goods and services footprint is the amount of wastes generated in the residences.

4.3 SIGNIFICANCE OF THE ECOLOGICAL FOOTPRINT STUDY FOR KOCHI CITY

As mentioned earlier, the average footprint (2.25 gha) in the city area, in the three consecutive years (2007 – 2009) is above the national average (0.8), and also its consumption exceeds the available bio productive space per person in the world (1.8).

According to the global footprint calculator if everyone like this, we would need 1.3 PLANETS to sustain our life. Over the years the footprint values are seen increasing. The shelter footprint constitutes the maximum followed by goods and services footprint, food footprint and mobility footprint. The high house area usage is increasing the shelter footprint, and improper waste disposal at the source is increasing the goods and services footprint. The ecological footprint study in the city showed that populations which have animal based products in every meal have high food footprint compared to other areas. More dependence on public transportation facilities and carpooling within family and friends decreases the mobility footprint. Thus by quantifying the ecological footprint, we can formulate strategies to reduce the ecological footprint and there by having a sustainable living. The ecological footprint of waste generation provides per capita land requirements for waste generation. Therefore calculating the footprint for an area, the ecological footprint can be a tool for sustainable environmental management (Ravi and Subha, 2011, 2013).

This study through the Global Footprint Calculator (GFC) gave us an idea of Kochi's ecological footprint indicating the position of the city's sustainability. But to get accurate results, we must categorize each of the consumption items in the region and must convert these into footprint values. This requires a detailed study of the various consumption items specific to that region and their equivalent factors and yield factors. Countries who have developed their own footprint calculators own a checklist of their consumption items specific to their country. Again, regarding the GFC, it was observed that the calculator is covering each and every aspects of life in general. But certain parameters like plot area usage, waste disposal and recycling methods, water usage, fuel usage, energy consumption etc. which are very much relevant to Kerala were not considered as such.

Plot area is very significant in Kerala. Most of the houses, except some in highly urbanized area, have vacant spaces around the house. Since this can also be considered as a productive space and a space to assimilate our waste we generate, it shall also be included in footprint calculations. In the GFC, only the waste generation is considered. A variety of waste disposal and recycling methods are practiced in Kerala. So in order to get a more accurate waste footprint of the population, a detailed comparative footprint studies on the waste disposal and recycling methods shall be included in the calculator. Another important factor is vehicle ownership. The calculator gives our mobility footprint values based on our fuel consumption, distance travelled, and dependence on public and private vehicles. But nowadays, it is a trend that most of the houses own cars which they rarely use. The footprint of such vehicles will not come to the mobility footprint values. Therefore the mobility footprint calculations may be improved by adding vehicle ownership details and the type of fuel usage and distance travelled in the each of the vehicles.

A detailed equipment ownership and usage of the house is very relevant in goods and services footprint calculations. The water usage of the population is not directly considered in the calculator. This can be included in the goods and services footprint. Energy usage inside the house also has to be given more importance. Modifying the existing global footprint calculator by incorporating the above said parameters will enable footprint calculations more accurate in the state of Kerala, which can the scope for further studies.

4.4 SUGGESTIONS TO REDUCE THE ECOLOGICAL FOOTPRINT OF KOCHI CITY

From section 4.2 and 4.3 it is clear that the ecological footprint of Kochi city is highly unsustainable. Region specific calculators have not been developed for India. In order to develop region specific calculators, the equivalence factors and yield factors for footprint calculations have to be developed for the country. The main objective of the thesis is to study EFA of Kochi city. Hence specific suggestions were unable to suggest reducing the footprint of Kochi city, instead general suggestions were provided. Once the region specific calculations are developed, each of the factors can be examined in detail. Bond (2002) presented that the ecological footprint can be reduced by suitable steps to reduce food, shelter, goods and services and mobility footprint. Hence the following suggestions are put forward for reducing the EF of Kochi city.

4.4.1 Reduction of Food Footprint

The food footprint can be reduced by:

1 Reducing the food consumption by:

- Reducing household food waste by reducing the quantity of food purchases by encouraging local stores rather than large supermarkets.
- Conduct education campaigns to minimize the gap between current consumption and local production.

2 Change of food composition by:

- Promoting healthy eating habits and diet awareness
- Education of the public - raise awareness of the environmental impacts of different food products making people aware of the effects of their choices. Increase media awareness of positive food messages. Undertaking a comparative study of the footprint of what an average person eats for lunch.

Increase public awareness of local and regional food markets by providing information.

- Encourage retailers and processors to introduce labeling schemes for fresh and processed products showing food miles, country/countries of origin and the environmental impact of production and distribution.

3 Increasing the efficiency of food production by promoting research and development into energy and space saving agriculture options.

4 Improving the efficiency of food distribution and delivery(reducing the food miles) by:

- Encouraging purchase of locally produced and seasonally available food items
- Integrating urban agriculture into policies, forthcoming community strategies etc. Encourage people to grow their own food in gardens or allotments or support local food growing initiatives.

5 Reduce waste associated with food

4.4.2 Reduction of Goods and Services Footprint

Goods and services footprint may be reduced by the following:

1 Reducing demand and shift demand for goods and services by

- Restricting use of disposable goods
- Economic incentives in the form of transferring taxes away from labour and onto the use of resources. Tax products on the basis of their embodied energy.
- Increase purchaser awareness by formulating policies to promote recycled/low footprint goods. A reduced VAT on all products containing a high recycled content to encourage use.
- Increase consumer awareness by labeling products that shows the ecological footprint value of the product.

2 Prolonging the life span of products by:

- Reusing materials which can be promoted by introducing a recycling department for the state. Exchange or donate unwanted office equipment, furniture and other materials rather than disposal to land fill, awareness creation can be carried out through media. Sponsor organized markets of second hand goods. Establish informal exchange centres at civic amenity sites and other suitable locations within the city.

- Promoting services and schemes that extend the life of goods purchased by encouraging the use of hire and lease schemes that result in more efficient use of products by consumers. Provide support for refurbishment, recycling and repair services and shops through promotion, funding and or tax incentives.
- Provide information on longevity of products at point of purchase
- Develop markets for used materials

3 Distribution: purchase goods that are sourced and manufactured locally.

4 Reduction of waste by pricing people on the basis of volume of waste and on the basis of frequency of collection of waste

5 Reuse of waste by means of reuse and recycling centres which enable reuse and recycling of waste materials disposed of at these sites through the resale of reusable items.

6 Recovery, recycling, re-engineering and composting of waste materials

- Household waste - Introduce a kerbside collection scheme for recyclables from all homes in the city, supported by a network of recycling centres for residents to drop off' recyclable materials. Invest in R& D to identify new uses for waste products (for e.g. clothing from PET plastic etc.) and through market intervention to reduce the prices of recycled products. Home and community composting may be promoted through the provision of biogas plants at low cost or with subsidies
- Construction waste - Segregate and reuse/ recycle all wastes by type on construction sites.

4.4.3 Reduction of Shelter Footprint

Shelter footprint can be reduced by:

1 Reducing house area usage by

- Increasing density of residential living by promoting vertical growth as there is unavailability of land due to high land cost.

- Apply building regulations on house area usage and house occupancy rate.
- Give tax reduction/incentives to joint families. Impose tax to residents based on their shelter footprint.

2 Reduce energy demand of housing by:

- Increasing energy efficiency standards for new housing
- Awareness raising - include energy efficiency rating in the sale of domestic properties. Undertake an awareness campaign that links climate change and household energy use, stressing the importance of action in households.
- Increase use of renewable energy sources

4.4.4 Reduction of Mobility Footprint

1 Infrastructure/urban design/planning - promote high density mixed use developments, promote and deliver through the planning system the concept of all major centers of education, retail, employment and health being located near to transport exchanges.

2 Facilitate a mode shift by promoting public transport, disincentives for car travel, promoting fuel efficient vehicles, encouraging use of electric cars, motorbikes etc., promoting walking and cycling. Raise the awareness of travelling public; promote health benefits of walking and cycling.

4.5 SUMMARY OF THE CHAPTER

The chapter gives an overview of the study area Kochi city, briefly describing its history of development, topography, land use, demography and socio-economic profile of the city. This highlights that Kochi, the commercial hub of Kerala is having a heritage, cultural and economic significance in the map of India. The economy of Kerala overlooks to the future of Kochi. Therefore the research focused on the application of the environmental impact assessment tool ecological footprint analysis

(EFA) to Kochi city through the Global Footprint Calculator (GFC). The study showed that, the residential areas of Kochi city are highly unsustainable with high shelter footprint (1.02 gha) followed by goods and services footprint (0.64 gha), food footprint (0.38 gha) and mobility footprint (0.32 gha). If everyone in the world live likes an average Kochi resident, we would need 1.3 planets to sustain our life.

Even though the shelter footprint stands the highest, it remains almost the same over the years (2007 to 2009). This can be attributed to the nature of one time investment in house construction of the residents. Food footprint also showed slight increase during the study period which may be due to increase in food consumption and waste generation. But the goods and services footprint and mobility footprint is found to be increasing steadily.

The high house area usage is shooting the shelter footprint whereas the improper waste disposal is causing high goods and services footprint. The study also showed that the shelter footprint for high rise building units is low compared to other types of housing units (row housing, low rise buildings and buildings in individual plots). The food footprint of the population which depend on animal based products also showed high values when compared to other products. The study also showed that the mobility footprint of the population which depend on public transportation facilities is low compared to others.

In order to reduce the EF of Kochi city, suggestions were provided to reduce the various footprint components of the city. In addition, the analysis of the global footprint calculator, pointed out modifications required to the calculator by incorporating parameters such as plot area usage, waste disposal and recycling methods, water usage, fuel usage, energy consumption etc. which are very much relevant to Kerala, to get more accurate results. These were not considered as such in the existing calculator.

Again, it is clear that a detailed monitoring of the house area usage, waste disposal, food and mobility habits of the residents is required for the sustainable well-being of the residents of the city. Government of Kerala has implemented many programmes to improve the housing situation in Kerala. This in turn helps in reducing the shelter footprint of the city.

The improper waste disposal at the source (residential units) especially the solid waste is increasing the value of goods and services footprint. If this problem is kept unattended, it will become a major threat to city, which affects the health of the inhabitants, economic development and serene nature of the city. Hence the second phase of the research focuses in the solid waste management issues in the city.

CHAPTER 5
SOLID WASTE MANAGEMENT ISSUES IN KOCHI CITY

Identifying the major sustainability issues of the Kochi city in the previous chapter, this chapter looks into the second major issue (solid waste management) of the city. The research examines whether ecological footprint analysis, through the waste footprint (a subset of the ecological footprint) concept can be used to solve the waste management issues in the city (first part of the third research question). For this, solid waste management issues in India, Kerala State and Kochi city is studied in detail. In addition, the concept of waste foot print and the methodology for calculating the waste footprint are also detailed in this chapter.

5.1 SOLID WASTE MANAGEMENT – AN OVERVIEW

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). 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. 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. 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).

The various solid waste management options practiced in and around the world are reuse, recycling, composting, on-site burial, landfill disposal, open burning, incineration, rendering, alkaline hydrolysis, digestion methods, autoclaving, bioremediation etc. These waste management options can assist in planning and can inform waste management decisions suitable for a location (White et al., 1995). Current thinking on the best methods to deal with waste is centered on a broadly accepted hierarchy of waste management (Figure 5.1), which gives a priority listing of the waste management options available (CPHEEO, 2014).

The hierarchy usually adopted is (a) waste minimization/reduction at source (b) recycling (c) waste processing (with recovery of resources i.e. materials (products) and energy) (d) waste transformation (without recovery of resources) and (e) disposal on land (land filling). The highest rank of the waste management hierarchy is waste minimization or reduction at source, which involves reducing the amount (and/or toxicity) of the wastes produced. This is followed by recycling which helps to reduce the demand on resources and the amount of waste requiring disposal by land filling. The third one is waste processing which involves alteration of wastes to recover conversion products (e.g., compost) and energy. Land filling is the last in the hierarchy and involves the controlled disposal of wastes on or in the earth's mantle. It is the most common method of ultimate disposal for waste residuals.

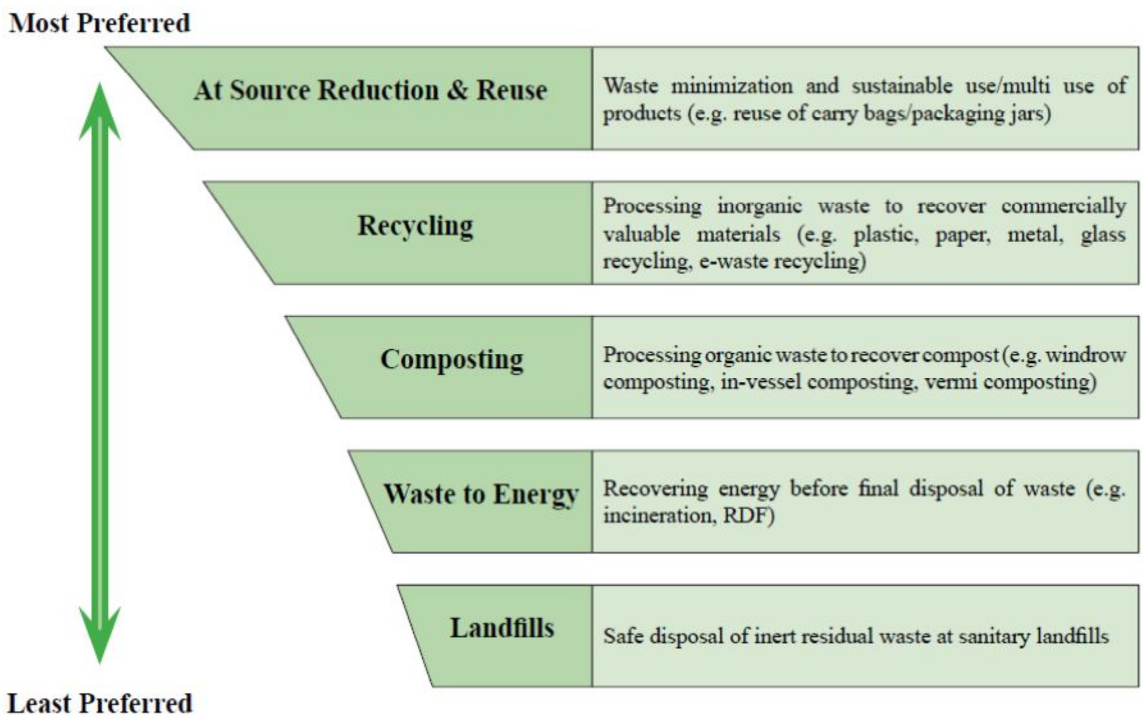

Fig. 5.1 Waste Management Hierarchy

Source: CPHEEO, 2014

Following this hierarchy rigidly will not always lead to the greatest reduction in the overall environmental impacts of a given system. Equally, its use also will not necessarily lead to economically sustainable systems. A danger exists that the hierarchy will become accepted as dogma; that reuse will always be seen to be better than recycling, for example, yet if heavy bottles have to be transported long distances to be refilled, reuse may opt to be preferable over recycling on either environmental or economic grounds. It is important to note that the hierarchy of waste management is only a guideline. Hence an integrated waste management system (ISWM) with prompt environmental assessment and cost efficiency must be done for each region under study.

ISWM is the application of suitable techniques, technologies and management programs covering all types of solid wastes from all sources to achieve the twin objectives of (a) waste reduction and (b) effective management of waste still produced after waste reduction. An effective waste management system includes one or more of the following options: waste collection and transportation; resource recovery through sorting and recycling i.e. recovery of materials (such as paper, glass, metals) etc. through separation; resource recovery through waste processing i.e. recovery of materials (such as compost) or recovery of energy through biological, thermal or other processes; waste transformation (without recovery of resources) i.e. reduction of volume, toxicity or other physical/chemical properties of waste to make it suitable for final disposal; disposal on land i.e. environmentally safe and sustainable disposal in landfills.

5.2 MUNICIPAL SOLID WASTE MANAGEMENT IN INDIA

In India, according to the Ministry of Environment and Forests 'municipal solid waste' includes commercial and residential wastes generated in municipal or notified areas in either solid or semi-solid form excluding industrial hazardous wastes but including treated bio-medical wastes (MoEF, 2000). Municipal Solid Waste Management (MSWM) in India falls under the public health and sanitation and hence as per the Indian Constitution is a state responsibility. In most Indian cities, the MSWM system comprises only four activities, i.e., waste generation, collection, transportation, and disposal.

The quantity of MSW generated depends on a number of factors such as food habits, standard of living, degree of commercial activities and seasons (Rajendra et al., 2012). Data on quantity variation and generation are useful in planning for collection and disposal systems. Indian cities generate eight times more MSW than they did in 1947 because of increasing urbanization and changing life styles (Sharholy et al., 2008). The rate of increase of MSW generated per capita is estimated as 1 to 1.33% annually (Pappu et al., 2007; Bhinde and Shekdar, 1998).

As compared to the western countries, MSW differs greatly with regard to the composition and hazardous nature, in India (Gupta et al., 1998; Shannigrahi et al., 1997; Jalan and Srivastava, 1995). MSW contains compostable organic matter (fruit and vegetable peels, food waste), recyclables (paper, plastic, glass, metals, etc.), toxic substances (paints, pesticides, used batteries, medicines), and soiled waste (blood stained cotton, sanitary napkins, disposable syringes) (Jha et al., 2008; Reddy and Galab, 1998). MSW composition at generation sources and collection points, determined on a wet weight basis, consists mainly of a large organic fraction (40–60%), ash and fine earth (30–40%), paper (3–6%) and plastic, glass and metals (each less than 1%). The C/N ratio ranges between 20 and 30, and the lower calorific value ranges between 800 and 1000 kcal/kg (Sharholy et al., 2008). Changes in the average composition of municipal solid waste for 1971-2005 have been shown in Figure 5.2 (Zurburgg, 2002).

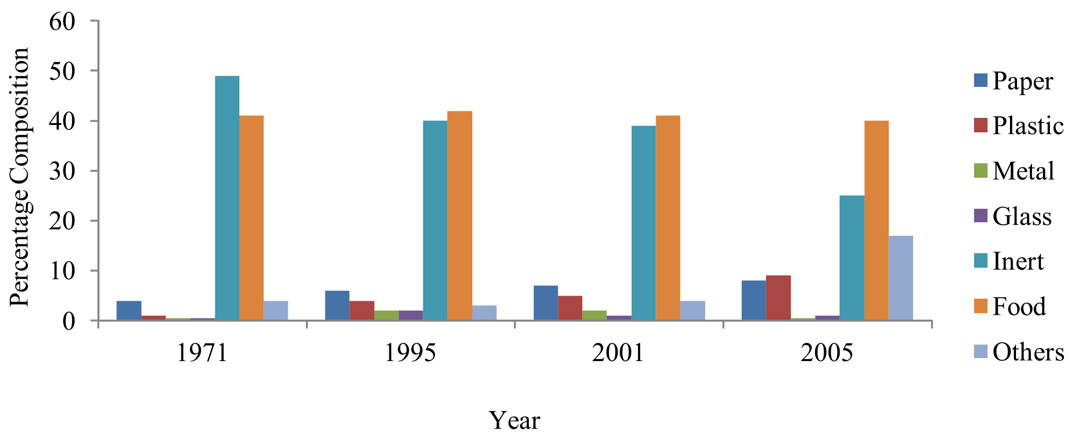

Fig. 5.2 MSW Compositional Changes in India (1971-2005)
Source: Zurburgg, 2002

Figure shows that MSW components like paper, plastic, glass are having the increasing trend from 4.1%, 0.7% and 0.4% respectively in 1971 to 8.18%, 9.22% and 1.01 respectively in 2005, metals are also having the increasing trend during the same period while inert materials and compostable matter are having the decreasing trend from 49.2% and 41.3% respectively in 1971 to 25.16% and 40% in 2005.

Poor collection, segregation and inadequate transportation cause the accumulation of MSW at every nook and corner. The management of MSW is going through a critical phase, due to the unavailability of suitable facilities to treat and dispose of the larger amounts of MSW generated daily in metropolitan cities. Adverse impact on all components of the environment and human health occurs due to unscientific disposal of MSW (Gupta et al., 2007; Rathi, 2006; Ray et al., 2005; Sharholy et al., 2005; Jha et al., 2003). The MSW amount is expected to increase significantly in the near future as India strives to attain an industrialized nation status by the year 2020 (Sharma and Shah, 2005; CPCB, 2004).

In India, most of the urban areas are lacking in MSW storage at the source, significantly. For both decomposable and non-decomposable waste common bins are used to collect the waste without any segregation, and disposed of at a community disposal centre (Nema, 2004; Malviya et al., 2002). Collection of MSW is the responsibility of corporations/municipalities. In most of the cities the predominant system of collection (through the communal bins) at various points along the roads, and sometimes this leads to the creation of unauthorized open collection points. House-to-house collection is practising in many megacities such as Delhi, Mumbai, Bangalore, Madras and Hyderabad with the help of Non Governmental Organisations and welfare associations. The average collection efficiency for MSW in Indian cities and states is about 72%, which shows that the collection efficiency is high in the states, where private contractors and NGOs are employed for the collection and transportation of MSW. Most of the states are unable to provide waste collection services to all cities (Rathi, 2006; Gupta et al., 1998; Nema, 2004; Maudgal, 1995; Khan, 1994). In low-income states MSW collection and disposal services are very poor (Rajendra et al., 2012). The Central Pollution Control Board (CPCB) has found that manual collection comprises 50%, while collection using trucks comprises only 49% (CPCB, 2000) in a survey of 299 class-I cities in India. The various disposal methods adopted in India has been shown in Figure 5.3 (Kaushal et al., 2012). For the years 2001 and 2005, waste dumps or open burning continued to be the principal method of waste disposal. These methods cause several accidents and are continuous source of emission of harmful gases and highly toxic liquid leachate.

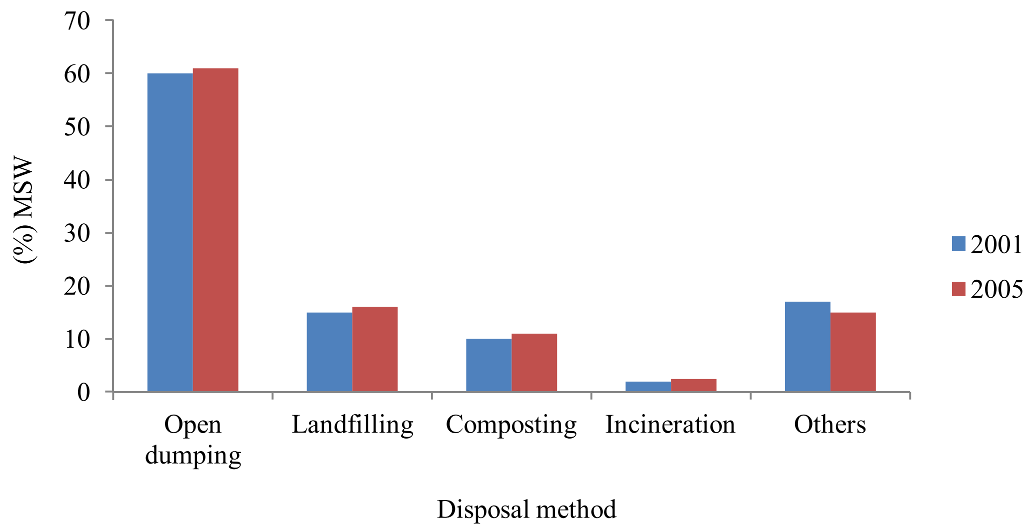

Fig. 5.3 Municipal Solid Waste Disposal Trends in India
Source: Kaushal et al., 2012

5.3 SOLID WASTE MANAGEMENT IN KERALA STATE

The Central Pollution Control Board (CPCB) had conducted a survey of solid waste management in two hundred and ninety nine cities and has given the data of waste generation for different cities (Table 5.1). Table shows that the state of Kerala with a low municipal population compared to others, generate 1220 Tonnes/day of municipal waste which accounts for a percapita generation of 0.393 kg/day.

Table 5.1 Status of Municipal Solid Waste Generation in the States of India

Name of the State	No. of cities	Municipal population	Municipal solid waste (t/day)	Per capita Generated (kg/day)
Andhra Pradesh	32	10,845,907	3943	0.364
Assam	4	878,310	196	0.223
Bihar	17	5,278,361	1479	0.280
Gujarat	21	8,443,962	3805	0.451
Haryana	12	2,254,353	623	0.276
Himachal	1	82,054	35	0.427
Karnataka	21	8,283,498	3118	0.376
Kerala	**146**	**3107358**	**1220**	**0.393**
Madhya Pradesh	23	7225833	2286	0.316
Maharashtra	27	22727186	8589	0.378
Manipur	1	198535	40	0.201
Meghalaya	1	223366	35	0.157
Mizoram	1	155240	46	0.296
Orissa	7	1766021	646	0.366
Punjab	10	3209903	1001	0.312
Rajasthan	14	4979301	1768	0.355
Tamil Nadu	25	10745773	5021	0.467
Tripura	1	157358	33	0.210
Uttar Pradesh	41	14480479	5515	0.381
West Bengal	23	13943445	4475	0.321
Chandigarh	1	504094	200	0.397
Delhi	1	8419084	4000	0.475
Pondicherry	1	203065	60	0.295

Source: Rajendra et al., 2012

According to the report by the Centre for Research in Medical Entomology, Madurai, Kerala is the first state ever where all the districts were affected by dengue fever for three consecutive years. The reasons are attributed to the unclear solid waste reservoirs (Dhanalakshmi, 2011). The waste attracts flies, which spread diseases like typhoid, ineffective hepatitis and diarrhoea. The other breeding grounds for the vectors are identified as the contaminated water ways, stagnant water, open drainage etc.

There has been significant importance given to implement the Municipal Solid Waste (Management & Handling) Rule, 2000 which envisages segregated storage of waste at source, collection from source, protected transportation to the treatment facility, establishment of environmentally safe treatment system and its operation and maintenance and safe disposal of inert rejects. A sectoral status study on MSW management in Kerala, undertaken with the support of WSP- South Asia in 2007, indicated that the total MSW generation in the state is about 8300 tpd. These studies indicated that 70-80% of the total waste generated is biodegradable in nature and these putrescible wastes needs to be managed within 24 hours. 13% of the waste is generated by the five City Corporations, 23% by the 53 Municipalities and the rest by the 999 Gram Panchayats.

As per the SEUF reports (2006), Figure 5.4 and 5.5 gives the major sources and composition of solid waste in Kerala.

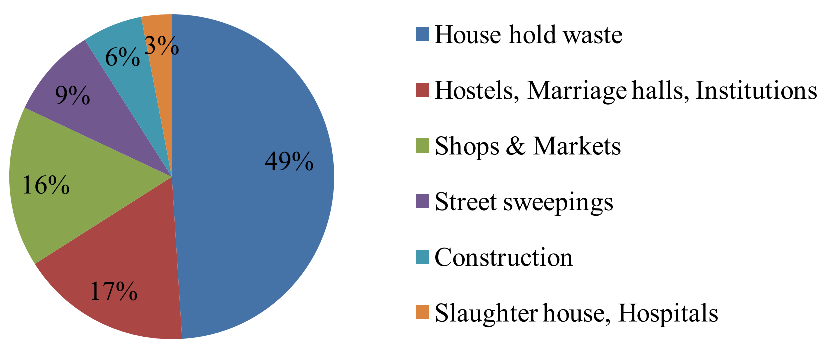

Fig. 5.4 Sources of Solid Waste Generation in Kerala
Source: SEUF, 2006

The figures shows that 49% of the solid waste in Kerala is the household waste, 17% comes from hostels, marriage halls and institutions, 16% from shops and markets, 9% from street sweeping, 6% from construction sites and 3% from slaughter house and hospitals.

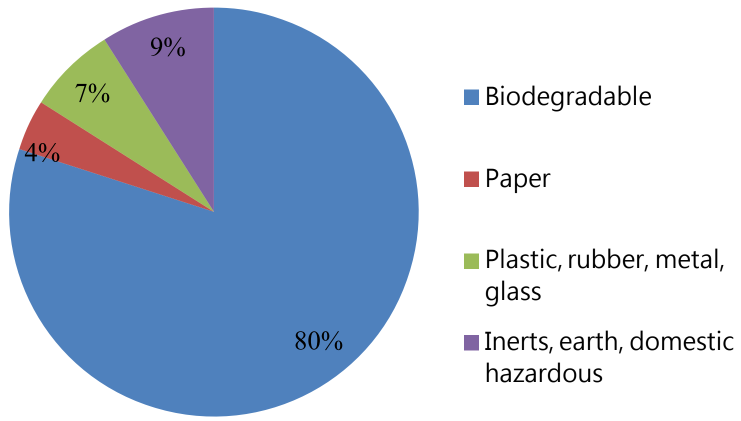

Fig. 5.5 Composition of Solid Waste Generated in Kerala
Source: SEUF, 2006

The Figure shows that biodegradable wastes constitutes about 80% of the waste stream followed by inerts (9%), plastic, rubber, metal and glass(7%) and paper (4%).

Supreme Court of India had directed all the local governments in India which has population strength of above ten lakhs need to set up proper facilities for processing waste generated within their limits. And again Supreme Court wanted waste management facilities to be in place in such municipalities by December 2003. But, a majority of the municipalities in India could not successfully implement this Supreme Court directive, even till now. Whereas Kerala is one of the few states in the country that took some measures to address this issue by launching an initiative called Clean Kerala Mission. The mission was launched in 2002. Objective of the mission was to create a garbage free Kerala. It was given a task of capacity building within local government institutions (LGIs) and enabling and preparing them taking up the challenge of implementing solid waste management projects. There were efforts to achieve this goal with the participation of NGOs, community organizations such as Kudumbashree across Kerala. The first phase of the project was implemented in five corporations and twenty six municipalities with the participation of Women Self-Help-Groups and `Kudumbashree'. In the second phase of the `Clean Kerala Mission' another twenty seven cities and twenty five villages were included.

Some success stories of the mission are described here

i. *Success Stories No.1: Solid waste management in Mangalapady village panchayat in Kasaragode district*

The Clean Kerala Mission assisted Mangalapady village panchayat in establishing a waste processing plant using vermi composting and biomethanation. As the plant had sufficient capacity, adjoining two panchayats joined with Mangalapady. These panchayats transported their waste to the processing plant in Mangalapady paying as fees of Rs.0.70 per kg. In return they get 25% of the organic manure generated by the waste supplied by them. Another innovation is the management of the plant is given as contract to Kasaragod Social Service Society, a local Non Governmental Organisation.

ii. *Success Stories No.2: Decentralized solid waste management in Chunakkara village panchayat in Alappuzha district*

Chunakkara is a backward village panchayat of Alappuzha district with 14 administrative wards covering 5411 households within an area of 17.32 km^2. Management of solid waste emerged as a major problem with waste piling up in all public places inviting the protest of the public. The water bodies got polluted and the canals became clogged. At this juncture, when the village panchayat was desperately searching for solutions, the Socio Economic Unit Foundation (SEUF), a leading NGO in the sanitation sector entered into a partnership with the village panchayat and decided to promote decentralized waste management with focus on the household through a process of intensive awareness building and community education. A trained resource group called the Programme Support Group (PSG) was setup. The expert members interacted with the community and convinced them about the issues related to waste management. The PSG and the village panchayat focused on localities within administrative wards. Each ward was divided into six to seven localities and from each locality two members were identified and a ward level committee was constituted, headed by the elected member from the ward. By drawing three members from each ward committee a panchayat level committee was also set up. These popular committees played an important role in mobilizing the public and converting their enthusiasm into action. Now Chunakkara has become a model for decentralized waste management in rural areas. Out of the 5411 households, 4980 have started vermi composting in the compound and the manure is used to feed the kitchen gardens which have been set up in all the houses. All schools have been motivated to segregate, store and process waste in situ. A community level vermi compost plant has been set up to deal with market waste.

iii. Success Stories No.3: Decentralized solid waste management in Alappuzha municipality.

Alappuzha municipality having 50 administrative wards and 32,203 households is spread over 47 km^2. With only about 50% of the 65 to 75 tonnes of waste generated every day being transported to the dumping yard in the adjacent panchayat, the remaining waste spilled over into the beautiful ancient Venice like canal system of the town converting it into one of the most insanitary towns in the state. Here again the Municipal Council and SEUF got into a partnership and initiated an action research programme called 'Women, Wellbeing, Work, Waste and Sanitation' (4 W-S). After a small pilot, six wards were identified covering 5624 households. The baseline survey indicated that only 10% of the households segregate their waste; 58% of the households burned their waste, while 16% threw them into their backyards and 15% resorted to dumping them in public places. Thus the challenge was quantified. Technical committees and popular committees were set up and the strategy of participatory social engineering was employed. The elements of the programme included the reduction at source, segregation at source, collection and sale of recyclables, household level processing of organic waste, substitution of plastic bags with cloth and paper bags and community policing to prevent people from violating the code of clean surrounding. In a short span of time, 3350 households started vermi-composting. In 35 places common vermi-compost units were set up. Nearly 2000 families started organic farming in their compounds. Three paper bag units have been started along with two plant nurseries. Through public action, 8 kms of canals and 12 ponds have been cleaned and rejuvenated.

iv. Success Stories No.4: Introduction of door to door collection in Kozhikode Corporation

Kozhikode city faced public protests and conflicts over the overburdened dumping site, as waste of all kinds reached the end point, totally unsegregated. It decided to outsource door to door collection to the Kudumbashree network of women below poverty line. Seventy five micro enterprise groups were set up with each group having ten members. They were trained and provided a total subsidy of Rs.90 lakh and bank finance of Rs.187 lakh which was utilized for purchase of auto-rickshaws and other equipment. To motivate the households two bins one white and the other green were given to each household for keeping the waste segregated. A user charge ranging from Rs.15/- to Rs.30/- per household per month was fixed, which is affordable to all households.

v. Success Stories No.5: Zero waste campaign at Kovalam

The zero waste campaign at Kovalam intervened and mobilized the people for finding out local solutions through 'Thanal'- a local NGO. After a preliminary study, discussions were held with different local groups and it was decided to whole heartedly ensure that garbage will not remain scattered in public places. The campaign decided to sustain this and create economic incentives for the waste generators as well as those involved in solving the problem. The main components of the project were biogas plant for biodegradable waste, s resource recovery centre for non-biodegradable discards, material substitution programme promoting products made of paper, jute, cloth and coconut shell, poison free farming, water conservation and community capacity building.

Despite several initiatives such as Clean Kerala Mission, solid waste management is a serious issue in almost all local bodies of Kerala. Lack of effective waste management system in the state is causing havoc to normal public life. Resorting to dumping the waste generated is also a serious matter since such insanitary methods of disposal of solid wastes would cause a serious health concerns. Part of the waste generated remains unattended and grows in the heaps at poorly maintained collection centres. The choice of a disposal site also is more a matter of what is available than what is suitable. In several places locals protest against prevalent practice of dumping and landfill.

5.4 SOLID WASTE MANAGEMENT IN KOCHI CITY

Out of the Kochi city region, which constitutes an area of 366.91sq.km. and produces about 670 tons of solid waste per day, the contribution of Kochi Corporation to the Kochi city region alone is nearly 300T (CoK, 2010). As per the solid waste generation studies (KSUDP, 2007) the physical composition of municipal solid waste in Kochi city is shown in Table 5.2. Table shows that organic wastes contribute to the maximum followed by paper and plastic wastes. The composition of metal waste is comparatively low.

Table 5.2 Physical Composition of Municipal Solid Waste in Kochi City

Type of municipal solid waste	Percentage of municipal solid waste
Paper	4.87
Plastic	4.83
Metal	0.35
Glass	1.06
Rubber & Leather	1.50
Inerts	1.74
Ash and fine earth	1.68
Compostable organics	**79.78**
Domestic hazard	0.28
Others	3.91
Total	100

Source: KSUDP, 2007

Figure 5.6 shows that, the solid waste in Kochi city is generated from a variety of sources, ranging from households, to commercial establishments, public and institutional areas (CoK, 2010).

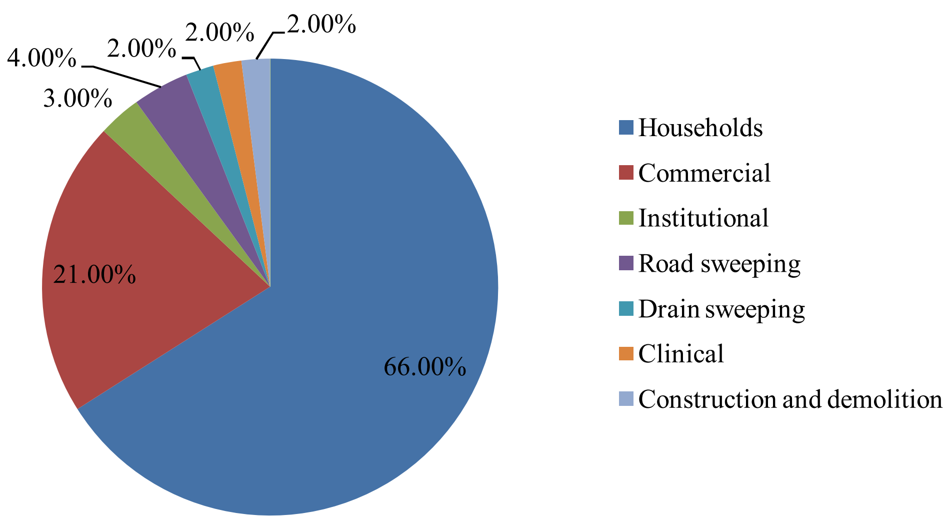

Fig. 5.6 Generating Sources of Solid Waste in Kochi City
Source: CoK, 2010

Figure also shows that, 66% of the wastes are generated by the households, 21% by the commercial establishments, 4 % by road sweeping, 3 % by institutions, and 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. Table 5.3 gives the chemical composition of Kochi city's solid waste.

Table 5.3 Chemical Composition of Kochi City's Solid Waste Stream

Chemical property	Value
Density	267.81 kg/m^3
Moisture content	55.29%
Calorific value	1759 k cal/kg
pH	7.46
C	26.39%
N	1.25%
C/n	21.11%
P as P_2O_5	129.25%
Ar	5.72 mg/kg
Ni	4.49 ppm
Cd	0.38ppm
Pb	2.48 ppm
Cu	475.53 ppm
Zn	98.98 ppm
Hg	< 0.1 mg.kg

Source: KSUDP, 2007

The chemical composition of the municipal solid waste shows the presence of harmful chemicals beyond the safe limits. This shows the harmful effect on the environment of the city and nearby areas. Table also indicates high moisture content, low calorific value and high nutrient content making the dominant organic fraction of waste more conducive for recycling in the form of manure. One of the notable features of the chemical characteristics of waste is the high content of heavy metals. It indicates that dumping of waste will lead to metallic pollution of land, especially if the waste is subjected to putrefaction.

As per Dhanalakshmi (2011), the solid waste generation in the Kochi Corporation is 255 tonnes and the ward wise waste generation in the corporation area is as shown in Figure 5.7.

