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SOLID WASTE AS AN ALTERNATIVE ENERGY SOURCE AND A MEANS OF SOLVING WASTE DISPOSAL PROBLEM IN NIGERIA

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ABSTRACT

This paper presents practical ways of generating energy from solid waste as a means of solving the problem of solid waste disposal which is confronting the major cities in Nigeria and also providing alternative energy source to supplement the high cost and fast depleting conventional sources of energy. It also discussed the conventional incineration, gasification and pyrolysis processes in which energy may be recovered from solid wastes and put to useful purposes.

KEYWORDS: Solid waste, Energy, Waste disposal, incineration

INTRODUCTION

We are living at a time when there is a greater awareness of the energy problems facing the world than at any other period in history. It is now widely accepted that the current rate of energy generation and supply can not match the rapid growth in the rate of energy consumption (Adegoke and Bolaji, 1999; Momoh and Soaga, 1999). The importance of energy in sustained economic development is a well-accepted fact. Energy has always been an essential input to all aspects of the modern age, it is indeed the life-wire in industrial production (Garba, 1999).

Over the centuries, man has used various source of energy in order to meet the basic essentials of life. Currently, fossil fuels provide bulk of the world's primary energy, with hydro-electricity providing about 2% and nuclear fission, wood and other sources each accounting for less than 1% of the primary industrial energy used in the world. Since fossil fuels are non-renewable natural resources, their reserve may soon got completely depleted (Garba et al, 1995). Therefore, the growing need for energy could be partially secured by rationalizing the usage of the existing energy resources, using optimal designs, recovering the waste heat and at the same time searching for new energy sources (Adegoke and Bolaji, 1999).

Present energy sources are yielding energy with greater and greater reluctance. Each gallon or unit of energy costs more to find, mine, and refine. Energy conservationists are battling offshore exploration efforts, the installation of new pipelines, and construction of refineries and nuclear plants, and these make the job of satisfying our ever-increasing demand for energy more difficult

According to Adeokun et al. (2003), energy consumption pattern and level in Nigeria have produced a serious exploitative and disruptive environmental stress. The exploitative stress is most obvious in the amount of fuelwood harvested daily to support the energy needs. As noted by Aina and Salu (1992), the rate at which the natural vegetation has been exploited to meet the exponential human demand for energy has become highly disruptive of the ecological system.

Meanwhile, as a result of human activity, an ever-increasing quantity of solid waste is being generated, approximately half of which by weight is a replaceable resource such as paper with a relatively high energy content (Maurice and Wilson, 1998). Solid waste or refuse is one of many types of wastes that must of necessity be generated as a result of daily activities in any inhabited areas. The continuous generation of these wastes calls for constant removal and effective management which will prevent environmental pollution and its accompanying health hazard caused by these wastes in dumping site and in its neighbouring environments.

The issue of waste generation and disposal has been a matter of great concern in Nigeria of recent. This has been the subject of several studies, conferences, strategic meetings and debates such as 11th Annual Conference of Environment and Behaviour Association of Nigerian (Ogontoke and Ogunwede, 2003) and 5th Annual Engineering Conference of Federal University of Technology, Minna, Nigeria (Paiko, 2004). Importance of waste generation and disposal lies in its visibility and clear intrusion in the daily lives of people, as well as the numerous secondary results of its negligence. This accounts for the global and national attempts to improve the management of waste.

As stated by Afon (2003), one of the major problems confronting medium to large urban centres in Nigeria is that of effectively managing solid waste generated by residents. Evidence of this is reflected in the presence of heaps of waste awaiting evacuation in the different residential areas. Efforts have been directed at this at various levels of governance especially at state and national levels. This situation has made it possible for governments to design programmes targeted at effective waste disposal and management.

