EFFECTIVENESS OF OPERATIONAL ASPECTS OF COMPOST PLANTS IN SRI LANKA

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Degree of Master of Science

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Thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in Environmental Engineering and Management

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DECLARATION

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Dr. S.H.P. Gunawardena

ABSTRACT

Solid waste is a major problem in Sri Lanka as it is in many other developing countries. Composting is proven to be a viable solution to address the Solid Waste Management issues the country is facing over many years due to the high content of organic matter composition available in the waste streams. More than 100 compost plants have been established in the country along with the introduction of National Solid Waste Management programme over the past few years. Nevertheless, uncertainty clouds over the long run of these compost plants due to many reasons which would ultimately lead them into failures. The objective of this research is to evaluate the factors contributing to the effectiveness of compost plants and thereby to evaluate the current situation of five selected compost plants with regards to operational aspects. The selected compost plants are currently being operated under Local Authorities in Western province and they were evaluated considering two criteria namely waste supply and compost quality. Under the first criterion effective operating level of the plants was evaluated while second criterion was focused on final compost product quality.

According to the results obtained, majority of the plants appear to be ineffective in their operation. Lack of institutional capacity in terms of technical expertise and finance is a major barrier for effective operation of compost plants. Facilitating proper training programmes among plant operators to improve their technical knowhow and introducing appropriate mechanisms for regular monitoring of process parameters are essential to ensure the effectiveness of compost plants. Strategies and practices from the successful cases could be replicated suitably in poor performing plants to address their drawbacks.

Key Words: effectiveness, composting, solid waste, quality of compost

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LIST OF ABBREVIATIONS

BETL	Burns Environmental & Technologies (Pvt) Ltd
CEA	Central Environmental Authority
CMC	Colombo Municipal Council
C:N	Carbon: Nitrogen
EC	Electrical Conductivity
FS	Faecal Sludge
LA	Local Authority
MC	Municipal Council
NPCPWMP	National Post Consumer Plastic Waste Management Project
NPK	Nitrogen, Phosphorous and Potassium
NSWMSC	National Solid Waste Management Supporting Centre
MSW	Municipal Solid Waste
PHI	Public Health Officer
PPE	Personal Protective Equipment
PPP	Public Private Partnership
PS	Pradeshiya Sabha
SLSI	Sri Lanka Standards Institute
WP	Western Province

1. INTRODUCTION

1.1.Solid waste Management in Sri Lanka

Solid waste management (SWM) issues are increasing in developing world mainly due to the rapid population growth and urbanization. Without an effective and efficient SWM program, the waste generated from various human activities, both industrial and domestic, can result in health hazards and have a negative impact on the environment (APO, 2007). Treatment methods such as composting, anaerobic digestion, and refuse-derived fuels (RDF) offer a more sustainable course of action which also produce value-added resources, including organic fertilizer and renewable energy, while generating environmental and economic benefits (ADB, 2011).

In Sri Lanka, Local authorities (LAs) are generally responsible for the provision of municipal solid waste (MSW) collection and disposal services. They become the legal owners of waste once it is collected or put out for collection. According to AIT (2004), the per capita per day waste generation on the average was 0.85 kg in Colombo Municipal Council (CMC), 0.75 kg in other Municipal Councils (MC), 0.60 in Urban Councils (UC) and 0.4 kg in Pradeshiya Sabhas (PS). Moreover, the best estimate of total MSW generation in Sri Lanka was around 6400 tonnes per day (AIT, 2004) and the daily waste collection by LAs is estimated as 2,900 tonnes, which is about 45% of the total MSW generation. Nevertheless, waste collection practices in LA areas differ greatly depending on the capacity of the LA to facilitate waste collection services and the demand for the collection by the people living within its territory.

In the past, the most common practice of MSW disposal in the country was open dumping. By then it was not a concern because of the free availability of degraded land. There was no proper management of MSW except for few cases where compost and biogas were produced as resource recovery. In most of the cases MSW was being dumped indiscriminately creating several negative environmental and health impacts. However, due to the arising land scarcity problem and also due to the environmental and health issues caused by improper disposal practices, LAs had to explore new solutions for the MSW disposal.

On the other hand, large proportion of the MSW in Sri Lanka comprises of biodegradable waste which enables its suitability for composting (figure 1). Moreover, it has a high moisture content (70–80% on a wet mass basis) and low calorific value (about 600– 1000 kcal/kg) (De Alwis, 2000) which would make the option of converting waste into energy unfeasible. Composting of MSW reduces the quantity of waste to be disposed of, thus lengthen the lifespan of the existing landfills. In addition to that, through composting many nutrient resources can be recovered to be utilized in agricultural applications. Thus, as a developing nation composting has been identified as a viable solution for the SWM issues in the country.

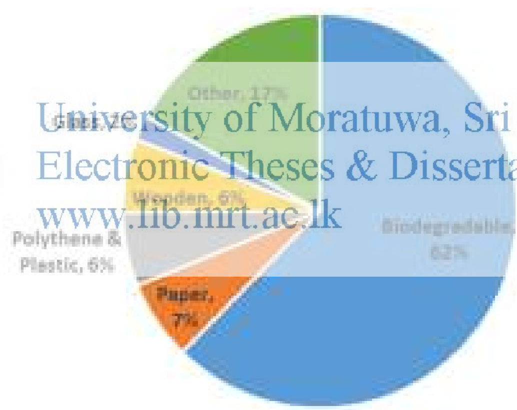

Figure1. 1: MSW composition in Sri Lanka
(Source: MENR, 2005)

Under these circumstances, a new waste management project, ‘Pilisaru’ was introduced by the Central Environmental Authority (CEA) in 2008 which was a national approach for SWM in Sri Lanka. Establishing the Pilisaru National Solid Waste Management programme was one of the major landmarks to address the SWM issue in the country. The programme was aimed to develop new MSW disposal facilities or assist to improve or expand existing MSW disposal facilities. Pilisaru programme influenced very positively on the improper waste management practices the country has been practicing over many years.

As far as the recyclable waste is concerned, a substantial portion of recyclable waste (metal and iron, paper and Cardboard, Plastics and Glass) is collected and sold mostly by the informal private sector as small scale businesses. However, National Post Consumer Plastic Waste Management Project (NPCPWMP) was set up by the CEA to address the behavioural change necessary among the Sri Lankan consumers to ensure proper disposal of plastic waste.

1.2.Overview of Compost plants in Sri Lanka

Composting is a proven technology that has been practiced in the country for a while. The first large scale compost plant in the country was initiated by a private sector firm called Burns Environmental & Technologies (Pvt) Ltd (BETL) in 2002. From then on, the responsibility of the disposal of garbage of CMC rested solely with BETL. The daily capacity was nearly 500 tonnes of fresh garbage at the compost plant. However, operation of the plant was disrupted due to some contractual matters, hence is currently not being operated.

Given the fact that the LAs hold the responsibility of managing the solid waste (SW) generated within its territory, composting sector in Sri Lanka is mostly managed by the public sector. Generally, CEA, Waste Management Authority of Western Province (WMA) and National Solid Waste Management Supporting Centre (NSWMSC) (under the Ministry of Local Government & Provincial Councils) are the main facilitators of waste management activities in the country including implementing composting projects. These government bodies individually or collaboratively assist LAs in waste management particularly by providing technical support via training courses & materials and with capital investment covering machineries, equipment and infrastructure. The long-term operation and maintenance of the compost plants and marketing of the compost remains with the LAs, thereby requiring LAs to allocate an adequate budget for this purpose. Although there were attempts to introduce Public Private Partnership (PPP) mechanisms to the composting sector, it has not properly been developed in the country yet. The compost plant owned and operated by Burns is an example where the PPP mechanism was not successful to be continued.

Prior to the Pilisaru project, there were only very few composting initiatives in the country which was limited to only 11 LAs. In recent past years, about 115 compost plants have been established in Sri Lanka under the Pilisaru project along with the other government bodies. Figure 1.2 illustrates the spatial distribution of composting sites funded by Pilisaru Project. Majority of these compost plants are being operated by the LAs whereas the balance few have been installed at institutions such as military bases or educational institutions and thus are being operated by the respective bodies.

Table 1.1 gives a summary of compost plants in Sri Lanka at provincial level detailing the operating entity, scale of the compost plant and its operating condition. Although the majority of the compost plants are functioning, few of them found to be nonfunctional mainly due to the constructional and institutional matters. These plants have been designed concentrating mostly on smaller towns and semi-rural areas resulting less industrial waste. Therefore more than 80% of the compost plants are small scale plants installed in PS. The major waste sources can be identified as market, domestic and commercial.

Figure 1.1 shows the locations of compost plants across the country. Essentially, these compost plants have been designed in accordance with simple technical process; the windrow method and the facilities have been erected to accommodate the necessary steps of the process. The additional infrastructure facilities such as non-biodegradable material store (recycling materials), worker facilities, product stores, water supply, electricity, access road development, machineries and transport vehicles have been provided in order to facilitate the process and workers hygiene improvement.

Table 1.1: Compost plants in Sri Lanka

Province	Operating Entity	Type of the composting facility	Operational Condition	No. of compost facilities
Central	LA	Small scale	Operational	8
	LA	Medium scale	Operational	1
Eastern	LA	Small scale	Operational	2
	LA	Small scale	Not operational	3
North Central	LA	Small scale	Operational	4
	LA	Small scale	Not operational	9
	Military Base	Small scale	Operational	3
	LA	Medium scale	Operational	1
	LA	Large scale	Operational	1
Northern	LA	Small scale	Operational	3
North Western	LA	Small scale	Operational	13
	LA	Small scale	Not operational	4
	LA	Medium scale	Operational	3
	LA	Large scale	Operational	1
Sabaragamuwa	LA	Small scale	Operational	4
	LA	Small scale	Not operational	2
	LA	Large scale	Operational	2
Southern	LA	Small scale	Operational	16
	LA	Small scale	Not operational	4
	LA	Medium scale	Operational	2
	LA	Large scale	Operational	2
Uva	LA	Small scale	Operational	3
	LA	Small scale	Not operational	1
	Military Base	Small scale	Operational	1
	LA	Medium scale	Operational	1
	LA	Large scale	Operational	1
Western	LA	Small scale	Operational	10
	Military Base	Small scale	Operational	3
	Educational Inst.	Small scale	Operational	3
	LA	Medium scale	Operational	2
	LA	Large scale	Operational	1
	LA	Large scale	Not operational	1
			Total	**115**

Source: Pilisaru Project, CEA (2013)