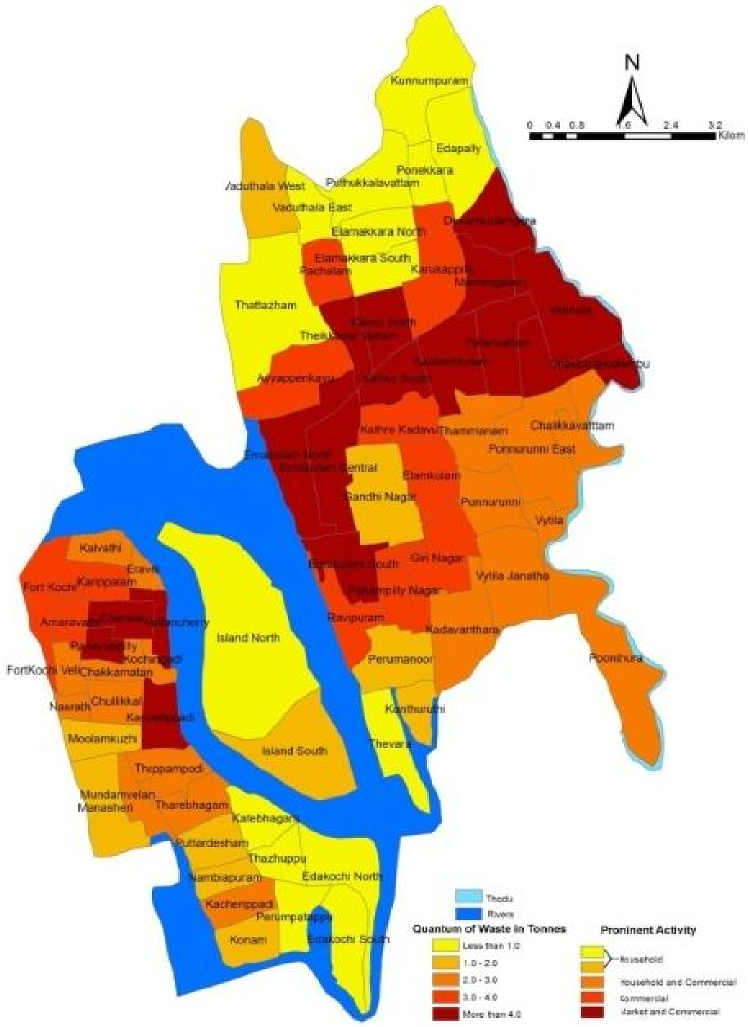

Fig. 5.7 Ward Wise Waste Generation in Kochi Corporation
Source: Dhanalakshmi, 2011

Vaduthala, Gandhi Nagar, Perummanoor, Island south, Puttardesham, Nambiapuram, Konam, Manasheri, Moolamkuzhi generated around 1.0 – 2.0 tonnes of waste per day. Kunnumpuram, Ponekkara, Puthukkalavattom, Elamakkara North, Thattazham, Island North, Thevara, Edakochi, Thazhuppu and Katebhagam wards generate less than 1.0 tonne of waste per day (Dhanalakshmi, 2011). The study also showed that the residential waste contributed the maximum waste generation of 2.0 Tonnes/day/ward in Kochi Corporation. It may be the due to the household with higher income living in the city centre generates more waste when compared to other income groups.

Health Department (HD) of the Kochi Corporation (CoK) is responsible for sanitation facilities, solid waste management and other public health functions (CoK, 2010). A Corporation Health Officer (CHO), a medical doctor, heads the HD. The collection, transportation, disposal of MSW is the responsibility of the health department while the engineering department assists them in planning, formulation of programs and in procurement of vehicles, equipment and developing the landfill site.

For the purpose of solid waste management, the entire municipal corporation is divided into 21 circles. Each circle comprises 1 to 5 wards and is managed by a Health Inspector who is assisted by Junior Health Inspectors. Deployment of vehicles for transportation is managed by the vehicle section headed by a senior HI. This section is also responsible for direct collection of waste from hotels and hospitals in eastern zone of the city.

The corporation has only 1155 employees employed for the purpose of collecting and moving the quantity of 250 tonnes of solid waste produced by 6 lakhs plus population living in Cochin City. Thus the ratio of waste collector to the population would be approximately 1:516, which is very low. Even among these 1155 employees, some, especially women, are employed solely for the purpose of sweeping city roads. This means that, each employee has to collect and remove solid waste roughly about 220-250 kg/day. Also the collection of waste is carried out by workers belonging to different groups like self-help groups under the banner of Kudumbashree, resident welfare associations and Kerala Builders Forum (KBF), rotary club, NGOs, etc. The study by Dhanalakshmi (2011) also highlights that the percentage deficit of manpower is 38.17 % in Kochi city and there is deficiency in the number of vehicles.

The CoK has provided 2 coloured bins, a green one with a 15-litre capacity, for biodegradable waste, and a white one with a 10-litre capacity, for dry waste to all households. The secondary collection and transportation of the waste is done by CoK. Kochi has undertaken two initiatives to facilitate solid waste collection and poverty alleviation, called 'Confederation of Real Estate Developers' Associations of India (CREDAI) Clean City Movement' and 'The Don Bosco Initiatives'. There is a solid waste pricing, which is 2% of the property tax and is collected along with the property tax. There are also user charges that are collected at the rate of Rs.30/- per household and Rs.50/- per commercial establishment. The present door to door (DtD) collection from each household ranges from Rs.40/- to Rs.60/- per month. For commercial establishments it would be in the range of Rs.60/- to Rs.80/- per month. The corporation staffs picks up waste only from road sides and community bins. Thus, there is no responsible system installed for the purpose of door-to-door waste collection. In the event of any household failing to segregate the waste, the task of segregating the waste falls upon the door-to-door waste collectors.

Records reveal that out of the 198 kms of public roads to be swept and cleaned each day, the corporation succeeds in covering only up to 115 kms a day. This means that roughly about 42% of the city roads are not cleaned each day, which creates serious back logs of work each day. Also, this would mean that most city roads are cleaned only on alternate days, and may be, on a much larger time gap (Justin, 2010).

Basically two important types of vehicles are used for transfer and transportation of wastes. All vehicles have well defined routes and schedules. The major problem faced by the local body is the narrow lanes and congested living. The high density of living, waste generation and its disposal pose a threat to health and hygiene in the concerned areas. The waste uncleared that remains for days generates disease causing vectors and pathogens and bad odour. Another problem associated with transportation of waste by vehicles is that the waste remains exposed during the transportation to landfills and so dry waste often gets splits on both sides of the road when wind blows. In addition, light vehicles are also used to unload the waste collected from different sources in transfer stations. There are about twenty one transfer stations in Kochi city.

The solid waste from the secondary collection points is transported to the Brahmapuram site (37.3 acre) which has a solid waste treatment plant, at a distance of approximately 20 km from the city centre. The site has the capacity to process 200 tonnes of mixed waste via mechanical composting and 50 tonnes of organic waste via vermicomposting daily.

The health department has a grievance redressal system which accepts complaints from the aggrieved and acts upon it. The aggrieved can give a complaint directly to the health inspectors of their locality or to the central circle office. Also, the grievance redressal system has a toll-free number for accepting complaints from the aggrieved. But this is not used effectively (Justin, 2010). Majority of the residents of Kochi are unaware of such a facility which leads to under-usage of the facility.

According to the existing provisions, if a person is found guilty of indiscriminate waste dumping on public places, a notice can be served upon him by the concerned Health Inspector. The Corporation Secretary is then informed about the serving of such notice. Upon receiving such information, the Corporation Secretary imposes a fine upon the guilty, which may range from Rs.250/- to Rs.1000/- depending on the gravity of the offence. But this remains merely as an official document which is not being implemented effectively.

Therefore, 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.

Thus, it is crystal clear that, the improper solid waste management in the city is the root cause of many problems like pollution, outbreak of diseases, nuisance and other urban problems in the city. Also the organic waste from residential areas constitutes the lion's 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. Hence urgent care is to be taken in the solid waste management issues in the city.

This brings the importance of waste footprint studies in the city, for the analysis of solid waste management issues in the city. Since the residential waste constitutes the major share of the municipal solid waste, the research focuses the footprint studies to waste management issues in the residential areas of Kochi city.

5.5 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. 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.

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 having the notion that, the government is the authority to dispose whatever waste people are generating. This is very pathetic situation. Only the generators can manage waste. Though there are campaigns and awareness programmes to reduce the waste generation and source reduction, it is very hard to maintain the enthusiasm after the campaigns. In these circumstances, we have to think of an alternative which is to be enforced by laws or encouragement in terms of rewards to reduce the amount of waste generation. A system, which gives the waste impact on earth quantified, just as we take the current bill, water bill etc. and an amount to be paid based on this quantity, should be imagined. Or, on the other hand the waste generators which are causing low impact should be rewarded or appreciated. There should be clear cut limit for this quantified value based on the locality we live in and its biocapacity to assimilate the waste. Waste foot printing is one such tool, which can meet these goals to some extent. Therefore the concept which is a subset of ecological footprint is studied in detail in the following sections.

5.5.1 Waste Footprint – Definition

Ecological footprint of waste generation or waste foot print 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 authority 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).

5.5.2 Methodology for Calculating the Waste Footprint

In calculating the ecological footprint of waste generation or waste footprint, methodology to assess the household waste footprint developed by Wackernagel et al. (2006) is used, who is the author of the ecological footprint concept. In the methodology, only three land use categories considered for waste assimilation was used. These include energy land, forest land and built up land. The biologically productive land required for this waste assimilation is calculated by the equations 5.1 – 5.10.

i. Biologically productive land required for paper

$$\begin{aligned}\text{Energy land} = {} & \text{World energy yield} \times \text{Energy intensity of paper} \\ & \times (\text{Amount of per capita waste per year}/\text{Waste factor of paper}) \\ & \times (1 - \%\ \text{recycling of paper} \\ & \times \%\ \text{of energy saved from recycling}) \qquad (5.1)\end{aligned}$$

where,

- The energy yield (assumed to be average fossil fuel = liquid fossil fuel) is 73000 Mj /10000 m^2-year.
- Energy intensity of paper is 35 Mj/kg.
- Waste factor is the percentage of paper consumed.

$$\begin{aligned}\text{Forest land} = {} & \text{World energy yield of round wood} \\ & \times \text{Ratio of round wood needed per unit of paper} \\ & \times (\text{Amount of per capita waste per year}/\text{Waste factor of paper}) \\ & \times (1 - \%\ \text{recycling of paper} \\ & \times \%\ \text{of energy saved from recycling}) \qquad (5.2)\end{aligned}$$

where,

- World average yield of round wood is 10000/2.6 m^3/hectare.
- Ratio of round wood needed per unit paper is 1.65/1000.
- Waste factor is the percentage of paper consumed.

$$\begin{aligned}\text{Builtup land} = {} & \text{Energy land required for paper waste} \\ & \times \text{Builtup land footprint component of waste} \\ & \div (\text{World average fossil fuel area of goods} \\ & + \text{World average fossil fuel area of waste}) \\ & \div \text{Primarybiomass equivalence factor for builtup area} \qquad (5.3)\end{aligned}$$

where,

- Energy land required for paper waste get from equation no. (5.1)
- Built up land footprint component of waste is 1100m^2.
- World average fossil fuel area of goods is 1324 hectare.
- World average fossil fuel area of waste is 1196 hectare.
- Primary biomass equivalence factor for built up area is 3.5

ii. Biologically productive land required for plastic

$$\begin{aligned}\text{Energy land} = {} & \text{World energy yield} \times \text{Energy intensity of plastic} \\ & \times \text{Per capita amount of plastic waste per year} \\ & \times (1 - \%\ \text{recycling of plastic waste} \\ & \times \%\ \text{of energy saved from recycling of plastic waste}) \end{aligned} \tag{5.4}$$

where,

- The energy yield (assumed to be average fuel = liquid fossil fuel) is 73000 Mj/ 10000 m^2 year.
- Energy intensity of plastic is 50 Mj/kg

$$\begin{aligned}\text{Built up land} = {} & \text{Energy land required for plastic waste} \\ & \times \text{Built up land footprint component of waste} \\ & \div (\text{World average fossil fuel area of goods} \\ & + \text{World average fossil fuel area of waste}) \\ & \div \text{Primary biomass equivalence factor for built up area} \end{aligned} \tag{5.5}$$

where,

- Energy land required for plastic waste get from equation no. (5.4)
- Built up land footprint component of waste is 1100 m^2.
- World average fossil fuel area of goods is 1324 hectare.
- World average fossil fuel area of waste is 1196 hectare.
- Primary biomass equivalence factor for built up area is 3.5

iii. Biologically productive land required for glass

$$\begin{aligned}\text{Energy land} = {} & \text{World energy yield} \times \text{Energy intensity of glass} \\ & \times \text{Amount of per capita glass waste per year} \\ & \times (1 - \%\ \text{recycling of glass waste} \\ & \times \%\ \text{of energy saved from recycling}) \end{aligned} \tag{5.6}$$

where,

- The energy yield (assumed to be average fossil fuel = liquid fossil fuel) is 73000 Mj/10000 m^2 year.
- Energy intensity of glass is 15 Mj/kg

$$\begin{aligned}\text{Built up land} = {} & \text{Energy land required for glass waste} \\ & \times \text{Built up land footprint component of waste} \\ & \div (\text{World average fossil fuel area of goods} \\ & + \text{World average fossil fuel area of waste}) \\ & \div \text{Primary biomass equivalence factor for built up area} \qquad (5.7)\end{aligned}$$

where,

- Energy land required for glass waste get from equation no.(5.6)
- Built up land footprint component of waste is $1100 m^2$.
- World average fossil fuel area of goods is 1324 hectare.
- World average fossil fuel area of waste is 1196 hectare.
- Primary biomass equivalence factor for built up area is 3.5

iv. Biologically productive land required for metal

$$\begin{aligned}\text{Energy land} = {} & \text{World energy yield} \times \text{Energy intensity of metal} \\ & \times \text{Amount of per capita metal waste per year} \\ & \times (1 - \%\ \text{recycling of metal waste} \\ & \times \%\ \text{of energy saved from recycling}) \qquad (5.8)\end{aligned}$$

where,

- The energy yield (assumed to be average fuel = liquid fossil fuel) is 73000 Mj/10000 m^2 year.
- Energy intensity of metal is 60 Mj/kg

$$\begin{aligned}\text{Builtup land} = {} & \text{Energy land required for metal waste} \\ & \times \text{Built up land footprint component of waste} \\ & \div (\text{World average fossil fuel area of goods} \\ & + \text{World average fossil fuel area of waste}) \\ & \div \text{Primary biomass equivalence factor for built up area} \qquad (5.9)\end{aligned}$$

where,

- Energy land required for metal waste get from equation no. (5.8)
- Built up land footprint component of waste is $1100 m^2$.
- World average fossil fuel area of goods is 1324 hectare.
- World average fossil fuel area of waste is 1196 hectare.
- Primary biomass equivalence factor for built up area is 3.5

v. **Biologically productive land required for organic waste (food)**

$$\text{Energy land} = \text{World energy yield} \times \text{Energy intensity of organic waste} \times \text{Amount of per capita waste per year} \times (1 - \%\ \text{recycling of organic waste} \times \text{Energy saved from recycling}) \quad (5.10)$$

where,

- The energy yield (assumed to be average fossil fuel = liquid fossil fuel) is 73000 Mj / 10000 m^2-year.
- Energy intensity of organic waste is 30 Mj/kg

The amount of recycling of organic waste is equal to the amount of composting. Energy saved from the recycling of organic waste is determined by the following way (Salequzzaman, 2006).

- Calculating the amount of biogas from the organic waste.
- Calculating the energy production from that biogas.
- Calculating the percentage of energy getting from organic waste.

i) Biogas production

The amount of biogas (X) generated from total areas is calculated from the relation:

$$X(m^3) = \text{Raw material (solid waste, kg)} \times \text{TSC(Total solid content)} \times \text{Gas generation rate per unit of solid} \left(\frac{m^3}{kg}\right) \quad (5.11)$$

ii) Energy production: The expected amount of energy from biogas in total areas is

$$E(kJ) = X(m^3) \times \%\ \text{of methane} \times \text{Lower heating value} \left(\frac{kJ}{m^3}\right) \quad (5.12)$$

3) Percentage of energy saved from organic waste

$$\text{Built up land} = \text{Energy land required for organic waste} \times \text{Built up land footprint component of waste} \div (\text{World average fossil fuel area of goods} + \text{World average fossil fuel area of waste}) \div \text{Primary biomass equivalence factor for built up area} \quad (5.13)$$

where,

- Energy land required for organic waste get from equation no. (5.10)
- Built up land footprint component of waste is 1100 m^2
- World average fossil fuel area of goods is 1324 hectare.
- World average fossil fuel area of waste is 1196 hectare.
- Primary biomass equivalence factor for built up area is 3.5

vi. Obtaining the total footprint for waste generation

The sum of the total land required for different waste categories is the biologically productive land required for waste assimilation, which means the ecological footprint of waste generation or waste footprint. Based on these 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.

5.6 SUMMARY OF THE CHAPTER

The chapter gives a brief idea on the need for solid waste management, the options in solid waste management and their hierarchy, integrated solid waste management and modelling of solid waste management. The descriptions in this regard highlighted that, solid waste management is a multi-dimensional issue. The chapter also analysed the solid waste management status and issues in India, Kerala state and Kochi city through available literature. The literature showed that, in India some of the future challenges for the management of solid waste are increasing quantities and changing composition, increasing severity of adverse impacts, increasing cost of waste management, limited policy framework and lack of political priority. The Kerala experiences in solid waste management showed many examples:- village panchayats can set up common facilities and share the costs as well as the benefits (solid waste management in Mangalapady village panchayat in Kasaragod district), a model of panchayat – professional – people partnership (decentralized solid waste management in Chunakkara village panchayat in Alappuzha district), an example of community based solid waste management in an urban situation (decentralized solid waste management in Alappuzha municipality), an example of a socially beneficial outsourcing to a community based organization of poor women (introduction of door to door collection in Kozhikode corporation) and an example of citizen demand leading to constructive action (zero waste campaign at Kovalam, an international tourist centre). The Alappuzha experiment has shown that through social engineering involving committed professionals and elected leaders, even in an urban setting, community behaviour can be changed for the better solutions of waste management. Coming to Kochi situation, the chapter analysed that, Kochi Corporation is generating the major share of solid waste (300 T) in Ernakulam district. Of this, the compostable organic wastes which are generated from the residential areas contribute the maximum waste generation in Kochi Corporation, followed by paper, plastic, metal, glass etc. The study also pointed out the waste management issues in the city detailing the various components of waste management in the Kochi Corporation. The study reveals that there exists inadequacy in solid waste management process of Kochi city from the organisation level to the disposal stage, which is to be attended urgently with utmost care.

In addition, the study also showed that the residential areas of the city are contributing the major share of the municipal waste stream. *Hence the study focuses to the solid waste management in the residential areas of Kochi city.*

The chapter also showed that, the concept of waste footprint (subset of ecological footprint) can convert the waste generated into an equivalent land area required to assimilate it, thereby making the common man aware of their local capacity to assimilate the waste, the effect of their waste generation and its impact on earth. With this, the next chapter examines, whether the concept of waste footprint can be applied to solve the solid waste management issues of the city by calculating the waste footprint of the residential areas of Kochi city, which focus the second part of the third research question.

CHAPTER 6
WASTE FOOTPRINT OF KOCHI CITY

The previous chapter analysed that, the solid waste management problem is found to be the root cause for many other problems like water logging, mosquito threat, environmental pollution etc. in the city and also it affects the serene nature of the city. Since, the residential wastes constitute the major share of the city's municipal waste stream; this chapter focuses the second part of the third research question i.e. to study the waste management issues in the residential areas of the city using the waste footprint concept, which is one of the indicators of ecological footprint analysis. Based on the equations of waste footprint detailed in the previous chapter, software named the waste footprint analyser was developed to calculate the waste footprint of Kochi city. A visual image display of waste footprint analyser is briefed in this chapter. The chapter also gives a general analysis of the waste footprint of the city, followed by a detailed statistical analysis and discussions in the forth coming chapters.

6.1 WASTE FOOTPRINT OF KOCHI CITY

From the previous chapter, it is crystal clear that solid waste management problem is one of the major problems in Kochi city. Again Table 5.2 of Chapter 5 clearly highlights that, the compostable organic waste generated from residential areas contributes the maximum in the city. 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 maintain the heritage city, a quantitative approach for waste management is to be applied for the city. 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 our location 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 on earth due to the waste generation. Keeping this as the core objective, this chapter analyses the waste footprint of the residential areas in Kochi city in general and the statistical analysis of the waste footprint values are explained in Chapter 7.

For calculating the waste foot print of the city, representative samples were selected in and around the city. A questionnaire was given to the selected households to collect details regarding house, households and the waste generation. In calculating the ecological footprint for household waste generation, the equations for waste footprint of paper, plastic, glass, metal and food waste which was detailed in the previous chapter was used. Using these equations, software in a visual basic platform was developed for the data entry and calculations, and the footprint values are estimated. The software is named the waste footprint analyser and is explained in Section 6.3. The analyser generates the footprint value in hectares per capita. The general analysis of the waste footprint values is given in Section 6.4.

6.2 DETAILS OF THE SURVEY CONDUCTED FOR WASTE FOOTPRINT CALCULATIONS

To study the waste footprint of the city, representative random samples of households were selected from the residential areas of the Kochi Corporation and outskirts. Five hundred samples were selected based on the following criteria:

- density of population (high and low)

- location (away / near of Central Business District (CBD) & Major Transportation Nodes (MTN))
- mode of waste disposal (household level or community level)
- type of housing unit (individual plots, low rise, row housing units & high rise buildings)
- ownership of the building (individuals, government, builders)

Samples were identified from low and high density areas within the corporation boundary and outskirts. Also residential samples away/near the CBD/MTN were also categorised and selected for survey. The modes of waste disposal in residences were taken into account for selecting the samples. Samples living in individual plots, in low rise buildings, row housing units and high rise buildings were also considered in survey, in order to assess the footprint variations. The ownership of the buildings was also a criterion taken into account for selecting the samples for survey.

The survey was conducted in three seasons namely dry season (April 2010 and December 2010-January 2011), wet season (July 2010) and festival season (August 2010). These three seasons were selected to study and analyse the seasonal variations in the footprint values in the city. The survey was carried out 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 analyse 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 with a participatory research (Pretty and Ward, 2001). 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 selected houses from already surveyed houses, in three consecutive years 2011 to 2013 based on their 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.

6.3 WASTE FOOTPRINT ANALYSER FOR WASTE FOOTPRINT CALCULATIONS

6.3.1 Waste Footprint Analyser - Program

The program of the waste footprint analyser is appended in Appendix 1.

6.3.2 Visual Display of the Waste Footprint Analyser

Waste footprint analyser, is a program developed based on the equations of ecological footprint of waste generation as explained in the previous chapter. The analyser is used for inputting the survey data and estimating the footprint values, in a visual basic platform. The analyser generated the footprint value in hectares per capita. Figure 6.1 gives a display of the analyser. The 500 samples' questionnaires in three different seasons were entered and the programme is executed to get the waste foot print of the residents of the city. 1500 datasets were created on this account for waste footprint calculations. The analyser displayed the waste footprint in hectare per capita. The analyser communicates mainly through 3 windows which are shown in Figure 6.1.

Window 1 and Window 2 are data input windows and Window 3 is execution cum output window. Window 1 has 10 sub windows which feeds the socio economic characteristics of the household under survey. The entries regarding season, ward number, house number, location, population density, household size, household income/month, mode of waste disposal, housing unit type and ownership details can be entered through these sub windows.

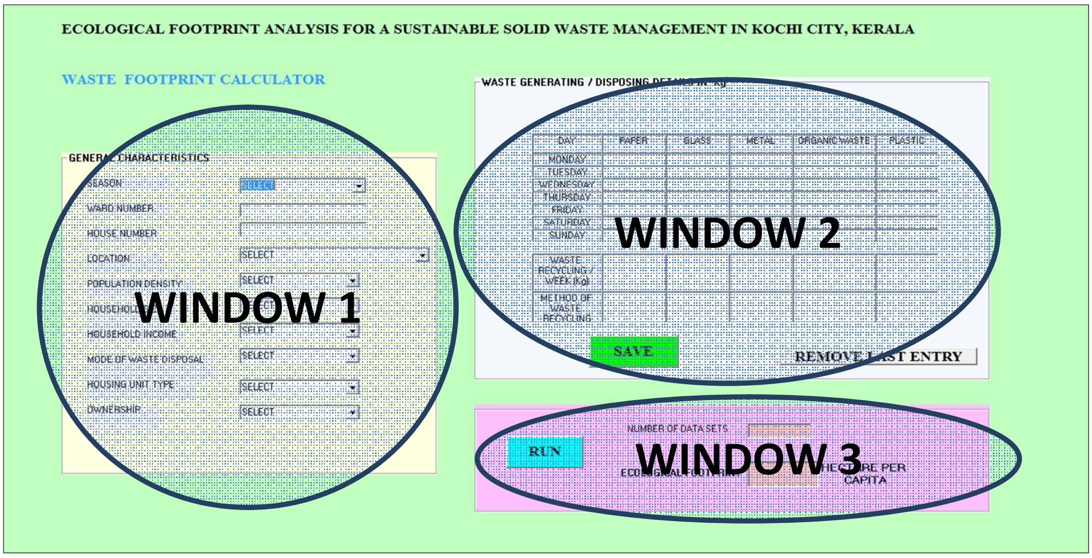

Fig. 6.1 Windows/Components of Waste Footprint Analyser

The description of these sub windows can be seen in the following figures. The sub window 1 as shown in Figure 6.2 will help the enumerator to select the season in which the survey is performed. This include dry, wet and festival season.

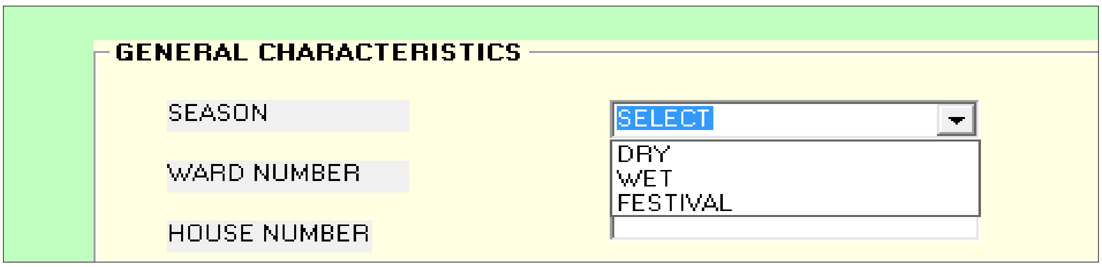

Fig. 6.2 Waste Footprint Analyser - Sub Window 1(Season)

The sub window 2 and 3 shown in Figure 6.3 will input the ward number and the house number of the household surveyed.

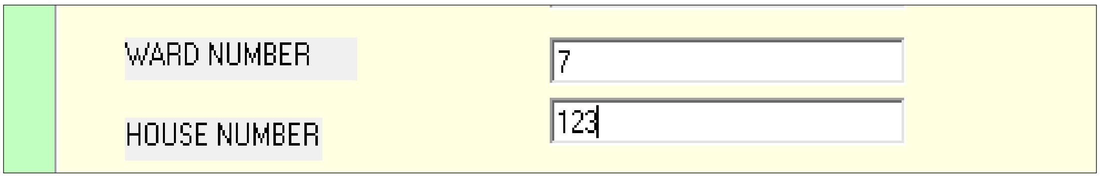

Fig. 6.3 Waste Footprint Analyser - Sub Window 2 and 3 (Ward Number and House Number)

In sub window 4 (Figure 6.4) the enumerator can decide and select whether the house surveyed is in an area near to the CBD/MTN or away from CBD/MTN.

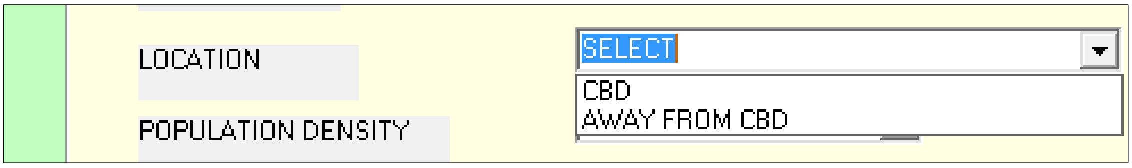

Fig. 6.4 Waste Footprint Analyser - Sub Window 4 (Location)

In sub window 5 shown in Figure 6.5, the enumerator can decide and select whether the house surveyed is in an area of high density or low density. The density mapping of the city area have been done and based on the ward number the enumerator who is engaged in collecting sample can select whether it is a high density area or low density area.

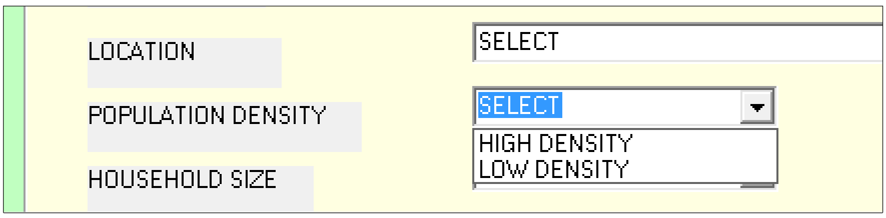

Fig. 6.5 Waste Footprint Analyser - Sub window 5 (Population Density)

Through the sub window 6 (see Figure 6.6) household size of the sample is selected. The household size is classified from 1 to 8 and above 8.

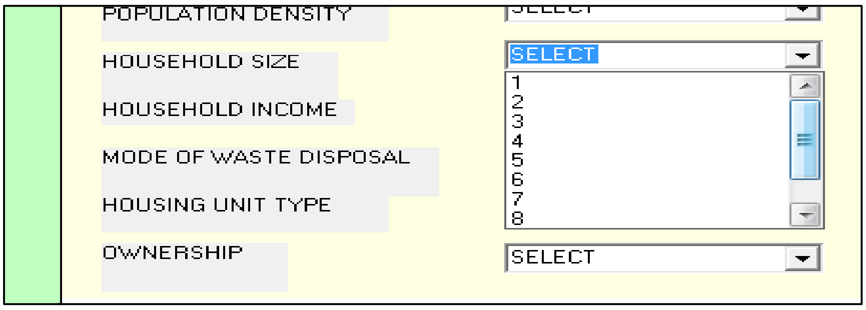

Fig. 6.6 Waste Footprint Analyser - Sub Window 6 (Household Size)

The household income per month can be entered in sub window 7 which is shown in Figure 6.7. Here one can select the household income in different ranges like less than Rs.5K, Rs.5K to Rs.10K, Rs.10K to Rs.15K, Rs.15K to Rs.20K and above Rs.20K (1K = Rs. 1000/-).

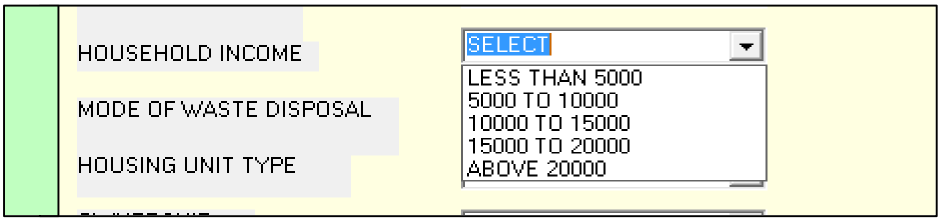

Fig. 6.7 Waste Footprint Analyser - Sub Window 7 (Household Income/Month)

Figure 6.8 shows the sub window 8, where the mode of waste disposal i.e. household level or community level can be entered. Sub windows 9 and 10 show the housing unit type and ownership details. These are shown in Figure 6.9 and Figure 6.10 respectively. The enumerator can select the housing unit type and the ownership details of the house in these windows.

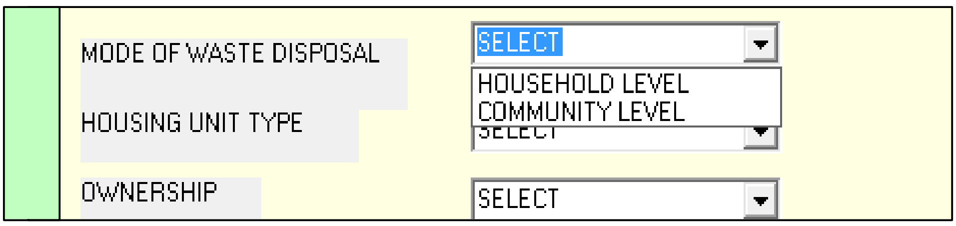

Fig. 6.8 Waste Footprint Analyser - Sub Window 8 (Mode of Waste Disposal)

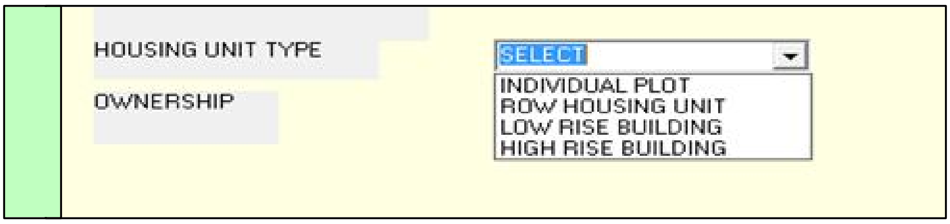

Fig. 6.9 Waste Footprint Analyser - Sub Window 9 (Type of Housing Unit)

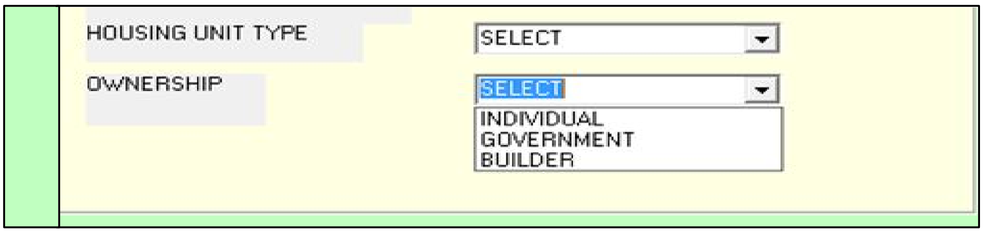

Fig. 6.10 Waste Footprint Analyser - Sub Window 10 (Ownership Details)

Window 2 deals with the waste generation characteristics of the household. This also has 2 sub windows, sub window 11 and 12, save button and remove last entry button. In sub window 11, one can enter the daily waste generation in kilogram and sub window 12 enters the amount of recycling and the method of recycling, if in action. This is shown in Figure 6.12 and 6.13 respectively.

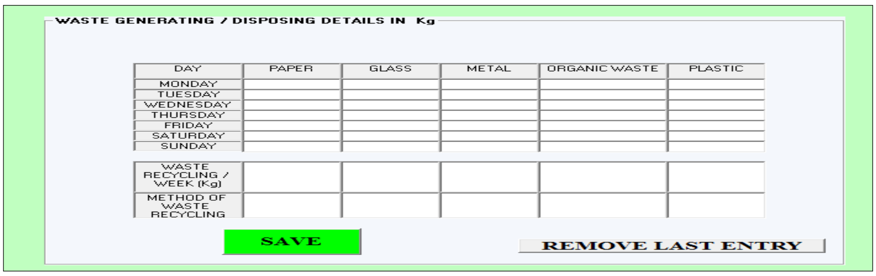

Fig. 6.11 Waste Footprint Analyser - Window 2

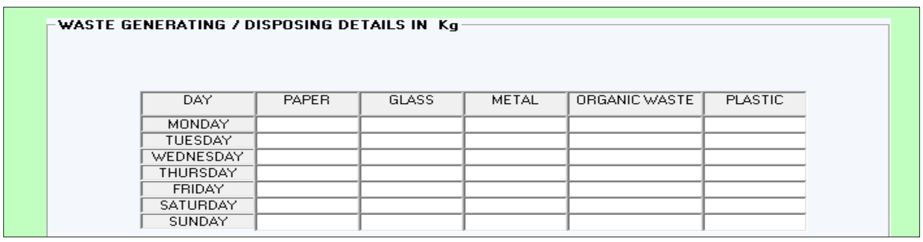

Fig. 6.12 Waste Footprint Analyser - Sub Window 11
(Amount of Waste Generation)

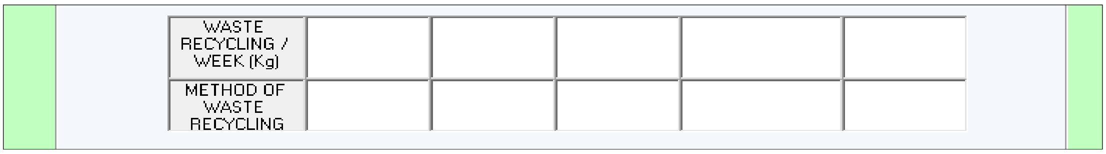

Fig. 6.13 Waste Footprint Analyser - Sub Window 12 (Amount of Waste Recycled and Method of Recycling)

After entering the data in Window 1 and Window 2 one has to press the SAVE button (Figure 6.14) in order to save the data in the analyser. If any error occurs one can delete the previous entry by pressing the remove last entry button (Figure 6.15).

Fig. 6.14 Waste Footprint Analyser (SAVE Button)

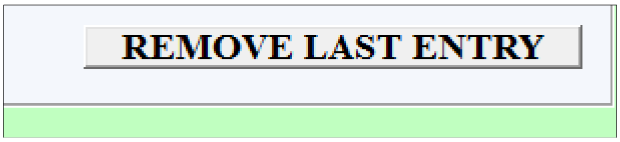

Fig. 6.15 Waste Footprint Analyser (Remove Last Entry Button)

Window 3 (Figure 6.16) is an execution cum output window. It consists of RUN button and 2 sub windows (13 and 14) which are shown in Figure 6.17 and 6.18 respectively. The button 'RUN' is an execution button which triggers the program execution. The sub window 13 displays the number of datasets entered and sub window 14 gives the footprint value in hectares per capita.

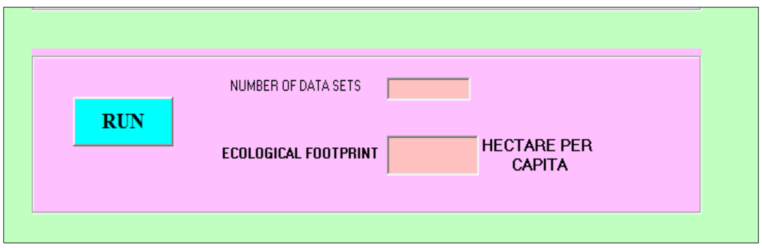

Fig. 6.16 Waste Footprint Analyser - Window 3

After entering all the data or if any intermediate results are to be found one can press the RUN button to get the total number of data sets entered so far and the total ecological footprint in hectares per capita of the data entered as shown in Figure 6.19.

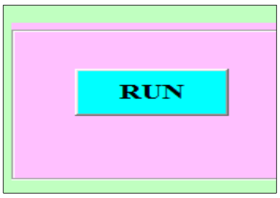

Fig. 6.17 Waste Footprint Analyser - RUN Button

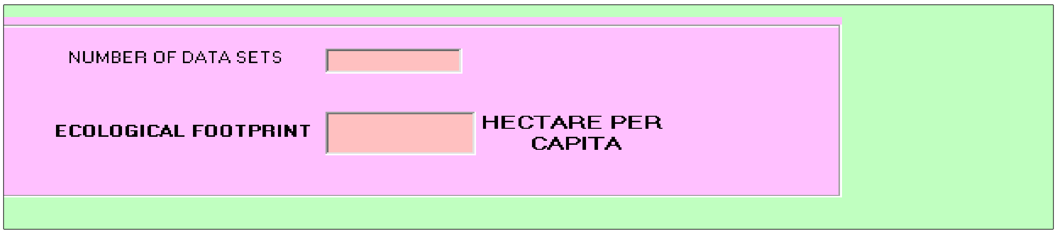

Fig. 6.18 Waste Footprint Analyser - Sub Window 13 and 14 (Number of Data Sets and Result Window)

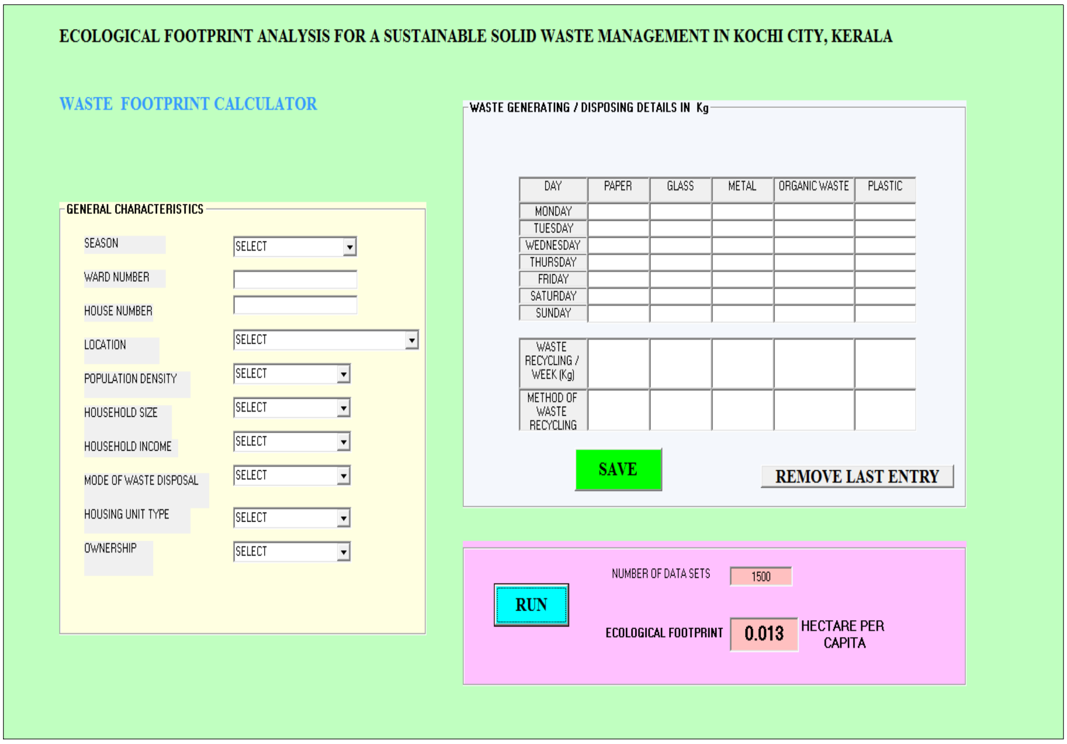

Fig. 6.19 Waste Footprint Analyser - Final Output

6.4 GENERAL ANALYSIS OF THE WASTE FOOTPRINT OF KOCHI CITY

The solid waste components in the three seasons (dry, wet and festival) for four consecutive years (2010 to 2013) were analysed in general. In all the years and all the seasons, the organic waste constitutes the maximum followed by metal waste, glass waste, paper and plastic waste. On an average, the total waste in Kochi city constitutes about 77-82% of organic waste, 9-12% metal waste, 4-6% glass waste, 2-3% paper waste and 1-2% plastic waste. The waste generation in Kochi city was estimated to be 0.51kg/capita/day as on 2013 with an average household size 3.72. In order to assimilate these wastes, an area of 0.012 hectare per capita was required in the dry season, 0.014 hectare per capita for the festival season and 0.013 hectare per capita for the wet season for the year 2010. The details are given in Table 6.1.

