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An Assessment of Air and Water Pollution Accrued from Stone Quarrying in Mukono District, Central Uganda

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Abstract

The unquenchable demand for rock materials has attracted many companies within the building and construction sector to invest in stone quarrying. However, this has brought about environmental impacts with health threats to people. There is a paucity of information about the magnitude of pollution on air and water and how it varies with quarry sites. This study, therefore, investigated the physical impacts of quarrying on air and water and explored the *in-situ* mitigations to undesirable effects due to stone quarrying. Four active quarry sites were identified. Field measurements of dust (particulate matter) were conducted within the four quarry sites and in the nearby community. Water samples were collected from quarry pits and nearby shallow wells for laboratory analysis of water quality. Statistical Analysis of Variance (ANOVA) was used to test for differences in pollution across the four studied sites. Results revealed that, amidst the use of wet crushing and water sprinkling on bare surfaces, dust emission was higher than the recommended permissible standards levels with a significant variation across the quarry sites with ANOVA (P-value = 0.003) for PM 2.5 and (P-value = 0.04366) for PM 10. Water pollution was mainly contributed by the non-permissive levels of nitrates, chromium, and pH. Polluted air and water are associated with sparking off health threats to the users in the community. In conclusion, quarry companies should strengthen the already existing mitigation of dust suppression. The study recommends additional measures such as treating quarry pit water before discharging to the open environment to enhance environmental protection against the accumulating undesirable quarry impacts.

Keywords

Stone Quarrying, Air, Water, Pollution, *In-Situ* Mitigation

1. Introduction

In Africa, a very strong impetus has recently been given to infrastructure development especially roads, power generation dams, and other construction ventures (National Planning Authority, 2015). Meeting the demand for such developments requires harnessing potential sources of raw materials such as aggregates, gravel, sand, and limestone (Hinton et al., 2018). The ever increasing demand for such raw material has led to increased quarrying activities in many parts of the country, which is a clear indication that rock extraction activity is a significant form of earth resource exploitation that is viewed to be a financially rewarding occupation to those involved, in terms of employment and providing income (Eshiwani, 2014; Mbandi, 2017). The activity has also contributed to the improvement of infrastructure such as roads which are later on ultimately left for local communities after decommissioning of the quarries (Akularemi, 2015). However, it is conceived that many rock extraction companies in various parts of Africa still use archaic and unregulated methods, and, they do not effectively follow the stipulated conditions in the respective permits/licenses from the authorizing agencies. This makes monitoring of their activities and enforcement of mineral extraction regulations very difficult (Eshiwani, 2014; Ministry of Energy and Mineral Development, 2015; UNDP, 2018). The consequences of such irregularities come with great environmental, healthy, and social costs to the host communities (Babayemi et al., 2016). There is thus a great public outcry against the quarry proprietors since most of these operators' main target is to maximize profit with less concern on the harm that they pose to the environment and the people (Mbuyi, 2017).

According to Nartey et al. (2012) four million deaths are reported annually from acute respiratory problems in developing countries owing to aggravated pollution from stone crushing and blasting. Missanjo et al. (2015) assert that plants near stone quarry areas tend to show heavy interference of photosynthesis processes because of the high intensity of dust although this reduces with distance and differs with plant species. On the other hand, cases of child labor have been reported in various quarry sites, a matter that has been of great concern to workers' unions and activists in the country since it falls under the Employment Act, 2006 which provides for the protection of children and guides that a child under 12 years cannot be employed under any circumstances (Acts Supplement, 2006).

Uganda's mining and quarrying industry is growing at a rate of 11 percent per annum and this has offered employment to about 300,000 Ugandans and created other livelihood opportunities along the mining value chain (National Environment Management Authority, 2014; United Nations Environment Programme, 2012). Irrespective of improving people's livelihoods, mineral extraction, and rock quarrying activities often impart long-term environment and social-economic footprints in areas in which it is carried out (Mebratu et al., 2021; UNDP, 2018). Several activities or stages of rock extraction normally result in permanent vegetation loss and destruction of habitat, threats to health and safety of host communities, damage to cultural sites, and eventual displacement of the community (Ming'ate & Mohamed, 2016). On the other hand, NEMA a coordinating, monitoring, regulatory and supervisory body for all activities relating to the environment in Uganda has been concerned with the negative implications. This applies especially to sites left without being rehabilitated observing that abandoned pits deface the landscape and make the soil structure weak. To transform the extraction subsector into a sustainable livelihood option for the population, there is a need to support and promote awareness creation of Occupational Health and Safety Policy. It is also important to support the formulation of policies that compel quarry developers to restore sites of rock extraction (National Environment Management Authority, 2014; Mbandi, 2017).

