

4-1 Estimation of Al- Khartoum Waste Generation Rate

Based on the studies and reports of Khartoum state generation rate for MSW (0.58 kg /d/person) [Abo baker H. A. 2013].

We would therefore adopt the value of 0.58 kg/d/person for the year 2013 and increase it at the net rate (growth rates less waste reduction rate) of the expected GDP increase of 2.7% per year. So the waste generation rate over the proposing duration of this research is presented in table (4-1).

Waste generation rates in cities and urban areas are usually significantly higher than those of rural areas.

Table (4-1), Total waste generation calculation for Al-Khartoum

Year	Waste generation rate (kg/d/person)	Adopted growth rate
2013	0.58	2.7%
2014	0.60	2.7%
2015	0.62	2.7%
2016	0.64	2.7%
2017	0.66	2.7%
2018	0.68	2.7%

4-2 Calculation of Waste Disposal

According to [Tchobanoglous, G., 1993]. Typical densities for various wastes as found in countries and its compaction factors are reported by constituents in table (4-2)

Table (4-2), Typical Densities of MSW Constituent As Discarded And Its Compaction Factors [Tchobanoglous, G., 1993]

Waste Constituent	Density Kg/ m ³	Compaction Factors	
		Normally Compacted	Well Compacted
Organic	288	0.35	0.33
Paper	66	0.24	0.22
Plastic	64	0.15	0.10
Glass	194	0.60	0.40
Metals	189	0.24	0.60
Others	410	0.36	0.33

Depending on the amount of solid waste, we will obtain the weight of each components of solid waste, then depending on the density in the table (4-5), we will obtain the volume of all the components of the solid waste that disposal (discarded) and when we apply the compaction factor, we obtain the volume of the solid waste after compaction (compacted), then we obtain the discarded and compaction density, see table (4-3).

Table (4-3), Discarded and compacted volume of solid waste for Al-Khartoum

Waste constituent	Percentage by weight	Waste weight kg	Volume M ³	Compaction factor	Volume in landfill
Organic	49.5%	1,866,150	6,480	0.35	2,268
Paper	11.8%	444,860	6,740	0.24	1,618
Plastic	12.7%	478,790	7,481	0.15	1,122
Glass	3.5%	131,950	680	0.60	408
Metals	1.7%	64,090	339	0.24	81
Others	20.8%	784,160	1,913	0.36	689
Total	100%	3,770,000	23,633		6,186

Note: Discarded density = 160 kg/m³ Compacted density = 609 kg/m³

Table (4-4) present the expected total waste generated per year for the duration of ELOT as discarded and compacted in the landfill site.

Table (4-4), Waste generation rate calculation for Al-Khartoum

Year	Waste generation rate Kg/d/person	Population estimate for the year	Daily waste			Yearly waste		
			(Ton/day)	(m ³ /day)*	(m ³ /day)**	(Ton/year)	(m ³ /year)*	(m ³ /year)**
2014	0.60	6.809.046	4,085	25,531	6,708	1,491,181	9,319,881	2,448,573
2015	0.62	7.095.148	4,399	27,494	7,228	1,605,632	10,035,200	2,636,505
2016	0.64	7.385.158	4,727	29,544	7,762	1,725,173	10,782,331	2,832,796
2017	0.66	7.687.547	5,074	31,713	3,332	1,851,930	11,574,563	3,040,936
2018	0.68	7.993.851	5,436	33,975	8,926	1,984,074	12,400,463	3,257,921

Note: * Discarded volume

**Compacted volume

In order to verify the rate of waste generation in Khartoum State, which was obtained in the table (4-1), 30 samples were taken from different houses in the localities of Shareq- Alneel and Khartoum for 7 consecutive days. The weights of these wastes were calculated using a precise numerical balance and shown in tables (4-5), (4-6) figure (A-21).

