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PUBTEXTO

Integration of Remote Sensing and Geophysical Investigation in Geological Mapping of the Yatta/Kwa Vonza Phonolite Lavas

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Abstract

This research was conducted in Yatta/Kwa Vonza Ward. The ward is located in Kitui County's westernmost region, bordering Machakos and Makueni Counties to the east and south. The ward has a surface area of about 780 square kilometers. The region is part of the Neoproterozoic Mozambique Belt, and the Yatta Plateau is a major igneous intrusion. The plateau stretches from northern Machakos County to southern Kitui County, cutting through Yatta/Kwa Vonza ward and into the Tsavo. The phonolite lava is thought to have flowed along an old river bed incised in an older surface. Subsequent erosion of the adjacent gneisses resulted in the present reversed morphological feature of the Yatta Plateau. To assess the deposit's economic potential, remote sensing investigation, geological field mapping, geophysical survey and engineering tests were carried out in the area. The study used Landsat-8/OLI satellite data that was classified using ArcGIS 10.8 software. Remote sensing techniques were used to determine the geological extent of the Yatta plateau in the study area, and thus the length of the phonolites that could be mined in the Yatta/Kwa Vonza ward. From the field assessments, the phonolite deposit in the area has a thickness of 20 meters and a width of 3 kilometers, which varies along the profile due to changes in the valley channel it overlies. It covers an area of 80 square kilometers and an estimated tonnage of 4.0 billion metric tonnes. The deposits can last for 660 years with an annual production of 6 million tonnes of aggregates. Mechanical tests show that the deposit is suitable for use as an aggregate in road, rail, and bridge construction.

Keywords: Neoproterozoic; Landsat-8/OLI; Yatta Plateau; Phonolite; Engineering test; Vertical electrical sounding

Introduction

Kenya's Vision 2030 is a long-term development strategy that aims to make the nation a newly industrializing middle-income economy by the year 2030, providing high-quality lives for all of its citizens [2]. The country's economic growth will be significantly aided by the construction sector as the supply of raw building materials to various works across the country increases. To achieve the plans set out in the vision 2030, the construction industry will be a key contributor.

Since the government began building missing link roads and major highways, the rate of infrastructure projects in the country has increased the demand for raw aggregate materials like phonolite aggregate to a completely new level. Construction aggregate materials of high quality are made from phonolite rocks. As a result, phonolite aggregate is now much more in demand than other building materials like sand and cement.

According to Jiao et al (2021), there are numerous phonolite deposits in the Nairobi area. The Yatta plateau is one of the phonolite abundant area closer to Nairobi City [3]. The plateau is endowed with enormous amounts of phonolite lava that flowed for at least 300 km [4]. The Yatta plateau cuts through Yatta/Kwa Vonza ward and into the Tsavo. The ward has a surface area of about 780 square kilometers and the Yatta plateau covers the southernmost part of the ward. The geology of the area is of the Neoproterozoic Mozambique Belt, and the Yatta Plateau is a major sub-Miocene igneous intrusion [1, 5].

Due to the proximity of South eastern Kenya University and Kenyatta University, Kwa Vonza town has experienced rapid population growth prompting an increase in infrastructural projects. Over the years, private investors have investigated and excavated some of the phonolite lavas in the Yatta/Kwa Vonza ward to help meet the town of Kwa Vonza's demand for ballast materials for the building of residences, hotels, and reactionary facilities.

With the sale of aggregate materials being a very profitable business, other players, including the Kitui County government, are

making efforts to start quarrying in the ward. The Yatta/Kwa Vonza phonolite lava deposit was geologically mapped using remote sensing and geophysical investigation. This study highlighted the total area coverage, depth, reserve and sustainability estimations of the phonolite lavas in the study area.

Materials and Methods

Study Area

The Yatta/Kwa vonza Ward is situated in Kitui County's westernmost region, bordering Machakos and Makueni Counties to the east and south, respectively (See figure 1). It is a ward in Kitui County that is under the control of the Kitui Rural sub-county. The Kitui-Machakos road, which is tarmac and in good condition, can be used to reach the area. Other reasonably good murram roads, such as the Mulutu-Kyusiani-Kanyangi and Wikililye-Katulani-Kavisuni-Kyusiani roads, can also be used to reach the area from Kitui town.