In Nakisunga sub-county, stone quarrying is mainly conducted in three phases namely site clearing, drilling and blasting. Site clearing entails the removal of the topsoil (overburden) to open up the rock surface (Oggeri et al., 2019). With drilling, holes are created within the selected rock using pressure drill wagons with compressor and later the created holes are filled with explosive (Ammonium Nitrate Fuel Oil and other catalysts) and in blasting phase drilled holes are filled with sand or soil to enclose the pressure of explosives then ignition which propels the blast (Walker, 2011). In the due course, quarrying brings about several environments and social impacts for instance water pollution (especially shallow wells) due to runoff from the quarries, increased dust and noise levels, destruction of people's houses, and accidents due to flying stones.

There is a paucity of information about the magnitude of consequences of quarrying on air, and water resources and how it varies with quarry sites. Despite the efforts by scholars such as Kulabako (2019) and Birabwa (2006) have made an enormous contribution towards twigging quarrying dynamics in Nakisunga but these had less emphasis on ascertaining the variation and magnitude of quarrying implication in Nakisunga accrued to the quarry sites. Therefore, the study sought to understand the pattern and extent of stone quarrying's implication on air and water resources. This information is crucial in interpreting the dynamics of quarrying in the area thus aiding in the formulation of sustainable and appropriate measures for the undesirable effects.

2. Impacts of Quarrying on Air and Water

Quarrying and Air pollution

Air pollution resulting from different extraction activities triggers airborne particulate matter and black smoke (Nanor, 2011). Stockpiles of fine material from crushing can be a source of airborne dust. The situation may be worsened if piles are highly exposed to wind erosion (Bhatasara, 2013). Dust may also originate from haulage trucks and conveyors inside the quarry sites (Akularemi, 2015).

Particulate matter is defined as air pollutants that comprise suspended particles in the air, varying in composition and size, resulting from various anthropogenic activities (National Institute for Occupational Safety and Health, 2012). Particulate matter (PM) or fugitive dust is the primary source of air pollution in quarries mainly from rock blasting and crushing activities. In this case, the extent of pollution will depend on the local microclimate conditions (Sayara, 2016; Eshiwani, 2014; Nartey et al., 2012). Dust particles are dispersed by their suspension and entrainment in an airflow. Dispersal is affected by the particle size, shape, and density, as well as wind speed and other climatic effects (NIOSH, 2012). Smaller dust particles remain airborne for longer periods, dispersing widely and depositing more slowly over a wider area. Large dust particulates (greater than 30 μm), that make up the greatest proportion of dust emitted from rock extraction workings will largely deposit within 100 m of sources. Intermediate-sized particles (10 - 30 μm) are likely to travel up to 200 - 500 m. Smaller particulates (less than 10 μm) which make up a small proportion of the dust emitted from most mineral workings or quarries are only deposited slowly. Concentrations decrease rapidly on moving away from the source, due to dispersion and dilution (Bada et al., 2013).

Particulate Matter of less than 10 μm (PM 10) is the term given to the fraction of total particles suspended in the air having diameters less than 10 μm. The PM 10 samples contain all particles less than 2.5 μm in diameter (PM 2.5) as well as particles in the 2.5 μm to 10 μm fraction (Leon-Kabamba et al., 2020). Silica content of PM 10 particles rather than PM 2.5 particles could lead to a greater crystalline silica mass due to the possible presence of silica particles in the 2.5 μm to 10 μm size range on the filter (Peter et al., 2018). Particulate air pollution especially PM 10 is associated with a wide range of health effects. When inhaled, it affects the respiratory and cardiovascular systems, causes asthma and later mortality. Particulates from blasting and crushing areas are considered to be more dangerous because they are occasionally inhaled deeply into the tracts, hence settling in areas where the body's natural cleaning mechanisms cannot remove them (Oyinloye & Olofinyo, 2017). Exposure to high concentrations of dust causes silicosis and fibrosis, a thickening of the lung walls leading to the development of scar tissue. This scar tissue restricts the vital exchange of oxygen and carbon dioxide in the blood causing difficulty in breathing which in turn places a strain on the heart. Numerous studies suggest that health effects can occur at particulate levels that are at or below the levels permitted under national and international air quality standards. According to WHO (2005), no evidence so far shows that there is a threshold below which particle pollution does not induce any adverse health effects, especially for the more susceptible populations.

Quarrying and water resources

Anthropogenic activities, such as mining and quarrying are a source of water contamination. Most pollutants are adsorbed by the suspended particles in water (Yi et al., 2020). Access to clean water is measured by the number of people who are capable of getting it expressed in percentage of the total population (WHO, 2003). Access to water reflects good health and sanitation for a particular community. Likewise, a good environment contributes to good living and assured health conditions of the human being (Babayemi et al., 2016). According to Wesaka (2014), the residents of Bumutakkude and Kiryamuli in Mukono represented by a civil society group sued a Chinese firm for allegedly violating and depriving them of their rights to access clean and safe water. They claimed that the quarry operations surrounding the natural water stream had led to the contamination of the natural stream with mud and rendered the stream inaccessible, especially during the rainy season. The verdict called upon the proprietors to establish an alternative source of water for the affected community. On the other hand, open pits within quarry sites act as water collection points/pools during heavy rains and this prompts quarry operators to empty these pits by pumping water into an open environment (Ozean et al., 2012). However, this is a challenge to the surrounding community who use shallow wells as their potential water sources because quarry wastewaters end up polluting these sources (NEMA, 2017). Uncontrolled dust from the drilling and crushing activities normally finds its way into community water sources especially rivers and shallow wells making water unpleasant for consumption, creating a source of unending conflicts between the community and quarry owners (Sayara, 2016).

