The Proposed Alumina Industry and How to Mitigate Against the Red Mud Footprint in Ghana

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ABSTRACT

Bauxite tailings, also known as red mud, are often generated in vast quantities by extracting alumina from bauxites. The relatively complex composition of the red mud, an insoluble residue from bauxite processing, coupled with its fine particle size distribution, high pH, poor settling properties and some toxic rare metal associations, make its disposal problematic. Two locations are being considered for the sitting of a bauxite refinery in Ghana. Since large quantities of tailings is expected to be produced at a selected site efforts need to be geared towards its management to ensure that the red mud footprint is not repeated in Ghana as happened elsewhere. This paper considers the two proposed sites and applies a site ranking criteria to identify the most suitable site, as well as an environmentally suitable disposal technology based on the selected site conditions and the general red mud characteristics. This study could serve as a sustainable development approach in site selection and the choice of disposal technologies.

1 Introduction

Bauxite is a naturally occurring raw material used for the production of alumina which may be further refined to aluminum. In Ghana the main bauxite deposits are found in Awaso, Kibi, Mt. Ejuamena and Nyinahin (Figure 1). The total estimated reserve base of bauxite in Ghana stands at 554100000 metric tons with the Awaso deposit producing and exporting bauxite mainly to Europe since 1942. Although alumina production is not done in Ghana, there is now a serious discussion of setting up such a processing plant.

The government of Ghana has signed two separate memorandum of understanding (MOU) with Aluminium Company of America (Alcoa) and Aluminium company of Canada (Alcan) to explore the feasibility of developing a bauxite mine from Ghana's bauxite deposit, and refinery with a production capacity of about 1.5 to 2 million tons of alumina per annum (Achiaw, 2005).

It is being contemplated that the bauxite will be mined and hauled to either Tema or Sekondi-Takoradi for processing due to existing infrastructure (i.e. habour, rail transport etc) in these cities.

Bauxite is a residual deposit formed by the weathering of source rocks with appropriate climatic conditions. As such the minerals formed during weathering are generally fine grained, poorly crystalline with large surface area that may be dissolved or modified by mild chemical treatments. Hence the tailings (also colloquially referred to as 'red mud') expected to be generated by a bauxite refinery may have peculiar characteristics that could be deleterious to the environment if not well managed. The characteristics include extremely fine particle size distribution, high suspended solids content, high pH (from the use of caustic soda in digestion) and dissolved metal content. The detrimental environmental effects of these characteristics may include dust pollution, increase in turbidity and pH of receiving water bodies and the migration of dissolved metals into surface water and groundwater.

Large scale environmental pollution caused by red mud in countries such as Brazil, India and Jamaica are noteworthy in appreciating and evaluating these environmental impacts. For instance in Jamaica, readings from domestic water wells, in communities around these tailings impoundments, have indicated high pH and dissolved metal concentrations (Anon, 1995). Lake Batata in Brazil has also been inundated with bauxite tailings (Anon, 1995). However, the choice of a favourable disposal site and the disposal technology adopted may either aid or ameliorate these known impacts. Therefore it would appear that the disposal of the waste that will be created by the refinery is probably one of the most critical environmental factors to be considered in the sitting of the refinery (Momade, 2007).

In the extraction of alumina from bauxite, refinery tailings (red mud) are generated in vast quantities. The tailings are generated as slurry of about 20% solids content. Depending on the quality and mineralogical composition of the bauxite processed, as well as, the digestion technology and the efficiency of the mud washing unit, between 1 to 2.5 tons of dry bauxite residue is generated per ton of alumina produced (Anon, 1998; Nguyen and Boger, 1998). With an estimated production capacity ranging from 1.5 to 2 million tons of alumina per annum the amount of tailings solids to be generated is about 5 million tons per annum or about 13000 tons per day.

The design of tailings impoundment depends on the quantity and individual characteristics of the tailings produced, as well as, climatic, topographic, geotechnical characteristics of the disposal site and the regulatory requirement (Anon, 1994 and Fourie, 1999).

