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Comparative Study of Local Mining Methods and Assay of Cassiterite with other Alluvial Mineral Deposits in Kuru-Jantar, Plateau State, Nigeria

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Abstract This research attempt to investigate and compare the local mining methods of cassiterite in Kuru-Jantar with the view to determine the mean recovery per day using statistical approach, separating the valuable minerals through the gravity and magnetic techniques, determine the grade of cassiterite (tin oxide) with the aid of volumetric and energy dispersive x-ray florescence (XRF) analyses; and determine the percentage composition of metals in cassiterite as well as its associate ores with the aid of (XRF). Sub-surface (lotto) and surface (Hand paddock) mining methods were carried out and the respective recovery from each of the method was subjected to processing, sampling and assaying to determine the quantity, quality (grade) and expected smelter-yield. The mean recoveries per day are 14.48 and 11.28 kg/day for lotto and paddock mining methods respectively. The burretting differential obtained for the lotto and paddock methods are 18.80 – 19.80 and 18.80 – 19.30 respectively while their respective percentage tin metal burretted are 90.40 – 97.83 and 92.51 – 97.80 %. The recoveries from the magnetic and gravity separations are 10.91 kg and 9.06 kg for lotto and paddock methods respectively. The XRF analysis gave 68.69 and 66.462 % Sn respectively for the lotto and paddock while the assaying of other associate minerals are 40.4 % Nb; 26.5 % Fe; 22.3 % Ti; 2.5 % Ta; 2.3 % Sn; and 5.1 % W for the paddock and 37.6 % Nb; 24.8 % Fe; 21.5 % Ti; 2.3% Ta; 5.8 % Sn; and 4.9 % W for lotto. It can be observed that the lotto mining method has the highest recovery per day and hence, gives better recovery than paddock mining method. Lotto mining was found to yield higher grade tin-ore concentrate than the hand paddock mining method in both volumetric and XRF analyses but hand paddock gives higher quantity and more associate minerals. It was also found out that the lotto method is more risky and life threatening than paddock mining while the paddock mining practices render more danger to environment than the lotto mining.

Keywords: *lotto, paddock, cassiterite, columbite, mining, grade, assay, ore*

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1. Introduction

Mining industries have been viewed as key drivers of economic growth and the development process [1], and as lead sectors that drive economic expansion which can lead to higher levels of social and economic well being [2]. Many countries of the world including Australia, Canada, Russia, India, Saudi Arabia and Botswana have depended on solid minerals wealth to finance their societies. In year 2006, Australia benefitted from mineral export, earning up to AUD 59.2 billion [3]. Nigeria, however with Botswana, Angola, South Africa and Liberia, falls into the category of mineral economies; each of these countries has a matured extractive economy which depends on mineral revenue [4].

Just of recent, the rising demand for primary commodities from fast-growing and emerging countries, like China, has added to the persistent high level of mineral demand in developed countries [5]. Likewise, high prices and demand of mineral have stimulated an investment surge in mineral exploration and production in particularly the developing countries [6,7,8]. In order to take advantage of increases in the price of commodities, as well as the push in the equities market, resource-rich countries like Nigeria have seen a new economic opportunity and development prospect arising from the exploitation of their mineral resources. Since the new decade, [9] observed that nations were either reviewing or reforming their policies to liberalize the mining sector that would encourage the inflow of foreign capital for investment. This situation has led to growing competition between nations to capture investments and, consequently, minerals policy, legal frameworks and institutions were reformed to encourage foreign and local investments in the extractive sector, and to optimize the contribution of mining to the national economy. For instance, Madagascar, Ghana, Tanzania, Peru, Argentina and Chile have achieved remarkable success in this regard [10]. Solid minerals in the Nigerian context include all minerals and metals, excluding oil and gas. These minerals, unlike oil, occur in all the different components of the Nigerian geology. Some of them are of commercial value, while others are small and unprofitable to exploit. Indeed, all the states of the federation have a share of the mineral inventory of the nation [11].

Exploitation of mineral resources has assumed prime importance in several developing countries including Nigeria. Nigeria is blessed with a lot of mineral resources, which have greatly contributed to the national wealth with associated socio-economic benefits. The mining of Cassiterite started in 1904 in Jos. But during the mid-1920s more cassiterite was discovered which resulted in more mechanized extraction techniques to meet up with the high demand for tin by 1960s however, the demand increased, got to a peak and gradually declined in the late 1980s [11]. Recently, the world demand for tin is quite steady, and is growing at about 5% a year [12]. Circuit-boards for televisions, computers, microwave ovens and the likes, contain tin due to its low melting point which makes it suitable for this purpose. However, electronic goods, for health reasons embarked on using solder with 97.5% tin instead of solder with 40% lead and 60% tin. This single policy change increased global tin demand by over 20% [12]. The rest of the tin is used for ‘tin-plating’ which is coating steel cans to make tin cans, for production of bronze, and various chemical processes. It is also used in lithium ion batteries. Also, provided the experiments for electric car use in countries like China are successful, then; this could further increase the demand for tin. Thus, the present and possible future demand for tin is high.