Various means of solving the problem were employed by various arms of government. According to Afon (2003); in 1976, Ibadan Waste Management Authority was created through edict No.33 of Oyo State of Nigeria. The edict was repealed a year later and replaced by edict No 10 of Oyo State of Nigeria of 1977. The edict though, did not change the nomenclature of the authority, but give it more powers and functions. Further in 1998, an environmental sanitation policy enforcement Board was established (Edict No 6 of OYN, 1998). By June 2002, Oyo State constituted a mobile court to try residents caught in the act of dumping waste indiscriminately (Guardian, June 10, 2002). Despite all these legislative and administrative efforts, the city is still battling with the problems of solid waste disposal. This problem of waste management is similar in most major cities in Nigeria, such as Lagos, Port Harcourt, Onitsha, Akure etc.

The national Environmental Sanitation Programme (ESP) introduced in Nigeria in 1985 was not sustained, the mode of implementation of the programme stripped it of the ingredients for sustainability. This observation was proved right when ESP was discontinued in 1999 and there was no evidence of any lost value. Even some states that tried to

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enforce ESP's on separate days after it has been cancelled by Federal government have discovered the futility of their policies and method (Afon, 2003).

Various studies reviewed above reveal that waste disposal management is one of the seemingly intractable problems of urban cities. The waste disposal through incineration, which has some basic advantages are less used in Nigeria while open dump and emptying into water bodies (streams, lakes, oceans) are the most common methods employed (Bolaji and Onipede, 2004). These methods and other forms of indiscriminate dumping of wastes are regarded as environmentally unfriendly and therefore constitute threats to the health of residents either directly or indirectly. According to Maurice and Wilson (1998), if residential and commercial waste generated yearly were incinerated and its heat recovered, we would obtain less than 3% of our total energy needs and by so doing solid waste will be a blessing in disguise.

Therefore, this paper analyses the techniques of converting solid waste to a potential energy source in order to reduce the problem of solid waste disposal. It discusses incineration, gasfication and pyrolysis processes of converting wastes to energy.

PROCESSES AND PRODUCTS OF THERMAL CONVERSION OF SOLID WASTE

Classification of Solid Wastes

Solid wastes can be classified into municipal wastes, industrial wastes and hazardous wastes. Municipal wastes are wastes generated from residences or activities from commercial and institution settings, which include food wastes, rubbish, waste from streets (leaves and content of litter receptacle) e.t.c. Those wastes arising from industrial processes and manufacturing operations including demolition and construction wastes are referred to as industrial wastes. Hazardous wastes are those wastes that posed substantial danger immediately or over a period of time to human, animal or plant life. This type of waste is either flammable, corrosive, reactive or toxic. They include radioactive substances, chemicals, biological wastes, flammable and explosive wastes.

Table 1: Classification of Solid Wastes.

TYPE	GROUP	CONTENT	MOISTURE CONTENT (%)	HEAT VALUE (kJ/kg)
0	Trash	Waste paper, cardboard and wood	10	8,500
1	Rubbish	Paper, wood scraps, floor sorcepts and foliages	25	6,500
2	Refuse	An even mixture of rubbish and garbage	50	4,300
3	Garbage	Animal and vegetables	70	2,500
4	Pathological wastes	Animal and human remains	85	1,000
5	Special wastes	Semi-liquid, explosive and radioactive materials from industries.	90	9,500

Sources: Ashworth, 1991.

Solid wastes can also be classified into six groups consist of trash, rubbish, refuse, garbage, pathological wastes and special wastes. This grouping (as illustrated in Table 1) is according to the level of their moisture content and heat value. The lower the moisture content of the waste the higher the heat value, except for the special wastes which has both highest moisture content and heat value due to the flammability of its liquid and gaseous content.

Thermal Conversion Processes and Products

Thermal conversion products that can be derived from solid wastes include flue gases, a variety oils, and various related organic compounds. The principal thermal conversion processes that can be used for the recovery of usable conversion products from solid wastes are shown in Table 2.

Table 2: Thermal processes for the recovery of conversion products from solid wastes.