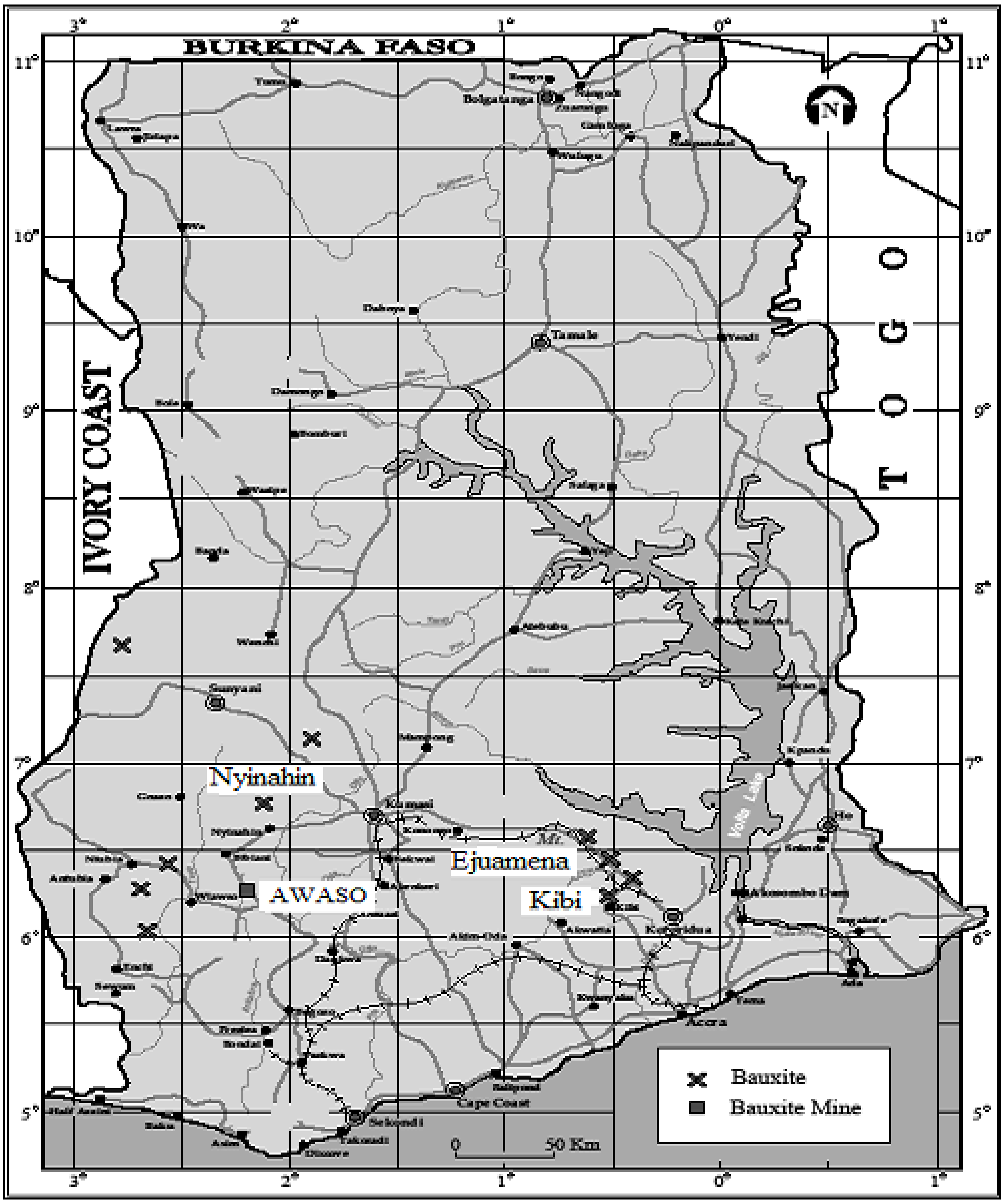


Figure 1: Location of the four major Ghanaian bauxite deposits (courtesy Minerals Commission, Ghana)

In this paper, a review of the likely tailings characteristics to be generated by the refinery based on the chemical composition of Ghana's bauxite deposits was conducted. A site comparability study was used to rank the best site based on a review of meteorological and environmental geological data as well as socio-economic conditions of the Tema Municipal Assembly (TMA) or Shama-Ahanta East Metropolitan Assembly (SAEMA) in the Sekondi-Takoradi area. Various tailings disposal technologies were also assessed to help identify an environmentally suitable disposal site, as well as, the most suitable disposal technology.

2 Methodology

Secondary meteorological and geological data were obtained from various sources including the Environmental Protection Agency (EPA), Volta Aluminum Company (VALCO), Ghana Geological Survey Department, Soil Research Institute of Ghana and the Meteorological Department of Ghana. Data obtained were studied and information gathered was used in the determination of a suitable disposal technology for red mud. Visits to the study areas for personal observations of the terrain, water sources and usage as well as land use were also conducted. The study also reviewed the characteristics of red mud (bauxite tailings), and the process liquor associated with it, to ascertain their suitability for a particular disposal technology as well as the likely environmental impact associated with its disposal. The general site characteristics of the study area were also examined. These assessments were done using a worse case scenario analysis. A site comparison criterion was used to compare the proposed sites and a technology compatibility test was also used to determine the best disposal technology.