Table (4-5), Samples of Waste Weight for Shareq- Alneel

Sample No.	F. size	D1	D2	D3	D4	D5	D6	D7
1	8	2.78	1.65	0.59	1.3	0.45	0	0
2	5	0.79	0.89	0.79	1.57	0.22	0	2.54
3	4	2.43	3.14	3.48	3.16	2.91	0	2.3
4	4	5.67	4.3	0	2.03	0	0	0
5	8	3.33	3.4	2.82	2.18	2.73	0.32	6.68
6	10	0.69	2.3	0.97	0.72	5.07	4.53	1.75
7	5	0.58	1.21	1.57	3.23	7.12	4.41	2.68
8	6	3.66	2.48	3.04	3.77	1.7	4.8	4.87
9	4	0.88	1.01	0.76	0.89	0	4.48	0
10	5	1.29	0.78	1.12	1.89	1.59	0.78	2.62
11	6	0	3.44	0.59	0.83	3.81	1.87	1.13
12	6	8.53	5.11	2.26	2.04	5.77	3.67	3.44
13	15	0	4.21	0	0.85	0	0	0
14	7	2.9	3.4	3.67	1.6	0	0	0
15	5	0	0	1.06	4.85	3.23	5.27	0
16	7	5.74	3.6	8.64	3.75	10.11	8.79	5.33
17	8	0	0	1.5	5.69	0	3.38	0
18	6	5.27	4.3	5.3	2.6	7.12	7.18	4.28
19	3	0	0	2.44	0	4.66	0.86	0
20	2	3.42	2.97	4.05	5.48	0	11.52	3.45
21	7	1.01	2.11	0.44	5.16	0.42	0.76	0.48
22	7	1.28	1.68	1.92	0.84	0.73	0.5	0.89
23	8	5.02	2.6	3.39	0.88	8.07	1.98	0.61
24	8	2.56	3.14	3.02	3.06	3.05	3.52	3.58
25	8	5.4	4.4	0.62	5.5	6.87	4.24	2.95
26	8	4.06	4.21	0.81	1.69	3.84	3.16	3.83
27	8	4.35	3.78	0.56	3.27	0.65	0.85	0.4
28	8	0.44	0.64	1.45	1.06	1.05	3.52	0.44
29	10	8.79	4.5	0.4	4.6	2.28	5.12	2.11
30	8	0	3.66	4.68	2.46	4.88	3	5.27

Note: Generation rate (0.45)

Table (4-6), Samples of Waste Weight for AL Khartoum

Sample No.	F. size	D1	D2	D3	D4	D5	D6	D7
1	7	2.4	2.2	7.3	5.5	3.3	3.5	1.8
2	7	5.1	5	19.3	4	2.8	6.5	3.2
3	4	19.2	7.4	18	25.9	6.9	8.7	5.7
4	7	2.2	2.7	5	4.5	2.6	2.1	2.3
5	7	2.6	0.2	33.9	9.5	13.2	8.5	0
6	4	0.9	0	5.8	4.1	1.7	1.6	1.9
7	6	0	12.2	52.8	21.6	6.8	9.8	2.6
8	12	3.8	4.5	15	9.4	8.7	4.3	4.9
9	9	3	3.6	8.9	6.8	2.5	2.1	3.2
10	5	2.7	1.5	9.5	5	3	4.4	2
11	6	3.8	2.4	14.4	3.5	0	0	0
12	3	13	0	0	2.2	0	0	0
13	10	2.9	5.6	9.7	8.3	3.3	5.6	2.7
14	5	0	3	0	0	0	0	0
15	5	4.8	3.6	0	4.6	0	1.2	0
16	6	5	0.8	2.7	3.6	1.4	0.9	1
17	10	6.2	0	0	15.9	0	0	0
18	6	2.6	3.8	7.6	5.7	1.2	2.9	2.5
19	6	5	3	1.9	2.8	2	2.8	4.1
20	8	6.9	4.6	14.7	11.3	4.3	5.2	5.7
21	7	4.7	3.8	0	5.4	1.6	0	6.5
22	4	1.6	1.2	4.9	5.1	0.7	2.3	0.7
23	5	0.9	1.9	4	2.8	1.5	1.1	1.8
24	3	3.7	3.3	4.5	4.1	3.8	1.8	2.1
25	4	2.4	0.7	7.8	2.8	1.4	1.2	2.4
26	4	3.3	2.9	0	12.4	3	0	0
27	9	4.8	1	0	2.7	1.5	0	0

