4.0 RESULTS AND DISCUSSION

4.1 System Analysis in Jeram Sanitary Landfill (JSL)

4.1.1 Municipal Solid Waste (MSW) characterization/Composition Studies

The highest percentage of MSW was organic waste. The collected MSW in JSL contains paper, food and garden waste and wood constituting 62% of the MSW (Table 4.1).This reflected a typical scenario observed among developing nations where organic contributed nearly half of the total waste stream. (Zhu *et. al.*,2009; Hao *et. al.,* 2008; Fauziah *et. al.,* 2004; Agamuthu *et. al.*,2003; World Bank,199). The rest are inorganic materials such as metals, glass, gypsum/asbestos from the construction and demolition industry and other minerals. This typically conforms with MSW generated worldwide from residential, commercial, industrial, institutional, construction, demolition and municipal services (World Bank, 1999 & 2012). The results show that the largest portion of the waste disposed in JSL is organic waste, particularly kitchen waste (32%). This is typically similar to other developing countries, as accounted by the World Bank (2012). High organic content also indicates that sanitary landfills are suitable for anaerobic decomposition and economic recovery of methane gas. On average, paper and plastic waste contributed 13% and 19% respectively. From Table 4.1, plastic waste contributed at 19% was slightly lower than typical trend. Plastic waste composition in most developing countries are given at 11% (World Bank, 2012). This may suggest the modern lifestyle of urban population. Plastics usage is inevitable at household level. Mohd Armi *et. al*., (2013) conducted a study on MSW generation has indicated that plastic waste contributed 17% while paper waste were 29 % from total waste stream in Selangor. Kitchen waste contributed the largest contribution to organic waste (32%) in JSL. Similar study has shown that organic waste contributed almost 40% from total waste stream in Selangor (Mohd Armi *et. al*., 2013). At least 50 tonnes of organic waste is disposed at JSL daily. This includes fruits, vegetables from wet market and

restaurants and unconsumed food. Unconsumed food due to expiry dates (for example expired canned food processed) is also common in JSL ranging from 0.2 to 0.3 tonnes per day. Textile waste received by JSL contributed 3.7% (Table 4.1) of total waste generated. Observation at JSL show that they are mainly generated by the industrial and commercial sector. In JSL, 9.25 tonnes of aluminium scrap ends up in landfill every year. Most of the aluminum cans (1.39 tonnes/day) were collected by waste pickers during on-site recycling. The high market price is a factor that motivate the on-site recycling. Sanitary waste (disposable diapers etc.) deposited at JSL should highly be considered as a trend viewed from social perspective in both developing and developed countries.

Table 4.1: Waste composition in JSL.

Type of Waste	Waste Tonnage (tonne)	Waste composition (% wet weight basis)	Typical waste composition in developing countries (World Bank, 2012, %)	Typical waste composition in developed countries (World Bank, 2012, %)
Organic Waste	52.3	32.4	58	50
Paper	21	13	15*	20*
Soft Plastic	18.6	11.5	-	-
Hard Plastic	13.8	8.5	11*	9*
Soft Paper	11.6	7.2	-	-
Debris	10	6.2	-	-
Glass	9.7	6	2	3
Wood	9	5.6	2.9	-
Textile	6	3.7	1.3	-
Tin/Alloy	4.3	2.4	-	-
Polystyrene	1.9	1.2	-	-
Aluminium Cans	1.6	1	-	-
Electronics (Wires)	0.5	0.3	-	-
Metal	0.4	0.3	3	5
Sanitary waste(diapers, etc)	0.7	0.7	-	-
TOTAL	**161.4**	100	-	-

*Hard paper and Soft paper are shown generally as Paper by World Bank (2012).
*Hard plastic and Soft plastic are shown generally as Plastic by World Bank (2012).

During the first year of the landfill operation in 2007, the JSL Management has set a maximum target of waste-receiving based on the population demography and frequency and demand from customers including waste collector, Solid Waste Company (SOWACO). Based on Table 4.2, the maximum target for 2007 was 569,561 tonne. In just after 7 months of operation in 2007, total wastes has exceeded 43 000 tonne (an increase of 18% from the projection). Since JSL started its operation back in 2007, the waste received shows an increasing trend. However it was observed that there was a significant or perhaps sharp increase of waste-received in 2010 as compared to 2009 which was 12,484 tonne. As of June 2013, a cumulative amount of 4.8 million tonne of waste have been landfilled.

Table 4.2: Cumulative waste disposed into JSL from 2007 to June 2013

Year	**Tonnage**	
	Per year	**Per day**
2007	569,561	1560
2008	730,547	2001
2009	752,547	2061
2010	740,063	2027
2011	736,644	2018
2012	819,840	2246
2013(until June)	436,237	2390
CUMULATIVE	**4,785,439**	**12,903**

Figure 4.1 shows the tonnage of waste landfilled monthly at JSL from 2007 until 2010. In 2011, 736,644 tonne was disposed at JSL while in 2012, 819,840 tonnes of waste was landfilled. It is almost 10% increase in waste disposed. Until June 2013 alone, 436,237 tonnes of MSW was landfilled in JSL. The operation area in JSL for landfiling is 48 hectares.

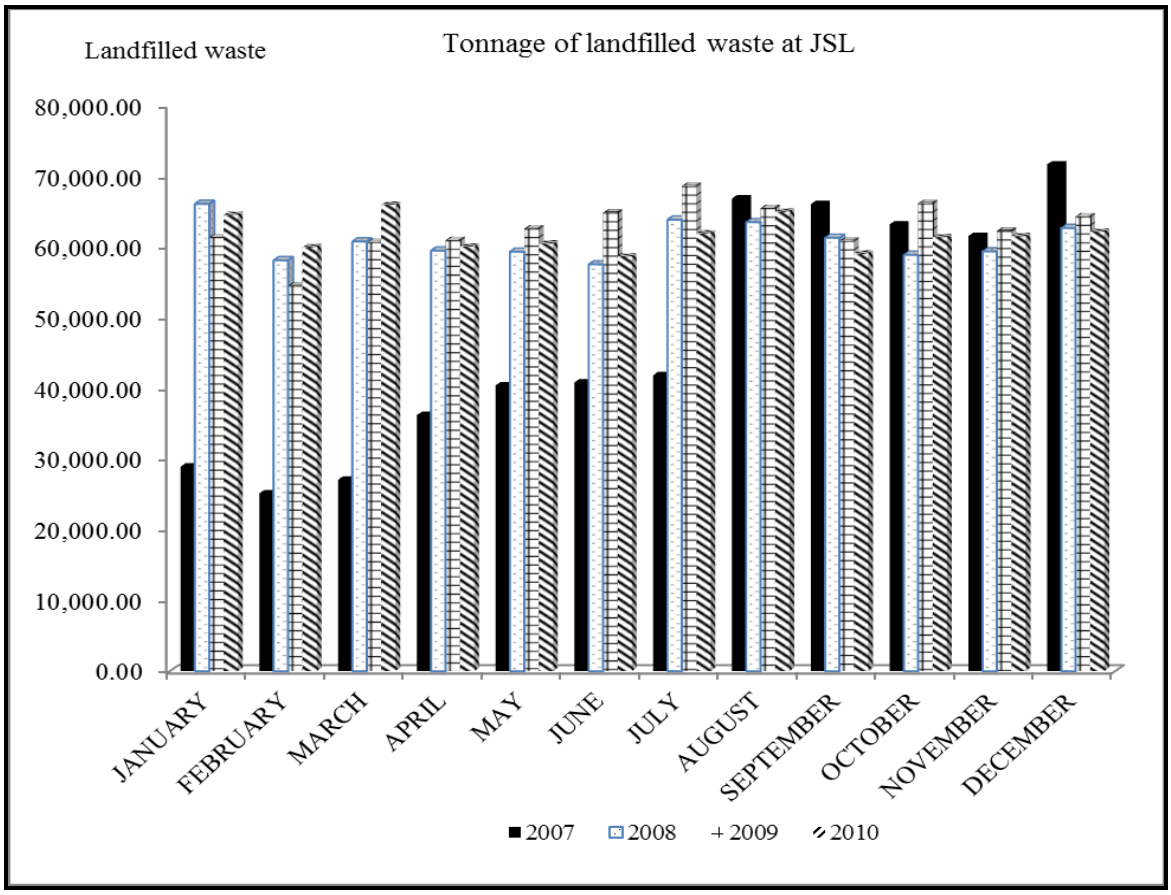

Figure 4.1: Tonnage of waste landfilled (tonne) monthly at JSL from 2007 to 2010.

Table 4.3 shows the actual waste received monthly compared to the target which JSL operation should handle. The target daily tonnage are 1400 tonne per day while actual receiving was 2002.36 tonne per day.

Table 4.3 : Actual waste received compared to monthly target in JSL operation from 2007 to 2010.

MONTH	2007	Target	2008	2009	2010	Target	CUMULATIVE
JANUARY	28,908.17	42,000.00	66,063.18	61,382.12	64,484.62	60,000.00	2,117,141.23
FEBRUARY	25,130.69	42,000.00	58,084.37	54,512.96	59,920.40	60,000.00	2,177,061.63
MARCH	27,067.97	42,000.00	60,743.40	60,678.84	65,943.42	60,000.00	2,243,005.05
APRIL	36,200.31	42,000.00	59,460.74	60,945.73	60,015.72	60,000.00	2,303,020.77
MAY	40,409.55	42,000.00	59,293.31	62,583.54	60,445.87	60,000.00	2,363,466.64
JUNE	40,821.02	42,000.00	57,494.25	64,831.57	58,594.04	60,000.00	2,422,060.68
JULY	41,850.28	42,000.00	63,830.90	68,587.17	61,873.48	60,000.00	2,483,934.16
AUGUST	66,831.73	42,000.00	63,474.49	65,475.48	64,920.58	60,000.00	2,548,854.74
SEPTEMBER	66,030.61	42,000.00	61,267.84	60,838.93	58,992.98	60,000.00	2,607,847.72
OCTOBER	63,154.70	42,000.00	58,854.38	66,156.49	61,329.54	60,000.00	2,669,177.26
NOVEMBER	61,516.05	42,000.00	59,338.59	62,244.53	61,470.19	60,000.00	2,730,647.45
DECEMBER	71,640.27	42,000.00	62,642.34	64,310.11	62,073.07	60,000.00	2,790,647.45
TOTAL	569,561.35	504,000.00	730,547.79	752,547.47	740,063.91	720,000.00	**2,792,720.52**

Figure 4.2 shows that in 3 years (from 2007 until 2010), the wastes received were mainly from 3 major sources: municipality/town council, solid waste company (SOWACO), special waste collector and non-significant sources classified as “others”. Each contribution is as follows: municipality/town council with 57628.38 MT, Solid Waste Corporation (SOWACO) with 455.96 tonne, special with 2622.12 and other non-classified with 1366.58 tonne. The latest volume data in 2013 from JSL management shows that 750,213 tonne were disposed and this makes the cumulative reaches 5,021,147 tonne waste for 7 years of landfilling operations. The yearly growth ratio from the volume of wastes is 1.01 each year.

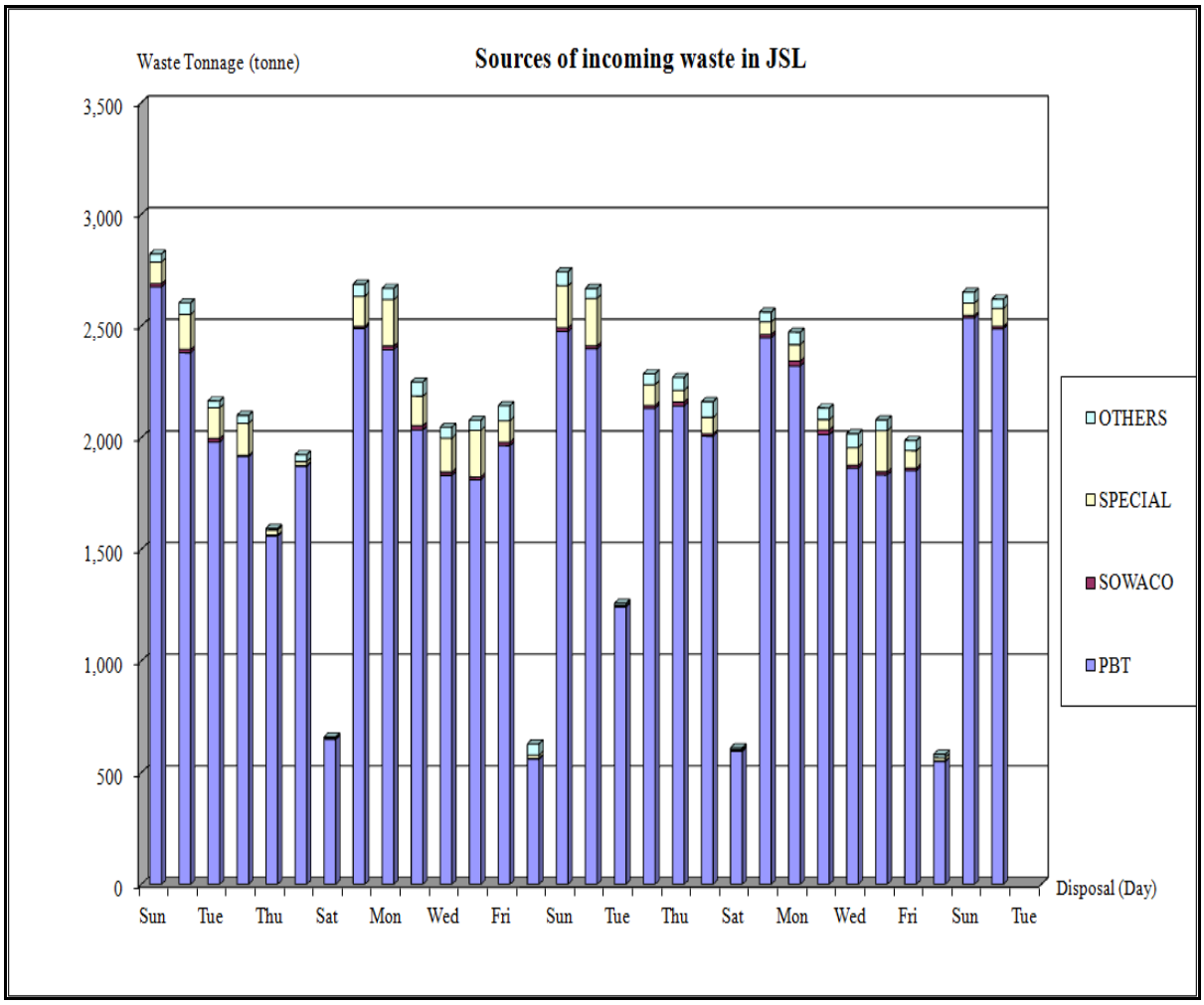

Figure 4.2 : 3 major sources of incoming waste (Acronym: PBT : Municipality Council, SOWACO : Solid Waste Company, Others, Special Waste).