The Nigerian economy is largely dependent on oil while non-oil minerals have relatively weak roles. However, the current global economic downturn, in particular oil price volatility in the international market, has compelled the Federal Government of Nigeria to reduce the risk of over dependence on oil by paying considerable attention to solid mineral development. Nigerian mining has tremendous potential for economic development [3]. [13] reported that the expansion of mining has the potential to contribute 15 per cent to Nigeria’s GDP by the year 2015 from the present one per cent. However, various policies have been formulated to regenerate the moribund sector for economic diversification and increased revenue.

The Younger Granite rocks of the Jos Plateau and surrounding areas are richly mineralized with cassiterite. Cassiterite is associated with other minerals such as Columbite, monazite and accessories like zircon and topaz. As a result, a lot of mining activities such as formal and informal mining have been carried out over the years in the area [14]. Presently, most of the mining activities carried out are still by trial and error means such has lotto mining. Therefore, the miners may not have fully mined the cassiterite in the areas they have worked and hence, some cassiterite is left untapped. These mining activities have resulted in environmental degradation and health hazards from improper waste disposal. Also, revenue due to the Federal Government of Nigeria through taxation is reduced since these informal miners evade being taxed and the income earned by them is not included in the record of the Nigerian national income.

Previous work, regional appraisal and geologic field revealed that the area is part of the Jos-Bukuru Younger granite ring complexes which is responsible for cassiterite mineralization of the study area [15]. Physiographic study of the area also plays an important role in the choice of mining method to be employed during a particular period of the year because during rainy season, the ground is not competent enough to support sub-surface (lotto) mining while during dry season the streams dries up making surface (had paddock) mining more difficult.

The study area is a village with coordinates latitude 9° 40’N – N9° 44’N and longitude E8° 51’ – E8° 53’ (Figure 1). It is located in Jos South Local Government Area of Plateau State, North Central Nigeria, located on Naraguta SE, Sheet 168. Kuru is significant for the mining of tin and columbite with other minerals like kaolin and tantalum. General Geology of the study area (Kuru) is generally characterized by the abundant occurrence of the Younger Granite rocks which were emplaced during the Jurassic era. The formation of the Younger Granite is associated with the hot spot magmatism. The rock bodies are massive occurring ring complexes. The Younger Granites are known for hosting tin and columbite within Jos Bukuru and environs [15]. The current prohibitive cost of mining and inaccessibility of placer deposits of the ores beneath the basalt flows of Jos are among the factors accounting for the collapse of the tin industry [16]. The sub surface mining called lotto mining was being used for mining of minerals since the 1950s in Nigeria; cassiterite was mined in 2 pounds per feet (cut-off grade) which was not profitable in anyway. Jig method was used for mining of both tin and columbites, using difference in their specific gravity. Rock blasting, the use of gravity pump to wash the minerals at the paddock phase to the jig where the minerals were sorted are the processes involved in jig method [15]. The solution methods are now being employed as techniques used for cassiterite ore analysis in Nigeria since 1990s [17] but have the disadvantage of low data due to incomplete solubilization of the ore minerals in aqueous medium [18]. This incomplete solubilization resulted in large number of tailing dumps. The residues contain tin ores and other heavy metals which today could be extracted as the prize of tin has risen to $23,300 per tonne, ranking more than Nickel [19]. Presently, several attempts have been made to correct the analytical deficiency. Either one or sometimes two are employed [17,20,21]. In each of these, either the elemental analysis was carried out or just the phase analysis which provides incomplete information about the ore. Recently, mineralogical characterization of Kuru cassiterite Ore by SEM-EDS, XRD and ICP Techniques was carried out [22]. The purpose of this study is to comparatively study the local mining methods and assay of cassiterite with other alluvial mineral deposits in Kuru-Jantar, Plateau State, Nigeria.