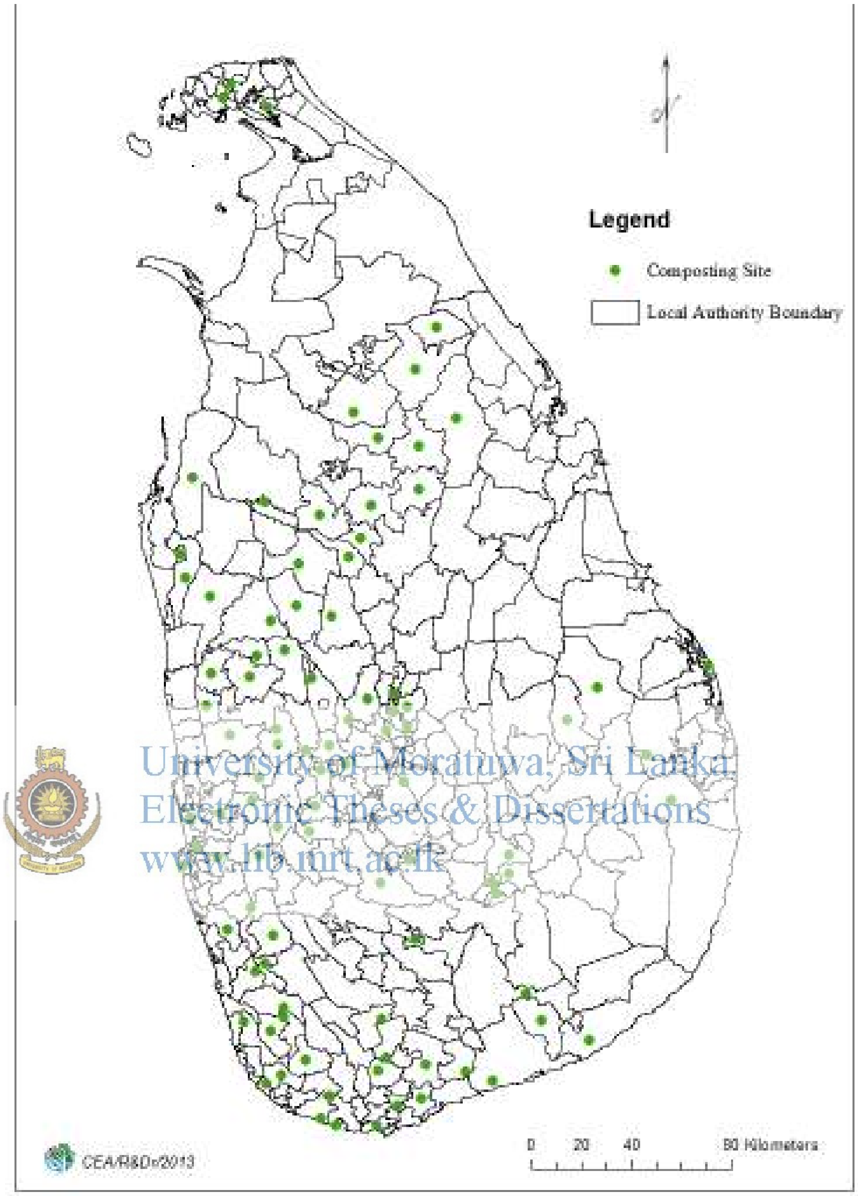

Figure1. 2: Spatial distribution of composting sites funded by Pilisaru Project

(Source: CEA, 2013)

Although the facility is called "compost plant", composting is not an isolated process. The entire project cycle of the compost plant covers activities such as receiving collected MSW, segregating them into organic and non-organic waste, resource recycling (of non-organic recyclable waste), composting of organic waste, and final disposal of residual waste at landfill. Figure 1.3 shows the waste management activities takes place at a typical compost plant in the country.

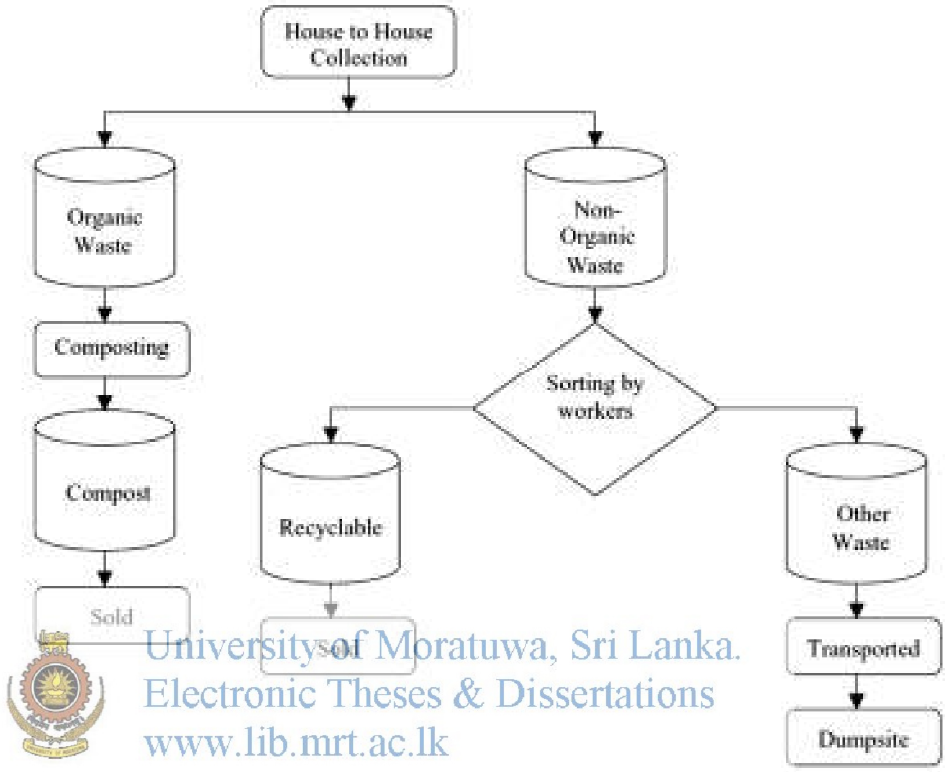

Figure1. 3: Waste management activities of a compost plant

Source segregation, is still not a common practice in Sri Lanka. At present, the common practice is to collect the mixed SW at source levels (from household and other entities) according to a routine plan scheduled by the LA. Normally, this routine collection plan differs from one LA to another depending on their resource availability and to which degree the collection is required. Segregation of the mixed waste is carried out manually by deploying labours, where in large scale plants conveying belt is employed additionally for this purpose in order to increase the efficiency of segregation.

1.3.Research Justification

Composting has been practiced in developing countries for many years. Despite the relative simplicity of composting, its suitability for developing countries, and its compelling economic and environmental benefits, several projects initiated over the past decades have failed due to technical, financial, and institutional reasons (Hoornweg et al, 2000).

In Sri Lanka, composting was initiated mainly as a solution to the SW mismanagement, essentially as a method of reducing quantities of SW to be disposed. The purpose of more than 100 compost plants constructed during past few years in the country was to address the improper waste disposal practices. It has been one of the major solutions looked upon by many LAs for proper managing of increasing amount of MSW. Thus compost plants have been designed in such a way that this purpose is served while maintaining beyond is often neglected.

Within the context of MSW management, composting projects have become more challenging in the country as in many other developing countries. Although composting has gained its momentum through the initiatives such as Pilisaru project, long run of compost plants in the country remains uncertain due to many reasons which would lead them into failures ultimately. Long run of these compost plants is essential considering the role of composting as a part of overall waste management system. Hence, it’s is of utmost importance to identify the critical factors to be maintained and monitored in order to make these compost plant effective which would lead this exercise be unsuccessful unless otherwise.

Having identified the timely need to address the SW issue in the country, many studies have been carried out for the betterment of the SWM in recent past years. Despite the fact that the national SWM programme has been developed mainly based on composting, studies on effective composting in Sri Lanka is minimal. Considering the significance of such studies, this study aims to assess the factors contributing to the effectiveness of compost plants within the country context. Furthermore, the findings of this study can be utilized by the regulatory bodies and policy makers to yield the guidelines for sound composting practices.

For better understanding of the effectiveness of compost plants, one should look at it in different parameters given that the effectiveness cannot be determined with one or two parameters alone, yet as an integrated approach. In this research effectiveness is attributed to various operational aspects in terms of waste input and compost processing for better evaluation of the effectiveness of compost plants.

1.4.Objectives

Therefore research was conducted to;

1. To understand the current status of the operational aspects of compost plants in Sri Lanka
2. To identify the factors contributing to the effectiveness of compost plants and thereby to evaluate the effectiveness of the selected compost plants

2. LITERATURE REVIEW

2.1.MSW composting and its effectiveness

SWM is an enormous task in developing nations all over the globe due to factors like poverty, population explosion, urbanization and lack of proper funding by the government (Taiwo, 2011). In order to develop more sustainable cities, the key challenges are how to de-couple the increase in quality of life from growth in SW generation and how to use less material but use them more efficiently (Veeken et al, 2005).

Sustainable management of SW is a global concern, as illustrated by the United Nations Millennium Development Goals (MDG). Sustainable MSW management is defined as the utilization of waste handling techniques, whether one method or a combination of methods, to divert the maximum possible waste fraction from landfills in order to extend their life span. Sustainable MSW management techniques include, but are not limited to: reduction, reutilization, material recovery (composting), and incineration with energy recovery (UNDESA, 2005 and Fehr et al., 2000). Given the reduced amount of waste that ends up in SW disposal sites, composting is considered a more viable and sustainable option for developing countries due to the high organic fraction of waste generated (Troschinetz & Mihelcic, 2008) and resource constraints in such countries (UNEP, 2005).

Composting has advantages such as lower operational cost, lessened environmental pollution and beneficial use of end products. It is full of nutrients and trace elements essential for healthy plant growth. As it breaks down, nutrients are released, providing a "slow release fertilizer" for plants. This reduces the need to use synthetic fertilizers by returning valuable nutrients to the soil. Compost also improves soil structure resulting in increased water holding capacity and nutrient retention of the soil. This reduces the irrigation needs of farms and the potential ground water contamination from synthetic fertilizers. Additionally, compost improves soil microbial activity, which potentially reduces the incidence of plant root diseases.

Despite being an attractive option for the SWM in many respects, implementation of composting projects has not always been successful due to various reasons. Hoornweg et al (1999) states following constraints commonly experienced in composting sector.

- inadequate attention to the biological process requirements
- over-emphasis placed on mechanized processes rather than labor intensive operations
- lack of vision and marketing plans for the final compost product
- poor feed stock which yields poor quality finished compost, for example heavy metal contamination
- poor accounting practices which neglect that the economics of composting rely on externalities, such as reduced soil erosion, water contamination, climate change, and avoided disposal costs
- difficulties in securing finances since the revenue generated from the sale of compost will rarely cover processing, transportation and application costs
- "subsidies" may be required to maintain programs; these reflect the benefits that accrue beyond local governments, and avoided disposal costs are not adequately addressed
- sensible preoccupation by municipal authorities to first concentrate on providing adequate waste collection
- inadequate pathogen and weed seed suppression
- nuisance potential, such as odors and rats
- poor marketing experiences
- poor integration with the agricultural community
- perverse incentives such as fertilizer subsidies or over-emphasis on capital intensive projects
- land requirements are often minimal, but can be a constraint

Although developing countries in Asia have gained more experience in implementing composting than anaerobic digestion projects, MSW composting is not a problem-free solution either. Most commonly, composting systems have failed due to economic and technical reasons (Pandyaswargo et al, 2014). A 1990 survey conducted in Brazil discovered that 57 municipalities had composting facilities, of which only 18 were operating and 15 were under construction. The other 24 plants were closed as the result of operational or financial failures (Hoornweg et al, 2000).