4.1.2 Physical and Chemical Analysis for Leachate and Rainwater

The JSL has received high amount of precipitation with a maximum of 3000 mm per year and ambient temperature between 37^{o} C and 40^{o} C which makes the JSL landfill hot and humid. Chemical analysis conducted for rainwater in JSL indicated it was acidic with pH value ranging from pH 4.48 to pH 6.82. NH_4-N concentration in rainfall is between 3.23 to 3.27 mg/l. Currently, an average of 150 m^3 of leachate per day goes to leachate treatment and during rainy season, the volume increases to 210 m^3 per day.

Initial data on N content and C was relatively low at 0.1 and 0.2 %, respectively. Elemental carbon in this study was typically dissolved organic carbon (DOC) which conforms with the classic study in terrestrial environment (John *et. al.,* 1983). As for raw leachate, the N content and C content were recorded at 3.45 and 9.34%, respectively (Table 4.4).

Table 4.4: Chemical Analysis for Carbon and Nitrogen for rainwater and raw leachate from JSL

Sample Marking	Test Parameter	Test Method	Result (%)
Rainwater	N	ASTM E778-87	0.1
	C	ASTM E 949	0.2
Raw Leachate	N	ASTM E778-87	3.45
	C	ASTM E 949	9.34

4.1.3 Emission from Small-scale Composting.

Composting is regarded as a secondary activity in JSL. The usual practice for composting is to do it *on-site* in open air environment. The compost mixture was one tonne of domestic sludge with three tonne of wood chips. The young compost were mixed using shovels. The final compost heap stands at one meter high. The mature compost produced was 3 tonnes per day. Approximately 21 tonnes of final compost

were produced per week. Greenhouse gases such as CH_4, CO and NH_3 as a product emitted during the composting process are not controlled nor treated by JSL management but emitted directly to atmosphere. Weekly monitoring of passive gas emission conducted *in-situ* for both ambient air and mature compost confirmed the initial observation that greenhouse gases emission from composting facility is not concentrated and relatively very low (between 0 to 4 ppm). An eight-week continuous monitoring recorded the absence of methane and carbon dioxide for both ambient air and compost. Figure 4.3 shows the weekly gas monitoring for mature compost in JSL.

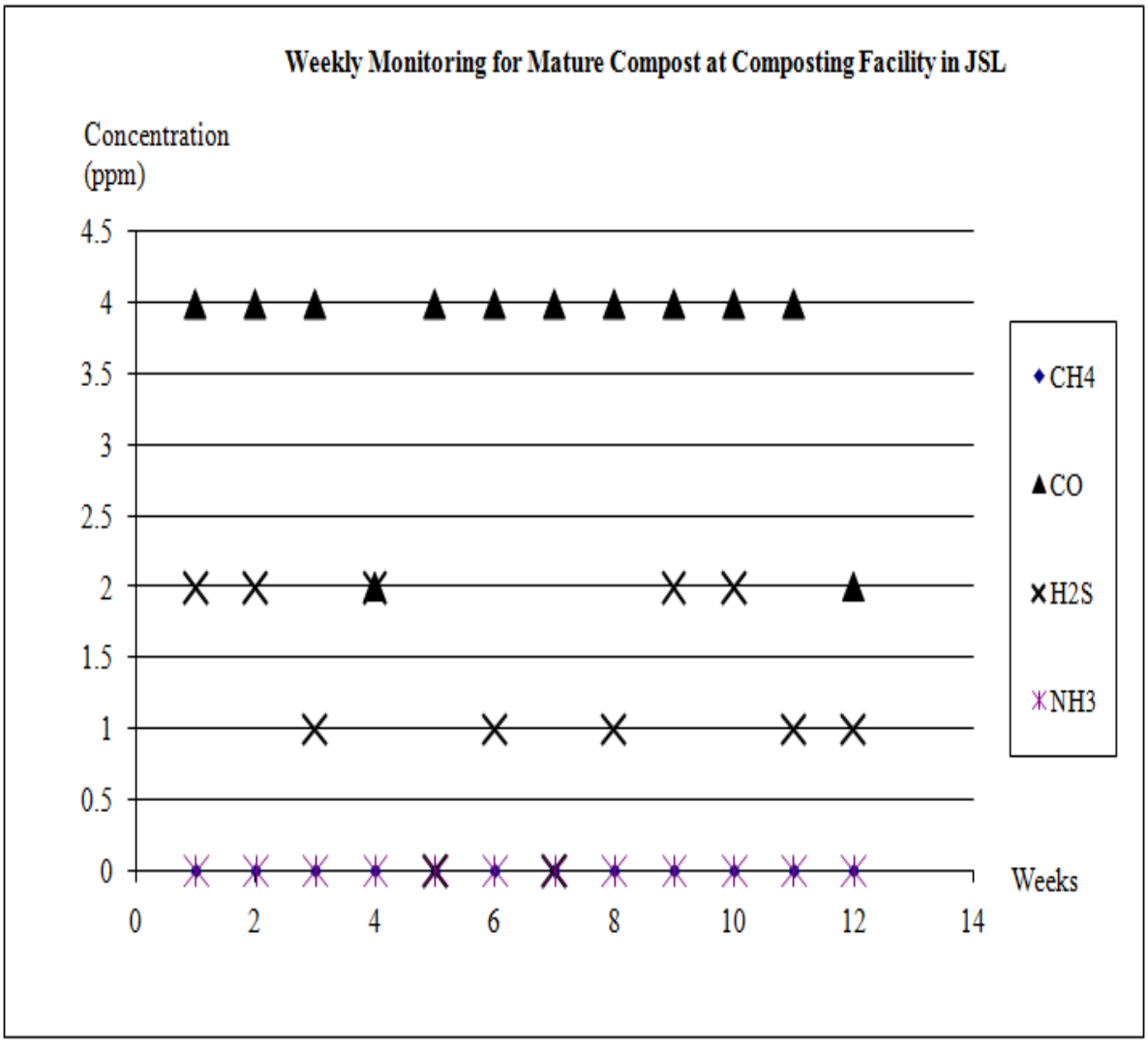

Figure 4.3: Weekly gas monitoring at JSL for mature compost for 12-weeks.

In JSL, the type of sludge used is mature and low-water content domestic sludge. However, CO was almost negligible. For ambient air, the CO concentration was 2 ppm

while compost CO was at 4 ppm. This reading is almost negligible after conversion to percentage (less than 0.01 %) of landfill gas composition using the basic formula where 1% = 10000 ppm. Trace gas for example hydrogen sulphide was also recorded with concentration between 1 and 2 ppm all weeks. NH_3 as one of the typical gas released from compost production was not detected (0 %) over eight-week observation. Therefore, the nitrogen flow from the small-scale composting facility in the landfill area was almost negligible and not significant to be considered in this study.

4.2 MSW Characterization and Flow in JSL

4.2.1 Quantitative Analysis on MSW as Waste Input

The system rstudied for this research is a sanitary landfill. A material balance was prepared for the period of one-year of landfilling. In any system, each flow-through is associated with the origin and the destination in the process which have been clearly identified. System boundaries define the temporal (i.e time) and spatial (i.e space) delimitation of system under investigation. The spatial system boundaries for this study include the landfill body, landfill surface and processes or cycles within a tropical sanitary landfill loop. This system includes facilities for gas and leachate treatment. Materials flowing to a system are termed imports while those from the system are known as exports.

The system boundary of the studied system is given in Figure 4.5 which shows the Mass Flow Analysis (in tonne/year) in JSL. This system analysis consists of landfill surface, landfill body, landfill gas collection and leachate treatment including the actual landfilling process. Some of influential components are contributing to the spatial system boundary. The spatial system boundary is usually fixed by the geographical area in which the processes are located (Bruner & Rechberger, 2005). Therefore, besides the waste loading there are rainfall to be considered. Major outputs are mainly landfill gas

and leachate. The system boundary does not include the collection and transportation of waste to and from landfill. A typical example of a sanitary landfill system analysis is shown in Figure 4.5. Processes are represented by boxes and flows by arrows. Models are designed from predefined elements such as processes, flows, system boundaries, and text fields in a graphical way (Figure 4.4).

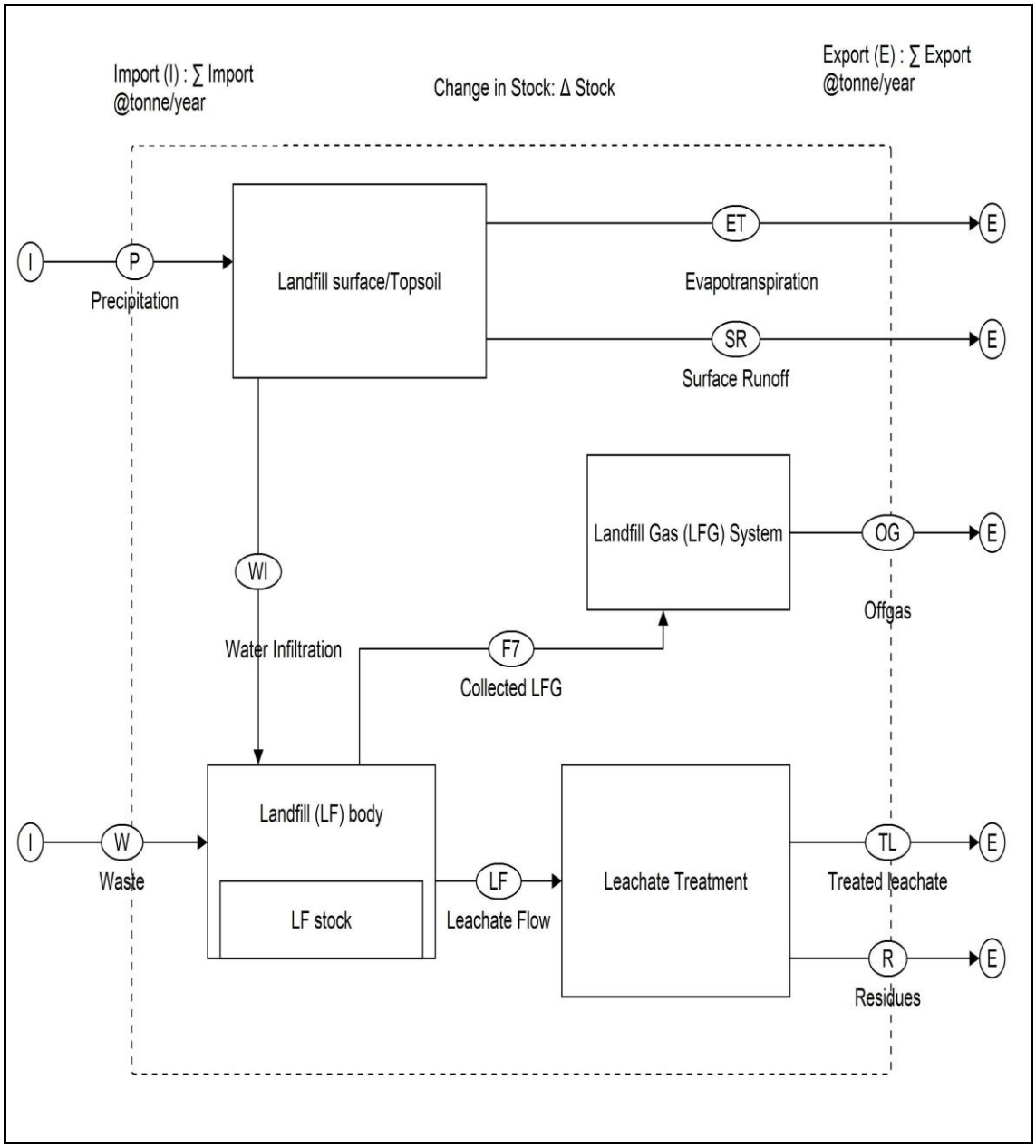

Figure 4.4 : System boundary identified in Jeram Sanitary Landfill study (Qualitative System Model modified from Spaun, 1995).

4.2.2 Quantitative Analysis on Waste Output: Leachate and Greenhouse Gas

The considerably new 4-year old JSL site with topsoil depth between 150 to 300 mm as daily cover, allows the rain to percolate vertically and collect as leachate (> 14 %) with some loss in evapotranspiration (> 56 %) or surface runoff (> 30%) (Refer to Figure 4.6) based on water balance components principles (Agamuthu *et. al.,* 2010). This section will discuss on this in details. The type of soil used for daily cover is clay loam which has high water retention and low water porosity. This will reduce rainfall percolation that eventually goes to leachate treatment. The higher the percolation, the more leachate that will be generated (EPA, 1991). The storage capacity of the cover soil is sufficiently high that percolation is low (Wenjie & Cheng, 2013). The thickness of the daily cover for clay loam soil between 150 to 300 mm affect the storage capacity and water balance in JSL. Daily soil compaction impacts soil bulk density and since clay loam has high water storage capacity property, they are relatively suitable for daily use. Higher bulk densities may reduce the storage capacity of the soil (Chadwick, 1999; Hauser, *et. al,* 2001). Currently, an average of 150 m^3 of leachate per day goes to leachate treatment and during rainy season, the volume increases to 210 m^3 per day.

Figure 4.5 shows the schematics material flow of JSL, involving inputs such as precipitations and solid waste and outputs in terms of leachate generation that may contaminate groundwater and the surrounding areas (Barnswell & Dywer, 2011) and also evapotranspiration. The quantification of inputs and outputs in a dynamic system such as landfill is to ensure a balanced state considering the substance stock in the landfill body, substance emissions and the substance concentration. This is shown in Figure 4.5 where input is quantified at 1,267,020 tonnes with a change in landfill stock at 782,530 tonnes.

