Application of Unmanned Aerial Photography for the Estimation of Extracted Rocks – Beautiful Rock Quarry, Nigeria Experience

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Abstract

This research was carried out to investigate the application of unmanned aerial photography in estimating the respective tonnages of extracted rocks at Beautiful Rock Quarry, Lokoja, Nigeria. To attain the aim of the research, the aerial views of the 2D images captured were used to generate aerial views in the form of 3D models, namely, Digital Terrain Models (DTMs) and Digital Surface Models (DSMs). ImageJ and Regard3D components of Image Processing Software, were used for the processing of the images. Owing to the tilted aerial photograph, correction checks were conducted for the sensor coordinates, and the ground coordinates were established. Images of the extracted pits and stockpiles were analyzed by applying image processing software, which identified elevation spots and generated Z-plots for these feature. With the results generated from the image processing software, the extracted rocks from the pit were calculated to weigh 1,027,204.512tons, while the total production of aggregates sold from the quarry between 2012 and 2020 was documented to weigh 1,715,800tons. The difference between the tonnage of extracted rocks from the pit and the total production of aggregates sold was due to the swell factor of the rock (1.70), the fly rock issuing from the blasting operations and the loss of aggregates during the loading and haulage phases of the mining operation. The stockpile calculated from the 3D images weighed 44,695.39tons. The expected tonnage of the extracted rocks from the pit after excavation and crushing into aggregates was expected to be 1,746,247.670tons, which is about two percent higher than the total aggregate weighing 30,447.67 tons produced from the quarry. Therefore, approximately two percent should be allowed for the extracted tonnage expected from the pit after excavation and crushing into aggregates, as well as for the total aggregate produced from the quarry.

Keywords: *Aerial Photography, Coordinate, Image Matching, DTM, DSM, Geometry, Estimation*

1. Introduction

Conventional surveying for effective estimations has proven to be erratic. The use of unmanned aerial vehicles (UAVs) could involve alternative and exact sets of data (Ľudovít *et al.*, 2017). These digital photogrammetric records will help to create both 2D and 3D models of the pit and stockpile, to define the geometric properties of the pit and stockpile, and to determine the tonnage of the mined out reserves and stockpile. In the past two decades, with the development of specialized digital cameras and the application of an innovative digital photogrammetric approach, the use of photogrammetric images; and particularly close-range photogrammetric images taken from above the ground surface, has become a distinctive practice in various uses (Miller, 2009). The incorporation of close-range photogrammetry in an unmanned aerial vehicle (UAV) to serve as a very flexible imaging stand has headed towards a different branch of UAV photogrammetry (Luhmann *et al.,* 2006). However, accuracy mining needs large-scale photogrammetric methods through high tenacity imagery of a gigabyte size to plot scales ranging from 1: 1000 to 1: 5000 (Fritz *et al.,* 2013). Furthermore, the entire procedure should involve the use of state-of-the art software and hardware for the fast processing of data and the successive generation of digital outputs.

Prominent studies by diverse authors principally (Aguiler *et al.,* 2005) and Schulz and Ingensand (2004) have established the value of exact 3D shaped modernization and volume estimation in several cases (e.g in erosion studies, with estimate of ore distant from a mine face and terrain valuations for construction etc.). Incredibly, mainly digital photogrammetry has gained acceptance owing to the technology progressions in gathering detailed spatial data relating to the size of the mineral resources in question through high-resolution cameras or laser scanners whereby digital 3D surface models are created and interpreted (Atkinson, 1996 and Patikova, 2004). Digital terrain models (DTMs) combined with additional data such as dip direction and dip measurements, joint spacing etc., have been shown to contribute to the valuation and classification of mineral volumes (Hao and Pan, 2011 and Wallace, 2008). Most essentially, digital photogrammetry has been verified to be more dependable and economical as an essential appraisal tool in that it is able to instantaneously plot ore stockpiles, pits and infrastructural areas on many sites and on a steady basis, usually at quarterly intervals (Yakara and Yilmazb, 2008). However, since the geomorphic formations and functions of the associated structures may have a definite impact on open-pit mining (Jianping et al., 2015 and Labant et al., 2013), digital photogrammetry has also been found to be significant in studying these aspects. In their turn, stockpile and pit mapping are used to determine the exact size measurements, while structural mapping is used in mine planning events overall (Chen and Lin, 1991) and (Raeva *et al.,* 2016).

Data precision is a serious consideration as it is used to assess stockpile data and to generate volume reports which drive the basis for computing the disbursements to subcontractors (Yanalak, 2005). In practice, if or otherwise advised, the workflow will always involve the mapping and volumetric reckoning of pits, before stockpiles, and lastly, infrastructural areas. The variances detected in the volume of the resources and its established average probable grade could be accredited to the generalizations made in terms of the real shape of the deposit by the modern technique applied through the relevant software (Afeni *et al.,* 2020). As an extreme overlay, established in this research at 80%, would result in a less precise DTM, one of the inventive methods offered has been to limit the use of the frames of the aerial photography to only those acknowledged for mapping (Hamzah and Shaharuddin, 2011).