3. Materials and Methods

3.1. Description of the Study Area

The study was conducted in Nakisunga Sub County which lies in Mukono North County in the south of Mukono district as shown in **Figure 1**. In Nakisunga Sub County, two parishes of Namuyenje and Wankoba were selected because of being famous for both large-scale and small-scale quarrying activities. These parishes are well known for Basement Complex rocks of granite which is an essential material in the building and the construction industry thus the many quarrying activities (UNDP, 2018; MEMD, 2015). The selected study area has been consistently reported to have serious health implications ranging from hearing impairments to irritation of eyes, especially amongst the workers and the neighboring communities.

The geology of the area can be grouped in the partially granitized formation with the greatest part of Mukono district being underlain by the Pre-Cambrian rock system. Specifically, it belongs to the Buganda-Toro system which occupies an extensive band across the South center of the country where argillites, including phyllites predominate. This system consists of mainly wholly granitized

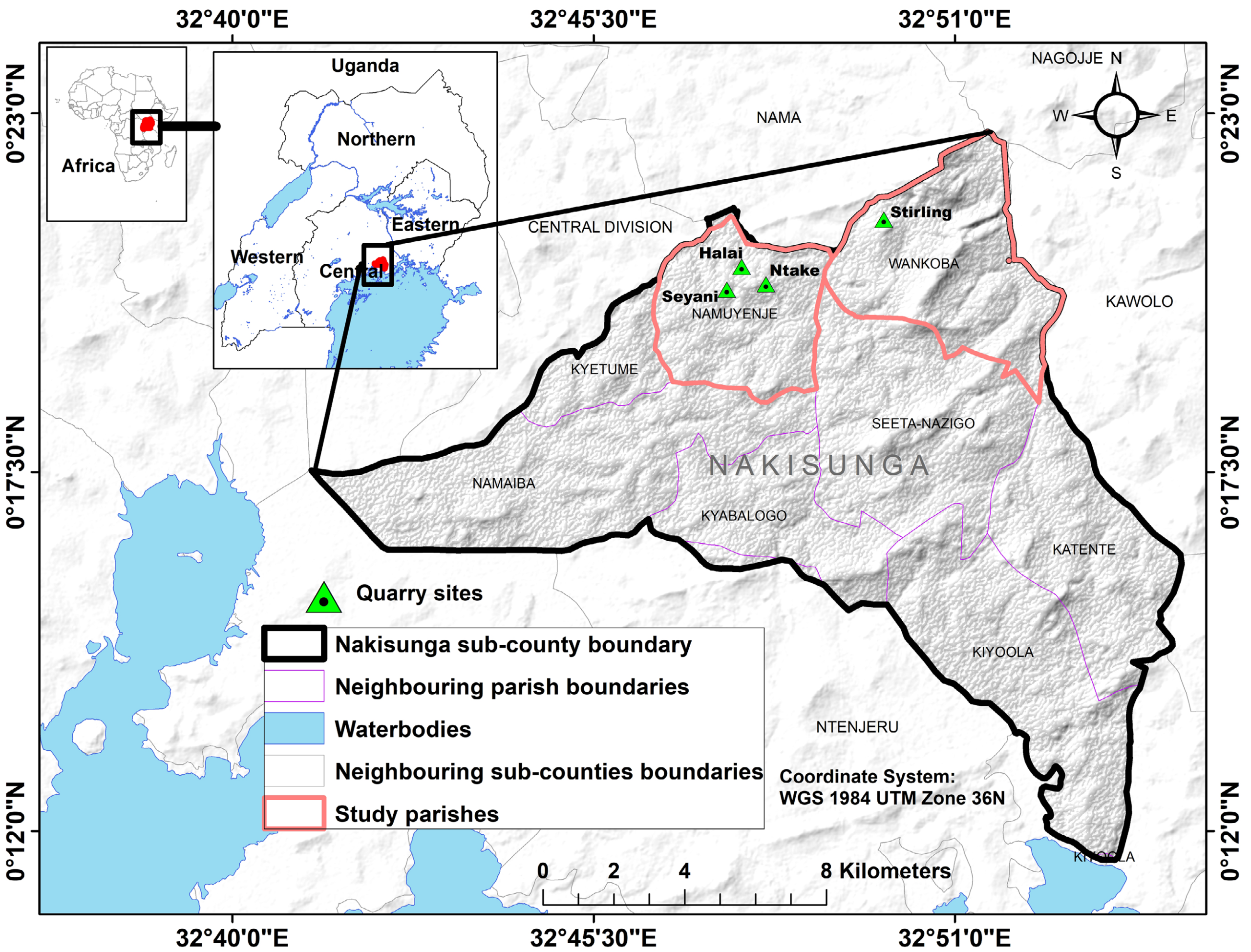

Figure 1. Location of the studied quarry sites.

or high to medium metamorphosed formations, consisting of undifferentiated gneisses and elements of partly granitized and metamorphosed formations (MEMD, 2015). Microscopically, the rock is medium-grained and comprised of three main minerals including biotite, quartz, and feldspars. The rock is compact, tough, and exhibits non-schistosity. It is pale grey with a pink tint in some cases.