Table 6.1 Waste Footprint Values for the Different Categories of Wastes with respect to Season, 2010

Season	Biological Productive Land Requirement /Waste footprint (m^2 per capita)					Total footprint (hectares per capita)
	Paper	Glass	Metal	Organic	Plastic	
Dry	2.99	3.05	25.24	**83.65**	1.81	**0.012**
Festival	3.22	2.70	22.20	**104.89**	3.25	**0.014**
Wet	3.12	2.79	22.61	**101.74**	2.87	**0.013**

The land use category (energy land, forest land and built up land) for each of the components is shown in Table 6.2. By land use category, in the dry seasons about 103.73 m^2 energy land, 0.06 m^2 forest land and 12.94 m^2 area of built up land was required per person. The festival seasons demand 121.10 m^2 energy land, 0.07 m^2 forest lands and 15.10 m^2 built up land for assimilating the waste generated by a single person in the Kochi city. For the wet season, the figures are 118.31 m^2, 0.06 m^2 and 14.76 m^2 for energy land, forest land and built up land respectively. Table 6.2

also shows that during the festival seasons, the impact caused by the wastes in the city is comparatively high. The consumption pattern of various goods during festival season may be the reason for the higher footprint values. Paper waste, organic waste and plastic waste seems increasing during the festival season and therefore the impact is caused by these components.

Table 6.2 Land Requirement for Waste Categories in Different Seasons, 2010

Components	Land requirement (m^2 per capita)								
	Dry Season			Festival Season			Wet Season		
	Energy land	Forest land	Builtup land	Energy land	Forest land	Built up land	Energy land	Forest land	Builtup land
Paper	2.60	0.06	0.32	**2.81**	0.07	**0.35**	2.71	0.06	0.34
Glass	2.71		0.34	2.40		0.30	2.48		0.31
Metal	22.44		2.80	19.74		2.46	20.11		2.51
Organic waste	74.37		9.28	**93.26**		**11.63**	90.46		11.28
Plastic	1.61		0.20	**2.89**		**0.36**	2.55		0.32
Total	103.73	0.06	12.94	**121.10**	**0.07**	**15.10**	118.31	0.06	14.76

Even though the percentage of plastic in the solid waste is low (1.4%) compared to the other components, its percentage share of total footprint is relatively higher (2%) than other components. For all other wastes except for metals, the percentage share of the footprint value is less than the percentage share of that waste in the total waste. Metals also contribute to higher footprint (17.4% versus 9.7%). This is evident from the Figure 6.20.

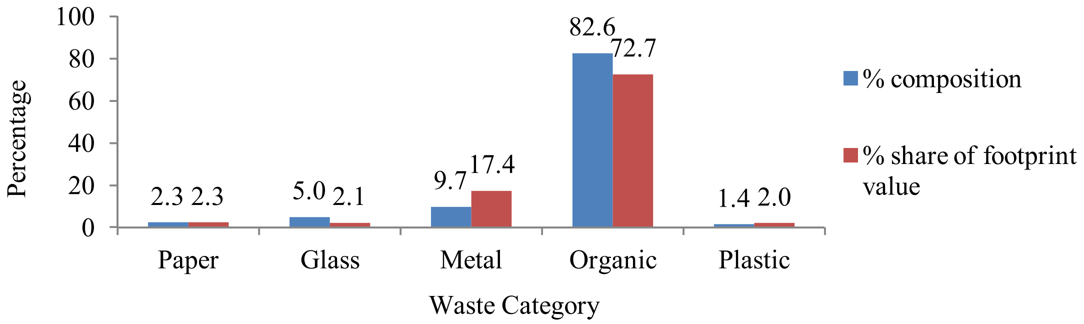

Fig. 6.20 Percentage Share of Each Category of Waste to Total Waste and Total Footprint (2010)

The corresponding analysis for the year 2011 - 2013 showed similar trends and variations. Table 6.3 shows the total land area required to assimilate waste in the year 2011. It shows that the total footprint is more in the festival season (0.016 hectares per capita) followed by wet season (0.015) and dry season (0.013).

Table 6.3 Waste Footprint Values for the Different Categories of Wastes with respect to Season, 2011

Season	Biological Productive Land Requirement /Waste footprint (m^2 per capita)					Total footprint (hectares per capita)
	Paper	Glass	Metal	Organic	Plastic	
Dry	4.12	3.62	28.21	93.88	3.47	0.013
Festival	4.08	3.04	29.71	113.70	4.83	**0.016**
Wet	4.14	3.45	28.56	110.62	3.29	0.015

The organic waste constitutes the maximum in all seasons. The lowest contributor to the total footprint is the plastic waste (Table 6.3) but the figure 6.21 shows that even though the percentage composition is low for plastic, its percentage share to footprint values is alarming (almost double) which shows the harmful effect of plastics.

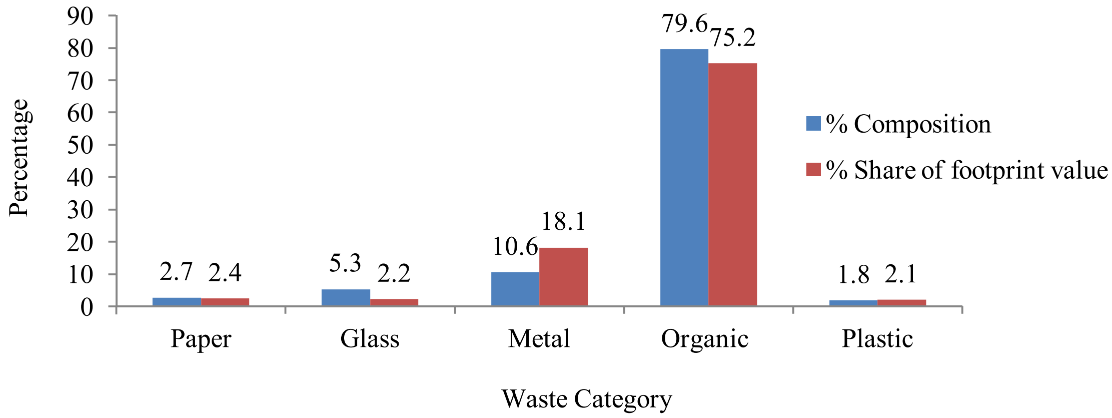

Fig. 6.21 Percentage Share of Each Category of Waste to Total Waste and Total Footprint (2011)

Table 6.4 shows the land use category for different components of waste. About 138.06 m^2 per capita of energy land is required for festival season, compared to 118.44 m^2 per capita in dry season and 133.33 m^2 per capita in wet season.

Table 6.4 Land Requirement for Waste Categories in Different Seasons, 2011

Components	Land use category (m^2 per capita)								
	Dry Season			Festival Season			Wet Season		
	Energy land	Forest land	Built up land	Energy land	Forest land	Built up land	Energy land	Forest land	Built up land
Paper	3.59	0.08	0.45	3.55	0.08	0.44	3.60	0.08	0.45
Glass	3.22		0.40	2.71		0.34	3.07		0.38
Metal	25.08		3.13	**26.42**		**3.29**	25.39		3.17
Organic waste	83.47		10.41	**101.09**		**12.61**	98.35		12.27
Plastic	3.08		0.38	**4.30**		**0.54**	2.93		0.36
Total	118.44	0.08	14.77	**138.06**	**0.08**	**17.22**	133.33	0.08	16.63

The land area of 0.08 m^2 per capita forest land is required in all seasons for the assimilation of wastes. 17.22 m^2 per capita of builtup land is required in the festival season followed by 16.63 m^2 per capita in the wet season and 14.77 m^2 per capita in the dry season.

Table 6.5 Waste Footprint Values for the Different Categories of Wastes with respect to Season, 2012

Season	Biological Productive Land Requirement /Waste Footprint (m^2 per capita)					Total footprint (hectares per capita)
	Paper	Glass	Metal	Organic	Plastic	
Dry	4.38	3.68	30.42	99.40	4.39	0.014
Festival	4.34	3.10	31.92	119.22	5.75	**0.016**
Wet	4.40	3.50	30.77	116.14	4.21	**0.016**

Table 6.5 shows the total land area required to assimilate the waste generated in 2012. The total footprint in the year 2012 is 0.014, 0.016 and 0.016 hectares per capita in the dry, festival and wet season respectively. The land use category for the components of wastes is shown in Table 6.6. Table shows that about 146.04 m^2 per capita of energy land is required for festival season, compared to 126.42 m^2 per capita in dry season and 141.31 m^2 per capita in wet season. The land area of 0.09 m^2 per capita forest land is required in all seasons for the assimilation of wastes. 18.21 m^2 per capita of

builtup land is required in the festival season followed by 17.62 m^2 per capita in the wet season and 15.77 m^2 per capita in the dry season.

Table 6.6 Land Requirement for Waste Categories in Different Seasons, 2012

Components	Land use category (m^2 per capita)								
	Dry Season			Festival Season			Wet Season		
	Energy land	Forest land	Built up land	Energy land	Forest land	Built up land	Energy land	Forest land	Built up land
Paper	3.82	0.09	0.48	3.78	0.09	0.47	3.83	0.09	0.48
Glass	3.27		0.41	2.75		0.34	3.11		0.39
Metal	27.05		3.37	28.38		3.54	27.36		3.41
Organic waste	88.38		11.02	**106.00**		**13.22**	103.27		12.88
Plastic	3.90		0.49	**5.12**		**0.64**	3.74		0.47
Total	126.42	0.09	15.77	**146.04**	**0.09**	**18.21**	141.31	0.09	17.62

Figure 6.22 shows the percentage composition versus the percentage share to total footprint in the year 2012. This shows that the percentage share to footprint of metal and plastic waste on comparison with the composition is considerably high when compared to other wastes.

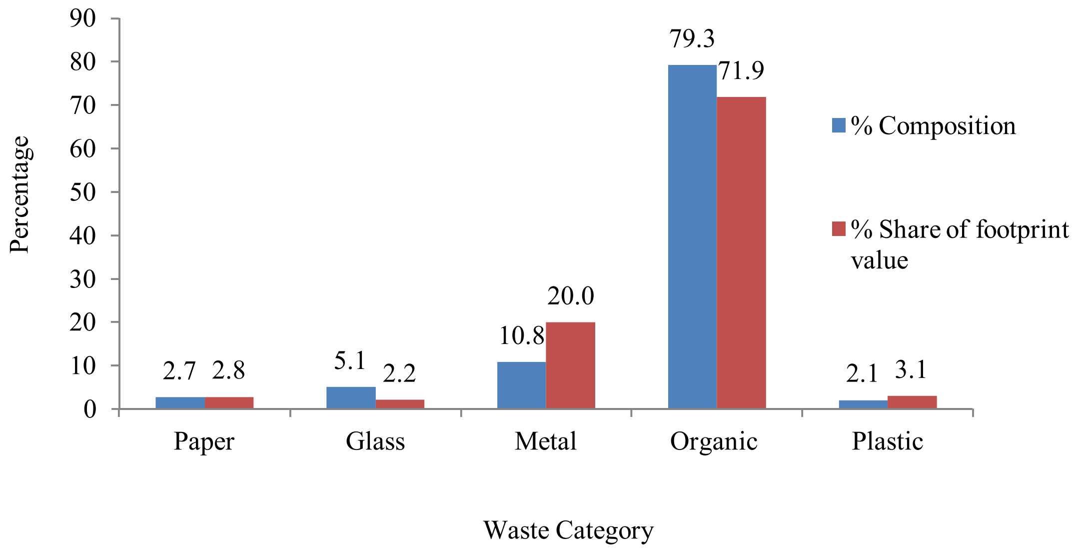

Fig. 6.22 Percentage Share of Each Category of Waste to Total Waste and Total Footprint (2012)

Table 6.7 Waste Footprint Values for the Different Categories of Wastes with respect to Season, 2013

Season	Biological Productive Land Requirement /Waste footprint (m^2 per capita)					Total footprint (hectares per capita)
	Paper	Glass	Metal	Organic	Plastic	
Dry	4.645	3.736	32.633	104.931	5.309	0.015
Festival	4.607	3.153	34.133	124.753	6.675	**0.017**
Wet	4.664	3.558	32.979	121.673	5.133	**0.017**

Table 6.7 shows the total land area required to assimilate the waste generated in 2013. The total footprint in the year 2013 is 0.015, 0.017 and 0.017 hectares per capita in the dry, festival and wet season respectively. The land use category for the components of wastes is shown in Table 6.8. Table shows that about 154.02 m^2 per capita of energy land is required for festival season, compared to 134.40 m^2 per capita in dry season and 149.29 m^2 per capita in wet season. The land area of 0.09 m^2 per capita forest land is required in festival season compared to 0.10 m^2 per capita in all the other seasons for the assimilation of wastes. 19.21 m^2 per capita of builtup land is required in the festival season followed by 18.62 m^2 per capita in the wet season and 16.76 m^2 per capita in the dry season.

Table 6.8 Land Requirement for Waste Categories in Different Seasons, 2013

Components	Land use category (m^2 per capita)								
	Dry Season			Festival Season			Wet Season		
	Energy land	Forest land	Built up land	Energy land	Forest land	Built up land	Energy land	Forest land	Built up land
Paper	4.04	0.10	0.50	4.01	0.09	0.50	4.06	0.10	0.51
Glass	3.32		0.41	2.80		0.35	3.16		0.39
Metal	29.01		3.62	**30.35**		**3.78**	29.32		3.66
Organic waste	93.30		11.64	**110.92**		**13.83**	108.18		13.49
Plastic	4.72		0.59	**5.94**		**0.74**	4.56		0.57
Total	134.40	0.10	16.76	**154.02**	**0.09**	**19.21**	149.29	0.10	18.62

The comparison of percentage share to composition to percentage share to footprint values is shown in Figure 6.23.

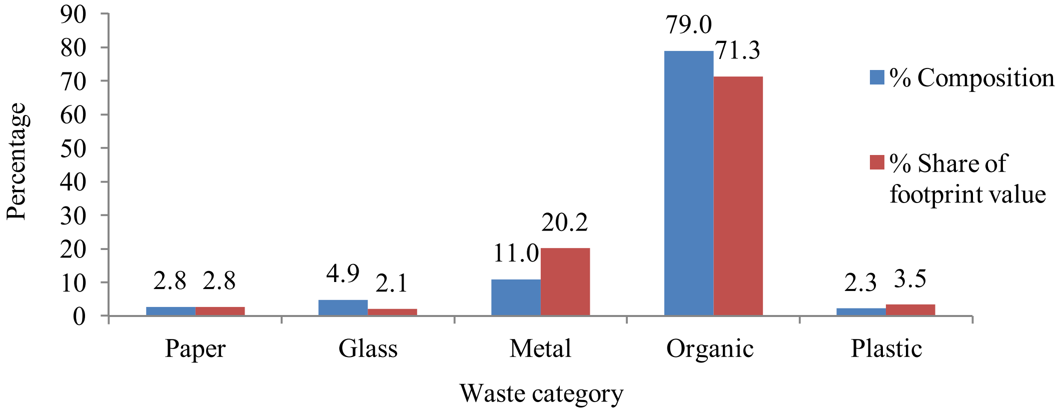

Fig. 6.23 Percentage Share of Each Category of Waste to Total Waste and Total Footprint (2013)

The temporal variations in the total footprint values in different seasons and the land use categories are shown in Figure 6.24, 6.25 and Table 6.9.

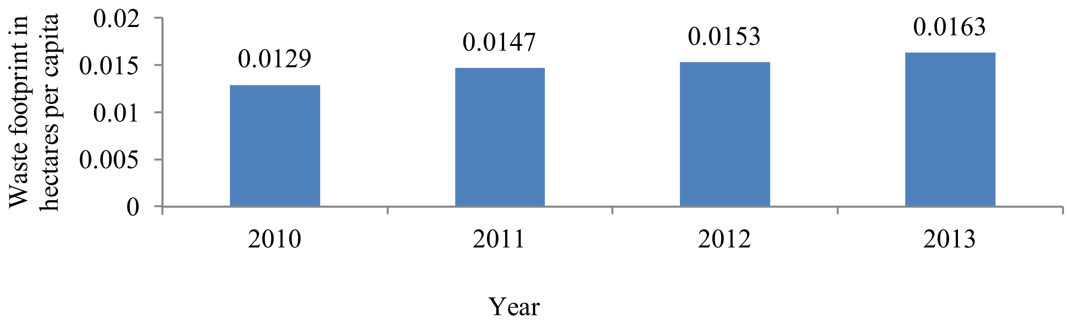

Fig. 6.24 Yearly Variations of Waste Footprint of Kochi City (2010-2013)

The temporal variations shows that the waste footprint of residential areas of Kochi city 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 four years. The increased value of waste footprint over the years shows that there is increase in waste generation. The seasonal variations and the land use category requirements showed similar variations throughout the years (Table 6.9). Table shows that the festival season demands the highest value of land area in all the years. The energy land is showing the highest variation in all the seasons in all the four years.

Table 6.9 Yearly Variation of Land Category Required with respect to Season (2010-2013)

Year	Land use category (m^2 per capita)								
	Dry Season			Festival Season			Wet Season		
	Energy land	Forest land	Built up land	Energy land	Forest land	Built up land	Energy land	Forest land	Built up land
2010	103.73	0.06	12.94	**121.10**	**0.07**	**15.10**	118.31	0.06	14.76
2011	118.44	0.08	14.77	**138.06**	**0.08**	**17.22**	133.33	0.08	16.63
2012	126.42	0.09	15.77	**146.04**	**0.09**	**18.21**	141.31	0.09	17.62
2013	134.40	0.10	16.76	**154.02**	**0.09**	**19.21**	149.29	0.10	18.62

6.5 SUMMARY OF THE CHAPTER

The chapter gives in detail, the methodology adopted for the waste footprint calculations in Kochi city. The waste footprint analyser, which is a program, developed for the data entry and footprint calculations for calculating the waste footprint of Kochi city was also detailed in the chapter. Then the waste footprint of the city was calculated and the chapter gave the general analysis of footprint values. Also the study pointed out the high percentage share of organic footprint and the harmful effect of plastic and metal waste on comparison with the percentage composition versus percentage share to footprint values. The analysis shows that there exist high unsustainability issues in solid waste management in the residential areas of Kochi city. Hence, there is an ample need to frame a waste management plan for the residential areas of the Kochi city. This requires technical and social innovations in the society. For example, a behavioural change of the people will influence the waste generation pattern in their institutions which will reduce the waste generation trends in the municipal stream also. Therefore statistical analysis of the waste footprint study was carried out in order to have a detailed analysis of the variation in waste generation and footprint values with respect to socio economic and technological factors affecting sustainability, which is explained in next chapter.

CHAPTER 7

STATISTICAL ANALYSIS OF THE WASTE FOOTPRINT OF KOCHI CITY

In this chapter, the statistical analysis of the waste footprint in the residential areas of Kochi city is carried out at different levels for social, economic and environmental factors, to assess the sustainability of waste generation in the city. The statistical method used for the analysis, year wise analysis of the primary survey data and analysis over the years is explained in this chapter.

7.1 STATISTICAL ANALYSIS AND METHOD

In order to statistically analyse the data regarding waste footprint calculations in Kochi city, dependent and independent variables were identified from the survey data. The dependentant variables identified are the amount of paper, glass, metal, organic and plastic waste and the corresponding footprint values. The independent variables are season, location with respect to Central Business District (CBD)/Major Transportation Node (MTN), population density (Popln density), household size (HH size), household income (HH income), waste disposal, housing unit and ownership. The independent variables consist of different types/classes. The variable season has three classes: dry, wet and festival; location: near to CBD/MTN and away from CBD/MTN; population density: high and low; household size: 2,3,4,5 and more than 5; household income: less than 5K (1K= Rs. 1000/-), 5K-10K, 10K-15K,15K-20K and above 20K; mode of waste disposal: household level and community level; type of housing unit: individual plot; row housing unit; low rise building and high rise building; and ownership: individual, government and builder. The statistical analysis of the waste footprint values for the dependentant 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 and Gomez, 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 and Gomez, 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.

The frequency table of the data for the year (2010 - 2013) with respect to the independent variables are given in Table 7.1 and the respective codes of these are shown in Table 7.2. For each of the independent variables codes are assigned, depending on the types/classes of that variable. For example, for the variable season there are three classes i.e. dry, wet and festival, which are assigned Code 1, Code 2 and Code 3 respectively. Similarly, for population density, the code 1 is assigned for low density and code 2 for high density. Likewise, the classes of other variables are also given the codes for analysis as shown in Table 7.2. Since the sample size of each year was different (Table 7.1), the analysis over the years was done by curtailing the sample size to the minimum sample size in all the years. For this the samples are selected at random. The pooled analysis has been done in split plot manner. Since the samples are restricted to minimum sample size, the means in the ANOVA for the years and that for pooled analysis will be different.

Table 7.1 Frequency Table of the Survey Data

Variables	Number of samples						% of samples					
	Code 1	Code 2	Code 3	Code 4	Code 5	Total	Code 1	Code 2	Code 3	Code 4	Code 5	Total
	2010											
Season	500	500	500	0	0	1500	33.33	33.33	33.33	0	0	100
Location	663	837	0	0	0	1500	44.2	55.8	0	0	0	100
Popln density	990	510	0	0	0	1500	66.09	33.91	0	0	0	100
HH size	247	352	636	181	84	1500	16.47	23.47	42.4	12.07	5.6	100
HH income	57	387	135	516	405	1500	3.8	25.8	9	34.4	27	100
Waste disposal	831	669	0	0	0	1500	55.4	44.6	0	0	0	100
Housing unit	1010	223	183	84	0	1500	67.33	14.87	12.2	5.6	0	100
Ownership	1434	24	42	0	0	1500	95.6	1.6	2.8	0	0	100
	2011											
Season	71	71	71	0	0	213	33.33	33.33	33.33	0	0	100
Location	84	129	0	0	0	213	39.44	60.56	0	0	0	100
Popln density	153	60	0	0	0	213	71.83	28.17	0	0	0	100
Hh size	45	63	69	26	10	213	21.13	29.58	32.39	12.21	4.69	100
Hh income	15	45	42	57	54	213	7.04	21.13	19.72	26.76	25.35	100
Waste disposal	102	111	0	0	0	213	47.89	52.11	0	0	0	100
Housing unit	117	57	33	6	0	213	54.93	26.76	15.49	2.82	0	100
Ownership	201	6	6	0	0	213	94.37	2.82	2.82	0	0	100
	2012											
Season	71	71	71	0	0	213	33.33	33.33	33.33	0	0	100
Location	84	129	0	0	0	213	39.44	60.56	0	0	0	100
Popln density	153	60	0	0	0	213	71.83	28.17	0	0	0	100
Hh size	45	63	69	26	10	213	21.13	29.58	32.39	12.21	4.69	100
Hh income	15	45	42	57	54	213	7.04	21.13	19.72	26.76	25.35	100
Waste disposal	102	111	0	0	0	213	47.89	52.11	0	0	0	100
Housing unit	117	57	33	6	0	213	54.93	26.76	15.49	2.82	0	100
Ownership	201	6	6	0	0	213	94.37	2.82	2.82	0	0	100
	2013											
Season	71	71	71	0	0	213	33.33	33.33	33.33	0	0	100
Location	84	129	0	0	0	213	39.44	60.56	0	0	0	100
Popln density	153	60	0	0	0	213	71.83	28.17	0	0	0	100
Hh size	45	63	69	26	10	213	21.13	29.58	32.39	12.21	4.69	100
Hh income	15	45	42	57	54	213	7.04	21.13	19.72	26.76	25.35	100
Waste disposal	102	111	0	0	0	213	47.89	52.11	0	0	0	100
Housing unit	117	57	33	6	0	213	54.93	26.76	15.49	2.82	0	100
Ownership	201	6	6	0	0	213	94.37	2.82	2.82	0	0	100

Table 7.2 Description of Code for Variables

Code	Season	Location w.r.t CBD/MTN	Population density	Household size	House hold income in Rupees	Mode of waste disposal	Housing unit type	Ownership
1	Dry	Near	Low	2	< 5K	Household level	Individual plot	Individual
2	Wet	Away	High	3	5K-10K	Community level	Row housing unit	Government
3	Festival			4	10K-15K		Low rise building	Builder
4				5	15K-20K		High rise building	
5				> 5	Above 20K			

1K = Rs. 1000/-

The descriptive statistics (Mean, SD & CV at 5%) of all dependent variables are given in Table 7.3. The mean, standard deviation (SD) & coefficient of variance (CV) of each of the dependent variables for the four consecutive years 2010 – 2013 is also shown in Table 7.3. The table shows that, there are reasonable variations in the mean value of the dependent variables. In the year 2010 for plastic waste and plastic footprint the CV% is greater than 100% which indicates the standard deviation of these variables are greater from their respective means.

Table 7.3 Descriptive Statistics of the Dependent Variables (2010- 2013)

Dependent variable	Year 2010 (N=1500)			Year 2011 (N=213)			Year 2012 (N=213)			Year 2013 (N=213)		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
Paper waste	0.26	0.10	40	0.34	0.09	26.47	0.36	0.09	25	0.38	0.09	23.68
Glass waste	0.58	0.52	89.48	0.66	0.47	71.21	0.67	0.47	70.15	0.68	0.47	69.12
Metal waste	1.13	0.87	77.17	1.31	0.84	64.12	1.41	0.84	59.57	1.51	0.84	55.62
Org waste	9.5	3.19	33.53	9.86	3.31	33.57	10.36	3.31	31.95	10.86	3.31	30.48
Plastic waste	0.16	0.17	**107.5**	0.22	0.17	77.27	0.27	0.17	62.96	0.32	0.17	53.13
Paper footprint	3.11	1.66	53.31	4.11	1.92	46.72	4.38	1.98	45.21	4.64	2.05	44.18
Glass footprint	2.85	2.5	87.72	3.37	2.23	66.17	3.43	2.23	65.02	3.48	2.24	64.37
Metal footprint	23.35	19.25	82.42	28.83	21	72.84	31.04	21.31	68.65	33.25	21.64	65.08
Org waste footprint	96.76	41.44	42.82	106.06	45.25	42.67	111.59	46.34	41.53	117.12	47.49	40.55
Plastic footprint	2.64	2.81	**106.52**	3.86	2.76	71.50	4.78	2.84	59.41	5.71	2.96	51.84
Footprint	128.71	56.82	44.14	146.23	63.29	43.28	155.21	65.07	41.92	164.19	66.96	40.78

7.2 YEAR WISE ANALYSIS

As explained in the previous section, ANOVA analysis has been carried out for the year wise analysis of the primary survey data. The analysis incorporates the analysis of rank, mean and parity string for each category of waste and footprint values with respect to each parameter (independent variables). The rank of each class of the independent variables is assigned based on the mean values in the ANOVA. Parity strings are assigned to each class of the independent variable. The combinations of the parity strings assigned to the variables, assess the compatibility with each other, which is explained in detail in the forthcoming sections. The analysis is done for all the variables described in Table 7.1 for the four consecutive years 2010 – 2013 (Table 7.4 – Table 7.19). The calculated F values of the data with respect to each category of waste and footprint values in that particular year are compared with the Table F values (1% and 5% level of significance). From this, the significance of the variations of dependent variables with respect to independent variable is tested and the significant variations are alone explained in the following sections.

7.2.1 Yearly Variations with respect to Seasons

The seasonal variations in the quantity of waste and the footprint values are shown in Table 7.4 and Table 7.5 respectively. Table explains the rank, mean, parity check and significance of the analysis for the consecutive years (2010-2013). The three different seasons i.e. dry, wet and festival were assigned with parity string a, b and c respectively. Table 7.4 shows, that only organic and plastic waste showed significant variations in all the years 2010-2013. The paper waste generation showed significance only in the year 2010.

The paper waste generation in the base year (2010) showed highest generation in the festival season followed by wet and festival season. The parity check shows that the generation of paper in the wet season is compatible with that of festival season. The organic waste showed highest value in the festival season followed by wet and dry season. The parity check of the organic waste generation shows that, the generation of waste in the wet season is compatible with that of festival season. The plastic waste generation in the base year (2010) showed highest value in the festival season followed by wet and dry season. But in the years 2011-2013, the plastic waste generation in the dry season is more than that in wet season. The parity check shows that, the generation of plastic waste in the wet season is at par with festival season in the year 2010 whereas in the other years the generation in the wet season is compatible with dry season. Table 7.5 shows that, only organic and plastic footprint values showed significant variations over the years 2010-2013. The variation of the footprint values of these wastes with respect to seasons showed similar variations with that of the quantity of wastes generation as explained above. The parity check of organic footprint values and plastic footprint values showed similar trend as that of organic waste generation and plastic generation respectively in Table 7.4. The high quantity of waste generation in the festival season can be attributed to the purchase of new commodities and the reliance of packed food items in the festival season.

7.2.2 Yearly Variations with respect to Location

The variations in the quantity of waste and the footprint values with respect to the two locations (near to CBD/MTN and away from CBD/MTN) are shown in Table 7.6 and Table 7.7 respectively. The two different locations were assigned with parity string a, and b respectively.

Table 7.4 Yearly Variations in the Quantity of Waste Generation with respect to Season

Paper waste

Variable	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Season: Dry	3	0.2	a	3	0.33	abc	3	0.35	abc	3	0.37	abc
Season: Wet	2	0.31	bc	1	0.35	b	1	0.37	b	1	0.39	b
Season: Festival	1	**0.32**	c	2	0.34	cb	2	0.36	cb	2	0.38	cb
F value	4.95			0.5			0.5			0.5		
Significant or not	**Significant**			Not significant			Not significant			Not significant		

Glass waste

Variable	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Season: Dry	1	0.6	a	1	0.71	a	1	0.72	a	1	0.73	a
Season: Wet	2	0.5	ba	2	0.67	ba	2	0.68	ba	2	0.69	ba
Season: Festival	3	0.5	cab	3	0.6	cab	3	0.61	cab	3	0.62	cab
F value	1.09			1.04			1.04			1.04		
Significant or not	Not significant			Not significant			Not significant			Not significant		

Metal waste

Variable	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Season: Dry	1	1.2	a	3	1.29	acb	3	1.39	acb	3	1.49	acb
Season: Wet	3	1	bac	2	1.3	bc	2	1.4	bc	2	1.5	bc
Season: Festival	2	1.1	ca	1	1.35	c	1	1.45	c	1	1.55	c
F value	0.38			0.1			0.1			0.1		
Significant or not	Not significant			Not significant			Not significant			Not significant		

Organic waste

Variable	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Season: Dry	**3**	7.82	a	**3**	8.53	a	**3**	9.03	a	**3**	9.53	a
Season: Wet	**2**	9.83	bc	**2**	10.32	bc	**2**	10.82	bc	**2**	11.32	bc
Season: Festival	**1**	**10.4**	c	**1**	**10.74**	c	**1**	**11.24**	c	**1**	**11.74**	c
F value	18.64			9.7			9.7			9.7		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

Plastic waste

Variable	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Season: Dry	3	0.1	a	2	0.2	a	2	0.25	a	2	0.3	a
Season: Wet	2	0.20	bc	3	0.19	ba	3	0.24	ba	3	0.29	ba
Season: Festival	1	**0.21**	c	1	**0.27**	c	1	**0.32**	c	1	**0.37**	c
F value	6.67			5.26			5.26			5.26		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

*Unit in kg/house/week
Table F value for the year 2010 is 3.03 (5%) and 4.68 (1%), for the year 2011 – 2013 the value is 3.04(5%) and 4.71(1%).

Table 7.5 Yearly Variations in the Footprint Values with respect to Season

Paper footprint

Variable	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Season: Dry	3	2.85	ab	2	4.12	ab	2	4.38	ab	2	4.65	ab
Season: Wet	2	3.13	bc	1	4.14	b	1	4.4	b	1	4.67	b
Season: Festival	1	3.31	c	3	4.08	cba	3	4.34	cba	3	4.61	cba
F value	1.97			0.02			0.01			0.01		
Significant or not	Not significant			Not significant			Not significant			Not significant		

Glass footprint

Variable	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Season: Dry	1	2.93	a	1	3.63	a	1	0.72	a	1	3.68	a
Season: Wet	3	2.56	bac	2	3.45	ba	2	0.68	ba	2	3.5	ba
Season: Festival	2	2.68	ca	3	3.04	cab	3	0.61	cab	3	3.1	cab
F value	0.53			1.27			1.04			1.04		
Significant or not	Not significant			Not significant			Not significant			Not significant		

Metal footprint

Variable	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Season: Dry	1	24.18	a	3	28.21	acb	3	30.42	acb	1	3.74	a
Season: Wet	3	21.91	bac	2	28.56	bc	2	30.77	bc	2	3.56	ba
Season: Festival	2	21.92	ca	1	29.71	c	1	31.92	c	3	3.15	cab
F value	0.44			0.1			0.1			1.27		
Significant or not	Not significant			Not significant			Not significant			Not significant		

Organic footprint

Variable	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Season: Dry	3	82.4	a	3	93.88	a	3	99.4	a	3	104.9	a
Season: Wet	2	102.8	bc	2	110.6	bc	2	116.2	bc	2	121.7	bc
Season: Festival	1	**104.25**	c	1	**113.7**	c	1	**119.23**	c	1	**124.75**	c
F value	8.08			4.06			3.86			3.67		
Significant or not	**Significant**			**Significant at 5% level of significance**			**Significant at 5% level of significance**			**Significant at 5% level of significance**		

Plastic footprint

Variable	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Season: Dry	3	1.76	ab	2	3.47	a	2	4.38	a	2	5.31	a
Season: Wet	2	2.34	bc	3	3.29	ba	3	4.21	ba	3	5.13	ba
Season: Festival	1	**2.94**	c	1	**4.83**	c	1	**5.75**	c	1	**6.68**	c
F value	6.35			7.05			6.6			6.05		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

*Unit in m^2 per capita
Table F value for the year 2010 is 3.03 (5%) and 4.68 (1%), for the year 2011 – 2013 the value is 3.04(5%) and 4.71(1%).

Table 7.6 Yearly Variations in the Quantity of Waste Generation with respect to Location of Houses

Component	Paper waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Location wrt to CBD/MTN: Near	1	0.27	a	**1**	**0.36**	a	1	0.35	ab	**1**	**0.40**	a
Location wrt to CBD/MTN: Away	2	0.25	ba	**2**	0.33	b	2	0.34	b	**2**	0.37	b
F value	3.76			4.55			0.05			4.55		
Significant or not	Not significant			**Significant at 5% level of significance**			Not significant			**Significant at 5% level of significance**		

Component	Glass waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Location wrt to CBD/MTN: Near	1	0.58	a	1	0.67	a	1	0.69	a	1	0.70	a
Location wrt to CBD/MTN: Away	2	0.53	ba	2	0.62	ba	2	0.66	ba	2	0.67	ba
F value	0.44			0.47			0.17			0.17		
Significant or not	Not significant			Not significant			Not significant			Not significant		

Component	Metal waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Location wrt to CBD/MTN: Near	**1**	**1.29**	a	1	1.44	ab	1	1.42	ab	1	1.52	ab
Location wrt to CBD/MTN: Away	**2**	0.92	b	2	1.26	b	2	1.40	b	2	1.50	b
F value	13.49			1.95			0.04			0.04		
Significant or not	**Significant**			Not significant			Not significant			Not significant		

Component	Organic waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Location wrt to CBD/MTN: Near	**1**	**10.20**	a	1	10.01	ab	1	10.72	a	1	11.22	a
Location wrt to CBD/MTN: Away	**2**	8.66	b	**2**	9.81	b	**2**	10.13	ba	**2**	10.63	ba
F value	16.85			0.16			1.64			1.64		
Significant or not	**Significant**			Not significant			Not significant			Not significant		

Component	Plastic waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Location wrt to CBD/MTN: Near	**1**	**0.17**	a	1	0.24	a	1	0.27	a	1	0.32	a
Location wrt to CBD/MTN: Away	**2**	0.12	b	**2**	0.19	ba	**2**	0.27	ba	**2**	0.32	ba
F value	5.87			3.35			0			0		
Significant or not	**Significant at 5% level of significance**			Not significant			Not significant			Not significant		

*Unit in kg/house/week

Table F value for the year 2010 is 3.87 (5%) and 6.72 (1%), for the year 2011 – 2013 the value is 3.88(5%) and 6.76 (1%).

Table 7.7 Yearly Variations in the Footprint Values with respect to Location of Houses

Component	Paper footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Location wrt to CBD/MTN: Near	**1**	**3.45**	a	**1**	**4.62**	a	**1**	**4.89**	a	**1**	**5.17**	a
Location wrt to CBD/MTN: Away	**2**	2.82	b	**2**	3.78	b	**2**	4.04	b	**2**	4.29	b
F Value	11.3			10.27			9.99			9.71		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

Component	Glass footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Location wrt to CBD/MTN: Near	**1**	**3.13**	a	1	3.57	a	1	3.63	a	1	3.68	a
Location wrt to CBD/MTN: Away	**2**	2.41	b	2	3.24	ba	2	3.29	ba	2	3.35	ba
F Value	6			1.07			1.09			1.11		
Significant or not	**Significant at 5% level of significance**			Not significant			Not significant			Not significant		

Component	Metal footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Location wrt to CBD/MTN: Near	1	**29.17**	a	1	28.90	a	1	31.19	a	1	33.48	a
Location wrt to CBD/MTN: Away	2	17.49	b	2	28.78	ba	2	30.94	ba	2	33.1	ba
F Value	28.21			0			0.01			0.02		
Significant or not	**Significant**			Not significant			Not significant			Not significant		

Component	Organic footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Location wrt to CBD/MTN: Near	1	**111.83**	a	1	111.10	a	1	116.82	a	1	122.53	a
Location wrt to CBD/MTN: Away	2	84.24	b	2	102.78	ba	2	108.19	ba	2	113.59	ba
F Value	32.23			1.72			1.77			1.81		
Significant or not	**Significant**			Not significant			Not significant			Not significant		

Component	Plastic footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Location wrt to CBD/MTN: Near	1	**2.91**	a	1	3.92	a	1	4.87	a	1	5.82	a
Location wrt to CBD/MTN: Away	2	1.9	b	2	3.83	ba	2	4.73	ba	2	5.63	ba
F Value	13.9			0.05			0.13			0.22		
Significant or not	**Significant**			Not significant			Not significant			Not significant		

*Unit in m^2 per capita

Table F value for the year 2010 is 3.87 (5%) and 6.72 (1%), for the year 2011 – 2013 the value is 3.88(5%) and 6.76 (1%).

