Geo-Hazards Assessment of Borrow Pits Excavation on the Environment

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Abstract

Geo-environmental hazards associated with abandoned borrow pits in Nigeria are on the rise and a major concern to citizens, environmentalists and governments. Several highway failure spots are directly linked to the action of erosion initiated by active or abandoned (inactive) borrow pits situated close to the roads. This study examines the negative environmental impacts of the continuous removal of soil from borrow pits in some areas of Ado Ekiti, Nigeria. Four borrow pits were selected; two active sites and two abandoned sites. At inception, topographical and 3-Dimensional maps of the borrow pits were drawn and modelled. The area of the borrow pits and the volume of overburden excavated soils were calculated. The soil over burden pressure at the average height of the borrow pits were measured. The active borrow pit sites were checked again after two months to know the difference in the volume of overburden removed in the pit for that period. The volume of soil removed from borrow pit 1 (Active site), 2 (Active site), 3(Abandoned) and 4 (Abandoned) are 37000 m^3, 34000 m^3, 114000 m^3 and 81000 m^3 respectively. Environmental assessment of the study area through photographs showed prevalence of landslides, erosion, flooding, vegetation removal and structural failure. The volume of soil overburden removed from the abandoned borrow pit is more than the volume extracted from the active sites, this significant change in the value of overburden removed causes significant change to the terrain of the borrow pit. Some measures were then suggested to curb the problem occurring from the uncontrolled and indiscriminate borrow pits excavation thereby improving environmental sustainability. This study serves as a basis for government to put in place laws that help protect the environment from indiscriminate mining of borrow pits.

Keywords: Borrow pits; Excavation; Landslides; Erosion; Vegetation; Environmental sustainability

1. Introduction

In ancient time, the process of excavation of sand and gravel started. Boxam (2011) reported that the concept of excavation from borrow pit started in year 1800 when slaves were used by their masters to burrow the soils for small construction purposes, although, this activity were done using non-sophisticated tools like hand diggers, shovel and head pan. However, increase in population and advancement in technology have necessitated the use of sophisticated equipment for ground excavation as there must be equilibrium between the constant construction of infrastructure and the demand for earth materials (which are mostly lateritic sand, river sand and gravels). The need for land development (cut and fill) in road construction, sports field development, and other groundwork often demand supplementary earth materials. In most developing countries where construction work like roads construction, erosion control projects, building construction projects and so on, is always ongoing, several acres of land are degraded by abandoned borrow pits that turn to ponds or waste dumping pits. Most lateritic soil obtained is used as sub-base and base course for construction of highway embankments and foundation filling for building construction (Head, 2010). Soils can prove problematic because they expand collapse, disperse, and undergo excessive settlement with a distinct lack of strength due to large volume changes that are directly related to changes in water content (Owolabi and Ola, 2014).

Undiscerning excavation of borrow pits for road construction and other Civil Engineering works, without the intention of restoring or reclaiming the pits will lead to serious environmental degradation. Some of which include erosion, formation of sinkholes, loss of biodiversity, contamination of soil, groundwater and surface water pollution by chemicals from mining activities. Lawal (2011) reported the disturbance of landscape and distortion of topography as a result of excessive soil excavation in Nigeria. The borrowpit soils excavated are mostly used for sub-grade and sub-base course after thorough geotechnical investigation has been done (Owolabi and Aderinola, 2014). In some cases, additional forest logging is done in the vicinity of mines to increase the available room for the storage of the created debris and soil. Besides creating environmental damage, the contamination resulting from leakage of chemicals also affects the health of the local population (Nuss and Eckelman, 2014). There are several abandoned borrow pits scattered mostly in South-eastern part of Nigeria and all over other developing countries of the world where the clearing of vegetation for borrow pits were not restored to its original states has caused distortion of ecosystem and has led to the extinction of some fauna and flora species (Nwachukwu and Osoro, 2013). Minimization of the negative effects of sand and gravel mining requires a detailed understanding of the reaction of site to these disturbances (Goddard, 2007). Mining operations involve deforestation, habitat destruction and biodiversity erosion (Saviour, 2012).