1.1. Estimation of Mineral Deposit

The minor comparative variance in the tonnage estimate verifies that the geometric technique is real for tonnage estimating tonnage and can be embraced by geologists and mining engineers for authenticating class approaches. (Afeni *et al.,* 2021). Stockpiles can present with possible "cratering" and do not necessarily emulate flawless shapes. As such, unevenly shaped stockpiles is tough when it comes to estimations. As such, owing to the high costs and prolonged duration of convectional resource surveys in some developing countries essential resource inventories have not been methodically or even partially carried out.

Estimations of the tonnage and average grade of the ore deposits (ore-reserve estimations) can be made for numerous purposes. Most functioning companies make periodic ore-reserve estimations, at least, on average, about once a year, to define their ore reserve as a basis for monitoring progress and for investigating and providing funds for that purpose, for defining deferred, depletion, and devaluation charges per ton, or as the basis for determining the operational policy on the expansion of or decline in operations, capital costs, and the like.

1.2. Study Area

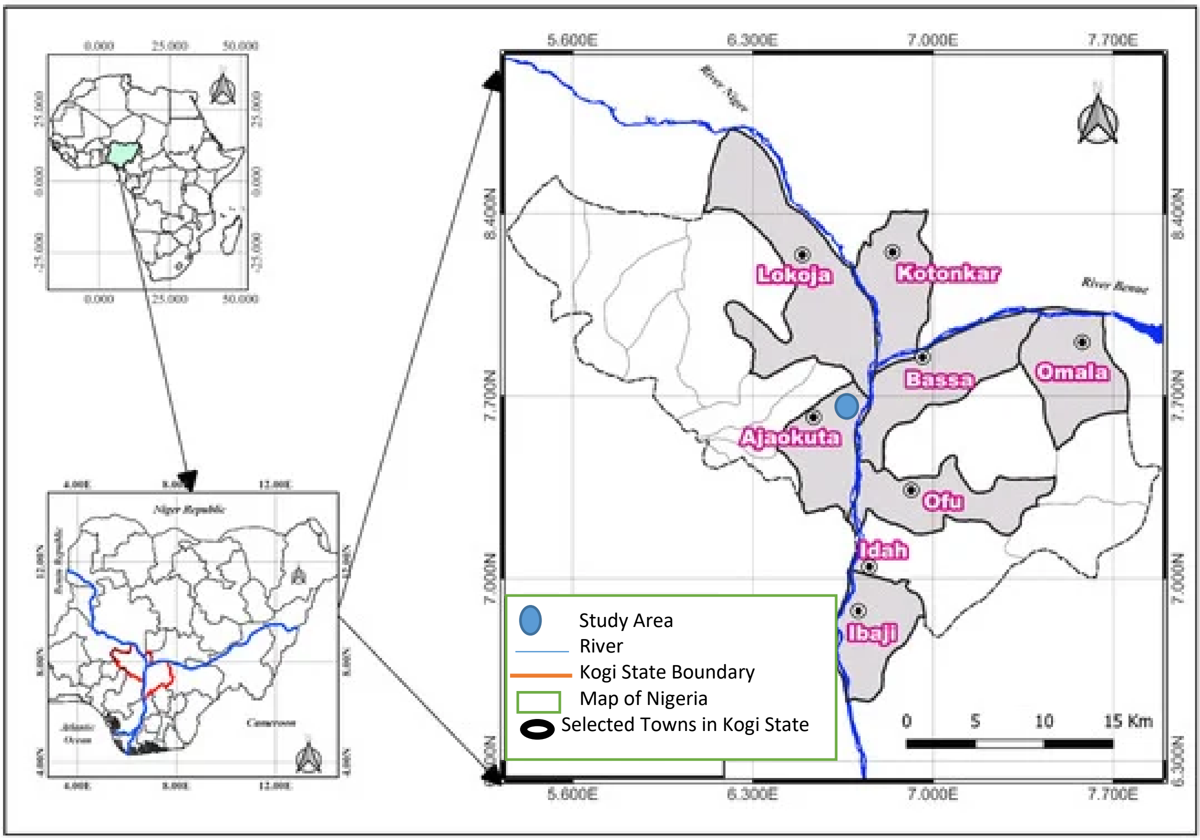

Figure 1: Physical Map of the Study Area

As shown below, in Figure 1, the study area is located along the Lokoja – Ajaokuta Road, Ganaja in Jimgba Village, Lokoja, Nigeria is located at latitude N07° 51' 11" and longitude E006° 43' 39". The study area is characterized by a geological formation belonging to the South-western Nigeria Basement Complex.

2. Materials

The materials used for this research included a Drone, with a remote controller, a portable flat screen, a Global Positioning System (GPS) and photogrammetric software namely, ImageJ and Regard3D.

2.1. Research Method and Design

The entire research method and design involved a distinct photogrammetric project workflow, beginning at aerial photo acquisition, and progressing to Aerial triangulation (AT), the graduation of the digital camera, image processing, and finally, the generation of an orthophoto and a map. The drone sensor coordinates were used as check points for the ground coordinates. The 2D digital images were processed using software to generate 3D digital images in which the geometric properties of the pit and stockpile were calculated. The geometric parameters were used to determine the tonnage of the material mined out from the pit and the tonnage set in place as the stockpile.