Moreover, an evaluation of composting projects in West Africa pointed out that apart from being too expensive, a common problem leading to project failure is poor co-ordination among institutions and stakeholders due to weak institutional linkages and the lack of an enabling institutional framework, including clear legislation and policies (Cofie et al, 2006). Experiences from six composting stations of different scales of production in five countries in West-Africa showed that compost stations in the sub-region suffer from a number of omissions (Drechsel et al, 2005). Lack of thorough market analysis including consideration of alternative soil inputs; transport costs; user's demand as well as willingness and ability to pay for compost prior to station set-up; lack of supportive legal frameworks and institutional arrangement to implement composting initiatives are some of these.

Apparently, failures of compost plants are commonly experienced in developing countries irrespective of the region. Aforementioned examples illustrate that the causes for these failures can be different from each other according to the country or regional context.

2.2.Compost processing and technologies

Composting is defined as the biological decomposition of biodegradable SW under controlled predominantly aerobic conditions to a state that is sufficiently stable for nuisance-free storage and handling and is satisfactorily matured for safe use in agriculture (UNEP, 2005).Through composting, readily available nutrient and energy sources are transformed into carbon dioxide, water, and a complex form of organic matter; compost. The key parameters for the composting are the available carbon to nitrogen (C: N) ratio, moisture, oxygen, and temperature (Richard, 1993).

Composting being a microbial process, providing the right environment for microbes is vital for successful composting. Once the optimum physical conditions are established mesophilic organisms colonize the organic material and initiate the composting process. With the rising of temperatures in the compost piles, active phase of the process starts. In the active “thermophilic” phase, temperatures are high enough (55^{o}C for at least 72hrs) to kill pathogens and weed seeds and to break down phytotoxic compounds. During this phase, oxygen must be replenished through passive or forced aeration, or turning the compost pile. As the active composting phase subsides, temperatures gradually decline. The mesophilic microorganisms recolonize the pile, and the compost enters the curing phase (Cooperband, 2002). Figure 2.1 illustrates the temperature variation throughout the compost processing.

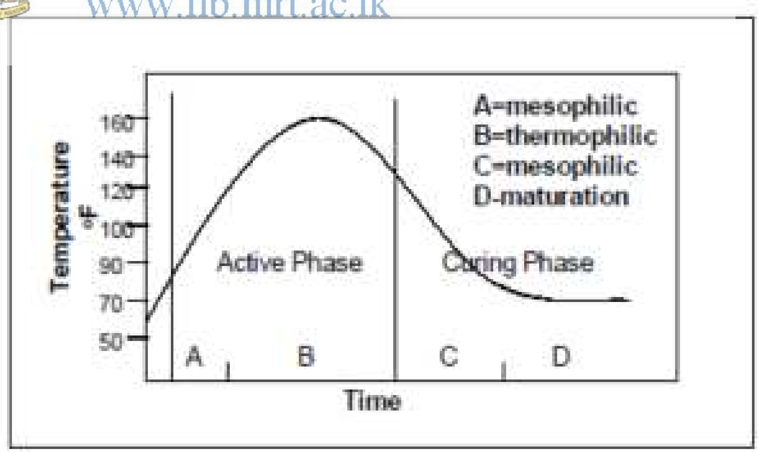

Figure 2.1: Temperature changes in an average compost pile

Composing occurs either aerobically (with oxygen) or anaerobically (without oxygen). However, aerobic composting is proven to be the most efficient form of decomposition, having produced the finished compost in the shortest time. When the favorable conditions are in place, which are proper amounts of food (carbon), nutrients, water and air, aerobic organisms will dominate the compost pile and decompose the raw organic materials most efficiently. Table 2.1 below lists the optimal conditions for rapid, aerobic composting.

Table 2.1: Optimal conditions for rapid, aerobic composting

Condition	Acceptable	Ideal
C:N ratios of combined feedstock	20: to 40: 1	25-35 : 1
Moisture content	40-65%	45-60% by weight
Available oxygen concentration	>5%	>10% or more
Feedstock	Particle size <1 inch	Variable
Bulk density	1000lbd/cu yd	1000lbd/cu yd
pH	5.5-9.0	6.5-8.0
Temperature	43-66 °C	54-60 °C

(Adopted from Rynk, 1992)

In general, mature compost should meet the following parameters to ensure that it is stable:

- should have a C/N ratio of less than 22 to be safe for agricultural use
- should not re-heat over 20 °C upon standing
- should reduce volume of raw organic material by at least 60 %

There are various technologies available for composting. Which composting system is the most appropriate however has to be decided based on its technological feasibility, economic costs, and social and environmental impacts within the given environment. Composting is site specific. Widely applied composting technologies can be given as;

- Static piles
- Windrow composting
- Passively aerated windrows
- Forces aeration, static piles
- Enclosed, or in-vessel, composting
- vermi-composting

Table 2.2: Overview of composting Technologies

Type of composting technology	**Description**
Static Piles	Simplest form of composting and require little management and equipment. Once established, it is very difficult to adjust moisture, and static piles tend to go anaerobic in the center. Aerobic conditions can be achieved if the initial pile porosity is high (>60%) and there is a high proportion of bulking materials. While simple, this method takes the longest to produce finished compost, and the composted material can be quite heterogeneous.
Windrow Composting	Windrow is the general term for an elongated pile of stacked raw materials. Piles need to be small and porous enough for air to pass through them over a long period of time. Turning remixes the materials, allowing all the raw materials to be colonized by microorganisms in the warmer, more active internal part of the pile. Oxygen is reintroduced, heat, water vapor and gases escape. The most important part of turning the pile is the reestablishment of porosity and the ability of air to get into the pile.
passively aerated windrows (PAWS)	This method includes perforated pipes placed at the base of each windrow to promote convective airflow throughout the pile. The key to this system is thorough premixing of feed stocks before placing on the perforated pipes. Also, windrows need to be insulated with finished compost to ensure thermophilic temperatures reach the outer edges of the windrow.
forced aeration,	Similar to PAWS piles, but blowers are installed at the ends of perforated pipes or air ducts. Air flow can be adjusted by changing the frequency

static piles	and duration of the blower. Usually, blowers are set to turn on when the compost reaches a maximum temperature (e.g., 150°F).
enclosed, or in-vessel, composting	Mainly for the commercial compost producer who needs more environmental control during the process. Some large scale composting operations use completely enclosed in-vessel equipment to achieve maximum control of temperature, oxygen and moisture. Some farms have also successfully used the smaller, less expensive bin equipment. Equipment ranges from a simple enclosed bin, an agitated bin or reactor, to an entire building devoted to composting.
Vermi-composting	Worm composting; in which red worms transform decaying organic matter into worm castings. The castings contain high concentrations of readily available nutrients for plants. Does not achieve the high temperatures in windrow and aerated static pile composting because the worms can't survive the high temperatures. However, research has shown that both pathogens and weed seeds can be destroyed in vermicomposting. Usually done in containers and can be done indoors and outdoors, allowing year round composting.

Source: Cooperband, 2002

2.3. Compost Markets and product quality

Marketing is an extremely important part of any sustainable composting project. One of the main problems faced by composters is in finding, stimulating or establishing a market for compost, and lack of market is one of the main reasons for the bankruptcy of composting plants (Ali, 2004). Studies conducted in India have revealed that because marketing approaches are rarely applied, many composting businesses have failed to realize their potential (Richardson, 2002).

Comprehensively planned composting stations based on a demand-supply analysis are hardly found. Most composting projects are not financially viable, especially when outside funding available for the initial set up is exhausted(Cofie et al, 2006). Thus it’s of importance to carry out a comprehensive feasibility study before setting up any composting project.

According to Rouse et al (2008), composting can be approached in two main ways.

1. The SWM approach, wherein composting is a way of treating organic waste within the SWM system. Compost is seen as a by-product.
2. The marketing approach, wherein composting is a way of producing a valuable product that can be sold. Compost is the core of all activities.

The marketing approach focuses on producing and selling a high-quality product. In contrast to the SWM approach, it is driven more by customer demand than material supply. However, a successful marketing approach to composting will usually result in all SWM objectives being met.

Revenue from sales of compost is particularly important in low and middle-income countries where subsidy and tipping fees are much less readily available than in Europe or the United States (Rouse et al, 2008). Compost is currently used by a wide range of end users, including commercial industries (e.g., agriculture, landscaping horticulture, and silviculture), public agencies, and private citizens. There is great potential for expanding these end-use markets. To market compost successfully, the compost must be available at the appropriate time of year, be consistent in composition and nutrient content, contain low levels of potentially toxic substances, and be offered at a low cost (USEPA, 1994). Detailed market surveys could be done to identify how a large share of the agricultural sector could be encouraged to use compost both at the state, national level and international level (Agbesola, 2013).

One of the major barriers in marketing compost is the subsidy imposed on chemical fertilizer. Chemical fertilizers are typically sold at a subsidized price, so in the medium to long-term such subsidies should be reduced to create a more level playing field for compost. A co-marketing policy for compost with chemical fertilizers would make compost more competitive in the agricultural market (ADB, 2011).In Sri Lanka, the central government spends around $400 million/year subsidizing fertilizer for rice production alone, and it has determined that the use of quality composts from urban organic wastes can reduce fertilizer use in rice production by 25% (ADB, 2011).

When compost is sold as a commercial product quality also becomes an important factor and the fact that compost quality standards are absent in many developing countries may inhibit the commercial status and sale (Ali, 2004). Quality of the finished product, i.e. compost is highly depending on the quality of the waste input. Low contaminant levels are essential, if MSW composting is to live up to its potential and recycle organic waste (ADB, 2011). Hence, it is vital to prevent waste contamination as much as possible during the waste collection process which may compromise the quality of compost in event of contaminated waste inputs. Moreover, source separating the MSW before collection is usually an environmentally and technically better way to improve the quality of the final compost (Dadi et al, 2012).

MSW composting, although often considered to produce lower quality products due to the unsorted feedstock, has produced composts that meet relatively stringent quality standards (USEPA, 1999).Many countries are now beginning to routinely publish compost guidelines with implied standards. Portions of these guidelines are required by certain laws; others are obscure (Brinton, 2000). However, compost quality standards should be stringent and enforced to protect public health and safety, and to increase confidence and demand among farmers. A quality control system needs to be put in place for producers, and producers should have their compost regularly tested at accredited laboratories. The results should be sent to agriculture agencies prior to marketing (ADB, 2011)

2.4.Health and safety aspects of compost

Composting is increasingly promoted as an effective and beneficial technology for processing compostable organic materials into a range of recycled organics products, thereby diverting valuable materials from disposal in landfill. However, the nature of composting as a process of biological transformation has led to increased recognition of potential health risks for compost facility employees (ROU, 2007).