Public safety has been threatened by some abandoned borrow pits due to the dangerous deep vertical walls created during excavation that are highly prone to landslides. In some other places, abandoned borrow pits were filled with stormwater and become ponds. Some without water serve as dump sites for end of live vehicles, illegal dumping of wastes and as hide-out for armed robbers (Nwachukwu et al. 2017). When all these situations arise close to residential areas, major socio-environmental problems confront residents but if these borrow pits are progressively reclaimed during its active excavation; the aforementioned problems can then be minimized. Slope failure in clay occurs on a very deep-seated surface, while it occurs on the surface for a sandy slope. Instability of a slope is linked with a change in cohesion or shear strength of the soil (Ola, 2013). As a way of fostering meaningful professionalism, sustainable engineering practice in the excavation of borrow pit must come to bear. This study therefore assessed some geo-environmental hazards caused by borrow pits in our immediate environment using four borrow pit sites in Ado Ekiti Nigeria as case study.

2. Materials and Methods

2.1 Assessment of borrow pits excavation Method

Field investigations covering the environs of Ado Ekiti were undertaken to study some geo-environmental impacts as a result of borrow pits. Four borrow pit sites were identified in some areas of Ado-Ekiti, Ekiti State and were each investigated by direct measurements and use of photographs. Two of the borrow pits are active and identified as BPA_1 and BPA_2 while the other two are abandoned and identified (Inactive) as BPI_1 and BPI_2. A reconnaissance visit was initially made to the sites and other features around sites for proper observations and survey to determine the normal state of the sites during mining (for active sites) and after mining has been done (for abandoned sites). Continual removal of soil and the three-dimensional state of the borrow pits were measured and modelled. Also, the longitude coordinates, latitude coordinates and elevations of the pits were measured with E-Trex Geographic Positioning System (GPS) and recorded. The height of the borrow pits at different points were measured using levelling instrument and the average height of the pit was determined. Photographs of the four sites and areas around the sites with the infrastructures (buildings, roads near the site) present were taken. The potential environmental impacts and hazards such as landslides, debris flow, erosion, flood and runoff pool of both the active and abandoned borrow pits were also assessed through visual inspection and photographs taken.

Data generated by the GPS were used to generate 3D maps for the sites using surfer software and AutoCAD. The data retrieved from the maps were then used to determine the volume of overburden that has been excavated from the borrow pits using Equation 1. The maps generated were used to calculate for the areas and volumes of the borrow pits.

$$p(z) = p_o + g\int_o^z \rho(Z)dz \qquad (1)$$

The average depths (Z) for each of the pits were measured at different points to get the soil overburden. Soil samples were collected from each of the sites to determine some geotechnical properties of the soils.

2.2 Determination of Borrow Pit Area and Volume

The shape of the borrow pit is not a regular manner. Therefore, to calculate their area and volume, different points around the borrow pit were gotten and used to create a diagrammatic representation of the surface of the pit using AutoCAD software. The area was calculated both manually and automatically using the scissors principle (or scissors method) and AutoCAD respectively. The scissors method is diagrammatically represented in Fig. 1.

Area of borrow pit is thus calculated as:

$$C = \frac{A + B}{2} \qquad (2)$$

Where A is the $\sum \text{Northing} \times \text{Easting of arrows facing right}$

Where B is the $\sum \text{Northing} \times \text{Easting of arrows facing left}$

Where C is the Area of selected borrow pit.

Volume of borrow pit is thus calculated as:

$$V = C * \Delta h \qquad (3)$$

Where Δh is the difference of the average height at the top of the borrow pit and the average height of the bottom of the borrow pit

Volume of water pooled into the borrow pit is calculated

$$V = A * D \qquad (4)$$

The coordinates (i.e. longitudes and latitudes), elevations and heights of both the active and abandoned (inactive) borrow pits identified as BPA_1, BPA_2, BPI_1 and BPI_2 respectively are presented in Tables 1 and 2.