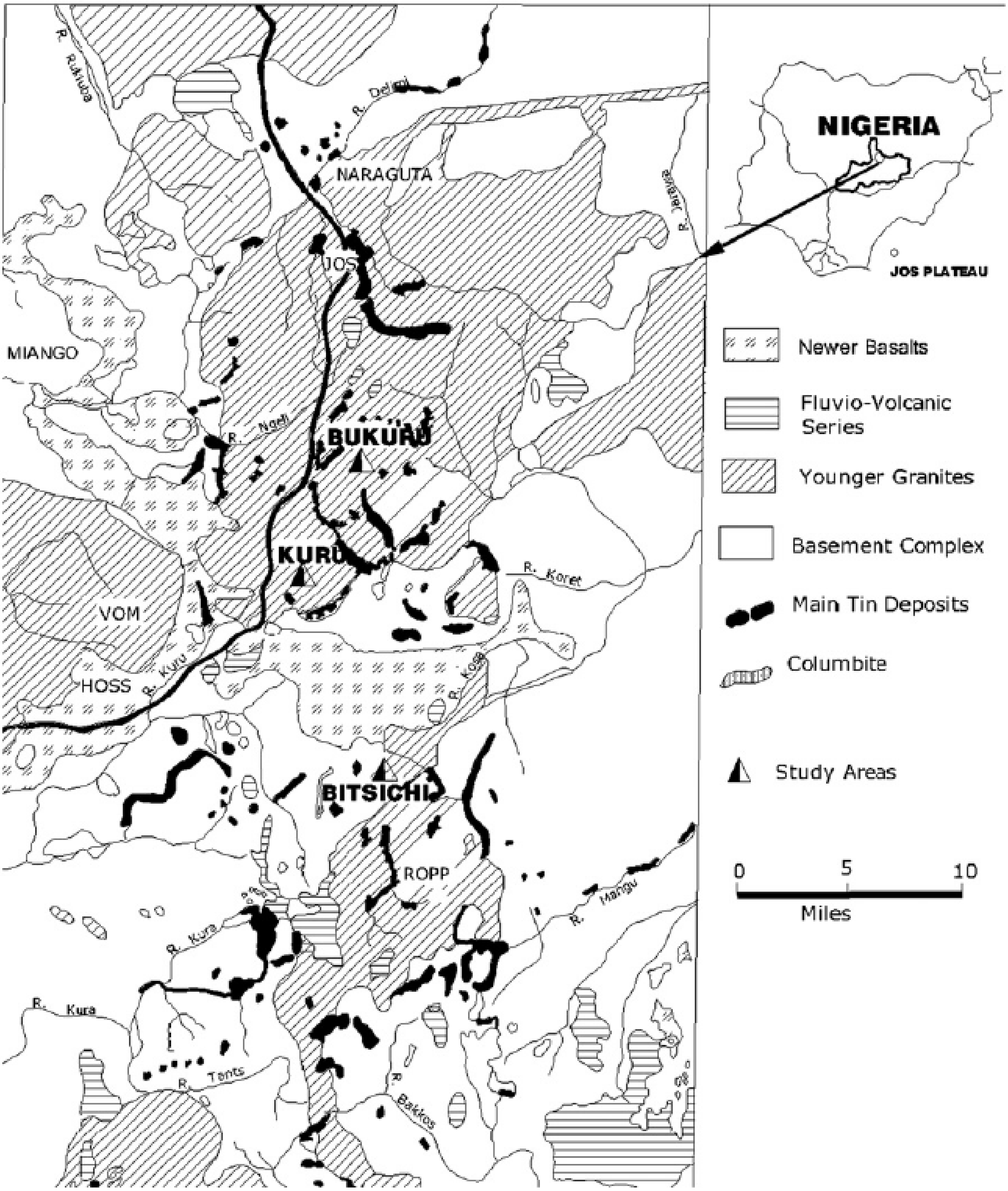

Figure 1. Geological map of the study are

2. Materials and Methods

2.1. Materials

The methodology of research involved on the spot assessment and field measurements of the study area using various tools like Global Positioning System (GPS), Compass, Tape, Camera, Field notebook and writing materials. The locations of the Mining Clusters were obtained from alluvial and primary deposits using GPS which was used to pick up the coordinates and then inserted on a Geo referenced map, using the software ILWIS 3.1 Academic. The digitized map was exported out of ILWIS 3.1 Academic into Microsoft word for further editing, water pumping machine, digger, shovel, calabash and a host of others.

2.2. Methods

The various methods used in carrying out this research are discussed below:

2.2.1. Subsurface (Lotto Mining)

Mine Development was designed and carried out through a series of vertical pits (shafts) as in Figure 2 and the extraction of mineral was carried out with the aid of diggers and shovels in a horizontal direction along the deposit vein. In the study area and specifically on the Main Cluster, ten (10) active mining pits and twelve (12) active sluice boxes illustrated in Figure 3 were sighted. The development and extraction of minerals was accomplished through the mine syndicate system consisting of about ten team members. The mine syndicate was divided into two, where three (3) people were developing new shafts; seven (7) members were involved in extraction and processing. Women were primarily involved in the haulage of the ore to the ground sluice boxes. The following procedures were adopted in lotto mining:

Digging

The digging extended to depth of between 50-55ft, the shallowest pits being about 47ft with a diameter of 2.5 – 3ft. plate 1, tools used include digger, shovel, torch light and wheel and bucket. When the wash (ore) was hit, the thickness was determined and the mining was accomplished along the strike.

Extraction

Excavation of horizontal openings (Plate 1) was carried out along the trend of mineralization. Horizontal opening was extended to about 20 ft depending on the extent of mineralization or availability of oxygen within the sub-surface.

Dewatering

Water pumping machine was used to pump water out of the mine pit into neighboring stream. The 2-inch inlet and outlet pump and 3-inch water inlet and outlet pump were used to pump the water. The 2-inch water pump was observed to be more efficient because of its higher water pumping height.

Haulage

Wheel and bucket were used to extract the washed from the well to the surface by the miners while women were involved in hauling the mineral ore with head pans to the ground sluice boxes locations. The wheel and bucket were also used as a transport system in taking workers in and out of the shaft.