2.1.1. Mapping of the Pit and the Deposit

The pit and deposit mapping segment of the project included the modernized mapping of the mined-out areas. Usually, the pit data entail those data pertaining to pit areas, spoilt areas and the adjoining natural surface feature. To map the pit and deposit faces perfectly, break streaks were used to enclose and outline the face between the top and the toe of the pit were sited exactly on the face.

2.1.2. Stockpile Mapping

Stockpiles were demarcated and the areas within the stockpiles were mapped. Provision was made for enough break streaks on the tops and toes of the stockpiles, for the required spot elevations, and a grid spacing to precisely outline the stockpile surface. For those areas where there were length of stockpile dumps, break streaks were introduced along the top and toe of each row. This was done by accurately outlining and scheming the “edge of the stockpile” borderline as the stockpile surface was being mapped using the appropriate stockpile mapping feature codes.

2.2. Data Analysis

The data collected for this research work were 2D digital images. These images were analyzed by Regard3D and ImageJ software to generate accurate 3D digital images and to determine the geometric parameters of the digital images and the tonnages from those images.

2.2.1. Determination of Scales and Ground Sample Distances

The scale for the aerial photograph was determined by applying the following formula:

$$\text{Scale} = \frac{f}{H} \quad [1]$$

where *f* is the focal length (mm) and H is the flight height (mm),

2.2.2. Digital Image and Ground Coordinates

The image of a ground point has coordinates of x and y on a photograph taken at a particular flight height (H) and at a particular focal length (f). Under the assumption that rotations of ώ = ϕ = k = +1°, were performed on exposure, equations 2, 3, 4, and 5 (Arthur *et al.,* 1998) were applied to determine the corrected coordinates, and hence, the ground coordinates with respect to the camera position.

$$x' = f\,\frac{x + ky + \phi f}{-\phi x + wy + f} \quad [2]$$

$$y' = f\,\frac{kx + y - wf}{-\phi x + wy + f} \quad [3]$$

where x' and y' are the corrected coordinates. ώ = ϕ = k = + 1° = $\frac{\pi}{180}$

$$x_G = x'\,\frac{H}{f} \quad [4]$$

$$y_G = y'\,\frac{H}{f} \quad [5]$$

where x_G and y_G are the ground coordinates (i.e the ground northing and easting coordinates).

2.2.3. Determination of Volume for the Mined Pit and the Stockpile

Based on the type or form of their shapes, the respective volumes of the mined pit and the stockpile were calculated using photogrammetric software.

Volume of the pit = Area x Average Depth [6]

$$\text{Volume of the stockpile} = \frac{\pi r^2 h}{3} \quad [7]$$

2.2.4. Determination of the Pit and Stockpile Tonnage

The tonnages from the mined out pit and the stockpile were calculated separately by applying the same formula.

Tonnage = Volume x Tonnage Factor [8]

2.2.5. Secondary Data Collection for Correlations between the Pit and the Stockpile at the Quarry

Data for the specific gravity of the rock and the annual production in tons were collected from the responses to a questionnaire presented to the workers in the quarry.

2.2.6. Swell Factor for Correlations between the Rocks extracted from the Pit and the Quarry.

The swell factor, expressed as a percentage, is the magnitude of the volume increase from the intact volume (undisturbed and in situ) to the loose volume (disturbed, excavated from the in situ site) of the material owing to voids (air pockets) added to the material after excavation.

Swell for Granite = (70) %, (*FHWA,* 2007) [9]

Intact Material = 100% / 100 = 1 [10]

Swell Factor = Intact Material + Swell/ (100%) [11]

Tonnage of the extracted rocks from the Pit after excavation and crushing into aggregates = Extracted rock from the Pit x Swell Factor [12]

3. Results and Discussion

3.1. Results generated for 2D and 3D Models

The results of the 2D images captured with a drone, with a 5.8 GHz transmitter and at a high -resolution of 12 MP, were used to generate 3D models in terms of Regard3D and ImageJ software for the mined out pit and stockpile. They are presented in Figures 1, 2 and 3.