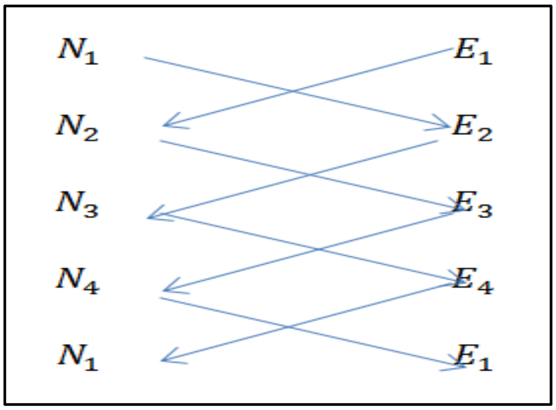

Figure 1. Scissors Method of Solution

Table 1. Coordinates, Elevation and Height of Active Borrow Pits

Longitude (N)		Latitude (E)		Height (m)		Elevation (m)	
BPA_1	BPA_2	BPA_1	BPA_2	BPA_1	BPA_2	BPA_1	BPA_2
844785.86	844922.00	742921.81	742813.00	9	5.2	432	486
844766.84	844909.57	742934.33	742856.43	12	5	465	481
844791.86	844897.32	742916.40	742897.88	13	5.8	498	476
844855.57	844884.40	742890.84	742934.35	15	6.5	342	487
844823.25	844793.00	742895.79	742936.00	16	5.7	467	467
844801.73	844765.00	742865.93	742922.00	12	5.9	343	443
844829.23	844779.57	742842.78	742896.29	11	6.4	432	432
844899.86	844786.00	742813.00	742881.00	10	5.5	421	421

Note: BPA_1 and BPA_2 represent Borrow Pit Active 1 and 2 respectively

Table 2. Coordinates, Elevation and Height of Abandoned Borrow Pits

Longitude (N)		**Latitude (E)**		**Height (m)**		**Elevation (m)**	
BPI_1	BPI_2	BPI_1	BPI_2	BPI_1	BPI_2	BPI_1	BPI_2
844922.00	844817.86	742813.00	742809.321	9	7.2	432	432
844909.57	844909.57	742856.43	742856.430	10	6.9	465	465
844897.32	844897.32	742897.88	742897.875	13	7.5	498	498
844884.40	844855.92	742934.35	742901.522	10	8.3	342	342
844793.00	844793.00	742936.00	742936.000	14	11	343	343
844765.00	844765.00	742922.00	742922.000	11	12	347	347
844779.57	844778.00	742896.29	742899.000	13	-	449	344
844786.00		742881.00		12	-	421	-

Note: BPI_1 and BPI_2 represent Borrow Pit Inactive 1 and 2 respectively

3. Results and Discussion

3.1 Topographical and 3-Dimensional Maps

From the coordinates and elevations recorded, contour maps were generated for all the borrow pits. Figs. 2 - 5 depict both the topographical and 3-Dimensional maps of both the active and inactive borrow pits respectively.