The climate displays comparative small variations in temperature, humidity, and wind throughout the year. This climate is generally humid moist sub-humid in the southern part of the district. The mean annual temperature recorded throughout the district is 20.7˚C, whilst the mean annual maximum and minimum temperature levels of 26.3˚C and 15.1˚C respectively (Nakato et al., 2017). In terms of rainfall, the area receives a bimodal type of rainfall, with two peaks occurring in March-May and October-November, the former being the most dominant.

By 2014, Nakisunga Sub County had a total population of 48,320 with 12,076 households contributing 8% of the total population in Mukono district (UBOS, 2014a). The population was projected to be 56,800 people by the year 2020 with a 2.8% annual population increase with 293 persons/km^2 density (UBOS, 2014b).

3.2. Research Procedure and Measurements

Four active quarry sites were selected in Nakisunga sub-county for experimental research on air and water pollution. Using the BRAMC air quality monitor (BR SMART-128SE), the total concentration of dust that is PM 10 and PM 2.5 was measured. Three replicate measurements were conducted within the quarry sites for drilling and crushing and at the neighboring homesteads. The BRAMC instrument was placed on a tripod stand 2 m above the ground and at stability to take readings. All readings were taken after twenty (20) minutes since dust particles can remain in the air for about 15 minutes. Dust in form of PM 10 and PM 2.5 were purposively considered for study because these are commonly investigated due to their surpassing health effects on man (Bada et al., 2013; Bhanu, Agrawal, & Singh, 2014; Nartey et al., 2012). For homesteads closer to the quarry sites, samples were only collected during sunny days. Only homesteads within a radius of 60 - 100 m were considered, because a majority of the homesteads were in that radius from the quarry sites.

For quarry pits, using a one-liter plastic container, four composite water samples taking one at each quarry site, were collected. The composite samples were made up of mixed water from four sampled quarry pits at each quarry site. For the nearby community shallow wells, using one-liter containers, two samples were collected from two existing shallow wells. The obtained water samples were then taken to the laboratory for analysis and test the physical and chemical properties of water quality at the Public Health and Environmental Engineering Laboratory of the Department of Civil Engineering, College of Engineering, Design, and Technology Makerere University. The standard methods as described by Baird & Bridgewater (2017) were followed in the analysis of parameters such as potential Hydrogen (pH), nitrites (NO_2) mg/L, nitrate (NO_3) mg/L, Total Dissolved Solids (TDS) mg/L, Total Suspended Solids (TSS) mg/L, Turbidity, iron total (μg/L), Zinc (Zn) mg/L and chromium (Cr) mg/mL.

4. Results

4.1. Air Pollution in the Nearby Environment

Results of dust emission tests in **Table 1** revealed that Halai quarry site emitted the highest to the nearby homesteads for PM 2.5 of 27 μg/m^3 and 50 μg/m^3 for PM 10. This was followed by Seyani with 24 μg/m^3 for PM 2.5 and 45 μg/m^3 for PM 10 dust emission to the environment. The effect of quarry dust air pollution across the sites varied significantly especially with (ANOVA P-value = 0.003656) and (ANOVA P-value = 0.04366) for PM 2.5 and PM 10 respectively thus a signal for a consequent variation in air pollution across the four study quarry sites. Dust emissions at Halai was above the permissive dust levels of 50 μg/m^3 for PM 10 μg/m^3 and 25 μg/m^3 for PM 2.5 μg/m^3 advanced by WHO (2005).

4.2. Variation of Dust Emission with Quarrying Processes

Results of variation in dust emission with processes are presented in Table 2. Air pollution was mainly attributed to dust from crushing and drilling. Statistical results indicated a significant variation (ANOVA P-v < 0.05) in the dust emission for PM 2.5 μg/m^3 between crushing and drilling for both sunny and rainy days with the highest emission recorded from the crushing section. There was a significant difference in dust emission between crushing and drilling (ANOVA, *P*-value = 0.028) for sunny days with mean dust emission levels recorded at 39.75 μg/m^3 and 26.75 μg/m^3 for crushing and drilling respectively. This consequently

Table 1. Measurement for dust (PM) at sampled homesteads at quarry sites.