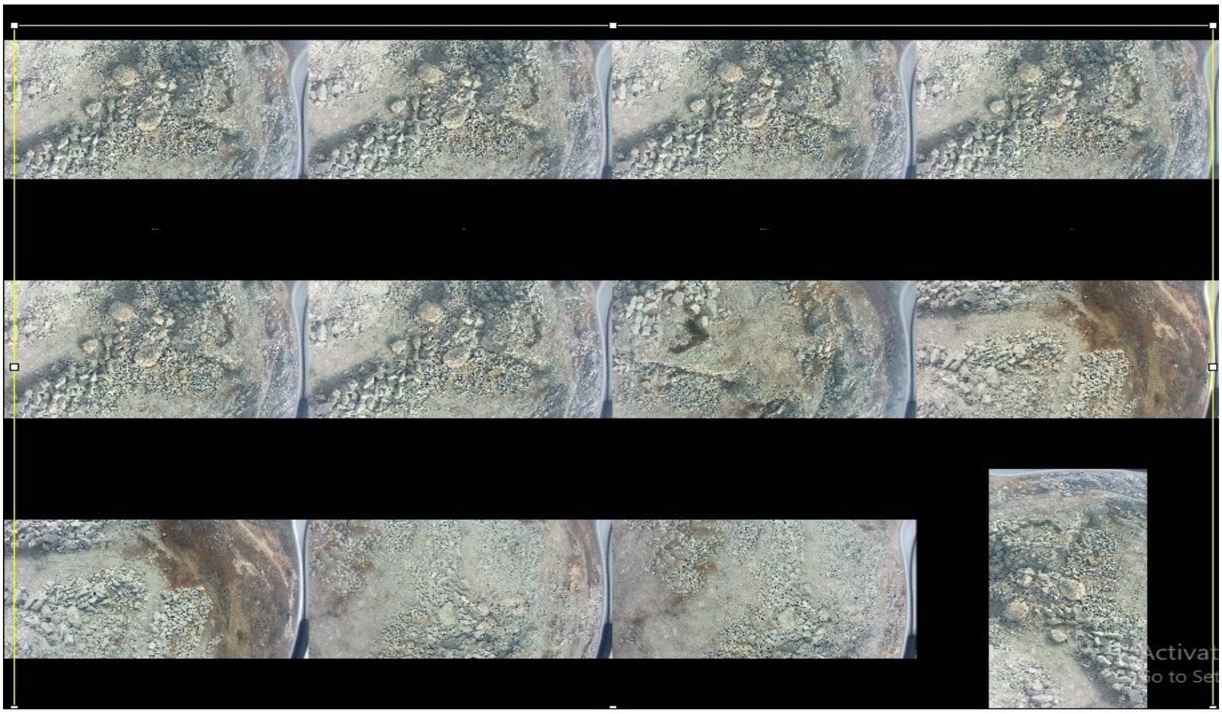

Figure 1: Montage of 2D Images for the Pit

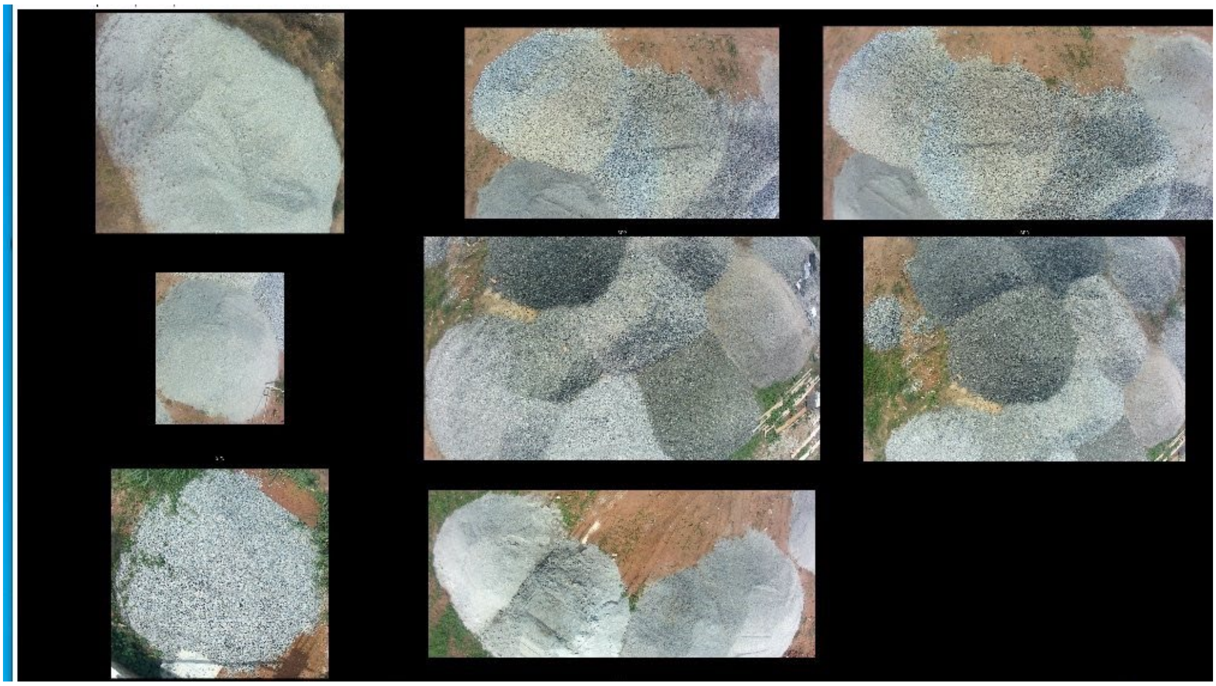
Figure 2: Montage of 2D Images for the Stockpile

3.2. Scale and Ground Coordinate Checks

From equation 1, f = 2.88mm and H = 83000mm

Scale = 0.00003

Ground sample distance, (GSD): 1m to represent 3,779.525pixels

Ground coordinate checks for the pit (x, y): 2048mN, 1152mE.

From equations 2 and 3,

$x' = -0.3809$ $y' = -0.2818$

where x' and y' are the corrected coordinates.