3 Compositions of Kibi and Awaso bauxite deposits

The compositions of the Kibi and Awaso bauxite deposits, both classified as lateritic bauxite, have been investigated by various groups. Table 1 presents the chemical composition of samples from four selected pits of the Kibi deposit together with an average sample according to ALUTERV-FKI whilst the major oxides, namely Al_2O_3, Fe_2O_3, SiO_2 and $Ti0_2$ are distributed in various mineralogical phases in Table 2. Table 3 shows the average of the bulk chemical compositions of samples from the various profiles of the Awaso (Ichiniso) bauxite deposit. The compositions shown in tables 1, 2 and 3 demonstrate that bauxite varies in composition very considerably. This variation is further exposed in Table 4 which shows the average chemical composition of some samples of Ghana's bauxite deposits.

Table 1: Chemical composition (wt %) of bauxite samples from four pits and an average sample (ALUTERV-FKI) of the Kibi deposit (*Momade, 1991 and Kesse, 1985*)

Component	Sample 1	Sample 2	Sample 3	Sample 4	Average Sample (ALUTERV-FKI)
Al_2O_3	45.6	56.5	46.0	53.7	46.6
SiO_2	4.5	1.0	5.2	1.8	2.5
Fe_2O_3	22.1	8.4	18.3	13.8	22.5
TiO_2	3.7	4.1	2.8	4.0	3.3
CaO	0.05	0.05	0.05	0.05	0.03
MgO	0.06	0.02	0.05	0.04	0.02
V_2O_5	0.15	0.11	0.11	0.13	0.12
P_2O_5	0.19	0.01	0.14	0.15	0.17
MnO_2	0.015	0.12	0.03	0.01	0.03
LOI	22.1	27.5	27.2	24.2	24.6

Table 2: Mineral composition (wt %) of bauxite samples from four pits and an average sample (ALUTERV-FKI) of the Kibi deposit (*Momade, 1991 and Kesse, 1985*)

Component	Sample 1	Sample 2	Sample 3	Sample 4	Average Sample (ALUTERV-FKI)
Al_2O_3 in gibbsite	31.9	42.0	36.1	40.0	38.5
in beohmite	8.4	12.5	4.8	9.8	4.0
in diaspore	0.3	0.2	0.2	0.5	0.6
in kaolinite	2.8	0.9	3.4	1.4	1.6
in goethite	2.0	0.8	1.5	1.8	1.6
in haematite	0.2	0.1	0.2	0.2	0.3
Fe_2O_3 in goethite	11.2	5.5	9.7	9.9	9.1
in haematite	10.9	2.9	8.6	3.9	13.4
SiO_2 in kaolinite	3.4	1.0	4.0	1.8	1.9
in quartz	1.1	-	1.2	-	0.6
TiO_2 in anatase	2.6	2.4	2.4	3.2	2.9
in rutile	1.1	1.7	0.4	0.8	0.4

Table 3: Major (wt %) and trace element (ppm) composition of bauxite samples from different litho-units in the lateritic profile of the Awaso (Ichiniso bauxite) deposit (Gawu, 1993)

Litho-units	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	K_2O	Na_2O	P_2O_5	LOI	SUM
Ferruginous Laterite[1]	1.14	1.38	33.57	43.27	0.07	0.01	0.01	0.2	0.27	0.13	19.87	99.92
Siliceous Bauxite[2]	3.65	1.36	60.94	2.78	0.06	0.01	0.01	0.02	0.02	0.06	31.09	100.02
Laterite[3]	0.60	1.57	37.71	37.79	0.04	0.02	0.01	0.24	-	0.08	21.92	99.98
Aluminious Laterite[4]	0.53	1.13	43.86	30.43	0.09	0.04	0.01	-	0.03	0.06	23.68	99.87
Ferruginous bauxite[5]	0.73	1.74	59.36	7.49	0.08	0.02	-	0.1	-	0.1	30.33	99.97
Bauxite[6]	0.3	1.83	61.21	4.59	0.05	0.01	-	0.05	0.01	0.07	31.74	99.80
Lithomarge[7]	42.0	1.47	40.7	0.74	0.01	0.03	0.01	0.2	0.02	0.05	14.73	99.98
Altered Phyllite[8]	54.2	0.55	13.62	24.22	0.17	0.1	-	1.42	1.15	0.16	4.33	99.99