Table 7.6 shows that, the variation of metal, organic and plastic waste are significant (2010) and the quantity of paper waste generation is significant (2011 and 2013) with respect to location of house.

The metal, organic and plastic waste generation in the base year showed that, the waste generation in locations near to CBD/MTN is more when compared to generation in locations away from CBD/MTN. This can be attributed to the over consumption of the people living in the CBD areas and the dependency on readymade goods and fast foods. The parity check showed no compatibility in the case of these wastes. The paper waste generation in the year 2011 and 2013 showed similar variations. The generation of paper waste in these years showed that, the generation is more in locations near to CBD/MTN when compared to the generation in locations away from CBD/MTN. The parity check also shows no compatibility between the waste generations in the two locations.

Table 7.7 shows the variations in the footprint values with respect to location. It shows that that, all the footprint values in the base year showed significance whereas, only the paper footprint values shows significance in all the years. The paper footprint values show maximum values in the locations near to CBD/MTN. The parity check shows no compatibility. The glass, metal, organic and plastic footprint (2010) also showed maximum values in the locations near to CBD/MTN. The parity check of these footprint values shows that the footprint values in locations near to CBD/MTN are not compatible with the footprint values in locations away from CBD/MTN.

7.2.3 Yearly Variations with respect to Population Density

Table 7.8 and 7.9 shows the variation in the quantity of wastes with respect to population density. Table shows that there are no significant mean variations in the case of generation of wastes with respect to density of the area except for paper (2011 and 2013).

Table 7.8 Yearly Variations in the Quantity of Waste Generation with respect to Population Density

Variables	Paper waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Population Density Low	2	0.25	ab	1	**0.36**	a	2	0.36	ab	1	**0.40**	a
Population Density High	1	0.27	b	2	0.33	b	1	0.36	b	2	0.37	b
F value	3.49			4.55			0.05			4.55		
Significant or not	Not significant			**Significant at 5% level of significance**			Not significant			**Significant at 5% level of significance**		

Variables	Glass waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Population Density Low	2	0.54	ab	1	0.68	a	1	0.69	a	1	0.70	a
Population Density High	1	0.57	b	2	0.63	ba	2	0.66	ba	2	0.67	ba
F value	0.14			0.47			0.17			0.17		
Significant or not	Not significant			Not significant			Not significant			Not significant		

Variables	Metal waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Population Density Low	2	1.03	ab	2	1.36	ab	2	1.40	ab	2	1.50	ab
Population Density High	1	1.19	b	1	1.54	b	1	1.42	b	1	1.52	b
F value	2.13			1.95			0.04			0.04		
Significant or not	Not significant			Not significant			Not significant			Not significant		

Variables	Organic waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Population Density Low	1	9.38	a	2	10.51	ab	1	10.72	a	1	11.22	a
Population Density High	2	9.28	ba	1	10.51	b	2	10.13	ba	2	10.63	ba
F value	0.06			0.16			1.64			1.64		
Significant or not	Not significant			Not significant			Not significant			Not significant		

Variables	Plastic waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Population Density Low	1	0.16	a	1	0.29	a	1	0.27	a	1	0.32	a
Population Density High	2	0.12	b	2	0.24	ba	2	0.27	ba	2	0.32	ba
F value	3.81			3.35			0			0		
Significant or not	Not significant			Not significant			Not significant			Not significant		

*Unit in kg/house/week
Table F value for the year 2010 is 3.87 (5%) and 6.72 (1%), for the year 2011 – 2013 the value is 3.88(5%) and 6.76 (1%).

Table 7.9 Yearly Variations in the Footprint Values with respect to Population Density

Variables	Paper footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Population Density Away	2	3	ab	2	4.30	ab	1	**4.90**	a	1	**5.17**	a
Population Density Near	1	3.3	b	1	4.56	b	2	4.04	b	2	4.29	b
F value	2.31			0.76			9.99			9.71		
Significant or not	Not significant			Not significant			**Significant**			**Significant**		

Variables	Glass footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Population Density Away	2	2.59	ab	2	3.43	ab	1	3.63	a	1	3.68	a
Population Density Near	1	2.99	b	1	3.43	b	2	3.30	ba	2	3.35	ba
F value	1.63			0			1.09			1.11		
Significant or not	Not significant			Not significant			Not significant			Not significant		

Variables	Metal footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Population Density Away	2	21.1	ab	2	29.4	ab	1	31.19	a	1	33.48	a
Population Density Near	1	25.72	b	1	35.21	b	2	30.94	ba	2	33.1	ba
F value	3.73			3.24			0.01			0.02		
Significant or not	Not significant			Not significant			Not significant			Not significant		

Variables	Organic footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Population Density Away	2	93.55	ab	2	107.93	ab	1	116.82	a	1	122.53	a
Population Density Near	1	102.15	b	1	120.93	b	2	108.19	ba	2	113.59	ba
F value	2.59			3.43			1.77			1.81		
Significant or not	Not significant			Not significant			Not significant			Not significant		

Variables	Plastic footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Population Density Away	1	2.51	a	1	4.92	a	1	4.87	a	1	5.82	a
Population Density Near	2	2.02	ba	2	4.45	ba	2	4.73	ba	2	5.63	ba
F value	2.88			1.16			0.13			0.22		
Significant or not	Not significant			Not significant			Not significant			Not significant		

*Unit in m^2 per capita
Table F value for the year 2010 is 3.87 (5%) and 6.72 (1%), for the year 2011 – 2013 the value is 3.88(5%) and 6.76 (1%).

Table 7.8 shows that, the paper generation is more in low density areas compared to high density areas. The parity check shows that, the generation of paper waste is not compatible in the low and high density areas. The density variations in footprint values (Table 7.9) show that, only paper footprint values are significant (2012 and 2013). The footprint values and the parity checks of paper waste also showed similar variations and trend with that of waste generation with respect to the population density of the area.

7.2.4 Yearly Variations with respect to Household Size

The variations based on household size in the quantity of wastes and footprint values are shown in Table 7.10 and Table 7.11 respectively. Table shows that, there are significant variations for glass, organic and plastic wastes in all the years, whereas the paper and metal waste variations are significant in the base year only. The paper waste generation in the base year (2010) is more in houses with household size five (HH5), followed by household size three (HH3), four (HH4), more than five (HH>5) and two (HH2). The parity checks showed that paper waste generation in HH3 showed parity with HH5; samples with HH4 showed parity with HH3 and HH5; HH>5 showed parity with HH5, HH4 and HH3.

The generation of glass waste in all the years (2010-2013) is more in HH5 followed by HH>5, HH4, HH3 and HH2. The parity checks in the base year (2010) showed that glass waste generation in HH2 showed parity with HH3; HH3 showed parity with HH4 and HH>5; HH4 showed parity with HH>5. The parity check in all the other years (2011-2013) shows that the quantity of glass waste generation in the wet season shows parity with that of dry season and that of festival season shows parity with the other two seasons. Metal waste was more on the festival season followed by wet and dry season. The parity check shows that the quantity of waste generation in the dry season shows parity with the other two seasons and the wet season shows parity with the festival season.

Table 7.10 Yearly Variations in the Quantity of Waste Generation with respect to Household Size

Variables	Paper waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Household size 2	**5**	0.22	a	5	0.31	acbe	5	0.33	abe	5	0.35	acbe
Household size 3	**2**	0.28	bd	3	0.34	bdc	3	0.36	bdc	3	0.38	bdc
Household size 4	**3**	0.27	cdb	2	0.35	cd	2	0.37	cd	2	0.39	cd
Household size 5	**1**	**0.28**	d	1	0.36	d	1	0.38	d	1	0.40	d
Household size More than 5	**4**	0.26	edbc	4	0.34	edcb	4	0.36	edcb	4	0.38	edcb
F value	3.86			1.45			1.45			1.45		
Significant or not	**Significant**			Not significant			Not significant			Not significant		

Variables	Glass waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Household size 2	**5**	0.35	ab	**5**	0.45	ab	**5**	0.46	ab	**5**	0.47	ab
Household size 3	**4**	0.52	bec	**4**	0.58	bc	**4**	0.59	bc	**4**	0.60	bc
Household size 4	**3**	0.52	ce	**3**	0.65	c	**3**	0.66	c	**3**	0.67	c
Household size 5	**1**	**0.98**	d	**1**	**1.13**	d	**1**	**1.14**	d	**1**	**1.15**	d
Household size More than 5	**2**	0.65	e	**2**	0.95	ed	**2**	0.96	ed	**2**	0.97	ed
F value	8.86			12.49			12.49			12.49		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

Variables	Metal waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Household size 2	**5**	0.81	ae	5	1.13	aecd	5	1.23	aecd	5	1.33	aecd
Household size 3	**1**	**1.32**	b	1	1.46	b	1	1.56	b	1	1.66	b
Household size 4	**3**	1.09	cbd	3	1.31	cbe	3	1.41	cbe	3	1.51	cbe
Household size 5	**2**	1.11	db	4	1.25	dbec	4	1.35	dbec	4	1.45	dbec
Household size More than 5	**4**	0.93	ebdc	2	1.40	eb	2	1.50	eb	2	1.60	eb
F value	2.84			1.11			1.11			1.11		
Significant or not	**Significant at 5% los****			Not significant			Not significant			Not significant		

Variables	Organic waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Household size 2	**5**	7.66	a	**5**	8.19	a	**5**	8.69	a	**5**	9.19	a
Household size 3	**3**	9.66	bd	**3**	10.03	bd	**3**	10.53	bd	**3**	11.03	bd
Household size 4	**4**	9.10	cdb	**4**	9.80	cdb	**4**	10.30	cdb	**4**	10.80	cdb
Household size 5	**2**	10.34	d	**2**	11.08	d	**2**	11.58	d	**2**	12.08	d
Household size More than 5	**1**	**12.95**	e	**1**	**13.59**	e	**1**	**14.09**	e	**1**	**14.59**	e
F value	11.56			7.87			7.87			7.87		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

Variables	Plastic waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Household size 2	**5**	0.10	abc	**5**	0.15	ac	**5**	0.20	ac	**5**	0.25	ac
Household size 3	**3**	0.13	bd	**3**	0.25	bd	**3**	0.30	bd	**3**	0.35	bd
Household size 4	**4**	0.13	cdb	**4**	0.21	cdb	**4**	0.26	cdb	**4**	0.31	cdb
Household size 5	**2**	0.15	d	**2**	0.25	d	**2**	0.30	d	**2**	0.35	d
Household size More than 5	**1**	**0.38**	e	**1**	**0.39**	e	**1**	**0.44**	e	**1**	**0.49**	e
F value	13.43			5.64			5.64			5.64		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

*Unit in kg/house/week, **los=Level of significance

Table F value for the year 2010 is 2.42 (5%) and 3.38 (1%), for the year 2011 – 2013 the value is 2.42(5%) and 3.41 (1%).

Table 7.11 Yearly Variations in the Footprint Values with respect to Household Size

Variables	Paper footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Household size 2	1	**4.35**	a	1	**6.01**	a	1	**6.43**	a	1	**6.84**	a
Household size 3	2	3.51	b	2	4.34	b	2	4.62	b	2	4.90	b
Household size 4	3	2.77	c	3	3.54	c	3	3.75	c	3	3.96	c
Household size 5	4	2.27	dc	4	2.65	dc	4	2.80	dc	4	2.95	dc
Household size More than 5	5	1.46	ed	5	1.92	ed	5	2.06	ed	5	2.19	ed
F value	21.6			30.6			35.49			40.71		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

Variables	Glass footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Household size 2	2	**3.09**	ad	1	**3.96**	a	1	**4.05**	a	1	**4.14**	a
Household size 3	3	3.05	bda	3	3.41	bad	3	3.47	bad	3	3.53	bad
Household size 4	4	2.29	cdab	4	2.84	cdb	4	2.89	cdb	4	2.93	cdb
Household size 5	1	3.45	d	2	3.91	da	2	3.95	da	2	3.98	da
Household size More than 5	5	1.77	ebc	5	2.72	edbc	5	2.74	edbc	5	2.77	edbc
F value	2.87			2.42			2.54			2.67		
Significant or not	**Significant at 5% los****			**Significant at 5% los****			**Significant at 5% los****			**Significant at 5% los****		

Variables	Metal footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Household size 2	2	28.46	ab	1	**39.61**	a	1	**43.12**	a	1	**46.64**	a
Household size 3	1	**30.98**	b	2	34.27	ba	2	36.61	ba	2	38.96	b
Household size 4	3	19.10	c	3	23.04	c	3	24.80	c	3	26.56	c
Household size 5	4	15.67	dc	4	17.26	dc	4	18.51	dc	4	19.75	dc
Household size More than 5	5	10.16	ecd	5	16.03	ecd	5	17.14	ecd	5	18.25	ecd
F value	9.1			9.56			11.34			13.29		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

Variables	Organic footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Household size 2	1	**134.77**	a	1	**144.10**	a	1	**152.89**	a	1	**161.69**	a
Household size 3	2	113.28	b	2	117.58	b	2	123.45	b	2	129.31	b
Household size 4	3	80.05	c	3	86.24	c	3	90.64	c	3	95.03	c
Household size 5	4	72.79	dc	4	77.42	dc	4	80.53	dc	4	83.65	dc
Household size More than 5	5	68.81	ecd	5	73.62	ecd	5	76.39	ecd	5	79.16	ecd
F value	30.32			22.83			26.43			30.29		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

Variables	Plastic footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Household size 2	2	2.95	ae	2	4.45	ab	1	**5.92**	a	1	**7.38**	a
Household size 3	3	2.60	bea	1	**4.86**	b	2	5.83	ba	2	6.81	ba
Household size 4	4	1.94	cb	4	3.02	ce	4	3.75	ce	3	4.48	c
Household size 5	5	1.74	dbc	5	2.86	dec	5	3.38	dec	5	3.90	dce
Household size More than 5	1	**3.41**	e	3	3.39	eba	3	3.86	e	4	4.32	ec
F value	3.59			5.55			9.34			14.74		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

*Unit in m^2 per capita, **los=Level of significance

Table F value for the year 2010 is 2.42 (5%) and 3.38 (1%), for the year 2011 – 2013 the value is 2.42(5%) and 3.41 (1%).

The metal waste generation in the base year (2010) is more in HH3, followed by HH5, HH4, HH>5 and HH2. The parity checks showed that metal waste generation in HH2 showed parity with HH>5; HH4 showed parity with HH3 and HH5; HH5 showed parity with HH3; and HH>5 showed parity with HH5, HH4 and HH3. The organic waste and plastic waste generation (2010-2013) is more in houses with HH>5, followed by HH5, HH3, HH4 and HH2. The parity checks also showed similar trend. The HH3 showed parity with HH5; HH4 showed parity with HH3 and HH4.

The variations based on the household size in the footprint values (Table 7.11) shows that the all the footprint values are significant in all the years (2010-2013). The paper footprint and the organic waste footprint are inversely proportional to the household size. For paper footprint the parity checks shows that the HH5 shows parity with HH4 and HH>5 shows parity with HH5. The parity checks for organic footprint values which show that the HH5 shows parity with HH4 and samples with HH>5 showed parity with HH4 and HH5. For glass footprint the footprint values are the highest for HH5, followed by HH2, HH3, HH4 and HH>5.

For glass footprint, HH2 shows parity with HH5; HH3 shows parity with HH2 and HH5; HH4 shows parity with HH2, HH3 and HH5. The HH>5 shows similarity with HH3 and HH4. The metal footprint values (2010-2013) shows high footprint values for HH3, followed by HH2, HH4, HH5 and HH>5. The parity check shows that the HH2 shows parity with HH3; HH5 shows parity with HH4; and HH>5 shows parity with HH3 and HH4.

The plastic footprint shows maximum value for HH>5, followed by HH2, HH3, HH4 and HH5. HH2 shows parity with HH>5; HH3 shows parity with HH2 and HH>5; HH4 shows parity with HH3; and HH5 shows parity with HH3 and HH4.

7.2.5 Yearly Variations with respect to Household Income

Table 7.12 details the variations based on household income in the quantity of waste generation. Table shows that all the wastes except plastic waste show significance in all the years (2010-2013). The plastic waste generation shows significance only in the base year (2010). Table 7.13 explains the variations based on household income in the footprint values.

It shows that the paper, glass and metal waste generation (2010) shows their maximum for samples with household income 10K-15K(HHIC), followed by above 20K(HHIE), 15K-20K (HHID), 5K-10K(HHIB) and less than 5K(HHIA). For the years (2011-2013) the generation of paper waste shows proportional increase to the household income. The parity check of paper waste (2011 -2013) shows that HHIB shows parity with the HHIE; HHIC shows parity with HHID and HHIE; HHID shows parity with HHIE. The glass waste generation (2011-2013) show their maximum for HHIE followed by HHIB, HHIC, HHID and HHIA. For glass waste, HHIB shows parity with HHIE; HHIC shows parity with HHID and HHIB; group HHID shows parity with HHIB and HHIC. The metal waste generation show their maximum for HHIE followed by HHIC, HHIB, HHID and HHIA. For metal waste, the HHIB shows parity with HHIC and HHIE; HHIC shows parity with HHIE; and HHID shows parity with HHIB. The organic waste generation (2011 – 2013) shows high values for HHIC followed by the HHIE, HHIB, HHID and HHIA. For organic waste, HHIB shows parity with HHIC and HHIE; HHID shows parity with HHIB; and HHIE shows parity with HHIC. The plastic waste generation (2011-2013) shows high value for HHIC followed by HHIE, HHIB, HHIA and HHID. For plastic waste, HHIA shows parity with the all the groups except the HHID. The HHIB shows parity with HHIE and HHID; HHID shows parity with all other groups except HHIC; and HHIE shows parity with HHIC.

Table 7.12 Yearly Variations in the Quantity of Waste Generation with respect to Household Income

Paper waste

Household income	2010 Rank	2010 Mean*	2010 Parity string	2011 Rank	2011 Mean*	2011 Parity string	2012 Rank	2012 Mean*	2012 Parity string	2013 Rank	2013 Mean*	2013 Parity string
Less than 5K	5	0.15	a	5	0.21	a	5	0.23	a	5	0.25	a
5K-10K	4	0.23	be	4	0.32	be	4	0.34	be	4	0.36	be
10K-15K	1	**0.28**	c	3	0.35	ced	3	0.37	ced	3	0.39	ced
15K-20K	3	0.28	dce	2	0.36	de	2	0.38	de	2	0.40	de
Above 20K	2	0.28	ec	1	0.37	e	1	0.39	e	1	0.41	e
F value	8.1			10.81			10.81			10.81		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

Glass waste

Household income	2010 Rank	2010 Mean*	2010 Parity string	2011 Rank	2011 Mean*	2011 Parity string	2012 Rank	2012 Mean*	2012 Parity string	2013 Rank	2013 Mean*	2013 Parity string
Less than 5K	5	0.13	a	5	0.34	a	5	0.35	a	5	0.36	a
5K-10K	4	0.46	bed	2	0.75	be	2	0.76	be	2	0.77	be
10K-15K	1	**0.84**	c	3	0.67	ceb	3	0.68	ceb	3	0.69	ceb
15K-20K	3	0.54	de	4	0.58	dbc	4	0.59	dbc	4	0.60	dbc
Above 20K	2	0.64	ec	1	**0.75**	e	1	**0.76**	e	1	**0.77**	e
F value	5.29			3.29			3.29			3.29		
Significant or not	**Significant**			**Significant at 5% los****			**Significant at 5% los****			**Significant at 5% los****		

Metal waste

Household income	2010 Rank	2010 Mean*	2010 Parity string	2011 Rank	2011 Mean*	2011 Parity string	2012 Rank	2012 Mean*	2012 Parity string	2013 Rank	2013 Mean*	2013 Parity string
Less than 5K	5	0.31	a	5	0.54	a	5	0.64	a	5	0.74	a
5K-10K	4	0.92	bd	3	1.34	bec	3	1.44	bec	3	1.54	bec
10K-15K	1	**1.41**	c	2	1.51	ce	2	1.61	ce	2	1.71	ce
15K-20K	3	0.98	d	4	1.07	db	4	1.17	db	4	1.27	db
Above 20K	2	1.41	ec	1	**1.61**	e	1	**1.71**	e	1	**1.81**	e
F value	7.47			7.43			7.43			7.43		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

Organic waste

Household income	2010 Rank	2010 Mean*	2010 Parity string	2011 Rank	2011 Mean*	2011 Parity string	2012 Rank	2012 Mean*	2012 Parity string	2013 Rank	2013 Mean*	2013 Parity string
Less than 5K	5	6.17	a	5	6.85	a	5	7.35	a	5	7.85	a
5K-10K	4	8.32	bd	3	9.90	bce	3	10.4	bce	3	10.9	bce
10K-15K	3	9.33	cd	1	**11.04**	c	1	**11.54**	c	1	**12.04**	c
15K-20K	2	9.52	d	4	9.00	db	4	9.50	db	4	10	db
Above 20K	1	**10.73**	e	2	10.66	ec	2	11.16	ec	2	11.66	ec
F value	8.91			6.88			6.88			6.88		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

Plastic waste

Household income	2010 Rank	2010 Mean*	2010 Parity string	2011 Rank	2011 Mean*	2011 Parity string	2012 Rank	2012 Mean*	2012 Parity string	2013 Rank	2013 Mean*	2013 Parity string
Less than 5K	3	0.15	aed	4	0.22	aceb	4	0.27	aceb	4	0.32	aceb
5K-10K	4	0.1	bea	3	0.23	bce	3	0.28	bce	3	0.33	bce
10K-15K	5	0.09	cab	1	0.25	c	1	0.3	c	1	0.35	c
15K-20K	2	0.16	de	5	0.18	deba	5	0.23	deba	5	0.28	deba
Above 20K	1	**0.19**	e	2	0.24	ec	2	0.29	ec	2	0.34	ec
F value	4.53			1.19			1.19			1.19		
Significant or not	**Significant**			Not significant			Not significant			Not significant		

*Unit in kg/house/week, **los=Level of significance

Table F value for the year 2010 is 2.42 (5%) and 3.38 (1%), for the year 2011 – 2013 the value is 2.42(5%) and 3.41 (1%).

Table 7.13 Yearly Variations in the Footprint Values Based with respect to Household Income

Paper footprint

Household income	2010 Rank	2010 Mean*	2010 Parity string	2011 Rank	2011 Mean*	2011 Parity string	2012 Rank	2012 Mean*	2012 Parity string	2013 Rank	2013 Mean*	2013 Parity string
Less than 5K	5	1.53	a	5	2.86	a	5	3.20	ac	5	3.54	ac
5K-10K	1	**3.26**	b	2	4.31	be	1	4.62	b	1	4.92	b
10K-15K	4	3.04	cbed	4	4.03	cebd	4	4.31	cbed	3	4.60	cbe
15K-20K	3	3.10	dbe	3	4.11	deb	3	4.33	dbe	4	4.55	dbec
Above 20K	2	3.20	eb	1	4.36	e	2	4.60	eb	2	4.83	eb
F value	3.04			1.46			1.46			1.46		
Significant or not	**Significant at 5% los****			Not significant			Not significant			Not significant		

Glass footprint

Household income	2010 Rank	2010 Mean*	2010 Parity string	2011 Rank	2011 Mean*	2011 Parity string	2012 Rank	2012 Mean*	2012 Parity string	2013 Rank	2013 Mean*	2013 Parity string
Less than 5K	5	1.00	a	4	2.43	ace	4	2.50	ace	4	2.57	ace
5K-10K	3	2.81	be	1	**4.36**	b	1	**4.42**	b	1	**4.48**	b
10K-15K	1	**3.72**	c	2	3.67	cb	2	3.73	cb	2	3.79	cb
15K-20K	4	2.38	deb	5	2.38	da	5	2.43	da	5	2.48	da
Above 20K	2	3.03	ec	3	3.63	ebc	3	3.68	ebc	3	3.73	ebc
F value	3.34			6.77			6.77			6.77		
Significant or not	**Significant at 5% los****			**Significant**			**Significant**			**Significant**		

Metal footprint

Household income	2010 Rank	2010 Mean*	2010 Parity string	2011 Rank	2011 Mean*	2011 Parity string	2012 Rank	2012 Mean*	2012 Parity string	2013 Rank	2013 Mean*	2013 Parity string
Less than 5K	5	9.99	a	5	16.14	ad	5	18.95	ad	5	21.77	ad
5K-10K	3	22.40	be	2	33.28	bc	2	35.81	bc	2	38.34	bc
10K-15K	1	**30.56**	c	1	**37.41**	c	1	**39.82**	c	1	**42.22**	c
15K-20K	4	18.48	db	4	18.61	d	4	20.47	d	4	22.32	d
Above 20K	2	27.98	ec	3	32.75	ecb	3	34.75	ecb	3	36.75	ecb
F value	5.14			8.53			8.53			8.53		
Significant or not	**Significant**			**Significant**			**Significant**			**Significant**		

Organic footprint

Household income	2010 Rank	2010 Mean*	2010 Parity string	2011 Rank	2011 Mean*	2011 Parity string	2012 Rank	2012 Mean*	2012 Parity string	2013 Rank	2013 Mean*	2013 Parity string
Less than 5K	4	90.00	abce	4	98.64	ae	4	105.70	abe	4	112.70	abe
5K-10K	1	**105.89**	b	2	122.61	bc	2	128.94	bc	2	135.27	bc
10K-15K	2	102.53	cb	1	**135.10**	c	1	**141.11**	c	1	**147.12**	c
15K-20K	5	85.61	da	5	76.22	d	5	80.87	d	5	85.51	d
Above 20K	3	100.33	ebc	3	103.25	eb	3	108.25	eb	3	113.24	eb
F value	2.95			15.67			15.67			15.67		
Significant or not	**Significant at 5% los****			**Significant**			**Significant**			**Significant**		

Plastic footprint

Household income	2010 Rank	2010 Mean*	2010 Parity string	2011 Rank	2011 Mean*	2011 Parity string	2012 Rank	2012 Mean*	2012 Parity string	2013 Rank	2013 Mean*	2013 Parity string
Less than 5K	1	3.22	a	2	4.83	ac	1	**6.00**	a	1	**7.17**	a
5K-10K	4	1.92	baed	3	4.29	bca	3	5.35	bac	3	6.40	bac
10K-15K	5	1.71	caeb	1	**4.95**	c	2	5.95	ca	2	6.96	ca
15K-20K	3	2.58	dae	5	2.68	de	5	3.45	d	5	4.23	d
Above 20K	2	2.59	ea	4	3.64	eab	4	4.47	eab	4	5.30	eb
F value	2.04			8.2			8.2			8.2		
Significant or not	Not significant			**Significant**			**Significant**			**Significant**		

*Unit in m^2 per capita, **los=Level of significance

Table F value for the year 2010 is 2.42 (5%) and 3.38 (1%), for the year 2011 – 2013 the value is 2.42(5%) and 3.41 (1%).

Table 7.13 shows that all the footprint values of wastes except for paper and plastic, showed significance in all the years (2010-2013). The paper and plastic footprint values show significant variations only in the base year (2010). Paper footprint (2010) is highest for the HHIB followed by HHIE, HHID, HHIC and HHIA. Glass and metal footprint (2010) is highest for HHIC followed by HHIE, HHIB, HHID and HHIA. Organic footprint (2010) is highest for HHIB followed HHIC, HHI5, HHIA and HHID. Plastic footprint (2010) is highest for HHIA followed by HHIE, HHIB, HHID and HHIC. Paper footprint (2011-2013) is maximum for HHIE followed by HHIB, HHID, HHIC and HHIA. Glass and organic footprint (2011-2013) shows maximum for HHIC followed by HHIB, HHIE, HHIA and HHID. Metal footprint (2011-2013) is highest for HHIC followed by HHIB, HHIE, HHID and HHIA. Plastic footprint (2011-2013) shows maximum for HHID followed by the groups HHIA, HHIB, HHIE and HHIC. The parity checks are also explained in the tables.

7.2.6 Yearly Variations with respect to Type of Waste Disposal

The variations based on the waste disposal method adopted are given in Table 7.14 and 7.15. The table shows that the metal and organic waste (2010) and the glass waste (2011-2013) generation shows significance. Glass waste generation (2011-2013) and organic waste generation (2010) in the houses which depends on community level waste disposal (CLWD) is more when compared to houses which opt for household level waste disposal (HLWD). The paper, metal, organic footprint values (2010-2013) and plastic footprint values (2010) shows more in CLWD than houses with HLWD. The reason for this can be put to the attitude of the people. If people are disposing in the CLWD methods, they are not bothered about the quantity of waste generation because they have the notion that the authorities responsible for the CLWD methods will dispose the waste. But people who opt for HLWD methods tend to reduce the quantity of waste generation as they are themselves responsible for the disposal and related problems.

Table 7.14 Yearly Variations in the Quantity of Waste with respect to the Type of Waste Disposal

Variables		Paper waste											
Year		2010			2011			2012			2013		
Factors		Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Waste disposal	Household level	2	0.26	ab	2	0.33	ab	2	0.35	ab	2	0.37	ab
	Community level	1	0.26	b	1	0.35	b	1	0.37	b	1	0.39	b
F value		0			1.23			1.23			1.24		
Significant or not		Not Significant			Not significant			Not significant			Not significant		

Variables		Glass waste											
Year		2010			2011			2012			2013		
Factors		Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Waste disposal	Household level	1	0.58	a	1	**0.73**	a	1	**0.74**	a	1	**0.75**	a
	Community level	2	0.52	ba	2	0.60	b	2	0.61	b	2	0.62	b
F value		3.72			4.08			4.08			4.08		
Significant or not		Not Significant			**Significant at 5% level of significance**			**Significant at 5% level of significance**			**Significant at 5% level of significance**		

Variables		Metal waste											
Year		2010			2011			2012			2013		
Factors		Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Waste disposal	Household level	2	**0.96**	a	2	1.22	ab	2	1.32	ab	2	1.42	ab
	Community level	1	1.24	b	1	1.40	b	1	1.50	b	1	1.60	b
F value		7.7			2.33			2.33			2.33		
Significant or not		**Significant**			Not significant			Not significant			Not significant		

Variables		Organic waste											
Year		2010			2011			2012			2013		
Factors		Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Waste disposal	Household level	2	8.97	a	1	9.86	a	1	10.36	a	1	10.86	a
	Community level	1	**9.79**	b	2	9.86	ba	2	10.36	ba	2	10.86	ba
F value		4.66			0			0			0		
Significant or not		**Significant at 5% level of significance**			Not significant			Not significant			Not significant		

Variables		Plastic waste											
Year		2010			2011			2012			2013		
Factors		Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Waste disposal	Household level	2	0.14	ab	1	0.23	a	1	0.28	a	1	0.33	a
	Community level	1	0.15	b	2	0.22	ba	2	0.27	ba	2	0.32	ba
F value		1.01			0.31			0.31			0.31		
Significant or not		Not Significant			Not significant			Not significant			Not significant		

*Unit in kg/house/week

Table F value for the year 2010 is 3.87 (5%) and 6.72 (1%), for the year 2011 – 2013 the value is 3.88(5%) and 6.76 (1%).

Table 7.15 Yearly Variations in the Footprint Values with respect to the Type of Waste Disposal

Variables		Paper footprint											
Year		2010			2011			2012			2013		
Factors		Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Waste disposal	Household level	2	2.91	a	2	3.77	a	2	4.02	a	2	4.27	a
	Community level	1	**3.33**	b	1	**4.42**	b	1	**4.70**	b	1	**4.98**	b
F value		4.8			6.21			6.41			6.58		
Significant or not		**Significant at 5% level of significance**			**Significant at 5% level of significance**			**Significant at 5% level of significance**			**Significant at 5% level of significance**		

Variables		Glass footprint											
Year		2010			2011			2012			2013		
Factors		Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Waste disposal	Household level	2	2.61	ab	1	3.42	a	1	3.47	a	1	3.52	a
	Community level	1	2.87	b	2	3.33	ba	2	3.39	ba	2	3.45	ba
F value		0.77			0.08			0.07			0.06		
Significant or not		Not Significant			Not significant			Not significant			Not significant		

Variables		Metal footprint											
Year		2010			2011			2012			2013		
Factors		Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Waste disposal	Household level	2	17.88	a	2	24.82	a	2	26.89	a	2	28.97	a
	Community level	1	**28.44**	b	1	**32.51**	b	1	**34.84**	b	1	**37.18**	b
F value		22.78			7.35			7.63			7.89		
Significant or not		**Significant**			**Significant**			**Significant**			**Significant**		

Variables		Organic footprint											
Year		2010			2011			2012			2013		
Factors		Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Waste disposal	Household level	2	86.23	a	2	99.42	a	2	104.62	a	2	109.82	a
	Community level	1	**108.82**	b	1	**112.16**	b	1	**118.00**	b	1	**123.83**	b
F value		20.94			4.28			4.5			4.71		
Significant or not		**Significant**			**Significant at 5% level of significance**			**Significant at 5% level of significance**			**Significant at 5% level of significance**		

Variables		Plastic footprint											
Year		2010			2011			2012			2013		
Factors		Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Waste disposal	Household level	2	2.04	a	2	3.71	ab	2	4.58	ab	2	5.44	ab
	Community level	1	**2.71**	b	1	4.00	b	1	4.98	b	1	5.95	b
F value		6.05			0.59			1.04			1.54		
Significant or not		**Significant at 5% level of significance**			Not significant			Not significant			Not significant		

*Unit in m^2 per capita

Table F value for the year 2010 is 3.87 (5%) and 6.72 (1%), for the year 2011 – 2013 the value is 3.88(5%) and 6.76 (1%).

7.2.7 Yearly Variations with respect to Housing Unit

Table 7.16 and 7.17 shows the waste generation trend and footprint variations with respect to the type of housing unit. There are no significant variation of means except for paper and metal waste generation (2010) and organic waste generation (2011-2013); glass (2010) and metal and organic footprint values (2010-2013).

For paper waste in 2010, the row housing units (RHU) generated more waste followed by houses in individual plots (HIP), low rise buildings (LRB) and high rise buildings (HRB). The parity check of the paper generation trend showed that the HIP showed parity with RHU; LRB showed parity with HIP and RHU; and the HRB showed parity with LRB.

The metal waste generation (2010) is more for LRB, followed by RHU, HIP and HRB. The parity checks showed that HIP shows parity with RHU; RHU show similarity with LRB; and HRB show parity with HIP in the case of metal waste generation. The amount of organic waste tend to get generate more in HRB, followed by samples in RHU, LRB and HIP. Parity checks show that the waste generation trend of HIP shows parity with LRB and HRB; RHU with HRB; LRB with HRB and RHU.

The paper footprint is more for HIP, followed by LRB, RHU and HRB. The parity check shows that the RHU show parity with HIP and LRB. LRB show parity with HIP. The metal footprint values, organic and plastic footprint values show the same trend of glass footprint. The parity check of organic footprint shows that the footprint values of RHU shows parity with LRB; HRB show parity with HIP.

The plastic footprint is more for HIP, followed by LRB, RHU and HRB. The parity check of plastic footprint shows that the RHU show parity with HIP and HRB; LRB show parity with HIP; and HRB shows parity with all the other three housing units.

Table 7.16 Yearly Variations in the Quantity of Waste Generation with respect to Type of Housing Unit

Variables	Paper waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Type of housing unit: Individual plot	2	0.26	ab	3	0.34	abd	3	0.36	abd	3	0.38	abd
Type of housing unit: Row Housing unit	1	**0.28**	b	1	0.36	b	1	0.38	b	1	0.40	b
Type of housing unit: Low rise building	3	0.24	cba	4	0.31	cbda	4	0.33	cbda	4	0.35	cbda
Type of housing unit: High rise building	4	0.21	dc	2	0.36	db	2	0.38	db	2	0.40	db
F value	2.64			1.67			1.67			1.67		
Significant or not	**Significant at 5% los**			Not significant			Not significant			Not significant		

Variables	Glass waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Type of housing unit: Individual plot	4	0.52	abd	4	0.63	acb	4	0.64	acb	4	0.65	acb
Type of housing unit: Row Housing unit	2	0.55	bc	3	0.66	bdc	3	0.67	bdc	3	0.68	bdc
Type of housing unit: Low rise building	1	0.73	c	2	0.74	cd	2	0.75	cd	2	0.76	cd
Type of housing unit: High rise building	3	0.53	dcb	1	0.88	d	1	0.89	d	1	0.90	d
F value	1.57			0.88			0.88			0.88		
Significant or not	Not Significant			Not significant			Not significant			Not significant		

Variables	Metal waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Type of housing unit: Individual plot	3	1.00	ab	3	1.21	acb	3	1.31	acb	3	1.41	acb
Type of housing unit: Row Housing unit	2	1.21	bc	2	1.47	bc	2	1.57	bc	2	1.67	bc
Type of housing unit: Low rise building	1	**1.54**	c	1	1.49	c	1	1.59	c	1	1.69	c
Type of housing unit: High rise building	4	0.64	da	4	0.84	dcb	4	0.94	dcb	4	1.04	dcb
F value	5.9			2.36			2.36			2.36		
Significant or not	**Significant**			Not significant			Not significant			Not significant		

Variables	Organic waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Type of housing unit: Individual plot	4	8.99	adc	4	9.25	ac	4	9.75	ac	4	10.25	ac
Type of housing unit: Row Housing unit	2	10.11	bd	2	10.99	bd	2	11.49	bd	2	11.99	bd
Type of housing unit: Low rise building	3	9.95	cdb	3	9.87	cdb	3	10.37	cdb	3	10.87	cdb
Type of housing unit: High rise building	1	10.26	d	1	**11.00**	d	1	**11.50**	d	1	**12.00**	d
F value	2.44			3.96			3.96			3.96		
Significant or not	Not Significant			**Significant**			**Significant**			**Significant**		

Variables	Plastic waste											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Type of housing unit: Individual plot	2	0.15	ad	3	0.22	abd	3	0.27	abd	3	0.32	abd
Type of housing unit: Row Housing unit	3	0.13	bda	1	0.25	b	1	0.30	b	1	0.35	b
Type of housing unit: Low rise building	4	0.12	cdab	4	0.19	cbda	4	0.24	cbda	4	0.29	cbda
Type of housing unit: High rise building	1	0.16	d	2	0.23	db	2	0.28	db	2	0.33	db
F value	0.61			0.79			0.79			0.79		
Significant or not	Not Significant			Not significant			Not significant			Not significant		

*Unit in kg/house/week, **los=Level of significance
Table F value for the year 2010 is 2.63 (5%) and 3.85 (1%), for the year 2011 – 2013 the value is 2.65(5%) and 3.88 (1%).