From equations 3 and 4,

$x_G =$ 10977.33mN $y_G =$ 6305.30mE

where x_G and y_G are the ground coordinates. (10977.33mN, 6305.30mE)

Ground coordinate checks for the stockpile (x, y), (2015.50mN, 1147mE)

From equations 2 and 3,

$x' = -0.3869$ $y' = -0.2248$

where x' and y' are the corrected coordinates.

$x_G =$ 11150.24mN $y_G =$ 6478.02mE

where x_G and y_G are the ground coordinates. (11150.24mN, 6478.02mE)

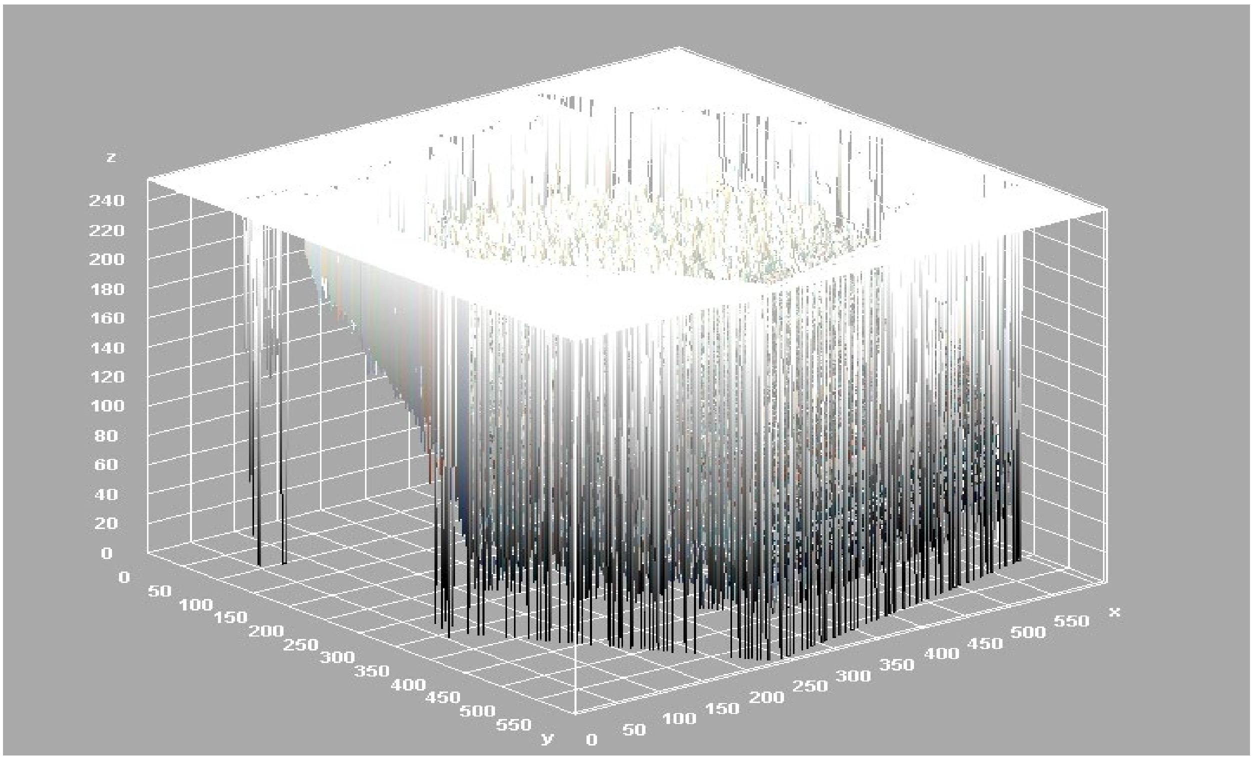

Figure 3: 3D Digital Terrain Model for the Pit. (Crest Elevation)