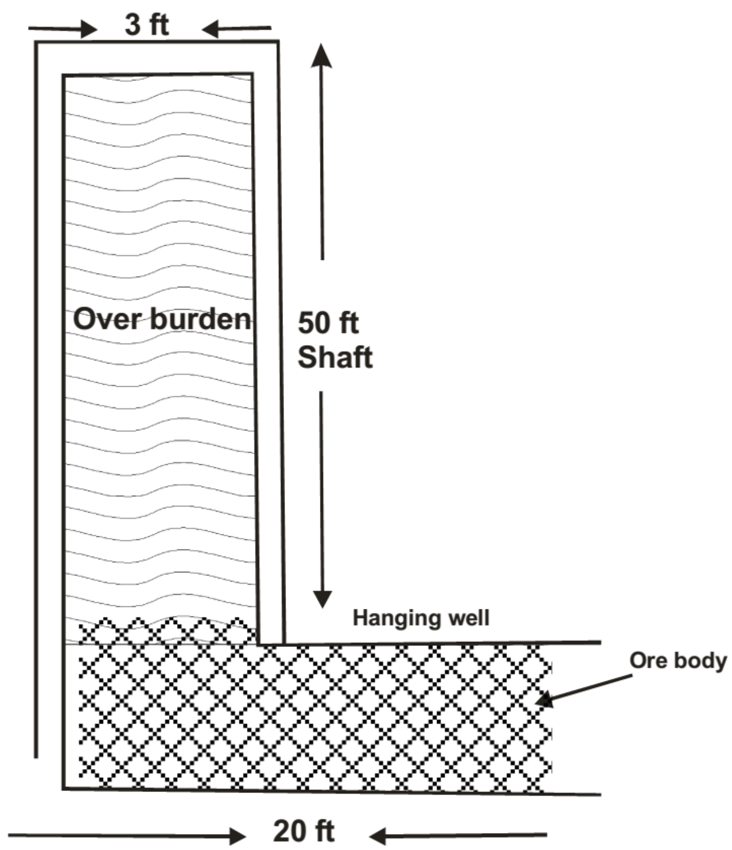

Figure 2. Cross sectional design of lotto mining

Plate 1. Overburden Removal in Lotto Mining

Washing

Washing was achieved through the aid of rudimentary method in the absence of a mechanized method as in Plate 2. Ground sluicing boxes were designed in a manner that the wash passed through several stages pushed by flowing water delivered by water pumps. The lighter materials float passed while the denser materials (those with higher specific gravity) tin, columbite and iron tailing were left behind. The quantity obtained from each pit was measured and recorded together with the quantity recovered after washed and the mean recovery per day was evaluated using equation 1 below:

$$Mean\ recovery = \frac{\sum f \times}{\sum f}. \quad (1)$$

The ground sluice box was designed in such a manner that it was inclined at an angle of about 25° to ease the washing and recovery process of the wash (Figure 3), as higher material such as silica and tailings were moved freely by the flow of water under increased gravity, leaving heavier cassiterite and other minerals that were closer in specific gravity.

Plate 2. Washing of the ore

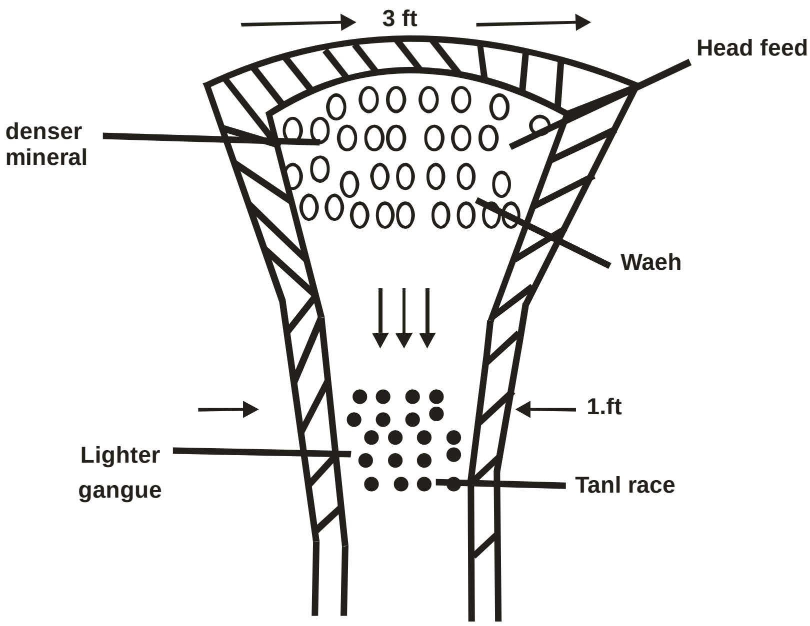

Figure 3. Design of ground sluice box

The head feed of the sluice was made wider than the tail, with the head feet at 3 ft while the tail race had a width of 1.7ft, this also contribute to increase in the velocity of flow of water and ease of recovery.

