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Quarrying and Land Degradation in Nyakach Sub County, Kenya

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ABSTRACT

Land degradation is a problem facing humanity on earth today as it threatens food security as well as viable land use activities. This study considered quarrying as a form of land degradation using human beings as geomorphic agents. The study established the extent of quarrying effects on land degradation on land use activities such as agriculture, transportation and biodiversity. The indicators of land degradation were soil erosion marked by presence of gullies, sand budget analysis and reference state analysis. The study used cross sectional study and quasi-experimental research designs involving measurement of gully dimensions, sand budget and reference state analysis of drainage channels. GPRS technology from window's tablet with Google earth software (CNES/Airbus, 2018) was used for capturing spatial data. The results were: gullies were cascaded all over the area with an average depth of 3.9m reducing portions of agricultural and grazing lands as well as cut transport lines. Reference state analysis showed that neem plant and monitor lizards species peculiar to the drainage channels in Nyakach are endangered. Sand budget analysis showed 5,118t and 8,986t of sand were appropriated during dry and wet seasons respectively with an annual gravel loss of 0.0128t/Km2 or 3.6t/Ha. equivalent to 9935.5t/y. Consequently, riparian and farmlands were invaded during dry seasons causing major degradation. The study recommends: terracing, building of gabions, afforestation and adoption of alternative land use activities to control land degradation.

1. Introduction

Quarrying of sand and gravel mining are some of the present serious environmental problems globally resulting to loss of agricultural land and biodiversity (Musa, 2009). It is among industries in the world that has remained widespread, highly unregulated, uncontrolled and is being carried out indiscriminately (Mwaura, 2013). The adverse effects of quarrying go beyond the immediate community and threatens not only the environment but also food security (Mwaura, 2013). Out of ignorance, greed for money or abject poverty, chiefs and land owners give out land for monetary gains unmindful about the effects of harvesting activities on people and the environment (Imoru, 2010).

Poor and unplanned aggregate exploitation methods coupled with lack of proper quarry management in most African nations have collectively led to serious degradation of land (Darwish et al., 2011). Consequently, quarries disfigure the land where they are located as they collapse due to lack of proper rehabilitation measures. Hence, the need for detailed study on the significance of quarrying management on mining industries. Quarrying negatively affects the environment as it damages biodiversity (Anand, 2006) and possesses great potential of destroying habitats and the species they support (Mabogunje, 2008). Thus, the need for an integrated and structured approach for effective management of quarries (Nyakeniga, 2009).

Quarrying is a form of land use activity that involves the extraction of non-fuel and non-metallic mineral materials from the earth's crust. Such materials include; sand, gravels and rocks e.g., sandstone, limestone, perlite, marble, ironstone, slate and granite which are exploited for construction in the built environment (Banez et al, 2010) and rock salt and phosphate for other uses. Depending on geological conditions, quarrying activities are spatially distributed in almost all settled mountains (Dávid, 2000). However, operations of mining, whether small or large scale, are disruptive and destructive to the environment (Makweba and Ndonde, 1996).

This study considered categories of quarry classified by nature of surface features as excavated macroforms and accumulated macroforms with the former being more destructive than the latter (Karancsi, 1999). Extraction of natural aggregates from quarries for building and construction purposes have caused extensive adverse environmental impacts especially where pits are abandoned leading to cumulative massive degradation (Corey et al., 2007).

