Application of the DPSIR framework for municipal solid waste management in south asian developing countries

（南アジアの発展途上国における都市廃棄物管理のための DPSIR フレームワークの適用）

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Abstract

Patterns of production and consumption in south Asian developing countries are shifting significantly as a result of rapid economic growth, urbanization, and life style change. Municipal solid waste management has gone through a history of shifting problems, demands and strategies over the years. This thesis addresses the issue of sustainable resource management from a sector perspective: the municipal solid waste. This thesis tries to find out the applicability of the Driving force- Pressure-State- Impact- Response model (DPSIR model), to assess the decoupling between economic growth and environmental threats by Environmental Kuznets Curve (EKC) and to discuss the feasibility of knowledge transfer in municipal solid waste management from developed country to south Asian developing countries as a possible solution.

The first contribution of this thesis is the comprehensive analysis and future estimation of municipal solid waste based on the present trend of municipal solid waste management. The DPSIR model was applied to analyze municipal solid waste management in developing countries. Applicability and indicators of the DPSIR model for waste management was discussed.

The major result of this thesis was to identify the main driving force of waste generation as well as relevant economic and population growth. A sign of decoupling was first detected in Indian nation wide analysis. In the specific case of the Indian States, possible response to promote the decoupling was investigated and it showed that education is effective to decouple driving force-pressure. However a domestic policy inside the developing countries is still not sufficient when compared with developed countries from the viewpoint of eco-efficiency. Finally four aspects of knowledge transfer aiming to improve waste management is shown and discussed; technology development, investment and managing practice, legal system and 3R policy. These four aspects of knowledge transfer could help solving the municipal solid waste issues in the developing countries.

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Chapter 1 INTRODUCTION

1.1 Background: Municipal solid waste management requirements in developing countries

Municipal solid waste management is a very wide topic where it involves the generation, storage, collection, transfer and transport, processing, treatment and disposal of the municipal solid waste with the best environmental and social consideration. Especially in the rapidly urbanizing cities of the developing world, problems and issues of municipal solid waste are of immediate importance. Human activities create waste, and the ways that waste is handled, stored, collected, and disposed off can pose risks to the environment and to public health. Therefore, management of municipal solid waste is indispensable to prevent loss of public wellness from those threats. Municipal solid waste management includes all activities that seek to minimize health, environmental, and aesthetic impacts of municipal solid waste. Within the scope of waste management, it includes all administrative, financial, legal, planning and engineering functions.

In the publication, “Our Common Future”[1] which is better known as Brundtland Report defined sustainable development as “to ensure that it (development) meets the needs of the present without compromising the ability of the future generations to meet their own needs”. In this context, sustainable and integrated municipal solid waste management puts a variety of aspects into a focal matrix; the urgent planning ncluding the environmental, socio-cultural, institutional, political, and legal aspects, as well as the important role of stakeholders as rag pickers and the informal recycling sector, and the other elements of the waste management system such as prevention, reuse and recycling, collection, street sweeping, and disposal. Sustainable and integrated municipal solid waste management should provide economical service and establishes cost-recovery mechanism to support institutional sustainability. It also helps in minimizing the resource use and environmental impact. Sustainable and integrated municipal solid waste management monitors the emission and environmental change related to municipal solid waste collection, storage, handling, and disposal activities.

Thus, an environmentally sound waste management should be implemented to reduce, reuse, recycle and reclaim the resources from depletion in order to ensure that we are not to consume what should be left for the future generation and also to minimize the pollution and negative effect of the municipal solid waste to the environment.

1.2 Concept of DPSIR framework

There are a few different methods developed and used to analyze structure and dynamics of environmental issues and impacts. The simple Pressure- State- Response (PSR) framework was developed by OECD[2] as a common framework for environmental evaluation. Environmental problems and issues were taken as variables to show the cause-effect relationships between human activities that exert pressure (P) on the environment, the change in conditions of the environment (R). This PSR model was further enhanced by the European Environmental Agency[3] to become the Driving force- Pressure- State- Impact- Response (DPSIR) framework, in order to provide a more comprehensive approach in analyzing environmental problems. The DPSIR framework is useful in describing the relationship between the origin and consequences of environmental problems, but in order to understand their dynamics it is also useful to focus on the links between DPSIR elements.

This DPSIR system view of analysis states that economic and social development, which are common driving force (D), exert pressure (P) on the environment, and as a result the state (S) of the environment such as depletion of natural resources and degradation of environmental quality changes. These changes then have impact (I) on the environment and human health. Due to these impacts, society responds (R) to the driving force, or directly to the pressure, state or impact through preventive, adaptive or curative solutions. The application of the DPSIR framework involves a great deal of information gathering to formulate indicators that can reflect the causal relationships between human activities, environmental consequences and responses to environmental changes.

1.3 Scope and Objectives of this Thesis

The field of municipal solid waste management has a strong concern with material flow in human society. Waste and environmental residual are generated in every stage of the material flow and they can become chemical pollutants and can accelerate climate change among the impacts.

Figure 1.1 Life cycle and consequent environmental burden of a product.

Source: (IGES and ADB[4])

The environmental performance of human system is widely determined by the quantity and quality of the induced material flow. The extraction of raw material on the one hand and the emission of waste material on the other hand exert a certain pressure to the environment (**Figure 1.1**). Every product has several stages in its life-cycle including

- extraction of natural resources,
- processing of resources,
- design of products and selection of inputs,
- production of goods or services,
- distribution,

- consumption,
- reuse of waste from production or consumption,
- recycling waste from consumption or production, and disposal of residual wastes.

Management issue of municipal solid waste is very important for our society. Most of the researchers so far have focused on the proper management of municipal solid waste and the ways to mitigate their environmental burden by its disposal. This research focuses on the model use of municipal solid waste generation indictors.

This research starts with an overview of municipal solid waste management of South Asian developing countries. The main research questions are to be determined with the contribution of this thesis:

- To overview municipal solid waste generation of developing countries: To study the current situation of municipal solid waste generation with different disposal techniques.
- To Forecast the future amount of municipal solid waste in developing countries: A comprehensive analysis of future prediction of municipal solid waste generation and required landfill area based on the current trend of municipal solid waste generation and its factors.
- To discuss the applicability of DPSIR model for municipal solid waste management in developing countries: The development of a DPSIR model helps to evaluate the main driving forces that influence the municipal solid waste generation along the pressure, state, impact and response factor.
- To assess decoupling of waste generation from economic growth, its factors and limitation in India by the DPSIR model: The Environmental Kuznets Curve helps to assess the decoupling of waste generation from economic growth in nation wide and state wide analysis in India.
- To discuss the feasibility of knowledge transfer from developed countries: To discuss the possibility of knowledge transfer in four aspects.

1.4 Outline of the Thesis

The remainder of the thesis has been structured as follows

Chapter 2 Overview of municipal solid waste generation of South Asian developing countries

Rapid economic growth by industrialization of the developing countries in Asia has caused serious problem of waste disposal due to the uncontrolled and unmonitored urbanization. This chapter makes an introduction to the municipal solid waste generation and the current trend is outlined with the detailed municipal solid waste generation factors.

Chapter 3 Forecast of the future municipal solid waste generation in South Asian developing countries

Based on the background, this chapter estimates the future amount of municipal solid waste generation in South Asian developing countries. It uses estimations of future population and urbanization. I also accomplish the importance of future predicted landfill area.

Chapter 4 Conceptualizing municipal solid waste management factors using DPSIR framework

To discuss the applicability of the DPSIR framework, this chapter reviews the brief history and overview of Driving force- Pressure- State- Impact- Response (DPSIR) framework from the view point of municipal solid waste management. Based on the economic and social development wide DPSIR analysis, the main input and output indictors of municipal solid waste generation are explained in detail.

Chapter 5 Economic growth decoupling solid waste loads in terms of Environmental Kuznets Curve: symptom of the decoupling in India

This chapter analyzes the relationship of economic growth with municipal solid waste generation mainly focusing on the detection of decoupling of economy and environment in India. Nation-wide time series data in India is analyzed in the first phase. Indian state wide data corresponding to the DPSIR factors is analyzed in the second phase. Possible response to promote the decoupling is also discussed.

Chapter 6 Potential evaluation of knowledge transfer in municipal solid waste management

This chapter discusses about the possibility of knowledge transfer from developed countries, which helps to implement advanced strategies in the developing countries in order to improve the municipal solid waste management.

Chapter 7 Conclusions

The last chapter of this thesis summarizes the major results and the most relevant conclusions, and at the same time further research perspectives are presented.

Figure 1.2 summarizes the structure of the thesis.

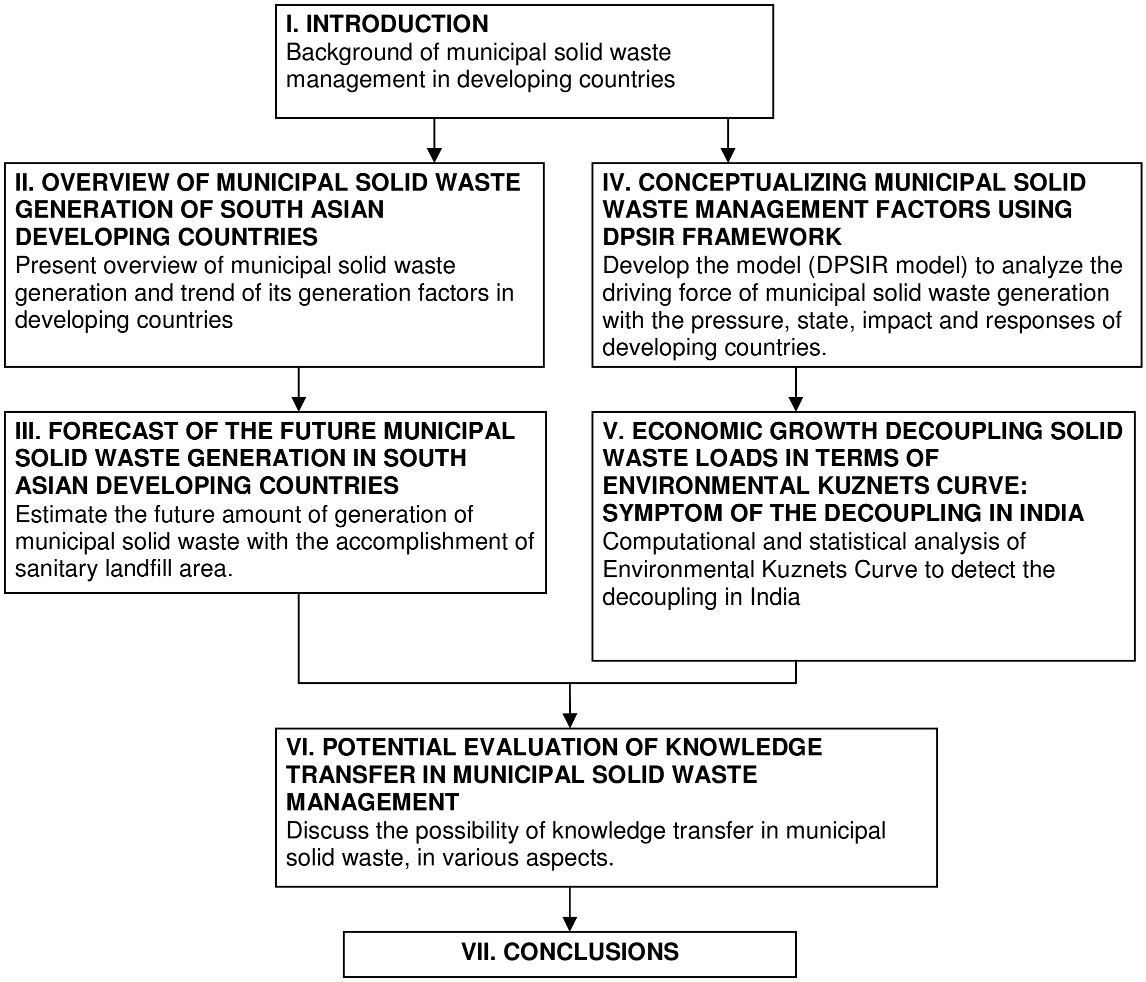

Figure 1.2 Structure of the Thesis

Chapter 2 OVERVIEW OF MUNICIPAL SOLID WASTE GENERATION OF SOUTH ASIAN DEVELOPING COUNTRIES

2.1 Introduction

Definitions of 'waste' invariably refer to lack of use or value, or 'useless remains'. Municipal solid waste is generated by human and animal activities that are discarded as useless or unwanted waste[5]. Municipal solid waste generation is an issue of worldwide concern. Municipal solid waste management is one of the critical environmental challenges of the developing countries facing rapid urban development. The generators of municipal solid waste are broadly classified as residential, industrial, commercial, institutional, construction, demolition, municipal and agricultural types. Now, Asia is the most economically dynamic region in the world. Economic development, urbanization and improving living standard in cities of Asian developing countries have lead to increase in the quantity and complex composition of municipal solid waste.

World population continues to rise with projections nearing 7.2 billion by 2015. Rapid urbanization accompanies this trend with an estimated two-thirds of the world's people living in cities by 2025. In fact, urban population in developing countries grows by more than 150,000 people everyday[6]. Although urbanization itself is not a necessary problem to discuss, haphazard and unplanned growth can result in many environmental problem such as public space and riverbank encroachment, air and water pollution and municipal solid waste generation.

UNDESA[6] Agenda 21 promoted the awareness regarding waste at the international level. The World Summit [7] focused on initiatives to accelerate the shift to sustainable consumption and production, and the reduction of resource degradation, pollution and waste. Several other factors like education standard and infrastructure of a country have significant effect on municipal solid waste generation. The quantity of municipal solid waste in developing countries has been consistently rising over the year. The municipal solid waste composition varies from place to place and also bears a rather consistent correlation with the average standard of living. The municipal waste generated in the developing countries is similar in composition, its variation among regions being dictated by the climatic, cultural and industrial, infrastructural and legal factors[8].

Developing Asian countries face serious problems in managing their municipal solid waste. The annual waste generation increases in proportion to the rise in population and urbanization, and issues related to disposal have become challenging as more land is needed for the ultimate disposal of these solid waste. Municipal solid waste is normally disposed off in open dumps in Asian developing towns and cities, which is not the proper method of disposal because such crude dumps pose environmental hazards causing ecological imbalances with respect to land, water and air pollution.

From this background, the purpose of this chapter is to identify the level of municipal solid waste generation and trend of its factors of South Asian countries for getting a clear grasp of the problems of municipal solid waste. Current status of municipal solid waste and its possible socio-economic drivers in South Asian countries were overviewed based on the national level statistics.

2.2 Study Area and Data Collection

Four South Asian developing countries, India, Nepal, Bangladesh and Sri Lanka were selected for the study area as shown in **Figure 2.1**. The countries have similar geographic position locating at the south end of Eurasia and their climate belongs to tropics. All of them experienced the colonial governance by the European nations until the middle 20th century and became independent after the World War II. The economies are on the way of modernization and the industrial structure is changing although agriculture still has a common significance. However, there is difference in the present level of economic development of the countries in which India has a significant economic growth after 1990s and is enumerated in the world emerging economies. Nepal and Sri Lanka have had political instability that may impede social and economic development.

Figure 2.1 Location of studied South Asian countries.

National level information on municipal solid waste and socio-economic indicators is collected. Used data is about urbanization (% of total population), gross domestic product per capita at PPP (Purchase Power Parity in international dollar in 2008) with the help of data available[9], and municipal solid waste generation (kg per capita per day). Also municipal solid waste composition and disposal technology in percentage were used from the available data source[10]. Other descriptive information of social factors was also referred.

2.3 Identification of factors affecting municipal solid waste discharge: Volume in incline

2.3.1 Urbanization: Changing lifestyle

Today, the total population of developing countries accounts for more than 70% of the world population**.** The growth pattern of metro cities (cities having population of a million or more) collaborates further the thesis of concentrated urban development. Natural growth of population, reclassifications of habitation and migration trends are important in urban population in developing countries. Urbanization is an index of transformation from traditional rural economies to modern industrialized one. It is a progressive concentration of population in urban unit.

Rapid urbanization has been synchronous with dramatic rate of economic growth as well as severe environmental problem[11]. **Figure 2.2** shows the trend of urbanization (% of total population) of the selected countries in the years 1995, 2000 and 2005. Urbanization is the most progressed in India (34.9%) followed by Bangladesh (25.5%), Nepal (16.2%) and Sri Lanka (15.1%) in 2005[9]. The urbanization trend in 10 years was rapid in Bangladesh and Nepal showing about 5% progress in the period. Only Sri Lanka showed a decrease of urbanization between 2000 and 2005 probably affected by the domestic war. The process of urbanization, inextricably linked to the municipal solid waste management issues, is progressing at a pace much faster than that was ever experienced by today's industrialized developing countries. Developing countries are producing municipal solid waste at an alarming rate. From the last two decades, the amount of municipal solid waste has been increasing rapidly.