Quary sites	Particulate matter (PM 10)								Particulate matter (PM 2.5)							
	Ntake		Stirling		Seyani		Halai		Ntake		Stirling		Seyani		Halai	
Homesteads	N1	N2	ST1	ST2	SY1	SY1	H1	H2	N1	N2	ST1	ST2	SY1	SY1	H1	H2
T1	21	24	9	13	17	45	10	35	20	8	3	6	6	16	27	17
T2	15	36	20	10	30	29	50	52	21	19	7	16	13	13	23	23
T3	17	13	13	27	27	23	39	48	14	11	4	9	14	24	16	22
Min	15	13	9	10	17	23	10	35	14	8	3	6	6	13	16	17
Max	21	36	20	27	30	45	50	52	21	19	7	16	14	24	27	23
Mean	18	24	14	17	25	32	33	45	18	13	5	10	11	18	22	21
Stdev	3	12	6	9	7	11	21	9	4	6	2	5	4	6	6	3
COV	17	47	40	54	28	35	63	20	21	45	45	50	40	32	25	16
	P-value = 0.04366								*P*-value = 0.003656							

Key: T = test, H = homestead, stdev = standard deviation, COV = coefficient of variation, Min = minimum, Max = maximum.

Table 2. Variation of dust emission between processes on rainy and sunny days.

Quaries	Dust emission (PM 2.5) between processes but same day			
	Sunny day		Rainy day	
	Crushing	Drilling	Crushing	Drilling
Stirling	28	23	28	17
Ntake	48	28	30	20
Seyani	40	26	34	27
Halai	43	30	27	21
Min	28	23	27	17
Max	48	30	34	27
Mean	39.75	26.75	29.75	21.25
Stdev	9	3	3	4
COV	21	11	10	20
P-value	0.028		0.017	

implies higher air pollution magnitude in the crushing section than the drilling section within the quarrying sections thus higher risk of health problems to the crushing operators. Dust emission between processes varied significantly and thus its implications to workers. Crushing and drilling processes had mean levels of dust emission of 29.75 μg/m^3 and 21.25 μg/m^3 respectively and ANOVA *P*-value of 0.017. Quarry workers in the crushing section were more exposed to dust (PM 2.5 μg/m^3) especially at Ntake with a maximum dust emission of 48 μg/m^3 followed by Halai with 43 μg/m^3 on sunny days.

Although lower amounts of PM 2.5 μg/m^3 were recorded on rainy days, all the quarry sites recorded higher levels of emission beyond the maximum recommended level of 25 μg/m^3 by WHO (2005). The mean level for dust emission at Seyani quarry on rainy days was recorded highest at 34 μg/m^3 followed by Ntake with 30 μg/m^3. This further revealed that quarry workers are exposed to high levels of PM 2.5 & 10 other associated health risks in case one has partial Personal Protective Equipment (PPEs) especially those in the crushing section on sunny days. On rainy days, the mean dust emission levels during drilling at Stirling, Ntake, Halai were 17 μg/m^3, 20 μg/m^3 and 21 μg/m^3 below the permissive levels of 25 μg/m^3 and only Seyani with mean dust emission exceeding the permissive levels of 25 μg/m^3 set by WHO (2005).

4.3. Pollution of Water Resources

The results from the water laboratory analysis are presented in **Table 3**. Samples

Table 3. Laboratory results for water quality of quarry pits and nearby shallow wells.

Water quality	Quarry pits				Neighboring shallow wells		Statistics			National Standards (UNBS, 2017)
Parameter	Halai	Stirling	Ntake	Seyani	SW1	SW2	Min	Max	Mean	
pH	6.18	5.74	4.87	5.65	5.28	5.09	4.9	6.18	5.5	6.0 - 8.0
EC	313	207.1	171.3	664	44.9	54.7	44.9	664	242.5	2500
Turbidity (NTU)	6	6	25	12	207	12	6.0	207	44.7	300
Nitrates (mg/l)	199.2	188	148.4	855.6	0	31.6	0.0	855.6	237.1	20
Nitrites (mg/l)	0.38	1.27	0.068	1.27	0.18	0.01	0.0	1.27	0.5	2
Iron (μg/1)	0.1	0.07	0.13	0.09	4.5	0.35	0.1	4.5	0.9	10
TSS (mg/l)	6	16	14	10.8	112	12	6.0	112	28.5	100
TDS (mg/l)	360	236	206	872	120	120	120.0	872	319.0	1200
Lead (mg/l)	0.02	0	0	0.0.3	0	0	0.0	0.02	0.0	0.1
Chromium (mg/l)	0.32	0.16	0.08	1.22	0.01	0	0.0	1.22	0.3	0.05
Zinc (mg/l)	0.39	0.11	0.03	0.64	0.01	0	0.0	0.64	0.2	5

Key: pH = Hydrogen Potential, EC = Electric Conductivity, TSS = Total Suspended Solids, TDS = Total Dissolved Solids, NTU = Nephelometric Turbidity Unit, SW = Shallow Wells (SW1: Lat. 0˚20'36.5", Lon. 32˚47'50.91"; SW2: Lat. 0˚20'13.89", Lon. 32˚47'44.11").