2.2.2. Surface (Hand Paddock Mining)

This is a local mining method employed to extract the minerals from the host rock using hand labor such as water pumping machine, digger, shovel, calabash and the likes as in Plate 3 and Plate 4. The depth of the open pit was between 15ft to 6ft. The overburden as illustrated in Figure 4 was removed and dumped into the old opening which were at the nearby and the benches were stepped down from the initial cut; and the deposit was removed. The deposit being removed was washed and processed as in plate 5. The quantity obtained from each pit was measured and recorded together with the quantity recovered after washed and the mean recovery per day was determined from equation 1. The choice of this method largely depends on the time of the season and the depth or extends of the deposit. Unlike in the subsurface lotto mining method, the whole ground was excavated in this method. The over burden was first stripped and dumped in a nearby space. Benches were constructed at an interval of 2.5-3ft to provide support for the pit against slope failure and also ease the haulage procedure, thereby allowing sub stained uninterrupted production. After the recovery and washing of the ore, the material recovered for each method was dried, sieved and concentrated using

- Gravity separation
- Magnetic separation.

Plate 3. Surface Excavation

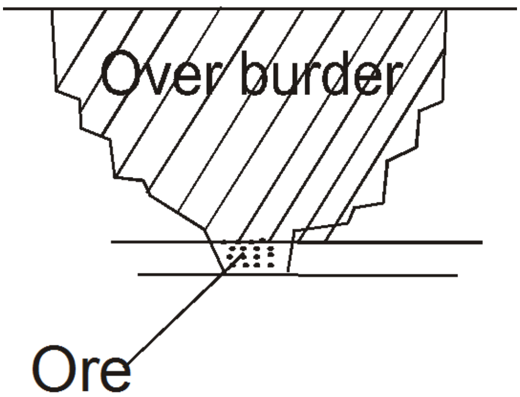

Figure 4. Illustration of ore deposit

Plate 4. Showing hand paddock mining method

Plate 5. Rudimentary Haulage and washing of recovered ore

Magnetic Separation

This was done to separate the minerals of high magnetic susceptibility from those of low magnetic susceptibility. A high intensity electromagnetic separator in Figure 5 was used. Direct current (DC) was converted to magnetic field with the aid of magnet. The magnetic field created was then reacted with the magnetization of the ore that was fed through a process of lifting effect and pinning effect. Minerals with the magnetic property were lifted by the magnet as they passed through the conveyor belt thereby falling into their respective buckets, while minerals with low affinity to magnetism remain pinned on the conveyor belt and dropped at the front end of the belt. The magnetic separation machine consists of different intensities increasing from the lowest intensity to the highest, a feed, a conveyor belt, control switch and control panel where the intensity of the magnets can be increased and an electric motor which provides the motion needed to move the conveyor belt.

Figure 5. Magnetic Separator

50 kg of the feed was fed into the funnel shape part of the machine and into the conveyor belt which conveyed it through the various magnets. Minerals such as hematite, ilmenite with high magnetic susceptibility was picked by the lowest intensity magnet, then followed by columbite, cassiterite (tin) ore and then zircon which has very low magnetic susceptibility were collected in the front of the conveyor belt.

Gravity Separation

This was carried out to separate minerals with different specific gravities such that the denser minerals were separated from the less dense minerals. The gravity separator machine used here made used of air as means of separation. It consists of a deck in form of a table with shallow corrugations, a moving belt (Figure 6) which provided the mechanism that vibrated and provided the vibrations that shake the table and an air system created by a vacuum pump to separate the clustered particles. The material was fed into the machine through the feed. The table surface (deck) was inclined at an angle of about 10^o to the horizontal with shallow corrugations running along its length at right angle to the direction by providing a rough surface that helped to group the minerals based on their density and specific gravity. The outlets consist of six openings with buckets lined up under each outlet. Mineral that dropped in buckets 1 and 2 in front and of the deck was high grade tin concentrate and did not require further separation. Buckets three to five contained low grade tin ore, high grade columbite, silica, titanium and illemite and other associate minerals hence require further separation. Because most of the associate minerals are magnetic in nature, a magnetic separator machine was used in further concentration in process. Bucket six was thrown out because it did not contain valuable mineral.

Figure 6. Gravity Separator Machine

2.2.3. Determination of Tin (Volumetric Analysis)

Preparation of Reagents

Standard N/10 – iodine solution: About 12.69 g of iodine and 26 g of potassium iodide were Weighed in a 500 ml. beaker and agitated with about 400 ml water until they dissolved. The contents were washed into a one liter graduated flask and made up to the correct volume. The solution was standardized against a standard $Na_2S_2O_3$ solution to find out the exact normality.

Starch solution: About 1 g of soluble starch was mixed with about 20 ml cold water; the mixture was added slowly to 80 ml boiling water and boiled for a few seconds.

The ore was grounded to 200 mesh particle size. 0.2 g of the finely grounded ore sample was taken in an iron crucible according to the anticipated amount of tin in the sample and about 8 times its weight of sodium peroxide was added. The constituents were mixed with a dry glass rod. A thin layer of peroxide was sprinkled over the top of the mixture and heated gently over a low flame at a temperature just sufficient to produce complete fusion. The mass melted was kept at a dull redness for about 5 minutes and with the aid of tongs, the crucible was given a swirling motion several times during that period. It was removed from the heat and allowed to cool.