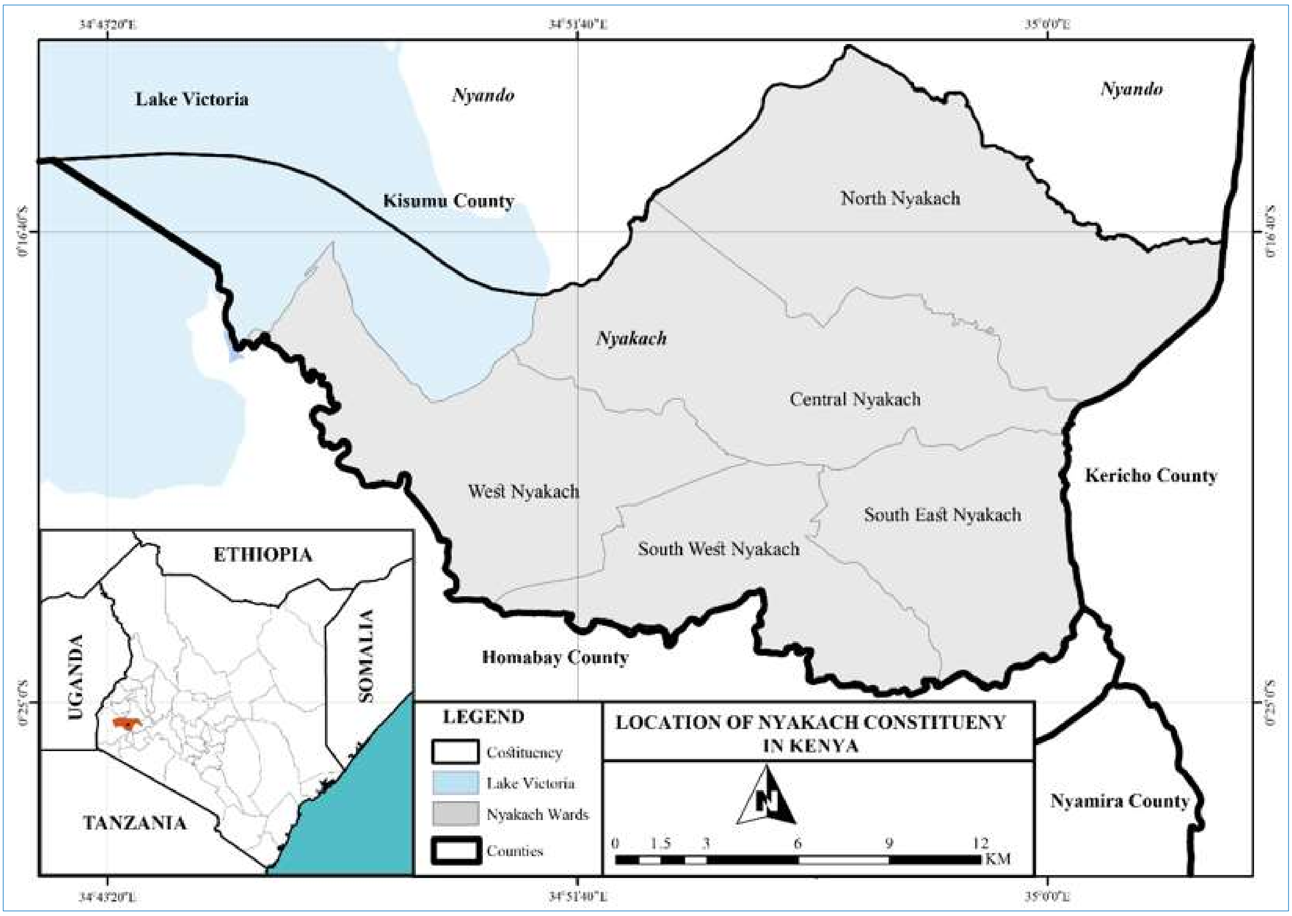

Fig. 1. Map of the area of study: Nyakach Constituency (Sub-County), Kenya

Extraction of crustal materials from their natural habitats by mining, drilling, harvesting and those that relate to large scale water resource development projects, construction, agriculture, energy, industry and development projects considerably affect the natural environment (Fedra et al., 1991). Siltation of water courses as well as land dereliction are menaces today across the world majorly due to quarrying near water bodies (Foody et al., 2004) contributing to wastage of agriculturally viable land.

Use of explosives in bombarding rocks in quarries generate high levels of vibrations and at times cause release of rock fragments outside the mining confinements triggering off mass wasting, soil erosion and subsequent land degradation (Wang et al., 2016). Hill and Kleyhans (1999) noted that soil mining has great potential in disrupting the natural environment, cause irreversible impacts to biota and their habitats as well as damaging vegetation and aquatic ecosystems near streams in South Africa. Dust pollution from quarry sites affect vegetation and crop life threatening their survival near quarries (Iqbal and Shafig, 2001). Consequently, the soil buffer zone is affected due to reduced vegetative cover resulting to soil erosion (Nanna, 1996; Mbandi, 2017) and subsequent land degradation.