Note: Generation rate (0.72)

The verification study to find the increase in waste generation rate reveals (0.59) kg/d/person in the first months of 2017 . This means the increase in the waste generation rate is about 0.003 i.e. 0.3% per year. Since the obtained rate of increase is less than the rate adopted in the study (2.7%) , then the suggested landfill areas will be satisfactory for future beyond 2018.

4-3 Quantities of Recyclable

In the previous sections, an estimate of the amount of MSW generated and its composition was presented. Extrapolation of these quantities over time was also provided for the 5 years constituting the duration of the Estimated Landfill Operation Time (ELOT).

The current MSW composition was considered to include the percentages of wastes categories were shown in the previous chapter, table (3-2) and figure (3-3).

Table (4-4) addressed the tonnage of waste expected to be generated on a yearly basis over the duration of the estimated landfill operation time.

As mentioned in the above sections, the composition of the waste stream changes over time. The waste we throw today is different from the waste we used to throw 5 years ago and therefore different from the waste we will be throwing in 5 years. Some of this difference is caused by industrial breakthroughs that have led to the larger presence of plastics, aluminum and paper products in our waste. The increase in these waste categories has been caused mainly by the use of new food packaging products (plastics), the use of soft drinks in cans (aluminum) and the use of photocopiers, personal computers and printers that have increase the amount of paper products in our waste stream. The anticipated change in waste composition caused by industrial breakthrough is difficult to estimate.

Another factor affecting the change in composition of the waste stream is the economic development of a country. Industrialized countries with a flourishing economy generate more waste than developing countries. The composition of the waste in such countries is also very different from the composition of the waste in developing countries [**Ground Structure Engineering Consultant Inc., 2004**]. The percentage of inorganic waste tends to increase because of more packaging of

the food while the percentage of the organic waste tends to decrease because of the packaging of smaller portion of food leading to less leftover or the pre-processing of the food in the industry.

Based on the above, anticipated waste composition in 2018 has been predicted. Extrapolation of the waste composition between 2013 and 2018 is presented in the table (4-7) and figure (4-1) in the key milestone dates at the ELOT.

Table (4-7), Modeled percentage of waste by constituent over the ELOT

Year	Modeled percentage of waste constituent					
	Organic	Paper	Plastics	Glass	Metals	Others
2014	49%	12%	13%	3.5%	2%	20.5%
2015	48%	12.5%	13%	4%	2%	20.5%
2016	46%	13%	13.5%	4%	3%	20.5%
2017	46%	13.5%	14%	4%	3.5%	19%
2018	44%	14.5%	14%	4.5%	4%	19%