Process	Conversion Products	Pre-processing
Combustion (Incineration)	Energy in the form of steam or electricity	Preparation of refuse derived fuels for suspension or semi-suspension firing in boilers
Gasification	Low – energy gas	Separation of the organic fraction, particle size reduction, preparation of fuel cubes or other Refuse Derived fuels (RDF).
Wet oxidation	Organic acids	Separation of the organic fraction, Particle size reduction, preparation of fuel cubes or other RDF.
Steam reforming	Medium – energy gas	Separation of the organic fraction, Particle size reduction, preparation of fuel cubes or other RDF.
Pyrolysis	Medium–energy gas, liquid fuel, solid fuel (char)	Separation of the organic fraction, Particle size reduction, preparation of fuel cubes or other RDF.
Hydrogasification, hydrogenation	Medium – energy gas, liquid fuel	Separation of the organic fraction, Particle size reduction, preparation of fuel cubes or other RDF.

Source: Howard et al, 1985.

INCINERATION OF SOLID WASTES

The principal elements of solid waste are carbon, hydrogen, oxygen, nitrogen, and sulphur. Under ideal conditions, when solid waste materials are burned the gaseous products include CO_2 (carbon dioxide), H_2O (water), N_2 (nitrogen), and SO_2 (sulphurdioxide). In practice, a variety of other gaseous compounds are also formed, depending on the operating conditions under which the combustion process is occurring.

The heat released from the combustion of solid wastes is partly stored in the combustion products (gases and ash) and partly transferred by convection, conduction, and radiation to the incinerator walls and to the incoming waste. The gaseous products (flue gases) are discharge from the top of the stack into the environment. The energy content of the waste can be estimated using the modified Dulong equation (Howard et al., 1985).