In Kenya, land degradation through quarrying (sand excavation) has escalated in the last ten years due to high demand for aggregates for construction industry. Remedial measures to control the vice have been put in place, for instance, the Machakos County Sand Harvesting Act 2014 (Kavilu, 2016) and existence of National Environment Management Authority (NEMA) to regulate issues that are deemed a threat to the environment. Nevertheless, sand harvesting is still a big threat causing land degradation in Machakos and the rest of Kenya (Kavilu, 2016).

In Nyakach Sub County, land degradation has been studied under various parameters. For instance, Maurice and Ang'awa (2012) analyzed agricultural land use intensity and land degradation. Kodiwo et al. (2019) also studied effects crop farming practices on soil degradation in Nyakach. However, no study on land degradation in Nyakach Sub

County has been conducted based on quarrying involving sand budget and state reference analysis.

Review of the available literature reveal that studies on Sediment budget analysis have used models such as; Soil and Water Assessment Tool (SWAT), Universal Soil Loss Equation (USLE) or a modified version such as Modified Universal Soil Loss Equation (MUSLE) (Schmidt et al., 2018). Therefore, this study brings a unique dimension where sand budget analysis is modified considering human beings as geomorphic agents to gauge the role of stream sand harvesting on stream channel degradation unlike the use of the aforementioned models. The modification was based on the fact that there are no readily available sediment measuring models involving human beings directly as geomorphic agents.

The study adopted the Systems Theory (ST) propounded by Bertalanffy (1969) which describes nature as an intricate arrangement of society and science which are interdependent to attain a shared purpose which gives it a description (Weber, 2008). According Systems Theory (ST), geology has a network of systems. Modification of any system causes a change of the whole set up. The environment is perceived as a complete set up made up of biophysical elements reliant on each other, both biotic and abiotic. Hence, alteration of any element causes a trickledown effect on the other sub-sets and ultimately interfere with the functions of the whole system (Mbandi, 2017).

Lithospheric extraction activities such as quarrying exert intense pressure on the physical environment to the extent that human beings, animals and plant lives have been endangered (Schaffler and Swilling, 2013; Mbandi, 2017). Since good systems interrelate with their surroundings unreservedly and subjectively, can gain new properties, (Bertalanffy, 1969) in ST, this study therefore, theorized land degradation as a product of quarrying which disrupts physical and biological sub-sets of the entire environment. Hence, the use of sand budget and reference state analysis to study land degradation in this study.

2. Research Methodology

Nyakach Sub-County (Constituency) is found in Kisumu County in the Western part of Kenya (Fig. 1). It has a total land area of 127.8 km^2 or 35,730 Ha (KCIDP, 2017). The area experiences two rainy seasons with long rainy season experienced in the months of March to June while the short rains fall in between the months of September to November. The area falls within the Lake Victoria lowlands and floodplain region. The two main topographical land formations are the Nyabondo Plateau and the Nyakach Plain (D'Costa and Ominde, 1973). Lower Nyakach plain region hosts sand excavation and consists of Central Nyakach, North Nyakach and West Nyakach wards while the scarp slopes involving South and South East Nyakach wards (Fig. 1) provide conducive ground for gravel and ballast excavation.

The study employed mixed research design (Creswell and Clark, 2006) bringing together cross-sectional study and quasi experimental designs. Cross sectional research design was used to collect quantitative data on sand extraction and extraction sites. Quasi experimental design was used in stream sand budget analysis to evaluate the difference in quantities between deposited and harvested sand. It was also used to determine average seasonal incision of the sand extracted drainage channels. The design also provided information that helped identify technically informed and sustainable mitigation measures to be employed to check land degradation caused by lithospheric exploitations.

The study targeted the entire population of Nyakach Sub County engaged in various lithospheric extraction activities. Purposive sampling was used to identify respondents who were directly involved in or affected by quarrying activities. Snowballing sampling was also applied since sand and gravel harvesters had social networks where one sand extractor would recruit others as the number grew towards the required sample size. Sloven's formula was used to calculate sample size given in Eq. 1.

$$n = N / (1 + Ne^2) \qquad 1$$

where; n is number of samples, N is total population and e is error tolerance.