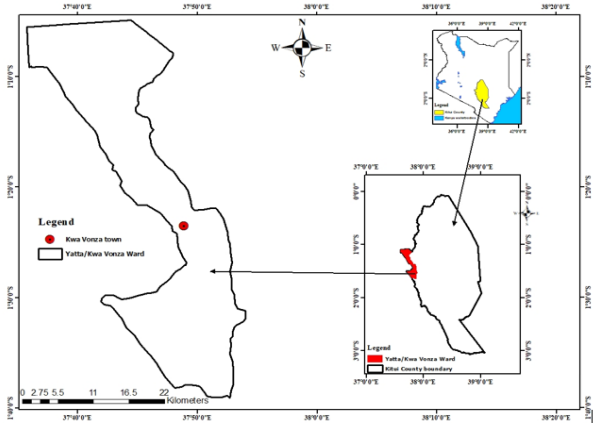

Figure 1: The Location of the study area in Kitui County.

To achieve the objectives of this research, materials and methods from remote sensing, geological mapping, geophysical investigation and engineering tests were used.

Remote Sensing Investigation

Digital satellite imagery (Landsat 8/OLI) from USGS (http://www.earthexplorer.gov) was used to map and ascertain the spatial distribution of phonolite in the Yatta/Kwa Vonza ward. Use of ArcGIS 10.8 was made for the image analysis. In terms of geology, the methodology for interpreting satellite images combined a variety of image-enhancement techniques, primarily color composite and spatial enhancement, to identify the distinctive qualities of the different rock formations and to highlight structural features. The technique was used to estimate the likely tonnage and map the size of the phonolitic lava flow.

Geological Mapping

The researcher carried out geological field mapping and sample collection in the study area to identify and determine whether the lithological units highlighted from satellite imagery were of phonolite lavas. Using a geological hammer along several foot traverses in a grid, fresh samples were collected. The outcrop characteristics were documented in a field notebook along with the samples that were collected and packaged in bags for laboratory analysis.

Geophysical Investigation

Vertical electrical sounding (VES) by Schlumberger configuration method with half the spacing between current electrodes (AB/2) and potential electrode (MN/2) ranging from 1.5 m to about 250 m and 0.5 m to about 20 m respectively was conducted at Southern part of Kwa Kilui crusher plant sites. The resistivity data were compared with actual field observations of the quarries. Schlumberger configuration was applied, and three measurement stations were identified. ABEM Terrameter SAS1000 was used which could send a maximum of 1000 mA current into the ground through a pair of conducting electrodes.

Engineering Test

The Yatta/Kwa Vonza phonolite aggregate material underwent the following tests to determine and qualify its suitability for use in various construction projects: crushing, abrasion, impact, soundness, shape, specific gravity, water absorption, and bitumen adhesion.

Result and Discussion

This project's findings and discussions from remote sensing analysis, geological field mapping, geophysical investigation, and engineering tests are presented.

Remote Sensing Investigation

The required UTM Projection, Zone 37S, and Arc WGS84 Datum were used to obtain the remote sensing imagery data. Landsat-8/OLI data were chosen from a number of spectral bands and combined into an RGB color scheme. In the true-color images 3,5,7, and 5,6,7 (Figure 2), the reddish-brown hue denotes unhealthy vegetation, the light blue hue bare ground and sands, and the green hue healthy vegetation.

According to the interpretations, the light blue hue denoting bare land and sands was caused by metamorphic outcrops weathering, whereas the green hue denoting healthy vegetation was brought about by volcanic outcrops, particularly phonolite lavas. Long-lasting vegetation can grow on phonolite rocks because of their capacity to retain water and their resistance to weathering. This aided the researchers in determining the Yatta/Kwa Vonza phonolite's geological extent in the study area to be comparable to that of the lush, green vegetation.

As a result of their frequent correlation, the various bands in multispectral data frequently contain similar information or exhibit

similar visual characteristics. This correlation indicates that there is information redundancy. This data redundancy was reduced by compressing multispectral data sets into a single greyscale image (Figure 3), using the principal components (PC) transformation. As a result, the length of the phonolites in the Yatta/Kwa Vonza ward that could be mined was established.