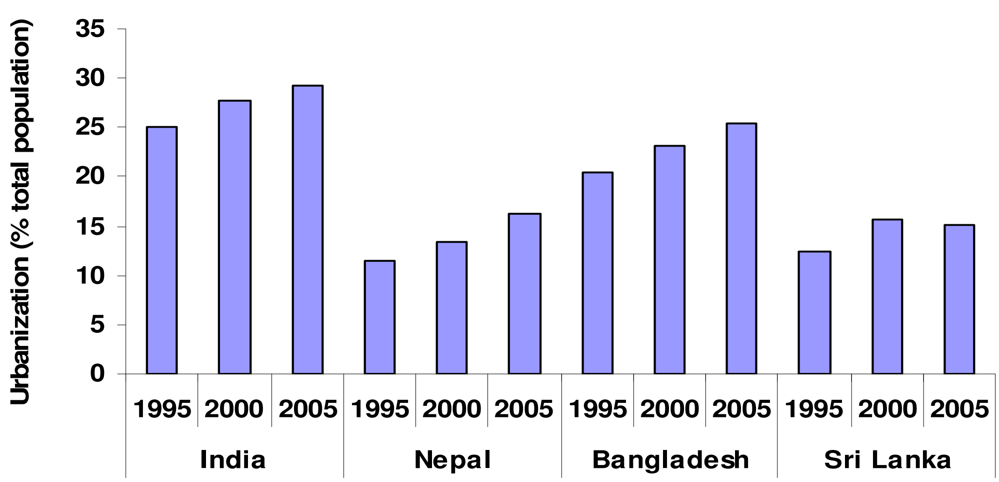

Figure 2.2 Trends of urbanization in studied countries

2.3.2 Economic Development: Gross Domestic Product per Capita (GDP per capita)

In developing countries, improvements in economic condition have changed the living standard and increase the rate of consumption of material. Most of the economic expansion has been associated with rapid urbanization. Subsequently, it causes the large amount of municipal solid waste generation. The generation and management of municipal solid waste occurred through the lens of economics.

Analyses across countries and over time show that the generation of municipal solid waste is positively correlated to the variations in per capita income, and that the generation of municipal solid waste per capita does not vary with population size among countries with comparable per capita income [12]. **Figure 2.3** shows the GDP per capita at PPP (international dollar in 2008). The minimum GDP per capita at PPP was found in Bangladesh and the maximum GDP per capita at PPP is found in Sri Lanka[9]. The high GDP per capita and its growth rate in Sri Lanka were the result of the most advanced economic open-door policy since 1970s and of the most export dominant economy among South Asian countries. GDP per capita keeps increasing also in the other South Asian countries and the abrupt growth in India between 2000 and 2005 is remarkable.

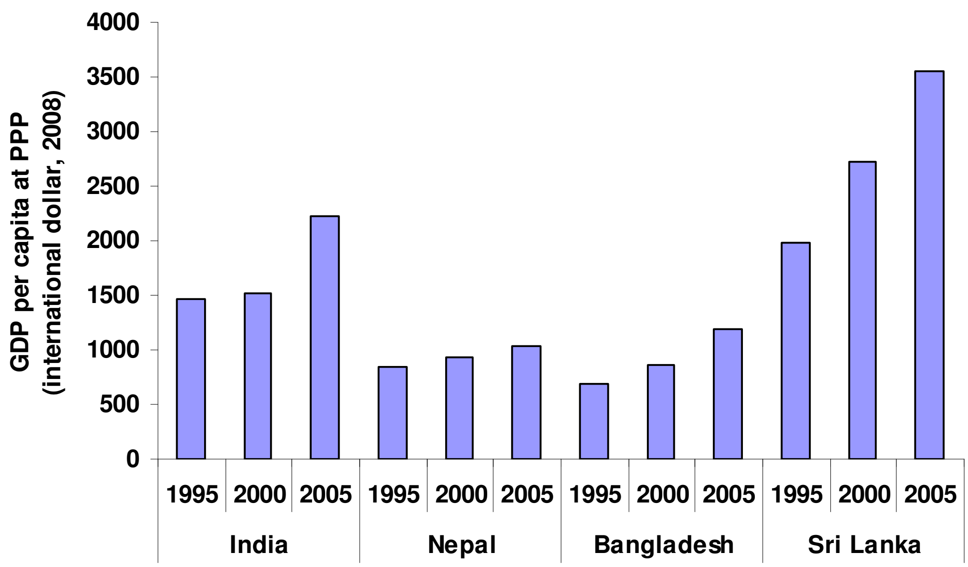

Figure 2.3 Trends of GDP per capita in studied countries

2.3.3 Literacy: Level of public awareness

National environmental and education levels are generally interlinked, and the higher literacy levels lead to the higher quality of environment. Literacy and primary education contributes to the general well-being[13].

Education will have a stronger and lasting effect as it encourages participation. Also, education promotes creative responses to shortcomings[14].

2.3.4 Sanitary Services: Urban poverty

High rate of population growth, declining opportunities in the rural areas and shift from stagnant and low paying agriculture sector to more paying urban occupation largely contribute to urbanization. Cities have grown haphazardly showing tale signs of saturation in services, infrastructure and employment potential. This is manifested in congestion, inadequate water supply and sanitation, urban poverty and environmental degradation, and poses a challenge to urban planners and citizens alike. The priority assigned to urban environmental issues has traditionally been low, resulting in substantial damage to human health and reduced productivity as well as development[15].

In developing countries, the rapid population growth has overwhelmed the capacity of the municipal authorities to provide even basic services. Municipal solid waste management is a part of the public health and sanitation, and is entrusted to the municipal government for execution[16]. The lack of proper infrastructure for sanitation service plays an important role in the increase of municipal solid waste. Environmental degradation impacts the poor most severely. The urban poor, who do not have a fair access to public health and sanitary services in a city, is subject to extremely unhygienic conditions in their settlements and periodic outbreaks of water and air borne epidemics[15].

2.4 Municipal solid waste generation

Municipal solid waste generation affected by the rapid urbanization of the developing countries has increased. In India, per capita waste generation rate increases with the size of city and varies from 0.3 to 0.6 kg per capita per day, and the estimated annual increase in per capita waste quantity is about 1.33 percent per year[17]. There are great variations in the per capita municipal solid waste generated in the studied countries (**Figure 2.4).** Generation of municipal solid waste is generally identified as an inevitable consequence of production and consumption activities related to the level of income and urbanization[18]. Municipal solid waste generation per capita per year of Sri Lanka was remarkably larger than that of other South Asian countries, and this may be attributed to the largest GDP per capita. However, the consequence of urbanization level of municipal solid waste generation was not clear by the comparison of national level statistics.

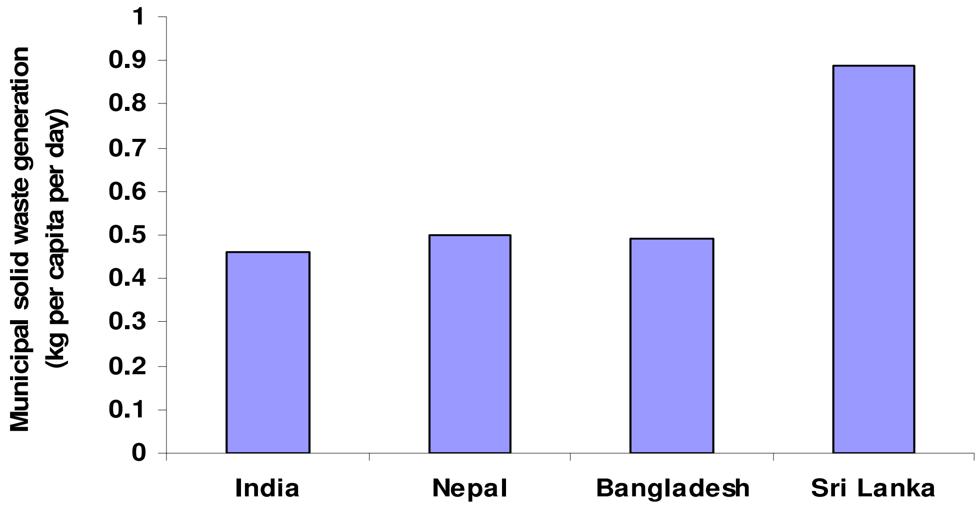

Figure 2.4 Municipal solid waste generation per capita per day in studied countries

2.5 Municipal solid waste composition

Information and data on physical components of the waste stream are important in selection and operation of facilities, in assessing the feasibility of energy and resource recovery, and in the design of a final disposal facility. The composition of municipal solid waste, in general, differs from country to country depending on the economic level of countries as well as other factors such as consumption pattern, climate, season, social development, cultural practices, etc. Most of the developing countries have high percentage (50–80%) of organic matter in disposed waste with high moisture content, and it makes them unsuitable for incineration[19].

Figure 2.5 shows the waste characteristics (i.e. biodegradable, paper, plastic, glass, metal, textile & leather and other) of studied countries. Waste composition generated in studied countries is normally dominated by biodegradable waste followed by paper and plastic waste. As the economy grows and the population becomes more urbanized, the substantial increase in use of paper and paper packaging is likely to increase, however in the studied countries, they occupied only a small portion. In India and Bangladesh, the lower percentage of plastic is due to the restrictions of using thin plastics. The ratio of paper and plastics is higher in Nepal where voluminous materials of such as food containers and wrapping materials are used for ease of distribution; however organic (biodegradable) waste is still the dominating factor in all of the countries being studied[20].

The biodegradable waste fraction is commonly quite high in the studied countries, essentially due to the habit of consuming much raw foods such as fresh vegetables than precooked foods. Ash and fine earth content of studied countries is reported to be high due to the practice of inclusion of street sweepings, drain silt, and construction and demolition debris in municipal solid waste. Percentage of inert material seems to increases with urbanization caused by inclusion of construction and demolition waste into the municipal solid waste disposal stream.

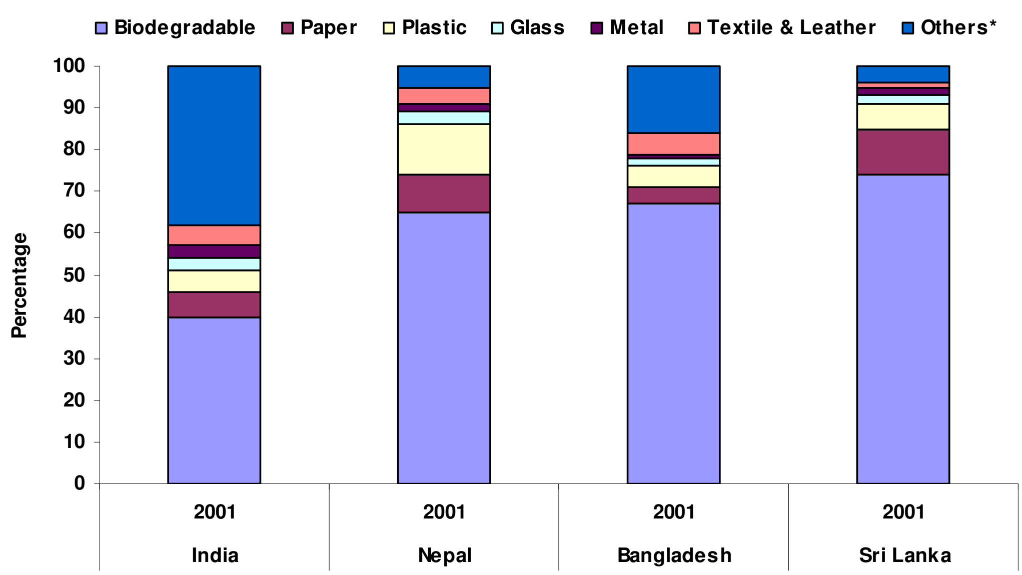

Figure 2.5 Composition of municipal solid waste in studied countries

2.6 Municipal solid waste treatment and disposal technology

Disposal is an ultimate fate of all types of municipal solid waste. Suitable treatment methods are different for different waste composition, thus differ among cities with different levels of economic development. The disposal method may be dependent on the type of material recycled, organic content of waste that could be composted, and the combustible material that could be a source of energy. A set of different methods of disposal has been adopted by Asian developing countries such as open dumping, composting, land filling, incineration and 3Rs (reduce, reuse and recycle).

2.6.1 Open dumping

Increasing incidents of unauthorized dumping along roadways and on vacant land are occurring in the developing country. Open dumping is distinguished from the sanitary land filling. It is an illegal process, in which any type of the waste such as household trash, garbage, tires, demolition/construction waste, metal or any other material dump at any location like along the roadside, vacant lots on public or private property even in parks other than a permitted landfill or facility. However, open dumping is the most preferred method by waste emitters for the final disposal of municipal solid waste because of the minimum cost. Open dumping poses a threat to human health and the environment because it causes land pollution[21] and it can depress the value of surrounding land.

Figure 2.6 shows the final disposal methods (i.e. open dumping, composting, land filling, incineration and 3R) in the studied countries. In the developing countries, municipal solid waste is commonly disposed off by discharge in open dumps by around 60-90%, which are environmentally unsafe. The highest value of open dumping is shown in Bangladesh and the minimum in India, and the maximum composting, land filling, incineration and 3R adopted by the India. Accidental burn of open dumped waste is frequently reported under the hot and dry climate condition; where burning of non-degradable component like plastic waste or tires generate air pollution and serious health hazards. Another problem of illegal dumping is land area occupation in and around cities that may result such as property value decrease and scarcity of land area in future.

2.6.2 Composting

Composting is the most preferred method of municipal solid waste, mainly due to the high percentage of organic material in the waste composition. Composting is the process of decomposition and stabilization of organic matter under controlled condition. Composting is a natural biological process that carried out under controlled aerobic (requires oxygen) or anaerobic (without oxygen) conditions. Anaerobic composting is not common because of the slow degradation rate and produce odorous intermediate product. However, it also produces methane gas which is a useful source of bio-energy [22]. Share of composting in municipal solid waste is low in South Asian countries and less than 10% excepting Nepal (**Figure 2.6**). This rate is quite low compared with the high biodegradable waste composition (**Figure 2.5**) showing requirements for promoting municipal solid waste composting systems. Centralized composting plants are not functioning effectively because of high operating and maintenance costs, incomplete separation and lack of effective marketing, among others.

Compost is used as an organic amendment to improve the physical, chemical and biological properties of cultivation soil. Adding compost helps to increase the ability of the soil to hold and release essential nutrients. Historically, organic waste was effectively recycled and used as fertilizer within rural area, but waste flow in modern emerged cities are isolated from the rural organic waste management systems. The feasibility of municipal solid waste composting as one step in the city-wide solid waste management system depends on regional market of compost product including the rural, as well as the technical and organizational set-up of the individual plants.

2.6.3 Landfill

In most of the cities of developing countries, landfill is the preferable method for the final disposal of municipal solid waste. As already mentioned, majority final disposal practice in South Asian countries is open dumping, and it is no regards to replace them with a sanitary landfill. National governments and municipalities are already working to develop the sanitary landfill sites in a few urban areas. Since land for new landfill is quickly becoming scarce within city limits, new sanitary landfill sited are often too distant, thereby the longer collection and delivery time make it ineffectively and expensive.

Next, three types of landfill are described and compared:

2.6.3.1 Open landfill

Open landfill is most common in developing countries. The so-called landfill is mostly covering this type of refuse waste in the dumpsite neither with proper technical input nor with treatment of the emerging emission to water, air and soil. Because of the uncontrolled burning of open landfill, contamination by various toxic chemicals including dioxin related compounds as polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and coplanar polychlorinated biphenyls (PCBs) occurs. Generation of methane gas is another problem of open landfill. Moreover, these open landfills become a haven for scavengers (animal and man alike). Thus, uncontrolled or open landfill is a perpetual pervasive problem that can be hazards on human health and can cause damage to vegetation, unpleasant odors, ground water pollution, air pollution and global warming.

2.6.3.2 Semi-controlled landfill

Semi-controlled landfill is operated at a designated site in which the dumped refuse is compacted and topsoil cover is provided daily to prevent nuisance. Every kind of municipal solid waste is dumped without segregation and it is not engineered to manage the leachate discharge and emissions of landfill gases. Exposure of dumped waste is improved by topsoil coverage in semi-controlled landfill, which prevents odors and waste pickers to a certain level compared with the open type; however emission of hazardous gases and liquids is not resolved essentially.

2.6.3.3 Sanitary landfill

Sanitary land filling is generally most preferable than other alternatives. Sanitary landfill involves well-designed engineering method to protect the environment from contamination by solid waste. Impervious clay liner and/or synthetic liner should be provided at the bottom of the landfill to protect ground water from pollution. Perforate polyvinyl chloride (PVC) pipes are used for leachate collection. It is also desirable to install gas collection and flaring system to prevent continuous escape of methane in the surrounding atmosphere. Necessary conditions in designing a sanitary landfill are the availability of vacant land that is accessible to the community being served and the capacity to handle waste material for several years. In addition, cover soil must be available. These practices will minimize migration of leachate through soil strata, suppress the foul odor and improve the aesthetic quality.

Among the three types, sanitary land filling is an engineered system which is the best option taking into account the likely environmental impacts by the municipal solid waste with respect to the pollution of air, water and soil. However, this kind of comparable secure system is scarcely found in the study region.

2.6.4 Incineration

Incineration is one of the waste treatment methods that involve the combustion of organic materials and other substances. Incinerator process converts the waste into bottom ash, particulates and heat. Heat can be used to generate the electric power. The volume of ash is usually 10% of the original volume of the waste[23]. The ash is typically disposed off in the landfill site. The studied countries, the use of incineration occupies only a small fraction around 1-5% (**Figure 2.6**). Incineration is a controversial method of waste disposal.

Due to the high initial, operation and maintenance costs involved for the installation of incineration plants, incineration is not popular as a waste disposal system in the countries being studies. In addition, the major portion of the municipal solid waste in these countries is organic with relatively high moisture content which leads to a low calorific value.