According to KCIDP (2017), population of Nyakach Sub County was 150,915 people, with a confidence level of 95% and a 0.05 margin of error, thus;

n=150,915/(1+150,915*0.052,) = 398 respondents.

The study employed research tools such as; questionnaires-administered to farmers, quarry workers and sand harvesters. Cameras for photography, direct observation to collect naturally occurring data, tape measures for measuring distances between excavation sites, farms and other infrastructure e.g roads. Observation checklists for determining frequencies of transported aggregates, GPRS technology from window's tablet with Google earth software (CNES/Airbus, 2018) for surveying and capturing spatial images on the distribution of quarries were used (Google Earth, 2019).

Both qualitative and quantitative data were collected from both primary and secondary sources through: direct observation, interviews, administering questionnaires and focused group discussion guides. Primary data constituted: depths of sand pits, sand deposition, quantities of sand (tones) excavated during the rainy seasons of March to June (long season) and September to November (short season), (2018). The data was obtained from Kisumu County Revenue (KCR) office located in the area.

2.1. Measurement of gullies sand pit dimensions

Google earth pro app; a computer software that enables one to take an aerial tour of spatial phenomena at varying elevations (CNES/Airbus, 2018) was used to remotely capture data of inaccessible areas on the scarps. Google pro app ruler of the 2018 CNES/Airbus of the Maxar Technologies was used to measure distances on dimensions such as gully widths, shift distances from rural access roads, sand pits and quarries depths which were corroborated through ground truthing. These data were essential in establishing the level of degradation in Nyakach.

2.2. Sand budget analysis

Sand budget is a mass equilibrium or difference between sediment in-put and out-put in a stream channel resulting from the cycle of erosion, transportation and deposition of sediments (Foltz, 1996). The net difference (input – output) should equal the amount of sediment passing a gauge at the mouth of the watershed (Foltz, 1996). Sand budget analysis has been used in Idaho to predict downslope travel of granitic sediments from forest roads (Megahan and Ketcheson, 1996).

Sediment budget analysis is one way of estimating the rates of erosion in which the differences between sediment in-put and out-put are used to gauge levels of erosion. Just like erosion, sand harvesting takes away sediments from one location to another, not within the same stream hence upsetting the supposed equilibrium between in-put and out-put (Fredriksen, 1970). Where erosion exceeds deposition, the stream channel becomes incised, widened and naturally degraded (Folle and Mulla, 2009). Similarly, where sediment harvests exceed the deposits then the stream channel floor and walls are excavated as is the case in many gullies in Nyakach, then the stream channel is deemed degraded by the sand scooping.

Sand budget analysis was modified in this study considering human beings as geomorphic agents to gauge the role of stream sand harvesting on stream channel degradation. The modification was informed by the fact that there are no readily available sediment measuring models involving humans directly as geomorphic agents. Sediment budget analysis models such as; SAWT, USLE or a modified version such as MUSLE (Schmidt et al., 2018) did not use humans as agents.

Sand free harvesting spots on channel floors were identified before the onset of the long rains between March and June, 2018 whose overland flows deposit sand in the streams. The depths of sand deposits were measured on calibrated metal rods dug deep in to the ground at the sampled sand harvesting sites. The calibrated metal rods were dug at the middle of the harvesting sites and on the downstream end of the harvesting sites. The readings were then averaged to come up with the general deposit depth. Initial measurements were taken alongside baseline conditions of the streams and the stream reference state.

The challenge however was the fact that sand harvesters usually don't wait for the end of the rains to begin scooping the sand. Therefore, it was difficult to get cumulative sand deposit depths to establish quantity of deposited sand against the scooped. Besides, some of the calibrated metal rods were swept away by sand load moved by moving water. To overcome this challenge and improve on the accuracy of the measurements, regular readings were taken at two week's intervals after substantial amount of sand had been deposited before being scooped away and sold. additionally, other metal rods were inserted on the downslope side of the sand harvesting site.