	Ba	Be	Co	Cr	Nb	Ni	Pb	Rb	S	Sn	Sr	V	Zn	Zr	Y
Ferruginous Laterite[1]	27	0.6	52.8	344	32	43.7	83.2	13	44	347	24	538	51	402	31
Siliceous bauxite[2]	-	0.9	33.4	345.5	-	19.4	110.7	-	-	121	-	-	24.1	266	37
Laterite[3]	36	0.7	27.6	542	25	39.5	7.2	11	-	374	37	477	81.2	394	35

Aluminous Laterite[4]	-	2.2	50	295	12	83.5	98.1	9	137	328	32	284	124	340	20
Ferruginous bauxite[5]	79	0.7	32.9	542	20	19.7	119	5	16	212	133	186	83.9	263	47
Bauxite[6]	34	0.8	39.1	510	21	18.2	86.6	3.9	85.3	130	36.4	100	28.7	421	53
Lithomarge[7]	69	1.6	26.4	233	15	96.3	27.7	11	12	9	30	54	31.8	499	43
Altered Phyllite[8]	344	1.7	35.1	123	3	51.7	23.9	57	32	169	163	82	67.1	150	18

[1]-average of **5** samples; [2]-average of **3** samples; [3]-average of **2** samples; [4]-average of **4** samples; [6]-average of **7** samples; [7]-average of **5** samples; [8]-average of **2** samples.

Table 4: Average chemical composition of some Ghanaian bauxite samples (Momade, 1999)

Component	**Composition (wt %)**
Loss on ignition (LOI)	15 – 20
Al_2O_3	48 – 52
Fe_2O_3	19 – 23
SiO_2	< 6.5
TiO_2	< 5
P_2O_5	~ 0.5
V_2O_5	~ 0.05
CaO	< 0.8
MgO	< 0.3

4 Bauxite tailings (red mud) characteristics

The type and concentration of the chemicals present in the mud depends on the composition of the bauxite ore and the digester technology. The red mud that can be generated after the extraction of alumina from bauxite ores would generally contain significant amounts of iron (20-50%), silica (10-20%), calcium (10-20%), sodium (10-20%). It may also contain trace amounts of elements such as barium, boron, cadmium, chromium, cobalt, gallium, vanadium, scandium, arsenic, lead, as well as radionuclide (Nguyen and Boger, 1998).

The process liquor is highly alkaline which is caused by caustic soda (NaOH) used in the Bayer process for bauxite digestion. The supernatant removed from most red mud facilities have been found to have a pH of around 11.6 (Anon, 1998). The alkaline nature may limit plant and animal growth when spilled because the leachate from red mud has the capability of dissolving and leaching plant nutrients from soils (Anderson and Haupin, 1978 and Nemerew, 1978). There is the potential for leachate from the mud to contain or dissolve heavy metal constituents which when released to groundwater resources could cause impacts through various pathways depending on the site specific conditions.

5 Particle size distribution of red mud

Fourie (1999) and Nguyen et al, (1998) in collaboration have intimated that generally, red mud has fine particle size distribution ranging from clay through fine silt with a small percentage of fine sand. These characteristics have been attributed to the bauxite ore and the extraction process. Figure 2 shows particle size envelopes for typical mineral processing residues. Red mud, unlike other tailings such as copper, tin, diamond or gold tailings, has extremely fine particle size distribution with high clay contents due to the high degree of weathering and to some extent the extraction process. The particle size distribution of red mud is less than 0.1mm with high clay content that has hydrophilic properties. Studies by Vick (1983) and (Anon, 1994) indicate that clayey tailings have low effective strength, very poor permeability with a high plasticity index. Red mud which falls within this class of tailings characteristics could cause drainage problems if slurry impoundment methods are employed to contain it. These factors affect the phreatic surface in the embankment which affects its stability.