Employees of composting operations can be exposed to a number of hazards due to the nature of waste handling. Hazards include pathogens, bio aerosols, toxic chemical substances in the air and materials, heavy metals in feed stocks and composts, and dust generated during feedstock preparation and composting (ROU, 2007). Any activity of the composting process can result in the emission of microorganisms to the air. Table 2.3 indicates the varying levels of exposure to components of organic dusts (including bio aerosols) that can occur at a composting facility during different activities.

Table 2.3: Results of parameters completed on personal samples* for various activities at a garden organics composting facility in Canada

Activity	**Dust (mg m^{-3})**	**Airborne bacteria & fungi (CFU m^{-3})**	**Viable thermophilic fungi (CFU m-3)**	**Speciation for Aspergillus fumigatus (CFU m-3)**	**Viable respirable gram negative bacteria (CFU m-3)**	**Endotoxin (g m-3)**
Debagging (raw feedstock)	0.58	5900	800	800	124	0.047
Turning active windrows	0.11	25100	7800	7800	1599	0.0017
Processing curing compost	1.15	137700	7300	7300	327	0.019
Shipping finished compost	0.12	700	362	362	415	<0.00019
* Personal samples were obtained from air collected on the person completing the various sampling activities						

(Source: van der Werf, 1996).

Simple health and safety protection measures can be taken to mitigate many of these health hazards by reducing the possible transmission pathways through the use of protective clothing. Compost workers should be equipped with rubber boots, work gloves, and mouth & nose masks to ensure protection. In composting plants, particularly where co-composting techniques are utilized, the regular monitoring of the final compost product is required to ensure that any pathogens present are inactivated during the decomposition process. (cofie et al, 2006).

Recycled organic unit of the University of New South Wales (2004) states key strategies that can be implemented at a composting facility to reduce employee exposure to bio aerosols and associated health risks as follows:

- **Induction for new employees** – share responsibility with employees by requiring them to follow procedures, report any symptoms and engage in regular medical checkups.
- **Monitor the workforce for respiratory illness** – this may include annual examinations by a medical practitioner or 'Lung Bus' on-site screening by the Workers Compensation Dust Diseases Board.
- **Implement and support procedures that minimize exposure** – ultimately reduce the amount of exposure to bio aerosols of all employees and employ strategies to prevent exposure altogether.
- **Make medical check-ups regularly available** – if staff present with symptoms such as dry coughing and shortness of breath (that gets progressively worse), send them to see a respiratory physician and act to minimize their exposure until advice is received from the doctor.

3. RESEARCH METHODOLOGY

3.1. Sample selection

According to the latest figures, daily waste collection by LAs is estimated as 2500T, of which the Western Provincial Council accounts for 60%. In addition to the Colombo MC which is having a SW collection of 680T/day, Western province (WP) has six MCs with a waste collection greater than 100 t/day and three MCs between 50-100 t/day. Considering the enormous amount of SW to be managed by the WP, this research was more focused on assessing composting practices within the western province.

Out of the 48 administrative LAs within the WP, only 24LAs are currently practicing MSW composting covering Colombo, Kaluthra and Gampaha districts. The stratified random sampling was carried out representing large and medium scale plants and geographical locations of the facility. Based on these two selection criteria five compost plants were selected representing 20% of the total compost plants in WP. If a composting facility has a capacity of receiving more than 10T to 20T per day of SW, that facility was considered as a medium scale plant where as plants having more than 20T per day of capacity were considered as large scale plants. Table 3.1 illustrates the background of the selected sample.

Table3.1: Selected Compost plants for the Study

	Location of the Selected compost plant	Waste qty (ton/day)	Type of the composting facility	District	Established year
1	Negombo MC	10	Medium	Gampaha	
2	Kaduwela MC	20	Large	Colombo	2007
3	Kalutara UC	28	Large- cluster based	Kalutara	2011
4	Bulathsinhala PS	10	Medium	Kalutara	2008
5	Attanagalle PS	13	Medium	Gampaha	2006

3.2. Questionnaire survey

A field survey was carried out covering the selected compost plants to gather data by means of a semi-structured questionnaires (appendix A) and stakeholder interviews. Questionnaire was prepared focusing operational aspects which were to be analysed eventually as an integrated approach towards effectiveness of each plants.

Formal and informal discussions were conducted with key informants, officers in charge of compost plants, Public Health inspectors (PHIs), supervisors and workers of the compost plants and the people living in the close vicinity of the compost plants etc. During these discussions data available on waste supply, composting process, final quality of the product and resources allocated by the LAs for the compost plants were collected.

3.3. Defining criteria for evaluating effectiveness of compost plants

In this study effectiveness of a compost plant is attributed to waste input and the quality of the final product. In order to analyse the effectiveness of compost plants different criteria were identified with respect to aforementioned aspects. Table 3.2 depicts a brief summary of the criteria identified related to effectiveness of a compost plant.

Table3. 2: Criteria of operational aspects to evaluate effectiveness of a compost plant

Operational aspect	**criteria**	**Description**
Waste supply	Percentage of waste composted at the plant	In general, Sri Lanka's waste streams comprise of high levels of compostable matters. According to the past studies on waste composition analysis, more than 60% of the waste is biodegradable. At present the common practice is to bring the mixed waste to the compost plant and then segregate. Hence theoretically, about 60% of the waste is expected to be processed as compost.

		Under this indicator the actual quantity of SW composted as a percentage of the design capacity of the plant was analysed. This gives an idea about the optimum utilization of the compost plant in terms of better managing SW. The values were obtained during field survey and represented as a percentage.
Quality of compost	Quality analysis of compost	Composting cycle occurs properly when the process parameters meet the optimum requirements. Under this indicator physical and chemical parameters that envisage the effectiveness of composting process were assessed to understand whether the composting process has been carried out effectively. Physico-chemical parameters such as pH, moisture content, electrical conductivity (EC), organic carbon content and C: N ratio were assessed against the acceptable ranges to evaluate whether the final product meets the required standards. Additionally percentage of sand content was also compared with the acceptable range to evaluate the final quality of the product. Compost quality data which were already available at the waste management authority of the Western Province (WMA) were utilized for the aforementioned analysis

Above criteria were evaluated for each compost plant using the data collected during filed visits and the stakeholder interviews. Overall effectiveness of the compost plants were determined based on the above parameters.

4. RESULTS AND DISCUSSION

4.1.Waste generation, collection and management at the LAs

Solid waste management (SWM) is a key activity of LAs. Generally, public health unit of a LA is responsible for the SWM activities at MC and UC level whereas at PS level it is vested upon environmental officers. Waste collection is an obligatory service provided by the LAs according to a routine collection plan set up by them. Table 4.1 depicts the amounts of daily waste generation, collection and management at each LA considered in this study. Waste generation amounts were calculated using per capita generation rates estimated as on the average 0.75 kg in MCs, 0.60 in UCs and 0.4 kg in PSs (Asian Institute of Technology, 2004).Waste collection coverage denotes how much SW is collected out of the SW generated within a given LA territory. In Kalutara UC the waste collection amounts appeared to be higher than the waste generation. This could be due to the fact that the waste contributed by high floating population caused by urbanization and tourism in the area has not been accounted while estimating the waste generated figures. Thus the collected amounts give a higher value than the generated amounts.

When SWM by each LA is considered, Kalutara UC shows remarkably high achievement, by better managing 76% of their waste collected through composting (50%) and recycling (26%). On the contrary, Negombo MC and AttanagallaPShave72%and 84% of their collected waste disposed at open dumps implying that a large percentage of SW collected is not managed well by the respective LAs (figure 4.1).Even though both these LAs have their own compost plants, they are not sufficient in bringing a total solution for the SWM at these LAs.

Table 4.1: SW generation, collection, and management at LAs

Name of the LA	SW generated (T/ day)	SW collected (T/day)	Waste collection coverage	Total SW directed to the Compost Plant (T /day)	Organic waste processed at the Compost Plant (T/ day)	SW directed to the open dumps (T/day)	Recyclable Waste Collected (T /day)	% (organic waste/ total waste collected)	% (recyclable / total waste collected)	% (SW directed to the open dump/ total waste collected)
Negombo MC	106.1	75.0	71%	10.0	10.0	53.8	11.3	13%	15%	72%
Kaduwela MC	188.0	75.0	40%	40.0	25.0	35.0	15.0	33%	20%	47%
Kalutara UC	24.3	31.0	128%	31.0	15.5	7.5	8.0	50%	26%	24%
Bulathsinghala PS	28.8	9.0	31%	9.0	2.5	4.3	2.3	28%	25%	48%
Attanagalla PS	79.3	21.4	27%	4.0	2.8	18.0	0.6	13%	3%	84%

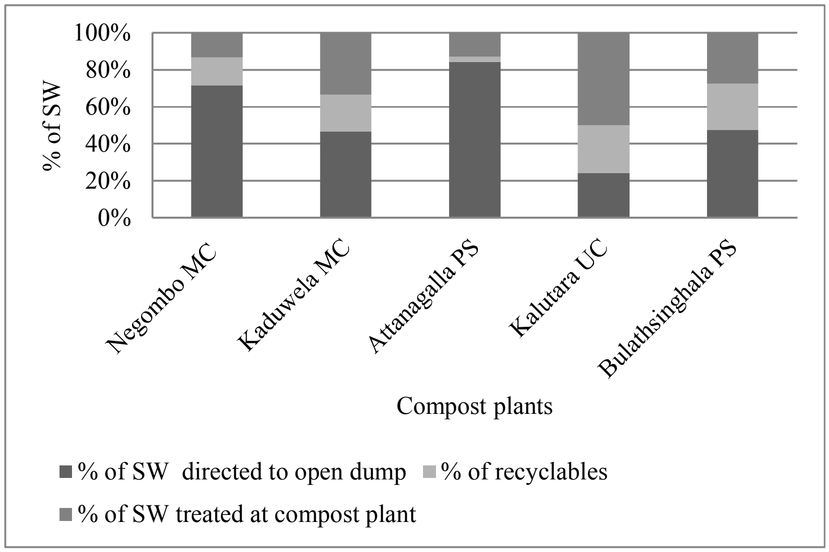

Figure 4.1: Solid waste management at LAs

4.2.Waste supply and management at the compost plants

Principally, compost plants are designed to cater a certain waste input. Capacities of compost plants are generally given in terms of waste supply at the plant. However, the amount of waste supply at the plant may often be different from the design capacity of the plant. These discrepancies may be due to the poor understanding of waste collection patterns at the design stage. Optimum operation of the compost plant depends on its capacity to manage the waste supplied at the plant. Higher or lower waste supply beyond the design capacity may hinder the optimum operation of the plant.

At present, waste segregation is not a common practice in the country. Thus waste is collected as mixed waste and segregated after it is brought to the compost plant. Sorted out organic waste is processed as compost while recyclables are stored separately. Wastes that can neither be composted nor recycled are directed to the open dump which is normally located adjacent to the compost plant. According to the national data bases, more than 60% of the SW is biodegradable. Hence, the proportion of waste composted at the plants is expected to be higher. Nevertheless, due to reasons such as lack of resources, technical expertise and interest, direct open dumping is preferred over composting at majority of plants, despite their capacities to manage total waste received. Table 4.2 gives details of design capacities of the plants, current waste supply and the actual percentage of waste composted.