Table1. Socio-demographic characteristics of the respondents (n=298)

Characteristics	Frequency	Percentage	Characteristics	Frequency	Percentage
Gender			**Marriage**		
Male	268	89.9	Single	145	48.7
Female	30	10.1	Married	153	51.3
Age			**Land in acres**		
≤18	30	10.1	0-1	72	24.2
19-25	42	14.1	2-3	130	43.6
26-30	57	19.1	4-5	44	13.1
31-35	58	19.5	6-7	21	6.3
36-40	39	13.1	8-9	16	4.7
41-45	31	10.4	10-11	11	3.4
46-50	21	07	≥12	04	1.3
			Mean acreage	**3.14**	
51-55	12	04	**Land tenure**		
≥56	08	2.7	Purchased	27	9.1
Mean age	29		Leased/rented	63	21.1
Education			Ancestral	152	51
Primary	119	39.9	Public	60	20.1
Secondary	130	43.6	**Residence**		
Tertiary	49	16.4	West	67	22.5
Occupation			North	59	19.8
Formal	25	8.4	Central	73	24.9
Informal	273	91.6	S. East	48	16.1
			S. West	51	17.1

2.3. Evaluating the reference state of the drainage channels

Reference state is the state of biodiversity in relation to ecosystems in a stream channel. Alterations there off are indicators of stream channel degradation (World Bank, 2012). Stream reference state provides a baseline reference point on biodiversity from which to gauge the degree of damage to stream by comparing the initial and the resultant biodiversity. It determines the quantity, method and technology in exploiting lithospheric resources taking biodiversity into consideration as well as levels of

Environmental impact assessment where lithospheric exploitations are carried out (Goddard, 2007).

The study established reference state of drainage channels of Nyakach where Omondo, Katuk-Odeyo, Ragen, Bugo and Olwalo channels were sampled as representative of the entire Sub County and state of biodiversity interrogated for the past ten years. This duration was considered as ideal to allow for indigenous species of biodiversity like trees, bushes and grasses as habitats to establish. Older members of the respondents sampled purposively, were interviewed thoroughly to provide data on flora and fauna over the past ten years and the difference currently. For instance, in Kitengela Sub County, Kajiado County Kenya, Mbandi (2017) found out that 12% plants species especially the medicinal plants were endangered, 40% reduced their value where as 48% reduced their yields. The aim of carrying out state reference analysis using data from the local community was to help understand the temporal change of flora and fauna in the cited drainage channels and engage the them (the local community) and other stakeholders such as the local administration in restoration (Legwaila et al., 2015).

3. Results and Discussion

3.1. Socio-demographic characteristics of the respondents

Since the study used human beings as geomorphic agents, an understanding of their socio-demographic characteristics was necessary. From Table 1, about 10% of the respondents were below 18 years, minors (Constitution of Kenya, 2010) showing indiscriminate engagement in lithospheric activities. Educational levels of the respondents were: 40% basic primary, 44% secondary and 16% tertiary (Table 1). Tertiary education holders among the aggregate extractors were an informed segment of the population which could easily comply with enforcement agencies to conserve land (NEPRK, 2013). Nevertheless, this was contrary to the observation. Males (89.9%) were the dominant source of labour for aggregate extraction (Table 1). Concomitantly, Mugedeza (1996) and Dreschler (2001) also found out that less than 10% and 25% of women were engaged in informal mining in Zimbabwe and Tanzania respectively. This was attributed to the fact that aggregate extraction is a labour-intensive activity attracting more males than females.

Slightly more than half (51.3%) of the respondents were married and were engaged in aggregate extraction (Table 1). This was attributed to the high number (91.6%) of informal occupation (Table 1) who depend on any activity to earn a living. Similarly, Salifu (2017) also found out that unemployment and high profits as well as income from the sale of sand were the major contributing factors to sand mining Brong Ahafo region of Ghana. Most of the aggregate extraction activities were done on ancestral land (51%) and public or leased land (21%) (Table 1) as the ancestral land owners failed to set limits or put checks and balances on excavation activities. Comparison of aggregate extraction in the five wards of Nyakach is shown in Fig. 2. Aggregate extraction and its subsequent degradation were highest in Central Nyakach (24.9%), followed by West Nyakach (22.5%) and North Nyakach (19.1%) but lowest in S.E Nyakach (16.1) Wards. The three wards with the high extractive activities are geographically located in lower Nyakach with numerous drainage channels where wet sand extraction took place in the wet season and dry pit extraction done on the riparian zones during dry seasons causing depletion of productive land.