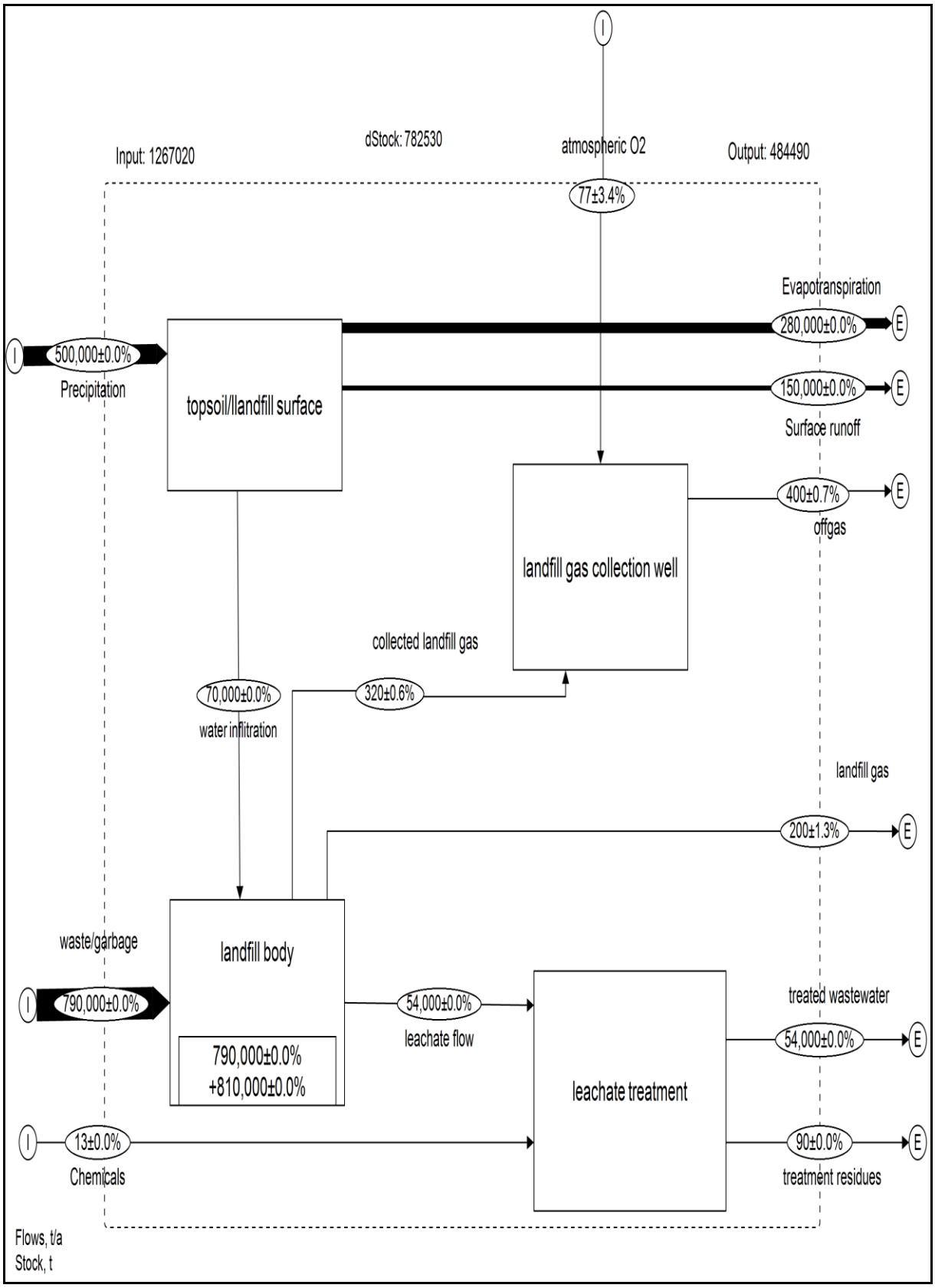

Figure 4.5: Mass flow analysis (in tonne/year) of Jeram Sanitary Landfill.

4.3.1 Precipitation in Terms of Rainfall in JSL

Water flow in this study is accounted mainly from rainfall. Currently, an average of 150 m^3 of leachate per day goes to the sequential batch reactor facility. The waste in a tropical country especially Malaysia is wet with approximately 65% to 70% moisture content (Agamuthu 2001; Nasir *et. al.* 1999). The considerably new 4-year old JSL site with topsoil depth between 150 to 300 mm as daily cover, allows the rain to percolate vertically and collect as leachate (> 14 %) with some loss in evapotranspiration (> 56 %) or surface runoff (> 30%) . Based on water balance components principles (Agamuthu *et al.*, 2010), clay loamy topsoil is proven to lower the percolation rate and encourage surface runoff due to the high water-retention property. The typical rainfall volume received except for the dry season for instance in 2009 and 2010 and 2013 was recorded at 1570, 1404 (the lowest) and 1702 mm, respectively (Figure 4.6).

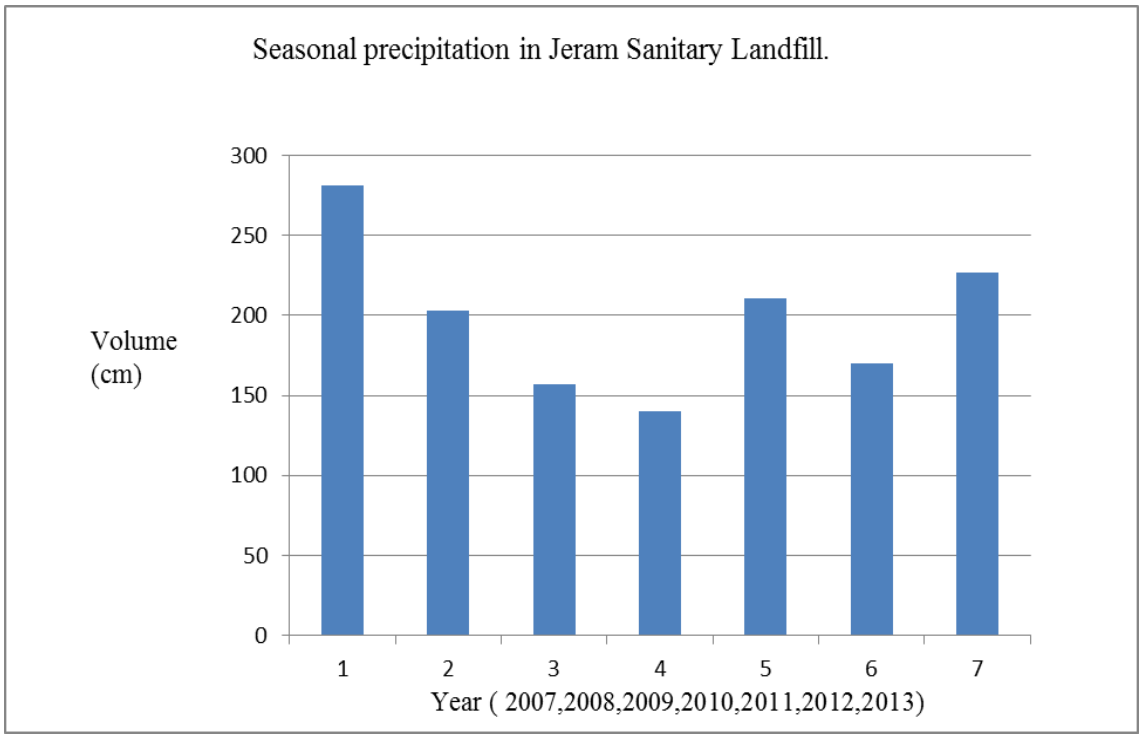

Figure 4.6: Seasonal precipitation in terms of rainfall in JSL from year 2007 until 2013

The highest rainfall was in 2007 during the landfill operation at 2813 mm. In 2013, the volume was 2266 mm. These classic examples show that for climates where annual precipitation is less than 400 mm, virtually all precipitation is evapotranspired (Christensen, 1992). In JSL, there is 56% loss of humidity in terms of evapotranspiration while loss as surface runoff is greater than 30%. Manaf *et. al.,* (2009) indicated that evapotranspiration is high despite heavy seasonal rainfall volume with average air humidity at 80%. The measured efficiency of landfill leachate evapotranspiration mostly depended on the physical and chemical properties of landfill leachate and the applied plants species (Białowiec, 2007). Based on calculation, surface runoff at 30% which is significantly high, suggests a large water-holding capacity where the waste materials might have retain an amount of water and also have a low percolation rate, resulting in a higher runoff rate.

4.3.2 Water Balance (Leachate and Rainfall)

The leachate concentration shown in Table 4.9 decreases over 3 to 5 years period including certain metal elements such as Fe, Zn, P, Cl, Na, Cu, organic N, Total Suspended Solids (TSS) at 2.31±1.08, 0.049±0.008, 46.66±5.77, ND (<0.01), 0.01±0.001, 2.5±0.5, 0.0066±0.01 mg/l, respectively (Table 5.1). This trend generally applies to the organic constituents and general organic indicators (Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC)) (Qasim & Burchinal, 1970 and Walsh & Kinman, 1979). The steady decrease is attributed to the continued flushing of the refuse, and the fact that easily decomposable and soluble materials were removed into leachate pathway. The compositions of leachate differ in terms of chemical and biological constituents as the age of landfill increases or gets mature. It also varies widely depending on waste type and waste age (Fatima *et. al.,* 2012). The concentration of leachate tends to decrease as the age of landfill increases and this enhances the leachate quality (Chian & De

Walle, 1976; Boltan & Evans,1991; Ragel *et al.* 1995; and Fatta *et al.,* 1998). This variation depends on many factors such as waste composition, degradability levels, solubility, geological condition and age of the landfill. The COD was recorded at 47300±2454.2 mg/l and BOD is 1540±223.17 mg/l. COD is a reliable indicator as a reference parameter to determine carbon mass balance in a landfill as it measures organic matter in the leachate. JSL has been in active operation for less than 5 years which is considered to belong in the young phase in terms of landfill age. The young landfill leachate is commonly characterized by high BOD (4,000 to 13,000 mg/l) and COD (30,000-60,000 mg/l). They also have high content of ammonium nitrogen (500 to 2000 mg/l) and high ratio of BOD/COD (ranging from 0.4 to 0.7) (Chian & De Walle 1976, Alvarez-Vazquez *et. al.,* 2004). The BOD and COD readings from JSL leachate are agreeable with the literature found as mentioned. A summary of landfill leachate classification versus age is presented in Table 4.5.

Table 4.5: Landfill leachate classification versus age (Chian & De Walle 1976, Alvarez-Vazquez *et.al*, 2004)

Selected characteristics of leachate	Type of leachate	Young	Intermediate	Old	JSL
	Age (years)	< 5	5- 10	>10	5
	pH	<6.5	6.5-7.5	>7.5	7.5
	COD (mg/L)	>10,000	4,000- 10,000	<500	47300
	BOD/COD	0.5-1.0	0.1 to 0.5	<0.1	0.03
	BOD/TOC	>2.8	2- 2.8	<2	225
	TOC/COD	<0.3	0.3-0.5	>0.5	(<0.01)
	Total Kjehdahl Nitrogen (mg/l TKN)	0.1-0.2	N.A	N.A	2.5
	Heavy metals (mg/l)	Low to medium (>2)	Low (<2)	Low (<2)	Refer Table 4.6
	Biodegradability	High	Medium	Low	Medium
Efficiency of treatment (McBean *et al.* 1982, Lema *et.al.*,1988)	Biological treatment	Good	Fair	Fair	Yes
	Chemical precipitation	Poor	Fair	Fair	Yes
	Chemical oxidation	Poor	Fair	Fair	Yes
	Ozonation	Poor	Fair	Fair	Yes
	Reverse osmosis	Fair	Good	Good	Yes
	Activated carbon	Poor	Fair	Fair	No

Ammonia nitrogen accounted for the majority of nitrogen present in leachate. It was recorded to be at 600±43.08 (mg/l NH_3-N). The BOD/COD ratio as biodegradability level of materials recorded at 0.03 was exceptionally low suggesting high toxicity of the

leachate. High concentrations of BOD and COD as well as BOD/COD ratio decrease with time in a landfill signify stability of the leachate. The result recorded for BOD, COD and BOD/COD ratio conforms with the literature showing that the leachate moves towards stabilization and maturity phase rapidly. Chian & De Walle (1976) reported that BOD/COD ratio decreases rapidly from 0.70 to 0.04 as landfill ages. The degree of solid waste stabilization has a significant effect on leachate characteristics in JSL, resulting in low BOD/COD ratio (0.03) and fairly high concentration of NH_3-N (600±43.08 mg/l NH_3-N. (Table 4.6). Total Organic Carbon (TOC) was recorded to be 6.84±0.5 mg/l. This value is slightly higher as compared to TOC recorded by Wang *et. al,* (2013) which was between 3.88 to 4.45 mg/l. Total Kjeldahl Nitrogen (mg/l TKN) was 2.5±0.5 mg/l. Another findings shown that organic nitrogen (TKN) recorded at 35 mg/l (Kulikowska & Klimiuk, 2004). The difference maybe caused by the the leachate characteristics of between intermediate and mature landfill. The chosen parameters of TOC and TKN are universal and used for software computation in flow analysis study. The relatively low TOC content via leachate path is agreeable with classic literature that less than 1% of total carbon emissions from MSW landfills can be found in the leachate (Baccini *et. al.,* 1987; Huber *et. al.,* 2004) despite high volume of rainfall.

Table 4.6 shows physical and chemical characteristics of raw leachate taken from the leachate treatment plant in JSL. The COD was recorded to be 47300±2454.2 mg/l. COD is a reliable indicator or reference parameter to determine carbon mass balance in landfill as it measures organic matter in leachate while the Dissolved Oxygen (DO) was recorded as 4.30±0.09 mg/l. Leachate treatment in JSL has also comply with Standard B for Leachate Standard 2009 Regulation. The standard are more stringent to ensure heavy metals such as Pb, Cd, and As are safely treated and within the standard range.