Table 4.2: Design capacities of the compost plants, current waste supply and actual waste composted

Compost plant	Design capacity (T/day)	Current waste supply at the plant (T/day)	Actual amount of SW composted (T/day)	SW composted as a % of design capacity
Negombo MC	10	10.0	10	100%
Kaduwela MC	20	40.0	25	125%
Kalutara UC	28	31.0	15.5	55%
Bulathsinghala PS	10	9.0	2.5	25%
Attanagalla PS	13	4.0	2.8	22%

According to table 4.2, percentage of SW composted at each plant varies drastically. Noticeably, Negombo MC composts 100% of SW supplied at the plant. The reason behind this is that the plant receives only market waste which is totally compostable and minimal with non-degradable matter. At all the other plants, except Negombo, SW is supplied as mixed waste. Hence the common practice at these plants is to segregate mixed waste manually. Evidently, manual separation is a labour intensive process which increases the cost of operation of the compost plant. It also decreases the resource recovery potential and the quality of compost due to contamination of waste.

It can be highlighted that although Kaduwela plant is designed to cater 20 tonnes/ day, its current waste supply is about 40 tonnes/ day. Out of that 25 tonnes is directed for composting. Consequently this shows 125% of waste is composted compared to its design capacity. However, during the field inspections it was observed that composting is hardly practiced at the plant; instead, the current practice is to pile up SW into large heaps and to leave for decomposition merely to reduce the disposal quantities at the open dump.

Kalutara plant manages to compost 55% of SW in terms of its design capacity. This can be considered as a remarkable achievement for a large scale compost plant. On the other hand, SW composted at Bulathsinhala and Attanagalla plants are substantially low. Hence, both these plants are currently underutilized. Lack of institutional capacity is a major reason for such poor performance of these plants.

Figure 4.2 shows the current waste treatment scenario atthe compost plants against their design capacities.

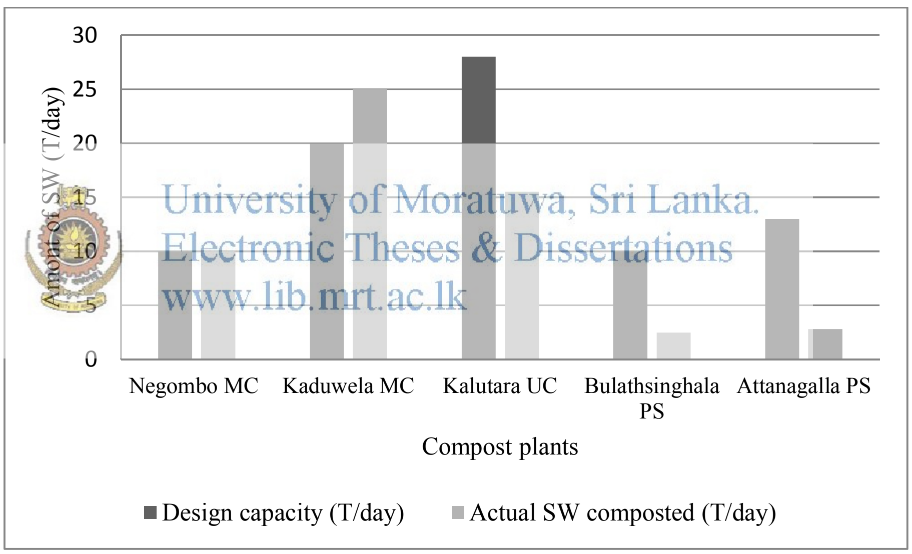

Figure 4.2: SW management at compost plants

4.3.Quality of compost

Although waste is expected to be transformed into compost at the plant, it cannot be considered as 'compost' unless the final product achieves the required product quality. The efficiency of composting process depends on factors such as nutrient balance, temperature, pH, electrical conductivity and moisture content. It is of paramount importance to maintain the optimum operational conditions in order to achieve the required quality.

Almost all the compost plants in Sri Lanka follow the same technology which is windrow composting. Turning of the windrows is carried out by skid steer loader at large scale plants, while medium scale plants practice manual turning. It was observed that turning of the piles at every plant is generally carried out seven day intervals until it reaches the maturation phase.

In this study, physico-chemical parameters such as pH, moisture content, electrical conductivity (EC), organic carbon and C: N ratio that are required to optimize the windrow process were evaluated in order to determine the final product achieved the required quality. These parameters were essentially the quality parameters of compost that were obtained at the end of the composting cycle. In addition, sand content was also compared against the permissible levels. Heavy metal contamination is a major concern in composts produced from MSW. A regular monitoring of heavy metals is necessary as application of compost may lead to the accumulation of heavy metals in soil surface. Heavy metals that are specified for organic fertilizers by Sri Lanka standard Institute (SLSI) were analysed and compared against the permissible levels. The specified heavy metals were Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (pb), Mercury (Hg), Nickel (Ni) and Zinc (Zn).

To determine the effectiveness of composting process, aforementioned parameters need to be checked at regular time intervals. Presently, regulative authorities in Sri Lanka recommend monitoring of physico-chemical parameters at a monthly basis and heavy metals at yearly basis. However, at present, compost quality testing is not carried out at frequent time intervals due to financial constraints of LAs. Instead quality is checked at random intervals.

The quality testing of the selected compost plants have been carried out at similar time period and therefore they are comparable with each other. Moreover, data available on heavy metals content of each plant were compared against standard permissible levels to determine heavy metal contaminations.

4.3.1. Moisture content

Moisture content is a key parameter for effective composting. It is critical to maintain an optimum level since microbial activity highly depends on the moisture content. Microbial activity is retarded at low moisture levels whereas at higher levels, the process is likely to become anaerobic generating a foul-smell. Excess leachate may also be produced if the moisture content is too high. Ideally, piles should contain 40to 60% moisture during the composting process. At the maturation phase moisture content should gradually decreases to 20 to 30%.Figure 4.3 depicts the moisture levels of the final compost product obtained at each compost plant during different time periods.

It can be seen that compost produced at Negombo plant mostly has higher moisture content than the acceptable limits whereas Kalutara plant produces compost with low moisture content. Only Bulathsinhala plant has been able to maintain the moisture content of the final compost product at the acceptable levels. Compost from Kaduwela and Attanagalla plant also satisfy the permissible levels when the average values are considered. Proper monitoring mechanisms are essential to maintain the optimum moisture content throughout the composting process and at the end of the maturation phase. However, it is important to note that moisture content of compost is often affected by the external weather conditions of the area.

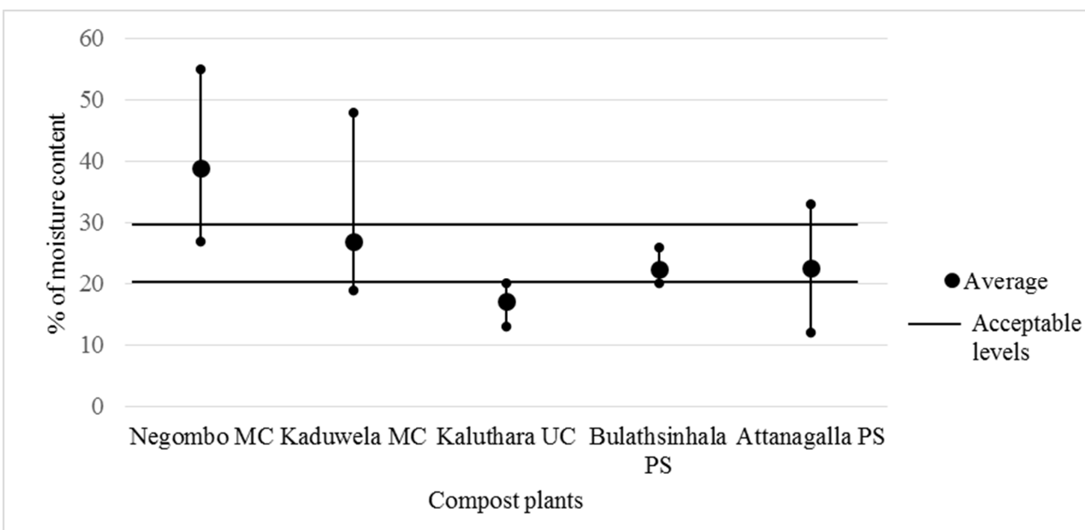

Figure 4.3: Moisture content of final compost product

4.3.2. Sand content

SLSI standards for organic fertilizers specify that’s and content of a final product has to be less than 10%. According to figure 4.4, compost produced by the selected plants does not maintain the permissible level. Main reason for high content of sand in the compost is due to waste collection patterns practiced by the LAs where all types of MSW are mixed with street sweeping waste which contributes to a substantial amount of sand. If street sweepings are collected separately, sand mixing with the compostable waste materials could be avoided and permissible sand level could be achieved. It was observed that poor financial status of the LAs has become a barrier in facilitating the additional requirements to deploy a separate waste collection arrangement for the street sweeping waste.

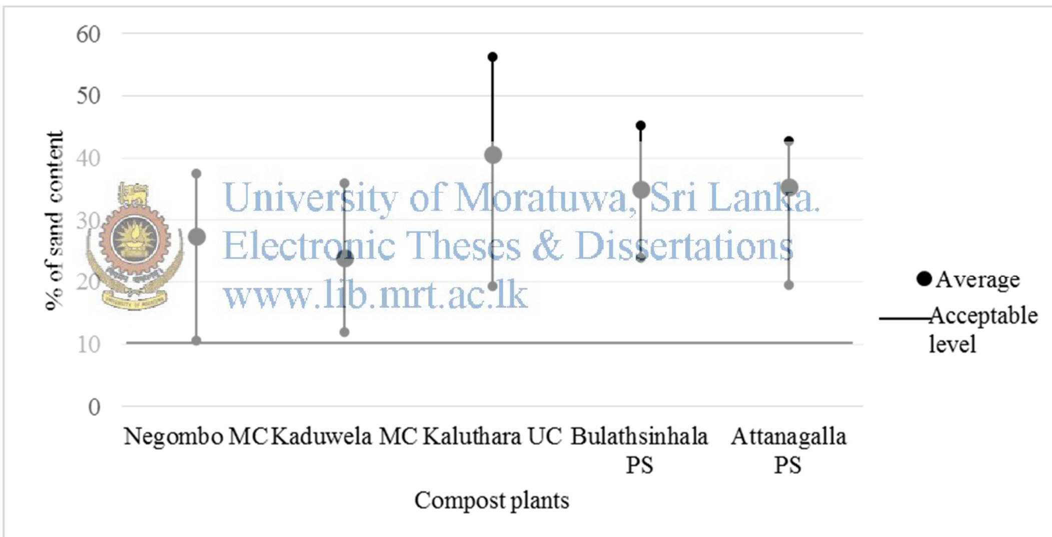

Figure 4.4: Sand content of final compost product

4.3.3. pH

The pH value of compost can be considered as an indicator for the process of decomposition and stabilization (Pathak et al, 2012).The pH level of composting mass usually drops at the beginning of composting process due to the synthesis of organic acids and begins to rise with the utilization of acids by the microbes.