2.6.5 3Rs (Reduce-Reuse-Recycle)

The 3R activity consists of reduce, reuse and recycling of waste along its material life cycle. Reduce: reducing the amount of waste by increasing the efficiency of resource use and extending the useful life of products, Reuse: using “recyclable resources” form used items again, as products or parts, after giving them proper treatment, Recycle: using “recyclable resources” as raw materials to make new products. Recycling is resource conservation activity and it may offer a greater return for many product in energy saving. It is generally carried out by the informal sector in the developing countries. There are no policies that promote recycling or resource conservation, and the municipalities do not have the expertise to launch the recycling activities. Reuse of organic waste material, which often contributes to more than 50% of the total waste amount, is still fairly limited but often has great recovery potential. It reduces costs of the disposal facilities, prolongs the disposal sites life span, and also reduces the environmental impact of disposal site as the organics are largely to blame for the polluting leachate and methane problems.

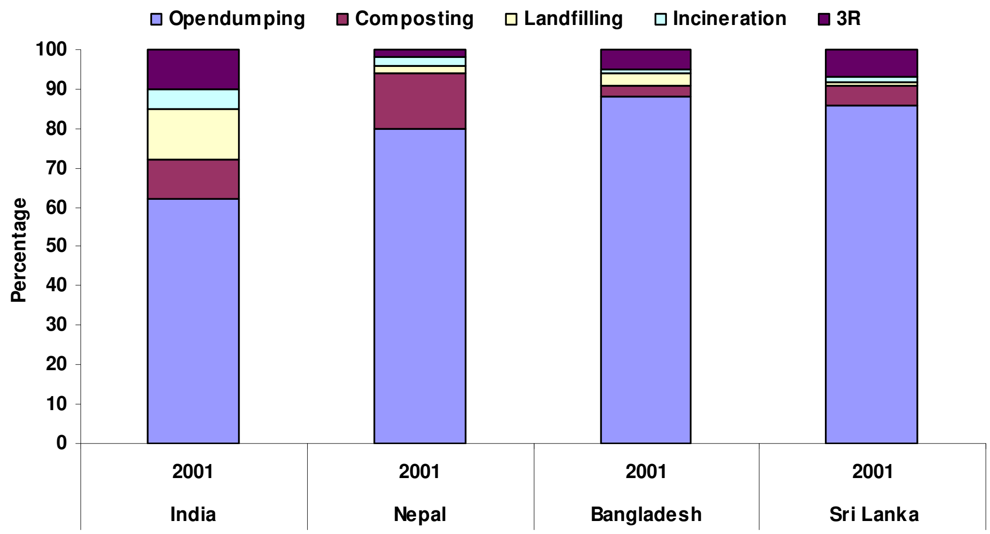

Figure 2.6 Use of different disposal methods of municipal solid waste in studied countries

The recyclable materials such as paper, plastic and metal are often collected at the source. After collection, these items are sent to factories for recycling[24]. But in studied developing countries, recycling percentage is very low around 10-15% **(Figure 2.6)** due to the inadequate and insufficient source segregation. Due to the faulty collection systems and low quality of scrap, the recycling rate is low despite a high number of waste pickers involved in the process. Although governments and manufacturers have been shaken by these revelations, they have not yet awoken fully to the need to close the curtains on this ugly form of international trade. It is a perverse form of commerce that victimizes the poorest communities while providing a counter-productive subsidy that allows manufacturers to care less about the end-of-life impact of their products.

2.7 Summary and Conclusions

On the basis of above study, I indicate that rapid urbanization and industrialization has caused tremendous increase of municipal solid waste generation in South Asian developing countries. With rapid development of economy and change of living standard, waste composition is expected to change. The waste composition is broadly similar, differing slightly due to the climatic and cultural variations. Illegal open dumping is most common practice for disposal of waste. Composting should be the major processing system for almost one half of the waste which is biodegradable and can be enhanced with economically friendly by the source separation. Incineration will not be viable disposal option in the near future for developing countries because of its high initial, maintenance and installation costs and also of the high moisture content of municipal solid waste. Municipal solid waste disposal needs immediate attention and strict monitoring. However, adaptation of this technology to local conditions taking account of the municipal solid waste characteristics is imperative.

Chapter 3 FORECAST OF THE FUTURE MUNICIPAL SOLID WASTE GENERATION IN SOUTH ASIAN DEVELOPING COUNTRIES

3.1 Introduction

Rapid urbanization in Asia has been synchronous with dramatic rate of economic growth as well as severe environmental problem. This increase puts more pressure on the relatively insufficient municipal solid waste management infrastructure. As the pace of urbanization accelerated, environmental problems may get worse due to a limited investment to urban environmental infrastructure. Municipal solid waste generation has been increasing proportionately with the growth of urban population[14]. Common problems for municipal solid waste management in developing countries include institutional deficiencies, inadequate legislation and resource constraints. Long and short term plans are inadequate due to capital and human resource limitations. There is a need for financing equipment for municipal solid waste management, training specialists and capacity building. The governments have formulated policies for environmental protection, but they were only implemented in the national capital or economically center cities. In rural areas, open dumping is still considered the most popular method of municipal solid waste disposal. Thus, the prevailing issues and conditions in these countries demand extensive studies and researches on solid waste management to improve significantly the local environment for more sustainable living conditions.

A recent World Bank report suggests two drivers for the growth of municipal solid waste generation: an increase in urban population and an increase in the income growth. The World Bank study estimates an overall growth in municipal solid waste of 2.4-fold by 2025, to a total of two-thirds of a billion tons annually in Asia alone. The municipal solid waste generated by human settlements and the associated problems are common in developing nations with variances among regions and locations based on geographic, socio-cultural, industrial, infrastructure, legal and environmental factors[8]. The waste stream is predicted to become more combustible and organic in composition, making incineration an increasingly attractive option, while landfills become scarier.

From the background of previous chapter, this chapter estimates the future potential amount of municipal solid waste generation without management and also forecast the future required land area for landfill in studied countries by the use of mathematical calculation.

3.2 Study Area and Methodology

India, Nepal, Bangladesh and Sri Lanka were selected as studied countries. This is because these countries' economy performed well in the 1990s and during the past 5 years it has done ever better. The economic growth rate has improved steadily occupy around 5.6 % in south Asia and thought to be representative countries of developing countries [25]. Municipal solid waste generation changes may be driven by many factors including economic growth, population growth and urbanization, rising energy use, policy change and so on, however, urban population is the most fundamental factor among them. Assuming that the effect of factors excepting for human population on municipal solid waste generation is negligible, potential waste generation can be estimated by next formula.

$$\text{Waste generation per day} = (\text{national population} * \text{urban population ratio} * \text{waste generation per capita per day}) \quad (1)$$

National population, urban population ratio and waste generation rate per capita per day in the studied countries were collected from statistics of demography[9] and waste[10, 26, 27]. Future national population predictions were published by a few international organizations and were used for estimating future municipal solid waste generation in the countries together with future urbanization ratio. Future required landfill area of studied countries was also estimated by using next formula.

$$\text{Required land area (hectare)} = 1.015 * (\text{annual waste generation}) / ((\text{waste density}) * (\text{landfill height})) \quad (2)$$

Where, waste density and landfill height was determined to be 500 kg/m^3 and 10m, respectively from reference report[28], and 1.015 is an area extension factor needed to take areas for cover, roads, receiving, fencing, etc. into account.

3.3 Results of future prediction

3.3.1 Future estimation of population

Table 3.1 shows population change from 1995 to 2005 and its average annual growth rate. India, Bangladesh and Nepal show high population growth rate over 0.5% suggesting a large population increase in future, however in Sri Lanka, annual growth is relatively low. **Figure 3.1** shows future population of India, Nepal, Bangladesh and Sri Lanka estimated by the United Nations[29]. Population of India was estimated to grow in high rate and to reach 1.5 billion in 2040. Nepal and Bangladesh are also estimated to grow in population rapidly in these 30 years. However, this prediction also estimates the population growth rate will reach at peak and then decline in 2010 or 2020 in these countries. Population of Sri Lanka is relatively stable and the estimated population growth until 2040 is small.

Table 3.1 Estimation of average annual population growth in studied countries

Country name	Population (in thousands) Year 1995	2000	2005	Average annual population growth
India	954,282	1,046,235	1,134,403	180,121
Nepal	21,672	24,419	27,094	5,422
Bangladesh	126,297	139,434	153,281	26,984
Sri Lanka	18,080	18,714	19,121	1,041

Source: (Time series data of each variable were assembled from the database of Asian Development Bank[9])

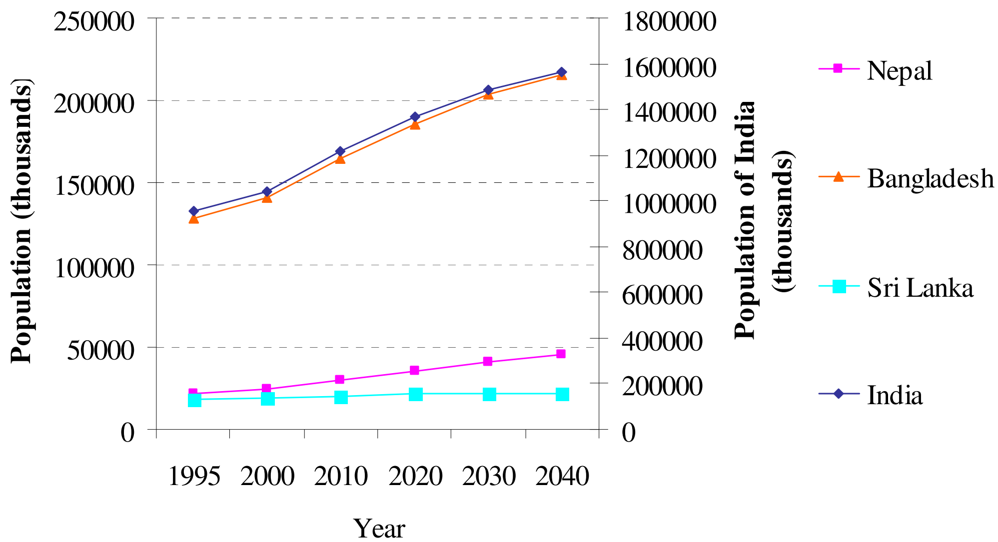

Figure 3.1 Future estimation of population in studied countries

3.3.2 Future estimation of urban population

Asia's urban population is expected to reach the figure of close to one billion by the year 2030 that is about 120 percent increase in three decades beginning with the year 2000. Urbanization level is increasing in all the countries of Asia and this trend is expected to be maintained in future as well at least up to the year 2020[14]. More alarmingly, the rate of change in the urbanization level is still increasing. Increasing urbanization in India is part of the global trend. In a number of town and cities, population has increased by a range between 5000 and 20,000[30].

Table 3.2 shows the urban population ratio (ratio of urban population to national population) of the studies countries between 1995 and 2005. Average annual change in urban population ratio was estimated by using the slope of simple regression analysis and shown in the table. Urban population ratio in 2005 was relatively high in India and Bangladesh and low in Nepal and Sri Lanka. Annual change of urban population ratio is the highest in Nepal (0.0049) and the second in Bangladesh (0.0040) indicating a rapid progress of urbanization. Rural to urban migration occurs due to the relatively high growth in the urban-based economy and thus, urban population growth rate exceeds national population growth rate. Annual change of urban population ratio is negative only in Sri Lanka showing decline growth of urban population.

Table 3.2 Urban population ratio and estimated annual change of urban population ratio in studied countries

	Urban population (ratio)			
	Year			Average annual urban
Country name	1995	2000	2005	population growth
India	0.266	0.277	0.287	0.0021
Nepal	0.109	0.134	0.158	0.0049
Bangladesh	0.217	0.236	0.257	0.004
Sri Lanka	0.164	0.157	0.151	-0.0013

Source: (Time series data of each variable were assembled from the database of Asian Development Bank[9])

Figure 3.2 shows the estimated urban population ratio in India, Nepal, Bangladesh and Sri Lanka assuming that present annual change of the ratio prolongs in future. Urban population ratio shows an upward direction in three countries namely in India from 0.27 to 0.34, in Nepal 0.1 to 0.29, and in Bangladesh from 0.23 to 0.37 between 1995 and 2030, respectively. However it shows a decrease in Sri Lanka from 0.17 to 0.11 in the same period.

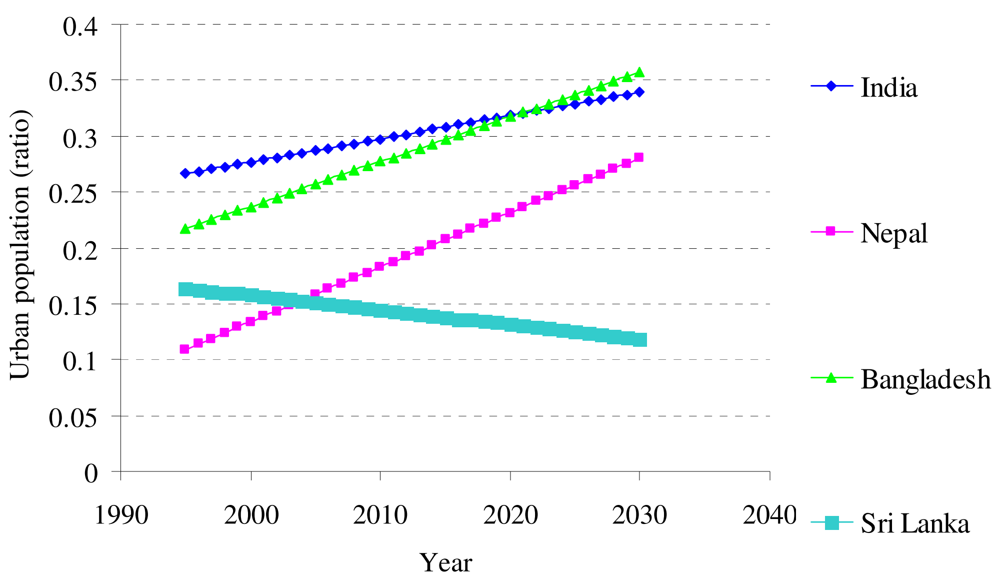

Figure 3.2 Future estimation of urban population ratio in studied countries

3.3.3 Future estimation of municipal solid waste generation

Table 3.3 shows municipal solid waste generation per capita per day in India, Nepal, Bangladesh and Sri Lanka. The values were collected from three different data sources[27],[26],[10]. Source 1 and 2 provided likely similar values but source 3 showed somewhat different values. Reliability of each data source could not be identified, thus I employed the average of three values. The maximum solid waste generation per capita is found in Sri Lanka (0.79 kg per capita per day) and the minimum in Bangladesh (0.41 kg per capita per day).

By using future population (**Figure 3.1**), future urban population ratio (**Figure 3.2**) and the municipal solid waste generation per capita per day (**Table 3.3**), and by the applying equation 1, annual municipal solid waste generation of each country until 2030 was estimated in **Figure 3.3.** Total municipal solid waste generation in 2005 was estimated to be 163, 1.9, 16 and 2.3 thousand tons per day in India, Nepal, Bangladesh and Sri Lanka, respectively. Future waste generation shows the similar trend in Bangladesh and India whereas more moderated increase in Nepal.

Table 3.3 Municipal solid waste generation from different data sources in studied countries

Country name	Municipal solid waste generation (kg per capita per day)			Average of municipal solid waste generation
	Source 1[27]	Source 2[26]	Source 3[10]	
India	0.46	0.46	0.60	0.50
Nepal	0.50	0.49	0.38	0.45
Bangladesh	0.49	0.49	0.25	0.41
Sri Lanka	0.89	0.87	0.62	0.79

Source: (Data of each variable were assembled from the database of IPCC[27], World Bank[26], ADB, IGES and UNEP[10])

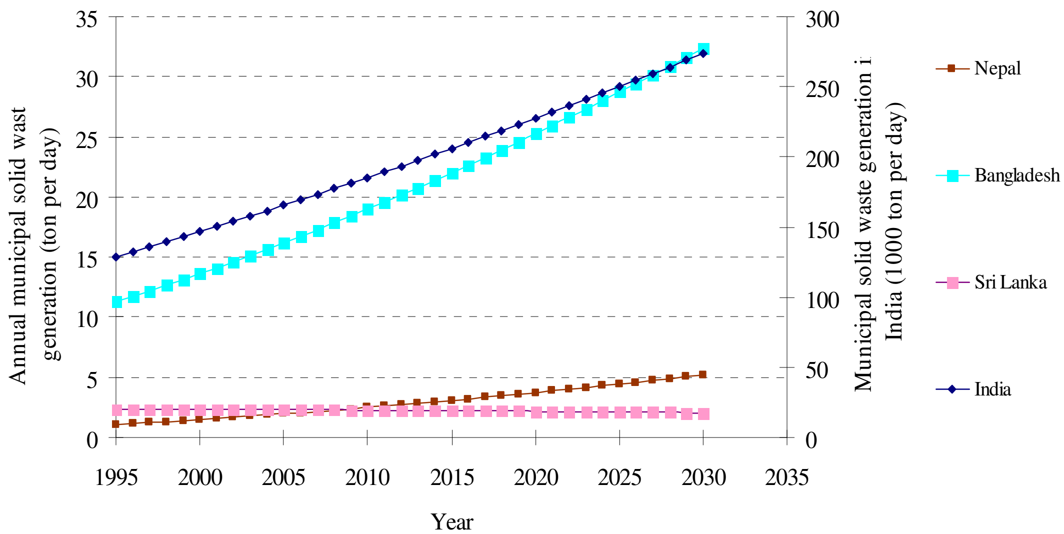

Figure 3.3 Future estimation of municipal solid waste generation in studied countries

The per capita generation of municipal solid waste in Asian cities is estimated to be in the ranges of 0.2 to 1.7 kg/day. The urban population is over 38 percent and the waste generation has been increasing over the years[8]. Municipal solid waste generation depending on per capita generation increases with the level of family or individual income.