$$E\ (kJ/kg) = 337C + 1428\,(H - O/8) + 9S$$

where C = Carbon in %

H = Hydrogen in %

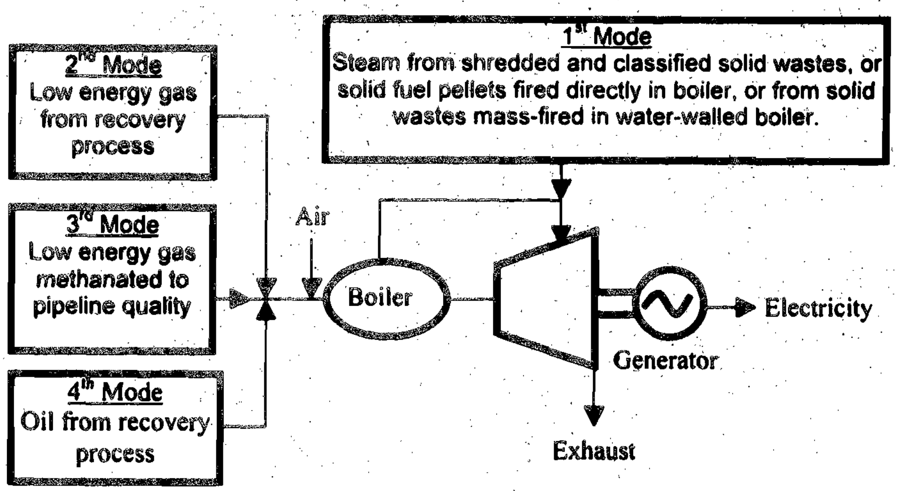

Fig. 1: Energy – recovery system with steam turbine – generator combination

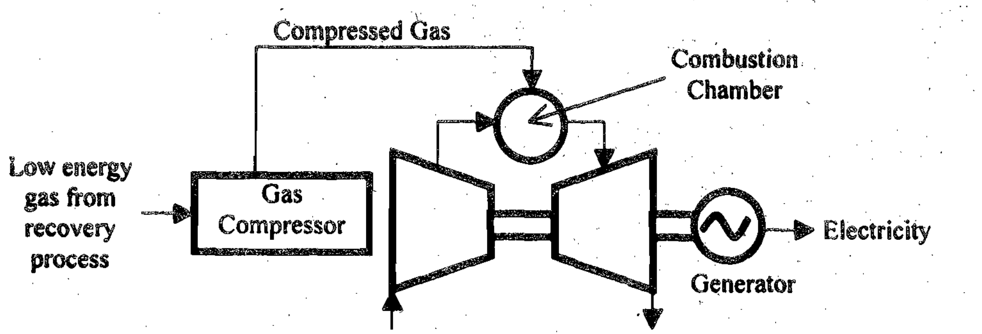

Fig. 2: Energy – recovery syst… mpressor – … – generator combination

O = *Oxygen in %*
S = *Sulpur in %*

Heat contained in the gases produced (flue gases) from the incineration of solid wastes can be recovered by conversion to steam. The low-level heat remaining in the gases after heat recovery can also be used to preheat the combustion air, boiler make-up water, or solid waste fuel.

Water – Wall Incinerators

In these incinerators, the internal walls of the combustion chamber are lined with boiler tubes that are arranged vertically and welded together in continuous sections. When water – walls are used in place of refractory materials they are not only useful for the recovery of steam, but also extremely effective in controlling furnace temperature without introducing excess air.

Gasification Process

The gasification process involves the partial combustion of a carbonaceous fuel to generate a combustible fuel gas rich in carbon monoxide and hydrogen. A gasifier is basically an incinerator operating under reducing conditions. Heat to sustain the process is derived from the exothermic reactions while the combustible components of the low-energy gas are primarily generated by the endothermic reactions. The reaction kinetics of the gasification process are quite complex and still the subject of considerable debate.

When a gasifier is operated at atmospheric pressure with air as the oxidant, the end products of the gasification process are a low – energy gas typically containing (by volume) 10% CO_2, 20% CO, 15% H_2, and 2% CH_4, with the balance being N_2 and a carbon – rich char. Because of the diluting effect of the nitrogen in the input air, the low-energy gas has an energy content in the range of 5.2 to 6.0 MJ/m^3 and when pure oxygen is used as the oxidant, a medium-energy gas with an energy content in the range of 12.9 to 13.8MJ/m^3 is produced (Howard et al., 1985).

PYROLYSIS

Pyrolysis is the term used to describe the process of splitting organic substances (when heated in an oxygen free atmosphere) through a combination of thermal cracking and condensation reactions into gaseous, liquid, and solid fractions. In contrast to the combustion process, which is highly exothermic, the pyrolytic process is highly endothermic, for this reason, the term destructive distillation is often used as an alternative term for pyrolysis.

The characteristics of the three major component fractions resulting from the pyrolysis are:

(i) A gas stream containing primarily hydrogen, methane, carbonmonoxide, carbondioxide, and various other gases, depending on the organic characteristics of the material being pyrolyzed.
(ii) A fraction that consists of a tar and/or oil stream that is liquid at room temperatures and has been found to contain chemicals such as acetic acid, acetone, and methanol; and
(iii) A char consisting of almost pure carbon plus any other material that may have entered the process.

It has been found that distribution of product fractions varies with the temperature at which the pyrolysis is carried out.

RECOVERY OF ENERGY FROM CONVERSION PRODUCTS

The principal components involved in the recovery of energy from conversion products are boilers for the production of steam, steam and gas turbines for motive power, and electric generators for the conversion of motive power into electricity.

Typical flow sheet for alternative energy recovery systems are shown in Fig. 1 and 2. The most common flow sheet for the production of electric energy involves the use of a steam turbine-generator combination (Fig. 1). As shown, when solid wastes are used as the basic fuel source, four operational modes are possible. A flow sheet using a gas turbine – generator combination is also shown in Fig.2. The low energy gas is compressed under high pressure so that it can be used more effectively in the gas turbine.