According to previous studies, microbial decomposition of organic materials is more effective at pH values between 6.5 and 8.5 during the composting process and the microbial activity may be inhibited at values beyond the above range. Generally final compost product also should have pH values between 6.5 and 8.5. According to the data presented in figure 4.5, it is observed that maximum values of pH in compost produced at Kaduwela and Kalutara plants have slightly exceeded the upper standard limit of pH. However, since these deviations are marginal, it can be considered that every plant has been able to maintain the pH between the given effective range.

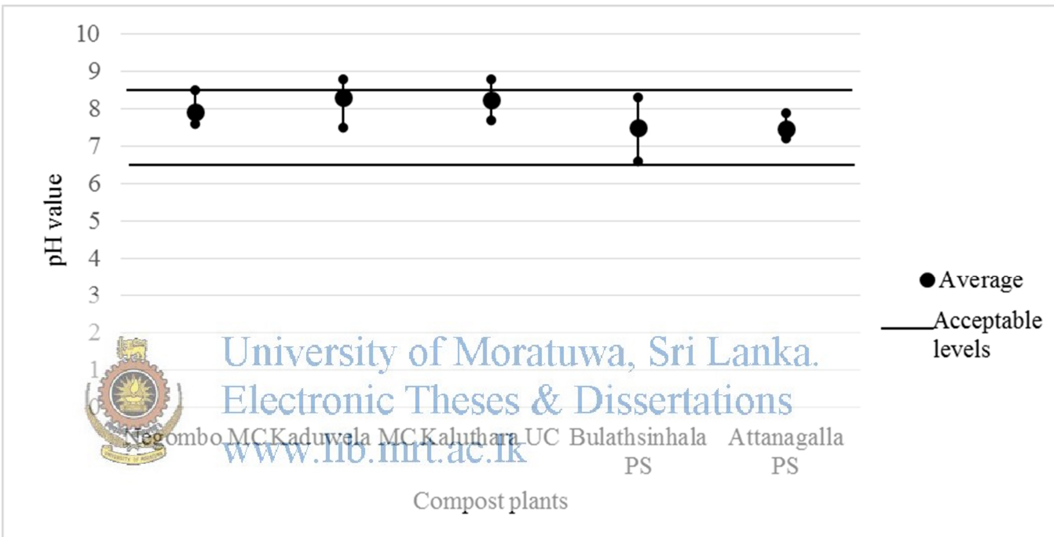

Figure 4.5: pH of final compost product

4.3.4. Organic Carbon

In general, organic carbon content decreases throughout the composting cycle due to decomposition. Part of the carbon evolves as CO_2 and a part is assimilated by the microbial biomass (Shyamala and Belagali, 2012). However during the maturity stage compost contains about 20 to 35% of organic carbon. It was observed that the average values of organic carbon content obtained for composts from Negombo, Kalutara, Attanagalla and Bulathsinhala plants are within the acceptable range (figure 4.6). On the other hand, final product at Kaduwela plant on an average show higher values of organic carbon than the acceptable levels. This is due to incomplete decomposition of waste at the plant where its main aim is merely waste reduction and not composting. This reflects poor performance of waste treatment at Kaduwela plant.

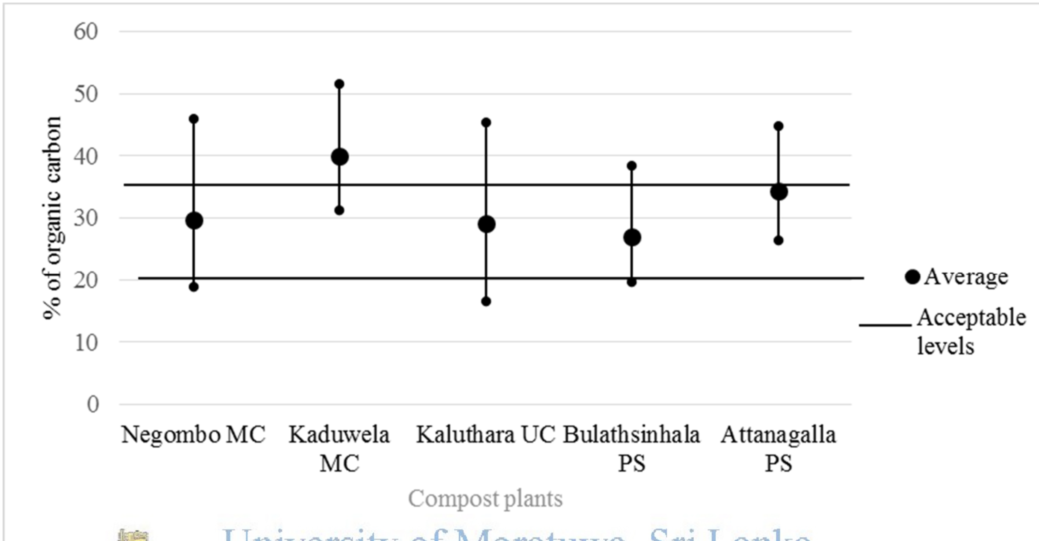

Figure 4.6: Organic carbon of final compost product

4.3.5. Electrical Conductivity

Electrical conductivity (EC) is an indirect measurement of soluble salts of a compost sample. This can be used as an indicator of the compost stability. EC affects the quality of composts significantly as it reflects their salinity and suitability for crop growth. The concentration of salts will change due to the release of salts from the organic matter as it degrades volatilization of ammonia, decomposition of soluble organics, and conversion of molecular structure. Permissible level of EC in matured compost is between 0.5 to 3 ds/m. Maintaining EC of final compost product at this range is important since high salt concentration in MSW compost can inhibit the seed germination when compost is used as a fertilizer or soil conditioner. Figure 4.7 depicts the variation of EC in different compost samples obtained from identified compost plant.

When average EC values are considered, the composts from Negombo and Kalutara plants have met the required standard of EC in their final product whereas the compost samples in all the other plants have exceeded the permissible levels. These high values of EC could be attributed to the incomplete decomposition of organic matter at the time of sampling. However, EC levels in compost can also vary considerably, depending on feedstock.

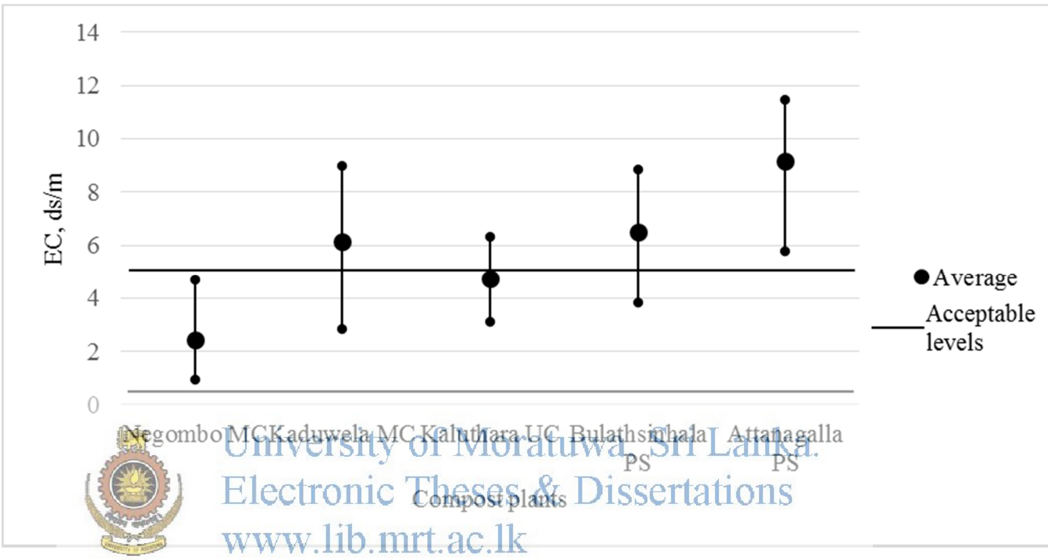

Figure 4.7: Electrical conductivity of final compost product

4.3.6. C: N ratio

C/N ratio is one of the most important parameters that determine the extent of composting and degree of compost maturity (Shyamala and Belagali, 2012). For best performance, composting microorganisms require the correct proportion of carbon and nitrogen. Carbon serves as an energy source for the microorganisms, while nitrogen is critical for microbial population growth, as it is a constituent of protein. Principally at the completion of composting process, final product should indicate a C: N ratio between 20 and 30. Decreased C: N ratio implies the transformation of organic carbon into carbon dioxide, followed by a reduction in the organic acid content. According to figure 4.8, except Bulathsinhala plant, all the other compost plants have maintained the C: N ratios of composts within the acceptable range.

A sample collected from Bulathsinhala plant shows a very high C: N ratio which has led its average value to deviate from the acceptable limits. This could be due to the fact that the sample was not representative and mostly comprised of high carbon materials such as market waste. It is essential to maintain the proper C: N ratio from the beginning of the composting. An unfavourably high C: N can be lowered by adding a nitrogenous waste to the compost feedstock such as manure, clean sewage sludge (bio-solids), septage and urea. On the contrary, a carbonaceous waste such as vegetable waste can be used to elevate a low C: N.

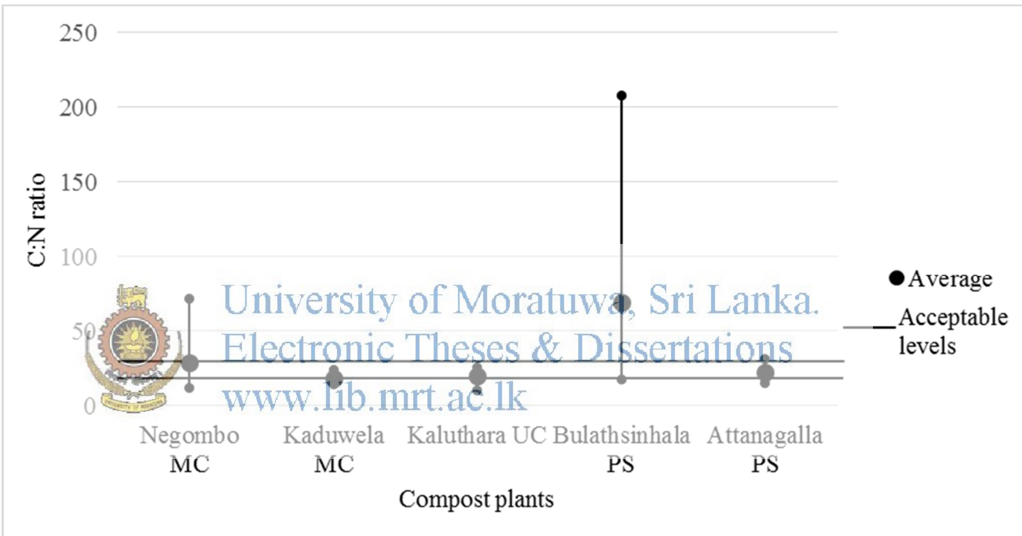

Figure 4.8: Analysis of C: N ratio of final compost product

4.3.7. Heavy metals content

Compost has not yet widely been utilized as a fertilizer in agricultural applications across the country. One of the main reasons for this is the concerns about safety and quality of compost made from organic urban waste. Heavy metals appear in the SW stream from various sources. Batteries, consumer electronics, ceramics, light bulbs, lead foils and inks etc can introduce metal contaminants into the SW stream. Composts made from SW collected as mixed waste, can possibly contain heavy metals containing materials, even after most of those are removed during segregation. Heavy metals present in compost may adversely affect plant growth, soil organisms, water quality, and animal and human health. Therefore it is of utmost important to analyse the contamination levels of compost in order to convince the public about utilizing it as a fertilizer. Table 4.3 gives the permissible levels of heavy metals recommended for organic fertilizer in Sri Lankan context.