The development of technological and advanced society with economic growth in Asian developing countries may cause the major effect to increase the quantity of municipal solid waste generation. The quantity of municipal solid waste and the proportion of the constituents also vary from season to season and place to place depending on lifestyle, food habits, standard of living, and degree of commercial and industrial activity. The level of waste generation rises due to increase of consumption as well as the movement of the people from rural area to urban areas[22]. Municipal solid waste generation rates are affected by socioeconomic development, degree of industrialization and climate. Generally, the greater economic prosperity and the higher percentage of urban population produce, the greater the amount of solid waste.

Consumption linked to per capita income has a strong relationship with waste generation. Urbanization not only concentrates waste but also raises generation rates since rural consumers consume less than urban ones. India will probably see a rise in waste generation from less than 40,000 thousand metric tons per year to over 125,000 thousand metric tons by the year 2030[31], which is comparative to the estimate in this study.

3.3.4 Future estimation of landfill area

Figure 3.4 shows the estimation of required land filled area in studied countries. The municipal solid waste generation is estimated to increase in coming years in each country as shown in **Figure 3.3** and it pushes up a requirement of land area for municipal solid waste disposal. Many disposal sites are still for open dumping and are managed poorly by local authorities or even by landfill operators. Several major cities in developing Asian countries have reported problems with existing landfill sites[32]. These problems will have negative short and long term impacts on the environment and human health. It is likely that the increasing municipal solid waste generation have become challenging and more land area is needed for the ultimate disposal of wastes.

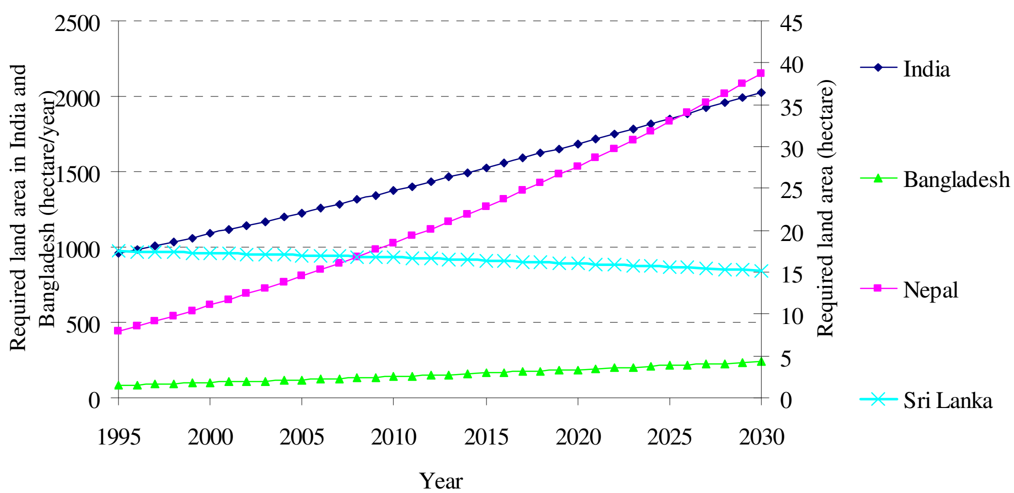

Figure 3.4 Future estimation of required land area in studied countries

3.4 Summary and Conclusions

For the purpose of this chapter to estimate the potential of annual municipal solid waste generation without management efforts in coming 30 years and also to estimate the required land area for disposal, the simple linear calculation was conducted assuming that waste generation is proportional to urban population. The results were concluded that the rapid urbanization has caused tremendous increase of municipal solid waste generation in studied countries. Landfill area requirement was also estimated to increase dramatically suggesting that dumping around cities will reach the limit sooner or later in these countries. Present trends of population growth and urbanization are difficult to reverse or decelerate by policies, and therefore, decreasing municipal solid waste generation rate (waste generation per capita per day) by natural or institutional forcing is strongly expected. Following chapters will discuss on factors that may affect the waste generation rate.

Chapter 4 CONCEPTUALIZING MUNICIPAL SOLID WASTE MANAGEMENT FACTORS USING DPSIR FRAMEWORK

4.1 Introduction

The Millennium Ecosystem Assessment (MA) determined that both anthropogenic and natural factors can be a driver "that directly or indirectly causes a change in an ecosystem" [33]. It employed the DPSIR framework to illustrate the cyclic consequences among human impact, ecosystem degradation, ecosystem service change, human wellbeing and responses to changes. Similarly, the DPSIR framework is applied in this thesis in order to understand the issues on the municipal solid waste management and assess the factors that contribute to its improvement.

The DPSIR framework is shown in **Figure 4.1**. Main properties and functions of elements in the DPSIR framework are described below:

Driving force is internal change of human or natural systems. Its indicators for example population are not very responsive and "elastic" to the external systems. They may serve a basis for scenario development and long-term planning and may help the decision-makers to plan actions "responses", needed to avoid future problems "pressures".

Pressure is induced by "driving force" and acts as the direct causes of problematic status change such as pollutant emission. One specific feature of pressure indicators is responsiveness, that is, a decision-maker has indeed a chance to reduce the indicator "problem" by launching appropriate countermeasures. It will also serve as an incentive for rational solutions, since it demonstrate the effectiveness of political action early enough to the responsible who launched them.

State of human or natural systems such as water quality changes under the existence of "pressure". State indicator shows the current state and also helps to find the appropriate measures which are applied to clean-up activities.

Impact is concrete change in value of human and natural factors corresponding to "state" such as human health. Its indicators also become the objective measures of policies, strategies and actions.

Response is voluntary or enforced action to mitigate "impact" by adjusting or removing "driving force", "pressure", "state" and "impact". It includes a variety of concrete procedures in policy, strategy and practice such as emission regulation, environmental tax, technology development, resident relocation, investment, insurance, compensation etc.

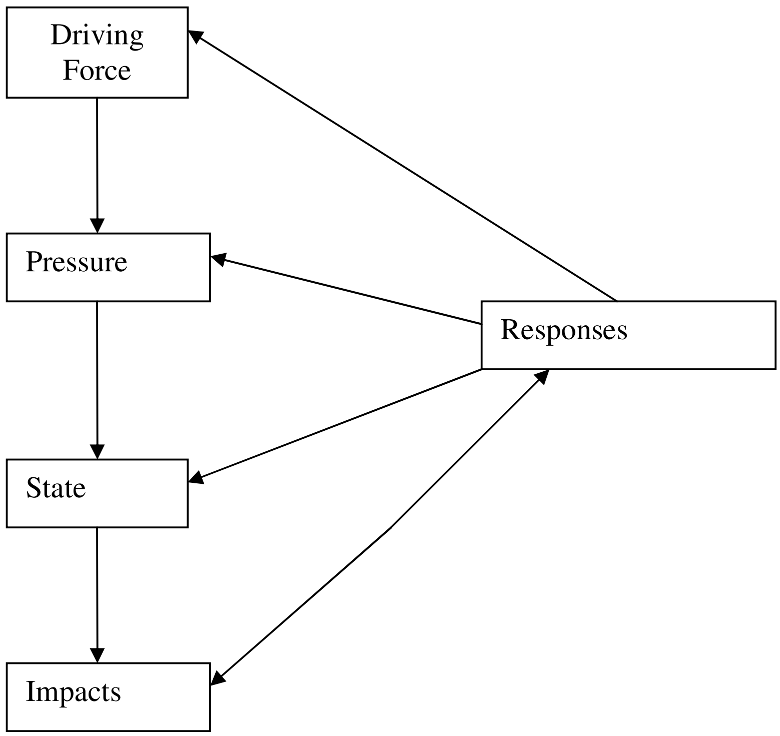

Figure 4.1 DPSIR framework – a conventional context

Source: (UN Division of Sustainable Development[34])

Common indicators of driving forces include economic, social and demographic changes in societies such as changes in production and consumption patterns and people's lifestyles. Intensive production and consumption exert pressure as these processes entail alteration in the uses of land and resources, and the release of substances or emissions. State indicators describe the changes in quantity and quality of the physical environment, biological structure (organisms) and chemical concentration in a certain area. Impact indicators involve the effects on the social and natural functions of the environment, such as provision of adequate conditions for health, resources availability and biodiversity. Response indicators refer to responses by different groups in the society, as well as government initiatives to prevent the negative consequences in the environment, to improve the condition of the environment or to adapt to changes in the state of the environment. These can be in the form of policy measures such as regulations, information or taxes.

The DPSIR model is dynamic and its focus is given on the important indicators for assessing municipal solid waste issues. From the background described in Chapters 2 and 3, the purpose of this chapter is to discuss the applicability of comprehensive assessment of DPSIR model through identifying the driving forces (increasing population, urbanization and economic development), pressure (generation of municipal solid waste, composition change and over-use of land area), state (GHG emission, environmental pollution), impacts (human health, flora and fauna), and response (treatment technology and involvement of management agencies) in the municipal solid waste management.

4.2 Customization of DPSIR framework for municipal solid waste management

Figure 4.2 depicts the assessment framework of complete DPSIR for municipal solid waste management. In this framework, trend of urbanization, accelerated economic development and operating cost on municipal solid waste management are used as the driving forces, which put pressure on the generation of municipal solid waste, changes in composition and overuse of land area. As the state factors, GHG attribute to methane emission and the environmental pollution are used, which cause impact on the human health, flora and fauna. Response indicators refer to the treatment technology and involvement of management agencies. Cause and effect relationship of the municipal solid waste issues are restructured using this framework and discuss on the links and indicators of each components of DPSIR.

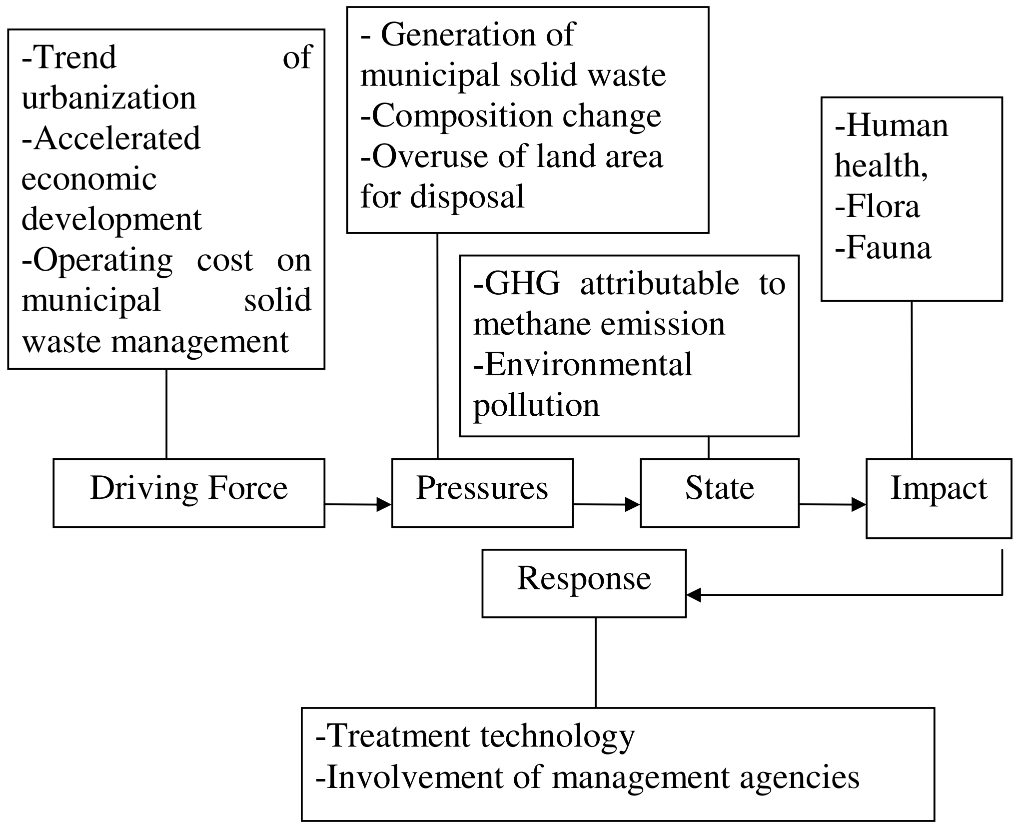

Figure 4.2 DPSIR – assessment framework for municipal solid waste management

4.3 Understanding factors and their interlinkage of municipal solid waste in South Asian countries by using DPSIR framework

4.3.1 In stage: Driving force

European Environmental Agency describes[3] driving forces as *"the social, demographic and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption and production patterns"*. The intensive industrialization, especially during the early stage of development in the urban areas is the common driving forces that exert pressure on the environment, which cause changes in the municipal solid waste management. Growth in the population size and density, economy has increased the generation of municipal solid waste.

4.3.1.1 Trend of urbanization and accelerated economic development

Population is an important source of development, yet it is a major source of environmental degradation when it exceeds the threshold limits of the support systems. Unless the relationship between the multiplying population and the life support system can be stabilized, development, however, can not yield desired results. Population impacts on the environment primarily through the use of natural resources and production of waste which is associated with environmental stresses like loss of biodiversity, air and water pollution and increased pressure on arable land. Urbanization shows increasing trends consistently from 1960 to 2000 in all South Asian countries **(Figure 4.3)** except Sri Lanka as noted in Section 2.3.

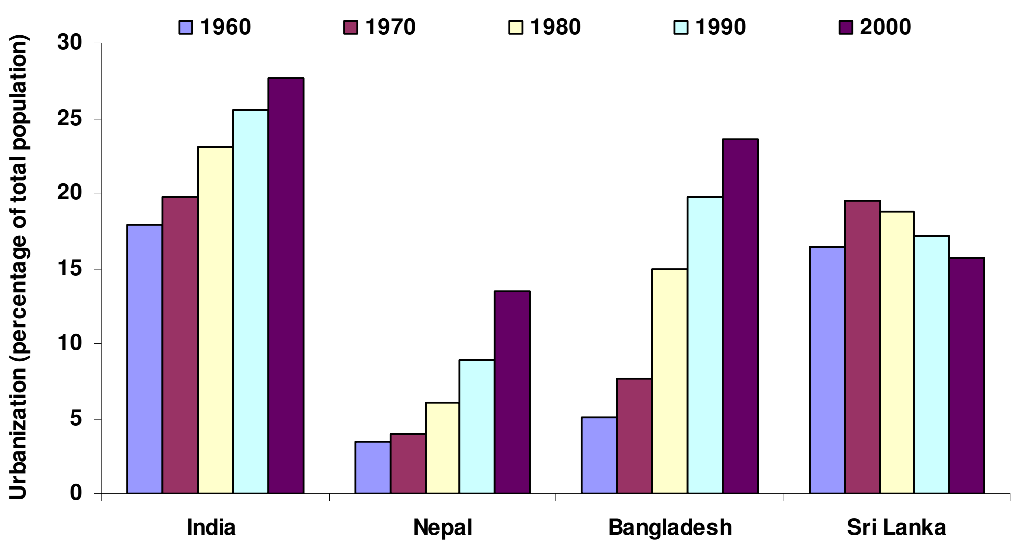

Figure 4.3 Trends of urbanization development in studied countries

Source: (World Bank[35])

Many Asian developing cities have experienced dramatic economic growth, reflecting the fact that the region is integrating into the new global economy[36]. The gross domestic saving showing in study countries is increasing and decreasing trend depending upon the economic development of the countries (**Figure 4.4**).

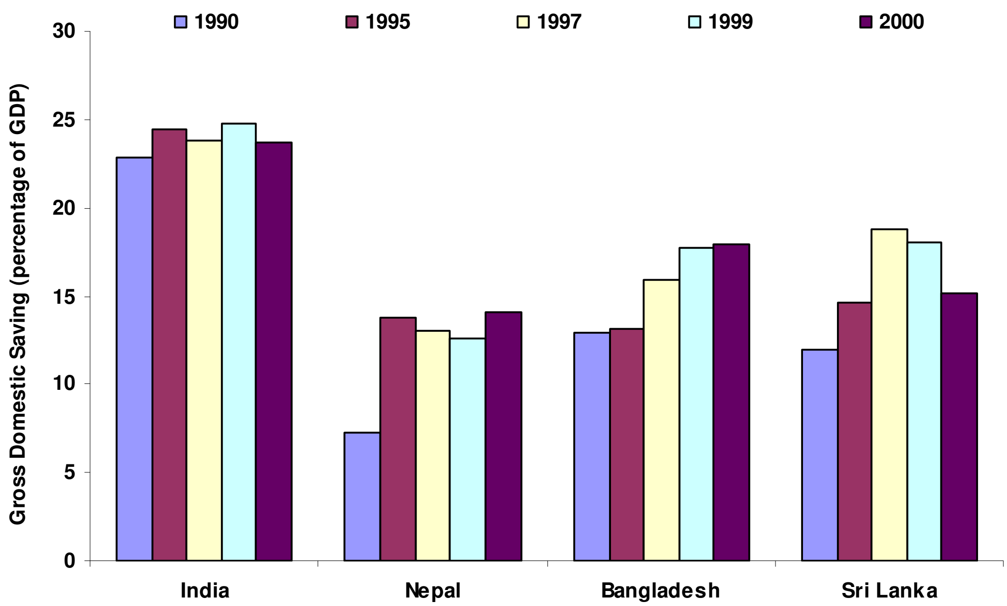

Figure 4.4 Trends of economic development in studied countries

Source: (Asian Development Bank[9])

4.3.1.2 Operation cost of municipal solid waste management

The developing countries cannot provide enough sanitary service due to the insufficient finance and efficient treatment technologies. **Table 4.1** shows GDP per capita, waste generation (kg per capita per day), disposal costs (USD/person/day), expenditure of total municipal solid waste budget (%) of the developing and developed countries.