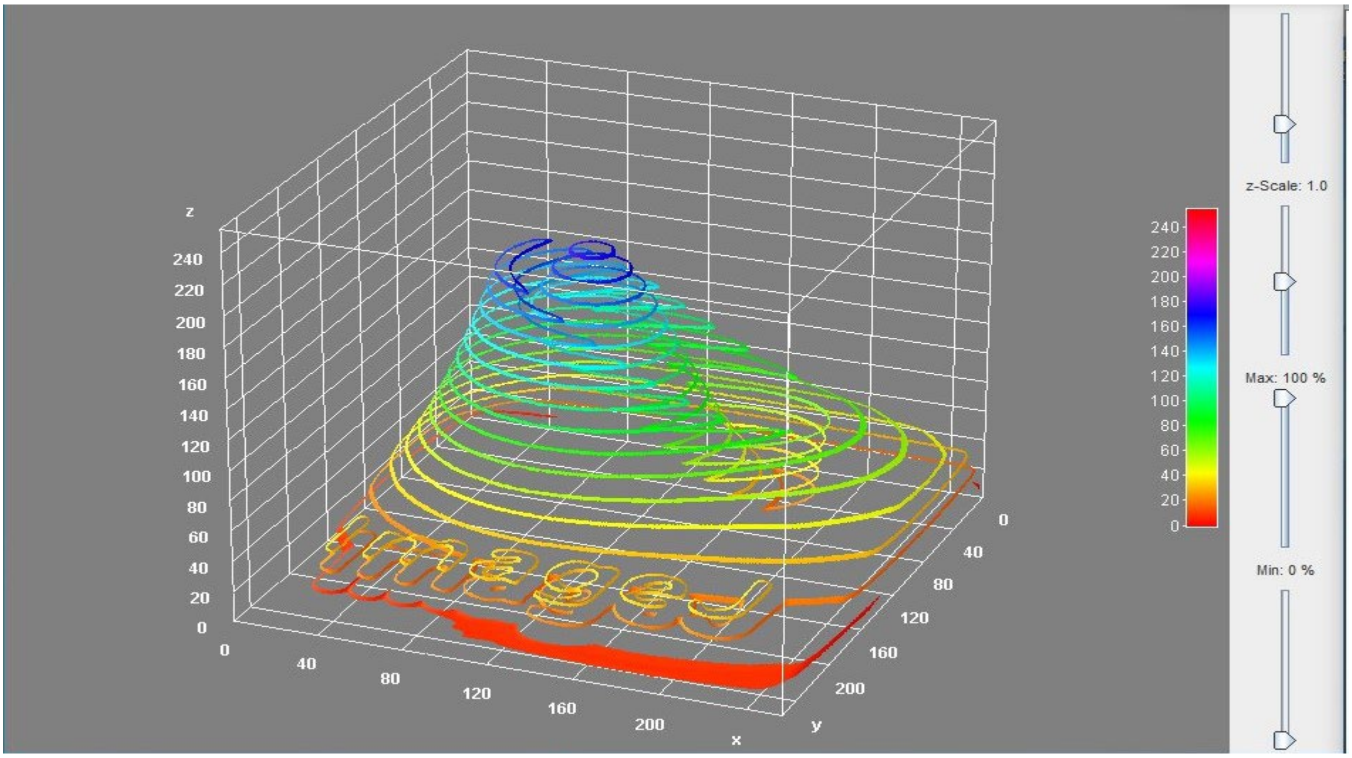

Figure 4: 3D Digital Terrain Model for the Stockpile. (Spot Elevation)

3.3. Results generated for the Geometric Properties of the Pit and Stockpile

The results generated to determine the average elevation of the pit and the stockpile to calculate their geometric properties are shown in Figure 5 (Z plot to determine the pit elevation) and Figure 6 (Z plot to determine the stockpile elevation).