The crucible was then upset with the aid of a glass rod in about 100 ml water in a 500 ml beaker and covered with a watch glass to prevent loss due to spattering. When the disintegration and solution of the fused mass was completed, the crucible was removed and washed with water. Concentrated hydrochloric acid was added until the precipitate dissolved. The solution was filtered with Whatman filter paper and the filter paper was washed with hot water.

The filtrate (acid solution) was transferred in a 500 ml conical flask, followed by the addition of 50 ml conc. hydrochloric acid, about 10 ml of 1:1 sulphuric acid and 15 g granulated lead foil. The solution was boiled for about an hour in an atmosphere of carbon dioxide to reduce the Sn^{4+} to Sn^{2+} state. The flask was removed from the heat and put in a cool water bath and allowed to cool rapidly while maintaining the carbon dioxide atmosphere. When the flask and its contents were cooled, the stopper was removed and rinsed off into the flask; about 5 ml of starch solution (indicator) was added and titrated immediately with N/10 iodine solution in a burette. The initial burette reading value was taken and recorded together with the final burette reading at the point where a faint permanent blue tinge. The procedures were repeated throughout the experiment and the buretting differential (D) was computed from the difference between the initial and final burette readings and recorded. The differential D gave the value of tin concentrate obtained and from that value; the percentage of tin oxide % SnO_2 was obtained from equation 2 while the percentage tin metal % Sn was also obtained from the equation 3. The burretting analysis served as the quality control check to reveal tin ore concentrate obtained from the mining methods

$$\%SnO = 7.87\left(28 - D\right) \quad (2)$$

$$\%Sn = \frac{\%SnO \times 100}{74}. \quad (3)$$

2.2.4. Assaying

5 kg of the ore was assayed to determine the percentage composition of the minerals in the ore. The ore was crushed, ground, mill and sieved to 75 µm particle sizes. 4 g of the sieved samples were mixed vigorously with 1 g of lithium tetraborate binder ($Li_2B_4O_7$) and pressed in a mould under a pressure of 10 tons/in^2 to a pellet. The pellets were dried at 110°C for 30 minutes in an oven to

get rid of adsorbed moisture content and were finally stored in a dessicator for analysis. The X-ray fluorescence spectrometer (XRFS) was switched on and allowed to warm up and also gained in order to stabilize the optics and the x-ray tube. It was then calibrated to determine the expected chemical composition in the ore. The samples were run using the prepared calibrations and the concentrations of the constituent elements present in the samples were calculated and displayed after applying automatic statistics to the results by the spectrometer. The results of the ED-XRF analyses are presented in the Table 9, Table 1, Table 1, Table 1 and Table 1.

3. Results and Discussion

The results obtained in this research are presented as follow:

Table 1. Recovery from Lotto Mining Method

Number of Pits	Depth (m)	Quantity obtained (kg)	Number of days	Recovery (kg)
1	15	50	3	9
2	16	60	4	17
3	14	60	4	13
4	15	70	5	7
5	17	60	4	26
6	18	80	6	10
7	16	50	3	19
8	14	60	4	22
9	16	50	3	8
10	18	60	4	16
Total		600	40	147

Table 2. Mean Recovery from Lotto Mining Method

Number of Days (F)	Recovery (Kg) X	FX
3	9	27
4	17	68
4	13	52
5	7	35
4	26	104
6	10	60
3	19	57
4	22	88
3	8	24
4	16	64
$\Sigma f = 40$		$\Sigma f X = 576$

Mean recovery = 14.48 Kg/day.

Table 3. Recovery from Hand Paddock Method

Number of Pits	Depth (m)	Quantity Obtained (kg)	Number of Days	Recovery (kg)
1	4	42	4	11
2	4	34	2	7
3	5	38	3	9
4	6	40	1	10
5	6	35	6	16
6	5	51	3	12
7	6	45	2	13
8	4	37	4	9
9	5	42	2	11
10	5	36	2	8
Total		400	29	95

Table 4. Mean Recovery from Hand Paddock Method

Number of days (F)	Recovery (Kg) X	FX
4	11	44
2	7	14
3	9	27
1	10	10
6	16	96
3	12	36
2	13	26
4	9	36
2	11	22
2	8	16
$\Sigma f = 29$		$\Sigma f X = 327$

Mean recovery = 11.28 Kg/day.