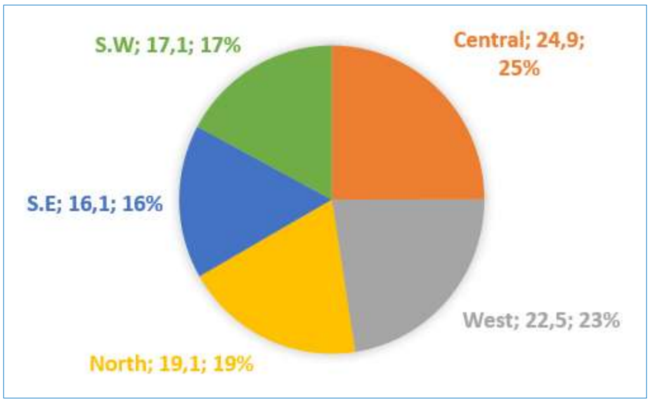

Fig. 2. Pie chart on comparison of aggregate extraction by wards in Nyakach Sub- County (n=5)

Empirical studies revealed that various sections of the Nyabondo plateau scarps experienced different degrees of exploitation. For instance, on the convex waxing section above the fall face, soil cover was removed together with vegetation exposing regions like Achego/Lwanda to aggravated erosion. This was evident by presence of bare rock out crops between 100-200m from the cliff. No quarrying was done on the free face slope due to inaccessibility of the near vertical slope, however, a lot of quarrying took place on the constant slope or the straight debris slope rich in loose debris (gravel).

Table 2. Distribution of quarries per ward in Nyakach Sub County

Ward	Frequency	Percentage
West Nyakach	14	18.7
Central Nyakach	13	17.3
North Nyakch	19	25.3
S.E Nyakach	11	14.7
S.W Nyakch	18	24

Heightened quarrying at the straight debris slope regions such as along the Nyamaroka-Nyabondo Road compromised the slope strength of the free face leading to rock falls that ended up on the roads on the waning slope. Such rocks were crushed to provide ballast used in the building and construction industry.

Hull et al. (2001) revealed that extraction of aggregates ranging from 0.08 to 4 inches was common in the region. Moreover, quarrying reconfigured the scarp slopes such that it increased the height of the free face in some regions through induced parallel slope retreat for scarp slopes that conformed to model of slope by Davis (1899), Penck (1953) and Simons (1962). Measurement of the quarry gullies revealed that the deepest open ditch was about 16 feet with continuous change in gully width. Deep open ditches left after extraction of gravel characterized the escarpment. Such ditches were partially filled with water and further induced mass wasting by lubricating the scarp slopes especially along the Nyamaroka Road running along the scarp to the top of the Nyabondo Plateau. Most quarries, both active and abandoned, were unevenly distributed on the constant and the waning slopes of the Nyabondo Plateau scarps.

Fig. 3. Satellite map showing distribution of quarries in West Nyakach (Google Earth, 2019)

Table 3. Quantities of gravel in trucks (tones) extracted in Nyakach Sub County per year (n=199)

Wards in Nyakach Sub County	Quantity in trucks (tones)	Mid-point (x)	Frequency (f)	fx
West Nyakach	30-39	34.5	58	2,001
Central Nyakach	40-49	44.5	49	2,180.5
North Nyakch	50-59	54.5	39	2,125.6
S.E Nyakach	60-69	64.5	32	2,064
S.W Nyakach	70-79	74.5	21	1,564.5
				Σfx=9,935.5

On the scarp slopes that did not conform to the Davis (1899) and Penck (1953) slope model, quarrying created a steep side falling vertically on the floors of the quarries in what conforms to the free face. Such quarries ate into peoples' arable land, compromised the strength of buildings in close proximity and led to dilapidation of roads apart from being preceded by vegetation removal.

From Table 2, North Nyakach and S.W Nyakach wards were the most quarried at about 25% followed by West Nyakach at about 19%. Observational studies assisted by satellite data revealed that these quarries were not evenly distributed and were strewn all over (Fig. 3). It was reported that 90% of the quarries were left unfilled or without any form of rehabilitation leading to the development of scar riddled land as well as badlands in areas of the Nyabondo plateau scarps.