Table 4.3: Permissible levels of heavy metal concentrations in compost

Heavy metal	Maximum acceptable limit, ppm
Cd	10
Cr	1000
Cu	400
Pb	250
Hg	2
Ni	100
Zn	1000

In this study, samples from the selected compost plants were analysed and compared with the acceptable levels shown in the table 4.3. Figure 4.9 to 4.14 show the results of heavy metal levels in two compost samples obtained from the selected compost plants and their permissible levels.

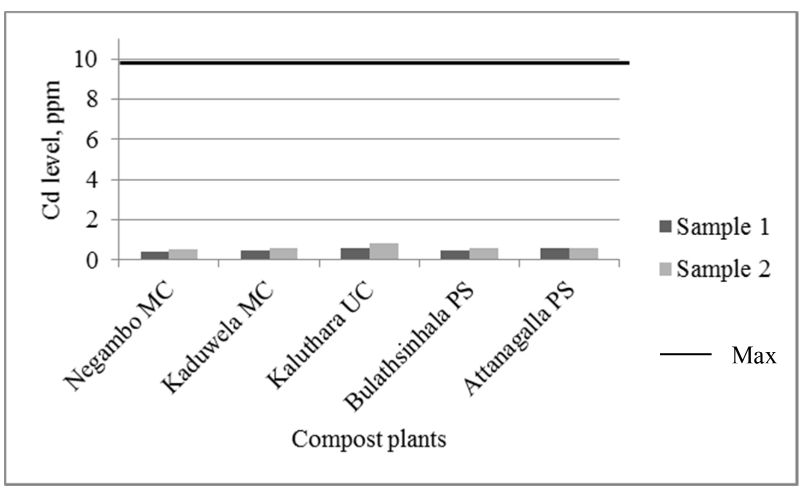

Figure 4.9: Cd levels of final compost product

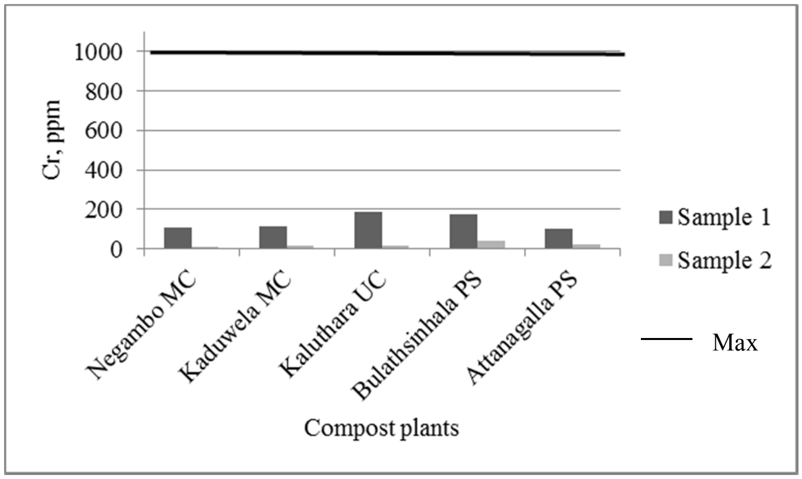

Figure 4.10: Cr levels of final compost product

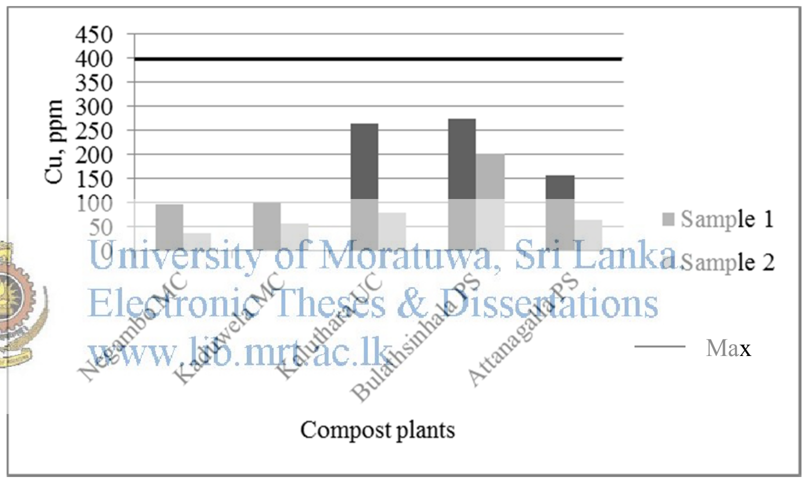

Figure 4.11: Cu levels of final compost product

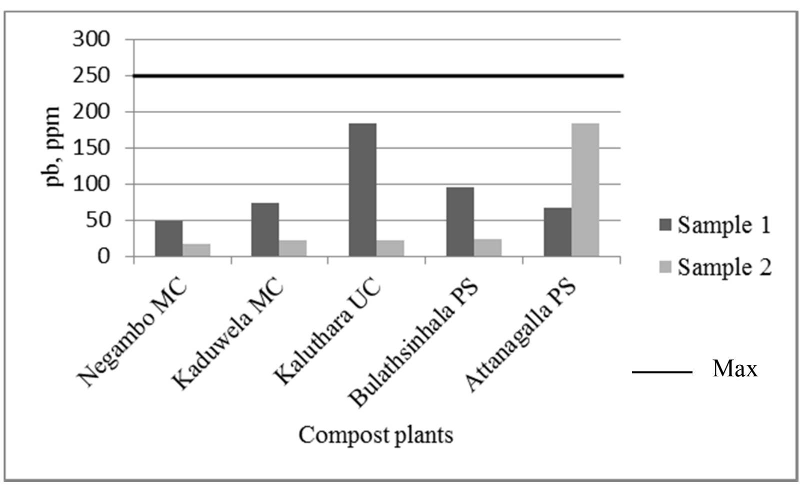

Figure 4.12: pb levels of final compost product

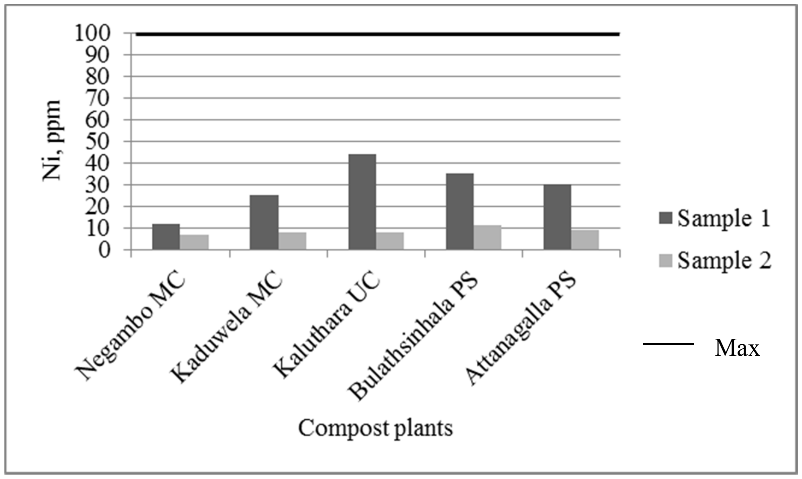

Figure 4.13: Ni levels of final compost product

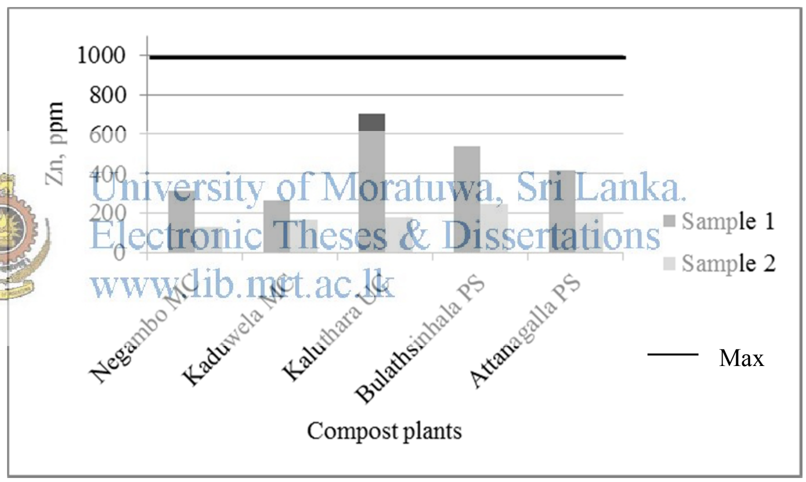

Figure 4.14: Zn levels of final compost product

Compost from any of the compost plants selected have not shown the presence of Hg. According to figures 4.9 to 4.14, it is observed that the levels of all the other heavy metals considered under this study, namely, Cd, Cr, Cu, Pb, Ni and Zn were also below the permissible levels. This implies that there was no risk of heavy metal contamination of the compost produced at these plants. The reason behind this could be the proper removal of potential heavy metal containments during sorting.

4.4.Overall effectiveness of compost plants

In this study, the effectiveness of compost plants was evaluated in two criteria namely waste supply and compost quality. Under the first criterion effective operating level of the plants was evaluated in terms of their design capacities while second criterion was focused on final compost product quality. Compost quality is difficult to assess from a single character, thus more characteristics should be taken into account. Consequently, quality of compost was analysed considering various parameters such as moisture content, sand content, pH, organic carbon, EC, C: N ratio and heavy metals specified under the SLS standards. Table 4.4 gives a summary of overall evaluation compost plants combining the results obtained under each criterion.

Table 4.4: Overall effectiveness of compost plants related to operational aspects

Name of the compost plant	Waste supply	Quality of compost						
	% of SW composted	Moisture content	Sand content	pH	Organic carbon	EC	C:N ratio	Heavy metals
Negombo MC	√	-	-	√	√	√	√	√
Kaduwela MC	-	√	-	√	-	-	√	√
Kalutara UC	√	-	-	√	√	√	√	√
Bulathsinhala PS	-	√	-	√	√	-	-	√
Attanagalla PS	-	√	-	√	√	-	√	√

In principle, 60% of SW supplied at the plants is expected to be composted. However, as depicted in table 4.4, only Negombo and Kalutara plants have satisfied this operating level. Both Bulathsinhala and Attanagalla plants currently process much lower proportions of SW towards composting, thus are underutilized. Kaduwela plant is over utilized and not following proper composting practices.