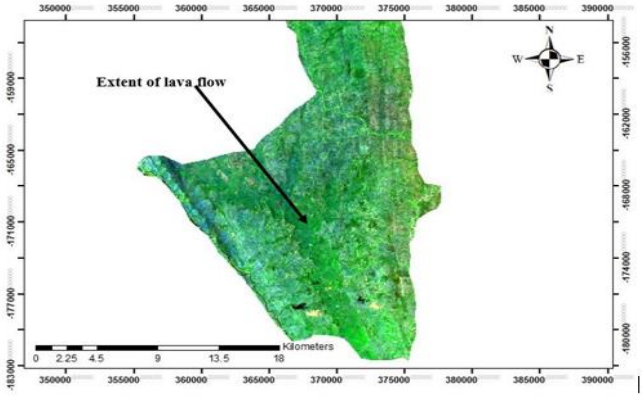

Figure 2: *Satellite image Band 3, 5, 7 of the Yatta/Kwa Vonza Ward.*

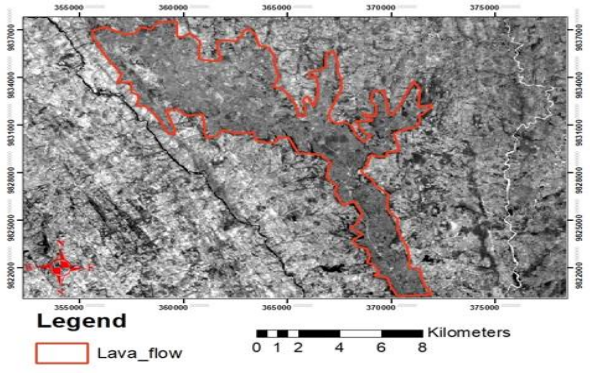

Figure 3: *Grey scale image of the Yatta/Kwa Vonza phonolites eligible for mining.*

Geological Mapping

It was determined that the Yatta/Kwa Vonza region is a medium- to high-grade metamorphic terrain with volcanic intrusions of phonolite lavas. The majority of the rocks, including granitoid gneisses, biotite gneisses, and quartzo-feldspathic gneisses, are from the Neoproterozoic Mozambique belt. They are covered by sub-Miocene volcanic rocks, such as the phonolite rocks that form the Yatta plateau's cap. The phonolites are covered by sandy soils of Pleistocene and Recent Age, including the red and black soils.

The phonolites are the main volcanic rocks on the Yatta plateau. This plateau runs across the southern part of the Yatta/Kwa Vonza ward. The rock is hard, black, and fine-grained, and is notable for its orthoclase, sanidine, and nepheline phenocrysts (Plate 1). Because of the groundmass's waxy nepheline content, it fractures when hammered, revealing a new surface with a greasy lustre. Most phonolite quarries are found in Kilawa and Kwa Kilui, where the rocks can be seen clearly. The phonolite in the region's active quarries was more than 20 meters deep, with the potential for even more depth, according to field observations.

Plate 1: Fresh surface of phonolite showing glassy sanidine phenocrysts.

Geophysical Investigation

A geo-electric section with nine geo-electric layers was indicated by the VES curve. From top to bottom, the layers have resistivities of 703 Ωm, 402 Ωm, 218 Ωm, 74 Ωm, 152 Ωm, 127 Ωm, 201 Ωm, 228 Ωm, and 296 Ωm (Table 1). The top layer's high resistivity is caused by the unsaturated top soils, also known as overburden. Below the phonolite lava, layers of freshly formed and compact gneisses can be found. The data from the geophysical survey and the quarry observation files were in good agreement. Using resistivity surveys, it was determined that the lava flow is typically 24 meters thick. Nevertheless, this thickness might change as the deposit is struck.