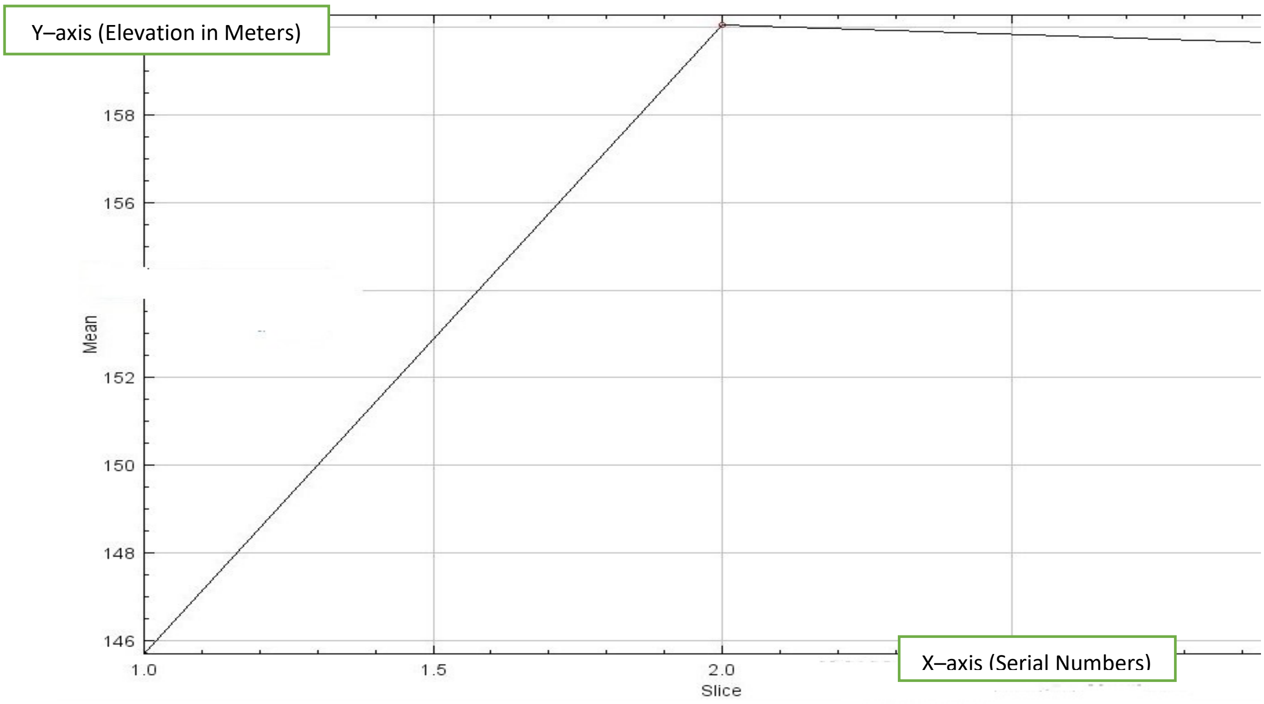

Figure 5: Z Plots for the Pit

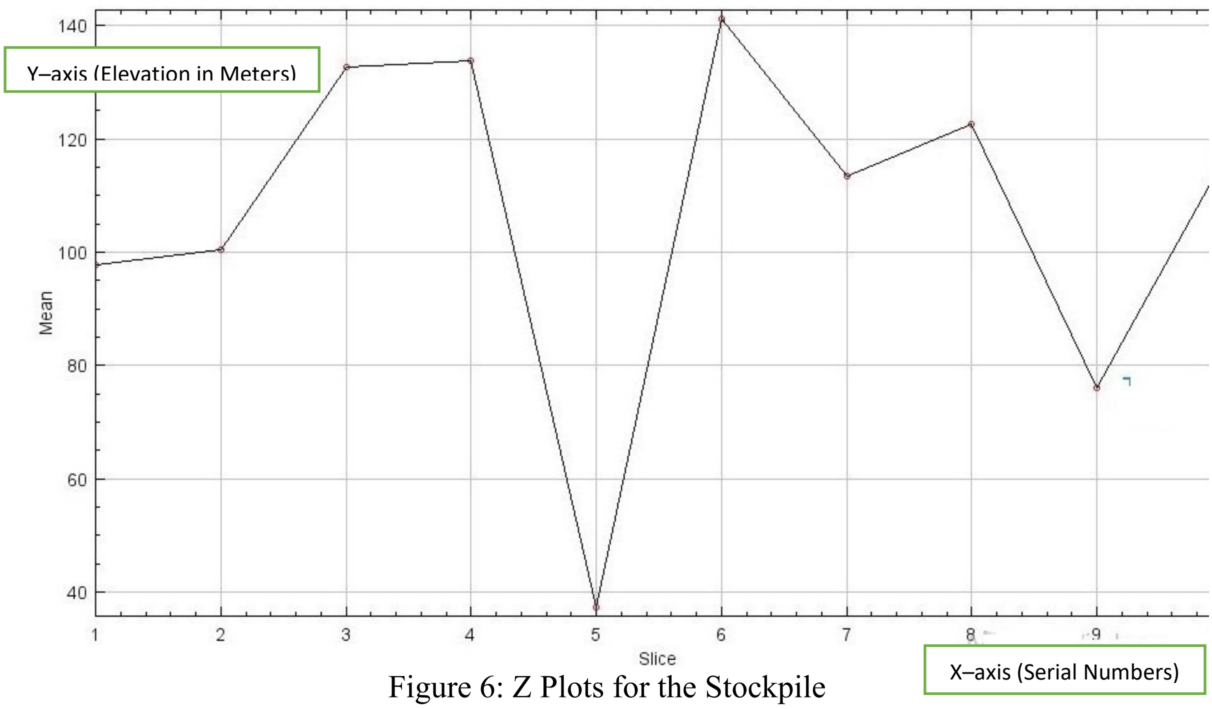

Figure 6: Z Plots for the Stockpile

3.3.1. 3.3.1 Area and Volume of the Pit and Stockpiles

The results, presented in Figures 5 and 6, were generated with ImageJ software in order to calculate the respective areas and volumes of the pit and stockpile.

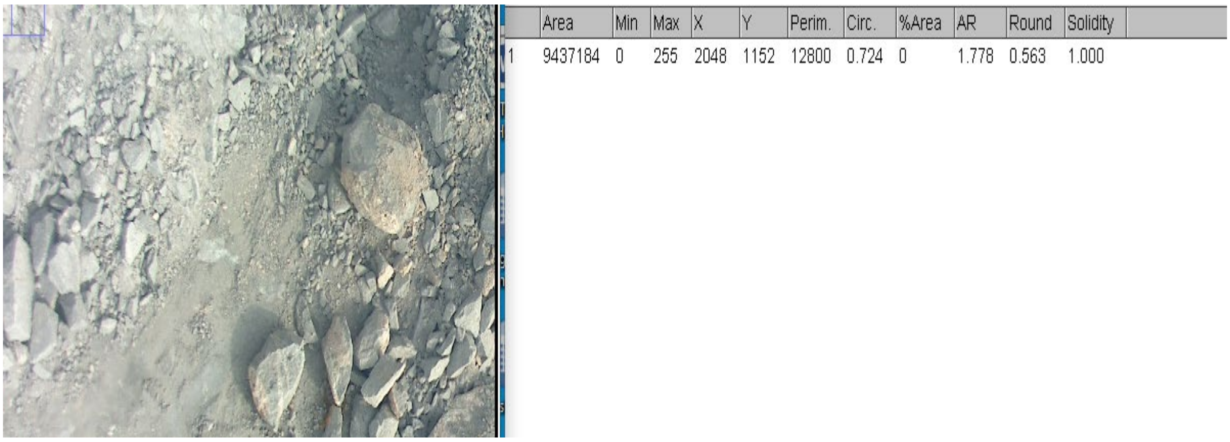

Figure 7: Area of the Pit in Pixels

As shown on Figure 7, and with the aid of ImageJ software, the area of the pit was calculated to be 9,437,184 pixels. The average depth of the pit was derived from Figures 3, 4, 5 and 6, and established as 155.124m.