Table 7.17 Yearly Variations in the Footprint Values with respect to Type of Housing Unit

Variables	Paper footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Housing unit: Individual plot	1	3.19	a	1	4.31	a	1	4.58	a	1	4.85	a
Housing unit: Row Housing unit	3	3.02	bac	3	3.82	bac	3	4.08	bac	3	4.34	bac
Housing unit: Low rise building	2	3.18	ca	2	4.04	ca	2	4.31	ca	2	4.58	ca
Housing unit: High rise building	4	2.05	d	4	3.35	dcb	4	3.54	dcb	4	3.73	dcb
F value	2.42			1.2			1.2			1.21		
Significant or not	Not Significant			Not significant			Not significant			Not significant		

Variables	Glass footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Housing unit: Individual plot	3	2.49	ab	4	3.16	adb	4	3.21	adb	4	3.27	adb
Housing unit: Row Housing unit	2	2.67	b	3	3.35	bcd	3	3.40	bcd	3	3.45	bcd
Housing unit: Low rise building	1	**4.26**	c	1	4.15	c	1	4.21	c	1	4.27	c
Housing unit: High rise building	4	2.21	dba	2	3.55	dc	2	3.59	dc	2	3.62	dc
F value	5.65			1.74			1.74			1.74		
Significant or not	**Significant**			Not significant			Not significant			Not significant		

Variables	Metal footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Housing unit: Individual plot	3	20.16	a	3	26.27	ab	3	28.50	ab	3	30.74	ab
Housing unit: Row Housing unit	2	26.34	b	2	31.88	bc	2	34.06	bc	2	36.25	bc
Housing unit: Low rise building	1	**36.46**	c	1	**35.28**	c	1	**37.56**	c	1	**39.84**	c
Housing unit: High rise building	4	11.47	d	4	14.29	d	4	15.88	d	4	17.46	d
F value	10.37			3.06			3.06			3.06		
Significant or not	**Significant**			**Significant at 5% los****			**Significant at 5% los****			**Significant at 5% los****		

Variables	Organic footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Housing unit: Individual plot	3	90.86	a	3	98.68	ac	3	104.27	ac	3	109.86	ac
Housing unit: Row Housing unit	2	107.73	bc	1	**119.11**	b	1	**124.58**	b	1	**130.04**	b
Housing unit: Low rise building	1	**118.94**	c	2	113.10	cb	2	118.81	cb	2	124.51	cb
Housing unit: High rise building	4	82.94	da	4	87.38	dca	4	91.34	dca	4	95.30	dca
F value	6.18			3.33			3.21			3.1		
Significant or not	**Significant**			**Significant at 5% los****			**Significant at 5% los****			**Significant at 5% los****		

Variables	Plastic footprint											
Year	2010			2011			2012			2013		
Factors	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Housing unit: Individual plot	1	2.42	a	2	3.78	ab	2	4.71	ab	2	5.64	ab
Housing unit: Row Housing unit	3	2.16	bac	1	4.32	b	1	5.23	b	1	6.14	b
Housing unit: Low rise building	2	2.28	ca	3	3.51	cba	3	4.46	cba	3	5.41	cba
Housing unit: High rise building	4	2.10	dacb	4	3.10	dbac	4	3.76	dbac	4	4.42	dbac
F value	0.22			0.89			0.89			0.91		
Significant or not	Not Significant			Not significant			Not significant			Not significant		

*Unit in m^2 per capita, **los=Level of significance
Table F value for the year 2010 is 2.63 (5%) and 3.85 (1%), for the year 2011 – 2013 the value is 2.65(5%) and 3.88 (1%).

7.2.8 Yearly Variations with respect to Ownership

The variations based on ownership details of the houses in the quantity of waste generation and footprint values are given in Table 7.18 and 7.19. The variations are not highly significant in the type of waste and the footprint values except for paper (2010), metal (2010), plastic waste (2011-2013), paper footprint (2010) and metal footprint values (2010 - 2013).

The paper waste (2010) is more in individual owned buildings (IOBs) followed by builder owned buildings (BOBs) and government owned buildings (GOBs). The parity check shows that the GOBs show parity with the other IOBs and BOBs and the BOBs show parity with IOBs in the case of paper waste generation (2010).

The metal waste generation (2010) is more for GOBs followed by IOBs and builder owned. In the case of metal waste, the IOBs show parity with the other two and the BOBs shows parity with GOBs. The plastic waste generation (2011-2013) is more in BOBs followed by GOBs and IOBs. Parity check for plastic waste (2011-2013) shows that the IOBs show parity with the GOBs and the GOBs showed parity with BOBs.

The paper footprint values (2010) are more for IOBs followed by BOBs and GOBs. The parity checks show that the GOBs show parity with the BOBs. The metal footprint is high in IOBs followed by GOBs and BOBs (2010-2013). The parity check shows that the GOBs shows parity with the IOBs and the BOBs shows parity with the GOBs.

Table 7.18 Yearly Variations in the Quantity of Waste with respect to the Type of Ownership of the House

Variables	Paper waste											
Year	2010			2011			2012			2013		
Factors: Ownership	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Individual	1	**0.26**	a	1	0.34	a	1	0.36	a	1	0.38	a
Government	3	0.16	bac	3	0.29	bac	3	0.31	bac	3	0.33	bac
Builder	2	0.2	ca	2	0.33	ca	2	0.35	ca	2	0.37	ca
F value	3.09			1.06			1.06			1.06		
Significant or not	**Significant at 5% level of significance**			Not significant			Not significant			Not significant		

Variables	Glass waste											
Year	2010			2011			2012			2013		
Factors: Ownership	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Individual	3	0.55	abc	3	0.65	abc	3	0.66	abc	3	0.67	abc
Government	1	0.68	b	1	0.89	b	1	0.90	b	1	0.91	b
Builder	2	0.60	cb	2	0.77	cb	2	0.78	cb	2	0.79	cb
F value	0.12			0.93			0.93			0.93		
Significant or not	Not Significant			Not significant			Not significant			Not significant		

Variables	Metal waste											
Year	2010			2011			2012			2013		
Factors: Ownership	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Individual	2	1.11	ab	2	1.33	ab	2	1.43	ab	2	1.53	ab
Government	1	**1.16**	b	1	1.37	b	1	1.47	b	1	1.57	b
Builder	3	0.34	cb	3	0.57	cb	3	0.67	cb	3	0.77	cb
F value	3.37			2.46			2.46			2.46		
Significant or not	**Significant at 5% level of significance**			Not significant			Not significant			Not significant		

Variables	Organic waste											
Year	2010			2011			2012			2013		
Factors: Ownership	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Individual	3	9.31	abc	3	9.83	abc	3	10.33	abc	3	10.827	abc
Government	1	11.32	b	1	10.62	b	1	11.12	b	1	11.617	b
Builder	2	9.58	cb	2	10.28	cb	2	10.78	cb	2	11.28	cb
F value	0.57			0.21			0.21			0.21		
Significant or not	Not Significant			Not significant			Not significant			Not significant		

Variables	Plastic waste											
Year	2010			2011			2012			2013		
Factors: Ownership	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Individual	2	0.14	ab	3	0.21	ab	3	0.26	ab	3	0.31	ab
Government	1	0.25	b	2	0.34	bc	2	0.39	bc	2	0.44	bc
Builder	3	0.11	cba	1	**0.42**	c	1	**0.47**	c	1	**0.52**	c
F value	0.86			5.94			5.94			5.94		
Significant or not	Not Significant			**Significant**			**Significant**			**Significant**		

*Unit in kg/house/week

Table F value for the year 2010 is 3.03 (5%) and 4.68 (1%), for the year 2011 – 2013 the value is 3.04(5%) and 4.71(1%).

Table 7.19 Yearly Variations in the Footprint Values with respect to the Type of Ownership of the House

Variables	Paper footprint											
Year	2010			2011			2012			2013		
Factors: Ownership	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Individual	1	**3.15**	a	1	4.17	a	1	4.44	a	1	4.71	a
Government	3	1.71	bc	3	2.99	bac	3	3.20	bac	3	3.41	bac
Builder	2	1.86	c	2	3.13	ca	2	3.32	ca	2	3.50	ca
F value	3.8			1.93			2.05			2.15		
Significant or not	**Significant at 5% level of significance**			Not significant			Not significant			Not significant		

Variables	Glass footprint											
Year	2010			2011			2012			2013		
Factors: Ownership	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Individual	2	2.74	ab	2	3.37	ab	2	3.42	ab	2	3.48	ab
Government	1	2.98	b	1	3.91	b	1	3.95	b	1	4.00	b
Builder	3	2.29	cba	3	3.08	cba	3	3.12	cba	3	3.16	cba
F value	0.15			0.22			0.22			0.22		
Significant or not	Not Significant			Not significant			Not significant			Not significant		

Variables	Metal footprint											
Year	2010			2011			2012			2013		
Factors: Ownership	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Individual	1	**23.23**	a	1	**29.55**	a	1	**31.79**	a	1	**34.03**	a
Government	2	20.41	ba	2	24.13	ba	2	25.89	ba	2	27.65	ba
Builder	3	5.54	cb	3	9.42	cb	3	11.01	cb	3	12.59	cb
F value	3.58			2.88			3.01			3.13		
Significant or not	**Significant at 5% level of significance**			**Significant at 5% level of significance**			**Significant at 5% level of significance**			**Significant at 5% level of significance**		

Variables	Organic footprint											
Year	2010			2011			2012			2013		
Factors: Ownership	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Individual	2	97.20	ab	1	107.19	a	1	112.80	a	1	118.40	a
Government	1	99.55	b	2	93.39	ba	2	97.79	ba	2	102.19	ba
Builder	3	72.10	cba	3	81.08	cab	3	85.04	cab	3	89.00	cab
F value	1.44			1.21			1.32			1.43		
Significant or not	Not Significant			Not significant			Not significant			Not significant		

Variables	Plastic footprint											
Year	2010			2011			2012			2013		
Factors: Ownership	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string	Rank	Mean*	Parity string
Individual	2	2.36	ab	3	3.77	acb	3	4.71	acb	3	5.64	acb
Government	1	3.63	b	2	4.91	bc	2	5.65	bc	2	6.38	bc
Builder	3	1.40	cba	1	5.84	c	1	6.50	c	1	7.16	c
F value	1.16			2.11			1.45			0.92		
Significant or not	Not Significant			Not significant			Not significant			Not significant		

*Unit in m^2 per capita

Table F value for the year 2010 is 3.03 (5%) and 4.68 (1%), for the year 2011 – 2013 the value is 3.04(5%) and 4.71(1%).

7.3 ANALYSIS OVER THE YEARS

The analysis of waste footprint values of the households over the years were carried out for variables like household size, household income, type of housing unit, ownership for the different category of wastes and footprint values. The homogenous error testing of variance found insignificant for the other variables and therefore they were omitted. Then, the pooled analysis over the years were carried out for significant parameters/variables (household size, household income, type of housing unit and ownership) to check whether there is variation in the quantity of wastes and footprint values within year, between the parameter classes and within year and between parameter classes.

7.3.1 Variations Based on Household Size

Analysis of the variation of various components of wastes and footprint values with respect to household size over the years is shown in Table 7.20 and 7.21 respectively. Table shows that within the year (2010-2013), the variations are significant for paper, glass and plastic wastes generation and for paper, metal, plastic footprint values. The average mean variations of the ANOVA analysis conducted for these variables over the years (2010-2013) are shown in Table 7.22. The ANOVA (7.22) shows that, the generation of paper waste is increasing from year to year. The temporal variations shows that the there is significant increase in the generation of glass waste up to the year 2012 (i.e. 0.61 kg in 2010 followed by 0.74 in 2011 and 0.90 in 2012) and then shows a decrease in the year 2013(0.69). The metal waste is also showing an increasing trend. The temporal variation in the paper footprint values over the years shows that, the footprint values were 2.86 hectares per capita in 2010 which has increased to 3.74 in 2011, then to 3.79 in 2012 and 4.18 in 2013. The metal footprint values also shows significant increase from 23.05 hectares per capita in 2010 to 33.67 hectares per capita in 2013.

Table 7.20 Household Size versus Quantity of Wastes Over the Years

	Paper waste			Glass waste			Metal waste			Organic waste			Plastic waste		
	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes
Calculated F value	24.37	2.52	0.40	3.12	8.70	1.04	2.29	1.09	0.75	0.44	74.10	0.20	11.13	20.05	0.69
Table F (5%)	2.9	3.26	1.83	2.9	3.26	1.83	2.9	3.26	1.83	2.9	3.26	1.83	2.9	3.26	1.83
Table F (1%)	4.46	5.41	2.33	4.46	5.41	2.33	4.46	5.41	2.33	4.46	5.41	2.33	4.46	5.41	2.33
Significant or Not	**S****	NS	NS	**S***	**S****	NS	NS	NS	NS	NS	**S****	NS	**S****	**S****	NS

S* - Significant at 5% level of significance, S** - Significant at 5% and 1% level of significance, NS – Not Significant

Table 7.21 Household Size versus Waste Footprint Values Over the Years

	Paper footprint			Glass footprint			Metal footprint			Organic footprint			Plastic footprint		
	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes
Calculated F value	5.97	131.13	0.33	1.05	12.80	0.28	4.03	21.80	0.71	1.43	56.48	0.55	11.41	2.67	1.91
Table F (5%)	2.9	3.26	1.83	2.9	3.26	1.83	2.9	3.26	1.83	2.9	3.26	1.83	2.9	3.26	1.83
Table F (1%)	4.46	5.41	2.33	4.46	5.41	2.33	4.46	5.41	2.33	4.46	5.41	2.33	4.46	5.41	2.33
Significant or Not	**S****	**S****	NS	NS	**S****	NS	**S***	**S****	NS	NS	**S****	NS	**S****	NS	**S***

S* - Significant at 5% level of significance, S** - Significant at 5% and 1% level of significance, NS – Not Significant

Table 7.22 Yearly Mean Variations of the Significant Dependent Variables with respect to Household Size.

Significant Dependent Variable	Average mean values			
	2010	2011	2012	2013
Paper waste*	0.27	0.34	0.36	**0.38**
Glass waste*	0.61	0.74	**0.90**	0.69
Plastic waste*	0.18	0.25	0.32	**0.37**
Paper footprint**	2.85	3.74	3.80	**4.18**
Metal footprint**	23.05	27.98	29.20	**33.67**
Plastic footprint**	2.67	3.98	4.04	**5.84**

* Waste generation in kg/week/house, ** Waste footprint value in sqm per capita

The analysis also shows that there are significant mean variations in the generation of organic waste between the HH size classes, which is increasing with the HH size but shows a slight increase for the households with HH size three. The plastic footprint values has been on the increase from year to year which have increased from 2.67 hectares per capita in 2010 5.48 hectares per capita in 2013. The dependentant variables which showed significant mean variations between the household size classes are shown and the mean variations are explained in Table 7.23.

Table 7.23 Mean Variations of the Significant Dependent Variables between Household Size Classes

Significant Dependent Variable	Average mean values with respect to HH size				
	2	3	4	5	More than 5
Glass waste*	1.09	1.35	1.32	1.20	**1.36**
Organic waste*	9.35	11.14	10.13	10.08	**14.55**
Plastic waste*	0.19	0.28	0.26	0.23	**0.45**
Paper footprint**	**6.19**	4.20	3.49	2.63	1.71
Glass footprint**	**4.03**	2.95	2.34	3.07	2.59
Metal footprint**	**43.62**	39.52	25.62	18.70	14.91
Organic footprint**	**150.71**	116.50	96.79	66.06	77.51
Total footprint**	**216.85**	178.1	119.60	98.51	100.67

* Waste generation in kg/week/house, ** Waste footprint value in sqm per capita

Table 7.23 shows that the there are fluctuations in the average mean values in the case of glass, organic and plastic waste generation. The paper footprint values show a decline among the household size classes.

7.3.2 Variations Based on Household Income

Analysis of the variation of various components of wastes and footprint values with respect to household income over the years is shown in Table 7.24 and 7.25 respectively. Tables shows that all categories of wastes and footprint values except metal and organic footprint values showed significant mean variations within year. The mean variations are shown in Table 7.26. The average mean variations of the ANOVA analysis conducted for the variables over the years (2010-2013) are shown in Table 7.27.

Table 7.25 shows that, all categories of wastes and footprint values show significant mean variations between HH income classes. But there are no significant mean variations in the variables within year and between HH income classes. All the variables except organic waste, paper footprint and plastic footprint values are showing increasing values up to the year 2012 and then show a decrease. Table 7.27 shows the mean variations of the variables between HH income classes. The variations based on household income shows that the quantity of generation of paper waste is directly proportional to the household income up to the class 15K-20K and then decreases for the income class above 20K. The temporal variations in the amount of glass waste generation over the years shows that, the quantity of glass waste generation has been on the increase from year to year up to 2012 and then shows a decline. The temporal variations in the amount of metal waste generation over the years show that the quantity of metal waste generation has been on the increase up to 2012 and then shows a decline.

Table 7.24 Household Income versus Quantity of Wastes Over the Years

	Paper waste			Glass waste			Metal waste			Organic waste			Plastic waste		
	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes
Calculated F value	24.97	274.50	0.11	3.02	58.29	0.19	4.34	41.20	0.48	4.99	20.61	0.96	13.33	8.11	0.15
Table F (5%)	2.78	3.26	1.8	2.78	3.26	1.8	2.78	3.26	1.8	2.78	3.26	1.8	2.78	3.26	1.8
Table F (1%)	4.15	5.41	2.27	4.15	5.41	2.27	4.15	5.41	2.27	4.15	5.41	2.27	4.15	5.41	2.27
Significant or Not	**S****	**S****	NS	**S***	**S****	NS	**S****	**S****	NS	**S****	**S****	NS	**S****	**S****	NS

S* - Significant at 5% level of significance, S** - Significant at 5% and 1% level of significance, NS – Not Significant

Table 7.25 Household Income Versus Waste Footprint values Over the Years

	Paper footprint			Glass footprint			Metal footprint			Organic footprint			Plastic footprint		
	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes
Calculated F value	10.16	79.57	0.09	3.10	27.28	0.49	2.49	39.23	0.43	1.92	25.23	0.54	23.50	8.15	0.63
Table F (5%)	2.78	3.26	1.8	2.78	3.26	1.8	2.78	3.26	1.8	2.78	3.26	1.8	2.78	3.26	1.8
Table F (1%)	4.15	5.41	2.27	4.15	5.41	2.27	4.15	5.41	2.27	4.15	5.41	2.27	4.15	5.41	2.27
Significant or Not	**S****	**S****	NS	**S***	**S****	NS	NS	**S****	NS	NS	**S****	NS	**S****	**S****	NS

S* - Significant at 5% level of significance, S** - Significant at 5% and 1% level of significance, NS – Not Significant

Table 7.26 Yearly Mean Variations of the Significant Dependent Variables with respect to Household Income

Significant Dependent Variable	Average mean values			
	2010	2011	2012	2013
Paper waste*	0.24	0.33	0.34	**0.36**
Glass waste*	0.50	0.66	**0.73**	0.68
Metal waste*	1.04	1.34	**1.48**	1.44
Organic waste*	9.09	9.28	10.48	**10.89**
Plastic waste*	0.15	0.25	0.30	**0.33**
Paper footprint**	2.80	3.92	4.23	**4.47**
Glass footprint**	2.83	3.23	**3.83**	3.38
Plastic footprint**	2.90	4.38	5.25	**6.33**

* Waste generation in kg/week/house, ** Waste footprint value in sqm per capita

The quantity of organic waste generation has been on the increase from year to year. The variations based on household income shows that the plastic waste generation is highly flexible with income levels. The footprint values showed similar variations as that of their corresponding wastes.

Table 7.27 Mean Variations of the Significant Dependent Variables between Household Income Classes

Significant Dependent Variable	Average mean values with respect to HH income				
	< 5K	5K – 10K	10K- 15K	15K – 20K	>20K
Paper waste*	0.21	0.31	0.35	**0.37**	0.35
Glass waste*	0.31	**0.76**	0.75	0.56	0.85
Metal waste*	0.57	1.55	**1.71**	1.34	1.45
Organic waste*	7.12	10.13	**11.34**	10.5	10.58
Plastic waste*	0.23	0.29	0.25	0.24	**0.35**
Paper footprint**	2.73	3.94	4.1	**4.29**	4.19
Glass footprint**	2.25	**4.56**	3.92	2.42	3.39
Metal footprint**	16.9	39.86	**43.65**	24.42	30.79
Organic footprint**	102.51	126.07	**145.74**	93.1	104.47
Plastic footprint**	5.12	5.43	**5.38**	3.62	4.03
Total footprint**	129.52	178.55	**202.79**	122.99	165.44

* Waste generation in kg/week/house, ** Waste footprint value in sqm per capita

7.3.3 Variation Based on Type of Housing Unit

Analysis of the variation of various components of wastes and footprint values with respect to the type of housing unit over the years is shown in Table 7.28 and 7.29 respectively. Tables shows that only paper waste, paper footprint and plastic footprint showed significant mean variations within year.

The mean variations show that the paper waste generation increased from 0.23 kg/week/house in 2010 to 0.36 kg/week/house in 2013. The plastic footprint also showed similar variation (2.95 sqm/capita in 2010 to 5.76 sqm/capita in 2013). The paper footprint shows an increase from 2.92 sqm/capita in 2010 to 4.56 sqm/capita in 2012 and then shows a decline.

The analysis also shows that paper, glass, organic wastes and paper, glass, metal and plastic footprint values showed significant mean variations between types of housing units. Table 7.30 shows the significant mean variations of the variables between housing unit classes. The paper wastes are showed more generation in row housing units followed by high rise building. Glass wastes and organic wastes showed high generation in high rise buildings. The paper footprint values are more in houses in individual plot. The glass and metal footprint values show highest values in low rise building. The plastic footprint is more in row housing units when compared to other type of housing units. And there are no significant mean variations in the variables within year and between housing unit classes.

Table 7.28 Type of Housing Unit versus Quantity of Wastes Over the Years

	Paper waste			Glass waste			Metal waste			Organic waste			Plastic waste		
	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes
Calculated F value	13.35	4.81	0.67	0.86	8.17	0.44	0.51	1.35	0.67	1.27	10.32	0.25	2.79	0.58	0.66
Table F (5%)	3.01	3.86	2.01	3.01	3.86	2.01	3.01	3.86	2.01	3.01	3.86	2.01	3.01	3.86	2.01
Table F (1%)	4.72	6.99	2.66	4.72	6.99	2.66	4.72	6.99	2.66	4.72	6.99	2.66	4.72	6.99	2.66
Significant or Not	**S****	**S****	NS	NS	**S****	NS	NS	NS	NS	NS	**S****	NS	NS	NS	NS

S* - Significant at 5% level of significance, S** - Significant at 5% and 1% level of significance, NS – Not Significant

Table 7.29 Type of Housing Unit versus Waste Footprint Values Over the Years

	Paper footprint			Glass footprint			Metal footprint			Organic footprint			Plastic footprint		
	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes
Calculated F value	4.82	17.85	0.25	0.68	12.53	0.16	0.86	5.97		0.38	2.12	1.36	7.92	3.92	0.76
Table F (5%)	3.01	3.86	2.01	3.01	3.86	2.01	3.01	3.86	2.01	3.01	3.86	2.01	3.01	3.86	2.01
Table F (1%)	4.72	6.99	2.66	4.72	6.99	2.66	4.72	6.99	2.66	4.72	6.99	2.66	4.72	6.99	2.66
Significant or Not	**S****	**S****	NS	NS	**S****	NS	NS	**S****	NS	NS	NS	NS	**S****	**S***	NS

S* - Significant at 5% level of significance, S** - Significant at 5% and 1% level of significance, NS – Not Significant

Table 7.30 Mean Variations of the Significant Dependent Variables between Housing Unit Classes

Significant Dependent Variable	Average mean values with respect to HH size			
	Individual plot	Row housing unit	Low rise building	High rise building
Paper waste*	0.30	**0.36**	0.29	0.33
Glass waste*	0.49	0.68	0.66	**0.86**
Organic waste*	8.99	10.88	10.22	**11.32**
Paper footprint**	**5.11**	3.84	3.96	3.35
Glass footprint**	3.50	3.49	**4.87**	3.71
Metal footprint**	31.78	27.50	**37.50**	19.83
Plastic footprint**	4.60	**5.48**	4.07	3.43
Total footprint**	140.31	**178.05**	163.85	126.43

* Waste generation in kg/week/house, ** Waste footprint value in sqm per capita

7.3.4 Variation Based on Ownership

Analysis of the variation of various components of wastes and footprint values with respect to the type of ownership of the house over the years is shown in Table 7.31 and 7.32 respectively. Tables shows that only paper waste, paper footprint and glass footprint showed significant mean variations within year. The analysis also shows that paper, glass, metal, plastic wastes and paper, metal and organic footprint values showed significant mean variations between types of ownership classes which is as shown in Table 7.33. And there are no significant mean variations in the variables within year and between housing unit classes. The paper waste, paper footprint and glass footprint values are increasing over the years with respect to the ownership of the house. The paper waste generation is increasing from 0.21 kg/week/house (2010) to 0.32 kg/week/house (2011), 0.33 kg/week/house (2012) and 0.37 kg/week/house (2013). The paper footprint values shows an increase from 2.43 m^2/capita (2010) to 3.72 m^2/capita (2011), 3.98 m^2/capita (2012) and 4.12 m^2/capita (2013). The glass footprint values shows an increase from 2.22 m^2/capita (2010) to 3.51 m^2/capita (2011), 3.98 m^2/capita (2012) and 3.46 m^2/capita (2013).

Table 7.31 Ownership versus Quantity of Waste Over the Years

	Paper waste			Glass waste			Metal waste			Organic waste			Plastic waste		
	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes
Calculated F value	27.37	7.81	1.07	1.25	20.64	0.12	1.13	11.94	0.98	1.50	2.57	0.27	2.27	14.98	0.19
Table F (5%)	3.1	5.14	2.34	3.1	5.14	2.34	3.1	5.14	2.34	3.1	5.14	2.34	3.1	5.14	2.34
Table F (1%)	4.94	10.92	3.29	4.94	10.92	3.29	4.94	10.92	3.29	4.94	10.92	3.29	4.94	10.92	3.29
Significant or Not	**S****	**S****	NS	NS	**S****	NS	NS	**S****	NS	NS	NS	NS	NS	**S****	NS

S* - Significant at 5% level of significance, S** - Significant at 5% and 1% level of significance, NS – Not Significant

Table 7.32 Ownership versus Waste Footprint Values Over the Years

	Paper footprint			Glass footprint			Metal footprint			Organic footprint			Plastic footprint		
	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes	Within Year	Between HH size classes	Within year and between HH size classes
Calculated F value	7.02	146.70	0.10	3.87	1.63	0.63	0.67	36.01	0.18	1.08	17.30	0.37	1.86	3.85	0.12
Table F (5%)	3.1	5.14	2.34	3.1	5.14	2.34	3.1	5.14	2.34	3.1	5.14	2.34	3.1	5.14	2.34
Table F (1%)	4.94	10.92	3.29	4.94	10.92	3.29	4.94	10.92	3.29	4.94	10.92	3.29	4.94	10.92	3.29
Significant or Not	**S****	**S****	NS	**S****	NS	NS	NS	**S****	NS	NS	**S****	NS	NS	NS	NS

S* - Significant at 5% level of significance, S** - Significant at 5% and 1% level of significance, NS – Not Significant

Table 7.33 Mean Variations of the Significant Dependent Variables between Ownership Classes

Significant Dependent Variable	Average mean values with respect to HH size		
	Individual owned	Government owned	Builder owned
Paper waste*	**0.34**	0.27	0.32
Glass waste*	0.58	**0.84**	0.73
Metal waste*	1.52	1.38	**1.61**
Plastic waste*	0.23	0.35	**0.41**
Paper footprint**	**4.79**	2.80	2.97
Metal footprint**	**25.72**	24.32	10.03
Organic footprint**	**114.29**	95.83	82.82
Total footprint**	**161.21**	131.74	104.42

* Waste generation in kg/week/house, ** Waste footprint value in sqm per capita

The variations based on housing ownership in the quantity of generation of paper waste shows that the amount of paper waste generation is more in individual owned buildings (IOBs) followed by builder owned (BOBs) and government owned (GOBs). The amount of glass waste generation is also more for (GOBs) followed by (BOBs) and (IOBs). The amount of metal waste generated is more for (IOBs) followed by (GOBs) and (BOBs). The amount of plastic waste generated is more for (BOBs) followed by (GOBs) and (IOBs). The variations based on ownership classes shows that the paper footprint is high for (IOBs) followed by (BOBs) and (GOBs). The metal footprint is more for (IOBs) followed by (GOBs) and (BOBs) The organic footprint is also more for (IOBs) followed by (GOBs) and (BOBs) the total footprint is more for (IOBs) followed by (GOBs) and (BOBs).

7.4 SUMMARY OF THE CHAPTER

This chapter gives the statistical analysis of the waste footprint of residential areas of Kochi city at different levels for social, economic and environmental factors. The methodology adopted was briefed and the year wise analysis of waste footprint for 2010 - 2013 data were analysed using ANOVA and combined analysis of the data over years were conducted by doing pooled analysis over the significant variables. Table 7.4 – Table 7.19 in the chapter, analysed the yearly variation in quantity of wastes and footprint values with respect to parameters such as season, location, population density, household size, household income, type of housing unit, method of waste disposal and ownership details. The corresponding tables explained the mean variations, significance and parity check with respect to the parameter classes. Then the pooled analysis over the years for significant parameters (household size, household income, type of housing unit and ownership) was carried out to check whether there is variation in the quantity of wastes and footprint values within year, between the parameter classes and within year and between parameters classes (Table 20 – Table 33). The findings of this chapter are consolidated in the next chapter which will also analyse various options for sustainable solid waste management in the residential areas of Kochi city.

CHAPTER 8

SUMMARY OF FINDINGS AND SUSTAINABILITY OPTIONS FOR REDUCING THE WASTE FOOTPRINT OF KOCHI CITY

The findings of the statistical analysis of the waste footprint calculations of the Kochi city are summarized in this chapter. In addition, sustainable options for reducing the waste footprint of residential areas of Kochi city which in turn helps for a sustainable solid waste management in residential areas of Kochi city is also attempted in this chapter.

8.1 SUMMARY OF FINDINGS

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 m^2 per capita of energy land, 0.08 m^2 per capita of forest land and 16.47 m^2 per capita of built up land is required to assimilate the waste generated by the residents of Kochi city. 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. This shows the negative impact of plastics on the environment. 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.

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 show in Table 8.1.

Table 8.1 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. Also the year 2081 was taken based on the life expectancy rate of a person in Kerala (Normally 70 years).

The analysis showed that, with the increase in the density of population, the footprint is increasing as the amount of waste generated is more (Figure 8.1). Also the average footprint is more in the festival season in both the locations.

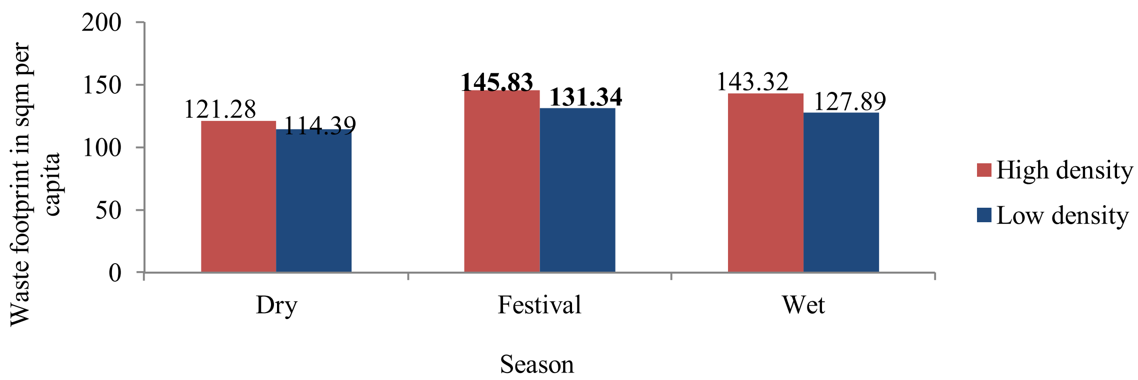

Fig. 8.1 Seasonal Variations in Average Waste Footprint v/s Density of Population

It is also observed that, the bio productive land requirements per person for the paper and plastic content is more in the low density areas whereas all other contents show comparatively high requirement in the high density areas. This may be due to the consumption pattern of the households which varies with the density of the area and seasonal requirements for products like periodicals, food, plastic and other accessories etc.

The amount of wastes generated in different locations in different seasons shows that, the amount of almost all the wastes in all seasons is more in locations near to Central Business District (CBD)/Major Transportation Network (MTN). Food wastes constitute the highest, and then come the metal wastes and glass wastes. The average value of footprint per sqm per capita in different seasons in different locations is given in Figure 8.2. Figure shows that the average foot print values are high in locations near to CBD/MTN. Residences which are near to CBD/MTN show high footprint values in the wet season and festival season. The footprint value is about 20% more when compared to that of the dry season. A similar trend is also noticed in the residences away from CBD/MTN. Over consumption or surplus purchases with seasonal requirements in different locations may be reason for increasing the waste generation, which in turn affects the footprint.

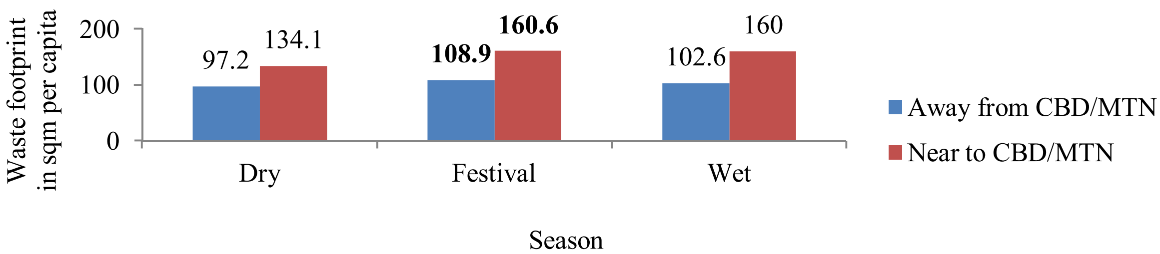

Fig. 8.2 Seasonal Variations in Average Waste Footprint v/s Location

Analysis based on household income shows that the average footprint is comparatively high for the income group Rs.10K - Rs.15K (1 K = Rs. 1000/-) followed by the income group above Rs.20K. The footprint is high in the festival season for all income groups. The lowest contributor to waste footprint is those belonging to the less than Rs. 5K income group. This may be due to high purchasing ability of the higher income groups (up to Rs.10K - Rs.15K) which increase the consumption of commodities. But at the same time the other high income groups (Rs.15K - Rs.20K and above) may be more aware of the harmful effects of waste generation. The comparison of the household income with average footprint is given in Figure 8.3.

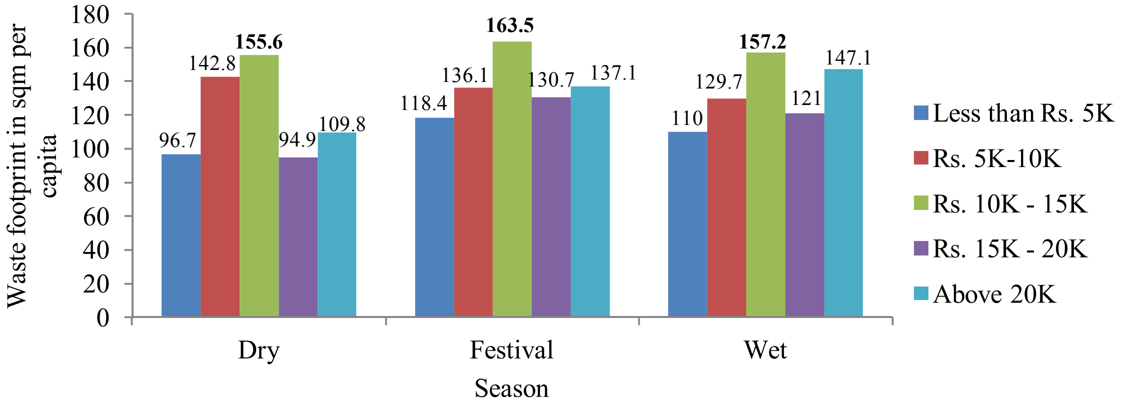

Fig. 8.3 Seasonal Variations in Average Waste Footprint v/s Household Income

Analysis based on the type of housing unit is given in Figure 8.4. Almost all the different types of houses show high footprint values in the festival season. The average waste footprint value is comparatively low for individual plots except in festival season. This may be due to the means of disposal of wastes for gardening, vegetable cultivation and other farming in the household level.

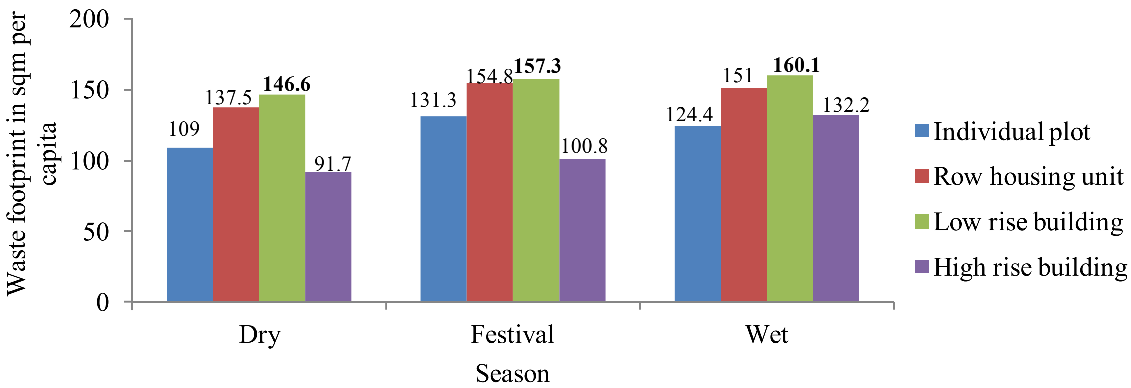

Fig. 8.4 Seasonal Variations in Average Waste Footprint v/s Type of Housing Unit

Residences owned by builders show low waste footprint values compared to other ownership in housing. The footprint values in the wet and festival season are high (Figure 8.5). The reason may be attributed to the variation in the consumption pattern of the residents with respect to the seasonal variations and ownership of the building.

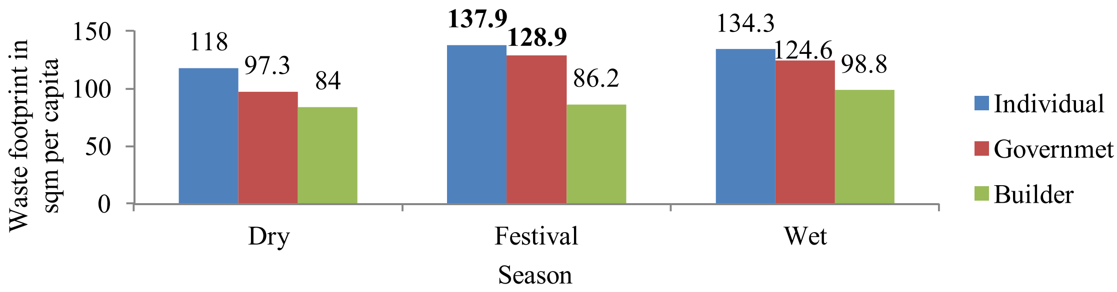

Fig. 8.5 Seasonal Variations in Average Waste Footprint v/s Ownership

Community level disposals is carried out through kudumbashree (a programme introduced by the government of Kerala for women empowerment) workers. They collect wastes from houses and delivered to the municipal solid waste collection points. Disposal of wastes collected through this system being transported to treatment plant/or disposal as land filling. This requires high cost of transportation, energy etc. Therefore community level disposals have high waste footprint values (Figure 8.6) compared to household level disposal methods (disposals in the house premises itself, vermi composting, biogas technology etc.). The waste footprint values are high in festival season. The low waste footprint values for household level disposals shows that the waste disposal at source itself shall be a sustainable option for proper solid waste management.

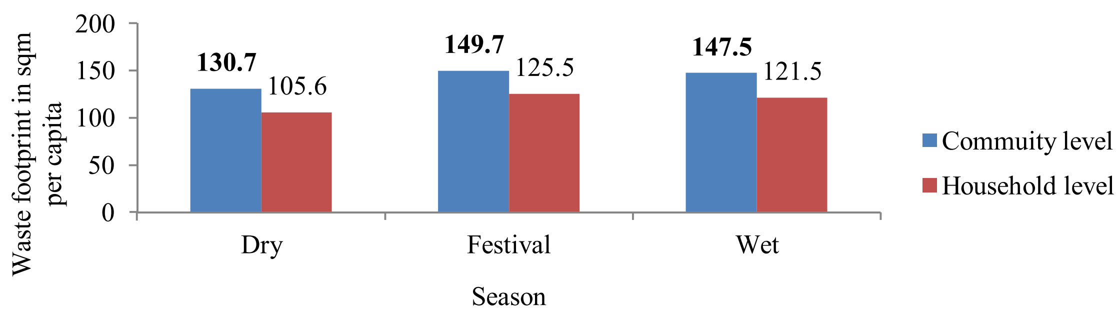

Fig. 8.6 Seasonal Variation in Average Waste Footprint v/s Mode of Waste Disposal

Analysis based on household size and average footprint value showed that the household size is inversely proportional to the average footprint values in all seasons (Figure 8.7). In most cases the footprint value is high in the festival season.