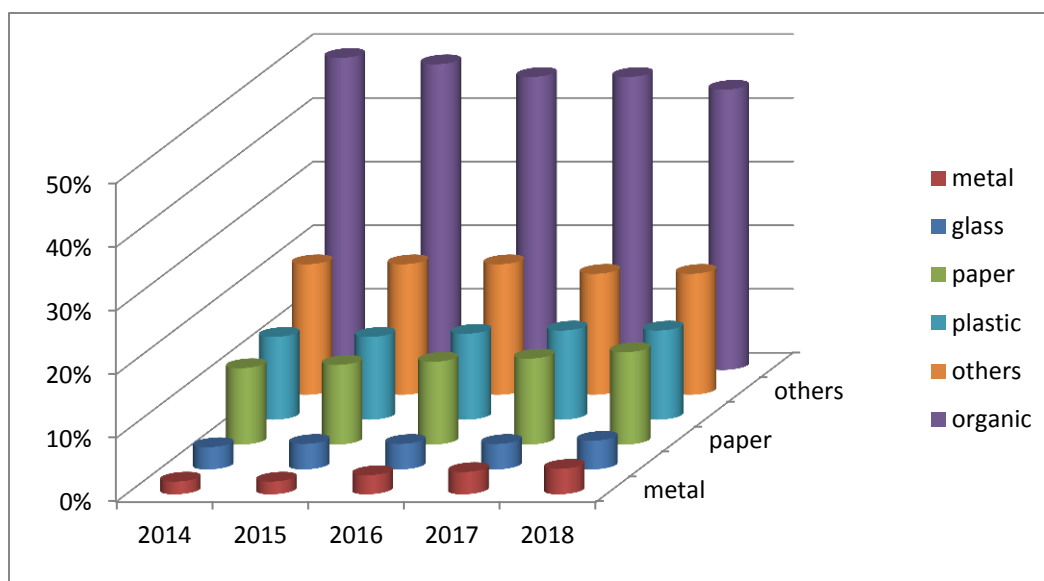


Figure (4-1): Modeled percentage Of Waste by Constituent over the Duration of the ELOT

Depending on tables (4-4), (4-7), the quantities of recyclables can be extrapolated (on a daily and yearly basis) for the duration of the ELOT as are presented in the tables (4-8), (4-9).

Table (4-8), Modeled daily tonnage of waste by constituent over the ELOT

Year	Modeled daily tonnage of waste by constituent(Tons/day)					
	Organic	Paper	Plastics	Glass	Metals	Others
2014	2002	490	531	143	82	837
2015	2112	550	572	176	88	902
2016	2174	615	638	189	142	969
2017	2334	685	710	203	178	964
2018	2392	788	761	245	217	1033

Table (4-9), Modeled yearly tonnage of waste by constituent over the ELOT

Year	Modeled yearly tonnage of waste by constituent(Tons/year)					
	Organic	Paper	Plastics	Glass	Metals	Others
2014	730679	178942	193854	52191	29824	305692
2015	770703	200704	208732	64225	32113	329155
2016	793580	224272	232898	69007	51755	353661
2017	851888	250011	259270	74077	64818	351867
2018	872993	287691	277770	89283	79363	376974

4-4 Expected Wastes Supply

4-4-1 Supply of Organic

According to the values adopted in the table (3-2), organic waste comprises about 49.5 % of the total waste stream disposed.

Based on a modeled total waste tonnage of 1,491,182 tons expected in 2014, the estimated amount of organic waste is expected to be in the order of about 730,679 tons.

According to the modeled percentage in the table (4-7), changes in waste composition over the duration of the ELOT are based on a decrease of organic waste from 49% to 44%. Despite this decrease, based on the increase in total waste quantities generated over 5 years of the proposing landfill operation time, significant increase in organic waste is expected over the coming 5 years as can seen in the table (4-10) below.

Table (4-10), Organic waste generation over the duration of the ELOT

Year	Total waste generated (Tons/day)	Total waste generated (Tons/year)	Percent organic waste (%)	Expected organic supply (Tons/day)	Expected organic supply (Tons/year)
2014	4,085	1,491,181	49%	2002	730679
2015	4,399	1,605,632	48%	2112	770703
2016	4,727	1,725,173	46%	2174	793580
2017	5,074	1,851,930	46%	2334	851888
2018	5,436	1,984,074	44%	2392	872993

4-4-2 Supply for the Paper Waste

According to the values adopted in the table (3-2), paper waste comprises about 11.8 %

Based on a modeled total waste tonnage of 1,491,182 tons expected in 2014, the estimated amount of paper waste is expected to be in the order of about 178,942 tons.