The volume of the pit was calculated by applying equation [6].

Area = 9437184 * 0.00026458

= 2,496.923m^2

Volume of the pit = 2,496.923 * 155.124

= 387,332.018m^3

Tonnage of the pit was calculated using equation [8].

= 387, 332.018 * 2.652 (Table 2)

= 1,027,204.512tons

The volume of the stockpiles were calculated from Table 1 by applying equation [7]. The radius, r and height, h were derived from Figures 4, 5 and 6.

Table 1: Volume of Stockpiles computed in Cubic Meters and in Tons

Stockpiles	π	r[m]	H[m]	r2	π r2h	Volume[m3]	Tons
1	3.14	8.3	97.74	68.89	21156.06	7,052.02	2,490.4
2	3.14	9.5	100.56	90.25	28515.35	9,505.12	3,356.7
3	3.14	12.2	132.66	148.84	62039.15	20,679.72	7,302.97
4	3.14	12.8	133.71	163.84	68831.94	22,943.98	8,102.59
5	3.14	12.4	37.34	153.76	18039.47	6,013.16	2,123.53
6	3.14	10.4	141.18	108.16	47978.43	15,992.81	5,647.81
7	3.14	10.5	113.35	110.25	39265.06	13,088.35	4,622.11

8	3.14	10.2	122.56	104.04	40064.09	13,354.7	4,716.17
9	3.14	9.8	76.12	96.04	22969.79	7,656.6	2,703.9
10	3.14	9.2	115.93	84.64	30830.29	10,276.76	3,629.21
						126,563.2	44,695.39

Table 2: Data collected from the Quarry Site

S/N	Data Required	
1	Tonnage Factor	2.652
2	Total Aggregate Production from Quarry between 2012 and 2020	1,715,800tons

4. Discussion

Table 2 shows the specific gravity (tonnage factor) of the rock and the Annual Aggregate Production of the quarry site from 2012 to 2020. The rocks extracted from the pit from 2012 to 2020 were computed to be 1,027,204.512tons, with an average annual production of 114,133.83tons while the production of aggregates from the quarry for that same period was documented as 1,715,800tons with an average annual production of 190,644.444tons. The 3D model can be used to compute the correct volume of the stockpiles at the sites, regardless of any of the possible shapes assumed (Sharan and Mohd 2020). The difference (688,595.488tons) between the calculated tonnage extracted from the pit and the total aggregate produced from the quarry is due to the swell factor, the loss of boulders of blasted rock (fly rock), and the loss of aggregates during the loading and haulage phases of the mining operation. The stockpile as presented in Table 1, (44,695.39tons) amounted to about three percent of the total aggregate produced from the quarry (1,715,800tons) between 2012 and 2020, while the rock extracted from the pit (1,027,204.512tons) amounted to about 60% of the total aggregate produced from the quarry (1,715,800tons). The difference (688,595.488tons) between the total aggregate produced from the quarry and the extracted rock from the pit is about 41%.

4.1. Swell Factor

The swell factor for granite was derived from equations 9, 10 and 11, and established as 1.70, which means that for every one ton of rock extracted from the pit, there are 1.70tons of voids.

Swell factor for granite = 1 + (70%) = 1.70 from equation [11].

The expected tonnage of the extracted rock from the pit after excavation and crushing into aggregate which includes the voids (swell factor) was calculated by applying equation [12] which is presented as follows:

1,027,204.512tons * 1.7 = 1,746,247.670tons

The expected tonnage of the extracted rock from the pit after excavation and crushing into aggregate (1,746,247.670tons) is about two percent higher than the total aggregate produced from the Quarry (1,715,800tons) and this can be attributed to the loss in granite aggregates during production and in the fly rock issuing from the blasting operations. Therefore, the expected tonnage of the extracted rocks from the pit after excavation and crushing into aggregate (1,746,247.670tons) is given an allowance of about minus two percent, while the documented tonnage of stockpile (1,715,800tons) is given an allowance of two percent.

5. Conclusion

The total aggregates produced from the quarry was 1,715,800tons. The swell factor of 1.70 was used to estimate the tonnage of the rock extracted from the pit after excavation and crushing of boulders into aggregate, it was established at 1,746,247.670tons. The total aggregate sold from the quarry (1,715,800tons) was 98.256% of the extracted rock from the pit after excavation and the crushing of the boulders into aggregate (1,746,247.670tons). The remaining aggregate about two percent (30,447.67tons) may not be accounted for owing to losses experienced during the loading and haulage of boulders, and the aggregate and fly rock that were released during the blasting operations. These remaining percentages are therefore, categorized as a plus two percent allowance (approximately) for the total aggregate sold from the quarry (1,715,800tons) or a minus two percent allowance (approximately) for the extracted rock from the pit after excavation and the crushing of boulders into aggregate (1,746,247.670tons). These allowances are necessary to accommodate the loss in production and the effect of the swell factor.

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