This revelation concurred with Ministry of Environment and Mineral Resources, Government of Kenya (GoK, 2010) report that more than 90% of quarries in Kenya are not rehabilitated. Consequently, scars altered the original landscape of nearly smooth slopes into rugged and steeper slopes on which little viable economic activity was possible. Interviews confirmed that even grazing of goats and sheep on such terrain had become difficult due to limited movements caused by the open scars with steep sides yet this had been the preferred grazing site for the browsers.

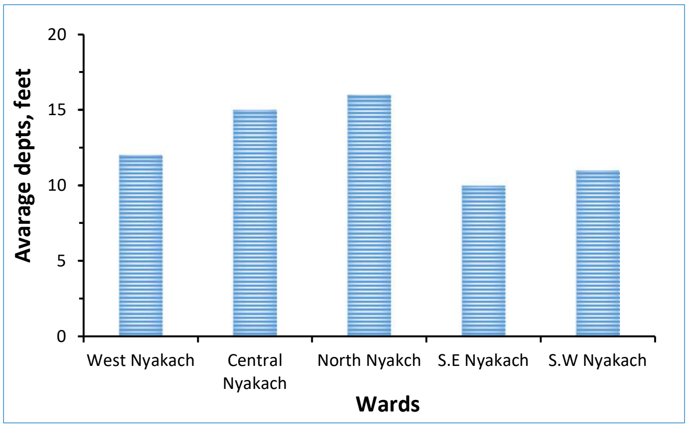

Fig. 4. Quarry depths in feet and land degradation in Nyakach

The removal and crushing of rocks into ballast resulted into steeper slopes than before. Quarry workers deliberately induced rock and gravel movement down slope to create ease in accessing mines hence accelerated mass wasting (talus creep). Similar scenario has been witnessed in Sorrento Peninsula in Italy (Guadagno and Revellino 2005). Nevertheless, mitigation measures to curb such scenario were put by establishing over twenty geo-mechanical measurement check stations along a 400-m-long slope of Mount Vico Alvano (Guadagno and Revellino 2005). This is contrary to the situation in Nyakach, Kenya where minimal measures have put in place.

Fig. 5. Satellite map showing quarries in Central Nyakach (Google Earth, 2019) (a), quarry along Pap-Olwalo Road (b) and quarry along Pap-Bodi Road

The bare ground in Fig. 3 shows unevenly distributed quarries in West Nyakach. Most of the quarries were left open without mitigation measures in sight except for eucalyptus variety of trees planted before excavation. The eucalyptus trees and indigenous vegetation species were cut down to pave way for excavation activities. Concomitantly, report by the Kenya's Ministry of Environment and Mineral Resources indicated that more than 90% of the quarries in Kenya have no rehabilitation plans exposing laxity of the enforcement agencies such as NEMA (GoK, 2010). Quarrying in Nyakach portrayed a tri-fold adverse effects on land in Nyakach. First, was removal of vegetative soil cover preceding actual aggregate excavation exposing soil to agents of erosion (Mkhonta, 2000). Secondly, the actual excavation of aggregates (sand/quarry) left behind wide-open scars of varied depths depending on nature of aggregate source and magnitude of extraction. Thirdly, aggregate transporting trucks plying the region also generated significant amounts of vibrations that weakened/stressed rocks and soil triggering mass wasting (talus and soil creeps).

Result from sediment budget analysis in relation to humans as geomorphic agents had it that, the amount of aggregates appropriated fur outweighed the amount deposited; 5,118 tones during dry season and 8,986 tones during wet season. The seasonal variation in supply of aggregates against its high demand led to invasion of riparian lands and farms where sand was available during dry season and facilitated land degradation. For instance, unregulated dry pit mining was observed to have morphologically transformed channel beds of Omondo, Katuk-Odeyo, Ragen and Nyalunya in Nyakach. This concurred with the findings by Olang and Fürst (2011) in Nyando River Basin, Kenya.

Table 3 shows that 9,935.5 tons of gravel was extracted from Nyakach (Kisumu County Revenue Office, 2018). With a total land cover area of 127.8 km^2 or 35,730 Ha. The annual soil loss (degradation) is thus;

Total land cover ÷ amount of soil loss/excavated

$(127.8 \div 9935.5)\ T/km^2 = 0.0128\ T/km^2$

or

$(35730 \div 9935.5)\ T/Ha = 3.596\ T/Ha$

Hence, this finding concurs with that of Haule et al. (2016) who found that limestone mining caused extensive soil loss and loss of vegetative cover in Mbeya region of Tanzania.