Table 4.6 : Physico-chemical characteristics of raw leachate taken from the leachate treatment plant (EQA B is for Malaysian Environmental Quality Act Standard B)

Parameter	**Concentration**	**EQA 1974 (Leachate Standard 2009)**	
		Std A	**Std B**
pH	7.45±0.1	6-9	5.5-9
Temperature (^{o}C)	25.96±0.15	40	40
Salinity (CaO_3)	0.236±0.02		
Conductivity ($CaCO_3$) ppm	457±23.5		
Turbidity	4143.33±7.63		
Dissolved Oxygen (mg/l)	4.30±0.09		
BOD (mg/l)	1540±223.17	20	50
COD (mg/l)	47300±2454.2	120	200
Total Suspended Solid (TSS) (mg/l)	0.0066±0.01		
Total Dissolve Solid (TDS)	1731.66±7.63	50	100
Chloride (mg/l Cl-)	46.66±5.77		
Alkalinity (mg/l $CaCO_3$)	90±10.8		
Hardness (mg/l Ca & Mg)	1.10±0.01		
Total Organic Carbon (TOC) (mg/l)	6.84±0.5		
Ammonium Nitrogen (mg/l NH_3-N)	600±43.08	20	50
Nitrate Nitrogen (mg/l NO_3-N)	1.13±0.23	10	10
Nitrite Nitrogen (mg/l NO_2-N)	0.45±0.11		
Total Kjeldahl Nitrogen (mg/l TKN)	2.5±0.5		
Inorganic Nitrogen (mg/l N)	0.23±0.05		
Total Nitrogen (mg/l N)	2.63±0.23		
K	ND (<0.01)		
Sulphide (Na_2SO_4)	10±2		
Ca	48.94±13.45		
Mg	65.26±3.48		
Pb	0.046±0.004		0.1
Cd	ND (<0.01)		0.01
Se	ND (<0.01)		0.02
Al	1.69±0.82		10
Mn	0.26±0.16		0.2
Cu	0.01±0.001		0.2
Zn	0.049±0.008		2
Fe	2.31±1.08		5
As	0.14±25.44		0.05
Na	ND (<0.01)		

COD does not differentiate between biologically available and inert organic matter. The TOC was 6.84±0.5 mg/l and TOC is the chosen reference parameter in carbon mass balance. The effectiveness of leachate treatment processes varies with the leachate from landfills of different ages (Fatima *et. al,* 2012). Biological treatment is proven to be more effective in treating leachate of relatively young landfill like JSL while physical and chemical methods has been proven to show better performance in treating old leachate (Cook & Foree,1975; Boyle & Ham, 1974). BOD was recorded at 1540±223.17 mg/l which is considerably high. A summary of practical considerations in the use of different leachate treatment processes is presented in Table 4.9 (Lema *et. al.,* (1988). The pH for the leachate was recorded at 7.45 which conforms with previous studies for young landfill. A complete analysis on nitrogen was carried out in terms of Ammonium Nitrogen 600±43.08 mg/l, Nitrate Nitrogen 1.13±0.23 mg/l, Nitrite Nitrogen 0.45±0.11 mg/l and Total Kjehdahl Nitrogen or TKN 2.5±0.5 mg/l. TKN is the chosen parameter used for nitrogen balance calculation. The pH of sanitary landfill varies widely throughout the world. In JSL, the pH is slightly 7 which is typical. Normally, young landfills have value lower than pH 7 (acidic) and mature landfills will have value more than pH 7 (alkaline). This is because young landfills are in acidogenic stage whereby the hydrolysis of organic matter is actively being carried out, resulting in production of organic acids. Heavy metals, also for example Plumbum (Pb) and Arsenic (As), are also present in the leachate recorded at 0.046±0.004 and 0.14±25.44 mg/l, respectively.

The waste may contain hazardous material such as alkaline battery. Cadmium (Cd) is undetected possibly due to low concentration. Precious metal such as aluminium (Al) and Chloride (Cl) in ionic form are useful to treat effluents containing suspended solids, oil and grease, and even organic and inorganic pollutants that can be flocculated using

electrocoagulation (EC) (Chen, 2004). Total Suspended Solid (TSS) is significantly low at 0.0066±0.01 mg/l while Total Dissolve Solid (TDS) was recorded to be 1731.66±7.63 mg/l. However the usefulness of such metal is not discussed in detail since only carbon and nitrogen are of concern in this study. It is worth to note the significance between fresh leachate (direct sampling from lorry) and leachate from treatment plant. One important aspect is that the BOD/COD ratio for leachate sample is less than 0.1 (between 0.02 and 0.03 respectively) (Table 4.9). In leachate initial assessment, higher BOD/COD ratio means that part of organic material in the leachate is biodegradable while lower ratio values (<0.1) means most of organic part has been biodegraded into biologically inert material (Kulikowska & Klimiuk, 2008). This suggests that fresh leachate is more reactive in terms of organic biodegradability while leachate which remained over a period of time in the treatment plant may deteriorate the efficiency of organic material removal in leachate. Figure 4 shows the percentage of C mass balance of landfilled waste.

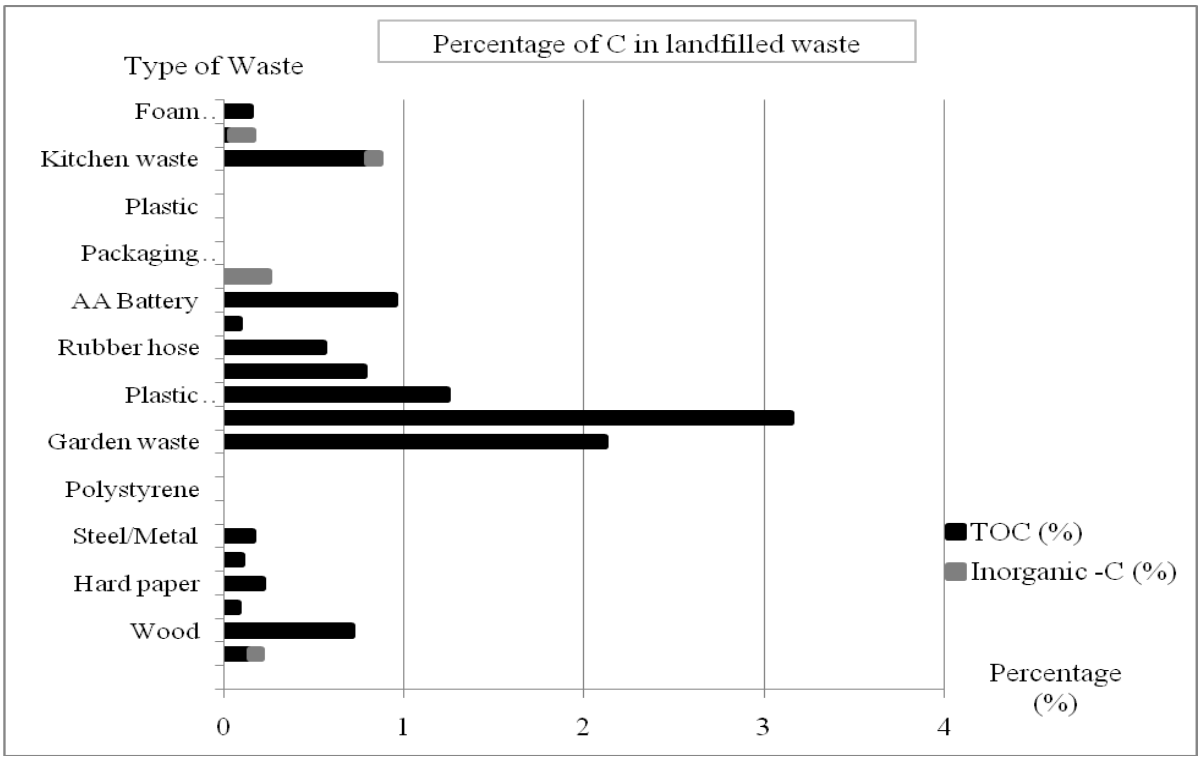

Figure 4.7: Percentage of C in landfilled waste

Garden waste recorded with 2.12 % TOC as the main source of organic carbon in landfill. Rubber mat and plastic container are each with 3.15 and 1.24%, respectively. They are combustible items suitable for incineration (Chapman *et. al.,* 2009). Aluminum can and tin/alloy on the other hand is at 0.1 % which is significantly low. Kitchen waste was recorded at 0.8% and TOC normally contains high moisture consist of organic fractions (fruits, vegetables, etc.). Synthetic materials items like rubber-based materials also contain TOC and have calorific value. In terms of waste management options, packaging paper, mineral bottle and plastics should opt for recycling rather than incineration based on flow analysis study. Most wastes are not found in their natural pure compound state. Some wastes have other additives added to suit the product need, for attractiveness or durability. Aluminum cans and aerosol containers, for instance have labels to differentiate product containing least or insignificant percentage of TOC due to soiled condition and waste heterogeneity in landfill.

Figure 4.8 shows the percentage of N mass balance in landfilled waste. Kitchen waste at 0.27% TKN is the highest nitrogen compound in waste while garden waste was recorded at 0.21 % of TKN. Paper and wood are both at 0.15 and 0.11 % TKN. Plastic is low with only 0.1% TKN content. Inorganic nitrogen is present only in kitchen waste and mineral bottle at 0.05 % TKN respectively. Most representative mass balances are based on frequent analysis of gas and leachate component, and the analysis is based on solid waste samples. N is one of the outputs in leachate in JSL, and the total N concentration was remarkably high, between 2.84% and 3.45% N outputs. This slightly low for N content in plastic waste recorded at only 0.1± 0.01% while Chuanbin *et. al.,* (2014) recorded the average N content at 1.045 ± 1.055% in landfilled plastics.

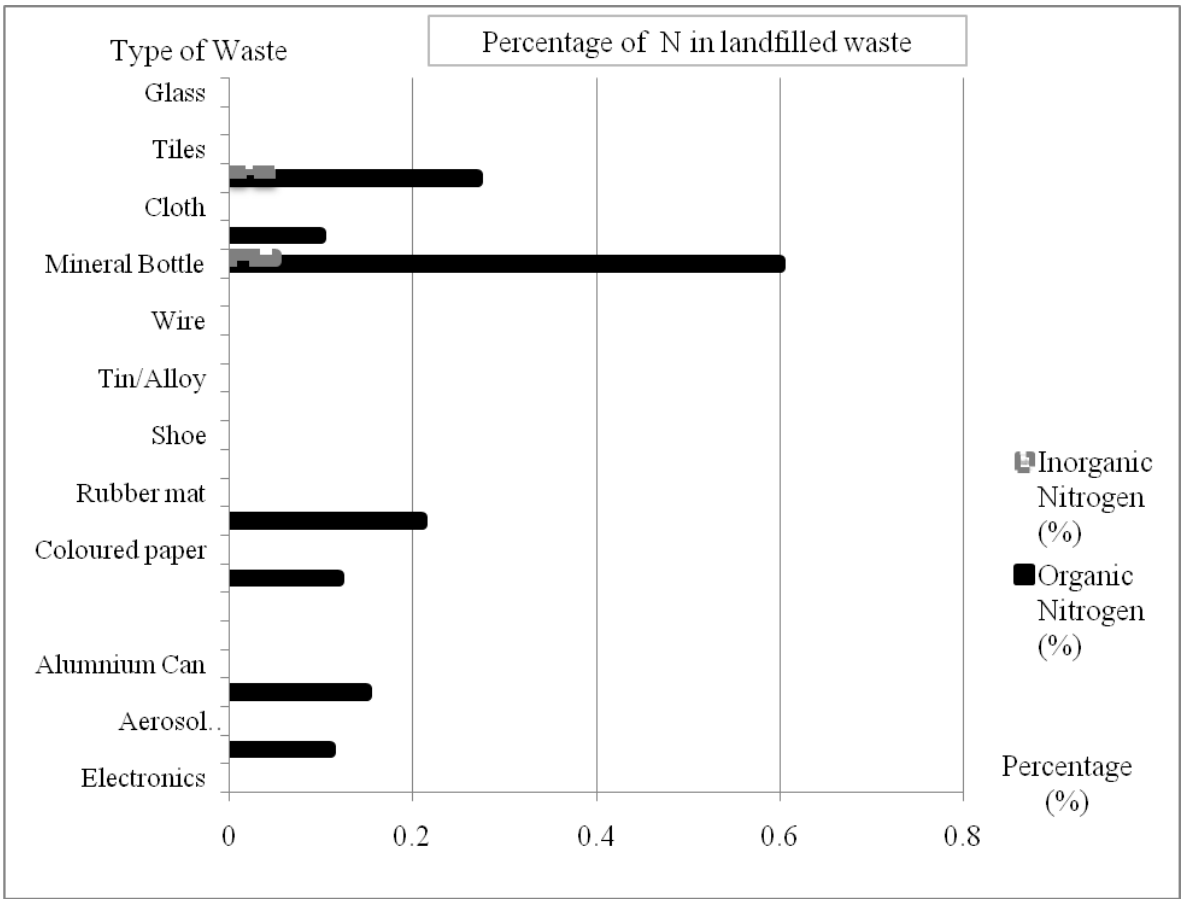

Figure 4.8: Percentage of N in landfilled waste.

4.4 Landfill Gas Emission (LandGEM)

4.4.1 Landfill gas (LFG) Emission Projection for 10 years

Since JSL first operated in 2007, no data in terms of generation and gas capture was ever recorded during its two years operation. Landfill gas (LFG) is one of the useful energy sources in the future for example in power (electric supply) generation, steam, heat or pipeline-quality gas (Dudek *et. al.*, 2010). The projection of landfill gas emission was generated using LandGEM software version 3.02.

In 2009, LFG generated was 3,238 m^3/h while in 2010 and 2011, the generation was 3,872 and 4,345 m^3/h, respectively. Flow analysis in this study quantified the output of landfilled waste considering input and stock of material that come into the sanitary landfill framework. The LFG generated in 2012 was 4,731 m^3/h while 2,365 m^3/h was captured as part of energy harvest from landfill. Energy capture efficiency is nearly (49.9%) from the hourly generation. Since 2008 was the first year of landfill operations, there is no credible data for landfill gas generation in JSL.

Table 4.7: Extrapolation for LFG generation rate and capture rate in JSL from 2009 until 2021 (JSL Management, 2013)

Year	LFG generation rate (m^3/h)	LFG capture rate (m^3/h)
2009	3,238	NA
2010	3,872	NA
2011	4,345	NA
2012	4,731	2,365
2013	5,056	2,528
2014	5,339	2,669
2015	5,591	2,796
2016	5,822	2,911
2017	4,963	2,481
2018	3,846	1,923
2019	3,069	1,535
2020	2,523	1,261
2021	2,132	1,066

In 2013, energy capture efficiency was at 50% where LFG generated was 5,056 m^3/h with only 2,528 m^3/h being captured (Table 4.7). The generation for subsequent years were calculated based on Clean Development Mechanism (CDM) formula to extrapolate the potential energy viable for electric supply. Energy capture rate are constant (50%) throughout 2017 and gradually decreases the following years due to landfill aftercare stabilization. LFG contains roughly 50% methane and 50% CO_2, with less than 1% non-methane organic compounds and trace amounts of inorganic compounds.

Figure 4.9 shows a gap in the scenario between LFG generated and LFG captured in JSL from 2009 through 2031. It is observed that in 2016, the LFG generation will be at its peak and gradually decreases years after that. The maximum CH_4 capture is almost 60% in terms of LFG volume.