Table 4.1 Comparison of cost expenditure budget on municipal solid waste management in developing and developed countries

Country	Developing Countries	Developed Countries
GDP per capita (USD)	Less than 3,000	Over 10,000
Waste generation (kg per capita per day)	0.3-0.6	1.4-1.5
Disposal costs (USD/person/day)	Less than 1	38 - 220
% of SWM expenditure in total municipal solid waste budget (%)	15.4 - 38	1.6 - 5

Source: (JICA[37])

4.3.2 In stage: Pressure

Pressures are anthropogenic factors inducing “unwanted” environmental change (impacts). According to European Environmental Agency[3], they are “developments in release of substances (emissions), physical and biological agents, the use of resources and the use of land by human activities”. Specific pressures for priority issues are presented under respective sectors, as a result of production or consumption processes, which can be divided into three main types: (i) excessive use of environmental resources, (ii) specifically on the over-use of land area and (iii) emissions to air, water and soil.

4.3.2.1 Generation and composition change of municipal solid waste

Municipal solid waste generation in the study countries is based on the economic development, density of population, size of the urban habitation and consumption rate of commercial goods. Per capita generation of municipal solid waste and municipal solid waste composition in study country were already shown and discussed in Section 2.5.

4.3.2.2 Overuse of land area for disposal: direct use before ecological footprint

Municipal solid waste disposal sites generally locate at the outer limb of residential area whether they are planned facilities or not (**Figure 4.5**); however expansion of urban area due to rapid urban population growth intakes existing dumping site inside the newly developed urban area. This may increase health risk of residents around the dumping sites. Another land use conflict may occur between waste disposal sites and cropland. Developing large scale disposal facilities in remote place from cities is one solution; however it increases cost and environmental burden due to a wide waste collection area and a distant waste transportation.

 

Figure 4.5 View of land fills
Source: (ADB, IGES and UNEP[10])

4.3.3 In stage: State

According to European Environmental Agency[3], state is "the quantity and quality of physical phenomena (such as temperature), biological phenomena (such as fish stocks) and chemical phenomena (such as atmospheric CO_2 concentrations) in a certain area". As a result of pressure, "state" of environment is affected; that is, the quality of the various environmental compartments like air, water and soil etc in combination of the physical, chemical and biological conditions. The condition or quality of the environment tends by human or other pressure, which as to be described for priority issues by presenting quantitative and qualitative data.

4.3.3.1 GHG attributable to methane emission in disposal

Currently most of the municipal solid waste is dumped in non-regulated landfills in developing countries and it generates methane, which is emitted to the atmosphere. Waste is one of the major anthropogenic methane sources and occupies about 20% of the world emission in 2000[38]**(Figure 4.6)**. Occasionally emitted methane from waste becomes the ignition of landfill burn.

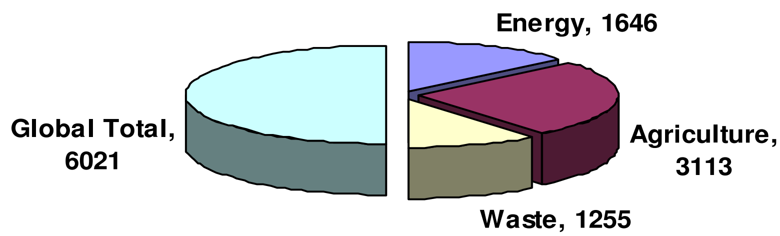

Figure 4.6 Methane emission in 2000 ($MtCO_2eq$)

4.3.3.2 Environmental pollution

Main pollution source of waste management is leachates from unsanitary dumping of refuse and other solid waste. As water filters through any material, chemicals in the material may dissolve in the water. This process is called leaching and the resulting mixture is called leachate. As water percolates through municipal solid waste, it makes a leachate that consists of decomposing organic matter combined with iron, mercury, lead, zinc, and other metals from rusting cans, discarded batteries and appliances[21]. It may also contain paints, pesticides, cleaning fluids, newspaper inks, and other chemicals. Contaminated water can have a serious impact on all living creatures, including humans, in an ecosystem[22].In the case contaminated water flows into ground or stream water used for municipal or irrigation water source, state is the most hazardous. Fly- or animal-bourn disease is another health risk for residents around dumping sites.

4.3.4 In stage: Impact

For defining impacts, socio-economic factors focus on effects on the human systems, associated with changes in environmental functions such as resources provision, water and air quality, soil fertility, physical and mental health, and social cohesion[3]. Thus, all kinds of concrete change in human and natural environment forced by state change are impacts. In most cities of studied Asian developing countries, open dumping is the most preferred method for the final disposal of municipal solid waste. Possible impacts on human health from unmanaged dumping are health hazard by polluted drinking water, polluted crops, fly and animals, odors and organic gases, burning smoke etc. Also increase of fire risk, greenhouse effect by emitted methane, biodiversity loss, traffic accident risk by waste transportation, aesthetic loss, decrease in land value are miscellaneous impacts from open dumping.

4.3.5 In stage: Response

"Response" from different levels of the society represented both by groups and by individuals, from the government, private or non-governmental sectors. The definition used by European Environmental Agency[3] focuses on the types of measures that can constitute response and is "Response indicators refer to Responses by groups (and individuals) in society, as well as government attempts to prevent, compensate, ameliorate or adapt to changes in the state of the environment."

4.3.5.1 Involvement of management agencies

Figure 4.7 shows the involvement of government, NGOs and international organizations towards promoting 3Rs activities in Asian developing countries. The highest presence of government is shown in India and the lowest is shown in the Sri Lanka. Many NGOs and international organizations are footing in the resources of local people to participate in waste management campaigns. The private sector is usually best in providing efficiency and technical expertise. Involving the private sector in municipal solid waste management services usually results in an efficient municipal solid waste management system.

Another aspect of response is the target and method of actions, i.e. to which stage of driving force, pressure, state or impact, and in what way the action is. For example, spreading pesticide is response to impact, purification of polluted water from landfill is response to state, changing disposal rule and treatment method are responses to pressure, and controlling urban population is response to driving force. Responses to impacts are direct and may be effective in short term but they cannot change cause of impacts (pressure and state) so that they require a permanent cost payment. Responses to the upper stream (driving force and pressure) take the longer time and their effect does not come sooner, however they can modify structure of the issue and can get a permanent effect. Therefore, the target and method of response should be chosen or combined considering cost, effects, emergency, etc.

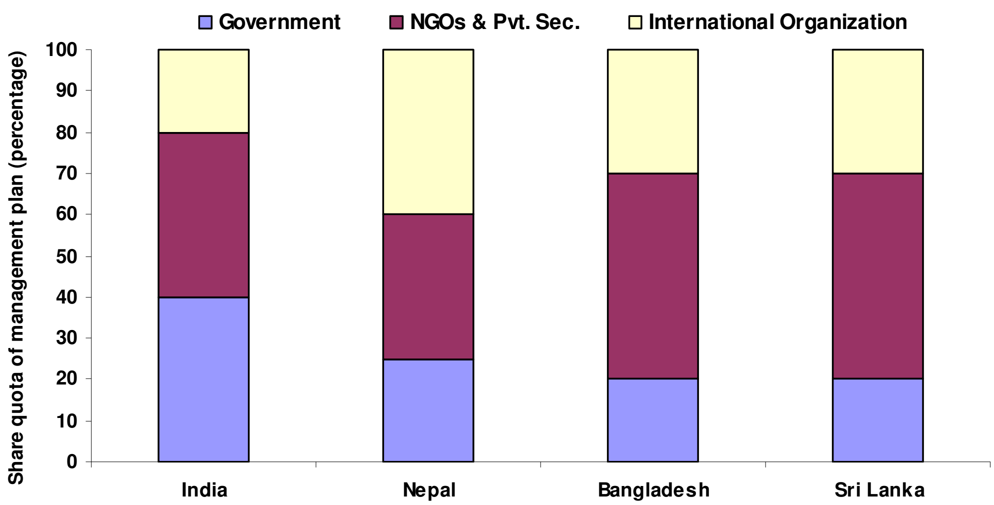

Figure 4.7 Involvement of management agencies of municipal solid waste in studied countries

Source: (ADB, IGES and UNEP[10])

4.4 Summary and Conclusions

One of the key advantages of the DPSIR framework relates to differentiation between structural features of the systems analyzed and to addressing the relationship between them. The application of the DPSIR evaluation framework is processing a holistic view on the performance of municipal solid waste management strategies. In this respect, the "four elements" of DPSIR framework "cause-effect relationship" is an important step forward in the analysis of a given environmental problems, its ability to identify the role of each elements in order to municipal solid waste management. And also analyze the causality behind the municipal solid waste generation in south Asian developing countries.

Chapter 5 ECONOMIC GROWTH DECOUPLING SOLID WASTE LOADS IN TERMS OF ENVIRONMENTAL KUZNETS CURVE: SYMPTOM OF THE DECOUPLING IN INDIA

5.1 Introduction

Discussion during the recent years on the dissociation of the positive relationship between economic growth and resource utilization is called Environmental Kuznets Curve (EKC). EKC is a hypothesis that states the resource utilization or pollution initially increases with the per capita income and then eventually declines because the willingness to pay for environmental quality increases with income and this characteristic form an inverted U-shaped relationship between pollution emission and affluence (**Figure 5.1**). Research works on linking of EKC to materials and municipal waste are less as compared to air pollution and GHG emission. As noted[39], most evidences on the determinants of municipal waste generation (collection) are based on US microeconomic studies carried out at the local community level. Wang[40]also found evidence in favor of a negative elasticity by focusing on US stocks of hazardous waste as an environmental impact indicator and by using a country-based cross sectional data set.

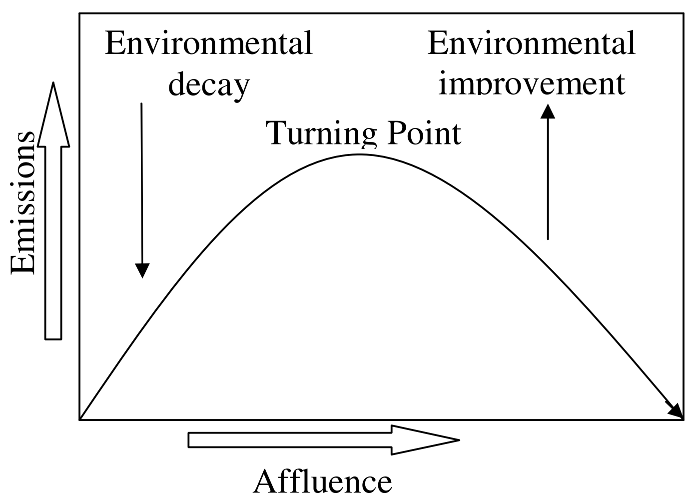

Figure 5.1 The Environmental Kuznets Curve (EKC)

Source: (Kuznets[41])

No relationship between EKC and municipal solid waste was found in Europe [42]. Mazzanti [43] stated "de-linking relation between Economic, Municipal solid waste and Environment" and also noted that "it has been shown to apply to a selected set of pollutants only," but some economists "have conjectured that the curve applies to environmental quality generally". Empirical evidences on de-linking related to environmental waste indicators are very scarce. No turning point in EKC was found[44] with environmental indicators such as per capita municipal waste, which monotonically increase with income from the period of 1975-1990 in 13 OECD countries.

In contrast, increased level of municipal solid waste may pose the significant threats to environmental quality and human health. Economic conditions may have a very important role in determining the emergence of the downward sloping part of the EKC[41]. The EKC is a story about how a country's pollution will change as that country's economy grows. The income of a country may be significant in determining the 'zeal and effectiveness' of its pollution regulatory structure because a richer state is likely to have more resources available to regulatory agencies, higher public preferences for improved environmental quality and a greater perceived danger from environmental factor[45].

This chapter focuses mainly on evidence of decoupling between economic growth and municipal solid waste generation in developing countries such as India, in which relevant data are more readily available. India is an interesting subject of study because of its large territory, rapid economic growth and differentiated regions. India also serves a kinds of improvement or opportunities that could be pursued in other developing countries. In the first phase, this chapter analyzes the course of GDP per capita with municipal solid waste generation from 1947 to onwards to 2004. In the second phase, regression analysis among the DPSIR factors is conducted on state wide data set in order to find the key stage for efficient environmental improvement.

5.2 Data Source and Methodology

5.2.1 Phase I

In this phase, the nation wide data of India on municipal solid waste generated per capita (tons) and Gross Domestic Saving (percent of GDP at current market prices) from the period of 1947-2004 was collected from different available data sources[9,26,27,46, 47] (**Table 5.1**). This phase analyzed the temporal course of municipal solid waste generation with gross domestic saving in the period of 1947-2004.

Table 5.1 Waste generation and gross domestic saving of India (1947 onwards)

Year	Waste generation (ton per capita per year)	Source	Gross Domestic Saving(% of GDP at current market prices)[9]
1947	0.107	Indiastat	18.5
1971	0.136	Eai club	20.2
1981	0.156	Eai club	21.7
1991	0.167	Eai club	22.8
1995	0.167	World Bank	24.4
1997	0.178	Eai club	23.8
2000	0.17	IPCC	23.7
2004	0.161	Indiastat	29.8

Source: (ADB[9], World Bank[26], IPCC[27], Eai club[46], Indiastat[47])

5.2.2 Phase II

Phase II used the data of 17 Indian States (**Figure 5.2**) with 10 variables corresponding the factors of the DPSIR framework; demographic and economic factors as well as literacy rate for "driving force", municipal solid waste for "pressure", and biological oxygen demand (BOD) and chemical oxygen demand (COD) of water body in 2001[47] (**Table 5.2**). The collected indicators were first mapped on the DPSIR framework (**Figure 5.3**), where no indicator of impact was available from the data sources. However, direct responses to mitigate impacts (ex. Human health) give instant effects, but investigation of them cannot give any valuable information systems (see section 4.3.4). Therefore in this phase, the linkage concerning impacts (i.e. S-I or I-R linkages; separated by dotted lines in **Figure 5.3**) were not analyzed. Next in this phase, correlation among the DPSIR factors was analyzed by regression analysis.