Table 5. Burette Result Cassiterite. (Lotto Mining)

Pits	Wt of ore sample (g)	Wt. of valuable mineral (g)	Initial Burret Reading (cm^3)	Final Burret Readings (cm^3)	Burretting differential D.
1	0.2	126	30.00	11.00	19.00
2	0.2	126	30.00	11.20	18.80
3	0.2	126	30.00	11.20	18.80
4	0.2	126	30.00	10.50	19.50
5	0.2	126	30.00	10.70	19.30
6	0.2	126	30.00	11.20	18.80
7	0.2	126	30.00	11.10	18.90
8	0.2	126	30.00	10.20	19.80
9	0.2	126	30.00	11.90	18.90
10	0.2	126	30.00	10.90	19.10

Table 6. Tin Metal Burette Result Cassiterite (lotto)

Pit	wt of ore g	Buretting differential D	SnO_2 %	Sn%
1	0.2	19.00	70.83	95.71
2	0.2	18.80	72.40	97.83
3	0.2	18.80	72.40	97.83
4	0.2	19.50	66.90	90.40
5	0.2	19.30	68.47	91.52
6	0.2	18.80	72.40	97.83
7	0.2	18.90	71.62	96.78
8	0.2	18.80	72.40	97.83
9	0.2	18.90	71.62	96.78
10	0.2	19.10	70.04	94.64

Table 7. Burette result of hand paddock

Pits	wt of ore Sample (g)	wt of valuable mineral(g)	Initial burette reading	Final burette reading	Burette differential
1	0.2	126	30	10.80	19.20
2	0.2	126	30	10.70	19.30
3	0.2	126	30	11.00	19.00
4	0.2	126	30	11.10	18.90
5	0.2	126	30	10.90	19.10
6	0.2	126	30	11.00	19.00
7	0.2	126	30	11.20	18.80
8	0.2	126	30	11.10	18.90
9	0.2	126	30	10.70	19.30
10	0.2	126	30	10.80	19.20

Table 8. Tin Metal Burette Result (hand paddock)

Pit	Wt of ore (g)	Burretting differential D	SnO_2 %	Sn%
1	0.2	19.20	69.25	93.58
2	0.2	19.30	68.46	92.51
3	0.2	19.00	70.83	95.71
4	0.2	18.90	71.62	96.78
5	0.2	19.10	70.04	94.64
6	0.2	19.00	70.83	95.71
7.	0.2	18.80	72.40	97.80
8.	0.2	18.90	71.04	96.78
9	0.2	19.30	68.46	92.51
10.	0.2	19.20	69.25	93.58

Table 9. Recovery from 50kg of sample through magnetic separation (lotto)

Mineral Obtained	Recovery Wt (kg)
Iron (Fe)	10.23
Columbite (Nb)	9.09
Cassiterite (Sn)	10.91
Zircon (Zr)	18.06
Total recovery	48.28

Table 10. Recovery from 50kg of sample through magnetic separation (Hand paddock)

Mineral Obtained	Recovery Wt (kg)
Columbite (Nb)	10.10
Cassiterite (Sn)	9.06
Iron (Fe)	9.60
Zircon (Zr)	20.54
Total	49.30

Table 11. Assaying of cassiterite from lotto mining (XRF)

Minerals	Percentage composition (%)
Tantalum (Ta)	1.140
Niobium (Nb)	10.254
Tin (Sn)	68.697
Titanium (Ti)	8.324
Iron (Fe)	7.801
Zircon (Zr)	4.273

Table 12. Assaying of cassiterite XRF (Hand Paddocking)

Mineral	Percentage composition (%)
Tantalum (Ta)	1.212
Niobium (N6)	9.511
Tin (Sn)	66.462
Titanium (T_1)	6.011
Iron(Fe)	8.231
Zircon (Zr)	6.212
Silica (S_1)	2.311

Table 13. Assaying of other associated mineral (paddock)

Minerals	Percentage Composition (%)
Tantalum (Ta)	2.5
Columbite (Nb)	40.4
Cassiterite (Tn)	2.3
Wolframite (W)	5.1
Magnetite (Fe)	26.5
Titanium (Ti)	22.3

Table 14. Assaying of other associated mineral (lotto)

Minerals	Percentage Composition (%)
Tantalum (Ta)	2.3
Columbite (Nb)	37.6
Cassiterite (Sn)	5.8
Wolframite (W)	4.9
Magnetite (Fe)	24.8
Titanium (Ti)	21.5

4. Discussion of Result

From Table 1, 147 kg of the ore was recovered in 40 days from the lotto mining while in Table 3, 600 kg of the ore was recovered in 29 days from paddock mining method. The mean recovery per day from Table 2 and Table 4 are 14.48 kg/day and 11.28 kg/day for lotto and paddock mining methods respectively. It can be observed from Table 2 and Table 3 that the lotto mining method has the highest recovery per day and hence, gives better recovery than paddock mining method.

From Table 5, Table 6, Table 7 and Table 8, the volumetric analysis result reveals that the range of the burretting differential obtained for the lotto and paddock methods are 18.80 – 19.80 and 18.80 – 19.30 respectively while their respective percentage tin metal burretted are 90.40 – 97.83 and 92.51 – 97.80 %. It can be observed that both the lotto and paddock mining methods have good burrette values [23] but the quality control checks reveals that tin ore concentrate obtained from lotto mining gives higher grade in the burette analysis. This can be attributed to the fact that in subsurface lotto mining; the operation targets only the vein where the ore body lies while in surface mining (paddock), anything closer to the ore is mined along to avoid unnecessary left over. This is the reason why lower grade cassiterite and more of associate mineral finds its way into the analytical result of surface hand paddock operation Table 7 and Table 8.