CONCLUSION

The world is faced with an ever-increasing demand for energy and it is also generating an ever-increasing quantity of solid waste, which could be used to an advantage in a country like Nigeria where solid waste disposal is a major environmental problem. This paper highlighted the processes of incineration, gasification and pyrolysis as practical methods of disposing our "mountains" of solid waste. Also discussed are the methods of converting thermal energy from waste incinerator to useful energy such as steam, which could serve as a motive power for electricity generation.

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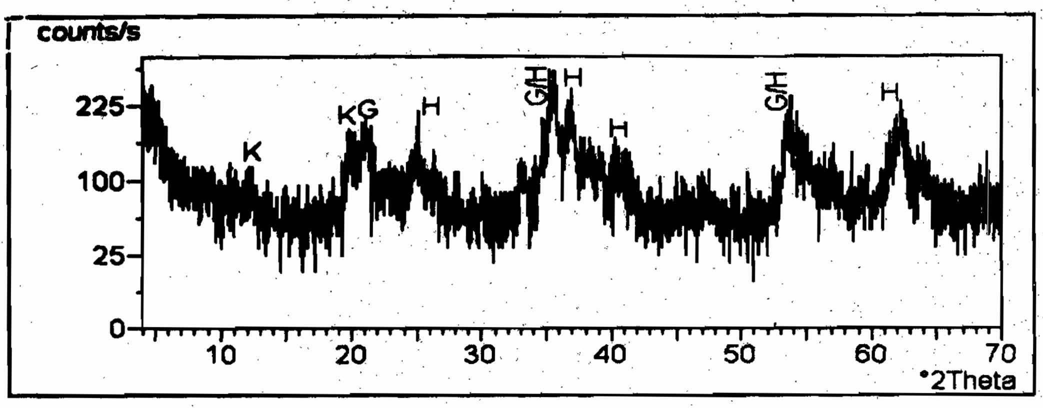

Figure 5: X-Ray diffractogram of representative saprolite from site three: K = kaolin; G = goethite; H = hematite

Table 2: Values of 2θ, *d*, relative intensity and peak height from X-ray powder diffraction analyses of samples A1

2θ(°)	*d* (Å) from λ_1	Relative intensity (%)	Peak height (counts/s)	Identified mineral
19.93	4.45	20.8	95.3	Augite
24.01	3.70	30.5	139.4	hematite
27.52	3.24	14.1	64.4	Augite
29.75	3.00	22.4	102.3	Augite
33 03	2.71	91.4	418.2	hematite
35.47	2.53	100.0	457.4	Augite/ hematite
40.70	2.22	30.0	137.1	hematite
43.15	2.10	4.2	19.3	Augite/ hematite
49.28	1.85	66.8	305.5	hematite
50.70	1.80	5.1	23.3	Augite
53.88	1.70	65.4	298.9	hematite
57.39	1.60	17.6	80.3	hematite
62.25	1.49	65.0	297.1	Augite/ hematite
63.77	1.46	44.7	204.5	hematite

Table 3: Minerals identified by X-Ray Powder Diffraction analyses in unconsolidated sediment and saprolite samples *(Note: AN = anatse, AE = annite, CP = clinopyroxene, MG = maghemite, AT = augite, GT = goethite, HT = hematite, KN = kaolinitic mineral, + = trace, ++ = minor, +++ = major)*

Sample identity	AN	AE	CP	MG	AT	GT	HT	KN
A1				+	++		+++	
A2		+			++		+++	
A3		+			++		+++	
A4		+			++		+++	
A5					+++		+++	
A6		+			++		+++	
B1	+ +				++	++	+++	
B2		+		+			+++	++
B3					++	+++	++	
B4					++	++	+++	
C1						+++	++	+
C2						+++		
C3				+	++	+++	+	
Saprolite			++			++	++	+

Clinopyroxene and particularly augite were the only pyroxene minerals identified. Clinopyroxenes are ferromagnesian minerals common in basalts. Augite was dominant in the sediments, and this could be attributed to its presence in the basalts (Suh *et. al.*, 2003). Maghemite occurs as traces only in a few samples because it is a high temperature mineral which is easily converted to hematite at temperatures below 500 °C (Deer *et. al.*, 1983). High temperature minerals such as olivine, which are less stable, must have weathered due to humid temperature and very high rainfall in the environment; and as such was not identified by XRPD. However the overwhelming presence of hematite could be an indication that of some of it could be a weathering product of olivine, and the continuous alteration of annite and augite.