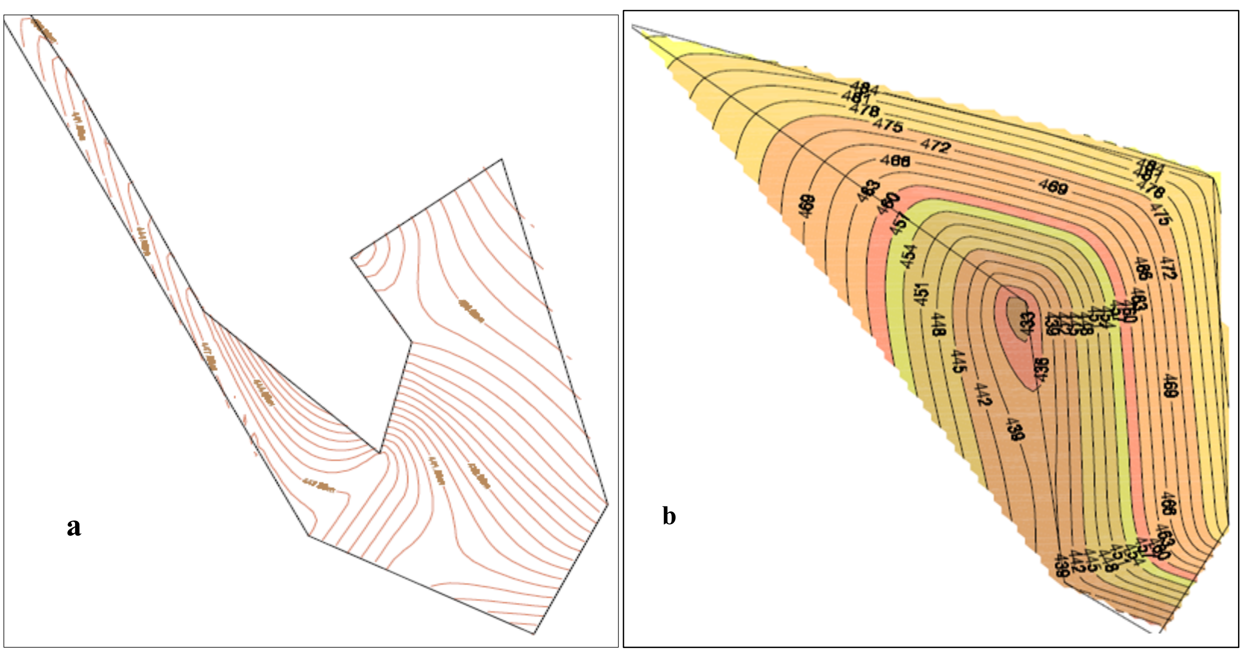

Figure 2. Topographical maps of the two active borrow pit sites (a. BPA_1 and b. BPA_2)

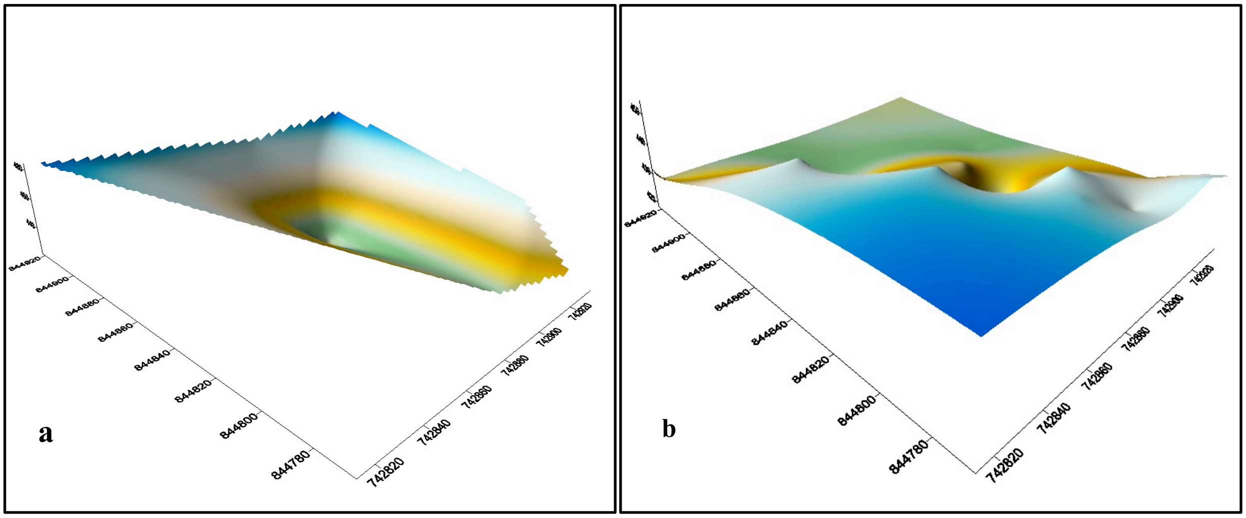

Figure 3. 3-Dimensional maps of the two active borrow pit sites (a. BPA₁ and b. BPA₂)