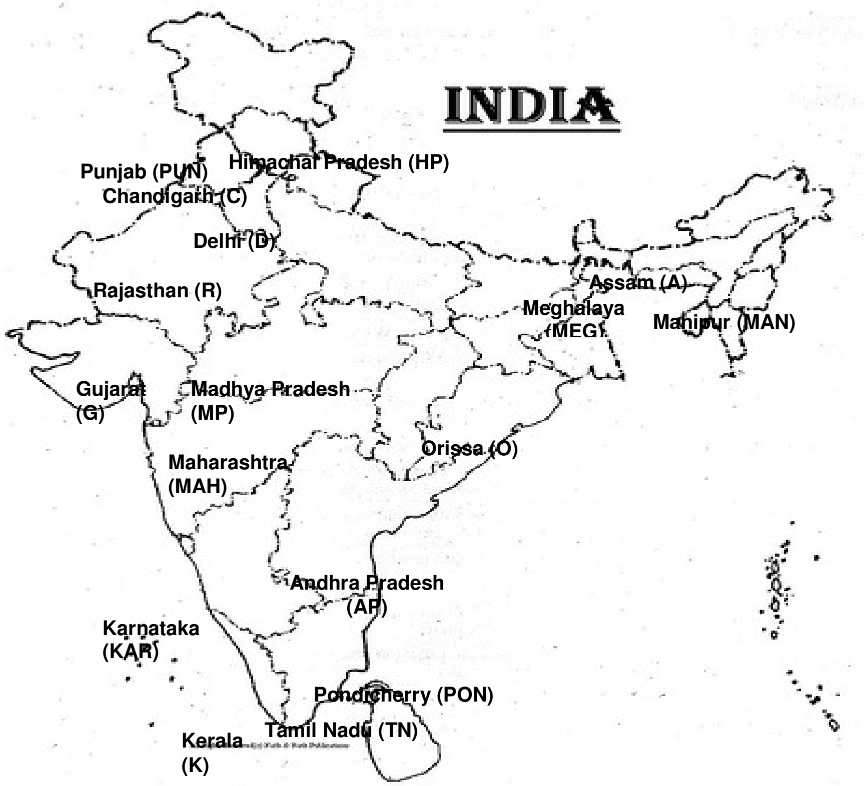

Figure 5.2 Selected 17 States of India for analysis in Phase II
Source: (Online map[48])

Table 5.2 Factors of the DPSIR analysis of selected 17 States in India in 2001

State name	Net State domestic product (in Rupee INR Crore)	Municipal solid waste generation (ton per capita per year)	Geographic area(sq. km)
Andhra Pradesh (AP)	157,150	0.208	275,045
Assam (A)	38,313	0.073	78,438
Chandigarh (C)	5,490	0.146	13,256
Delhi (D)	65,027	0.193	16,152
Gujarat (G)	123,573	0.128	196,024
Himachal Pradesh (HP)	17,148	0.110	55,673
Karnataka (KAR)	112,847	0.142	191,791
Kerala (K)	77,924	0.084	38,863
Madhya Pradesh (MP)	86,745	0.139	308,245
Maharashtra (MAH)	273,188	0.146	307,713
Manipur (MAN)	3,369	0.037	22,327
Meghalaya (MEG)	4,478	0.124	22,429
Orissa (O)	46,946	0.131	155,707
Punjab (PUN)	79,611	0.190	50,362
Pondicherry (PON)	4,259	0.183	50,148
Rajasthan (R)	91,771	0.110	342,239
Tamil Nadu (TN)	148,861	0.110	130,058

Source: (Web site of Indiastat[47])

State name	Biological Oxygen Demand (mg/l)	Chemical Oxygen Demand (mg/l)	Literacy rate (%age)
Andhra Pradesh (AP)	6.500	39.520	60.47
Assam (A)	4.100		63.25
Chandigarh (C)			81.94
Delhi (D)	16.000	56.500	81.67
Gujarat (G)			69.14
Himachal Pradesh (HP)			76.48
Karnataka (KAR)			66.64
Kerala (K)			90.86
Madhya Pradesh (MP)			63.74
Maharashtra (MAH)			76.88
Manipur (MAN)			70.53
Meghalaya (MEG)	1.100	3.200	62.56
Orissa (O)			63.08
Punjab (PUN)	1.500	8.000	69.65
Pondicherry (PON)			81.24
Rajasthan (R)	16.300	79.000	60.41
Tamil Nadu (TN)	5.400	56.500	73.45

Source: (Web site of Indiastat[47])

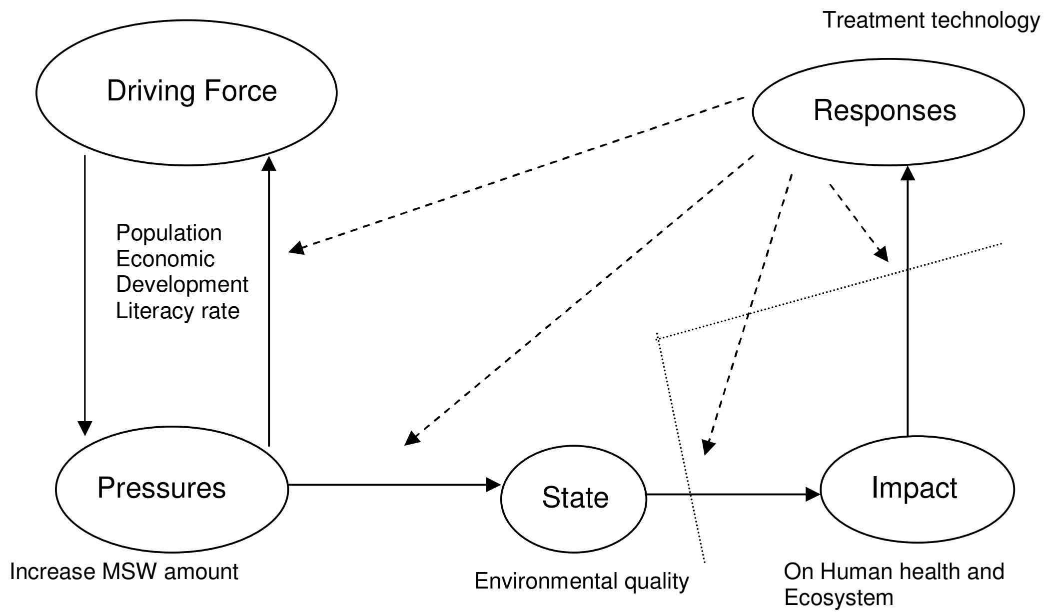

Figure 5.3 DPSIR conceptual framework for assessing municipal solid waste management factors

5.3 Results of Phase I

Several empirical studies of 1980s and 1990s give an optimistic view; in industrialized countries many pollution indicators decreased despite a growing per capita income, while in less developed countries economic growth yielded increasing pollution. Therefore, economic progress with less environmental impact seems to be possible. The idea that economic growth is ultimately beneficial for the environment, therefore, to maintain the economic growth is necessary, because the surest way to improve the environment is to become rich [49] . This viewpoint implies that environmental problems are a temporary phenomenon, since economic growth and technological innovation will resolve these problem in due time.

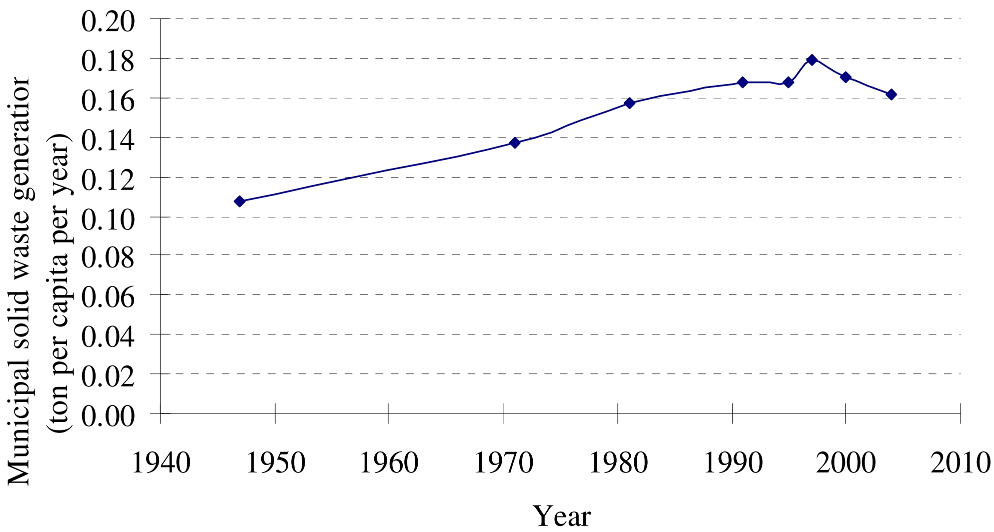

Figure 5.4 Time series of municipal solid waste generation

Figure 5.4 shows the trend of municipal solid waste generation in India over the studied period from 1947 to 2004. It shows that a turning point was found in 1997. It is possible to make only one statement if an economic indicator would keep growing during the same period; the presumption that economic growth can be conformed to environmental improvement has been proven. Indeed, gross domestic savings increased monotonously from 1947 to 2004. **Figure 5.5** shows the relationship of municipal solid waste generation and gross domestic savings during studied period in India which shows decoupling and the turning point around at 26.7 percent of GDP of gross domestic savings. After reaching the turning point, slope went downward very slowly.

In this analysis, I used gross domestic savings (GDS) percentage to GDP instead of GDP as the indicator of economic growth because it may be more sensitive one of financial capacity to pay for environmental improvement. GDS generally has a high correlation to GDP, however in the course of industrialization in developing countries, GDP increases earlier than GDS due to intensive for industrial production. Consequently, GDS percentage to GDP increases later after sufficient investment recovery from the industrial production has accumulated, and then a portion of savings could be used for environmental countermeasures. The high curve fitness in **Figure 5.5** supports the validity of GDS percentage to GDP as the indicator of EKC.

Wooldridge[50] reported a non-logarithmic form for analysis of serial correlation and defined turning point with respect to waste generation and GDP per capita. In this study, not sufficient samples were available to conduct similar moving correlation analysis. Robustness of the inverted U-shape curve obtained in this work is critical because only two samples exist after the turning point. However, correlations of the former and the latter half of samples differed significantly indicating, at least, that correlation between gross domestic savings and waste generation rate became weak after 1995. Therefore a cautions conclusion of the result can be that a sign of decoupling between economic growth and municipal solid waste generation was detected. It will take a decade or more to confirm the validity of this result.

Cole[44] pointed out that the U-shape form of EKC has been raised mainly for emission externalities. According to the result of this study, a specific policy is worked out. The key policy is that even if such a curve characterized past growth, there is no reason for developing countries passively to accept "historical determinism" along their future development path. In effect, lower-income countries could learn from the experience of wealthier nations and adopt policies that permitted them to "tunnel effect" through the curve[51]. Some recent studies showed that economic and social policy may have a very important role in determining the emergence of the downward sloping part of the Environmental Kuznets Curve[42].

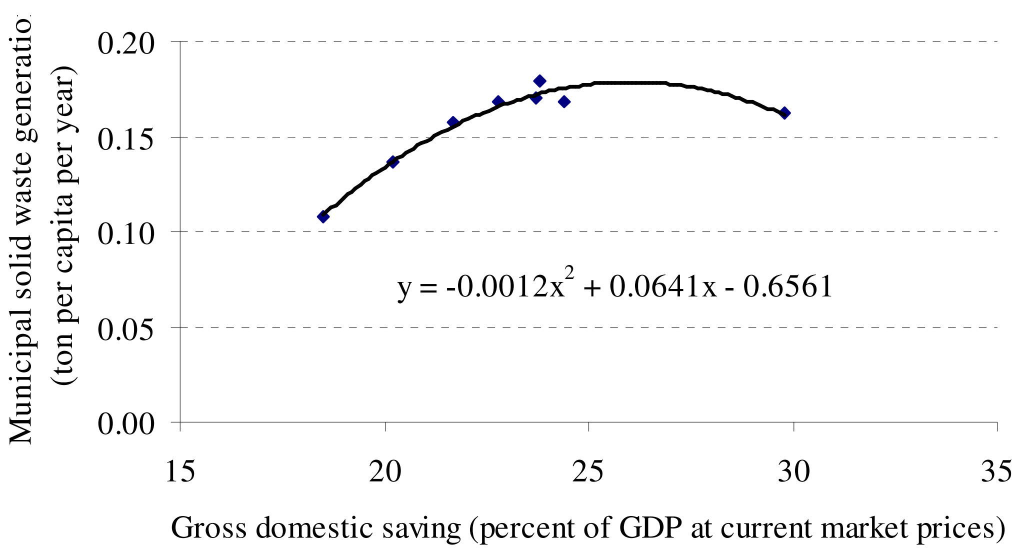

Figure 5.5 Relationship of municipal solid waste generation and gross domestic savings

5.4 Results of Phase II

5.4.1 Driving force-pressure linkage

Correlation between factors corresponding to driving force, pressure and state of DPSIR framework for municipal solid waste management was analyzed using a state wide dataset. In **Figure 5.6**, the relationship between net states domestic product as driving force factor and annual amount of municipal solid waste as a pressure factor is shown. The high correlation coefficient (r^2=0.78) shows a strong relation between net state domestic product and municipal solid waste generation, and it implies no decoupling between them.

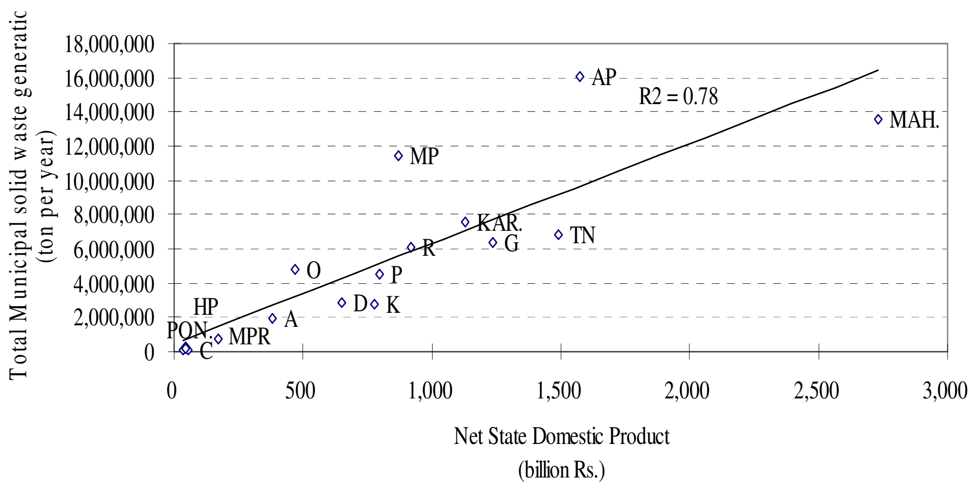

Figure 5.6 Relationship of Net State Domestic Product and the amount of municipal solid waste generation

The present correlation analysis of seventeen states of India showed that the higher net state domestic product leads to the high amount of municipal solid waste in general, whereas there are a few unique states. Andhra Pradesh (AP) showing the highest total municipal solid waste generation per year and a moderate high net state domestic production experiences on going rapid industrial development and urbanization. Hyderabad city, the capital of Andhra Pradesh State holds more than 300 industrial estates[52] of mainly chemical and pharmaceutical, and some heavy metal industries. The lowest total municipal solid waste generation is shown in Chandigarh State (C) because it is the Union territory and urbanization occurs as moving to the sustainable society promoted by the government. In the other states of India like Assam (A), Delhi (D), Gujarat(G), Himachal Pradesh (HP), Karnataka (KAR), Kerala (K), Madhya Pradesh (MP), Manipur (MAN), Meghalaya (MEG), Orissa (O), Punjab (PUN), Tamil Nadu (TN) is showing the increasing order of waste generation corresponding the increasing order of urbanization and industrialization.

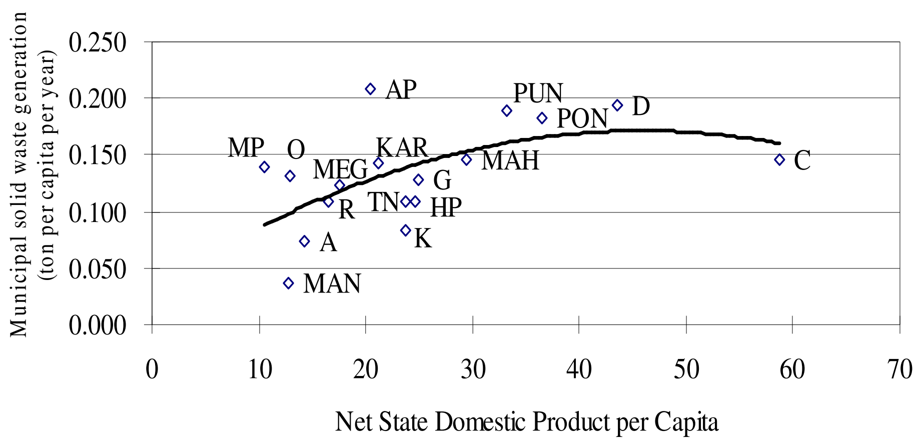

Figure 5.7 Relationship between Net State Domestic Product per capita and municipal solid waste generation per capita

Above analysis was based on state total economy and state total amount of waste. Next analysis compared activity intensities in economy and waste generation. In **Figure 5.7**, the relationship between net state domestic product and annual municipal solid waste generation per capita is shown. Municipal solid waste generation had weak positive correlation with net domestic product per capita for entire range, but showed different properties in the lower and higher product range. Most states positioned under 30 thousand Rs of net domestic product per capita and the waste generation per capita of them significantly correlated with net domestic product per capita. Whereas for the higher product states, waste generation per capita was almost similar or was slightly decreasing with increasing net domestic product per capita. Therefore, per capita municipal solid waste generation showed decoupling with per capita net domestic product in the higher product states. Again, robustness of this EKC-like shape would depend on a few samples in the higher economic product states; however reliability of the used dataset in this analysis is should be higher than the previous one because the same governmental organization conducted measurement in all states in the equal methodology.

Positions of some states in the per capita measure (**Figure 5.7**) were different from those in the state total measure (**Figure 5.6**). For example, Chandigarh State (C), having the lowest total waste generation, actually showed a middle higher waste generation per capita, and more extremely, it showed the highest economic product per capita although it belonged in the bottom states of total net domestic product. Another important measure is environmental performance of the states. There exists a considerable gap in per capita waste generation among states having similar net domestic product per capita. For example, waste generation per capita of Andhra Pradesh State (AP) is more than twice of Kerala State (K) indicating a worse environmental performance. Comparison among states having different performance can provide valuable knowledge for improvement, and this aspect will be discussed in the section of “response”.

5.4.2 Pressure-state linkage

The pressure of increased waste generation and lack of infrastructure has had a number of undesirable impacts such as the export of waste, illegal dumping, fly tipping and backyard burning. The significant quantities of recyclable waste materials are exported for actual recovery and recycling, as the indigenous recycling industry is almost non-existent. Such pressures have placed an enormous burden on local authorities to effectively manage municipal solid waste.

The average annual rainfall of Andhra Pradesh State ranges from 500 mm annually in the South–West to 1,100 mm in the North-East. It has 27.5 million hectares of geographical area with gross and net cropped area of 13.2 and 11.5 million hectares respectively, and irrigated area occupies 5.77 million ha. The net irrigated area is 3.88 million ha of which 34.7% is under canals, 12.3% is under tanks and 53% is under tube wells and other sources. The irrigation potential in Andhra Pradesh has been estimated to be 11.3 million ha[53].

Due to frequent poor and erratic rainfall, there is a pressure on groundwater utilization. Indiscriminate tapping of groundwater in the State by too much drilling and construction of deep tube wells and bore wells followed by unregulated water pumping have resulted in over-exploitation and depletion of groundwater resources in certain areas.