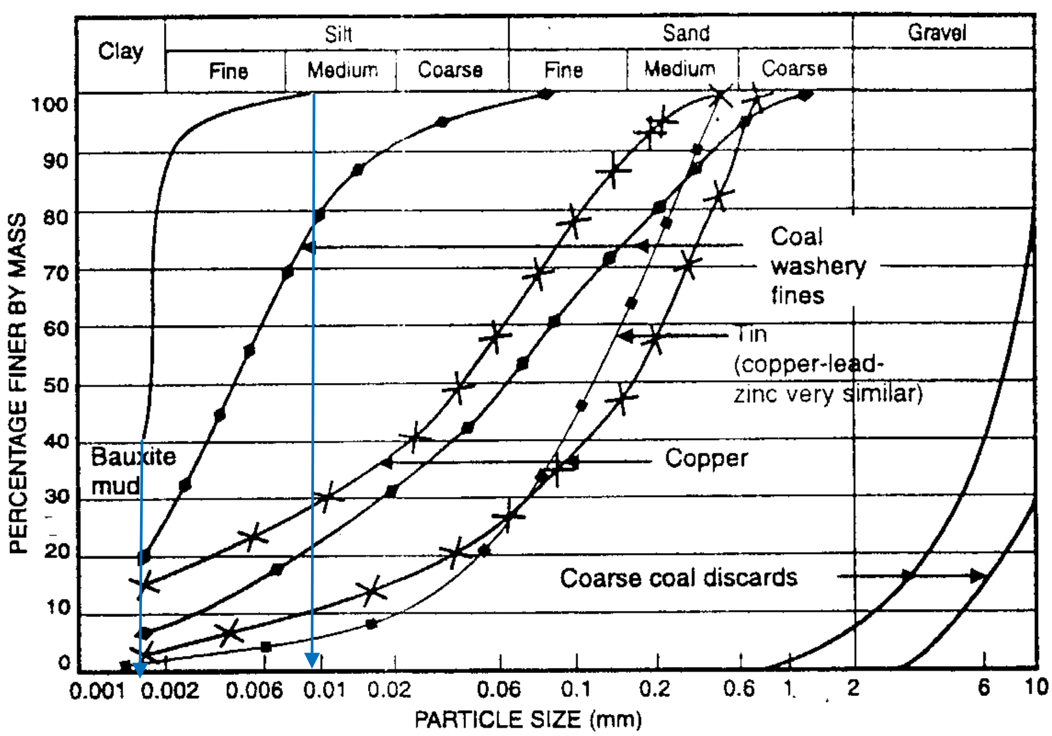


Figure 2: Particle size envelopes for typical mineral processing residues (Source: Fourie, 1999).

6 Site assessment

The study was conducted in two municipal assemblies, namely, Tema Municipal Assembly (TMA) or Shama-Ahanta East Metropolitan Assembly (SAEMA) with existing basic infrastructure required for the setting up of a bauxite refinery in Ghana. Comparison of the suggested locations was based on identified environmental criteria based on data reviewed from which Table 6 was compiled. A site was scored a point ranging from 1-5 with a higher mark indicating that the sitting of the tailings disposal facility had a low disturbance to the environment. A scoring and staring system as shown in Table 5 was used to summarize how negative or positive a particular site criteria limits or enhances the possible development of the tailings disposal facility. A record sheet was used to record the basic reasons that informed each score.

Table 5: Scoring and staring system for instant visual impression of the overall best choice

Star code	Score	Explanation
☆☆☆☆☆	5	Development activity is encouraged as it will resolve an existing environmental constraint
☆☆☆☆	4	Development is acceptable as there are no potential environmental issues or constraint.
☆☆☆	3	Potential environmental issues and development needs mitigation measures to ensure environmental safety.
☆☆	2	Problematic due to known environmental constraint.
☆	1	There is an absolute environmental constraint to the development.

Table 6: Site comparison between Tema Municipal Area (TMA) and the Shama-Ahanta East Metropolitan (SAEMA)

Geological characteristics			
Criteria	SAEMA	TMA	**Reason for Score**
Seismicity of site	4 ☆☆☆☆	2☆☆	TMA lies in a seismically active zone and therefore sitting the TSF favours SAEMA.
Topography, surface hydrology and drainage	4 ☆☆☆☆	3☆☆☆	The topography and hydrology of the SAEMA study area indicate a well drained area with the Whin river and the Pra river as compared to the TMA area which is generally low lying and flat with little or no pronounced outcrops. In the event of extreme weather conditions the TMA site will be more susceptible to flooding and most TSF may fail under such conditions when not properly managed and therefore sitting the TSF favours SAEMA.
Groundwater quality and quantity	2 ☆☆	☆☆☆☆ 4	The groundwater quality in the SAEMA area is better than that of the TMA area and therefore sitting the TSF favours TMA. Groundwater in the TMA possesses saline characteristics, with salinity being more pronounced near the coast.
Underlying mineral potential	3☆☆☆	4 ☆☆☆☆	The SAEMA area is underlain in part by the Birimian system and associated granitic complexes that are considered as one of the most important mineral bearing formations of the country (Anon, 1993) and therefore sitting the TSF favours TMA.
Bedrock permeability	4☆☆☆☆	4 ☆☆☆☆	Both sites are underlain mostly by rocks that can be impermeable, namely, the Birimian for SAEMA and the Dahomeyan for TMA.
Presence of Geological drawbacks (seismic activity)	4 ☆☆☆☆	☆☆ **2**	The main drawbacks are that the TMA area lies in an active seismic zone (figure 3) with known faults whiles the SAEMA site is basically stable and therefore sitting the TSF favours SAEMA.