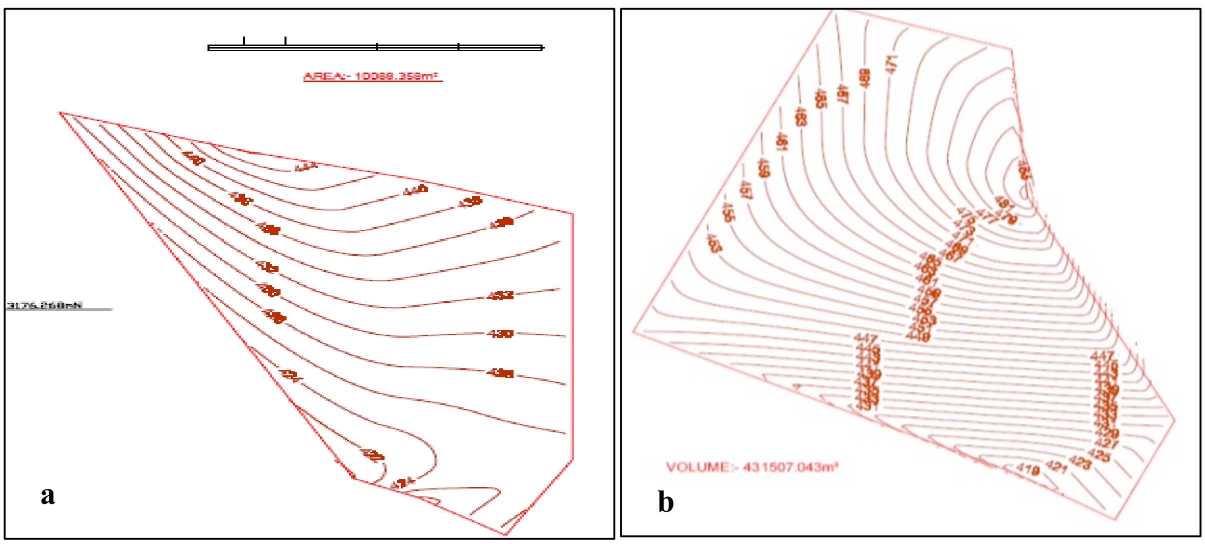

Figure 4. Topographical maps of the two inactive borrow pit sites (a. BPI₁ and b. BPI₂)