Groundwater is an important source of drinking water but is polluted because of the waste generated in the industrial, agriculture and domestic sectors. In this section, water quality as an environmental state indicator was compared with municipal solid waste generation as the pressure indicator in the DPSIR framework.

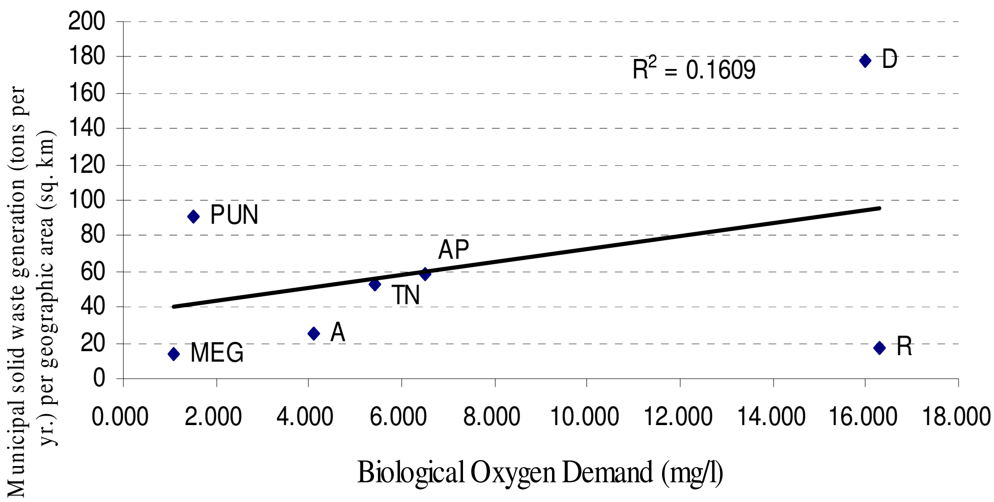

Figure 5.8 Relationship between municipal solid waste generation per area and BOD of wild wetlands

Figure 5.8 shows relationship between municipal solid waste generation per area and Biological oxygen demand (BOD) of water from wild wetlands in seven Indian states. BOD was found the minimum in Meghalaya State (MEG) and the maximum in Rajasthan (R) and Delhi (D) States. Urbanization is low in Meghalaya while the highest in Delhi, and waste generation per area is also the lowest in Meghalaya and the highest in Delhi. While Rajasthan has the low urbanization and low waste generation similar to Meghalaya, its water quality is the worst among studied states unlike Meghalaya. The weak positive correlation between waste generation per area and BOD was actually not significant. The source of organic pollutant that increases BOD is not only municipal solid waste but also municipal waste water, sludge, as well as organic fertilizer and manure from agriculture are included. Hydrological path between pollutant sources and waterbodies is also a determinant factor at a specific site but is unknown in the used dataset. BOD of wild wetlands is not a valid indicator of environmental state affected by municipal solid waste.

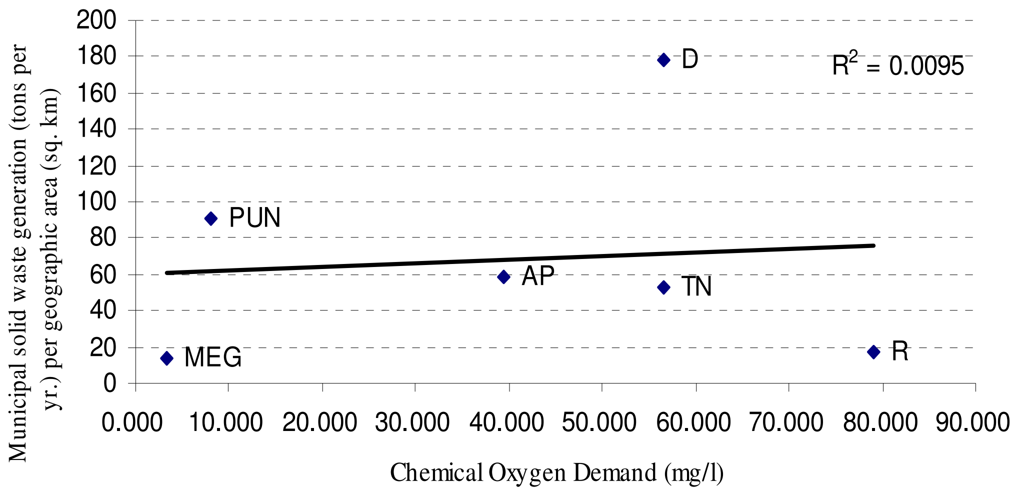

Figure 5.9 Relationship between municipal solid waste generation per area and COD of wild wetlands

Figure 5.9 shows relationship between municipal solid waste generation per area and chemical oxygen demand (COD) of water from wild wetlands in six Indian states. COD was the highest in Rajasthan State (R) and the lowest in Meghalaya State (MEG). COD and BOD had quite high correlation, and therefore, also COD did not show significant correlation with municipal waste generation per area similar to BOD.

5.4.3 Response to attain the decoupling

In previous sections, inter-linkages between driving force and pressure and between pressure and state in the DPSIR framework for municipal solid waste management were investigated. Economic development was found to link strongly to municipal solid waste generation, whereas a sign of decoupling between economy and environment has been detected in the states with high net domestic product per capita. This chapter discusses on the response aiming to promote the decoupling between driving force and pressure by comparison of environmental performance among the states.

As discussed in section 5.4.1, environmental performance of a state in waste management can be measured by waste generation and economic standard. This study proposes an index "eco-efficiency" as net state domestic product per municipal solid waste generation. Eco-efficiency of 17 Indian states is shown in **Figure 5.10**. The best eco-efficiency in India was in Chandigarh State (C) showing 0.40 million Rs per ton followed by Manipur (MAN) and Kerala (K) States, whereas the worst was in Madhya Pradesh State (MP) showing 0.08 million Rs per ton followed by Andhra Pradesh (AP) and Orissa (O) States. Chandigarh State, as already mentioned, is a small and highly urbanized state where sustainability is promoted by the government. Manipur and Kerala States are moderately urbanized but population density is quite different; low in Manipur and quite high in Kerala. Net state domestic production per capita is high in Chandigarh, middle in Kerala and low in Manipur. Thus, there are no common demographic, geographic and economic properties among the highest eco-efficiency states. Alike, no common properties are found among the lowest eco-efficiency states; Madhya Pradesh, Andhra Pradesh and Orissa.

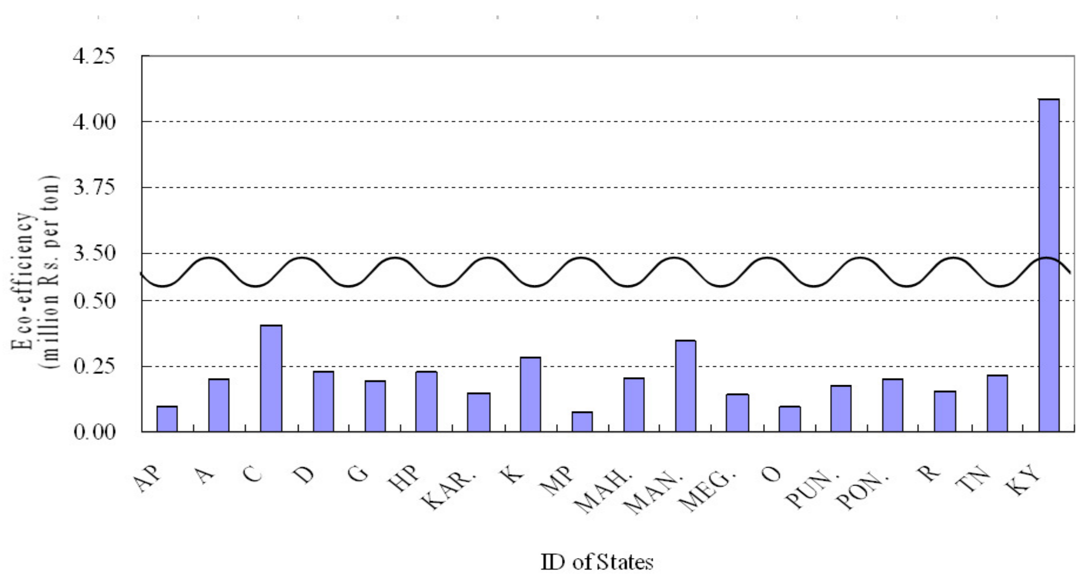

Figure 5.10 Eco-efficiency of 17 Indian states and Kitakyushu (KY), a developed city of Japan

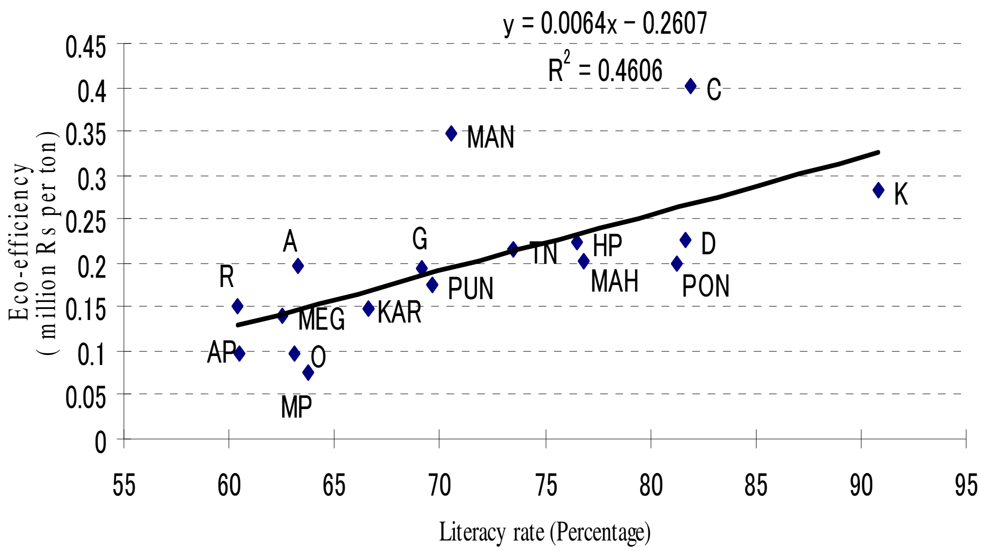

Figure 5.11 Relationship between literacy rate and eco-efficiency of 17 Indian states

There is a very probable factor that defines eco-efficiency. **Figure 5.11** shows Relationship between literacy rate and eco-efficiency of 17 Indian states. Literacy can explain 46% of variation in eco-efficiency. The highest literacy rate was 90.86% in Kerala State (K) of which eco-efficiency was the third highest. The fact literacy rate was positively correlated with net state domestic product per capita but not correlated with municipal solid waste generation per capita suggests that education would promote decoupling between economic growth and environmental burden.

Figure 5.10 shows also eco-efficiency of Kitakyushu (KY), Japan as reference of developed country. Economic measure of Kitakyushu was converted into the same unit of Indian states by currency exchange rate. Kitakyushu has a population comparative to Chandigarh State (C) but generates twice larger municipal solid waste per capita. Domestic product per capita of Kitakyushu was 25 times larger than Chandigarh making 10 times larger eco-efficiency. Literacy rate of Kitakyushu is 100%. By predicting from the regression line in **Figure 5.11**, the maximum eco-efficiency that Indian states can attain by achieving 100% literacy rate is 0.38 million Rs per ton, and there still exists a big efficiency gap with developed countries. This may be the limit of domestic policies in developing countries to raise eco-efficiency.

Kitakyushu is one of the advanced model cities that promote the 3Rs initiative both in municipal and industry sectors. Matsumoto[54] found that, in the absence of a comprehensive recycling policy for individual products and appropriate technology development, it is extremely difficult to improve recycling levels for end of life products. Another gap with developed counties is infrastructure as 'though waste management infrastructure has improved in recent years there are considerable infrastructure deficits, including large-scale and local facilities'. To narrow the policy and infrastructure gap on the way of economic growth, transfer of advanced knowledge in developed countries is indispensable. The next chapter will discuss on this aspect.

5.5 Summary and Conclusions

Dissociation of economic growth and environmental degradation are discussed based on the concept of Environmental Kuznets Curve. In phase I, a historical change in municipal solid waste generation of India showed a monotonous increase before 1997 but saturated or slightly decreased after that point. Municipal solid waste generation per capita depicted a clear inverted U-shape curve against gross domestic savings percentage to GDP and it suggested a sign of decoupling between economic growth and waste generation.

In an optimistic view, the process of globalization may render the world's development more sustainable simply by pushing the world economy towards the decreasing part of the bell-shaped Environmental Kuznets Curve. However, progress of research still needs to be made in order to learn which variables do have a turning point in their relation with output so that we can decide which policies to follow. A practical application of the DPSIR framework was conducted in Phase II to investigate relationship between factors corresponding driving force, pressure and state in municipal solid waste management, and to find possible response to attain the decoupling through analysis of Indian states. A sign of decoupling between economic "driving force" and waste generation rate as "pressure" was also found in a few economically advanced states. Eco-efficiency was defined as an indicator of decoupling progress, and it was found that literacy rate significantly determines the eco-efficiency of Indian states. This suggests importance of education as domestic policy to improve waste management; however its limit was also shown by comparison with a developed country.

Chapter 6 POTENTIAL EVALUATION OF KNOWLEDGE TRANSFER IN MUNICIPAL SOLID WASTE MANAGEMENT

6.1 Introduction

Globalization that implies a strong cultural, technological and especially economic interconnection between people and countries has been widely promoted as a process, which will improve the well being of both the developed and developing worlds [55]. For the developing world in particular, globalization is seen as an economic transformation, a break through to poverty alleviation, and inflation reduction thus expected to help narrow the gap between the two worlds as well as between and within individual nations.

Based on the results of previous chapters, the purpose of this chapter is to compare the present strategies of developed and developing countries and also suggest the best strategy for the knowledge transfer on municipal waste management from Japan as a developed country to India as a developing country.

6.2 Discussion

Solid waste management policy and implementation may vary from country to country and city to city. In most developing countries as India, the local governments are responsible for municipal solid waste management. The management system may be evolved over a period of time depending on the variations in solid waste, political and administrative system, socioeconomic situation, and geo-climatic condition. Hence, it is useful to capture the evolving process with respect to laws, institutions, financial mechanisms, technology and infrastructure and stakeholder participation.

As per previous chapter, domestic policy has limitation to improve the municipal solid waste management. Now, this chapter discusses about the possibility of knowledge transfer from developed country in four aspects: Technology development, Investment to good practice, Legal system and 3R policy, where these aspects correspond the responses in the DPSIR framework of municipal solid waste management as illustrated in **Figure 6.1**.

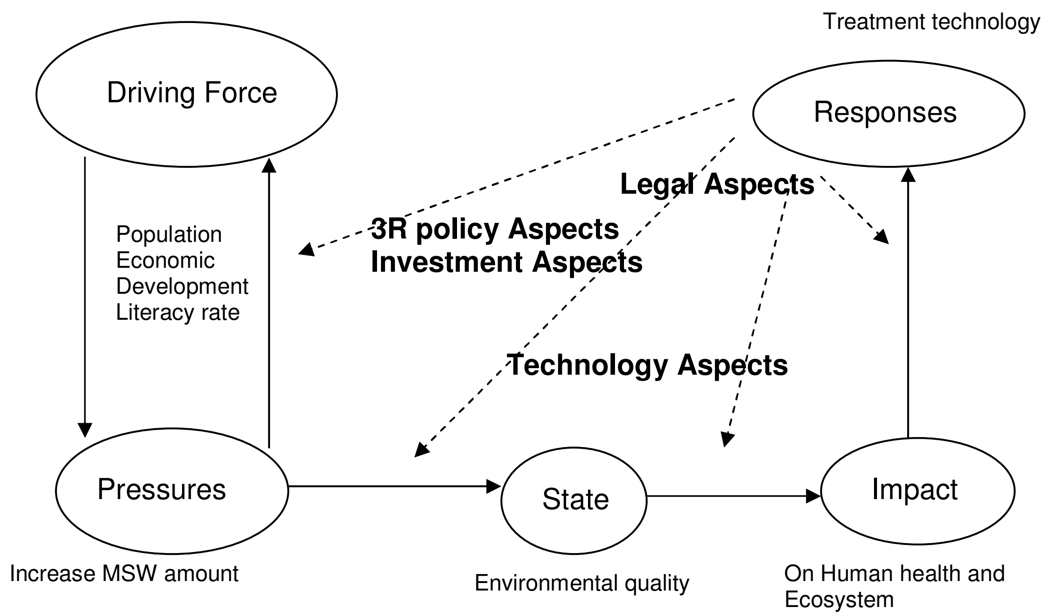

Figure 6.1 Aspects of knowledge transfer in the DPSIR framework of municipal solid waste management.

6.2.1 Strategy I: Technology

The technology aspect deals with the improvement of assimilative capacity as well as supportive capacity of the environment. The proper treatment technology is a key component of municipal solid waste management.

- Recycling technology
  - High level separation including a laser identifying device
  - Refinery to extract valuable materials from waste
  - Composting of biodegradable waste
  - Methane recovery that catches and utilizes biogas generated from landfills
  - Thermal and energy recovery including refused derived fuel (RDF) and co-generation at incineration plants
- Waste treatment technology
  - Advanced clean incineration without emitting toxic gases
  - Non-hazardous treatment
  - Advanced full controlled land filling

6.2.2 Strategy II: Investment and project management

The Eco-Town Project introduced by the Ministry of Economy, Trade and Industry (METI) of Japan in 1997 aims to promote a "Zero Emission Society" at local and national levels by creating new environmentally sound towns and introducing advanced technologies for recycling.