of rainwater that collects in quarry pits with the quarry sites as shown in **Figure 2(a)** and **Figure 2(b)** and water in shallow wells nearby was analyzed. Water quality was observed to vary across the quarry sites with different parameters. On overall, the pH concentration in water across all the four active quarry sites was averaged at pH 5.5 with a minimum value of pH 4.9 at Ntake and a maximum of 6.18 at Halai. The average pH of 4.9 was below the standard national permissive levels for pH in the water of 6 to 8 as indicated in water quality guidelines by the Uganda National Bureau of Standards (2017). Water with less than the recommended minimum permissive pH of 6 is associated with the acidic characteristic. According to the guidelines for drinking water quality by WHO (2003), consuming water of pH below 4, is associated with health implications such as soreness and irritation of eyes and the severity escalates with decreasing pH. Below pH 2.5, damage to the epithelium is irreversible and extensive.

The laboratory tests for EC at all quarry sites returned values of 313 μS/l for Halai, 207 μS/l for Stirling, 171 μS/l for Ntake, 664 μS/l for Seyani, and 54.7 μS/l and 5.09 μS/l for the two neighboring shallow wells. However, all these values are below the critical threshold levels of 2,500 μS/l for EC recommended by UNBS (2017) water quality guidelines. According to the interpretation and standards of water quality parameters by the United States Environmental Protection Agency (2017) water below the threshold of 2500 μS/l has lower levels of ionic concentration activity due to small dissolved solids and thus less aggressive.

The results for turbidity at all quarry sites were below critical threshold levels of 300 (NTU). For example, 6 mg/l for Halai, 6 mg/l for Stirling, 25 mg/l for Ntake and 12 mg/l for Seyani. Those for the two neighboring shallow wells were 207 mg/l and 12 mg/l. Water in the area especially at Halai and Stirling was associated with low turbidity levels which reduce satisfactoriness to consumers as well as its utility in certain Nakisunga.

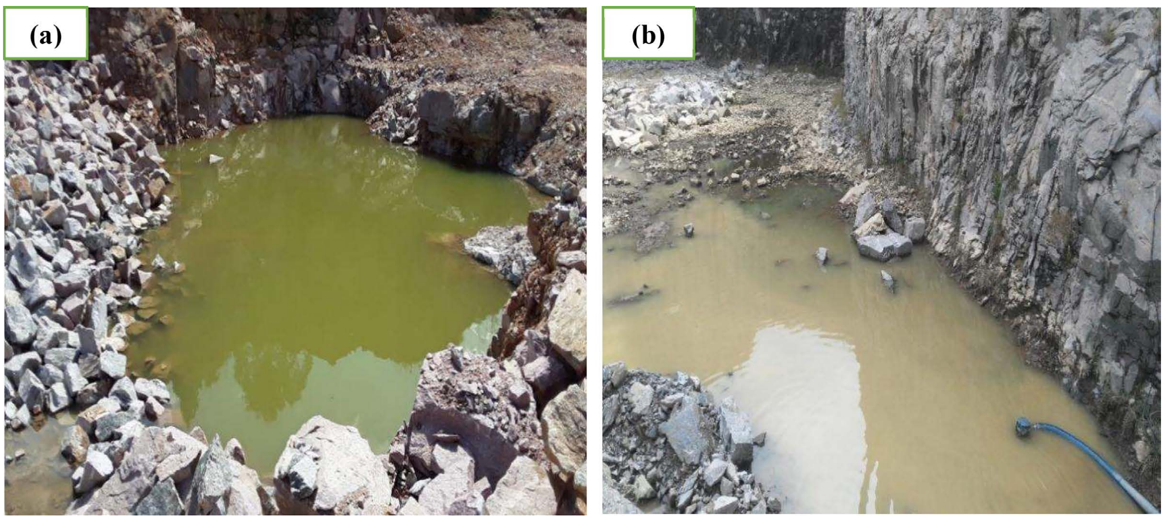

Figure 2. (a) Water collected in the quarry pits awaiting discharge to the open environment, (b) quarry pit water being discharged to open environment.

The concentration of nitrates across all the quarry sites and one shallow well had values above threshold levels of 20 mg/l with an average of 237.1 mg/l. Nitrate concentration above 20 mg/l is an indication that during drilling and blasting a lot of ammonium nitrate fuel is used.

Values of nitrite across the four active quarry sites and two shallow wells were below the critical threshold levels of 2 mg/l. For instance, it was 0.38 mg/l for Halai, 1.27 mg/l for Stirling, 0.068 mg/l for Ntake, 1.27 mg/l for Seyani, and 0.18 mg/l, 0.008 mg/l for the two shallow wells respectively.