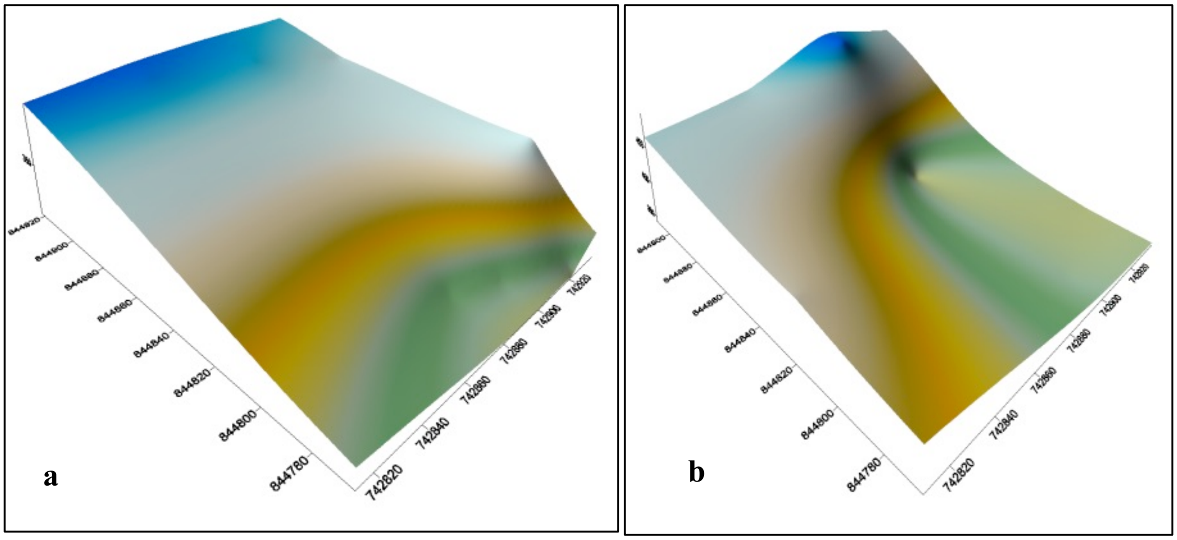

Figure 5. 3-Dimensional maps of the two inactive borrow pit sites (a. BPI_1 and b. BPI_2)

3.2 Area Volume of Borrow Pit

The area, volume, overburden pressure of the borrow pits were calculated using equations 2, 3 and 4. The summary of the results obtained for the four borrow pits considered are presented in Table 3.

Table 3. Summary Result of the Area, Volume and Overburden Pressure of the Borrow Pits

Borrow Pits	Dimension of borrow pit during the first visit		Dimension of borrow pit after two months		Overburden pressure on soil (KN/m^2)	Volume of water pool (m^3)
	Area (m^2)	Volume (m^3)	Area (m^2)	Volume (m^3)		
Active Pit 1	3061.9	36,956.9	3894.1	43,808.1	101.4	1.4136
Active Pit 2	9912.2	11,399.0	6515.4	35,916.0	98.9	0.157
Inactive Pit 1	5965.5	34,301.9	-	-	101.26	8.824
Inactive Pit 2	9550.7	81,044.9	-	-	99.97	3.769

3.3 Field Measurement and Assessment

Four borrow pits were assessed; a situation of unsustainable engineering practice was demonstrated. Figs. 6a to 6f illustrate the present site conditions. Each of the borrow pits visited shows great potential for landslides occurrence in the area. As landslide occurrence is dependent on factors like height, steepness of the slope, density and strength (cohesion and friction) of material on the slope of the excavated area, the geometry of the borrow pit sites revealed a slope angle of between 80° and 85° which is a compromise of the standard slope of 70° and 75° during excavation process (Fig. 6a). The pits were also excavated in a vertical manner to depths as high as 15 m. Due to heavy rainfall which usually occurred around May and July, the borrow pit slopes has been weakened and if they are not quickly reclaimed, more loss of properties will be experienced. Sliding angle, overburden stress, resisting force, water saturation, pit slope angle, and pit effective depth will facilitate the occurrence of landslides in each of the borrow pits. The buildings around the area are at risk if landslides occur and this could lead to destruction of buildings, properties and even lives.

The vegetation of areas surrounding the borrow pits are characterized by thick and dense vegetation, typical of the tropical rainforest. The excavation activities carried out in the pits have turned the area to degraded land and danger zones as no meaningful agricultural practices can be carried out. Also, there is great threat on both the animal and plant species within the area and this can result in extinction of some species due to the destruction of their natural habitat occurring through unlawful and unguided excavation. Fig. 6b illustrates the soil of the area to be mostly lateritic soil. Before excavation, the topsoil (consisting of dark humus soil for agriculture) of the area is around 0.3 to 0.5 m thick. This top soil is then followed by the reddish lateritic soil which constitutes the borrow pit material. Both the active borrow pits the inactive borrow pits are currently under serious susceptibility both to water and wind erosion. The sites have all been laid bare due to the excavation activities carried out. The excavations were done in both triangular and trapezoidal manner hence creating slopes that encourage the pooling of water after rainfall (Fig. 6c). This pooled water in turn cause erosion and wash away soils to nearby settlements (Fig. 6d). Absence of functional drainage systems causes the washing off of soil from the un-tarred road surface resulting in potholes and depression. Stagnant water in the borrow pits also encourage the breeding of mosquitoes resulting in environmental quality.