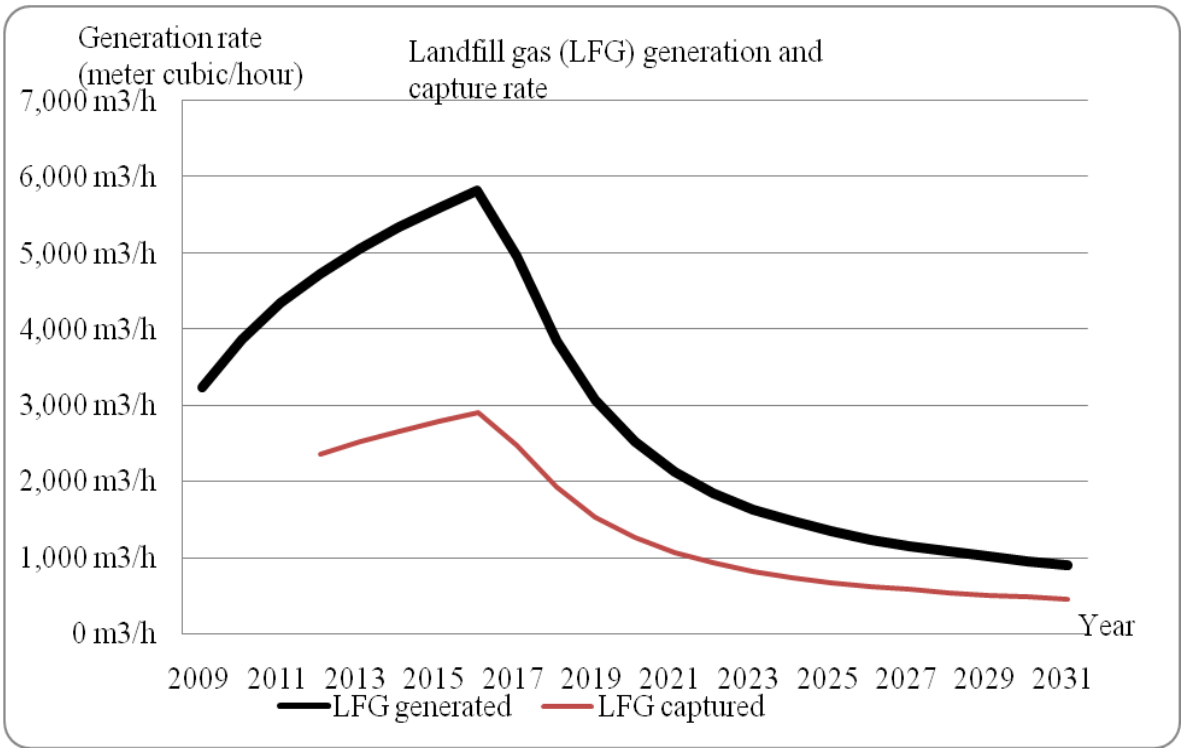

Figure 4.9 : Gap scenario between LFG generation rate and capture rate in JSL

Gas concentration at seven wells in JSL landfill are shown in Figure 4.10. Mass balance through gas is the main output in JSL, apart from the leachate. Ammonia and methane gas are the main sources for nitrogen and carbon in JSL. The percentage of CH_4 concentration is typically between 50% and 60%. The least recorded value was between 28 and 30% at certain gas well.

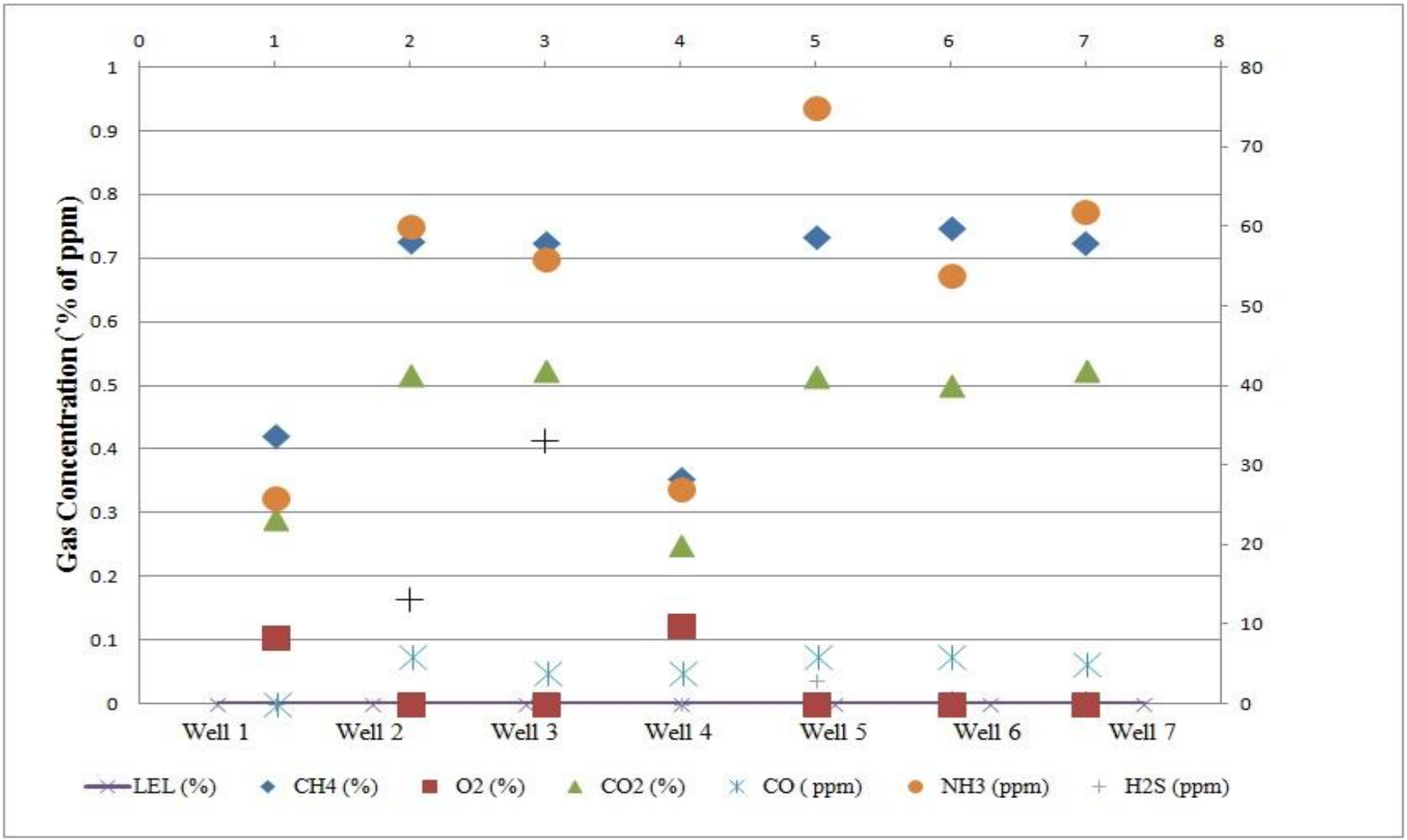

Figure 4.10: Landfill gas (LFG) concentration at selected wells in JSL.

Concentration for CO_2 is between 20% and 40%. Carbon monoxide is one of greenhouse gases which has been typically recorded to be less than 10% (from 4 to 6 %). Landfill gas is a well-known product of biodegradation of refuse in landfills, and it contains primarily methane (CH_4) and carbon dioxide (CO_2) (ISWA, 1997) which is the main input for carbon substance from sanitary landfill. Other gases such as O_2 were also recorded at less than 10%. H_2S gas was also present at lowest 1% while some at 30% (maximum). Previous research suggested that landfill gas production will last about one to two decades from operation years, closure and aftercare period (Ehrig, 1986; Stegmann, 1978; Stegmann, 1979). In this period, elements are exported by gas as well as by leachate during landfill operation years. Afterwards, the export continues as leachate. Huber *et al.*, 2004 emphasized on landfill topography that affected the landfill gas distribution and concentration. Preferential gas flow mat occur at certain gas well in landfill just like carbon and nitrogen substance flow based on mobilizable potential in landfill via leachate. Previous studies have attempted to quantify methane gas generation per tonne of MSW in regards to CO_2 and CH_4.

Figure 4.11 shows the laboratory test on headspace gas composition from gas wells using gas chromatography. The composition for CH_4 gas is the highest between 60 to 70% v/v. The readings were taken consistently for 12 weeks to determine the composition for O_2, CO_2 and CH_4 gas in laboratory. The O_2 content was typically low between 2 to 6 % while CO_2 was recorded at 9 to 25% v/v.

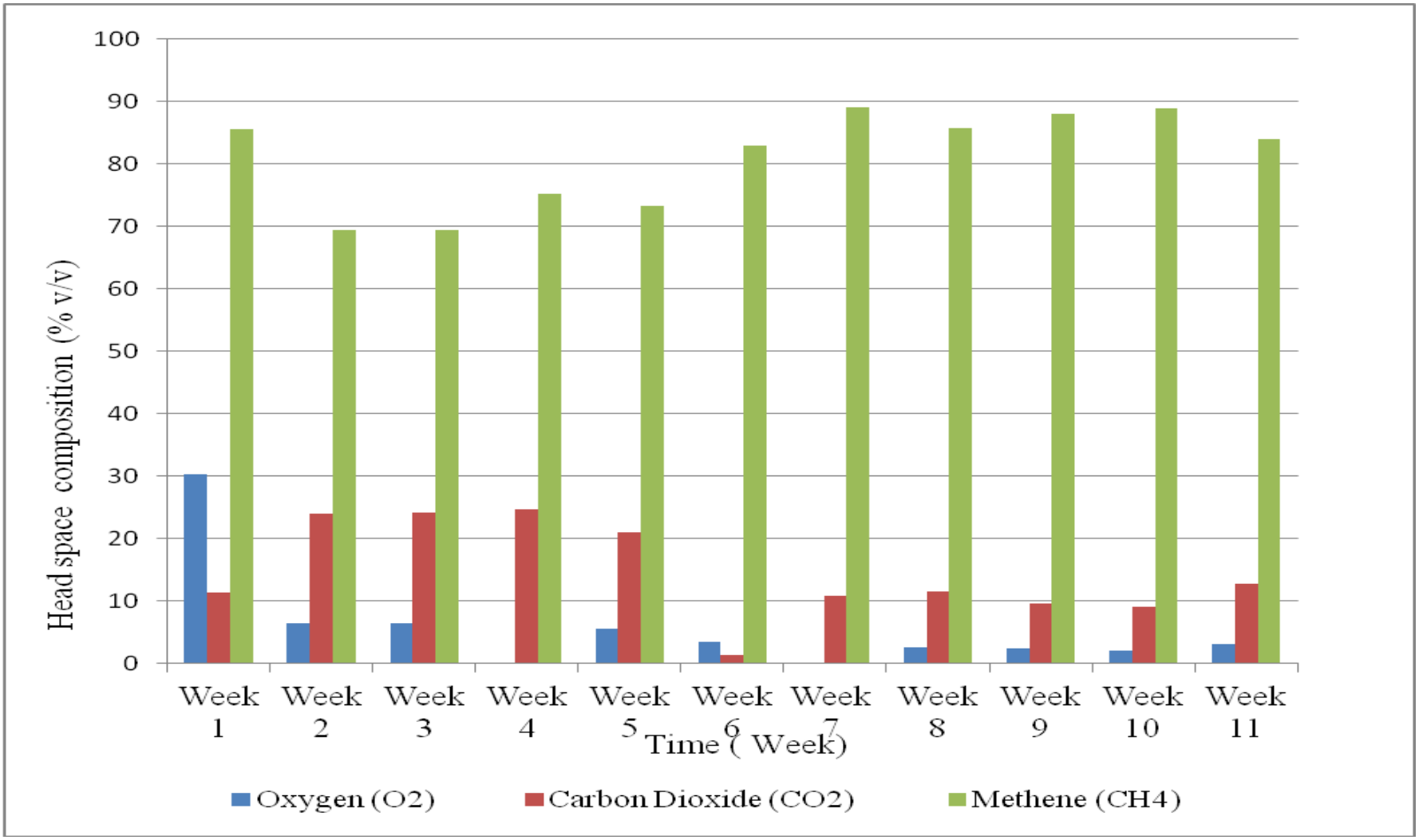

Figure 4.11: Headspace gas composition from gas wells using gas chromatography.

Another important gas observed in JSL is ammonia (NH_3) which is the nitrogen substance via landfill gas path. Continuous monitoring for all gases gave average concentrations over short periods of time, usually less than an hour and analyzed in real time. The gas monitoring was carried out at seven gas wells. The readings were 26, 60, 56, 27, 75, 54, 62 ppm, respectively. An average of 51±7 ppm indicating a significant value as one source of nitrogen compound released as landfill gas. Figure 4.12 shows NH_3 gas concentration at JSL over a period of 2 years.

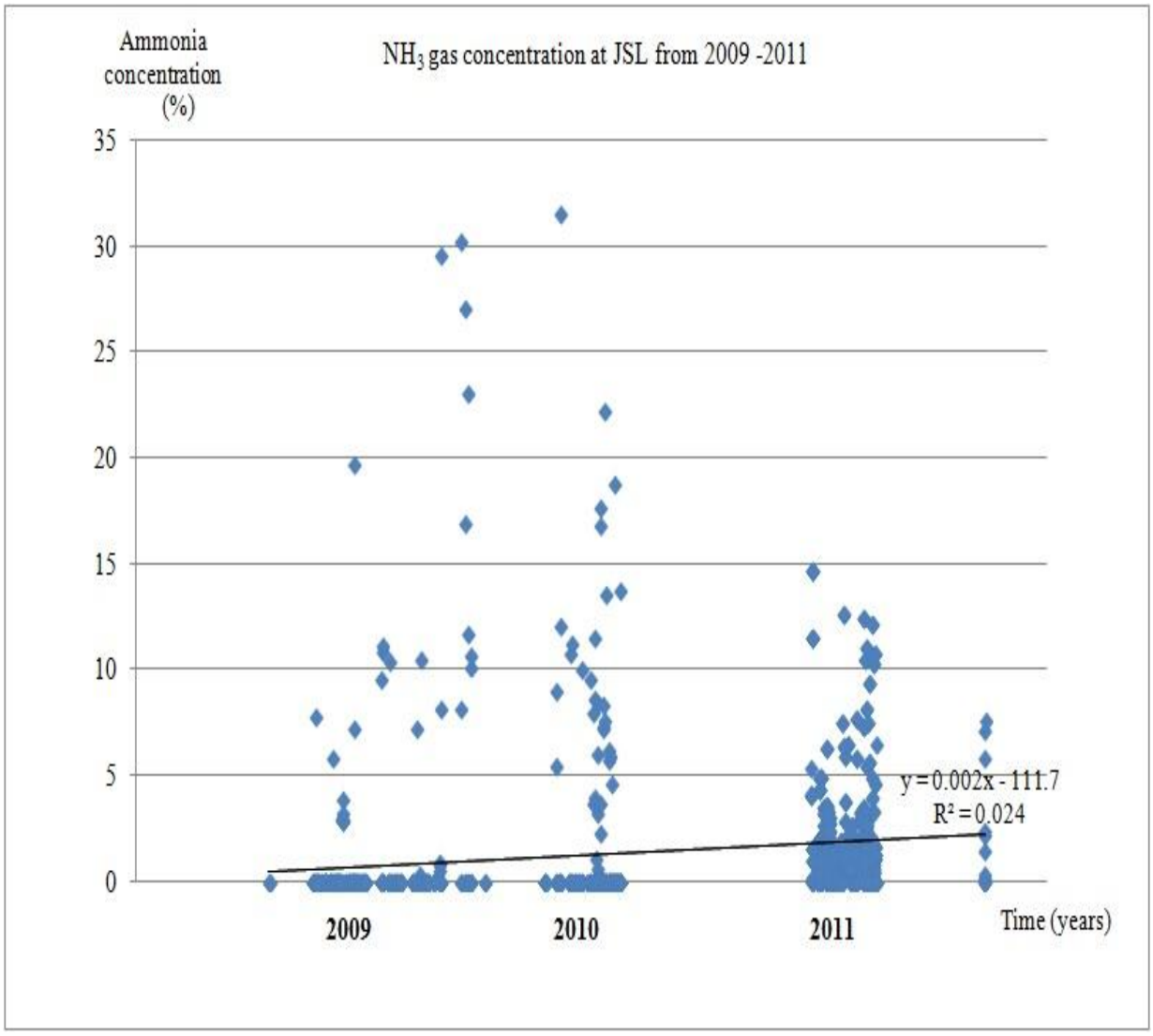

Figure 4.12 : NH_3 gas concentration at JSL

The ammonia flux was typical with less than 10% but it could reach as high as 35% v/v in JSL. Novel processes has been stimulated by the demonstration of anaerobic oxidation of ammonia to nitrogen gas via classic 'Anammox' process (Van de Graaf *et al.* 1990). Simon & Irene (1998) stated that no experimental evidence has demonstrated the loss of ammonia from landfills as nitrogen gas, and that the principal route for the removal of nitrogen from refuse is likely by ammonification and solubilisation in leachate. However, the test in JSL revealed that ammonia released via gas pathway is a promising result in nitrogen mass balance in landfill. Flow analysis study shows that the largest part of total-N (almost 80%) remained as landfill stock with N-output (< 5% N) in discharged leachate while another 25% via landfill gas during Ammonification process.