Fig. 4 has it that North Nyakach and Central Nyakach had the deepest quarries at 16 and 15 feet respectively. This was attributed to a geologically hilly and rich gravel and other aggregate (North Nyakach) and lowlands with deep deposited sand (Central Nyakach) (Shackleton, 1951). The Nyabondo plateau region in S.E and S.W Nyakach had the lowest quarry depths owing to presence of black cotton soil and red loams unsuitable for quarrying except brick making which are done at shallow depths. Nevertheless, quarrying activities affect the natural landscape resulting to habitat loss (Menta, 2012) disrupting the ecosystem. Interview sources revealed that streams in the region provided habitat for various wild life species, however, very few of such species are existing today and are greatly endangered e.g., neem plant and the monitor lizard. Contrastingly, in Nigeria, Lameed and Ayodele (2010) found out that reptiles were the most dominant animals in the un exploited quarry site at Ogbere town of Ogun state. The variation in the number of wildlife species in the exploited and unexploited quarry sites could be attributed to the clearance of the undergrowth vegetation by quarrying which is the main cause of environmental degradation and exhaustion of local communities (Akanwa et al., 2016). Hence, quarrying disturbs the ecosystem balance by endangering wildlife species thus, supporting the Systems Theory by Bertalanffy (1969).

Fig. 5a presents a satellite image of a section of Nyakach scarps slopes. It vividly shows the uneven and un patterned distribution of quarries on the plateau scarps especially along the rural access roads such as Pap-Olwalo and Pap-Bodi roads. They measured approximately 100 by 50 m and 80 by 35 m encroaching into arable lands with depths of 15feet and 8 feet respectively. They were located about 2meters away from the roads, abandoned, unfilled and collected overland flows into them as shown by ground photographs (Fig. 5b and 5c). These quarry pits (Fig. 5b and 5c) were occasion by the demand for materials for road construction in the area thus, justifying the assertions by Anunda (2014) that rise in real estate and construction industry positively correlate with the rise of quarrying problems like soil erosion and loss of bio-diversity due to active and abandoned mines (Mwangi, 2014).

4. Conclusion and Recommendations

In conclusion, quarrying activities in Nyakach Sub County was responsible for massive land degradation as witnessed by numerous gullies caused by sand and gravel extraction. The deepest gully measured approximately 4.8 (16 feet) by 100 m by 50 m. The gullies were cascaded in the entire Nyakack Sub County with an average gully depth of 13 feet (3.9). The gullies did not only reduce the size of agricultural land, but also grazing land for the browsers as well as transport routes on the scarps rendering the land almost derelict.

From sediment budget analysis in relation to humans as geomorphic agents, an annual degradation of 0.0128 T/km2 or 3.596 T/Ha was realized equivalent to 9935.5 T of gravel lost. The amount of sand appropriated was 5,118 T during dry season and 8,986 T during wet season. The huge seasonal variation in aggregates supply led to invasion of riparian lands and farms for sand extraction during dry seasons causing land degradation.

Based on reference state analysis, sand extraction was responsible for endangering of both animal and plant species in the main drainage channels as neem plant and monitor lizard known to have inhabited the region in large numbers in the previous years are currently limited. Quarrying activities, was therefore responsible for disruption of the ecosystem causing decline of wildlife species and alteration of the biophysical environment as proposed in the System Theory. The study therefore recommends:

Use of physical structures such as gabions to control gully erosion especially on the lowlands, planting of trees as well as construction of terraces on the scarps to check erosion as terracing materials/ debris are abundantly available on the scarps of Nyabondo plateau. Terracing will not only help check erosion on the plateau scraps but also stabilize the slopes by increasing slope resistance for both the scarp slopes and the gully banks in lower region. Adoption of alternative land use economic activities to reduce over reliance on sand and other aggregate mining in the area to curb land degradation. Environmental impact assessment be made mandatory even for artisanal mining in the region to help mitigate the adverse effects of lithospheric exploitation and also strict enforcement of laws governing environment by NEMA.

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