Meteorological Characteristics

Criteria	SAEMA	TMA	**Reason for Score**
Rainfall / precipitation	3☆☆☆	☆☆☆☆ 4	The TMA area lies in the coastal savannah zone which is the driest climate zone with average annual rainfall of 810mm whiles the SEAMA area lies within the wet tropical rain forest zone with average annual rainfall of 1905mm and therefore sitting the TSF favours TMA.
Prone to flooding	4☆☆☆☆	2☆☆	The topography and hydrology of the SAEMA study area indicates a well drained region by the Whin and the Pra rivers as compared to the TMA area which is generally low lying and flat with little or no pronounced outcrops. In the event of extreme weather conditions the TMA site will be more susceptible to flooding and most TSF fail under such conditions and therefore sitting the TSF favours SAEMA.

Socio-economic Conditions

Criteria	SAEMA	TMA	**Reason for Score**
Population density	3☆☆☆	2 ☆☆	The TMA area has a higher population density than the SAEMA area and therefore sitting the TSF favours SAEMA.
Cost of land	☆☆☆☆ 4	☆☆ 2	Demand and cost of land in the TMA area is higher than that of the SAEMA area and therefore sitting the TSF favours SAEMA.
Potential for agriculture	2☆☆	☆☆ 2	Both SAEMA and TMA site have potential for mechanized agriculture
Proximity to nature conservation	☆☆☆ 3	☆☆☆ 3	Both sites are rated equal

Presence of hunting and fishing	☆☆☆ 3	☆☆☆ 3	Both sites are rated equal
Access to effective means of transportation	☆☆☆☆ 4	☆☆☆ 3	The SAEMA area is still being serviced by the Ghana railway corporation hauling bauxite and manganese to the Takoradi habour
Cost / access to energy (gas and electricity)	5☆☆☆☆☆	4☆☆☆☆	The SAEMA location will be in close proximity to the offshore Jubilee oil/gas fields in the Tano basin which will start production in the last quarter of 2010.
Access to water for operation	☆☆☆☆ 4	☆☆☆☆ 4	Both sites are rate equal

It can be deduced from Table 6 that, overall the SAEMA site, from an environmental perspective scored the highest (i.e. stars) and hence a more favourable site as compared to TMA. Identified drawbacks could be mitigated with design or choice of disposal technology.

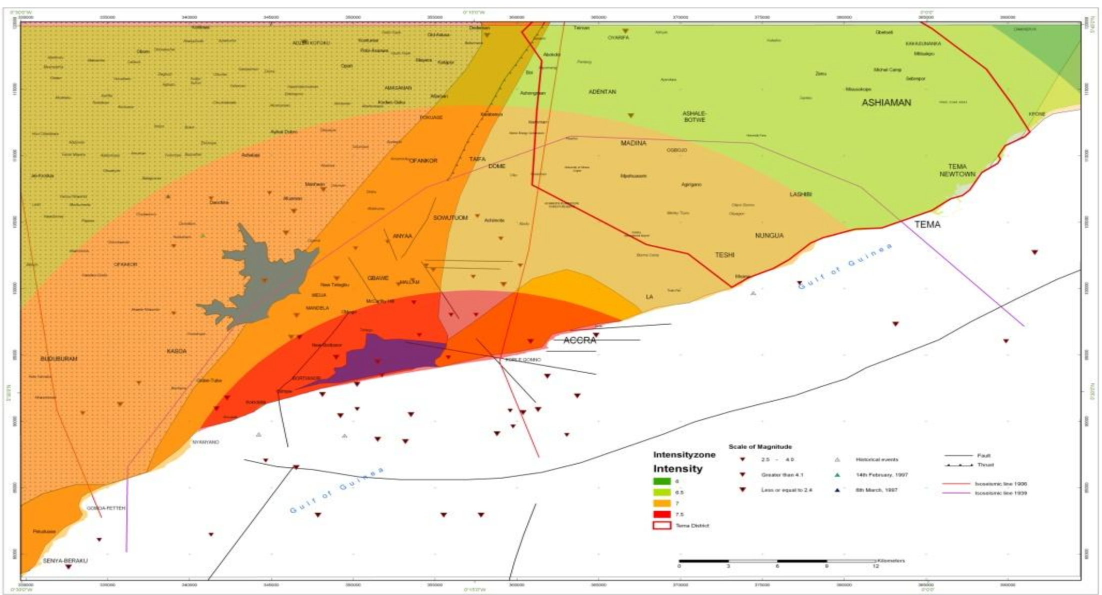
7 Site specific factors for the two proposed locations