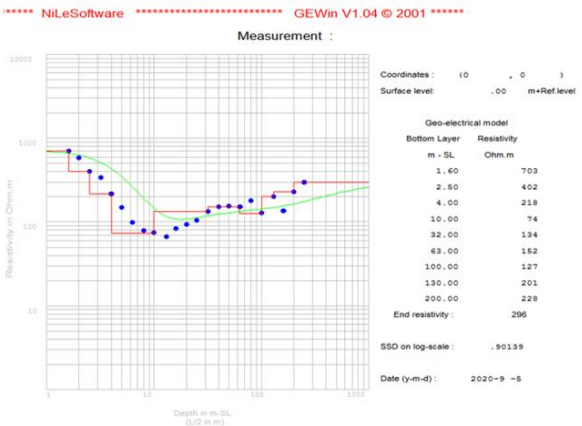

Figure 4: *VES curve.*

Table 1: Geo-electric parameters.

Elevation(m)	Formation Thickness (m)	True Resistivity	Expected Geophysical formation
1160	0.00—1.60	703	Top unsaturated soils
	1.60 – 2.50	402	Weathered phonolite
	2.50 - 4.0	218	Fractured and weathered phonolite
	4.0 - 10.0	74	Fractured phonolite
	10.0 – 32.0	134	Fresh Phonolite
	32.0 – 63.0	152	Fractured and weathered gneisses
	63.0 - 100.0	127	Fractured and weathered gneissess
	100.0 - 130.0	201	Fractured gneissess
	130.0 – 200.0	228	Fresh gneisses
	>200.0	296	Basement rocks (Fresh gneisses)

Engineering Test

At the Ministry of Transport, Infrastructure, Housing, and Urban Development's Materials Testing and Research Division, samples of aggregate materials underwent a number of tests (Table 3). With the exception of a few variations in the A.C.V and A.I.V, samples from the tests showed essentially similar Properties (Table 2). Sample from the Dagaat quarry had a 22.8 A.C. V whereas the County Government of Kitui quarry had a 14.8 A.C V. Both sets of findings are generally positive and show that the phonolite rocks are suitable for use in the construction of buildings, bridges, and roads.

Table 2: *Aggregate impact value Classification.*

Aggregate Impact Value	Classification
Less than 10%	Exceptionally strong
10-20%	Strong
20-30%	Satisfactory for road surfacing
Greater than 35%	Weak for road surfacing

Table 3: *Aggregate test.*

Location	Dagaat Quarry	County Quarry site	Recommended Limits (British Standards)
Sample No	**CGK414**	**CGK404**	
Aggregate Crushing Value A.C.V (%)	22.8	14.8	≤35%
Los Angeles Abrasion L.A.A (%)	23.4	26.8	≤50%
Aggregate Impact Value (%)	25.8	9.4	≤30%
Sodium Soundness Test (%)	1.2	1.2	≤20%
Bitumen Affinity 80/100	Good	Good	Good
MC70	Good	Good	Good
K3-60	Good	Good	Good
A4-60	Good	Good	Good
Specific Gravity (S.S.D)	2.52	2.93	Greater than 2.65
Water Absorption (%)	1.9	2	≤2.5%
Loose bulk density	1430		

Conclusion and recommendations

Conclusions

The study concludes that integration of remote sensing investigations, geological mapping and geophysical survey is an effective method of mapping economic rock deposits like phonolite lavas. Although ground truthing is required to supplement the results from remote sensing, Landsat 8/OLI data is effective in delineating geological structures such as lava flows. Geophysical survey (VES) results validated geological mapping from active quarries that the average depth of the phonolite lavas is about 20 meters, which is a good indication of the resource for quarry siting.

Remote sensing was used to help determine the geological extent of the phonolitic lava in the project area. The length of the phonolite eligible for mining in the ward, according to ArcGIS software calculations, was 80 km2. With an estimated average depth of 20 metres, a rock bulk density of 2.5g/cm3, and a reserve of 4 billion tonnes, the phonolite resource is economically valuable. A good phonolite mine in the Yatta/Kwa Vonza area is estimated to last 660 years with an annual production of 6 million tonnes.

Recommendations

According to this research, phonolite deposits are abundant in Kitui County, running all the way from Yatta/Kwa Vonza ward to Tsavo National Park in Kitui south. Some of these locations are inaccessible for resource utilization. As a result, in order to establish quarries in these areas, this study recommends that the Kitui County government set aside funds for critical infrastructure development such as roads and electricity, among other things. This study recommends drilling in some active quarries to determine the true depth of the phonolite deposit.

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