4.5 Data Modelling Approach: Substance Analysis Software (STAn) .

4.5.1 Substance Flow Analysis (SFA) for Nitrogen

For total N, the highest contributors were garden waste at 0.2%, mineral bottle at 0.7% and kitchen waste at 0.3%. Both mineral bottle and kitchen waste were the only waste types which were taken into account due to significant inorganic N content. The principal nitrogenous compound in refuse is protein which comes from the putrescible fraction of refuse. MSW in JSL contains plants and animal debris/carcass (crows and wild dogs), kitchen and food waste, soiled nappies (diapers) and domestic sewage sludge (Simon and Irene 1998). In JSL the amount of sanitary waste (diapers etc.) constitutes 0.7% (w/w basis) and is one of the nitrogenous compounds (Table 4.8).

The chemical transformation of nitrogenous compound from MSW in landfill condition need to be studied further since sanitary waste products constitute of very diverse materials during its manufacturing stages. EDANA (2007) reported that in one baby diaper, 35% are cellulose pulp, 33% superabsorbant polymer (SAP), 17 % polypropylene (PP), 6% polystyrene, adhesives and other material each with 4% and 1% elastics. One important observation in JSL was the co-disposal of sewage sludge (almost 0.5 tonne per day) from domestic sewerage services operated by Indah Water Consortium (IWK). Soiled nappies, which accounted for 0.7 % generation in JSL, is also one source of nitrogenous compound. Disposable diapers have significant contribution to total plastic waste stream in JSL. Future trend is expected to have more disposable diapers due to convenient and affordability factor. The co-composting process of source-separated organic fraction of MSW with disposable diapers has shown to have no technical difficulties in the biological process and it is possible at full-scale (Colón. *et al.* 2010). In addition to that, polystyrene from food packages is also prominent in JSL which contributed to 1.2% of total waste stream with 0.12% organic N. Studies indicated that consumer with higher living standard demand higher quality and more convenient items/goods with less preparation on the consumers' end regardless of its high price (Odum and Odum, 2006). Therefore, plastic packaging and polystyrene usage are widely utilized and disposed in sanitary landfill. Table 4.8 shows the detailed chemical analysis for Nitrogen for various waste samples.

Table 4.8 : N from various waste samples

Sample marking	Ammoniacal N (ppm)	Organic N (%)	Inorganic N (%)
Electronics	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Wood	ND (<0.01 ppm)	0.11	ND (<0.01%)
Aerosol Container	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Hard paper	ND (<0.01 ppm)	0.15	ND (<0.01%)
Aluminum Can	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Steel	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Polystyrene	ND (<0.01 ppm)	0.12	ND (<0.01%)
Coloured paper	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Garden waste	ND (<0.01 ppm)	0.21	ND (<0.01%)
Rubber mat	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Plastic Container	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Shoe	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Rubber hose	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Tin/Alloy	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
AA Battery	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Wire	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Packaging paper	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Mineral Bottle	ND (<0.01 ppm)	0.60	0.05
Plastic	ND (<0.01 ppm)	0.10	ND (<0.01%)
Cloth	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Kitchen waste	ND (<0.01 ppm)	0.27	0.05
Tiles	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Foam (superlon)	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)
Glass	ND (<0.01 ppm)	ND (<0.01%)	ND (<0.01%)

Based on literature review and research conducted in other Asian countries, it is assumed that all N in the organic material will transform to ammonia (gas form) or ammonium (liquid form) (Sundqvist, 1999). NH_3 or NH_4-N emitted in the leachate is the final product from the formed ammonia outflow into leachate system. NH_4-N concentration in leachate ranged between 900 to 2400 mg/l. According to Huber-Humer *et. al.* (2010), a lab-scale investigation on the fate of organic and inorganic N compounds of different waste via landfill simulation reactor indicated that NH_4-N in the leachate can be significantly reduced via *in-situ* aeration and the leached NO_3-N cannot compensate the reduction of NH_4-N. Even at high aeration rates, there are anaerobic zones where NO_3-N is denitrified to gaseous N_2. At JSL leachate lagoon/pond, there is no *in-situ* aeration resulting in the possibility of high NH_4-N concentration in the landfill leachate. Andersen *et al.,* 1998 explained that little is known about the nitrogen transformations and inter-relationship between NO_3-N and NH_4-N during refuse degradation inside landfill body. There may be undescribed nitrogen transformations occurring within it (Andersen *et. al.,* 1998). Time and cost are the main limit in this study. However, assumption made was that high NH_4-N leachate concentrations persist coincidentally with high organic content (Andersen *et al.,* 1998). This conforms with this study where NH_4-N concentration in leachate ranges between 900 to 2400 mg/l ammonia outflow into leachate system. Landfilled waste contained various materials such as wood, paper, textile, organic sludge and food that emit N_2O gas via denitrification and nitrification process in soil during microbial oxidation of ammonium NH_4^+. Landfill system is one important part of terrestrial environmental study. Denitrification of NO_2 releases N_2 gas and nitrification of NH_4^+ releases N_2O gas to the atmosphere (Wollast, 1981). One of the significant sources of

nitrogen emission came from ammonia (NH_3) via leachate and gas pathway. Ammonia is released during aeration process in leachate treatment. The *in-situ* gas reading of ambient air within JSL leachate treatment facility indicated that ammonia concentration was between 4 to 17 ppm, while at gas wells it was between 26 ppm and 75 ppm. Oxidation of ammonium NH_4^+ and N_2O gas released to the atmosphere is a very important topic and studied in coastal ecosystem at different depths (anoxia and hypoxia condition) (Naqvi, 2010). Also observed was that high NH_3 gas concentration into the atmosphere mainly from leachate treatment suggest that ammonia is released from the decomposition of protein in the refuse, even though concentrations of various nitrogenous components/fractions in the refuse during the decomposition are not known (Simon & Irene 1998). *Ex-situ* analysis of topsoil taken from landfill's new cell indicated that the total organic, total-N, ammoniacal-N, organic-N and inorganic-N were less than 0.01% (w/w). Looking at the N output in leachate from JSL, the total N concentration was remarkably high, between 2.84% and 3.45% N output. Increasing amount of water flowing through the landfill body for example via rainfall percolation increases the substance volume but not substance concentration. The uncertainty for all N-outputs from the system was underestimated as all are < 10% except for paper which is 17.5% (Figure 4.13) whereas the largest part of total-N (almost 80%) remained as landfill stock. Assumption was made by Huber *et al.*, (2004) that the low N-output is due to high mobilizable potential for N. This supports the findings of low N-output (< 5% N) in the discharged leachate. The landfill age could be one of many important factors to eventually quantify substance/material balance in a sanitary landfill.

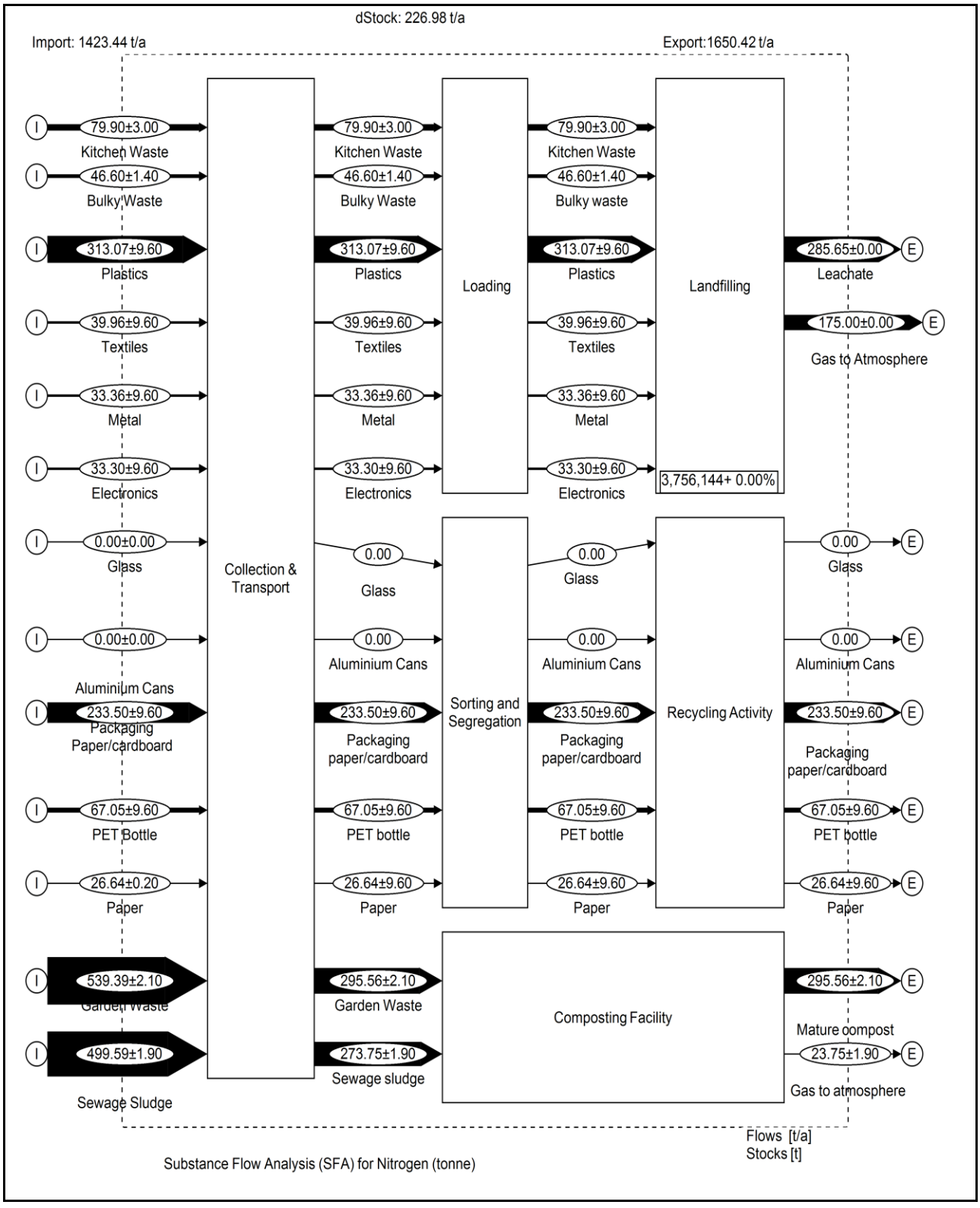

Figure 4.13 : Substance Flow Analysis for N in JSL (tonnes/year).

Table 4.9 was derived from STAn software and the breakdown of the process is indicated by the source process, destination process, mass flow as the input based on the laboratory analysis and calculated mass flow, considering data uncertainty to reconcile redundant data information. These process identified in the sanitary landfill operations for this study are typical including loading, collection and transport, actual landfilling (MSW input to landfill body), composting facility, sorting and segregation and recycling. The table presents the actual and calculated mass flow for nitrogen. Kitchen waste, bulky waste, plastics, textiles, metal and electronics are the main input and output from loading, collection and transport and final landfilling calculated at 77.87±2.96, 46.16±1.40, 292.30±8.35, 19.19±8.35, 12.59±8.35 and 12.53±8.35 tonne per year, respectively. Definition for textile waste varies, sometimes including rubber, leather and diapers (Sokka *et al.*, 2004). During the actual landfilling process, the calculated output for landfill gas and leachate accounted for 175.00±0.00 and 285.65±0.00 tonne/year, respectively. As for recycling activity the main inputs were packaging paper/cardboard, PET bottle and paper amounted to 264.77±8.38, 98.32±8.38 and 57.91±8.38 tonne/year, respectively. Since most of the N in municipal waste are associated with wastewaters, sewage sludge is important when improving the level of recycling in the municipal waste system (Sokka *et al.*, 2004). However, the glass and aluminum cans collected by informal recyclers at the landfill itself almost has no N value and accounted as informal recycling activity by waste pickers. As for composting facility, the final mature compost accounted for 366.54±1.79 tonne/year of N flow. The main inputs for compost ingredient were garden waste and household sewage sludge (mature) with 229.07±1.79 and 219.32±1.67 tonne per year of N respectively.