The main benefit of the Shama-Ahanta East Metropolitan (SAEMA) location is that it has no known significant geological drawback in terms of seismicity. Also the underlying bedrock is mainly the Birimian meta-volcanic rocks which are generally massive and impermeable. The topography is such that relatively less constructional material would be required to construct a tailings storage facility as compared to the TMA location. It has a comparatively lower population density and the cost and demand for land is relatively lower than that of the TMA location. The SAEMA location has a fairly good transportation network with the western rail line still operational hauling bauxite from Awaso to the Takoradi Habour. The cost of upgrading the western corridor railway will as a result be less than that of the TMA site. Moreover, recent development in the Tano Basin with oil and gas production projected by the last quarter of 2010 could provide the energy resources required for the project. The drawback to the SAEMA location are that the Birimian formation is known to contain high quality groundwater resource and it is also considered as one of the most important mineral bearing formations of the country (Anon, 1993).

The main benefits of the Tema Municipal Area (TMA) site are that the location is closest to the aluminium smelter (Valco) and transportation cost implications will be reduced as compared to SAEMA. The underlying bedrock is the Dahomeyan gneiss which is generally impermeable and massive with few joints which serve as barriers to groundwater contamination. The geotechnical characteristics of the area show that the gneiss weathers into an impermeable clay cover and groundwater abstraction, quality and quantity are already poor in the area. The main drawback is that the area lies in an active seismic zone (Figure 3). The demand and cost of land is high and that the use of large tracts of land for disposal will encounter public displeasure and rejection. The low-lying topography renders the area susceptible to flooding under extreme weather conditions.

8 Disposal Technology assessment

The two technology options available for the disposal of tailings to be generated are the traditional slurry impoundments and thickened tailings disposal impoundments. Comparison between the two disposal technology options for potential environmental impact is shown in Table 7.



Appendix 10: SEISMICITY MAP OF ACCRA-TEMA METROPOLITAN AREAS 1: 100 000

Figure 3: Seismicity map of Accra-Tema Metropolitan Area (Source: Ghana Geological Survey Department)

Table 7: Comparison of the two technologies

Criteria	Thickened tailings (A)	Slurry impoundments (B)	Reason for score
Pollution criteria			
Groundwater pollution risk	4 ☆☆☆☆	2 ☆☆	Thickened tailings have little or no water association and hence problems associated with seepage to groundwater is non -existent
Flood risk	4 ☆☆☆☆	2 ☆☆	In adverse weather conditions slurry impoundments are more susceptible to breach due to flood induced rise in phreatic levels than thickened tailings.
Increase turbidity risk	4 ☆☆☆☆	2 ☆☆	Red mud generally has concentration of colloidal particle content and this poses a turbidity risk when slurry impoundments are used as compared to thickened tailings where binders are used to bind and solidify these particles
Air pollution risk	4 ☆☆☆☆	2 ☆☆	Dry slurry impoundments will generate significant amount of dust
Efficiency of water resource use	4 ☆☆☆☆	2 ☆☆	The amount of recyclable water back to process is generally higher in the case of thickened tailings technology as compared to conventional slurry impoundment. Re-handle time and cost of pumping is also reduced
Size of land required	3 ☆☆☆	2 ☆☆	Thickened tailings require a lesser disposal area as compared to the same amount of tailings in a conventional slurry impoundment
Fresh water requirement	4 ☆☆☆☆	2 ☆☆	Since most of the water is quickly recycled back to process in the case of thickened tailings, its fresh water requirements is less than that of slurry impoundments
Tailings characteristics			

Volume of tailings	3 ☆☆☆	2 ☆☆	The volume of tailings produced in thickened tailing technology is low since the associate water is removed before disposal
Stability of tailings	4 ☆☆☆☆	3 ☆☆☆	Thickened tailings are very stable and have little or flow when deposited making it very stable

From an environmental perspective thickened tailings disposal scored the higher stars as compared to the traditional slurry impoundment. Hence thickening the tailings prior to disposal offers the best disposal technology, since a better environmental performance is expected with little or no impact to groundwater and less land and water are required.

Thickened tailing disposal technology requires a lesser acreage of disposal land size than slurry impoundments. Taking into consideration that the refinery would be sited in a municipal district with a high demand and cost of land, it would be prudent to use the thickened tailings technology. According to the Canadian Center for Mineral and Energy Technology (Anon, 1997), an average of about 15 acres of pond area is required per 1000 tons of tailings solids transported each day and that a five day retention time should be provided. The United States Environmental Protection Agency (Anon, 1994) supports this and reports that, fine particles of size 2µm or less settles very slowly at rates less than 0.025cm/sec in still water. In conditions that are likely to be prevalent in slurry impoundments, several more days would be required to settle these fine particles due to turbulence to be caused by wave action.