Descriptive Petrography of Minerals Constituting Sediments

Details of the descriptive petrography of the mineral assemblages in the samples of sediments of the study area are given in Table 4. These results were complementary to those obtained for colour characterization and minerals identification by XRPD, and are in conformity with information reported on in literature for the different minerals (Philpotts, 1989). Annite, augite, hematite in the unconsolidated sediments, and clinopyroxene and hematite in the saprolite were characterized.

Table 4: Descriptive petrography of the identified minerals occurring in the unconsolidated sediments of the 2001 landslides at the Mabeta New Layout area.

Mineral	Hardness (Mohr scale)	Cleavage	Fracture	Color	Streak	Luster	Crystal appearance
Annite	2.5	Perfect	Uneven	Dark greenish grey	Brownish white	Sub metallic to vitreous	Pseudo hexagonal
Augite	5.5	Good	Brittle	Greenish black	grey	Vitreous resinous	Prismatic
Hematite	6.2	None	Conchoidal and brittle	Reddish brown	red	Metallic dull	trigonal
Clinopyroxene	6.0	Good	Brittle	Brownish black	grey	Vitreous resinous	Prismatic

The kaolin minerals, maghemite and anatase were not distinguished and characterized by OM. Kaolinitic minerals and anatase are too fine to be characterized by OM. According to results obtained by XRPD, maghemite was in trace amounts. The clinopyroxene group of minerals includes diopside, augite, jadeite, pigeonite and hedenbergite. These minerals were not individually identified except for augite which was abundant in the sediments. Because olivine minerals were not identified by XRPD and petrographically, they could possibly have been chemically altered to form hematite and other compounds.

Influence of Mineral Assemblages on the Mabeta New Layout landslides

The weathering of the basalts could account for the relatively large amount of iron in the unconsolidated sediments. The soils are lateritic with no distinct horizons of stratification. They are enriched in Fe as is indicated by their reddish-brown, yellowish-red and dark reddish-brown colour shades. Most of the other elements especially Na, K, Mg and Ca have been removed from the environment by intense leaching due to heavy rainfalls and high temperatures.

The alteration of the primary minerals into secondary ones in the area has been dominantly governed by the weathering environment which is characterized by high temperatures and heavy rainfall. Alteration of minerals in the sediments took place under favorable geochemical conditions. Whereas maghemite conversion to hematite was controlled principally by decrease in temperature, hematite alteration to goethite was influenced by the hydrography of the environment as shown in equations 2 and 3.

$$\gamma\text{-}Fe^{+3}{}_2O_3 \rightarrow \alpha\text{-}Fe_2O_3 \quad (2)$$

maghemite → hemaetite

$$\alpha\text{-}Fe_2O_3 + H_2O \;\square\; 2\,\alpha\text{-}FeO.OH \quad (3)$$

hematite + water → goethite

Annite which belongs to the biotite subgroup is a tri-octahedral mica. It is altered to kaolin as demonstrated in equation 4. The kaolin mineral could be kaolinite or halloysite 7 Å. The later is further altered to halloysite 10 Å as indicated in equation 5.

$$K_2Fe_6[Si_6Al_2O_{20}](OH)_4 + H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 6FeO.OH + 2K(OH) + 2Si^{2+} + O_2 \quad (4)$$

Annite water kaolinite/ haollysite 7 Å goethite

$$2Al_2Si_2O_5(OH)_4 + 8H_20 \rightarrow Al_4Si_4(OH)_8O_{10}.8H_2O \quad (5)$$

Kaolinite/haollysite 7 Å → haolloysite 10 Å

Clinopyroxenes and specifically augite $[Ca_2(Al\text{-}Fe)_4(Mg\text{-}Fe)_4Si_6O_{24}]$, is basically calcium sodium magnesium iron aluminum silicate. As K from annite, and Na, Mg and Ca are leached away from the clinopyroxene minerals, non-crystalline silicic acid (which could not be detected by XRPD analysis), goethite and kaolin are formed.