Levels of Iron (total) across the quarry sites and two quarry wells showed values below the critical threshold of 10 mg/l for examples 0.1 mg/l for Halai, 0.07 mg/l for Stirling, 0.13 mg/l for Ntake, 0.09 mg/l for Seyani, and 4.5 mg/l, 0.35 mg/l for the two shallow wells.

Total Suspended Solids across the quarry sites indicated values below the critical threshold of 100 mg/l (6 mg/l for Halai, 16 mg/l for Stirling, 14 mg/l for Ntake, and 10.8 mg/l for Seyani). However, one of the shallow wells (SW1) showed a value above the critical threshold (112 mg/l). Higher concentrations of suspended solids can serve as carriers of toxins, make drinking water unpalatable, and might have an adverse effect on people who are not used to drinking such water.

Total Dissolved Solids across the quarry sites and two shallow wells (SW1 and SW2) showed values below the critical threshold of 1200 mg/l being 360 mg/l for Halai, 236 mg/l for Stirling, 206 mg/l for Ntake, 872 mg/l for Seyani and 120 mg/l for both shallow wells. Results for lead across the four active quarries and two shallow wells indicated values below detection level thus zero especially at Stirling and Ntake with only Seyani at 0.03 mg/l and Halai at 0.02 mg/l for whose results were below the critical threshold of 0.1 mg/l according to National standard levels of Lead in water advanced by UNBS (2017).

The concentration of chromium in the water across the four quarries showed values above National Standards for potable water of 0.05 mg/l with an average of 0.3 mg/l. The values for zinc concentration in water across the four active quarries and two shallow wells were below the critical threshold of 5 mg/l for instance 0.39 mg/l for Halai, 0.11 mg/l for Stirling, 0.03 mg/l for Ntake, 0.65 mg/l for Seyani and 0.01 mg/l for the shallow wells.

4.4. Mitigation Measures Put in Place by the Quarry Proprietors

Figure 3 below presents results of in situ mitigation measures to check on the undesirable effects of quarrying. Wet crushing and water sprinkling on bare surfaces was attested to be the most widely used dust mitigation measure across all the studied quarry sites with (68%). Under a wet crushing system, the rock is moistened before crushing and this process happens within the grinder machine (National Institute for Occupational Safety and Health, 2012). The quarry workers indicated that water sprinkling on bare surfaces is carried out when there is excessive dust generated especially in a dry season.

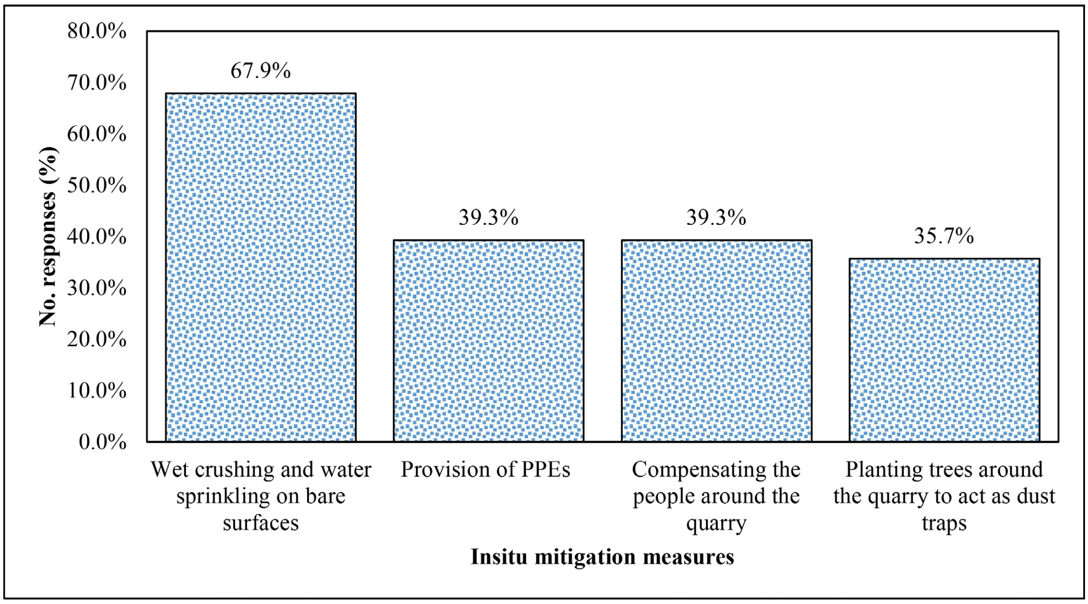

Figure 3. Mitigation measures put in place to minimize undesirable effects of quarrying to people within and around quarries.