Table 4.9: Complete process list for N mass flow (actual and calculated) in JSL

		Process	Flow	Flow name	Source process	Destination Process	Mass flow [t/a]	Mass flow (calculated) [t/a]
Process name: Loading								
	Output							
		P2	F32	Kitchen Waste	P2, Loading	P5,Landfilling	79.90±3.00	77.87±2.96
		P2	F33	Bulky waste	P2, Loading	P5,Landfilling	46.60±1.40	46.16±1.40
		P2	F34	Plastics	P2, Loading	P5,Landfilling	313.07±9.60	292.30±8.35
		P2	F35	Textiles	P2, Loading	P5,Landfilling	39.96±9.60	19.19±8.35
		P2	F36	Metal	P2, Loading	P5,Landfilling	33.36±9.60	12.59±8.35
		P2	F37	Electronics	P2, Loading	P5,Landfilling	33.30±9.60	12.53±8.35
	Input							
		P2	F13	Kitchen Waste	P1,Collection & Transport	P2, Loading	79.90±3.00	77.87±2.96
		P2	F14	Bulky Waste	P1,Collection & Transport	P2, Loading	46.60±1.40	46.16±1.40
		P2	F15	Plastics	P1,Collection & Transport	P2, Loading	313.07±9.60	292.30±8.35
		P2	F16	Textiles	P1,Collection & Transport	P2, Loading	39.96±9.60	19.19±8.35
		P2	F17	Metal	P1,Collection & Transport	P2, Loading	33.36±9.60	12.59±8.35
		P2	F18	Electronics	P1,Collection & Transport	P2, Loading	33.30±9.60	12.53±8.35

Table 4.9 Continued								
Process name: Collection & Transport								
	Output							
		P1	F13	Kitchen Waste	P1,Collection & Transport	P2, Loading	79.90±3.00	77.87±2.96
		P1	F14	Bulky Waste	P1,Collection & Transport	P2, Loading	46.60±1.40	46.16±1.40
		P1	F15	Plastics	P1,Collection & Transport	P2, Loading	313.07±9.60	292.30±8.35
		P1	F16	Textiles	P1,Collection & Transport	P2, Loading	39.96±9.60	19.19±8.35
		P1	F17	Metal	P1,Collection & Transport	P2, Loading	33.36±9.60	12.59±8.35
		P1	F18	Electronics	P1,Collection & Transport	P2, Loading	33.30±9.60	12.53±8.35
		P1	F19	Glass	P1,Collection & Transport	P3,Sorting and Segregation	0.00	0.00
		P1	F20	Aluminum Cans	P1,Collection & Transport	P3,Sorting and Segregation	0.00	0.00
		P1	F21	Packaging paper/cardboard	P1,Collection & Transport	P3,Sorting and Segregation	233.50±9.60	264.77±8.38
		P1	F22	PET bottle	P1,Collection & Transport	P3,Sorting and Segregation	67.05±9.60	98.32±8.38
		P1	F23	Paper	P1,Collection & Transport	P3,Sorting and Segregation	26.64±9.60	57.91±8.38
		P1	F29	Garden Waste	P1,Collection & Transport	P4,Composting Facility	295.56±2.10	229.07±1.79
		P1	F39	Sewage sludge	P1,Collection & Transport	P4,Composting Facility	273.75±1.90	219.32±1.67

Table 4.9 Continued

Input								
		P1	F10	Garden Waste		P1,Collection & Transport	539.39±2.10	534.90±2.09
		P1	F9	Kitchen Waste		P1,Collection & Transport	79.90±3.00	70.74±2.98
		P1	F8	Packaging Paper/cardboard		P1,Collection & Transport	233.50±9.60	139.68±8.91
		P1	F7	Aluminum Cans		P1,Collection & Transport	0.00±0.00	0.00±0.00
		P1	F6	Glass		P1,Collection & Transport	0.00±0.00	0.00±0.00
		P1	F5	Electronics		P1,Collection & Transport	33.30±9.60	-60.52±8.91
		P1	F4	Metal		P1,Collection & Transport	33.36±9.60	-60.46±8.91
		P1	F3	Textiles		P1,Collection & Transport	39.96±9.60	-53.86±8.91
		P1	F2	Plastics		P1,Collection & Transport	313.07±9.60	219.25±8.91
		P1	F1	Bulky Waste		P1,Collection & Transport	46.60±1.40	44.60±1.40
		P1	F11	PET Bottle		P1,Collection & Transport	67.05±9.60	-26.77±8.91
		P1	F12	Paper		P1,Collection & Transport	26.64±0.20	26.60±0.20
		P1	F38	Sewage Sludge		P1,Collection & Transport	499.59±1.90	495.91±1.89

Table 4.9 Continued								
Process name: Composting Facility								
	Output							
		P4	F50	Mature compost	P4,Composting Facility		295.56±2.10	366.54±1.79
		P4	F51	Gas to atmosphere	P4,Composting Facility		23.75±1.90	81.85±1.67
	Input							
		P4	F29	Garden Waste	P1,Collection & Transport	P4,Composting Facility	295.56±2.10	229.07±1.79
		P4	F39	Sewage sludge	P1,Collection & Transport	P4,Composting Facility	273.75±1.90	219.32±1.67
Process name: Landfilling								
	Output							
		P5	F46	Gas to Atmosphere	P5,Landfilling		175.00±0.00	175.00±0.00
		P5	F45	Leachate	P5,Landfilling		285.65±0.00	285.65±0.00
	Input							
		P5	F32	Kitchen Waste	P2, Loading	P5,Landfilling	79.90±3.00	77.87±2.96
		P5	F33	Bulky waste	P2, Loading	P5,Landfilling	46.60±1.40	46.16±1.40
		P5	F34	Plastics	P2, Loading	P5,Landfilling	313.07±9.60	292.30±8.35

Table 4.9 Continued								
		P5	F35	Textiles	P2, Loading	P5,Landfilling	39.96±9.60	19.19±8.35
		P5	F36	Metal	P2, Loading	P5,Landfilling	33.36±9.60	12.59±8.35
		P5	F37	Electronics	P2, Loading	P5,Landfilling	33.30±9.60	12.53±8.35
Process name: Recycling Activity								
	Output							
		P7	F44	Packaging paper/cardboard	P7,Recycling Activity		233.50±9.60	264.77±8.38
		P7	F43	Glass	P7,Recycling Activity		0.00	0.00
		P7	F47	Aluminum Cans	P7,Recycling Activity		0.00	0.00
		P7	F48	PET bottle	P7,Recycling Activity		67.05±9.60	98.32±8.38
		P7	F49	Paper	P7,Recycling Activity		26.64±9.60	57.91±8.38
	Input							
		P7	F24	Glass	P3,Sorting and Segregation	P7,Recycling Activity	0.00	0.00
		P7	F25	Aluminum Cans	P3,Sorting and Segregation	P7,Recycling Activity	0.00	0.00
		P7	F26	Packaging paper/cardboard	P3,Sorting and Segregation	P7,Recycling Activity	233.50±9.60	264.77±8.38

Table 4.9 Continued								
		P7	F27	PET bottle	P3,Sorting and Segregation	P7,Recycling Activity	67.05±9.60	98.32±8.38
		P7	F28	Paper	P3,Sorting and Segregation	P7,Recycling Activity	26.64±9.60	57.91±8.38
Process name: Sorting and Segregation								
	Output							
		P3	F24	Glass	P3,Sorting and Segregation	P7,Recycling Activity	0.00	0.00
		P3	F25	Aluminum Cans	P3,Sorting and Segregation	P7,Recycling Activity	0.00	0.00
		P3	F26	Packaging paper/cardboard	P3,Sorting and Segregation	P7,Recycling Activity	233.50±9.60	264.77±8.38
		P3	F27	PET bottle	P3,Sorting and Segregation	P7,Recycling Activity	67.05±9.60	98.32±8.38
		P3	F28	Paper	P3,Sorting and Segregation	P7,Recycling Activity	26.64±9.60	57.91±8.38
	Input							
		P3	F19	Glass	P1,Collection & Transport	P3,Sorting and Segregation	0.00	0.00
		P3	F20	Aluminum Cans	P1,Collection & Transport	P3,Sorting and Segregation	0.00	0.00
		P3	F21	Packaging paper/cardboard	P1,Collection & Transport	P3,Sorting and Segregation	233.50±9.60	264.77±8.38
		P3	F22	PET bottle	P1,Collection & Transport	P3,Sorting and Segregation	67.05±9.60	98.32±8.38
		P3	F23	Paper	P1,Collection & Transport	P3,Sorting and Segregation	26.64±9.60	57.91±8.38

4.5.2 Substance Flow Analysis (SFA) for Carbon

Most wastes are not found in their natural pure compound state. Some wastes have other additives added to suit the product need, for attractiveness or durability. Aluminum cans and aerosol containers, for instance have labels to differentiate products. The label quantifies the carbon value in aluminum tins as shown in Table 4.10. The highest organic C was found in rubber mat. However, this product is not common in JSL. The high organic C quantified and yet common in JSL is garden waste and plastic containers with 2.12 % and 1.24 %, respectively. These products, which constitute a significant input of organic C are the main contributors to GHGs. This is due to their biodegradability and ability to be easily degraded by other existing compounds found in waste. These products of high C value should be seen as the main culprit in generating methane (Göran *et. al.*, 2000). At its peak, the methane to carbon dioxide ratio is 1.2:1 (Johannessen, 1999). The SFA study by Huber et al. (2004), at a 15-year test landfill, showed that 85% organic C available and > 95% of total-N was still inside the landfill body after 15-years of landfilling. Substance balance results from a 4-year old sanitary landfill show that in 1-year of landfilling, 29% of the input of the organic C left the landfill via gas pathway and less than 1% via leachate pathway, while 70% of C remained in the landfill body. The concentration of many constituents, including pollutants in landfill leachates decreases with refuse age. Leachate concentration peaks at landfill life of within 2 to 3 years from refuse placement and it gradually declines in the following years. Variation in leachate composition and cumulative mass removal of pollutant in solid waste is greatly attributed to age factors such as time since refuse placement or time since the first appearance of the leachate. Carbon flow in leachate and gas has also been studied.

Table 4.10: Initial C analysis in domestic waste, bulky waste and garden waste in JSL

Sample marking	TOC (%)	Inorganic -C (%)	Total C (%) (IPCC, 2006)
Electronics	0.15	0.06	2.7
Wood	0.27-0.71	ND(<0.05%)	19.6
Aerosol Container	0.08	ND(<0.05%)	0
Hard paper	0.22	ND(<0.05%)	41.4
Aluminum Can	0.10	ND(<0.05%)	0
Steel/Metal	0.16	ND(<0.05%)	0
Polystyrene	ND(<0.05%)	ND(<0.05%)	2.7
Color paper	ND(<0.05%)	ND(<0.05%)	41.4
Garden waste	2.12	ND(<0.05%)	19.6
Rubber mat	3.15	ND(<0.05%)	56.3
Plastic Container	1.24	ND(<0.05%)	75
Shoe	0.78	ND(<0.05%)	2.7
Rubber hose	0.56	ND(<0.05%)	56.3
Tin/Alloy	0.07-0.09	ND(<0.05%)	0
AA Battery	0.95	ND(<0.05%)	2.7
Wire	ND(<0.05%)	0.25	2.7
Packaging paper	ND(<0.05%)	ND(<0.05%)	41.4
Mineral Bottle	ND(<0.05%)	ND(<0.05%)	75
Plastic	ND(<0.05%)	ND(<0.05%)	75
Cloth	ND(<0.05%)	ND(<0.05%)	40
Kitchen waste	0.80	0.07	15.2
Tiles	0.04	0.12	2.7
Foam (superlon)	0.15	ND(<0.05%)	2.7

Mass-balance from field studies have indicated that only one percent (w/w) of the organic C is imported via leachate mainly as fatty acids while 99% would leave via the landfill gas as CH_4 and CO_2 (Baccini *et al.,* 1987 & Sundqvist, 1999). The organic C concentration inside JSL leachate pond was less than 10% which represents the overall outflow of only 1% from JSL. The ratio of BOD/COD varies during the lifetime of the landfill (Sundqvist, 1999). Seasonal variations of leachate affect the long term behavior of MSW degradation inside the landfill body. The BOD_5 during leachate sampling ranged from 1290 to 2270 mg/l, while COD was between 3200 and 65400 mg/l. The analysis shows that leachate collected from the compactor valve has high BOD and COD as compared to those taken from leachate lagoon. From the data, high leachate concentrations were observed in the early acid phase because of strong decomposition and rainfall leaching and supported by lab experiment by Otal *et. al.* (2005). The results of BOD and COD show higher leachate concentration in the compactors as compared to leachate treatment plant. This is due to chemical characteristics and nature of leachate that depends on dilution factor as a result of high rainfall volume.

The collection yields have often been very low in JSL and gas flow rate fluctuates over time. The quantity and quality of methane gas were recorded to estimate the future electricity generation. In actual landfill condition, the non-recovered gas will migrate through the topsoil cover, and methane-oxidizing micro-organisms will oxidize a part of the methane to carbon dioxide. *Ex-situ* analysis of topsoil taken from the landfill's new cell indicated that the total organic carbon (TOC) was 36% (w/w) while other parameters such as inorganic carbon, were less than 0.01% (w/w). Looking at the N output in leachate in JSL, the total N concentration was remarkably high, which is between 2.84%

and 3.45% N output. The question is how a higher material output is possible with a lower discharge. The answer lies in the inhomogeneity of the deposited MSW and possible inhomogeneous water flow characteristics (Renate *et al.,* 2002). As mentioned earlier, increasing amount of water flowing through the landfill body for example via rainfall percolation necessarily increases the substance volume but not substance concentration. Figure 4.9 shows the SFA for MSW for C in JSL for 2010. The GHG emission from landfilling was estimated, with respect to C. The readings for CH_4 is 50.7±13.5 % while CO_2 recorded at 35.6±9.6% . CO was low at 4.4± 2.1%. With GHG, total amount of waste generation and a fraction of waste disposed to landfill sites can be calculated (Yamada *et. al.,* 2003). Low uncertainty of C in the atmosphere (Figure 4.14) indirectly shows that there are adequate gas venting systems on-site to minimize C and N emissions to the atmosphere. However surface emission from cracks and fissures from topsoil is of concern in the long run. In addition, uncertainties in the SFAs were quite low for all compounds except for C in aluminum, for which the uncertainty was high (129.1%). For some materials, their degradation rate is unclear. The degradability potential of plastic and aluminum remains unknown. Hence, the carbon that is reutilized in the form of polymers (from the plastic recycling chain) is not landfilled and will not contribute to greenhouse gases (Arena & Gregario, 2013). Biogenic carbon compounds, for example garden waste and plastic, which contain high calorific value, maybe economical for energy-harvesting (except for kitchen waste and food waste with significantly high water content). There are potentially large losses of C and N via landfill gas from the landfill body.