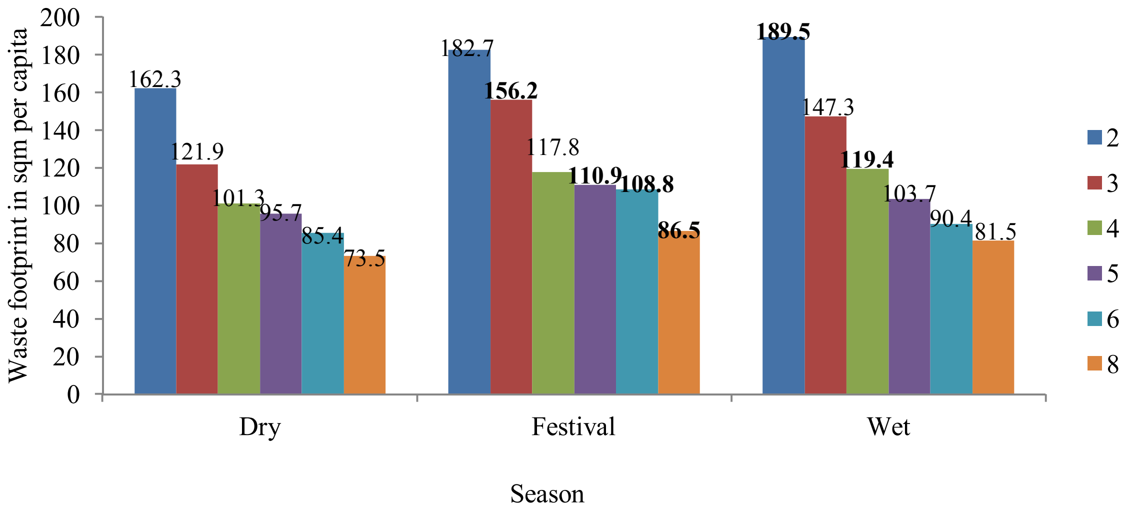

Fig. 8.7 Seasonal Variation in Average Waste Footprint v/s Household Size

The variation of footprint value is given in Table 8.2. It shows that the waste generated per person in low household size families are more when compared to families with large household size. This is because the waste generation/ footprint value will be less for shared commodities like periodicals, carry bags etc. in large household size families. This is contributing the high footprint values in families with small household size.

Table 8.2 Household Size and Percapita Footprint

Household size	Average quantity of waste generated (kg)	Waste generated per person (kg)	Average footprint per person (sqm per capita)
2	9.30	**4.65**	178.13
3	11.09	**3.70**	141.59
4	11.78	**2.94**	112.84
5	13.73	**2.75**	103.54
6	15.09	**2.51**	94.82
8	17.30	**2.16**	80.52

Regarding the recycling status in the city, during the year 2010, only 10.6% of the houses surveyed responded that newspapers and magazines are collected by agencies from households once in six months or more. The households were unaware of the type of recycling method. Since the actual amount of recycled paper is difficult to estimate, it was assumed that about 90% of the paper waste is recycled from each house. It was observed that no active recycling method for glass and metal wastes exists in the study area. Majority of the households revealed that the pickers/scrapers mostly from the state of Tamil Nadu working in the city for the scrap dealers used to visit the houses once in a year. But nowadays residential associations are not permitting such collections, due to security reasons. 8.4 % of the samples practiced organic waste recycling methods like biogas technology and vermi composting. The production of biogas itself made 58% reduction in the organic footprint values. During the course of survey many of the recycling projects for organic waste, mainly pipe composting and biogas production promotion was on the pipe line as per the local body records.

Table 8.3 and 8.4 shows the consolidated findings of the analysis of various components of wastes and footprint values. Table 8.3 shows the analysis of various components of wastes in Kochi city. The table explains the quantity of paper, glass, metal, organic and plastic wastes in percentage to the total waste, the composition of each of the component, average footprint value, the energy land, forest land and built up land required for the assimilation of these wastes, variation of each of the wastes according to seasons, density, location, household size, household income, type of house, waste disposal and ownership.

Table 8.4 explains the analysis of footprint values of different components of wastes. The table shows the average footprint, percentage share of each footprint value to the total footprint, variation of footprint values of the wastes according to seasons, density, location, household size, household income, type of house, waste disposal and ownership.

Table 8.3 Analysis of Various Components of Wastes in Kochi City

Factors	Paper waste	Glass waste	Metal waste	Organic waste	Plastic waste
Quantity	2.6 % of total waste	5.1% of total waste	10.5% of total waste	80.1 % of total waste	1.9 % of total waste
Composition	Magazines, newspapers, paper for packing, notices, information bulletins, paper items related to school, offices, from the house	Bottles, storage jars, crockery etc.	Utensils, equipment parts etc.	Mainly include the food waste.	Includes the carry bags, utensils, storage bins etc.
Average footprint	4.06 m^2 per capita	3.28 m^2 per capita	29.12 m^2 per capita	107.88 m^2 per capita	4.25 m^2 per capita
Energy land	3.53 m^2 per capita	2.92 m^2 per capita	25.89 m^2 per capita	95.92 m^2 per capita	3.78 m^2 per capita
Forest land	0.08 m^2 per capita				
Built up land	0.44 m^2 per capita	0.36 m^2 per capita	3.23 m^2 per capita	11.96 m^2 per capita	0.47 m^2 per capita
Seasonal variation	Maximum during the wet followed by festival and dry season.	Maximum in the dry season followed by wet & festival season.	Maximum in the festival season followed by wet & dry season.	Maximum in the festival season followed by wet & dry season.	Maximum in the festival season followed by dry & wet season.
Density	More in high density areas.	More in low density areas	More in high density areas.	More in low density areas.	More in low density areas
Location	More in locations near to CBD and MTN	More in locations near to CBD and MTN	More in locations near to CBD and MTN	More in locations near to CBD and MTN	More in locations near to CBD and MTN
Household size	More in houses with household size five, followed by household size three, four, more than five and two.	More in houses with household size five, followed by household size more than five, four, three and two.	More in houses with household size three, followed by household size five, four more than five and two.	More in houses with household size more than five followed by household size five, three, four and two.	More in houses with household size more than five followed by household size five, three, four and two.
Household income in rupees (1K = Rs. 1000/-)	Maximum for samples with household income 10K-15K, followed by above 20K, 15K-20K, 5K-10K and less than 5K.	Maximum for samples with household income above 20K followed by 5K-10K, 10K-15K, 15K-20K and less than 5K.	Maximum for samples with household income above 20K followed by 10K-15K, 5K-10K, 15K-20K and less than 5K.	Maximum for samples with household income 10K-15K followed by above 20K, 5K-10K, 15K-20K & less than 5K.	Maximum for samples with household income 10K-15K followed by above 20K, 5K-10K, less than 5K and 15K-20K.
Mode of waste disposal	More in community level disposal methods than household level waste disposal methods.	More in community level disposal methods than household level waste disposal methods.	More in community level disposal methods than household level waste disposal methods.	More in household level waste disposal methods than in community level disposal methods.	More in household level waste disposal methods than in community level disposal methods.
Type of house	Row housing units generated more waste followed by individual plots, low rise buildings and high rise buildings.	High rise buildings generated more waste followed by low rise buildings, row housing units and individual plots.	Low rise buildings generated more waste followed by row housing units, individual plots and high rise buildings.	High rise buildings generated more waste followed by row housing units, low rise buildings and individual plots.	High rise buildings generated more waste followed by individual plots, low rise buildings and row housing units.
Ownership	More in individual owned buildings followed by builder owned and government owned.	More in government owned buildings followed by builder owned and individual owned buildings.	More in individual owned houses followed by builder owned and government owned.	More in government owned followed by individual owned buildings and builder owned buildings.	More in builder owned followed by government owned and individual owned buildings.

Table 8.4 Analysis of Various Footprint Values

Factors	Paper footprint	Glass footprint	Metal footprint	Organic footprint	Plastic footprint
Average footprint	4.06 m^2 per capita	3.28 m^2 per capita	29.12 m^2 per capita	107.88 m^2 per capita	4.25 m^2 per capita
% share to total footprint	2.74%	2.23%	22.02%	70.25%	2.76%
Seasonal variation	More in the wet season followed by dry season and festival season.	Maximum in the dry season followed by wet & festival season.	More in the festival season followed by wet season and dry season	Maximum in the festival season followed by wet & dry season.	Maximum in the festival season followed by wet& dry season.
Density	More in high density areas.	More in high density areas	More in high density areas.	More in high density areas.	More in low density areas
Location	More in locations near to CBD and MTN	More in locations near to CBD and MTN	More in locations near to CBD and MTN	More in locations near to CBD and MTN	More in locations near to CBD and MTN
Household size	Inversely proportional to the household size.	Highest for samples with household size two, followed by household size five, three, four& more than five.	Inversely proportional to household size.	Inversely proportional to the household size except for the class more than five.	Maximum value for household size three followed by two, more than five, four and five.
Household income in rupees (1K = Rs. 1000/-)	Highest for the income group 5K-10K followed by the groups above 20K, 15K-20K, 10K-15K and less than 5K.	Maximum for samples with household income above 20K followed by 5K-10K10K-15K, 15K-20K and less than 5K.	Highest for the 10K-15K group followed by the groups 5K-10K, above 20K, 15K-20K and less than 5K.	Maximum for the group 10K-15K followed by the groups 5K-10K, above 20K, less than 5K and 15K-20K.	Directly proportional to the household income up to the class 10K-15K and then decreases.
Mode of waste disposal	More in community level disposal methods than household level waste disposal methods.	More in community level disposal methods than household level waste disposal methods.	More in community level disposal methods than household level waste disposal methods.	More in community level disposal methods than household level waste disposal methods.	More in community level disposal methods than household level waste disposal methods.
Type of house	More for samples in individual plots followed by low rise buildings, row housing units and high rise buildings.	More for low rise buildings followed by high rise buildings, individual plots and row housing unit.	Maximum in low rise buildings followed by row house buildings, individual plots and high rise buildings.	Maximum in low rise buildings followed by row house buildings, individual plots and high rise buildings.	Maximum in row house buildings followed by individual plots, low rise buildings and high rise buildings.
Ownership	Highest for individual owned buildings followed by builder owned and government owned buildings.	Maximum for the government owned buildings followed by individual owned and builder owned.	Maximum for the individual owned buildings followed by government owned and builder owned.	Maximum for the individual owned buildings followed by government owned and builder owned.	More for the builder owned followed by government owned and individual owned buildings.

8.2 SUSTAINABLE WASTE MANAGEMENT OPTIONS FOR REDUCING THE WASTE FOOTPRINT OF KOCHI CITY

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 (Metro Vancouver , 2010), 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 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 which were mainly 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, going to get launched in the residential areas of the city and outskirts. This includes the biogas production by Kerala Suchitwa Mission, vermi-composting in residential flats by Confederation of Real Estate Developers' Associations of India (CREDAI) Kochi and other programmes by Non Governmental Organisations (NGOs) etc. 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 is expected to happen. 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.

8.2.1 Analysis Based on Different Recycling Levels

Table 8.5 shows, how the waste categories and their recycling levels affects footprint. The 'present recycling' level values for all categories of waste were assigned zero percentage (Column 2). By the initiatives mentioned earlier, 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 for the waste footprint analysis. This will generate the waste footprint for present, targeted and projected values of each category of waste.

Table 8.5 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 8.5 anticipate a 39% reduction (128.86 get reduced to 78.48) in footprint value through the above said programmes going to get launched 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.

8.2.2 Analysis Based on Different Waste Generation Levels

An analysis of the different waste generation levels is attempted in this section. The details are shown in Table 8.6. On entering the various waste reduction level values as explained earlier to the waste footprint output table provided by the waste footprint analyser, the present, targeted and projected waste footprint values are obtained.

Table 8.6 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**

Table shows that, with present waste generation trend, (i.e. 0.1 kg of paper waste, 0.03 kg of glass waste, 0.05 kg of metal waste, 0.42 kg of organic waste and 0.01 kg of plastic waste per capita per day) 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) (i.e. 50% reduction of paper waste; 30% reduction of glass waste and metal waste ; 50% reduction of organic and plastic waste). By projected waste reduction levels (Column 4) (i.e. 80% reduction of paper waste; 50% reduction of glass waste and metal waste; 90% reduction of organic waste; and 75% reduction of plastic waste) 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 8.6 and 8.7, 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.

8.2.3 Analysis Based on the Combination of Waste Reduction and Recycling

Table 8.7 gives a combined analysis of a situation where there is waste reduction and appropriate recycling. According to the analysis, with the recycling techniques proposed to launch in the city as explained in Section 8.2.3 (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 8.7 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**		

And 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.

8.3 PROJECTED LAND REQUIREMENT FOR WASTE MANAGEMENT OF THE CITY

The analysis of ecological footprint of waste generation in the residential areas of Kochi city in the Table 8.1 showed 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 8.8 shows 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.

Table 8.8 Projected Land Requirements for the Waste Management of the City wrt 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 shows that by the targeted value of footprint (43.09 m^2 per capita in Table 8.8), 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 8.8) only 9% area of the city (836.5 hectares) is required for waste assimilation by 2051.

This shows that recycling practices along with waste reduction at source will make the solid waste management sustainable in Kochi city.

8.4 SUMMARY OF THE CHAPTER

The chapter summarizes the findings of the general and statistical analysis of the waste footprint calculations of Kochi city and analysed various options which can reduce the waste footprint of the residential areas of Kochi city. The chapter consolidated the quantity, composition, average footprint and bioproduce land area requirements for each component of waste. The seasonal variations and variations based on density, location, household size, household income, type of house, ownership etc. for these waste components was also discussed. Also findings were arrived from the analysis of footprint values with respect to the variations discussed above. The study also analysed various sustainable options for reducing the footprint values by means of different waste reduction and recycling levels and a combination of the both. The analysis of various sustainable options for reducing the waste footprint of Kochi city also 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 addition, from the waste footprint studies, it is clear that the process of biogas production from organic waste considerably reduce the organic waste of the residents which in turn reduces the waste footprint of the city. Therefore, the research attempts to evaluate the feasibility of biogas production, which is practised in the city, as a sustainable domestic organic waste management measure for waste footprint reduction.

For this, a conceptual framework was developed by identifying different aspects of sustainable domestic organic waste management which is explained in the next chapter. Again, various options for the sustainable waste management of recyclable wastes (paper, metal, glass and plastic) are discussed in the forthcoming chapters.

CHAPTER 9

CONCEPTUAL FRAMEWORK FOR SUSTAINABLE DOMESTIC ORGANIC WASTE MANAGEMENT

The chapter puts forward a conceptual framework for evaluating the sustainability of the domestic organic waste management techniques, which answers the first part of the fourth research question. In addition, for evaluating the existing domestic organic waste management (biogas technology) practiced in the city, a set of factors are identified for each of the aspects of SDOWM to assess whether it can be used as a sustainable domestic organic waste management measure for the Kochi city.

9.1 INTRODUCTION

The idea of sustainable solid waste management, similarly to the integrated solid waste management technique (Van de Klundert et al., 2001), implies the integration of technical, environmental, socio-economic, institutional, legal, political, and even cultural dimensions. Such elements are further discussed in Cointreau (2001) where the 'Declaration of Principles for Sustainable and Integrated Solid Waste Management' (Cointreau, 2001) is listed. These comprise: good governance (accountability, transparency, equity); economic service delivery (cost efficiency, affordability, budget allocation); financial sustainability (cost recovery mechanisms, cash flow); natural resources conservation (resource consumption); public participation (participatory dialogue, awareness raising); environmentally appropriate technologies and sites (minimize impact, monitoring emissions); source segregation, recycling and resource recovery (integration of recycling, markets for recyclables); strategic planning and development (forward looking); capacity building (staff skill development); involvement of private sector actors (integration of alternative actors) etc.

To achieve sustainable and effective waste management, development strategies must go beyond purely technical considerations to formulate specific objectives and implement appropriate measures with regard to political, institutional, social, environmental, economic and technical aspects of solid waste management (Schubeler et al., 1996) For sustainable domestic organic waste management, the waste management system should be socially and economically acceptable to all groups of the society. The environmental impacts of such systems should be minimum or negligible. The system should be preferably locally manufactured, should have maximum efficiency, durable and of good quality. The system should be adaptable and affordable to all sections of the society, simple and easy to operate, low initial and maintenance cost, energy efficient etc. Thus, *we define the sustainable domestic organic waste management as 'the domestic organic waste management system which is environmental friendly, technically feasible, economically viable, and socially acceptable with adequate institutional/organizational support'.*

9.2 WHEEL OF SUSTAINABLE DOMESTIC ORGANIC WASTE MANAGEMENT (SDOWM)

The research figures out the sustainable domestic organic waste management as a wheel and the aspects as its parts. The wheel will rotate only if all the parts move in same direction simultaneously. It can be in a clockwise or an anticlockwise direction which depends on the movement of the first trigger of any of the parts (aspects) (Figure 9.1). If any of the part does not move, the entire system fails. The wheel represents the sustainable domestic organic waste management and its parts represents the different aspects of sustainability such as environmental, technological, economic, social and institutional.

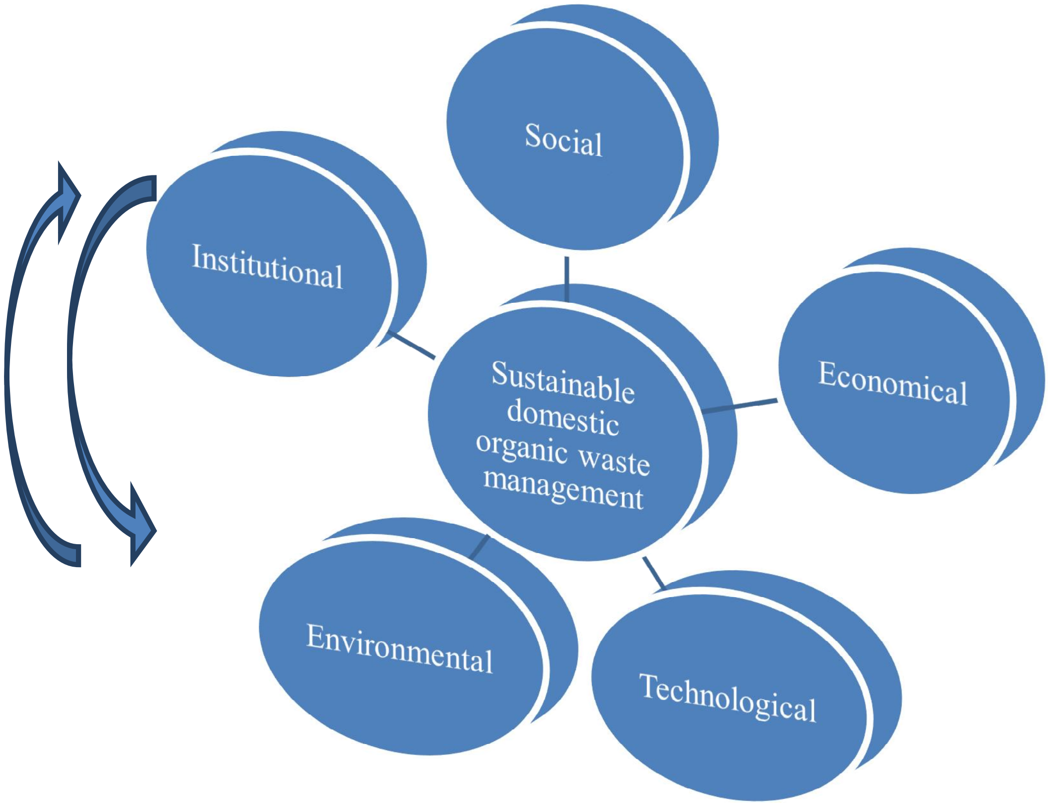

Fig. 9.1 Wheel of Sustainability for Domestic Organic Waste Management

9.3 ASPECTS OF SUSTAINABLE DOMESTIC ORGANIC WASTE MANAGEMENT (SDOWM)

For developing the conceptual framework, firstly, the different aspects of sustainable domestic organic waste management was identified. And then, the different factors that affect the sustainability of each aspect were found out. A brief description of each aspect is given in the following sections.

9.3.1 Environmental Aspects

Besides the objective to protect public health, a second main purpose of solid waste management is the conservation of the (global) resource base and the protection of environment. Achievement of these environmental goals is measured through resource and environmental sustainability. The method of health risk assessment to describe threats to humans is also to be assessed for environmental sustainability (Zurburgg et al., 2014, Yang et al., 2012). In the context of organic waste management in residential areas a sustainable system should not release pollutants into environment, protects existing natural habitat, restores viability of ecosystems, recycles organic nutrients and creates top soil, produces food, cause no health impacts to the users and conserves renewable resources (ISSOWAMA, 2011).

9.3.2 Technical Aspects

The technology assessment of a system long days back refers to a process which is scientific, interactive and communicative, which aims to contribute to the formation of public and political opinion on societal aspects of science and technology. The procedure evaluates possible environmental and societal consequences of new scientific or technological developments which usually do not have a site-specific perspective. As per UNEP-IETC (2012), the assessment became site specific as the overall consequences of the technology are evaluated in the light of local conditions. Later additional aspects are included in the sustainability assessment of technologies such as: stability or resilience; size/scale of operation; flexibility/adaptability; skill levels needed; and other pre-requisites (availability of space, etc.). Also technical assessment should focus on the appropriateness of the technology which was originally articulated as the concept of intermediate technology (Hazeltine and Bull, 1999; Akubue, 2000) which is generally recognized as encompassing a technological choice and application that is low cost, small scale, labor intensive, energy efficient, environmentally sound, locally controlled and people centered.

The technological sustainability is also measured based on the use of local materials, affordable, comprehensible, controllable and maintainable by the users without high levels of education or training (Zurburgg et al., 2014, Tharakan, 2010). Also a system that is technically sustainable also focuses on repair ability (if the technology can be repaired easily by the user after it breaks down), self maintenance, locally grounded, skills, robustness and replicability. Acceptance and perception of users also influence the successful and long term performance of the system (Roma and Jeffery, 2011). With specific reference to solid waste issues the characteristics of appropriate technology should rely on (1) low investment cost per unit of output; (2) organizational simplicity; (3) high adaptability; and (4) sparing use of natural resources (Baetz and Korol, 1995). In addition the technology development by engineers needs to go beyond the functionality and cost effectiveness criteria. But the technology needs an evaluation through the following criteria: (a) integration (within ecosystems); (b) simplicity; (c) resource inputs required; (d) functionality; (e) adaptability; (f) diversity; and (g) observing environmental carrying capacity (Baetz and Korol, 1995).

9.3.3 Economic Aspects

For a waste management system to be economically sustainable it should be cost effective (Zurburgg et al., 2014, Cellini and Kee, 2010). The system should be affordable to all sections of the society. It actually means the access to capital and ability to pay. Ability to pay depends, among others, on the eligibility of subsidies. It should also promotes small scale production, local ownership, bio-regional production, promotes 'right livelihood' (meaningful work, income) and should be labor intensive (Nelson and Yudelson, 1976). Construction costs and maintenance, materials and labour should be optimum for the adoption of the technology. The technological choice is highly depended on the overall cost of construction. Low income groups hesitate to adopt new technologies partly due to their suspicion about the benefits of technologies and partly due to their socio economic constraints (Vishnudas et al., 2006; Paudel and Thapa, 2004). Therefore an economically sustainable system also should recover the operational expenditures by the revenues (ISSOWAMA, 2011).

9.3.4 Social Aspects

Solid waste management is not something that can be solved only by smart innovative, technology or engineering. As a dominant urban issue, it relates closely to people through waste generation and is linked to lifestyles and resource consumption patterns. As people are the source of waste, socio-economic and cultural issues are important aspects to tackle. The interaction among people their participation and empowerment are critical in all phases of a solid waste project. Furthermore social acceptance, affordability and willingness to pay are additional aspects that have to be established and coordination using a common platform in order to ensure a long term solution for sustainable solid waste management.

Social endorsement of any proposed project by the residents and community will necessitate their interest, motivation and willingness to participate and contribute to the process and the objectives of the project (Zurburgg et al., 2014, Luthi et al., 2011). This may include changing behaviour and mind sets or also financial contributions. Social impact criteria may include: equity (distribution of impact on different social groups), participation/collaboration, gender equity, employment, relationships, acceptance, motivation, interest, and influence (power). Understand what people want, what drives them and how they perceived things is considered fundamental to all sustainable development projects and is also true for solid waste management activities. For a well-functioning solid waste management activity, acceptance by all actors, and participation with a certain behaviour, is important (Zurburgg et al., 2014; Varma, 2007).

9.3.5 Institutional/Organizational Aspects

With regard to solid waste issues, an institutional analysis can help identify and assess (Morgan and Taschereau, 1996) local context in terms of roles, responsibilities as defined by legislation and policy, environmental rules, policy and planning frameworks, political drivers, key institutions, governance processes and actors, how governments make decisions, processes at national and sector levels related to environment and services of public good , links or lack of links between institutions, institutional incentives, opportunities and blockages that may influence change and potential champions in government, civil society, private sector, etc. A well-functioning solid waste system requires adequate organizational strength of the involved governmental authority or of a respective private sector stakeholder. The organization should rely on committed skill staff and strong leadership, should interact with other stakeholders in the system, to structure and maintain a successful cooperation (Zurburgg et al., 2014, Nelson and Yudelson, 1976).

9.4 CONCEPTUAL FRAMEWORK FOR SUSTAINABLE DOMESTIC ORGANIC WASTE MANAGEMENT (SDOWM)

Based on the above discussions on different aspects of sustainable domestic organic waste management and their objectives, the factors were identified for each aspect of sustainability. Figure 9.2 presents a conceptual framework for sustainable domestic organic waste management. The framework developed shows the interdependence of the five factors of sustainability as well as their equality. This will help in formulating strategies for sustainable organic waste management.

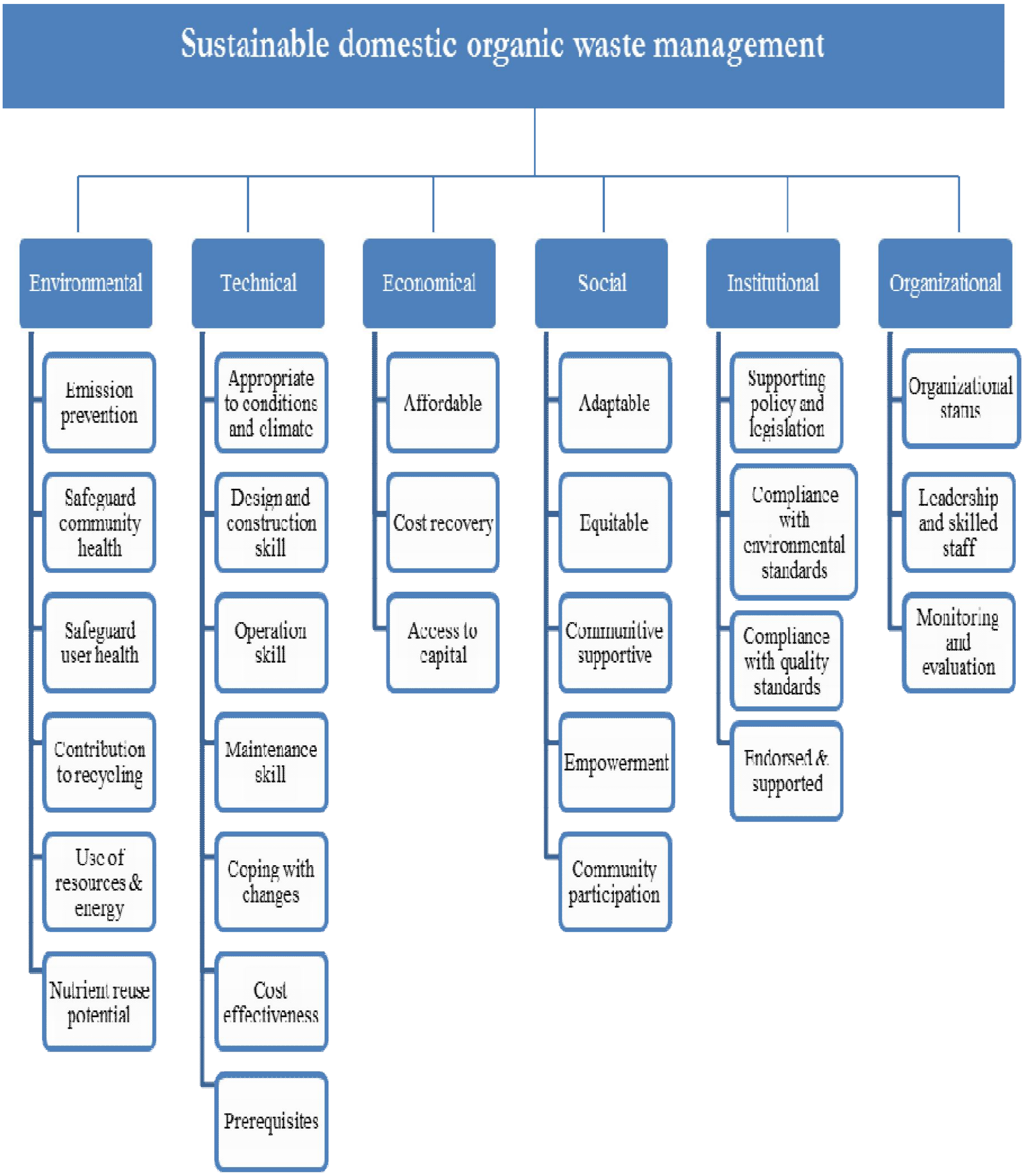

Fig. 9.2 Conceptual Framework for Sustainable Domestic Organic Waste Management

The conceptual framework outlined here can be used to evaluate the sustainability of that domestic organic waste management technique not only in Kerala but also elsewhere in the world with similar situations. For this, a set of measurable factors have to be identified for each factor which describes the aspects of sustainability for that particular type of waste management technique. The measurable factors identified for the evaluation of vermi composting, pipe composting and biogas technology will be different. Hence it has to be considered independently. The next section explains the measurable factors identified for the sustainability evaluation of biogas technology.

9.5 MEASURABLE FACTORS IDENTIFIED FOR EVALUATING BIOGAS TECHNOLOGY

In order to evaluate the sustainability of the existing domestic organic waste management technique i.e. biogas technology practised in the city, a set of measurable factors were identified for each factor of the sustainability aspect in the frame work. For example Table 9.1 describes the factors identified to measure the environmental aspects of sustainable domestic organic waste management.

Table 9.1 Factors Identified to Measure Environmental Aspects of SDOWM

Sl.No.	Factors which describe the environmental aspects	Measurable factors identified
1	Emission prevention	Air pollution status in the kitchen
2	Safeguard community health	Complaints from neighbours regarding smell or other issues
		Mosquito breeding
3	Safeguard user health	Infections after the installation of the plant
		Diseases after the installation of the plant
4	Contribution to recycling	Percentage reduction in the amount of organic waste
5	Use of resources and energy	Daily availability of biogas
		Purpose of the gas
6	Nutrient reuse potential	Use of bio slurry

The various aspects are emission prevention, safeguard of community health and user health, contribution to recycling, use of resources and energy and nutrient reuse potential which measure the environment friendliness of the system. For measuring the factor 'emission prevention' the measurable factor identified is the air pollution status in the kitchen. Similarly, complaints from neighbours regarding smell or other issues and mosquito breeding are the measurable factors identified for the factor ‘safeguard community health’. Likewise the measurable factors were identified for factors which describe the sustainability aspect. The following tables will explain each of the aspect and the factors in detail. Factors which measure the *technical aspects* are appropriateness to conditions and climate, design and construction skill, operation skill, maintenance, coping with changes, cost effectiveness and prerequisites (Table 9.2) which measure the technical feasibility.

Table 9.2 Factors Identified to Measure Technical Aspects of SDOWM

Sl.No.	Factors which describe technical aspect	Measurable factors identified
1	Appropriate to conditions and climate	Working condition of the plant
2	Design and construction skill	Who constructed the plant
3	Operation skill	Who operates the plant Is this operable by all members of the family
4	Maintenance	Frequency of repairs Ease of repair
5	Coping with changes	Cope with the amount of waste produced
6	Cost effectiveness	Perception of the user for cost effectiveness
7	Prerequisites	What are the prerequisites required

Affordability, cost recovery and access to capital are the factors identified to measure *economic aspects* (Table 9.3). These aspects measure the economic sustainability.

Table 9.3 Factors Identified to Measure Economic Aspects of SDOWM

Sl.No.	Factors which describe the economical aspect	Measurable factors identified
1	Affordable	Income range of people who uses the plant
2	Cost recovery	Cost recovery in terms of LPG cylinder numbers Cost recovery in terms of fertilizer purchase
3	Access to capital	Source of fund

Adaptability, equitability, community support and participation and empowerment are the factors identified to measure the *social aspects* of sustainable domestic organic waste management (Table 9.4). These aspects measure the social sustainability.

Table 9.4 Factors Identified to Measure Social Aspects of SDOWM

Sl.No.	Factors which describe the social aspect	Measurable factors identified
1	Adaptable and equitable	Educational status of people Gender equity Occupation of the people
2	Community support & participation	Is the plant shared by neighbours
3	Empowerment	Time saved after the installation of the plant Involvement in other activities after the installation of the plant

Table 9.5 describes the factors which measure the institutional/organizational aspects of sustainable domestic organic waste management. Supporting policy and legislation, compliance with environmental standards, quality standards, leadership and skilled staff, monitoring and evaluation and endorsement and support of any agency are the factors identified.

Table 9.5 Factors Identified to Measure Institutional/Organizational Aspects of SDOWM

Sl.No.	Factors which describe the Institutional/Organizational aspect	Measurable factors identified
1	Supporting policy and legislation	Whether any policy standards available?
2	Compliance with environmental standards	Whether any environmental standards available?
3	Compliance with quality standards	Whether any quality standards available?
4	Endorsed and supported	Is the institution/enterprise endorsed or supported by any agency
5	Leadership and skilled staff	Details of skilled staff
6	Monitoring and evaluation	Is there is frequent monitoring and evaluation?

A questionnaire framed based on these measurable factors of each aspect of the sustainability based on the framework can be used for evaluating the present organic waste management method (biogas technology) practiced in the city. This will help in formulating strategies for sustainable domestic organic waste management in Kochi city.

9.6 SUMMARY OF THE CHAPTER

Finding that the organic waste management is highly unsustainable in the city and the biogas production technology practised in the city reduces the organic footprint to considerable extend, the chapter develops a conceptual framework for evaluating the biogas technology practiced in the city and outskirts as a sustainable option for domestic organic waste management. For this, the chapter defined the sustainable domestic organic waste management (SDOWM) as the domestic organic waste management system, which is environmental friendly, technically feasible, economically viable and socially acceptable with adequate institutional/organizational support. A wheel of SDOWM was figured out with the aspects as its parts. Based on these aspects and factors, a conceptual framework for sustainable organic waste management was formulated. This framework outlined here can be applied to evaluate any domestic organic waste management techniques not only in Kerala but also elsewhere in the world with similar situations. For evaluating the domestic organic waste management techniques a set of measurable factors have to be identified for each factor which describes the aspects of sustainability for that particular type of waste management technique.

In order to evaluate the biogas technology practised in the city and outskirts as a sustainable domestic organic waste management measure, measurable factors were identified for the each of the factor which describes the aspects of sustainability with respect to biogas production technology. Questions framed based on these measurable factors can be used to evaluate the sustainability of biogas technology. The next chapter evaluates the sustainability of the existing domestic organic waste management method (biogas production technology) in the city using a questionnaire survey in selected samples.

CHAPTER 10

EVALUATION OF BIOGAS TECHNOLOGY FOR SUSTAINABLE DOMESTIC ORGANIC WASTE MANAGEMENT

This chapter presents the evaluation study of the biogas technology practiced in Kerala. The evaluation method is detailed and the perception of biogas users with respect to different aspects of sustainability is presented here. The technological benefits and bottlenecks of the system are also reviewed in this chapter.

10.1 EVALUATION OF BIOGAS TECHNOLOGY IN KOCHI CITY, KERALA

The evaluation of the biogas technology practiced in Kochi city was carried out through a survey conducted in fifty households who are using this technology inside the city and outskirts. The overall objective of the evaluation study was to get an idea of existing biogas plants constructed over the past few years, which will help to formulate guidelines for the sustainable domestic organic waste management in the city. The assessment tool used was a simple questionnaire which is intended to evaluate the perception of biogas users by providing a list of questions, which are made based on the framework developed in the previous chapter. The structured questionnaires were discussed in a panel of experts from various organizations involved in biogas promotion and extension in the city prior to the field testing. An interactive approach rather than a question and answer session with the respondents during the field survey process was adopted to enhance the quality of data and information collected.

10.1.1 General Aspects

The study on household size revealed that the average household size of the respondents using the biogas plant is 4.3. The plant is used more by households of medium household size (3 - 4) followed by households with sizes more than four and least by the 0 – 2 size household group. The study revealed that the size of the land holdings is not a criterion for owning the biogas plant. The plant works almost equally in the land holdings of the size of less than five cents and above twenty cents. The plant is seen more in households with small land holdings. Only 3% of the samples reported livestock farming in their house. 97% own a plant of size $1m^3$. The installed plants were of the age two to more than five year. The survey revealed that the service providers decide the size of the plant and the respondents are not aware of the capacity determination. The non-availability of other fuel sources especially LPG and as a solution to reduce the organic waste mainly motivated the respondents to install the plant. The users also responded that they were motivated to install the plant by their friends/ relatives who are well-wishers of the technology. 74% of the households who own the plant have a vegetable garden in their home which provides them with the essential needy vegetables for their diet. This will help to attain self-reliance on organic vegetables rather than depending on the other states. Most of the respondents were doing some sort of organic farming even in small parcel of land.

10.1.2 Social Aspects

As discussed in the previous chapter the various social aspects for a sustainable management can be measured by the educational status of the people (whether the plant can be operated by people of different educational status), gender equity (operable or handy by both male and female), occupation. The community support and participation aspects can be measured by use of a single plant by multiple families or houses. The empowerment aspect can be measured by the time saved after the installation of the plant and utilization of time saved by involvement in other activities after the installation of the plant.

10.1.3 Economical Aspects

As arrived in the previous chapter the economical sustainability was measured mainly by the factors like the income range of the people who uses the plant, measuring the cost recovery aspect in terms of the number of LPG cylinders, fertilizer purchase etc. and by measuring the access to capital in terms of source of fund.

The total monthly income of the households includes the income of the respondent and the family members from all sources. 40% reported that their income falls in the Rs.10K to 15K category. Income category Rs.15K to 20K constituted 33.33% and more than 20K group constituted 26.67%. The study reads that the plant is not accessible to the low income groups but accessible to the middle income groups due to the high initial cost. Almost all of them were able to afford the cost of the plant themselves. Only 13.33% of the households responded that there is no reduction in the number of LPG cylinders in a year whereas the rest of the households responded that there is considerable reduction in the number of LPG cylinders in terms of 1-4 or even more than 4 numbers. 53% of the households reported that they not even purchase fertilizer before or after the installation of the plant. 33% reported that there is reduction to some extend in the purchase of fertilizer where as 13% responded that there in considerable reduction in the purchase of fertilizers.

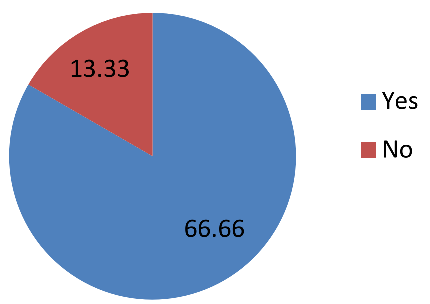

Fig. 10.1 Response of the People in Percentage Regarding the Reduction in the Number of LPG Cylinders after the Installation of Biogas Plants

10.1.4 Technical Aspects

The technical aspects of sustainability is assessed by the factors like working condition of the plant in all climate and location, design and construction skill, operation skill of the family members irrespective of age, gender or any other discrimination, maintenance skill, ability of the plant to cope with the changes in the amount of wastes, cost effectiveness and the prerequisites required. Most of the plants were constructed outside the house (90%) whereas two households constructed inside the house and one outside the plot. 93% reported that the plant is working normal in all climates.