According to the modeled percentage in the table (4-7), changes in waste composition over the duration of the ELOT are based on an increase of paper waste from 12% to 14.5%. This is considered a relatively significant increase over 5 years of the proposing landfill operation time, Such an increase compound with the increase in waste quantities over same duration would result in large quantities of paper waste as shown in the table (4-11) below.

Table (4-11), Paper waste generation over the duration of the ELOT

Year	Total waste generated (Tons/day)	Total waste generated (Tons/year)	Percent paper waste (%)	Expected paper supply (Tons/day)	Expected paper supply (Tons/year)
2014	4,085	1,491,181	12%	490	178942
2015	4,399	1,605,632	12.5%	550	200704
2016	4,727	1,725,173	13%	615	224272
2017	5,074	1,851,930	13.5%	685	250011
2018	5,436	1,984,074	14.5%	788	287691

4-4-3 Supply of Plastics Waste

According to the waste composition for the Khartoum state (table (3-2)), plastics comprises about 12.7 % of the total waste stream disposed with the following expected composition. Based on a modeled total waste tonnage of 1,491,181 tons expected in 2014, the estimated amount of paper waste is expected to be in the order of about 193,854 tons.

According to the modeled percentage in the table (4-7), changes in waste composition over the duration of the ELOT are based on an increase of plastic

waste from 13% to 14%. This is considered a relatively significant increase over 5 years of the proposing landfill operation time, Such an increase compound with the increase in waste quantities over same duration would result in large quantities of paper waste as shown in the table (4-12)

Table (4-12), Plastics waste generation over the duration of the ELOT

Year	Total waste generated (Tons/day)	Total waste generated (Tons/year)	Percent plastics waste (%)	Expected plastics supply (Tons/day)	Expected plastics supply (Tons/year)
2014	4,085	1,491,181	13%	531	193854
2015	4,399	1,605,632	13%	572	208732
2016	4,727	1,725,173	13.5%	638	232898
2017	5,074	1,851,930	14%	710	259270
2018	5,436	1,984,074	14%	761	277770

4-4-4 Supply of Glass Waste

According to the waste composition for the Khartoum state (table (3-2)), glass comprises about 3.5 % of the total waste stream disposed with the following expected composition. Based on a modeled total waste tonnage of 1,491,181 tons expected in 2014, the estimated amount of paper waste is expected to be in the order of about 52,191 tons.

According to the modeled percentage in the table (4-7), changes in waste composition over the duration of the ELOT are based on an increase of glass waste from 3.5% to 4.5%. This is considered a relatively significant increase over 5 years of the proposing landfill operation time, Such an increase compound with

the increase in waste quantities over same duration would result in large quantities of glass waste as shown in the table (4-13)

Table (4-13), Glass waste generation over the duration of the ELOT

Year	Total waste generated (Tons/day)	Total waste generated (Tons/year)	Percent glass waste (%)	Expected glass supply (Tons/day)	Expected glass supply (Tons/year)
2014	4,085	1,491,181	3.5%	143	52191
2015	4,399	1,605,632	4%	176	64225
2016	4,727	1,725,173	4%	189	69007
2017	5,074	1,851,930	4%	203	74077
2018	5,436	1,984,074	4.5%	245	89283

4-5 Recycling Targets

1. A realistic sorting target for organic waste is typically in the order of 70% [Tchobanoglous, G., 1993]. According to a realistic composting target of sorted organic waste is typically around 50%. The remaining 50% typically consist of impurities and moisture.
2. If properly separated, recycling rates in excess of 50% of the various paper products could be achieved [Maryanne Grieg, May 2004].
3. Recycling targets for plastics are relatively high based on the technologies available for separating this waste category from the general waste stream. However, as certain plastics are not recyclable, or there is relatively no market for their recycling, it is usually not possible to recycle more than about 60% of the total plastic wastes [Information on plastics & Environment].