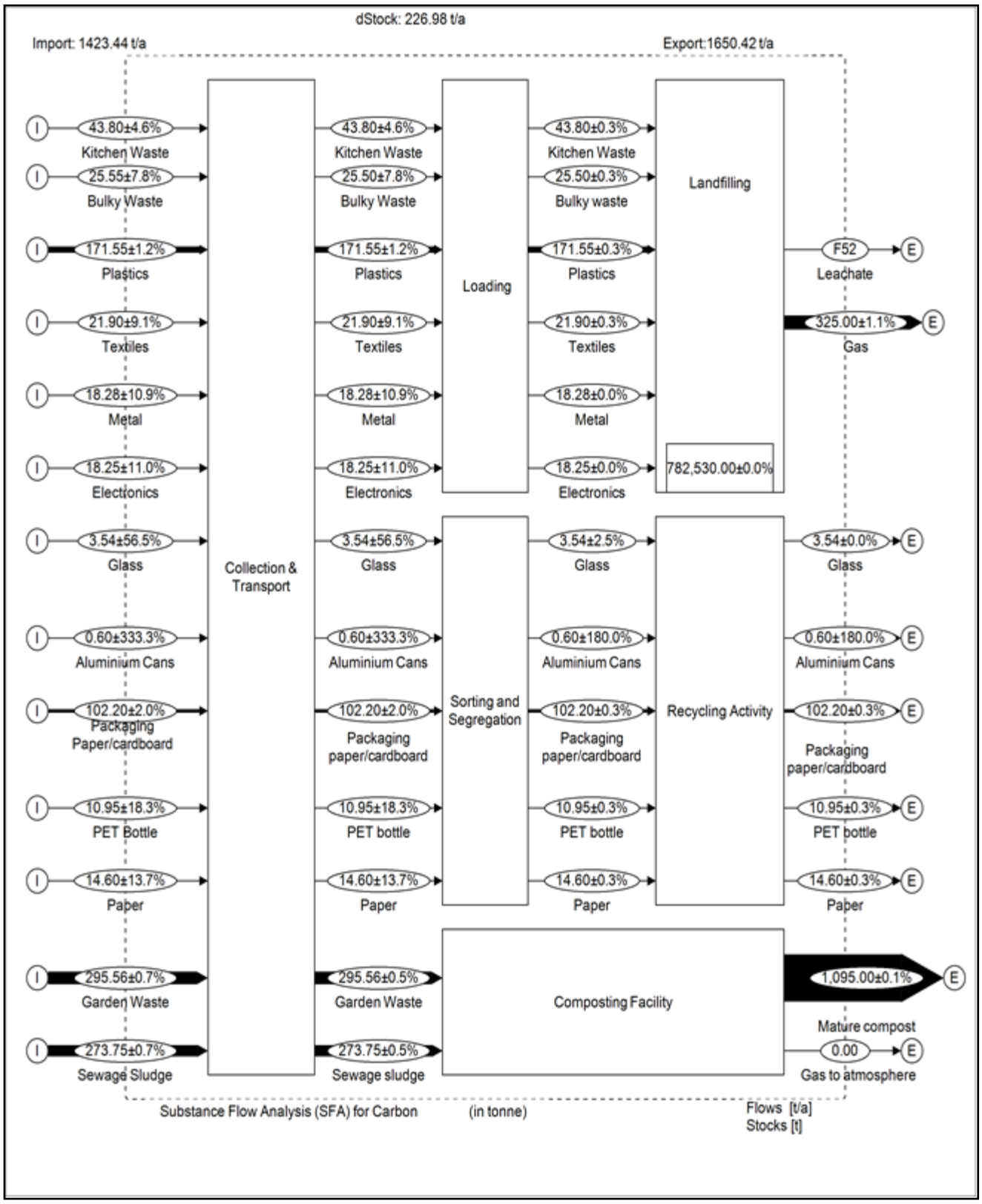

Figure 4.14 : Substance Flow Analysis for C in JSL (tonnes/year).

A complete process list for carbon mass flow (actual and calculated) in JSL is shown in Table 4.11. Methods of waste disposal prior to landfilling where wastes are subjected to physical, chemical and biological treatment and segregation are both costly and time consuming (AbdelNaser, 2008). Kitchen waste, bulky waste, plastics, textiles, metal and electronics are the main inputs and outputs from loading, collection and transport and final landfilling amounted to 43.71±0.12, 25.47±0.07, 170.14±0.47, 21.88±0.06, 18.28±0.00 and 18.25±0.00 tonne per year, respectively. Food waste trend among urban, suburban and rural consumers may be contributed by three significant sector namely; commercial, institutional and residential ranged between 37 to 40% of total waste generated (Fauziah, 2010). Similar findings were obtained in most developing countries (Zhu *et. al.*, 2009; Korner *et. al*, 2008; Agamuthu *et. al*, 2003; World Bank 1999). The disposal of unconsumed food waste including expired food products were also observed in JSL. This confirmed the existence of "throw-away society" among Malaysians and agreeable with various findings by Choy *et. al.*, (2003) and Irina and Shamuri (2004). During the actual landfilling process, the calculated output for landfill gas was 325.00±3.70 tonne/year. As for recycling activity the main inputs were packaging paper/cardboard, glass, aluminum cans, PET bottle and paper with 101.95±0.28, 3.54±0.00, 3.06±0.77, 10.95±0.03 and 14.59±0.04 tonne/year, respectively. Paper waste (newspaper or magazines) have lower recycling rate because of less market demand (Woodard *et. al.*, 2006; Alhumoud, 2005; Alhumoud *et. al.*, 2004). The commercial sector generates the largest percentage of corrugated paper (e.g carton boxes and packaging) and this was observed in JSL due to the disposal of packaging wastes upon receiving bulky supplies (Fauziah, 2010). Just like food waste, the trends indicate the

increase in corrugated paper waste generation with the increase of income level. The ability to purchase household items increased with increase in income level resulting with more packaging material including corrugated papers. As for composting facility, the final mature compost calculated for C flow was 910.10±1.21 tonne/year. The main input for compost ingredients were biomass which are garden waste and domestic sewage sludge (mature) with 465.95±1.22 and 444.14±1.22 tonne per year of C-flow, respectively. Komilis *et. al.,* (2012) indicated that biogenic carbon compounds contain high calorific value, for example garden waste (17,000 to 18,000 kJ dry matter/kg) and plastics (20,000 to 40,000 kJ dry matter/kg), and it might be economical for energy-harvesting (except for kitchen waste and food waste with significantly high water content). Food waste contains a number of substrates, and some are more degradable than others (Eleazer *et. al.*, 1997). This may indicate that from waste management perspective, composting and recycling activity are viable options to significantly reduce the amount of landfilled waste in JSL. Composting for instance should be in a big scale for commercialization purpose. Marketability for organic compost among related industries for example agricultural sector should be explored. Recycling should also be a formal activity in landfill even though such recycling practice at household level is still lacking even with the government promoting many recycling programs (AbdelNaser, 2008). During sorting and segregation process, the C flow from glass, aluminum cans, packaging paper/cardboard, PET bottle and paper were 3.51±0.09, 3.03±0.77, 101.96±0.28, and 10.95±0.03 and 14.60±0.04 tonne of C per year, respectively.

Table 4.11: Complete process list for carbon mass flow (actual and calculated) in JSL

		Process	Flow	Flow name	Source process	Destination Process	Mass flow [t/a]	Mass flow (calculated) [t/a]
Process name: Loading								
	Output							
		P2	F32	Kitchen Waste	P2, Loading	P5,Landfilling	43.80±0.12	43.71±0.12
		P2	F33	Bulky waste	P2, Loading	P5,Landfilling	25.50±0.07	25.47±0.07
		P2	F34	Plastics	P2, Loading	P5,Landfilling	171.55±0.47	170.14±0.47
		P2	F35	Textiles	P2, Loading	P5,Landfilling	21.90±0.06	21.88±0.06
		P2	F36	Metal	P2, Loading	P5,Landfilling	18.28±0.01	18.28±0.00
		P2	F37	Electronics	P2, Loading	P5,Landfilling	18.25±0.00	18.25±0.00
	Input							
		P2	F13	Kitchen Waste	P1,Collection & Transport	P2, Loading	43.80±2.00	43.54±1.83
		P2	F14	Bulky Waste	P1,Collection & Transport	P2, Loading	25.50±2.00	25.24±1.83
		P2	F15	Plastics	P1,Collection & Transport	P2, Loading	171.55±2.00	171.29±1.83
		P2	F16	Textiles	P1,Collection & Transport	P2, Loading	21.90±2.00	21.64±1.83
		P2	F17	Metal	P1,Collection & Transport	P2, Loading	18.28±2.00	18.02±1.83
		P2	F18	Electronics	P1,Collection & Transport	P2, Loading	18.25±2.00	17.99±1.83

Table 4.11 Continued								
Process name: Collection & Transport								
	Output							
		P1	F13	Kitchen Waste	P1,Collection & Transport	P2, Loading	43.80±2.00	43.54±1.83
		P1	F14	Bulky Waste	P1,Collection & Transport	P2, Loading	25.50±2.00	25.24±1.83
		P1	F15	Plastics	P1,Collection & Transport	P2, Loading	171.55±2.00	171.29±1.83
		P1	F16	Textiles	P1,Collection & Transport	P2, Loading	21.90±2.00	21.64±1.83
		P1	F17	Metal	P1,Collection & Transport	P2, Loading	18.28±2.00	18.02±1.83
		P1	F18	Electronics	P1,Collection & Transport	P2, Loading	18.25±2.00	17.99±1.83
		P1	F19	Glass	P1,Collection & Transport	P3,Sorting & Segregation	3.54±2.00	2.76±1.80
		P1	F20	Aluminum Cans	P1,Collection & Transport	P3,Sorting & Segregation	0.60±2.00	0.18±1.80
		P1	F21	Packaging paper/cardboard	P1,Collection & Transport	P3,Sorting & Segregation	102.20±2.00	101.42±1.80
		P1	F22	PET bottle	P1,Collection & Transport	P3,Sorting & Segregation	10.95±2.00	10.17±1.80
		P1	F23	Paper	P1,Collection & Transport	P3,Sorting & Segregation	14.60±2.00	13.82±1.80
		P1	F29	Garden Waste	P1,Collection & Transport	P4,Composting Facility	295.56±1.50	465.95±1.22
		P1	F39	Sewage sludge	P1,Collection & Transport	P4,Composting Facility	273.75±1.50	444.14±1.22

Table 4.11 Continued								
	Input							
		P1	F10	Garden Waste		P1,Collection & Transport	295.56±2.00	321.35±1.92
		P1	F9	Kitchen Waste		P1,Collection & Transport	43.80±2.00	69.59±1.92
		P1	F8	Packaging Paper/cardboard		P1,Collection & Transport	102.20±2.00	127.99±1.92
		P1	F7	Aluminum Cans		P1,Collection & Transport	0.60±2.00	26.39±1.92
		P1	F6	Glass		P1,Collection & Transport	3.54±2.00	29.33±1.92
		P1	F5	Electronics		P1,Collection & Transport	18.25±2.00	44.04±1.92
		P1	F4	Metal		P1,Collection & Transport	18.28±2.00	44.07±1.92
		P1	F3	Textiles		P1,Collection & Transport	21.90±2.00	47.69±1.92
		P1	F2	Plastics		P1,Collection & Transport	171.55±2.00	197.34±1.92
		P1	F1	Bulky Waste		P1,Collection & Transport	25.55±2.00	51.34±1.92
		P1	F11	PET Bottle		P1,Collection & Transport	10.95±2.00	36.74±1.92
		P1	F12	Paper		P1,Collection & Transport	14.60±2.00	40.39±1.92
		P1	F38	Sewage Sludge		P1,Collection & Transport	273.75±2.00	299.54±1.92

Table 4.11 Continued								
Process name: Composting Facility								
	Output							
		P4	F50	Mature compost	P4,Composting Facility		1,095.00±1.50	910.10±1.21
		P4	F51	Gas to atmosphere	P4,Composting Facility		0.00	0.00
	Input							
		P4	F29	Garden Waste	P1,Collection & Transport	P4,Composting Facility	295.56±1.50	465.95±1.22
		P4	F39	Sewage sludge	P1,Collection & Transport	P4,Composting Facility	273.75±1.50	444.14±1.22
Process name: Landfilling								
	Output							
		P5	F46	Gas	P5,Landfilling		325.00±3.70	325.00±3.70
		P5	F52	Leachate	P5,Landfilling		0	0
	Input							
		P5	F32	Kitchen Waste	P2, Loading	P5,Landfilling	43.80±0.12	43.71±0.12
		P5	F33	Bulky waste	P2, Loading	P5,Landfilling	25.50±0.07	25.47±0.07
		P5	F34	Plastics	P2, Loading	P5,Landfilling	171.55±0.47	170.14±0.47

Table 4.11 Continued								
		P5	F35	Textiles	P2, Loading	P5,Landfilling	21.90±0.06	21.88±0.06
		P5	F36	Metal	P2, Loading	P5,Landfilling	18.28±0.01	18.28±0.00
		P5	F37	Electronics	P2, Loading	P5,Landfilling	18.25±0.00	18.25±0.00
Process name: Recycling Activity								
	Output							
		P7	F44	Packaging paper/cardboard	P7,Recycling Activity		102.20±0.28	101.95±0.28
		P7	F43	Glass	P7,Recycling Activity		3.54±0.00	3.54±0.00
		P7	F47	Aluminum Cans	P7,Recycling Activity		0.60±1.08	3.06±0.77
		P7	F48	PET bottle	P7,Recycling Activity		10.95±0.03	10.95±0.03
		P7	F49	Paper	P7,Recycling Activity		14.60±0.04	14.59±0.04
	Input							
		P7	F24	Glass	P3,Sorting & Segregation	P7,Recycling Activity	3.54±0.09	3.51±0.09
		P7	F25	Aluminum Cans	P3,Sorting & Segregation	P7,Recycling Activity	0.60±1.08	-3.03±0.77
		P7	F26	Packaging paper/cardboard	P3,Sorting & Segregation	P7,Recycling Activity	102.20±0.28	101.96±0.28
		P7	F27	PET bottle	P3,Sorting & Segregation	P7,Recycling Activity	10.95±0.03	10.95±0.03

Table 4.11 Continued								
		P7	F28	Paper	P3,Sorting & Segregation	P7,Recycling Activity	14.60±0.04	14.60±0.04
Process name: Sorting and Segregation								
	Output							
		P3	F24	Glass	P3,Sorting & Segregation	P7,Recycling Activity	3.54±0.09	3.51±0.09
		P3	F25	Aluminum Cans	P3,Sorting & Segregation	P7,Recycling Activity	0.60±1.08	3.03±0.77
		P3	F26	Packaging paper/cardboard	P3,Sorting & Segregation	P7,Recycling Activity	102.20±0.28	101.96±0.28
		P3	F27	PET bottle	P3,Sorting & Segregation	P7,Recycling Activity	10.95±0.03	10.95±0.03
		P3	F28	Paper	P3,Sorting & Segregation	P7,Recycling Activity	14.60±0.04	14.60±0.04
	Input							
		P3	F19	Glass	P1,Collection & Transport	P3,Sorting & Segregation	3.54±2.00	2.76±1.80
		P3	F20	Aluminum Cans	P1,Collection & Transport	P3,Sorting & Segregation	0.60±2.00	0.18±1.80
		P3	F21	Packaging paper/cardboard	P1,Collection & Transport	P3,Sorting & Segregation	102.20±2.00	101.42±1.80
		P3	F22	PET bottle	P1,Collection & Transport	P3,Sorting & Segregation	10.95±2.00	10.17±1.80
		P3	F23	Paper	P1,Collection & Transport	P3,Sorting & Segregation	14.60±2.00	13.82±1.80