METI promotes this project to support local governments and provides subsidies for the construction of high-technology model recycling facilities and for marketing efforts in the environmental industry. In August 2002 "the Eco-Town Project Second Stage Plan" was instituted and went into practice. While the first stage of this project (1997-2002) focused on the "recycle", the second stage (2002-2010) emphasizes "reuse". For example, Kitakyushu Eco-Town Project located in the eastern part of the Hibiki landfill area of the city, which was the first approved by the government, was planned to develop comprehensively from basic research to technological development, demonstration, research and commercialization [56] **(Figure 6.1)**. The first stage of the project consists of a Comprehensive Environmental Industrial Complex, the Hibiki Recycling Area, and the Practical Research Area. More than 20 companies join the project and produce a variety of reused or recycled goods (fluorescent lamp, wood board, automobile parts, recycled plastics, metals and solvents, BDF, etc.).

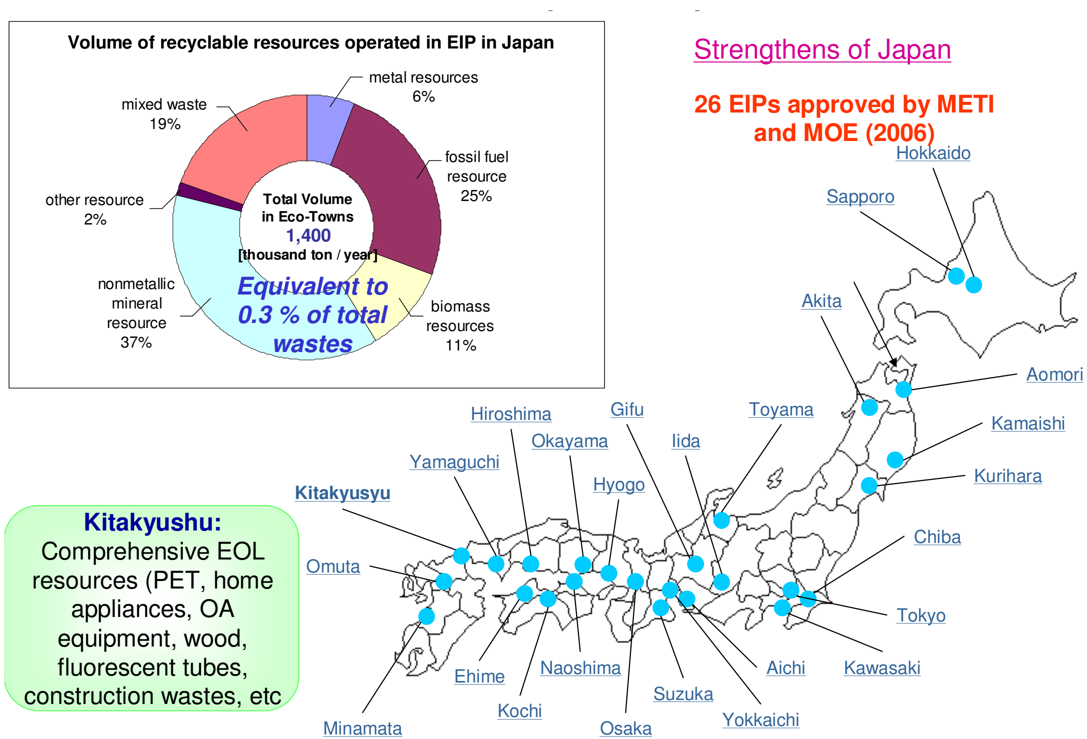

Figure 6.2 26 Eco-town projects approved by Japanese government

Cases of waste management projects in Asian developing countries are shown in **Table 6.1** in which engagement of local residents and stakeholders is rather high at the time of project implementation. Some of the cases are considered successfully if they completed the implementation of the intended initiative[57]. These initiatives illustrate the importance of implication for local government to play facilitative and enabling roles.

Local knowledge is underlined as a key factor in applying and managing technologies. As per analysis of Indian states, the highest eco-efficiency was shown in Chandigarh State (C), where an advanced practice of waste management has been implemented. Aiming to improve sanitary conditions of the city, the State Pollution Control Board introduced the novel concept of "Bin Free Sector Scheme". Under the scheme, all garbage bins placed at the various locations in the sectors are removed and one or two suitable places are earmarked for construction of Sahaj Safai Kendras for the storage of municipal solid waste from that area. The local municipal corporation is also setting up a "Garbage Processing Unit" which produces refused derived fuel (RDF) in a joint public private partnership venture with some private companies[58].

Table 6.1 Projects of waste management in developing countries

Country name	Project
India	Waste to energy project in Okhla landfill
Bangladesh	NGO-led community waste management and composting
Philippines	Community waste composting and separation of valuable materials
Indonesia	Reducing waste through composting
Thailand	Using organic waste from the public market to produce fertilizer and detergent

Source: (IGES white paper[57])

The Eco-Town projects of Japan and good Asian local practices introduced above direct to promote environmental industry, research and technology development. Success and transfer of these good practices depend on strategic investment by government, private and international finances.

6.2.3 Strategy III: Legal system

The majority of Japan recognizes that modern society has approved a "mass production, mass consumption and mass disposal" economy and that future society should be changed towards recycle-oriented one. In 2001, the Basic Law for Establishing the Sound Material-cycle Society and related laws were promulgated or revised (**Figure 6.3**). The basic concept of municipal solid waste management has been extended according to the development of society. At first, it was based on public health, and environmental protection was added later, which includes resource recovery, especially energy recovery and recycle-oriented society. In Japan, the final disposal of waste has reduced drastically and the recycling rate has gone up because of 3R legislations and policies.

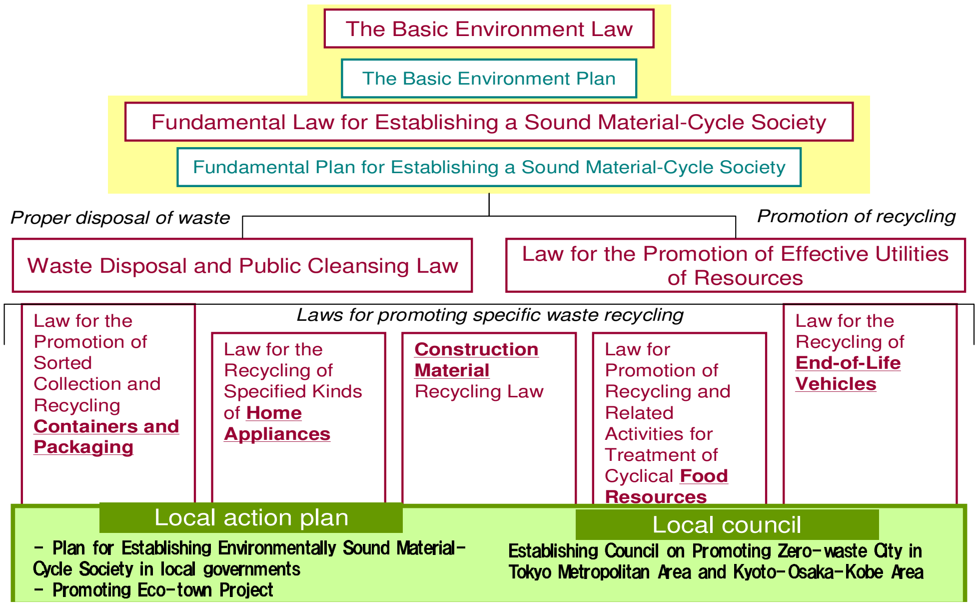

Figure 6.3 Legislation framework to establish a sound material-cycle in Japan.

Source: (MOE, Japan[59])

In India, the first Environment Protection Act was established in 1986 which was not mentioned municipal solid waste management. The first municipal solid waste rule (Management and Handling) was established in 2000 which includes the collection, treatment and disposal norms. In 2005, National Environmental Policy was implemented which corporate the 3R policy but still it's under consideration to implement (**Table 6.2**). The system of law for waste treatment and 3R promotion in Asian developing countries are still immature in measures of structure, coverage, effectiveness including penal rules compared with that in developed countries.

Table 6.2 Comparison of legal institutions for municipal solid waste management in Japan and India

	Japan	India
Basic law	Basic Act for the promotion of the Recycling-Oriented Society (2001); Law for promotion of effective utilization of resource (2001)	Not available
Resource Efficiency	Container and Packaging (1997); Green purchase (20000	Not available

Recycling	Home appliance (1998); Construction material (2000); Food resources (2000); Container and packaging (1997); End-of-life vehicles (2005); Waste management (2003)	Under consideration
Final disposal	Many laws of proper disposal like incineration, land filling, sanitary etc.	Municipal solid waste (Management and Handling) (2000); Hazardous waste (1989); Biomedical waste (1998)

Source: (MOE, Japan[59])

6.2.4 Strategy IV: 3R policy

In recent years, global environmental problems have urgently required to develop the environmental protection technologies which will realize the low-loading society in the global scale. The concepts of waste reduction, reuse and recycle, often referred to as "3Rs", are particularly applicable in the context of production and consumption cycle **(Figure 6.3)**. It calls for an overall reduction in resources and energy use, increase in ratio of recyclable materials and further reusing of products. The 3R ideas can be applied to the entire lifecycle of products from extraction of raw material to manufacture or use, reuse and disposal.

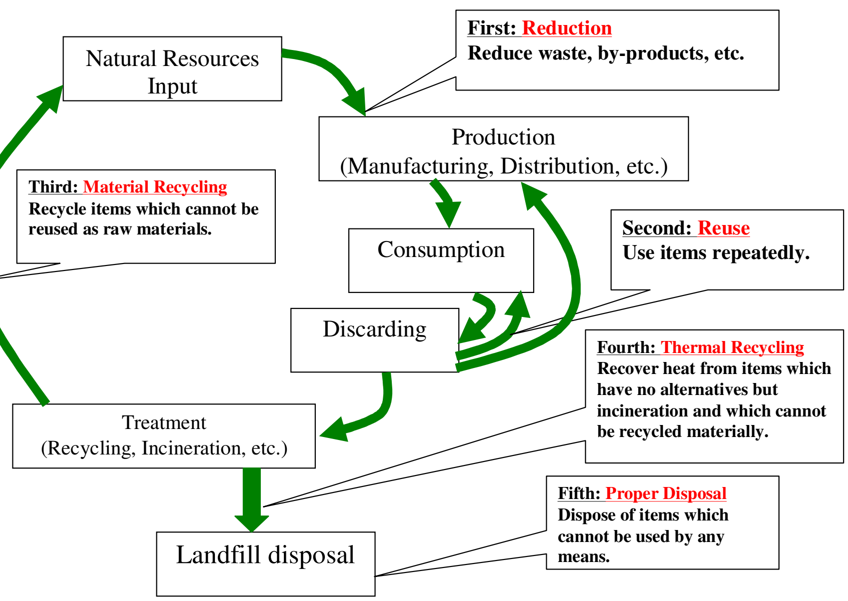

Figure 6.4 Concept of 3R system

Source: (MOE, Japan[59])

Due to the rapid growth of urbanization, the amount of waste is rapidly increasing. From the context of overall waste management practice, it is environmentally preferable to avoid or reduce the rapid generation rate of waste in the first instance before considering the second best options of reuse, the third option of material and thermal recycling, and following proper final disposal. The success of a '3R' initiative will largely depend on the policies and programs, which is implemented at the local and national level.

Material flow design depends on process input (based upon collection system), the desired process output (based upon the availability markets), the degree of mechanization, the value of recovery efficiency of both manual and mechanical sorting processes and the economic viability of the whole process[59]. This suggests that accurate and comprehensive information on resource, process, production, consumption and disposal is indispensable to design a proper 3R system both in national and local levels. Local governments of Japan, who are responsible to municipal waste management, can hold information of waste generation and disposal. In the national level, Japanese government and institutes conducted research of material flow across industry, market and household and detailed information is published, which makes 3R design in various levels easy and actual. Hence in developing countries, information of material flow is very limited and this impedes a proper 3R design. Fundamental information on material flow is a necessary condition to promote and support 3R activities in developing countries.

6.3 Summary and Conclusions

Municipal solid waste management requires intensive use of environmentally sound technologies suitable in each stage of development; from simple containers for primary collection to complicated incinerators with co-generation, which are generally exported from developed countries to developing countries. However, knowledge transfer should cover not only advanced technology of waste treatment but also management system, legal system, policy and investment in order to build a sustainable society. This chapter reviewed and discussed about a wide range of knowledge hold by developed countries as Japan and needed by developing countries as India. Not all advanced knowledge is usable in developing countries depending on their stages of development or social, economical and physical conditions. It is preferable to diagnose the weakness of current system and to select the most effective method to improve it through a systematic analysis. The DPSIR framework may help it.

Chapter 7 CONCLUSIONS

7.1 Conclusions

The study applied the DPSIR framework to analyze the status and problems of municipal solid waste management in the developing countries and to obtain valuable knowledge to improve it. The key findings of each chapter are as follows:

- In chapter 2, the situation of municipal solid waste management in South Asian developing countries was overviewed. Rapid urbanization and industrialization has caused tremendous increase of municipal solid waste generation in developing countries. Waste composition reflected a social status. Municipal solid waste is still collected without segregation and treatment facilities are also very limited and most waste is dumped haphazardly in open areas.

- In chapter 3, future trends of population, urbanization, municipal solid waste generation and required area for landfill in South Asian developing countries were estimated. These results suggest that municipal solid waste disposal needs immediate attention and strict monitoring. The present research also indicated the shortage of natural resources such as land because the municipal solid waste generation will be increase, this create a lot of problems in future.

- In chapter 4, the DPSIR framework for evaluating the performance of municipal solid waste management in Asian developing countries was discussed. Using this DPSIR model helps the analysis of the causality behind the municipal solid waste generation problem in Asian developing countries. Indicators corresponding to each factor of the customized DPSIR framework in south Asian developing countries were reviewed. The results suggested that economic growth is one of the key driving forces contributing to the increasing amount of municipal solid waste generation. The cause-effect relationship of the DPSIR framework and the focus of responses were also identified.

- In chapter 5, the hypothesis of Environmental Kuznets Curve (EKC) that foretells the decoupling of economic growth and environmental degradation was investigated in the case of municipal solid waste generation in India. As the result, a sign of decoupling between municipal solid waste generation and economic growth was detected in Indian nation wide level. The inter-linkage between driving force, pressure and state as well as possible responses to the factors in the DPSIR framework were investigated using state level data in India. Strong correlation was shown between economy as a driving force and solid waste generation as pressure; however a sign of decoupling between them was also detected in a few most developed states. In order to find effective response to promote this decoupling, eco-efficiency was employed as its indicator. A significant correlation between literacy rate and eco-efficiency was found suggesting that education is an effective measure to decouple driving force and pressure. On the other hands, there is big gap in eco-efficiency between the most developed Indian states and a city in developed country (Kitakyushu, Japan). This result suggests that knowledge transfer in inter-State level as well as from developed country is needed.

- In chapter 6, four strategies were discussed to improve the municipal solid waste management in developing countries in the context of knowledge transfer. I conclude that the possibility of knowledge transfer from developed countries is recognized, and that from the aspect of technology, investment, project management, legal system, and 3R policy should be implemented in the developing countries in order to improve their municipal solid waste management.

7.2 Future perspectives

In utilizing the DPSIR approach presented in this thesis in developing countries, there are three issues as below:

First issue is the development of monitoring system about resource and waste information including municipal solid waste. There are many barriers of data availability because of the lack of monitoring system. Advantage of the DPSIR approach is the function of evaluating the management factors in the stage of not only end-of-pipe but also input and resource metabolism. In order to plot more effective 3R strategies by employing additional factors, it is needed to establish monitoring and review system through lifecycle.

Second issue is the enhancement of variables in the DPSIR model. Only limited variables were used to detect decoupling and best practices in this research because of the first issue. For instance, industrial structure, geographical characteristics and life style must become strong driving forces to municipal solid waste generation in addition to educational and economic factors. I found one of the decoupling promoters, literacy rate, in this study, and if it is possible to use other variables, other options effective to the municipal solid waste management may be obtained.

The final issue is the integration with "Sustainability" approach. Sustainability is a complex issue because it emerges as the result of the interplay of a whole range of different dimensions, in which not only ecological, social and economic dimension but also political dimensions are also included. When we think about municipal solid waste management system, we have to integrate ecological, economic and social dimensions into the system in order to attain synergy effects. In this way, the concept of sustainability refers to the need of balance among the dimensions.

Ecosystem is the context in which all human activity ultimately depends on. The ecological dimension of municipal solid waste management should focus on environmental impacts to ecosystems, and also on natural biological processes and ecosystem productivity and functions. Economic aspect is also an important dimension of municipal solid waste management because of its broader functions of production, distribution and consumption of goods and services. And engineering designs, products and processes should be a primary driver for the development of sustainable technologies.

There are many socio-cultural issues which influence the municipal solid waste management. The most prominent issue is inter-generational equity for the welfare of human. The social dimension also includes the continued satisfaction of basic human needs, as well as higher-level of social and cultural necessities. It is concern and responsibility of engineers to design products, processes and technologies as well as systems balancing these dimensions.

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A. Academic Journal (Peer Reviewed Full Articles)

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D. Academic Journal (Full Article)

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