5. Discussion

5.1. Dust Air Pollution

Air and water pollution was mainly due to the dust emission from crushing and drilling activities as also asserted by Bada et al. (2013) during his study of air quality assessment in Jagun village, Ogun state in Nigeria. In addition, findings of dust air, and water pollution are in line with those of Mbandi (2017). Dust accumulation on plant leaves resulted in wilting leading to lowering of crop yields or failure in during a study on assessment of the environmental effects of Quarrying in Kitengela Subcounty of Kajiado in Kenya. Furthermore, similar findings of dust water pollution in quarry communities are reported by Mbuyi (2017) during a study on assessment of Environmental Impacts of Quarry operations in Ogun State, Nigeria. Mbuyi found out that quarry operations were associated as reported by 44% and 44% for air pollution and water pollution. The higher elements of dust emission in Nakisunga cause threats of vegetal wilting, especially during dry spells as reported by Akanwa et al. (2017). Akanwa et al. (2017) revealed enormous vegetal wilting caused by unsustainable quarrying practices. This thus limited the vegetal ecological functioning role in their study on Quarrying and its effect on vegetation cover for sustainable development using high-resolution satellite image and GIS in Ebonyi State, Nigeria. Significant variation in dust air pollution and its implication between the studied quarry sites was due to the difference in the size and number of types of machinery such as crushers, wagon drillers, and heavy-duty trucks. This agrees with findings by Bhanu et al. (2014) during a study on assessment of air pollution around coal mining area: Emphasizing on spatial distributions, seasonal variations in Jharia coalfield (JCF), in Dhanbad district of Jharkhand state of India. Bhanu also discovered that major sources of air pollution in Jharia were quarrying related activities and vehicular emissions as well as windblown dust through unpaved roads. The higher amounts of particulate matter (PM 10) in Nakisunga sub-county especially in the neighborhood areas will increase asthmatic conditions among the nearby communities as reported in a study by Moghtaderi et al. (2016).

5.2. Dust Water Pollution

Results of high values of chromium in the water of Nakisunga are in line with findings in a study by Darkoh & Asre (2015) on Socio-Economic and Environmental Impacts of Mining in Botswana: A Case Study of the Selebi-Phikwe Copper-Nickel Mine. They also found out that Chromium was among the pollutants accrued to quarrying-related activities in Botswana. Sapphire et al., (2016) revealed that heavy metals such as chromium are poisoning to human health. Besides, the United States Environmental Protection Agency (2017) parameters of water quality interpretation and standards, high chromium contents in water can act as a skin irritant. This may result in limited domestic water supplies in Nakisunga. Water pollution in form of high mean turbidity value (44.7 NTU) and EC (242 μS/cm) were slightly higher than results advanced (Meride & Ayenew, 2016) in their study on drinking water quality assessment and its effects on residents' health in Wondo Genet campus, Ethiopia. Their results showed a mean turbidity value of (0.98 NTU), and EC was 192.14 μS/cm in Wondo Genet Campus Ethiopia. This was majorly attributed to the inappropriate discharge of quarry pit water before drilling as well as inadequate liquid waste disposal. A similar result was also revealed by Mehmet (2016) during a study on environmental pollution and its effect on water sources from marble quarries in western Turkey.

Water had a mean Nitrates concentration of (237.1 mg/l) higher than the permissive levels of 20 mg/l. According to Ward et al., (2018), consuming much nitrate distorts blood oxygenation (also known as a blue baby syndrome). Babies under six months old are at the highest risk of getting methemoglobinemia. This can further cause the skin to turn a bluish color and can result in serious illness or death. Other symptoms connected to methemoglobinemia include decreased blood pressure, increased heart rate, headaches, stomach cramps, and vomiting.

5.3. Mitigation

The mitigation measures found by the study were wet crushing and water spraying on bare ground. This finding corroborates with results reported by the United States Department of Energy (2018) in the study titled Water Application for Dust Control in the Central Plateau: Impacts, Alternatives. Besides water sprinkling was used because it was believed to reduce dust emission and reduce adverse impacts of dust both to quarry workers and the nearby environment as also conveyed in a study by Pinder (2013). This was also evidenced by the dust field measurements taken across dry and rainy days where dust emission (PM

2.5) decreased to 27μg/m^3 for PM 2.5 on a rainy day from 28 PM 2.5 on a sunny day during crushing. The higher dust emission on sunny days compared to rainy days accounts for the use of water sprinkling as a priority method of dust emission mitigation also resonated by Murrow (2020) who recommended the use of water-mist while crushing and drilling as an efficient method of dust suppression in and around quarry sites.

6. Conclusion

Dust is a prominent implication of quarrying with its consequential effects on air and water pollution, especially during dry periods. There was a significant difference in dust emission across the studied quarry sites as well as between crushing and drilling especially in dry seasons or sunny days. Water pollution was majorly depicted through amounts of nitrates, chromium, and pH that exceed permitted levels. Although insufficient, wet crushing and tree planting around the quarry sites were the most prioritized mitigation measure for dust suppression.

Author Contributions

H.B, W.M Y.K & A.M conceptualized the study and designed data collection methods; Y.K & W.M performed the statistical analysis; W.M, & Y. K wrote the original first draft manuscript; H.B, W.M & Y.K reviewed and edited & H.B met the publication costs. Special thanks to the co-authors who have worked tirelessly to see that this research is published and prompt inputs.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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