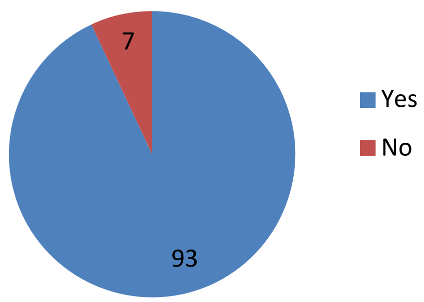

Fig. 10.2 Response of the People in Percentage Regarding the Normal Working of the Biogas Plant in all Climates

The female members are more sensitive to use the plant than the male members. 73% of the households answered that female member mostly operates the plant, while 13% answered male member mostly operates the plant and 13.33% answered both men and women operates the plant. The amount of gas production in biogas digester depends upon the quantity of feeding added to it daily provided the plant is technically all right. Kitchen waste and other household wastes were the two major feeding materials used. Majority of the respondents (93%) used kitchen waste as the feeding material. 3.33% used cow and buffalo dung in addition to the kitchen waste. Another 3.33% used the poultry droppings from their farm and nearby areas to feed the plant.

The response of the households were also taken regards the latrine connection to biogas plants. Few people responded that people are hesitant to handle bio-slurry from latrine-attached plants. 53% answered that the quantity of wastes produced is adequate for the production of gas whereas 47% answered that the feed is not sufficient for the working of plant. All the plants were installed by the service provider itself and the respondents were not aware of the standards and quality controls insisted during the design and construction. The 87% of households responded that the initial cost of the plant and its installation is quite expensive and 13.33% responded that the cost is reasonable. 87% responded that water is an essential prerequisite for the functioning of the plant. 7% each responded that land and agricultural land is also a prerequisite for the functioning of the plant.

10.1.5 Environmental Aspects

The measurable factors identified for the assessing the environmental aspect of sustainability are emission prevention by means of air pollution status in the kitchen, safeguard of community health by means of complaints from neighbours regarding smell or any other menace like mosquito breeding, safeguarding user health by means of enquiries about infections and diseases after the installation of the plant, contribution to recycling by measuring the percentage reduction in the amount of organic waste, use of resources and energy by measuring the daily availability of biogas and the purpose of gas, nutrient reuse potential by means of the use of bio slurry.

All the households do not find any pollution in their kitchen after the installation of the plant. Most of the respondents reported that with the installation of biogas, cooking using firewood has decreased and this has reduced the smoke due to firewood stoves in the kitchen after the installation of biogas plant. The households were asked to report whether there are any complaints from neighbours regarding smell or any other thing after the installation of biogas. All of the respondents reported that no such complaints have been raised by the neighbours. Households were asked whether increase in mosquito breeding has noted after the installation of the plant. 40% reported that there is considerable increase in the breeding of mosquitoes are noted after the installation of the plant since the plant is of floating type and the bioslurry is exposed. 60% have managed the mosquito menace by preventive measures. The following preventive methods looked essential to avoid mosquito breeding: covering the whole plant with net; using guppies which feed on mosquito larvae; using bacillus thuringiensis as a biological control agent for killing larvae; and by means of kerosene or oil dropped in the bio slurry.

All the households reported that no infections or diseases have been affected after the installation of the plant. 87% confirmed that there is 100% reduction in the percentage of organic waste after the installation of the plant whereas 13% reported 75% reduction of organic waste. No accidents due to fire or burning from biogas have been reported by the households. 73% reported that the daily availability of biogas is up to one hour and 8% reported that they are getting 1-2 hours daily (Table 10.4). Single burner gas stoves were installed in all the biogas-households. When asked about the reasons for lesser gas production, the respondents felt that it was small-sized plant; under-fed plants (more the fish waste more gas is produced); lack of timely repair and maintenance work; and some others replied that they are not aware of the reason. Biogas produced was used only for cooking purpose in all the households. 87% households reported that they effectively use the bio slurry produced from the plant. Of this 87% use this as organic fertilizer without composting, 10% give out to others and 3.33% drain to water course or drain. 13.33% reported that they do not use the bio slurry as it is difficult to use (40%) and no land to use (60%) then effectively.

10.1.6 Institutional/Organizational Aspects

The factors identified for measuring the organizational or institutional aspect of sustainability are the stress on policy standards, environmental and quality standards set for the plant, whether the institution is endorsed or supported, details of skilled staff who installed the plant and the details of monitoring and evaluation. The study findings revealed that biogas plants were installed by the service provider themselves. The respondents (43%) are not aware of the standards set by their service providers or government. Though of the plant owners felt that some technical standards were set by the service providers as regards the quality of construction materials and construction methods, 47% of the respondents did not know about those standards. The rest of the respondents (10%) believed that no such standards were set. All of the respondents revealed that, only the spot instruction with palm lets from mason/company/supervisor etc. was received. Regarding the after sale services 90% reported that they had not even requested for services and 10% reported that the services have been availed on call.

To strengthen the study the technological benefits and bottle necks of the biogas technology were reviewed in detail.

10.2 BENEFITS AND BOTTLE NECKS OF BIOGAS TECHNOLOGY

10.2.1 Benefits

Biogas is an odourless and colourless flammable gas which burns with a clear blue flame similar to that produced by Liquified Petroleum Gas (LPG). It is produced from the bacterial decomposition and fermentation of organic matter in a bio-digester. The process is enabled by the addition of water to the organic matter and happens within an optimal temperature range of between 35 and 40 degrees Celsius (Parker, 2007; Sathianathan, 1975).

One of the main attractions of biogas technology is its ability to generate a flammable gas from organic waste which is freely available in most communities. Biogas produced from the controlled bacterial decay of organic matter in a bio-digester largely consists of methane and carbon dioxide, with these gases constituting two thirds and one third of the total gas output respectively. Small amounts of nitrogen, hydrogen and hydrogen sulphide are also produced (Fulford, 1988; Parker, 2007). The calorific value of biogas is roughly 20 Mega Joules per m^3 and it usually burns with 60% efficiency in a conventional biogas stove (Fulford, 1988). Apart from the flammable gas produced as primary output, bio-digesters also produce a secondary product as the digestion process readily converts organic waste into bio-manure. This by-product, also known as sludge, carries an added advantage in its potential application as a highly nutritious fertilizer (Parker, 2007, Savola, 2006).

Austin (2003) states that biogas holds wide ranging potential at the household level in its domestic application to meet heating needs and to provide energy for cooking, lighting, running water pumps and even generating electricity through internal combustion processes. Akinbami et al. (2001) furthermore report that biogas has equally positive agricultural applications in its use for drying crops, pumping water for irrigation and providing a steady supply of fertiliser as by-product.

In its role as a way to conserve soil nutrients and also to manage organic waste, countries such as Finland and Sweden have already formally adopted biogas technology. Moreover, biogas has many useful applications in small-scale industrial operations. Apart from its benefits in terms of electricity production, biogas energy can be used wherever industrial heating applications are required, such as in the case of scalding tanks and drying rooms. In addition to the above, biogas production is associated with significant advantages in the field of environmental health and environmental management.

Biogas production promotes environmental sanitation by transforming biodegradable organic waste from a potential public health liability in the form of pathogens and groundwater pollution into something with positive environmental utility in the form of useful organic fertilizer and a sustainable and in expensive form of energy. The latter of course aids air quality by displacing wood and fossil fuels such as charcoal and diesel, thereby reducing deforestation, greenhouse gas emissions as well as air pollution with its negative consequences for human health and respiratory function (Engler et al, 1999).

When using biogas, people can involve more additional activities, and social benefits such as village self-reliance, local employment and skill generation will occur (Ravindranath, 1992). The daily time spent in feeding a small biogas digester could be as little as 15 minutes compared to several hours with the collecting of biomass. Time consumed cleaning vessels and other kitchen equipment can also be lowered since biogas produces less soot than biomass generally does. Most importantly, the more economical use of time, results in more time available for education. (Gautam et al, 2009).

Varma (2007), analyzed various technological options, their salient features, environmental implications, cost norms and suitability to the biophysical environment of Kerala and concluded that windrow composting, vermi composting and biomethanation (anaerobic composting for biogas) are the most appropriate techniques for organic waste management as far as Kerala is concerned.

Some of the health related benefits achieved from the implementation of biogas plants in Nepal include: reduced smoke exposure in the indoor environment, reduced acute respiratory infections on population of all ages, improved infant mortality rates, reduced eye ailments, reduced concentrations of carbon monoxide, formaldehyde and suspended particles in indoor environments (Pandey, 1984).

A properly managed compost operation promotes clean and readily marketable finished products, minimizes nuisance potential and is simple to operate (World Bank, 2011). There is a reduction in landfill space where composting is operated as waste management technique (He et al., 1992, Awomeso et al., 2010). There is also a reduced surface and groundwater contamination, which is a phenomenon in landfill. According to WHO, 900 million people experience diarrhoea or contact diseases such as typhoid and cholera through contaminated water (WHO, 2008). Through composting waste blocking of rivers, canals, drainages could be reduced (World Bank, 2011). As a flexible waste management, composting enhances recycling of materials, low transportation cost. In composting there is a minimal emission of greenhouse gases with subsequent effect on climate change and global warming (Seo et al., 2004). Moreover, addition of compost to soil reduces soil erosion as well as improvement of soil's structure, aeration and water retention. The use of chemical fertilizer could lead to groundwater pollution. But the use of compost discourages this water pollution.

In short the advantages and benefits of biogas technology can be listed as follows

- Provides a non-polluting and renewable source of energy thereby conserve energy in an efficient manner.
- Saves women and children from drudgery of collection and carrying of firewood, exposure to smoke in the kitchen, and time consumed for cooking and cleaning of utensils. This meets the most popular worldwide objective of women empowerment.
- Produces enriched organic manure, which can supplement or even replace chemical fertilizers.
- Leads to improvement in the environment, and sanitation and hygiene, a source for decentralized power generation and employment generation in the rural areas.
- The technology is cheaper and much simpler than those for other bio-fuels, and it is ideal for small scale application.
- Anaerobic digestion inactivates pathogens and parasites, and is quite effective in reducing the incidence of water borne diseases.
- Environmental benefits on a global scale: Biogas plants significantly lower the greenhouse effects on the earth's atmosphere. The plants lower methane emissions by entrapping the harmful gas and using it as fuel.

10.2.2 Bottle Necks

Biogas production is however also challenged by limitations. Balsam (2006) explains, firstly, that the process of digestion in bio-digesters can be relatively slow. Thus, for biogas to be delivered at useful rates, a fairly large volume of organic waste as input material would be required. Secondly, biogas cannot be easily bottled for transportation and use at a relatively large distance away from the source of production. It is therefore only useful if bio-digesters are located fairly close to the end-users. In view of such limitations, Balsam states that it is important that decision-makers understand what biogas production entails if it is to be effectively produced and if its advantages are to be enjoyed by people.

A biogas plant is said to be defective if it does not yield the expected gas as per the specifications of the plant. This may be due to the operational problems or shortcomings in the accessories and inputs such as stove, pipeline, valve and feeding rate and installation problems due to deviation from the standard specification of construction such as using quality, dimensions and trained masons.

According to Khoiyangbam et al.(2011) the problems faced by biogas technology include high cost of construction, corrosion of gas holder, leakage of digester tank, defective pipeline, accumulation of water in pipeline, low biogas production in winter and at high altitude, slurry comes through the pipeline, plenty of gas inside the plant but will not come in the stove or lamp, slurry level would not rise in the displacement chamber / outlet pipe, low pH, fluctuation of gas pressure, carbon dioxide reducing the calorific value, hydrogen sulphide leading to corrosion, gas does not burn, improper combustion, elongated yellowish flame, flames lifts off, flame extinguishes, flame too small and too big.

10.3 SUMMARY OF THE CHAPTER

The chapter evaluated the sustainability of the biogas technology system practised in the city and the major findings are as follows.

When measuring the *social aspects* of sustainability the evaluation study reveals that the respondents who have installed the plant are mainly government/salaried and self-employed. A noticeable percentage of daily wage and other occupation groups also installed the plant. The plants have been installed by the people having different educational status ranging from school education to post graduation and above. Sharing of the plant with the neighbours has not been seen during the study except for some cases. 53% revealed that time is saved in kitchen due to the availability of extra fuel which increase their involvement in organic farming and gardening activities in their houses. Apart from this, the technology is used as an alternate for waste disposal. The decision to install the plant has been done mainly by the female member and after discussion in the family. These findings show that the technology is affordable and equitable. In addition it has adequate community support and participation and promotes women empowerment.

While measuring the *economic aspects*, the study point out that the system is affordable to all income groups and almost all of them afforded the cost of installation themselves. The majority of respondents experienced a reduction in the number of LPG cylinders in one to four numbers in a year and also reported that there is economic gain in terms of fertilizer purchase also. Even though the initial capital cost is high it is economical in the long run in terms of saving of other fuels used in kitchen. These findings reveal that the system is economically sustainable.

Regarding the *technical aspects* the study assessed that the plant is adaptable to climate and location and is easily operable, but mostly female members operates it. The plant feeds on kitchen waste in most cases but also accommodates dung, poultry droppings, leaves etc. Most of the households responded that the quantity of their feed is sufficient for the functioning of the plant and almost all the plants are installed by the service provider. This explains the technically feasibility of the plant.

The plant is free from emission, foul smell or any other menace. It was observed that preventive measures are done for controlling mosquito breeding. The user or community health is safe and cases of contagious disease were not reported after the installation of the plant. The majority of the respondents reported that there is 100% reduction of organic waste. The availability of gas is about one to two hours. The produced gas is used only for cooking purpose which can be expanded to many energy saving options like lighting. Apart from this, the nutrient reuse potential of bio slurry can be efficiently utilized by means of vegetable gardens or for sale the bio slurry to others. This highlights the *environmental friendliness of the system*.

The plant is installed by service providers who are mainly NGOs or installation supervisors. The respondents were given on the spot instruction and through palm lets. This is adequate for majority of respondents but the training for regular maintenance of the plant is felt not adequate. The after sale services is satisfactory among the respondents. Even though the technical sustainability is not at par with standards and other aspects of sustainability, the installation and maintenance of the plant can be promoted through local bodies to make it more sustainable.

In general, the biogas technology system is socially acceptable, economically viable, environmental friendly, technically feasible and institutionally stable apart from some minor issues. The issues include improper operation and maintenance, improper segregation of waste for feeding the plant, improper application of slurry, optimal use of biogas etc. The key to proper operation of biogas plant is the daily feeding with mix of right proportions of the wastes and water, frequent draining of condensed water in the pipeline through the water outlet, cleaning of stoves and lamps, oiling of gas valves and gas taps, cleaning of overflow outlet, checking of gas leakage through pipe joints and gas valves and adding of organic materials to slurry pits. As long as these tasks are carried out reliably and carefully the plant will function properly.

From the technical review it has been strengthened that biogas production process has become attractive as its technology has been successfully tested through experience on both small- and large-scale projects. Feeding upon renewable resources and non-polluting in process technology, biogas generation serves a triple function: waste removal, management of the environment, and energy production.

Hence the biogas technology can be accepted as a sustainable measure/option for the waste management of organic wastes produced in the residential areas of Kochi city. Therefore the next chapter focuses the waste management of recyclable wastes which discusses various measures or options for the sustainable waste management of paper, glass, metal and plastic wastes.

CHAPTER 11

SUSTAINABLE WASTE MANAGEMENT OF PAPER, GLASS, METAL AND PLASTIC WASTES

Evaluating that, biogas technology can be used a sustainable measure for disposing domestic organic wastes in Kochi city in the previous chapter, this chapter point outs the various quantity reduction and recycling options for the sustainable management of recyclable wastes like paper, glass, metal and plastics. This forms the part of answering the fourth research question.

11.1 INTRODUCTION

Sustainable solid waste management aims to offer a chance to prevent waste through designs based on the full life cycle of the product, similar to natural cycles, which function without producing waste. Generally natural cycles are driven by the sun, which provides the energy for the system; the energy drives the photosynthesis process that orders atoms and molecules to higher value such as forest and food products. Dead matter is processed by microbes in the soil to become food for the next cycle. By this way, waste should, like any residue, be thought of as potential inputs for starting new processes. Waste materials that are generated must be recovered for reuse and recycling to reach the goal of 'using everything, nothing left'. In the waste management of recyclables sustainability is said to be achieved mainly through '3Rs', Reduce, Reuse and Recycle (McDonough and Braungart, 2002).

Among the 3Rs, to reduce waste means to avoid making garbage in the first place. This requires rethinking design for the total life cycle of the product and behavioural change in customers. Reusing an item means that it continues to be a valuable, useful, productive item, and replaces new items that would utilize more water, energy, timber, petroleum, and other limited natural resources. To recycle is the act of processing used or abandoned materials for use in creating new products. Everything from paper, cans to electronic waste can be properly recycled. Recycling of wastes generated, is the thought of the day as many wastes are still dumped inside and outside the residential areas and people find it difficult to manage the same. The people cannot treat these wastes individually, but there are options if these are collected and segregated, recycling of all wastes can be a growing concern for an area. Certainly, the regulations as well as guidelines for waste recycling must be respected and adhered to strictly. However the first option, waste reduction has to be done in line with the present programs of recycling as all the reduction and reutilization is always easier than recycling.

The next sections of the chapter will discuss the waste reduction and recycling options for the recyclable wastes i.e. paper, glass, metal and plastic waste. These options are discussed based on the literatures and experiences from the different organizations practicing in this field in and around the world.

11.2 SUSTAINABLE MANAGEMENT OF PAPER WASTES

Industrialized paper making has an effect on the environment both upstream (where raw materials are acquired and processed) and downstream (waste-disposal impacts) (Hershkowitz, 2002). Paper production accounts for about 35% of felled trees and represents 1.2% of the world's total economic output (FAO, 2004). There are a lot of options for reducing the amount of paper waste. Some of the options for reducing the quantity of paper waste are using both sides of paper, reuse of paper that is already printed on one side for documents like drafts, meeting agenda or temporary signs, book marking or saving the emails/web page in hard drives instead of printing, visual displays showing how to load paper to avoid misprints, utilization of size reduction features offered by many printers like duplex, booklet printing etc., use of two way or send and return reusable inter and intra office envelopes, using durable products instead of disposables like paper plates and cups, paper napkins etc. Recovered printing and writing paper can be used to make new recycled copy paper. Recovered paper can be used in a variety of other products as well. Recycled pulp can be moulded into egg cartons and fruit trays. Recovered paper can be used for fuel, ceiling and wall insulation, paint filler, and roofing. During the survey it was observed that the major share of the paper waste was newspapers, periodicals and the paper wastes generated by the school children. *The children, parents, teachers and authorities should be made aware of any of the paper waste reduction techniques mentioned above.*

11.3 SUSTAINABLE MANAGEMENT OF GLASS WASTES

The options for reducing the quantity of glass waste entering the waste stream is to go for sustainable alternatives like ceramic dishes and other kitchen wares and to refuse the disposable glass items and accept durable ones like refillable pens, fountain pens, mechanical pencils etc. All types of used glass containers can be reused indefinitely to make new glass products. It is actually easier to manufacture new glass containers from recycled glass than from raw material. Glass, especially glass food and beverage containers, can be recycled over and over again. In fact, 90 percent of recycled glass is used to make new containers. Recycled glass can also be used in kitchen tiles, counter tops, and wall insulation. Glass recycling has grown considerably in recent years through increased collection through curb side recycling programs and glass manufacturers' increased demand for recycled glass. *Therefore proper collection of glass wastes from residential areas and effective recycling of glass waste shall be ensured for sustainable management of glass wastes.*

11.4 SUSTAINABLE MANAGEMENT OF METAL WASTES

The metals that we use in our daily life usually come in the form of steel, aluminium, scrap metal and others. The steel industry has successfully been able to reduce the amount of material needed to make the same products. Technological developments in gauge control are further reducing thicknesses from 0.20 mm to 0.12 mm. Steel for automobiles has also become more lightweight, especially given recent demand for lighter, more fuel efficient vehicles. It also is cheaper to recycle steel than it is to mine virgin ore to manufacture new steel (EPA, 2015). Recovering steel not only saves money, but also dramatically reduces energy consumption, compared to making steel from virgin materials. In turn, this reduces the amount of greenhouse gases released in to the air during processing and manufacturing steel from virgin ore. Aluminium can be recycled into a lot of different products such as tractor, trailer and car bodies; however, aluminium cans usually become new aluminium cans. Recycling aluminium does not reduce the quality of the metal, so it can be recycled indefinitely. Producing new cans from recycled aluminium saves 95% of the energy used to produce cans from ore, known as bauxite (Rousakis and Bernard, 1994). Lead can be recycled from old car batteries. Service stations and car battery retail outlets will generally accept car batteries for trade in, or take them to a metal recycler for recycling. The plastic coating found on some wiring can be removed by metal recyclers in a process called 'granulation' (Stensel and Coleman, 2000). *Collection and recycling of the metal wastes shall be initiated at local body level. These collected wastes shall be handed over to the local manufacturers on demand or may be handed over to agencies handling recycling of metal wastes in the country level.*

11.5 SUSTAINABLE MANAGEMENT OF PLASTIC WASTES

Plastics have substantial benefits in terms of their low weight, durability and lower cost relative to many other material types (Andrady et al., 2009; Thompson et al., 2009). Most types of plastics are not biodegradable (Andrady, 1994), and are in fact extremely durable, and therefore the majority of polymers manufactured today will persist for at least decades, and probably for centuries if not millennia. Even degradable plastics may persist for a considerable time depending on local environmental factors, as rates of degradation depend on physical factors, such as levels of ultraviolet light exposure, oxygen and temperature (Swift and Wiles, 2004). There available a long list of alternatives to plastic (to reduce the use of plastics) we commonly use and might think we can't live without. The first option is to discard the items which contain plastic packaging. Another option is to use glass or steel containers, earthen cook wares, homemade reusable shopping bags, wooden/steel utensils for kitchen instead of plastic containers, plastic utensils, and plastic carry bags respectively. Next option is to buy in bulk bins as often as possible. Shopping from local farmers market is another option to reduce the use of plastic carry bags. These markets usually rely on paper packing. Carrying a container or a bag for purchasing meat/fish or other item can reduce the amount of plastic waste. The use of natural materials instead of plastics scrubbers and synthetic sponges is another option for reducing domestic plastic waste.

The use of biodegradable plastics (Smith, 2005) is another option for reducing plastic wastes. Recycling of plastics is one method for reducing environmental impact and resource depletion (Sinha et al., 2010). Energy recovery from waste plastics (by transformation to fuel or by direct combustion for electricity generation, use in cement kilns and blast furnaces, etc.) can be used to reduce landfill volumes, but does not reduce the demand for fossil fuels as the waste plastic was made from petrochemicals (Garforth et al., 2004). There are also environmental and health concerns associated with their emissions. One of the key benefits of recycling plastics is to reduce the requirement for plastics production. In terms of energy use, recycling has been shown to save more energy than that produced by energy recovery even when including the energy used to collect, transport and re-process the plastic (Morris, 1996).

Therefore the bottom line for sustainable waste management of plastic wastes in the city is to discard plastics and stick on to alternatives for plastics as mentioned above. Steps may be taken to collect the plastic already in the waste stream of residential areas and adequate measures shall be done to dispose the same with least environmental disturbances.

11.6 SUSTAINABLE MANAGEMENT OF HAZARDOUS AND E-WASTES

The quantity of hazardous wastes and e-wastes was of negligible value in the residential areas during the primary survey in 2010. So the quantity of these materials was not taken into account for segregation and the study. But nowadays, as we all know, electronics waste is becoming a major global issue (Chatterjee, 2012). Non rechargeable batteries contain harmful metals, so should never be thrown away with daily rubbish, they should be returned to manufacturer for disposal or recycled elsewhere. Rechargeable batteries are the most environmentally friendly option as can last for up to several hundred charging cycles resulting in less waste being produced. Some of the tips to reduce the quantity of e-wastes are use of second hand electronics, games, and toys, refurbished equipment from a certified e-steward, care full use of materials, avoid buying new CDs and DVDs since they are made from polycarbonate plastic, recycle old disks, choose healthier electronics, donation to charity and recycling printer cartridges really is worthwhile as cartridges can be expensive and remanufactured printer cartridges can cost as little as 10% of what original cartridges do. By lessening the amount of cartridges ending up in landfill sites, we are being kinder to the environment too.

11.7 SUMMARY OF THE CHAPTER

The chapter highlights the various quantity reduction and recycling options for the sustainable management of recyclable wastes. The chapter concludes that awareness creation about the paper waste reduction techniques; proper collection and effective recycling of glass waste from residential areas; initiation for collection and recycling of the metal wastes at the local body level, steps for discarding plastics; sticking on to alternatives for plastics; and collection of the plastic wastes already in the waste stream of residential areas and adequate measures to dispose them are the effective measures for the sustainable waste management of the recyclables. The chapter concluded that recycling is one strategy for end-of-life waste management of inorganic wastes especially plastic products presently in the waste stream. It makes increasing sense economically as well as environmentally, but some significant challenges still exist from both technological factors and from economic or social behaviour issues relating to the collection of recyclable wastes, and substitution for virgin material. At the same time, discarding the inorganic wastes and sticking on to alternatives also proved effective measure for the sustainable waste management of these wastes.

With the lessons learned from the chapters 8 - 11, the research formulates the strategies for sustainable solid waste management in the residential areas of Kochi city in the following chapter.

CHAPTER 12

STRATEGIES FOR SUSTAINABLE SOLID WASTE MANAGEMENT IN THE RESIDENTIAL AREAS OF KOCHI CITY

This chapter answers the fourth research question. Based on the lessons learned and studies carried out; results of the analysis and discussions, this chapter presents the strategies for sustainable solid waste management in the residential areas of Kochi city.

12.1 INTRODUCTION

There are different types of strategies which can be implemented to carry out waste management plans. The waste management strategies can typically be classified as working through command and control approaches, economic incentives and stimulation of innovation in the market place, and information and educational efforts (Sachs, 2006). Command and control strategies such as legislation and enforcement create a set standard and minimum guideline for all to follow. Many countries has passed a series of laws promoting the reduction and recycling of waste including the basic law for promoting the creation of a recycling oriented society; the revised waste management law; the law for the promotion of effective utilization of resources; and the green purchasing law in Japan (Loughlin and Barlaz, 2006). Economic instruments have been shown to have a direct influence on waste management systems (Bilitewski, 2008; Skumatz, 2008) as well as recycling behaviour (Bolaane, 2006; Iyer and Kashyap, 2007) which is a critical component to waste management systems.

The success of any waste management plan will rely upon the cooperation of different stakeholder groups involved in the waste management. Monitoring is an essential component to the continued success and growth of the plan. It also allows the expected impacts of the strategy to be measured against actual changes, and this can inform future revisions of the waste management plan. Regular waste audits should be scheduled at least annually, but optimally at any time significant fluctuations in the waste stream are expected to occur throughout the year (CCME, 1996).

The waste management strategies recommended for sustainable solid waste management in the residential areas of Kochi city is divided under three heads; strategies for improving the biogas technology program, strategies for waste management of recyclables in residential areas and a generalized strategy for sustainable solid waste management in the residential areas of Kochi City.

12.2 STRATEGIES FOR IMPROVING THE BIOGAS TECHNOLOGY PROGRAM IN RESIDENTIAL AREAS

From the evaluation study it was observed that, the biogas technology requires initial capital cost of installation which may not be feasible for low income groups. Therefore *linking the biogas program with government initiatives* is an essential strategy for improving the program. The outcome of the study also indicated that people are not aware of the standards regarding the quality, design, construction of the plant. To improve the quality standards there is *high need for the modification of the design of biogas plants* to suit the gas use pattern in the city. This will help in optimization of the plant and there by reduction in cost of installation. The plant owners in most of the cases are not able to carry out required maintenance of all defective parts on time due to technical and financial constraints. *After sale service provisions* therefore shall be viewed as major tool to preserve the interest of the users and safeguard the fate of the plant against any further deterioration.

There is *high need of user's training on operation and maintenance of biogas plant* to ensure the continuous functioning of biogas plant. *Small scale industries* shall be promoted for biogas construction. *Private sector involvement* shall be viewed as a means to develop a more productive and efficient economy and to increase the economic participation of the population.

In addition, the study reveals that the biogas technology has a number of synergies with other development sectors like health, women's development, agriculture and livestock management etc. These synergies can be utilized effectively if biogas technology is integrated functionally with other programs. It is therefore recommended that the *biogas program is to be integrated with the women's development, agriculture, health and other rural development programs.* There is an ample *need to develop and establish linkages between potential stakeholders for program integration at the policy level.* The participation of stakeholders varies from consultative, contributory, operational and collaborative depending upon the nature of tasks to be performed.

Efficiency and suitability of the present models of biogas plants was not conducted in detail in this study. Hence *detailed study of the present model of biogas plants, prior to taking decision on the type and size of plant is to be disseminated.* One of the factors observed during the field investigation is the improper use of slurry in most of the biogas households because of the ignorance of its potential. Hence *training course for users shall be prepared and implemented on effective composting, handling and application slurry in the farms.* Under sanitation programmes of the local bodies, people may be made aware of *attaching toilet to biogas plants* by highlighting the major benefits such as improvement in environmental sanitation in and around the house, production of more gas, elimination of harmful pathogens after digestion of excreta into the digester and enrichment of bio-slurry by added nutrient value.

Motivation is a vital component of any program like biogas that is aimed at a wider section of the population. Developing an effective motivation strategy will help in areas where people developed unfavourable attitudes towards the technology because of various reasons especially the failure of the existing plants. Similarly, in areas where the general awareness among the people on biogas technology is low or not existent, it is necessary to actively publicise it. The following could be some strategies for motivation in the context of Kochi city. The existing biogas plants have some positive impacts on the promotion and development of the technology which can be utilized for future promotional strategy. Motivation can be done through governmental and non-governmental officials. Local leaders, village heads, school teachers and other influential persons in the community could play an important role in selecting and motivating beneficiaries. School children could play the role of motivation worker. Subsidy can be provided for the needy and low income groups to attract more people to install biogas plant.

12.3 STRATEGIES FOR SUSTAINABLE WASTE MANAGEMENT OF RECYCLABLES

Sustainable waste management of recyclable wastes is possible by the active involvement of all stakeholders. A separate *recycling department* has to be constituted under the local self-government department. This department shall monitor, implement, and organize research and development activities for the management of recyclable wastes in the existing waste stream and also to suggest waste reduction techniques to avoid these wastes in future. Government should ensure *people's participation* in the waste management plan in order to efficiently handle and dispose the waste, as if they are the actual generators and end users. These will make the waste management plan more sustainable. Apart from the waste reduction and recycling options discussed in the previous chapter, the following strategies are to be taken into account for the sustainable waste management of recyclables.

- *Social responsibility* – Active participation and perception of the people are the key factors towards deciding the apt measure to be considered for the preparation of a sustainable waste management for Kochi city.
- With a view to encourage and promote the maximum possible investment in waste management operation, government will have to look at ways and means to *assist operators and individuals* to embark upon a change programme that aligns with the national objectives of waste management. By providing incentives/rewards more people can be attracted to this field.
- As a society we need to be *aware of the wide range of technologies* available to address particular problems or particular waste streams. Research & Development initiatives shall also be encouraged which builds on the ability and knowledge of the society.
- The *legal implication* of our obligation to have a *waste management plan* which specifically takes into account waste minimisation issues is driven by the legal obligations. There is no doubt that we need stronger enforcement in this area in order to secure that the direction selected is met by all so as to achieve convergence with our objectives. This will require administrative capacity building in the area but will also encourage those of good intentions to put forward self-regulatory regimes which may alleviate the administrative burden from within the public administration.

- Increasing *public awareness* on the need for sustainable production and consumption has to be encouraged by local authorities to organize collection of recyclables, encouraged some manufacturers to develop products with recycled content, and other businesses to supply this public demand.
- *Economic instruments* can take the form of taxes, while innovation can be stimulated through investments in program funding for emerging technologies.
- *Signage* is a critical component to waste management systems. Signage helps inform the public about what materials are acceptable for recycling and which are not and it can also encourage participation in recycling programs. The local body can create their own by-laws regarding signage for sustainable waste management.
- Promote reuse of materials - Promotion of *local level second hand markets* related to the life style of human beings will be an attractive method for reuse of goods. A *reuse cycle for human life* has to be detailed for this. For example the *crib* which we buy in an infant stage shall be replaced by a *study table* in a childhood stage. In adolescent age, this will be replaced by a *computer table*. This will be replaced again by a *wardrobe* & *crib* and finally to a *wheel chair or walking stick* in old age. Hence second hand markets can play a major role in the reuse life cycle of human being. Therefore local merchants shall be encouraged to provide products based on this reuse cycle of human being.

12.4 STRATEGIES FOR SUSTAINABLE SOLID WASTE MANAGEMENT IN THE RESIDENTIAL AREAS OF KOCHI CITY

Thorough literature review was conducted in order to formulate objectives, targets and strategies for the waste management plan of Kochi city. For this, the works of Metro Vancouver (2010), Environmental Defense - McDonald's Waste Reduction

Task Force (1991), Resource Recovery Fund Board (2008) , Nova Scotia Government (2010) etc. were reviewed in detail. The various objectives formulated are

(1) Minimize waste generation;
(2) Maximize reuse, recycling and material recovery;
(3) Develop waste management practices with people's participation;
(4) Adjust procurement policies;
(5) Develop educational programs;
(6) Ensure waste management is safe and effective and;
(7) Become a regional leader in waste management.

Table 12.1 shows the residential waste management plan for Kochi city which describes the objectives, targets and strategies for sustainable solid waste management in the residential areas of Kochi city. The initiation for implementation of the plan has to be started from country level to the individual level.

- *Country level*- Encourage and initiate *Research & Development (R&D) programmes* based on the tool ecological footprint analysis and develop country specific data sets and equivalence factors so that the footprint values will be more precise for the country.
- *State level*- A *recycling department* for the state should be established & there is a need to identify local bodies which offer less economic development and give offer to them to act as 'kidneys' of the rest of the population, without affecting the social life of the people but enhancing the economic development by processing the population's waste into valuable products like manure, recycled products etc. Invest in R & D to identify new uses for waste products & through market intervention to reduce the prices of recycled products are to be encouraged. The waste footprint model developed shall be make use of to assess the waste footprint of the population at individual level.

- *City level* - Create awareness among the population, enable reuse and recycling centres to reuse waste materials disposed of at these sites through the resale of reusable items, and sustain a give and take relationship with suburban local bodies, impose tax on people on the basis of volume of waste footprint values and offer incentives to households which produce less waste.
- *Community level* - Introduce a kerbside collection scheme for recyclables from all homes in the city, supported by a network of recycling centres for residents to drop off recyclable materials, communicate through residential associations the various effects of solid waste management problems, share new ideas and techniques of effective solid waste reduction and disposal methods.
- *Household level* - Promote home and community composting in the city through the provision of biogas plants and other apt technologies at low cost or with subsidies.
- *Individual level*- People should changes their approach towards the waste disposal and related issues in a sustainable manner. The individual should be aware that they are the generators and they can only solve the problem. Observe and compare the individual waste footprint regularly so that the individual can stick on to the techniques of waste reduction which offer low footprint values thereby less harming the environment.

Table 12.1 Residential Waste Management Plan for Kochi City

Objectives	Targets	Strategy
(1) Minimize waste generation	Reduce the quantity of waste generated per capita Eliminate unwanted materials Systematize solid waste reduction and management practices into standard operating procedures and packaging/product specifications	Advocate for transfer of additional waste management roles and responsibilities to producers and consumers. Reduce or eliminate materials entering the solid waste system which hinder or limit the opportunities to achieve reuse, recycling, or energy recovery. Provide information and education on options to reduce waste. Evaluate shipping and packaging procedures to identify items which could be eliminated or reduced. Document details of the city waste stream and review regularly so that trends can be assessed.
(2) Maximize reuse, recycling and material recovery	Increase the waste diversion rate Use alternate materials which reduce production impacts. Substitute reusable items for disposable items in shipping, handling, storage and operations.	Introduce a recycling department for the city. Increase the opportunities for reuse and recycling and the effectiveness of existing recycling programs. Target specific materials for reuse, recycling and material recovery. Utilize non-recyclable material as fuel to provide electricity from waste-to-energy facilities. Develop reusable containers for shipping. Outline the roles and responsibilities of all stakeholders involved with waste management in recycling.
(3) Develop waste management practices with people's participation	Develop waste management plans in consultation with participant groups (working groups) and effective communication links. Work with regional organizations to minimize duplication of resources and facilities.	Create materials and tools to target community members and groups. Develop communication links between different groups involved in waste management activities by holding activity sessions detailing the importance of waste management and what people can do, which will avoid both gaps and overlaps in the plan. Identify options for cooperative product purchasing, including price and discounts for bulk purchases. Invite comment from regional organizations and businesses.
(4) Adjust procurement policies	Use the commitment to waste management as a lobbying point when pursuing funding for capital works. Support policies for reducing the front end of the waste stream. Develop regional alliances to maximize purchasing power and encourage waste avoidance specifications for products.	Develop purchasing guidelines consistent with the waste management strategy. Design tender specifications in such a way that those submitting tenders can address waste management issues. Identify regional bodies that have similar purchasing requirements.
(5) Develop educational programs	Involve the community Raise skill amongst waste management staff in the identification of opportunities for avoidance and minimization of waste currently being disposed of. Ensure that operational staff has the training to comply with relevant guidelines or legislation, and the support to report negative events or failures of the system.	Conduct awareness programmes, meeting specific information needs, and fostering a sense of community commitment. Conduct waste characterization studies to establish waste reduction goals. Track diversion progress and make information available Develop marketing program to attract regional organizations to participate
(6) Ensure waste management is safe and effective	Develop a combined environmental committee and health and safety committee Ensure compliance with waste management regulations Assign responsibility for the regular review of the available technologies for waste storage and disposal.	Document the segregation, containment, storage, collection, and disposal mechanisms for each category of waste, with particular attention paid to harmful categories. Develop accident response strategies for harmful categories of wastes and provide training for those who will be responsible for carrying them out. Provide staff training.
(7) Become a regional leader in waste management	Support regional waste management initiatives. Commit to environmental excellence beyond regulatory requirements.	Document a waste management wish-list that includes options, costs and benefits, and parameters that need to be met before each option can be actively considered. Advertise waste management initiatives. This should not be overstated and should include discussion of the limitations. Invite comment from regional organizations and businesses.

12.5 SUMMARY OF THE CHAPTER

This chapter put forward the strategies for sustainable solid waste management in residential areas of Kochi city. The strategies were discussed under three heads: strategies for improving the biogas technology program; strategies for waste management of recyclables in residential areas; and generalized strategy for sustainable solid waste management in the residential areas of Kochi city.

The plan implementation should be initiated at the country level and should extend to the individual level. Therefore strategies at country level, state level, city level, household level and individual level for the reduction of waste footprint and waste management issues in the city were also suggested. The study also highlights the initiation of a *recycling department* in the state level as the first and foremost step for the *sustainable waste management of the recyclable wastes.* The department will monitor, implement, and organize research and development activities for the management of recyclable wastes in the existing waste stream and also to suggest waste reduction techniques to avoid these wastes in future. Finally the *solid waste management plan for the residential areas of Kochi city* was formulated with specific objectives. Targets and strategies were formulated for each of these objectives in waste management plan. Each of the target and strategies formulated in the residential solid waste management plan of Kochi city can be individually taken for further detailed study. This provides scope for further researches.

The chapter concludes that integrated waste resource management planning enables local bodies to create a comprehensive strategy that can remain flexible in light of changing economic, social, material and environmental conditions. In many cases, the most efficient and cost effective way to manage waste is to not have to deal with it at all. Therefore waste diversion and waste minimization should be the primary focus for integrated waste management plans for local bodies. After implementation of the plan, waste audits are recommended for measuring the success and progress of the plan and to identify areas which require review. The plan will work well with effective people's participation and motivation with adequate public policies.

CHAPTER 13

WASTE FOOTPRINT MODEL FOR KOCHI CITY

As per the waste footprint studies in the city and the analysis of solid waste management issues in the city, the study observed that solid waste management initiations at individual level are very much important as they are the source of waste generation. Effective waste management occurs only through people's participation supported by adequate political policies. Therefore a model is developed, which can take the dual role of awareness creation for waste footprint reduction for the people; and at the same time as an economic instrument for implementation of policies for the government, which in turn helps in the sustainable waste management of the city. This chapter demonstrates the development of a waste footprint model for Kochi city, with which the individuals can themselves, calculates the waste footprint.