The Mabeta New Layout landslides may have been influenced by gravitational forces, the types of particles constituting the sediments (particle size, particle shape, and mineral type), hydrology and seismic forces. Gravity is invariably involved in the processes. The component forces are the normal force perpendicular to the sediment surface, and a second force acting parallel to the sediment surface. With increase in the steepness of the topographic gradient, the force pulling the sediments on the parallel surface approaches the angle of repose, which is the steepest angle at which particles of sediments could remain stable.

Factors which influence and determine the angle of repose include the particle sizes, particle shapes and their densities. Particle density is also governed by mineral type. Sand, gravel, and clay all have different angles of repose. Once the angle of repose is exceeded, the sediments slide off. In the Mabeta New Layout area, slopes of the volcanic cones have gradients from 40° to 80 ° (Ayonghe *et. al.*, 2002);

Kaolinitic minerals have particle density of 2.6 kg m^{-3}, and hematite 5.3 kg m^{-3}. The former has a pseudo-hexagonal morphology whereas the later is trigonal. Annite also has a pseudo-hexagonal morphology, and its particle density is 3.2 kg m^{-3}. The clinopyroxenes are prismatic with a particle density of 3.4 kg m^{-3}. In the study area, clinopyroxenes were identified to be associated with saprolite. Since the sediments are unconsolidated, with little or no cementation and no compaction, regional tectonic and seismic activities would easily disaggregate any elementary binding of the particles, and make them lie in angles of repose which could easily be overcome by heavy rains. The heavy rains lubricated the surfaces and facilitated sliding movements between the kaolinitic minerals and annite particles, as well as the heavier clinopyroxene and hematite particles. As the rains decreased, the friction between the surfaces of particles also decreased and chunks fell off, thereby causing landslides at the Mabeta New Layout, Limbe, Cameroon.

In a more correlated manner, heavy rains caused deep weathering of the volcanic tuff into layers of clays. Friction between bedding layers reduced due to increase of pore water pressure in saturated regolith and soils because of heavy rainfall. The saturation therefore reduced cohesion of particles because the pores were completely filled, and the clays either adsorbed or absorbed water considerably causing some swelling. The additional weight of sediment environment due to the filling of the pores with rain water increased the shearing stress. Sliding of particles therefore occurred as there was a downward pull of gravity, thereby overcoming friction.

CONCLUSIONS

The primary objective of this study was to mineralogically identify and characterize the unconsolidated sediments and saprolite where landslides at the Mabeta New Layout, Limbe, Cameroon, occurred in order to postulate any possible role the mineral assemblages. Sediment colour characterization, identification of mineral phases and OM of particles were conducted

The hue/value/chroma of the sediments ranged from 5YR/5/3 to 5YR/4/6 to 5YR/3/4 with corresponding colour shades from reddish-brown to yellowish-red to dark reddish-brown. Mineral phases identified in the samples included anatase, annite, augite, goethite, hematite and kaolin, with the Fe-bearing minerals being the most dominant. There were traces of maghemite in a few of the samples, and clinopyroxene was present in the saprolite. The OM results were complementary to those obtained for colour characterization and mineral identification.

Hydrologic, tectonic and seismic factors played combined with the physical properties of the mineral assemblages in triggering the landslides. These physical properties included the shapes and sizes of the mineral particles as well as mineral density. The phyllosilicates created a lubricating surface for the Fe-bearing minerals to slide upon. Therefore, the physical properties of the mineral constituents coupled with hydrologic, tectonic and seismic forces were responsible for the landslide events.

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