When the quality of the final product is considered, compost produced at none of the plants has been able to meet the right quality in overall. Remarkably, in every plant, sand contents of compost samples have always been much greater than the permissible level. However, composts from Negombo and Kalutara plants indicate better quality compared to the other three plants.

With the integration of all the results, it can be considered that Negombo and Kalutara plants are operating effectively in comparison with other compost plants. Nevertheless, adequate measures should still be implemented at both these plants to maintain the moisture content and sand content of compost within the permissible levels. Moisture content and sand content of the final product are physical requirements of the quality, thus does not require high technical expertise to implement corrective measures. Moisture content of the final product can be achieved by practicing careful monitoring mechanisms while sand content can be maintained if only segregated organic waste is used as compost feedstock.

5. CONCLUSIONS AND RECOMMENDATIONS

Composting is proven to be a viable solution to address the SWM issues the country is facing over many years. By diverting organic materials from land filling to, composting gives numerous environmental benefits. Composting also brings economic benefits by converting organic waste into a valuable resource. Assuring long run of compost plants is of utmost importance considering role of composting as a part of overall waste management system. However, with the past experience, it is well known that the failing of compost plants has been relatively common due to various reasons.

This research was conducted to evaluate the factors contributing to the effectiveness of compost plants and thereby to evaluate the current situation of five selected compost plants with regards to operational aspects. According to the results obtained, most of the plants appear to be ineffective in their operation. Only Negombo and Kalutara plant show promising results in terms of the operational aspects considered in this study. Lack of institutional capacity in terms of both technical expertise and finance is a major barrier for the effective operation in many cases. Worker's technical knowhow and proper supervision are vital for proper composting. It is of importance to educate and train workers to monitor process parameters at regular basis to maintain the optimum conditions for aerobic composting. Facilitating training programmes to transfer knowledge and good composting practices from successful plants to the other plants would be an appropriate mechanism in this regard.

In most of the LAs, the budget allocation on SWM is barely sufficient to meet the waste collection and transportation related costs. Therefore, a SWM activity beyond that level, for an example composting, is of less interest to most of the LAs. Implementing strategies to self-finance compost plants as much as possible through increasing compost sales would be a way forward. However, to succeed the compost market, compost should be of the right quality. Regular quality checking and monitoring is essential to ensure effective operation of compost plants. It is understood that frequent quality testing through a standard laboratory is an expensive process. Instead practical means that are indicative of the quality of compost such as conducting field tests at demonstrational farm plots can be proposed. This would consequently increase confidence and demand among farmers.

Except Negombo plant, SW is supplied as non-segregated waste at all the other plants. Mixed waste processing is a key constraint for the effectiveness of the compost plants. It increases the cost of operation of the plants and also is one of the reasons for the poor quality of compost. Source segregation can be promoted through community awareness and demonstrational initiatives. Strategies such as introducing a user collection fee for citizens who are not practicing waste segregation would be a strategic way to enforce such good practices.

It is advisable for LAs to explore strategies to ensure effective operation of the plants. The results of this research were intended to assist towards to gain understanding of the operational aspect that affect the effectiveness of compost plants.

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Appendix A: Questionnaire Survey

Assessment of sustainability of Compost plants in Sri Lanka

1. **General Information**

1.1. Name of Composting Facility: ……………………………..
1.2. When was the Compost Facility established:…………………………………..
1.3. What is the total design composting capacity (input)?.......................Tonnes /day
1.4. Funding Arrangement: ………………………………………………….
1.5. Capital cost: ……………………………………………………………

2. **Waste Supply Assessment:**

2.1. Population of the LA:………………………………. Persons / Families
2.2. Percentage of Population Covered by MSW Collection:…………………..%
2.3. Number of Days collection is carried out per week………………….Days
2.4. Total Weight of Mixed Waste **Collected** by the LA:…………Tonnes /Day
2.5. Weight of Mixed Waste **directed to the Composting Plant**:……Tonnes / Day
2.6. Weight of **Sorted Special Organic Waste directed to the Composting Plant**:
(Food & Market Waste / Bio Solids / Bulky Green Waste / Agricultural Waste / Animal Waste): ……………….…Tonnes / Day

2.7. Weight of **Residual Waste returned to the Landfill / Disposal** site after the Sorting: …………Tonnes/Day
2.8. Weight of **Recyclable Waste (Plastic/Glass/Paper/ Metal) Collected** by LA:
…………………..Tonnes / Day

2.9. Average Weight of Finished Compost Product: ……………. ………kg / Month

2.10. Describe current strategies and bottlenecks to waste segregation practices at household or plant.

……………………………………………………………………………

3. **Operation and Maintenance aspects:**

3.1. Please indicate the Composting Process: **Turned Windrow Composting Or** Any of the followings.
(**Inclined Step Grate (ISG) Composting Method / Trommel Method /** Passive Windrow Composting / Aerated Static Pile Composting / In-Vessel Composting / Wormy Composting)

3.2. Sorting of Mixed Waste

Number of days needed to sort the daily mixed Waste :……………….(Less than a Day/ One day / Two days / More than Two days)

3.3. Total Decomposition Period:……………………………..Weeks (8 – 10 weeks)

Average Maturation Period:…………………………Weeks (2 - 3 Weeks)

Average Period of Final Product Stored before the sale: …………Weeks

3.4. Turning the Composting Pile: (From the latest piles in decomposition stage at the Plant)

First Turning of the Pile: ……Days after(Manual/ Skid Steer Loader)

Second Turning of the Pile: ….Days after (Manual/ Skid Steer Loader)

Third Turning of the Pile: …………Weeks after(Manual/ Skid Steer Loader)

Fourth Turning of the Pile: …………Weeks after (Manual/ Skid Steer Loader)

Fifth Turning of the Pile:…………Weeks after (Manual/ Skid Steer Loader)

Sixth Turning of the Pile: …………Weeks after (Manual/ Skid Steer Loader)

Seventh Turning of the Pile: ………Weeks after (Manual/ Skid Steer Loader)

Eighth Turning of the Pile: …………Weeks after (Manual/ Skid Steer Loader)

Ninth Turning of the Pile: …………Weeks after (Manual/ Skid Steer Loader)

Tenth Turning of the Pile: …………Weeks after (Manual/ Skid Steer Loader

3.5. Value Addition:

Bio Solid Addition:…………………………………

Blending with Chemical Fertilizer:…………………..

Wormy Composting:……………………………...

3.6. Frequency of Process Failure:……………………..(Once in)

Reason for Past Failures.(e.g. Breakdown of Equipment / Holidays)

……………………………………………………………………………

…………………………………………………………………………..

3.7. Details of Monitoring Mechanism adopted

……………………………………………………………………………

…………………………………………………………………………

3.8. Details of Technological Modification / Enhancement / Improvement adopted

……………………………………………………………………………

……………………………………………………………………………

3.9. Potential Capacity of the Plant:…………………………tonnes / day
3.10. Current Operational Capacity of the Plant:…………… tonnes / day
3.11. Demand & Supply Difference:………………………….tonnes / month
3.12. Customer Segment as a percentage:

Individuals / Farmers:………………………….…
Government Subsidy Programmes:…………………..
Plantation Sector:……………………………………
Commercial Sector (Bulk Fertilizer)…… ………….
City Parks and Landscaping………………………..
Others………………………………………………..
Total: 100%

3.13. Market Strategies adopted

………………………………………………………………………………
………………………………………………………………………………

3.14. Average **monthly** Cost:

Operation Cost:
Salaries:……………………………………………(Rs)
Maintenance Cost (Equipment)::………..………..(Rs.)
Transport Cost (Fuel Cost)……………………….(Rs.)
Utility Cost…………………………………………(Rs.)
Any other Cost:……………………………………(Rs.)

Total Monthly Cost:……………………………….(Rs.)

3.15. Percentage of Operational Cost recovery:……………………%

3.16. Other opportunities such as urban development programs, home garden development programs

……………………………………………………..………………………..
………………………………………………………………………………

4. Institutional capacity

4.1. Resource Requirement:

Buildings
Under Cover Pilling:…………………….m2
Unloading & Sorting:..…………………..m2
Preparation & Store:..…………..……….m2

Facility Building (Rest room, Wash room & Toilets):.…………………..m2
Office:.……………………….m2
Watcher hut:.………………….m2

<u>Equipment</u>: Exclusively for the Composting Plant
Tractors:…………………………Nos
Skid Steer Loaders:……………...Nos (….tonne unit)
Screening machine………………Nos (….tonne unit)
Shredding machine……………...Nos (….tonne unit)
Sealing machine………………... Nos (….tonne unit)
Sawing machine………………… Nos (….tonne unit)
Weight Scale:………………………….unit

<u>Labourers</u>
Supervisor:………………..Person
Workers:…………………..Person
Security:…………………..Person
General absentees Percentage:……………..%

5.2. Details of the steps that council adopted to increase the capacity to cover the deficit, technical knowhow of the operators.

………………………………………………………………………………………
………………………………………………………………………………………

5.3. What are the institutional factors influences for the sustainability of the Plant and how those factors contribute for the continual improvement? (Views of the Mayor / Chairman / Commissioner / Secretary / Engineer / PHI / TO)

………………………………………………………………………………………
………………………………………………………………………………………

5.4. Description of the bottlenecks & the barriers met from different actors (eg: political) during implementation to present and strategies used to overcome

………………………………………………………………………………………
………………………………………………………………………………………

Appendix B: Requirements for compost products (Sri Lanka standard 1246:2003)

Category of requirements	Evaluation item	Acceptable Range	Method of test
Physical Requirements	1) Colour	Brown/ grey to dark black	
	2) Keeping properties	within 12 months from date of production	
	3) Moisture content	Less than 25% moisture by dry mass	
	4) Odour	no unpleasant odour	
	5) Particle size	Residue of not more than 2% by mass	
	6) Sand content	Not more than 10% sand contained	
Nutrient Requirements	1) pH	6.5 - 8.5	ISO 10390
	2) Organic carbon	20%	Walkley - Blak Method
	3) Nitrogen	1.0%	SLS 645: Part 1
	4) Phosphorus (P_2O_2)	0.5%	SLS 645: Part 5
	5) Potassium (K_2O)	1.0%	SLS 645: Part 4 Section 1
	6) Magnesium (Mg)	0.5%	SLS 645: Part 6
	7) Calcium (Ca)	0.7%	SLS 645: Part 6
Nutrient Requirements	1) Cadmium	10 ppm max	ISO 10390
	2) Chromium	1000 ppm max	Walkley - Blak Method
	3) Copper	400 ppm max	SLS 645: Part 1
	4) Lead	250 ppm max	SLS 645: Part 5
	5) Mercury	02 ppm max	SLS 645: Part 4 Section 1
	6) Nickel	100 ppm max	SLS 645: Part 6
	7) Zinc	1000 ppm max	SLS 645: Part 6

Biological requirements		Should not contain more than 16 viable need seed per 1 msq	
Micro biological requirements	1) Faecal coliforms per g	Free	SLS 516: Part 3
	2) Salmonella per 25g	Free	SLS 516: Part 5

Source: Sri Lanka Standard Institution, 2003