13.1 WASTE FOOTPRINT MODELS

For the development of waste footprint model for Kochi city, various models were developed which focuses on different parameters and they were analysed and compared. From these models, the suitable model which satisfies the regression and model fit was selected as the waste footprint model for Kochi city.

13.1.1 Waste Footprint Model 1

This model focuses on parameters which found significant for the other variants during the homogeneous error testing done during the statistical analysis of the data. The significant parameters/variables were household size, household income, type of housing unit and ownership. The regression statistics of the parameters with respect to the footprint values is given in Table 13.1.

Table 13.1 Regression Statistics – Model 1

Multiple R	0.571
R Square	0.327
Adjusted R Square	0.252
Standard Error	1.887
Observations	1500

The resultant model which is having f value 181.65 & t stat of the intercept 38.318 is as follows.

$$\begin{aligned} \text{Wastefootprint} = {} & 8.045 - (1.252 * \text{household size}) + (0.30 * \text{household income}) \\ & + (0.352 * \text{type of housing unit}) - (0.618 * \text{ownership}) \end{aligned} \tag{13.1}$$

The very lower R square value (0.327) makes the model unfit.

13.1.2 Waste Footprint Model 2

Since the R square value of the first model is very low, the second model was developed based on the significant parameters and the amount of wastes. The regression statistics for the model is as follows (Table 13.2) with f value 1591.372 and t stat of the intercept 47.74.

Table 13.2 Regression Statistics – Model 2

Multiple R	0.952
R Square	0.906
Adjusted R Square	0.905
Standard Error	0.707
Observations	1500

The resultant model is as follows

$$\begin{aligned} \text{Wastefootprint} = {} & 4.568 - (1.5985 * \text{household size}) - (0.0572 * \text{household income}) \\ & + (0.1336 * \text{type of housing unit}) - (0.0212 * \text{ownership}) \\ & - (0.1262 * \text{paper}) + (0.3741 * \text{glass}) + (0.8049 * \text{metal}) \\ & + (0.4409 * \text{organic}) + (0.5530 * \text{plastic}) \end{aligned} \tag{13.2}$$

The model gives a good R square value (0.906) compared to the first model and satisfies the requirements of model fit. But when all the other dependent variables are constant and when the quantity of paper waste increases, the footprint decreases. This case is questionable.

13.1.3 Waste Footprint Model 3

In the second model, when all the other dependent variables are constant and when the quantity of paper waste increases, the footprint decreases. It may be because the average quantity of paper is low compared to the other quantity of wastes except plastics and the paper waste is more easily biodegradable compared to any other waste except food waste. Therefore a third model developed, in which the amount of paper wastes is discarded from the second model. The regression statistics is as follows (Table 13.3) with f value 1790.931 and t stat 51.384.

Table 13.3 Regression Statistics – Model 3

Multiple R	0.952
R Square	0.906
Adjusted R Square	0.905
Standard Error	0.707
Observations	1500

The resultant model is as follows

$$\begin{aligned}\text{Wastefootprint} = {} & 4.544 - (1.5977 * \text{household size}) - (0.0599 * \text{household income}) \\ & + (0.1359 * \text{type of housing unit}) - (0.0165 * \text{ownership}) \\ & + (0.3714 * \text{glass}) + (0.8049 * \text{metal}) + (0.4398 * \text{organic}) \\ & + (0.5588 * \text{plastic}) \qquad (13.3)\end{aligned}$$

The R square value is 0.906 which is again same as that for model 2 which satisfies the regression model fit.

13.1.4 Waste Footprint Model 4

A fourth model is attempted considering all the parameters both significant and insignificant like season, location, population density, method of waste disposal, type of housing unit, household size, household income, ownership; and amount of wastes generated. Table 13.4 shows the regression statistics with f value 1116.898 and t stat 18.632.

Table 13.4 Regression Statistics – Model 4

Multiple R	0.952
R Square	0.907
Adjusted R Square	0.906
Standard Error	0.703
Observations	1500

The resultant model is as follows and satisfies the regression model fit.

$$
\begin{aligned}
\text{Wastefootprint} = {} & 3.986 - (0.0714 * \text{season}) + (0.1704 * \text{location}) \\
& + (0.0411 * \text{population density}) - (1.6013 * \text{household size}) \\
& - (0.0549 * \text{household income}) + (0.2202 * \text{type of waste disposal}) \\
& + (0.1030 * \text{type of housing unit}) - (0.0011 * \text{ownership}) \\
& - (0.0173 * \text{paper}) + (0.3877 * \text{glass}) + (0.7826 * \text{metal}) \\
& + (0.4512 * \text{organic}) + (0.5647 * \text{plastic}) \qquad (13.4)
\end{aligned}
$$

Table shows that this model also give satisfactory goodness of fit since R square is 0.907.

13.1.5 Waste Footprint Model 5

The fifth model is attempted after removing the amount of paper waste from the fourth model as already mentioned above. Table 13.5 shows the regression statistics with f value 1210.78 and t stat 19.3201 and the resultant model is as follows

Table 13.5 Regression Statistics – Model 5

Multiple R	0.952
R Square	0.907
Adjusted R Square	0.906
Standard Error	0.703
Observations	1500

$$\begin{aligned}\text{Wastefootprint} = {} & 3.9810 - (0.0716 * \text{season}) + (0.1714 * \text{location}) \\ & + (0.0408 * \text{population density}) - (1.6013 * \text{household size}) \\ & - (0.0553 * \text{household income}) + (0.2206 * \text{type of waste disposal}) \\ & + (0.1034 * \text{type of housing unit}) - (0.0006 * \text{ownership}) \\ & + (0.3874 * \text{glass}) + (0.7826 * \text{metal}) + (0.4511 * \text{organic}) \\ & + (0.5656 * \text{plastic}) \end{aligned} \quad (13.5)$$

Here again the R square value of 0.907 which satisfies the regression model fit.

13.2 WASTE FOOTPRINT MODEL FOR KOCHI CITY

Previous section developed five different models for waste footprint calculations in Kochi city. Among this, the first model doesn't satisfies the regression model fit but all the other four models satisfies the regression model fit with good R square value. In order to recommend the suitable model for waste footprint calculations in Kochi city, the comparison of the different models developed was tabulated in Table 13.6. From the above developed models, the model 3 is recommended as the waste footprint model for Kochi city, since the R square value is greater than 0.9 and F value (1790.931) and the t stat value (51.384) of the model is more than the other developed models. Therefore the waste footprint model for Kochi city is given by the equation 13.3.

Table 13.6 Comparison of the Waste Footprint Models Developed

Regression statistics	Model 1	Model 2	Model 3	Model 4	Model 5
Multiple R	0.571	0.952	**0.952**	0.952	0.952
R Square	0.327	0.906	**0.906**	0.907	0.907
Adjusted R^2	0.252	0.905	**0.905**	0.906	0.906
Standard Error	1.887	0.707	**0.707**	0.703	0.703
Observations	1500	1500	**1500**	1500	1500
f value	181.65	1591.372	**1790.931**	1116.898	1210.78
t stat value	38.318	47.74	**51.384**	18.632	19.3201
Factors considered	Household size, income, type of housing unit and ownership.	Household size, income, type of housing unit and ownership, amount of paper, glass, metal, organic and plastic waste.	**Household size, income, type of housing unit and ownership, amount of glass, metal, organic and plastic waste.**	Season, location, population density, Household size, income, type of housing unit, waste disposal and ownership, amount of paper, glass, metal, organic and plastic waste.	Season, location, population density, Household size, income, type of housing unit, waste disposal and ownership, amount of glass, metal, organic and plastic waste.
Fit/Unfit	Unfit	Fit	Fit	Fit	Fit

$$\begin{aligned}\text{Wastefootprint} = {} & 4.544 - (1.5977 * \text{household size}) - (0.0599 * \text{household income}) \\ & + (0.1359 * \text{type of housing unit}) - (0.0165 * \text{ownership}) \\ & + (0.3714 * \text{glass}) + (0.8049 * \text{metal}) + (0.4398 * \text{organic}) \\ & + (0.5588 * \text{plastic}) \qquad (13.3)\end{aligned}$$

13.3 SUMMARY OF THE CHAPTER

The research highlighted that technical and scientific innovations in the field of waste management should go in line with measures to create awareness among the public and their behavioural change promotion in waste generation and disposal trends. Therefore the chapter presented the waste footprint model for Kochi city after the regression analysis of a set of variables and tests. The model developed is user friendly and can be made available to the media and individual households themselves can calculate and compare the waste footprints. The model can be used to create awareness among the people about their impact of waste generation, by calculating the percentage of city area required to assimilate the waste, if everyone in the city is having similar waste generation trend of the person entering the values. Also the model can be used as an economic instrument for the implementation of government policies for sustainable solid waste management in the city. By considering the relevant parameters, similar waste footprint models for cities can be developed elsewhere in the world.

CHAPTER 14
CONCLUSION

This research aimed to study and explore the environment management tool ecological footprint analysis (EFA) and to suggest a solution to the solid waste management issues in the residential areas of Kochi city, the commercial capital of Kerala, South India, through ecological footprint analysis.

To attain this aim, research objectives were formulated and research questions were framed. In order to answer the research questions, methodology was framed in three phases. In the first phase, literature review of EFA was conducted and ecological footprint of Kochi city was studied. From the study, it was found that the solid waste management is one of the major issues which affect the sustainability of the city. In the second phase, the solid waste management issues in the city were studied in detail and observed that, the residential waste contributes the lion's share of municipal solid waste. Therefore, the research focused in the solid waste management issues in the residential areas of Kochi city through the waste footprint concept (subset of ecological footprint). The waste footprint of the residential areas of Kochi city was calculated and analysed. It was found that there are sustainability issues in the management of wastes especially organic and plastic waste and the disposal of organic waste by biogas production reduces the organic footprint to a considerable extend. In the third phase of the research, a conceptual framework was developed to evaluate the existing domestic organic waste management techniques in the city. Evaluating the biogas technology as a sustainable measure for the disposal of domestic organic waste, sustainable strategies for improving the program and waste management of the recyclables were discussed in detail. Policies and strategies were formulated for a sustainable residential waste management in Kochi city. Finally, a model to assess the waste footprint of the individual households of the city was developed. The succeeding paragraphs conclude the findings of the research.

Ecological footprint analysis and its application:

The environmental management tool ecological footprint analysis (EFA) was studied and explored and the application of the tool in civil engineering and urban planning problems were analysed in Chapter 2 and 3 respectively. The review of the EFA in Chapter 2 showed that the ecological footprint tracks humanity's demands on the bio-sphere by comparing the renewable resources people are consuming, against the earth's regenerative capacity, or bio capacity. The comparison of EFA with Environmental Impact Assessment (EIA) showed that, EFA can be used as an impact assessment tool for India and the assessment through EFA is easy, quick, highly quantifiable, unique and consistent. The applications and case studies (Chapter 3) showed that ecological footprint accounts allow government to track a city or region's demand on natural capital, and to compare this demand with the amount of natural capital actually available. The transportation and housing case studies showed that ecological footprint analysis can be used as a valuable tool for measuring the sustainability of infrastructure projects which in turn help to assess the sustainability of urban areas. The ecological footprint indicator shows clearly where we are and where we need to be.

Ecological footprint of Kochi city and the major issues in the city:

The ecological footprint studies in Kochi city (Chapter 4) showed that the average footprint (2.25 gha) in the city area is much above the national average (0.8gha) and exceeds world average biocapacity (1.8gha). If everyone in the world live likes an average Kochi resident, we would need 1.3 planets to sustain our life.

The condition of the city is highly unsustainable with high shelter footprint (1.02gha) followed by goods and services footprint (0.64gha), food footprint (0.38gha) and mobility footprint (0.32gha). The high house area usage is shooting the shelter footprint whereas the improper waste disposal is causing high goods and services footprint. The temporal variation of ecological footprint of the Kochi city showed that the footprint values are increasing from 2.19 to 2.35 global hectares per person over the years (2007-2009). The chapter also shows that there exists high un-sustainability dilemma in the field of housing and waste management of Kochi city. Of this, solid waste management was observed as the crucial and most threatening one which affects the health of the population, environment and serenity of the city.

Application of the tool ecological footprint analysis to solid waste management issues in Kochi City:

The solid waste management status and issues in India, in Kerala state and in Kochi city through available literature were analysed in Chapter 5. From this, it was observed that the compostable organic wastes from the residential areas of the city constitute the major share of the municipal waste stream of the city. So, the research focus on the solid waste management issues in the residential areas of Kochi city. To solve the solid waste management issues, the waste footprint concept was studied in detail and observed that the waste footprint concept can convert the waste generated into an equivalent land area required to assimilate it. This makes the common man aware of their local capacity to assimilate the waste, the effect of their waste generation and the impact on earth.

The waste footprint analysis of the city in Chapter 6 and the detailed statistical analysis in the Chapter 7 concluded that 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, the projected generation in 2020 will be 0.58kg/capita/day. 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 m^2 per capita of energy land, 0.08 m^2 per capita of forest land and 16.47 m^2 per capita of built up land is required to assimilate the waste generated by the residents of Kochi city. For all other wastes except for plastics and metals the percentage share of the footprint value is less than the percentage share of that particular waste in the total waste. 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. The analysis also showed that the production of biogas itself made 58% reduction in the organic footprint values. The Chapter 8 summarized the findings of the waste footprint of the city and concluded that by 2051 the whole area of the city corporation will be required to assimilate the waste generated by the residents, if the present trend of waste generation continues.

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 attempted. The analysis also showed that the source reduction proved the first order hierarchies, as per the waste management hierarchy theories in terms of waste footprint values. The analysis showed that by the targeted value of footprint (43.09 m^2 per capita) which is achieved by a combination of targeted recycling and waste reduction, only 33% of the total area

(3091.2 hectares) of the city is required for waste assimilation by 2051. By the projected value (11.66 m^2 per capita) which is achieved by a combination of projected recycling and waste reduction, only 9% area of the city (836.5 hectares) is required for waste assimilation by 2051. Therefore for effective footprint reduction both recycling and reduction in waste generation shall be practiced simultaneously.

Conceptual framework for sustainable domestic organic waste management (SDOWM); policies and strategies to reduce the waste footprint and waste management issues in the Kochi city.

To strengthen the findings of the research, various aspects for sustainable domestic organic waste management were studied in detail and a conceptual framework for SDOWM was formulated (Chapter 9) which can be used for evaluating the domestic organic waste management techniques. We define the sustainable domestic organic waste management as *'the domestic organic waste management system which is environmental friendly, technically feasible, economically viable, and socially acceptable with adequate institutional/organizational support'.* The *sustainable domestic organic waste management is represented as a wheel and with the aspects as its parts. The wheel will rotate only if all the parts will move in same direction simultaneously. It can be in a clockwise or an anticlockwise direction which depends on the movement of the first trigger of any of the parts. If any one of the part doesn't move or stops movement in between, the entire system fails.* The framework developed showed the interdependence of the five aspects of sustainability (social, economical, environmental, technical, and institutional/organizational). The interdependence of the various aspects of sustainability as well as their equality will help in formulating strategies for sustainable domestic organic waste management. The conceptual framework outlined in this research, based on these aspects can be used to evaluate sustainable domestic organic waste management not only in Kerala but also elsewhere in the world with similar situations. In addition, various measurable factors of the sustainability aspects of SWODM were identified for evaluating the biogas production technology in the city.

The evaluation study was conducted to get an overall idea of the existing biogas plants used inside and outside the city over the past few years (Chapter 10) which helps to formulate guidelines for the sustainable domestic organic waste management in the city. The study shows that, the biogas technology system is socially acceptable, economically viable, environmental friendly, technically feasible and institutionally stable apart from some minor issues. Feeding upon renewable resources and non-polluting in process, technology of biogas generation serves a triple function: waste removal, management of the environment and energy production. Hence, the biogas technology can be accepted and recommended as a sustainable measure and or option for the waste management of organic wastes produced in the residential areas of Kochi city.

The Chapter 11 highlighted the various quantity reduction and recycling options for the sustainable management of recyclables. The chapter concluded that recycling is one strategy for effective waste management of inorganic wastes especially plastic products. It makes increasing sense of economical as well as environmental benefits and also recent trends demonstrate a substantial increase in the rate of recovery and recycling of plastic wastes. These trends are likely to continue, but some significant challenges still exist from both technological factors and from economic or social behaviour issues relating to the collection of recyclable wastes, and substitution for virgin material. This focuses the importance of constituting a recycling division with people's participation under the local self-government department.

The Chapter 12 put forward the strategies for sustainable solid waste management in the residential areas of Kochi city and concluded that integrated waste resource management planning enables organizations to create a comprehensive strategy that can remain flexible in light of changing economic, social, material (products and packaging) and environmental conditions. The chapter also concluded that in many cases, the most efficient and cost effective way to manage waste is waste diversion and waste minimization with effective peoples' participation supported by adequate legislative policies. This shall be the primary focus for the integrated waste management plan of the Kochi city.

Development of a sustainable model to calculate the waste footprint of the city:

From the factors identified for the waste footprint calculations, the waste footprint model was generated based on regression equations and a program in visual basic platform (Chapter 13). The model can estimate the percentage of city area required to assimilate the waste, if everyone is having similar waste generation trend of the person entering the data. This model is user friendly and can be made available through the media or the official website of the local body so that individual households themselves can assess their waste footprint and compare with the sustainable limits. In addition, it can be used as an awareness raising tool for waste footprint reduction or as a policy instrument for the implementation of government policies and strategies. By considering the relevant parameters, similar waste footprint models for cities can be developed elsewhere in the world.

Therefore the research highlights the following recommendations.

- The ecological footprint analysis can be used as an effective environmental management tool to assess the sustainability of urban areas.

- The waste footprint studies of Kochi city can be used as a model for waste footprint studies in other urban areas in India and elsewhere in the world with similar situations.
- The conceptual framework developed can be used to evaluate the domestic organic waste management practices not only in Kerala, but elsewhere in the world.
- The waste footprint model developed if made available to the public will surely generate awareness among them about the sustainable reduction of wastes. By considering the relevant parameters, similar waste footprint models for cities can be developed elsewhere.
- The objectives, targets and strategies in the residential waste management plan for Kochi city (Table 12.1), calls upon further scope of research.
- The research recommends the initiation of ecological footprint calculations and studies at the country level so that country specific data will be generated which will in turn reflect the quality of region specific studies.

Sustainable Solid Waste Management Will Make the City Cleaner, Greener and Liveable

APPENDIX 1

The waste footprint analyser program

```
Private Sub Form_Load()
'INPUTTING
Combo1.AddItem ("DRY")
Combo1.AddItem ("WET")
Combo1.AddItem ("FESTIVAL")
Combo2.AddItem ("CBD")
Combo2.AddItem ("AWAY FROM CBD")
Combo3.AddItem ("HIGH DENSITY")
Combo3.AddItem ("LOW DENSITY")
Combo4.AddItem ("1")
Combo4.AddItem ("2")
Combo4.AddItem ("3")
Combo4.AddItem ("4")
Combo4.AddItem ("5")
Combo4.AddItem ("6")
Combo4.AddItem ("7")
Combo4.AddItem ("8")
Combo4.AddItem ("9")
Combo4.AddItem ("10")
Combo5.AddItem ("HOUSEHOLD LEVEL")
Combo5.AddItem ("COMMUNITY LEVEL")
Combo6.AddItem ("INDIVIDUAL PLOT")
Combo6.AddItem ("ROW HOUSING UNIT")
Combo6.AddItem ("LOW RISE BUILDING")
Combo6.AddItem ("HIGH RISE BUILDING")
Combo7.AddItem ("INDIVIDUAL")
Combo7.AddItem ("GOVERNMENT")
Combo7.AddItem ("BUILDER")
Combo8.AddItem ("LESS THAN 5000")
Combo8.AddItem ("5000 TO 10000")
Combo8.AddItem ("10000 TO 15000")
Combo8.AddItem ("15000 TO 20000")
Combo8.AddItem ("ABOVE 20000")
End Sub
Private Sub Command1_Click() 'save option button
' SUMMING UP DAILY WASTES
Dim S As Double
S = Val(Text4.Text) + Val(Text5.Text) + Val(Text6.Text) + Val(Text7.Text) +
Val(Text8.Text) + Val(Text9.Text) + Val(Text10.Text)
Text39.Text = S
S = Val(Text11.Text) + Val(Text12.Text) + Val(Text13.Text) + Val(Text14.Text) +
Val(Text15.Text) + Val(Text16.Text) + Val(Text17.Text)
Text40.Text = S
S = Val(Text18.Text) + Val(Text19.Text) + Val(Text20.Text) + Val(Text21.Text) +
Val(Text22.Text) + Val(Text23.Text) + Val(Text24.Text)
Text41.Text = S
```

```
S = Val(Text25.Text) + Val(Text26.Text) + Val(Text27.Text) + Val(Text28.Text) + Val(Text29.Text) + Val(Text30.Text) + Val(Text31.Text)
Text42.Text = S
S = Val(Text32.Text) + Val(Text33.Text) + Val(Text34.Text) + Val(Text35.Text) + Val(Text36.Text) + Val(Text37.Text) + Val(Text38.Text)
Text43.Text = S
'ENTERING DETAILS TO TABLE.DBF
If Text1.Text = BLANK Or Text1.Text = " " Or Text2.Text = BLANK Or Text2.Text = " " Or Combo1.Text = "SELECT" Or Combo2.Text = "SELECT" Or Combo3.Text = "SELECT" Or Combo4.Text = "SELECT" Or Combo5.Text = "SELECT" Or Combo6.Text = "SELECT" Or Combo7.Text = "SELECT" Or Combo8.Text = "SELECT" Or Val(Text39.Text) + Val(Text40.Text) + Val(Text41.Text) + Val(Text42.Text) + Val(Text43.Text) < 0.00000001 Then
errormsg = MsgBox("Some Cells are not filled", vbOK, "")
Else
Data1.Recordset.MoveLast
Data1.Recordset.AddNew
Data1.Recordset.Fields(0) = Combo1.Text
Data1.Recordset.Fields(1) = Val(Text1.Text)
Data1.Recordset.Fields(2) = Text2.Text
Data1.Recordset.Fields(3) = Combo2.Text
Data1.Recordset.Fields(4) = Combo3.Text
Data1.Recordset.Fields(5) = Combo4.Text
Data1.Recordset.Fields(6) = Combo8.Text
Data1.Recordset.Fields(7) = Combo5.Text
Data1.Recordset.Fields(8) = Combo6.Text
Data1.Recordset.Fields(9) = Combo7.Text
Data1.Recordset.Fields(10) = Val(Text39.Text)
Data1.Recordset.Fields(11) = Val(Text40.Text)
Data1.Recordset.Fields(12) = Val(Text41.Text)
Data1.Recordset.Fields(13) = Val(Text42.Text)
Data1.Recordset.Fields(14) = Val(Text43.Text)
Data1.Recordset.Fields(32) = Val(Text44.Text)
Data1.Recordset.Fields(33) = Val(Text45.Text)
Data1.Recordset.Fields(34) = Val(Text46.Text)
Data1.Recordset.Fields(35) = Val(Text47.Text)
Data1.Recordset.Fields(36) = Val(Text48.Text)
'paper
'Energy land = world energy yield * energy intensity of paper * (amount of per capita paper waste per year /waste factor of paper) *
'(1 – % of recycling of paper * % of energy saved from recycling)
If Data1.Recordset.Fields(10) = 0 Then
Data1.Recordset.Fields(15) = 0
Data1.Recordset.Fields(16) = 0
Else
Data1.Recordset.Fields(15) = 7.3 * 35 * ((Data1.Recordset.Fields(10) / (7 * Data1.Recordset.Fields(5))) / 1) * (1 - (Data1.Recordset.Fields(32) / Data1.Recordset.Fields(10)) * 0.45)
'Forest land = World average yield of round wood * ratio of round wood needed per unit paper * (amount of per
```

```
'capita paper waste per year / waste factor of paper) * (1 - % of recycling of paper * % of energy saved from recycling)
Data1.Recordset.Fields(16) = (10000 / 2.6) * (1.65 / 1000) * ((Data1.Recordset.Fields(10) / (7 * Data1.Recordset.Fields(5))) / 1) * (1 - (Data1.Recordset.Fields(32) / Data1.Recordset.Fields(10)) * 0.8)
'Built up land = Energy land required for paper waste * built up land footprint component of waste / (world
'average fossil fuel area of goods + world average fossil fuel area of waste) / primary biomass equivalence factor for built up area
End If
Data1.Recordset.Fields(17) = Data1.Recordset.Fields(15) * 1100 / (1324 + 1196) / 3.5
'biologically productive land for paper
Data1.Recordset.Fields(18) = Data1.Recordset.Fields(15) + Data1.Recordset.Fields(16) + Data1.Recordset.Fields(17)
'glass
If Data1.Recordset.Fields(11) = 0 Then
Data1.Recordset.Fields(19) = 0
Else
Data1.Recordset.Fields(19) = 7.3 * 15 * ((Data1.Recordset.Fields(11) / (7 * Data1.Recordset.Fields(5))) / 1) * (1 - (Data1.Recordset.Fields(33) / Data1.Recordset.Fields(11)) * 0.3)
End If
Data1.Recordset.Fields(20) = Data1.Recordset.Fields(19) * 1100 / (1324 + 1196) / 3.5
Data1.Recordset.Fields(21) = Data1.Recordset.Fields(19) + Data1.Recordset.Fields(20)
'metal
If Data1.Recordset.Fields(12) = 0 Then
Data1.Recordset.Fields(22) = 0
Else
Data1.Recordset.Fields(22) = 7.3 * 60 * ((Data1.Recordset.Fields(12) / (7 * Data1.Recordset.Fields(5))) / 1) * (1 - (Data1.Recordset.Fields(34) / Data1.Recordset.Fields(12)) * 0.95)
End If
Data1.Recordset.Fields(23) = Data1.Recordset.Fields(22) * 1100 / (1324 + 1196) / 3.5
Data1.Recordset.Fields(24) = Data1.Recordset.Fields(22) + Data1.Recordset.Fields(23)
'organic waste
If Data1.Recordset.Fields(13) = 0 Then
Data1.Recordset.Fields(25) = 0
Else
Data1.Recordset.Fields(25) = 7.3 * 30 * ((Data1.Recordset.Fields(13) / (7 * Data1.Recordset.Fields(5))) / 1) * (1 - (Data1.Recordset.Fields(35) / Data1.Recordset.Fields(13)) * 0.58)
End If
Data1.Recordset.Fields(26) = Data1.Recordset.Fields(25) * 1100 / (1324 + 1196) / 3.5
Data1.Recordset.Fields(27) = Data1.Recordset.Fields(25) + Data1.Recordset.Fields(26)
'plastic
If Data1.Recordset.Fields(14) = 0 Then
Data1.Recordset.Fields(28) = 0
Else
```

```
Data1.Recordset.Fields(28) = 7.3 * 50 * ((Data1.Recordset.Fields(14) / (7 * Data1.Recordset.Fields(5))) / 1) * (1 - (Data1.Recordset.Fields(36) / Data1.Recordset.Fields(14)) * 0.7)
End If
Data1.Recordset.Fields(29) = Data1.Recordset.Fields(28) * 1100 / (1324 + 1196) / 3.5
Data1.Recordset.Fields(30) = Data1.Recordset.Fields(28) + Data1.Recordset.Fields(29)
'footprint
Data1.Recordset.Fields(31) = Data1.Recordset.Fields(18) + Data1.Recordset.Fields(21) + Data1.Recordset.Fields(24) + Data1.Recordset.Fields(27) + Data1.Recordset.Fields(30)
Data1.Recordset.Update
MsgBox ("DATA SAVED")
End If
If errormsg = vbOK Then
Else
'clear at the time of save
Combo1.Text = " "
Combo2.Text = " "
Combo3.Text = " "
Combo4.Text = " "
Combo5.Text = " "
Combo6.Text = " "
Combo7.Text = " "
Combo8.Text = " "
Text1.Text = " "
Text2.Text = " "
Text4.Text = " "
Text5.Text = " "
Text6.Text = " "
Text7.Text = " "
Text8.Text = " "
Text9.Text = " "
Text10.Text = " "
Text11.Text = " "
Text12.Text = " "
Text13.Text = " "
Text14.Text = " "
Text15.Text = " "
Text16.Text = " "
Text17.Text = " "
Text18.Text = " "
Text19.Text = " "
Text20.Text = " "
Text21.Text = " "
Text22.Text = " "
Text23.Text = " "
Text24.Text = " "
Text25.Text = " "
Text26.Text = " "
Text27.Text = " "
```

```
Text28.Text = " "
Text29.Text = " "
Text30.Text = " "
Text31.Text = " "
Text32.Text = " "
Text33.Text = " "
Text34.Text = " "
Text35.Text = " "
Text36.Text = " "
Text37.Text = " "
Text38.Text = " "
Text44.Text = " "
Text45.Text = " "
Text46.Text = " "
Text47.Text = " "
Text48.Text = " "
Text49.Text = " "
Text50.Text = " "
Text51.Text = " "
Text52.Text = " "
Text53.Text = " "
Form1.Show
End If
End Sub
' total number of records'counting
Private Sub Command2_Click()
Dim I As Integer
I = 1
Data1.Recordset.MoveFirst
Data1.Recordset.movenext
For J = 1 To 5000
If Data1.Recordset.EOF Then
Else
I = I + 1
Data1.Recordset.movenext
End If
Next J
Text54.Text = I
'average
Data1.Recordset.MoveFirst
b = 0
For I = 1 To 5000
   If Data1.Recordset.EOF Then
      Else
       a = Data1.Recordset.Fields(31)
           b = b + a
      Data1.Recordset.movenext
  End If
     Next I
Text55.Text = Round(b / (Val(Text54.Text) * 10000), 3)
If Val(Text54.Text) < 2500 Then
```

```
'MsgBox ("SUCESS, BUT SMALLER SAMPLE SIZE MAY CAUSE UNRELIABLE RESULTS",vbYesNo,"xxxxx")
Else
MsgBox ("SUCESS")
 End If
End Sub
Private Sub Command3_Click() 'CLEAR PREVIOUS
MsgBox ("LATEST ENTRY WILL BE REMOVED")
Data1.Recordset.MoveLast
Data1.Recordset.Delete
Dim I As Integer
I = 1
Data1.Recordset.MoveFirst
Data1.Recordset.movenext
For J = 1 To 5000
If Data1.Recordset.EOF Then
  Else
    I = I + 1
    Data1.Recordset.movenext
 End If
Next J
Text54.Text = I
Text55.Text = ""
End Sub
```

Appendix 2

SCHOOL OF ENGINEERING, COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING
QUESTIONNAIRE FOR THE SURVEY

This study is undertaken by Athira Ravi, Research Scholar, Department of Civil Engineering, School of Engineering, CUSAT as part of her research work. The aim of this survey is to evaluate the waste footprint of the region. The outcome of this study will only be used for academic purposes

House No. Ward No.

1. Personal details

Plot area:

Area of house:

2. Family structure

No.	Relationship with head of the family	Age	Sex	Occupation/education	Distance to Place of work /education*	Monthly Income #
Member 1						
Member 2						
Member 3						
Member 4						
Member 5						
Member 6						
Member 7						
Member 8						

*Distance to place of work/ education

A < 1 km	B 1- 5 km	C 6-10 km	D 11-15 km	E >15 km

Income range

A <5000	B 5000-10000	C 10000-15000	D 15000-20000	E >20000

3. House hold expenditure

Item	Amount
Food	
Medical treatment	
Travel expenses	
Education	

Electricity	
Telephone	
Water supply	
Cooking gas	
Petrol/ diesel	
Others	

4. Social infrastructure facility

Facility	1-2 km	2-4 km	Above 4 km
Educational			
Recreational			
Library			
Municipal halls			
Shop (Daily need)			
Shop (Others)			
Health facility			

5. Is there any waste recycling methods practiced in your house? If yes, specify

Yes No

………………………………………………

………………………………………………

6. Physical infrastructure

a. Source of water

Municipal	Common tap	Tube well	Private well

b. Sewage disposal

Septic tank	Municipal sewerage system	Leach pit	Other

c. Solid waste disposal

Dumping	Burial	Clearance by municipality	Other

7. Remarks of the respondent:

8. Solid Waste Details

1. Amount of waste generated in Kg

Month 1	Paper	Glass	Metal	Organic Waste	Plastic
Day 1					
Day 2					
Day 3					
Day 4					
Day 5					

Month 2	Paper	Glass	Metal	Organic Waste	Plastic
Day 1					
Day 2					
Day 3					
Day 4					
Day 5					

Month 3	Paper	Glass	Metal	Organic Waste	Plastic
Day 1					
Day 2					
Day 3					
Day 4					
Day 5					

2. Amount of waste recycled in Kg

Method of recycling paper -----------------------------------
Method of recycling glass------------------------------------
Method of recycling metal-----------------------------------

Method of recycling organic waste--------------------------
Method of recycling plastic ----------------------------------

	Paper	Glass	Metal	Organic Waste	Plastic
Month 1					
Month 2					
Month 3					

Details of Biogas production if any

Raw material : -----------------------------------kg

Total Percentage of solid content: --------------------------%

Capacity of the tank: ----------------------------

Energy usage: ---------------------------

Appendix 3

QUESTIONNAIRE FOR BIOGAS USERS

Objective: To substantiate whether sustainable organic waste management in the residential areas of Kochi city is possible through the biogas technology.

A. GENERAL DETAILS

1. Name of the respondent:
2. Sex:
3. House Number:
4. Contact Number:
5. Location:

B. FAMILY DETAILS

Sl.No.	Member's name and relation with head of household	Sex*	Age	Education**	Profession***

* 1= Male, 2=Female

**00=Nursery or KG, 01-09=From Class 1 to 9, 10=SLC, 11=+2 not completed, 12=+2 Completed 13=Degree not completed , 14= Degree completed , 15= Post graduate not completed, 16= Post graduate not completed, 17= More than Post Graduation, 18=Informal Education, 19=Don't Know, 20= illeterate

***1=Agriculture, 2=Government or salaried, 3=Self Employed, 4=Daily Wage, 5=Foreign Employment, 6=Unemployed, 7= Student, 8=Other (Specify)

C. LAND, HOUSE AND OTHER DETAILS

1. Plot size*:
2. Total house area**:
3. Type of housing unit***:
4. Agricultural land available in addition in cents*:
5. Floricultural land available in cents*:
6. Agricultural activities in terrace****:
7. Distance to nearest motor able road:
8. Water source*****:
9. Domestic organic waste generation: kg

*1=Less than 5 cents, 2=5 to 10 cents, 3= 10 to 15 cents, 4= 15 to 20 cents, 5= More than 20 cents

**1=Less than 500sqft, 2=500 to1000sqft, 3=1000 to1500sqft, 4=1500 to 2000sqft, 5=More than 2000sqft

***1=Pucca, 2=Moderate, 3=Kutcha

****1=Yes, 2=No

*****1=Own well, 2=Municipal water supply, 3=Others(Specify)

D. Other details

1	Plant size	$2m^3$	$4\ m^3$	$6m^3$	$8m^3$	$10m^3$	More than $10m^3$
2	How long have you been using biogas?				Number of years:		
3	If you are using the plant, condition?			Good	Satisfactory		Poor
4	If you are not using the plant, how long have you not used it?					Number of years:	
	Why?	Failure of appliances					
		Damaged physically					
		No feed/ Insufficient feed					
		Switched completely to other fuel					
		Don't Know					
5	Type of feed		Kitchen waste	Cow dung	Toilet waste		Others(Specify)
6	Daily availability of biogas			Up to 1 hour			1-2 hour
				2-3 hour			above 3 hours
7	Who constructed/installed the biogas plant?						
	Service provider						
	My self						
	Myself with a skilled Mason with good knowledge on biogas plant						
8	Whether any standards set by the service providers as regards the quality of construction, materials, mason to construct biogas plants?					Yes	No
	If yes, what type of quality standards were set?		Trained masons should be used				
			Standards on construction materials				
			Standards on pipe and appliances				
			Standards on plant design				
			Don't know				
9	How did you come to know about biogas plant?						
	Through public media						
	Through government officials						
	Through service providers						
	Through NGO						
	Through community leaders						
	Through friends/relatives						
	Through other biogas owners						
	Others(Specify)						
10	Who in your family took decision to install a biogas plant?						
	The head of the household, male member						
	The head of the household, female member						
	Son/Daughter						
	After discussion in the family						
	Service provider						
	Others(Specify)						
11	What are the motivating reasons behind installing a biogas plant?						
	Subsidy						
	Non availability of other fuel sources						

	Social benefits/prestige	
	Health benefits	
	Environmental benefits	
	Economic benefits	
	Motivation from service providers	
	Motivation from existing plant owners	
	Compulsion from neighbours	
	Saves time and energy	
	Others(Specify)	
12	Has anyone in your family received training on operation and maintenance of biogas plant?	
	No training received	
	Training not provided but leaflet booklet manual provided	
	One day orientation training provided by the service provider	
	Short term O&M training (7 days or less)	
	Long term O & M training (more than 7 days)	
	On the spot instruction from mason/company/supervisor etc	
	Others(Specify)	
13	Have you received any follow up services from the service provider?	
	No, not even when requested	
	No, not at all	
	Yes, on call	
	Yes, regularly	
14	Is there any service centre nearby?	
	No	
	Yes, very near (within 5 km)	
	Yes, quite far (5-10km)	
	Yes, very far (more than 10 km reach)	
15	How did you manage financing for construction of biogas plant?	
	Self	
	Loan from persons	
	Micro credits/Cooperatives	
	Bank	
16	Have you received any subsidy	
	Yes	
	No	
	Don't know	
	If yes, what kind of subsidy have you received?	
	Instrument/Appliances	
	Construction materials	
	Don't know	
17	Have you experienced that your expenditure in fuel has gone down because of the biogas plant?	
	No, not at all	
	Yes, to some extent	

	Yes, significantly	
	It has gone up	
	Don't know	
18	Have you experienced any saving in chemical fertilizer after the use of biogas?	
	Yes	
	No	
19	What is your opinion on the cost of installation of your biogas plant?	
	It is cheap	
	It is reasonable	
	It is quite expensive	
	It is very expensive	
20	Purpose of biogas produced	
	Cooking	
	Lighting	
	Both	
21	What types of fuel did you use for cooking before installation of biogas?	
	LPG	
	Wood	
	Electricity	
	Others(Specify)	
22	How long your LPG cylinder last before and after the installation of biogas?	
	Less than 1 month	
	1 month	
	1 month-1 $^{1/2}$ month	
	1 $^{1/2}$ -2 months	
	2-3 months	
	More than 3 months	
23	Air pollution status in Kitchen by smoke	
	Severe	
	Moderate	
	Minimal	
	No Pollution	
24	Whether breeding of mosquitoes has increased after the installation of biogas?	
	Yes	
	No	
25	Any other infections before and after the installation of biogas	
	Before	After
	Typhoid	Typhoid
	Tuberculosis	Tuberculosis
	Diarrhoea	Diarrhoea
	Gastro intestinal diseases	Gastro intestinal diseases
	Eye infection	Eye infection
	Respiratory diseases	Respiratory diseases

	Others(Specify)	Others(Specify)
26	Accidents due to fire/burning from biogas	
	Before	After
	Severe	Severe
	Moderate	Moderate
	Minimal	Minimal
27	Do you use the bio slurry for farming?	
	If no, what do you do to the slurry?	
		Sale to others
		Give out to others
		Drain to water course or drains
		Others(Specify)
	Why don't you use slurry	
		It has lesser nutrient value
		It is difficult to use
		People are hesitant to handle the bioslurry from toilet attached plants
		No land to use
		Others(Specify)
	If yes, what do you do to the slurry?	
		Use as organic fertilizer without composting
		Use as organic fertilizer with composting
		Use as fish feed
		Others(Specify)
28	Reduction in the percentage of organic waste	
	100%	
	75%	
	50%	
	25%	
	Less than 25%	
29	Any other prerequisites required for plant functioning	
		Electricity
		Water
		Land
		Agricultural land
30	Any drawbacks noted for the system	

Any other suggestions:

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LIST OF PUBLICATIONS FROM THE THESIS

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II. CONFERENCES

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