Thickened tailings disposal requires little and in some cases, no starter dykes/dams since the tailings form a non-segregating material with little or no critical flow. Since bauxite would be hauled over long distances to these processing sites, waste rock from the mine, which is normally incorporated into the construction of embankment walls, would not be available due to transportation cost and borrow material from the vicinity would be the alternate source. These materials are known to have poor drainage characteristics and high clay content and if employed in the embankment construction for a slurry impoundment, the long term stability of the system would have to be assessed. This is because moisture content and phreatic surface conditions, which are dependent on drainage characteristics, are critical for dam stability. On the other hand, when thickened tailings disposal is employed, the problems to be caused by moisture content would be non-existent. Also in the choice of slurry impoundments, the generally low lying topography indicates that the ring-dyke method of construction would be employed. This increases the construction and under-drainage costs.

In the choice of thickened tailings disposal technology, the tailings can be modified (with binders) to successfully mitigate dust pollution (which is a significant environmental concern in the industry). The same cannot be said for slurry impoundments since the use of a binder if successful may lead to problems downstream in the process plants where recycle water is used.

There is always a finite probability that there could be the occurrence of some form of failure. The scenario is emphasized by the fact that TMA lies relatively in an active seismic zone within the slightly to moderate isoseismals intensity zone as characterized by the geological Survey department of Ghana (Muff et al, 2006).

In the extreme case of a seismic impact, a breach or failure (which is an inherent hazard) can occur. Thickened tailings disposal technology when applied will subject the tailings to a minimal flow as there would be little or no water to aid the transportation of the tailings over long distances. In contrast to this fact, most tailings impoundments failure leads to the transport of tailings and debris over long distances with catastrophic destruction to property and the environment.

Surface and groundwater hydrology favours thickened tailings disposal technology. Generally, groundwater quality, abstractions and recharge is very poor in the study areas. However, when thickened tailings disposal technology is employed the availability of recycle water to the process plant would be faster and more reliable. This will also reduce the dependence of the refinery on surface freshwater resources which serves as the main source of water apart from pipe-borne water.

The thickened tailings technology can be structured in such a way that, both disposal and reclamation can be run concurrently. This will also reduce the overall closure cost as reclamation is spread over the life of the plant.

In considering thickened tailings technology, the following basic but important steps need be followed so as to realize all the potential advantages.

1. The first step is to obtain a representative sample of the tailings and to determine the physical properties. This should include particle size distribution, particle specific gravity and the Atterberg limits. This is important not only for the classification of the tailings but also the effect on the rheological characteristics. The percent minus 20 and minus 75 microns size fractions are of particular interest. The grain size distribution should be done

with and without a dispersing agent. A grading curve obtained by using distilled water and de-flocculant is normally not representative of the effective-size distribution on a hydraulic beach although it provides the full range of true particle sizes. In addition, the mineralogy and chemistry of the tailings should be determined. These give an idea of the potential for acid generation. The surface chemistry also provides a guide as to the type of flocculant to be employed in thickening.

2. The next step is to determine the rheological properties of the thickened tailings. This must include the determination of the flow curve as well as the shear yield stress. It is important to determine the structure breakdown property by subjecting the material to a constant rate of shear until equilibrium is attained. This is relevant in assessing whether handling can cause any significant change in the rheology of the tailings. In case it does, the shear yield stress at the point of deposition must be known since this value is responsible for the profile that will be formed when the material is deposited (Fourie and Gawu, 2010). The rate of change of shear yield stress with shear rate must therefore be ascertained.
3. The third step is to obtain a relation between solids concentration and the shear yield stress. The importance of this is seen when developing a relationship between the depositional profile and percent solids
4. Finally, the desiccation behaviour must be ascertained through the establishment of soil shrinkage and water retention characteristic curves. This will enable an accurate air-entry value to be obtained. Air-entry values are particularly significant for acid generating tailings in that oxygen influx into the tailings occurs at suctions exceeding air-entry values. Below these values, acid mine drainage is insignificant. Additionally, an idea of the water content at which crack development will be expected to commence may also be obtained (Gawu, 2004).

9 Conclusions

Relevant conclusions from this study are that:

- A large quantity of tailings solids (about 5 million tons) will be generated by the proposed bauxite refinery plant in Ghana.
- Between the two proposed locations considered, the Shama Ahanta East Municipal area (SAEMA) offers the least environmental impact risk as compared with the Tema Municipal area (TMA).

- Thickened tailings disposal technology offers the best disposal technology for both locations, since a better environmental performance is expected with little or no impact to groundwater and less land and water are required.

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