From Table 9 and Table 10, the recoveries from the 50 kg magnetic and gravity separations are 10.91 kg and 9.06 kg for lotto and paddock methods respectively. It can then be said that the concentrate recovered from subsurface (lotto) mining yield higher grade than the hand paddock operation and hence, confirm the result of the burretting analysis in Table 6.

From Table 11 and Table 12, it can be deduced that the percentage compositions of tin in the cassiterite ore through the XRF analysis are 68.69 and 66.462 % respectively for the lotto and paddock mining methods and this indicates that the lotto mining method produces higher grade of tin than the paddock method.

In Table 13, the assaying of other associate minerals are 40.4 % columbite, 26.5 % iron, 22.3 % titanium, 2.5 % tantalum, 2.3 % tin, and 5.1 % wolframite for the paddock mining method while Table 14 gives the assaying of the associate minerals from the lotto mining method which are 37.6 % columbite, 24.8 % iron, 21.5 % titanium, 2.3 % tantalum, 5.8 % tin, and 4.9 % wolframite. These percentage compositions of the other mineral values that occur along side with the cassiterite and columbite concentrates were obtained after the assaying and this help to determine the types of minerals that occur along side cassiterite and columbite together with their respective percentage compositions in the concentrate; hence, their presence or absence is one of the factors that determine the grade or quality of the concentrate [20]. It can be observed from Table 13 that there are more of iron ore, columbite and titanium in the tailing from the paddock mining and this can be inferred that the paddock mining method produces more recovery than the lotto method in terms of the associate minerals and these can have economic value in part or as a whole based on demand.

Hazard

The mining activity is of great economic and social significance. As it currently exists, artisanal mining in Kuru is high risk activity most especially the lotto. The activity is practiced on a small scale by people who are often poor, and although educated, they lack other employment opportunities. It is a highly unregulated sector and subject to harsh working conditions. That the artisanal miners are not trained, they often do not realize that the un-supported and / or un-reclaimed pits of sub-surface mining methods they use to mine minerals are devastating their environment and their health with potential fatal consequences. In regulated mining the mined out area is expected to be reclamation, this involves filling the excavated area with mine spoils. This is followed by restoration which involves putting the area into use once again after exploitation for activities such as fish farming, dry season farming of assorted vegetables such as pepper, beans and potatoes. Around the study area, Community Forest Area (CFA) was spotted within the mining area these are relics of reclamation activities carried out at the advent of the mining law of 1946 by the Mine operators [15]. The forest was subsequently handed over and managed by the community (traditional rulers). The forest is harvested within a period of ten years interval and proceeds (revenue) from the forest are converted into community use and development. The reclamation activities by the natives using assorted waste and domestic materials portend future danger to the sub-surface water quality and human health. Mining operations normally upset the equilibrium in the geological environment, which may trigger off certain geological hazards such as landslide, subsidence, flooding and erosion together with their secondary effects. Since land is a non-renewable resource at a human time scale, some adverse effects of these degradation processes on the land quality of Kuru are irreversible [3].

The productivity of some lands of these areas has declined by 50% due to soil erosion and poor crop yield. Land degradation is a decline in land quality caused by human activities which in Kuru's case, it had been mining. This un-scientific method of mining lives behind devastated land area with abandoned pits and mine dumps littering the environment. This artisanal mining activity although constitutes a menace to the environment as the mined out pits are not reclaimed through adequate re-filling to forestall roof collapse leading to land subsidence, provide a formidable source of income to the miners. The hand paddocking method is less cost effective, less risk involved, man power are very few and operation hours are also very small.

5. Conclusion

This research attempt to investigate and compare the local mining methods of cassiterite in Kuru-Jantar area of Plateau State Nigeria with the view to determine the mean recovery per day using statistical approach, separating the valuable minerals through the gravity and magnetic techniques, determine the grade of cassiterite (tin oxide) with the aid of volumetric and energy dispersive x-ray florescence (XRF) analyses; and determine the percentage composition of metals in cassiterite as well as its associate ores with the aid of (XRF).

It was observed that the lotto mining method has the highest recovery per day and hence, gives better recovery than paddock mining method.

The percentage composition of tin (Sn) obtained after assaying is higher in lotto mining than hand paddock method which indicate that tin has the highest percentage composition of the ore. This shows that Kuru-Jantar is rich in cassiterite deposit where tin ore can be mined economically via lotto mining technique than the hand paddock technique. Cassiterite is the major mineral with the highest occurrences in this area, hence; tin has the best viability for profitable exploration.

Other minerals associated with cassiterite are tantalum, zircon, columbite, and Iron while the associated minerals that occur alongside columbite concentration are tantalum, cassiterite, wolframite, lron and titanium. The rudimentary sub-surface method (Lotto) of mining being deployed which is un-supported, un-illuminated and unventilated portends serious dangers to the miners in terms of accidental roof collapses, suffocation and other forms of health hazards while the paddock mining practices render more danger to environment than the lotto mining.

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