Clearing of vegetation and stripping of soil from the borrow pits can cause debris flow during raining season to the downhill causing flooding of the communities, creating potholes, cutting off the road, and reducing soil fertility. The operation of heavy equipment along access roads and surrounding areas of the borrow pits leads to compaction of affected areas, thus disturbing the natural state of soils. During heavy rains, water pooled into the pits can overflow. Structural failure was noticed around the active borrow pits. There is an on-going foundation been laid just beside the excavated borrow pit (Fig. 6e). Also, some existing buildings were sighted (Fig. 6f). This failure most likely results from the use of heavy-duty equipment like bulldozers, pay loaders and trucks used for excavation and loading of the laterite soil to designated construction sites. These equipment have tendencies of producing vibration which sends lateral waves to the surrounding structures thereby weakening the foundation and can finally result into displacement of structures. Also, during rainy season, there will be creation of micro cracks which will gradually become water infiltration pathways and finally grow to mega cracks that can cause pit slope failure which can eventually lead to collapse of structures such as buildings, roads and drainage system certainly causing huge economic loss.

The borrowed area of BPI_2 has the largest volume of soil removed than the other borrow pits which shows the effective and regular removal of earth materials and hence vulnerable to risk. Table 3 indicates that large volume of water has been pooled in to BPI_1, Long-time effect of this large water will cause continuous digging of the pit and leads to gully erosion, scarring, siltation, changes in geochemical conditions and flooding. These four borrow pits can rarely be returned to its former state, every effort should be made to address potential residual impacts during the closure process of the borrow pit. Indiscriminate borrow pit excavation without due regard for the desired final shape of the borrow pit should not be permitted and should be rectified immediately. Undiscerning roadside excavation of borrow pits for road construction and other civil Engineering works without the intention of restoring or reclaiming the pits will lead to environmental degradation. The earth materials removed from the pits and not replaced, resulting in areas that are typically lower than their original ground levels. Some unwanted screened material will return to these borrow pits but will not complement what the original level should be. These borrow pits are usually clearly visible as low-lying areas filled with water alongside roads.

Figure 6a. Risk potential for landslide at borrow pit 1

Figure 6b. Core lateritic soil at borrow pit 2

Figure 6c. Pool of water captured at borrow pit 2

Figure 6d. Path created by erosion at borrow pit 3

Figure 6e. Building foundation laid which is susceptible to structural failure at borrow pit 4

Figure 6f. Buildings susceptible to landslides and water runoff from borrow pit 4

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4. Conclusion

Borrow pits excavation and its associated risks are gradually on the increase following the rising trend in various construction works which are on-going in many developing countries. Four borrow pits have been assessed in this study in which two were active while the other two were abandoned (inactive). The volume of soil overburden removed from the abandoned borrow pits is much more than the volume extracted from the active sites, this significant change in the value of overburden removed causes significant change to the terrain of the borrow pit. It can be concluded from the study that the geohazards caused by excavation of borrow pits on the environment is of no small measure. Some of the potential and active risks include landslide occurrences, water and wind erosion, dumping of wastes that cause contamination of surface and groundwater, structural failures, depletion of soil nutrients, flooding and so on. It is therefore required that some critical measures be put in place to safeguard the environment. Government agencies and communities where both the active and abandoned borrow pits are situated must enforce proper closing and reclamation of borrow pits. Operators of borrow pits should also be encouraged to agree on reclamation terms before opening any site as this will provide for sustainable environment on the long run.

Declaration of Competing Interest

The authors wish to declare that there are no known conflicts of interest associated with this publication and this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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