4. Based on the difficulty to market mixed cullet and some of the colored glass, the recycling target for glass is not very high. Recycling targets could be obtained for clear glass. However, since clear glass is only about 50% of the total glass quantities generated, the recycling target for glass overall cannot realistically exceed 50% [EPA, 1992].
5. The recycling target for aluminum could be 50 to 65% based on the available technologies to efficiently separate such wastes [EPA, 1993].
6. The target for steel recycling could be around 50% [Michael D. Fenton, 1998].
7. Recycling rates of up to 60% have been obtained for C&D wastes.

Based on above, it can be conclude the reduction of solid waste stream of Khartoum state if using proper recycling technology as shown in tables below.

Table (4-14), Modeled Daily Tonnage Reduction of waste by constituents over the duration of the ELOT

Year	Modeled Daily Tonnage of waste by constituent (Tons/day)						
	Organic 50%	Paper 50%	Plastic 60%	Glass 50%	Metals 50%	Others 60%	Total
2014	1001	245	319	72	41	502	2180
2015	1056	275	343	88	44	541	2347
2016	1087	308	383	95	71	581	2525
2017	1167	343	426	102	89	578	2705
2018	1196	394	457	123	109	620	2899

Table (4-15), Modeled Yearly Tonnage Reduction of waste by constituents over the duration of the ELOT

Year	Modeled Yearly Tonnage of waste by constituent (Tons/year)						
	Organic 50%	Paper 50%	Plastic 60%	Glass 50%	Metals 50%	Others 60%	Total
2014	365340	89471	116312	26096	14912	183415	795546
2015	385352	100352	125239	32113	16057	197493	856606
2016	396790	112136	139739	34504	25878	212197	921244
2017	425944	125006	155562	37039	32409	211120	987080
2018	436497	143846	166662	44642	39682	226184	1057513

Consequently, if proper recycling technology used for all waste constituents as mentioned above. The overall waste reduction per day and year were shown in the table (4-16).

Table (4-16), Modeled Daily and Yearly Tonnage Reduction of waste over the duration of the ELOT

Year	Modeled Daily and Yearly Tonnage of waste reduction						
	(Tons/ day)	(Tons/ year)	(Tons/ day)	(Tons/ year)	(Tons/ day)	(Tons/ year)	Reduction
2014	4,085	1,491,181	2180	795546	1905	695635	46%
2015	4,399	1,605,632	2347	856606	2052	749026	46%
2016	4,727	1,725,173	2525	921244	2202	803929	46%
2017	5,074	1,851,930	2705	987080	2369	864850	46%
2018	5,436	1,984,074	2899	1057513	2537	926561	46%

4-6 Recycling Difficulties

Recycling is not a direct income generator. It has non-negligible capital and operating costs. Actually, most programs are subsidized and cannot support themselves. However, other benefits such as prolonged landfill life, and other savings and socio-economic and environmental aspects need to be entered into the equation in order to justify recycling. In order to achieve a sustainable income generation from the sale of the recyclable, and a significant reduction of waste ultimately disposed of at a landfill site, the recycling program required a series of investments associated with long term operating costs [**Bill Sheehan, 2000**].

Even with the right level of investment, successful recycling is not guaranteed. Programs must be properly dimensioned with the support of enforceable legislations. Furthermore, public participation must be-maximized in order to make the programs economically efficient. Market values should be well studied in order to ensure that the waste separation program implemented would result in a waste reduction at the disposal site and a cost effective recovery of the waste separation investment. The worst scenario is to invest in a sorting facility, to separate the waste only to find out there is no market for the separated waste and that the waste has to be taken back to the local landfill after sorting. This has often been the case with glass, compost or contaminated and commingled paper [**Washington State Department of Ecology, 2000**].

A number of recycling programs have failed because the market was not available, not sustainable or not compatible with the quality of the sorted waste. Other reasons have often included incompatibility between the investment and the demand or the supply or the limited participation of the population in recycling programs.