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Full Length Research Paper

Assessment of leachate contamination potential of landfills in Ibadan, Nigeria

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Environmental pollution leads to poor health and has been a worrisome experience to humanity for the past few decades. This research was conducted to determine the pollution potential of landfill leachates (LFL) in Sub-Saharan Africa, using Ibadan as case study. Survey of landfills in the metropolis was undertaken; the two major active unlined landfills (Ajakanga and Awotan), were considered for this study. During sampling, eighteen parameters of interest were analyzed. The leachate pollution indices (LPI) of each landfill were calculated. The LPI of Awotan landfill is 17.55 while that of Ajakanga is 15.67. With the exceedances of the 7.378 standard LPI value, all landfills in the metropolis is recommended to be closed down in line with international best practices and new sanitary landfills set up in their stead. Based on the sub-LPI values obtained, biological treatment would be the most viable treatment option for the LFL produced. The findings from this study are applicable in landfill management in other countries within the African sub-region; thereby contributing to the attainment of Sustainable Development Goals (SDGs).

Key words: Leachate pollution index, landfill, sustainable development goals, Ibadan, Nigeria, assessment.

INTRODUCTION

Landfilling still remains the most popular method of solid waste disposal practiced by municipal authorities worldwide, despite the use of Integrated Municipal Solid Waste Management. Landfills Leachates have been associated with the alteration of ecological balance, and has been a major source of environmental concern. In a rather responsive fashion, landfills have now evolved into well-engineered facilities that are equipped with bottom liners and leachate management setups to minimize the migration of this leachate into the environment. Regrettably, most developing economies, like Africa and Asia, have failed to keep up with the pace of this evolution (Johannessen and Boyer, 1999; Onibokun and Kumuyi, 1999; Rafizul et al., 2012; Waste Atlas Report,

2014). With the increasing volume and variety of waste constantly finding their way into landfills owing to rapid population growth and urbanization, chances are that the contiguous habitat, to say the least would continue to suffer from increasing impact of landfill leachate. Sub-Saharan Africa is of particular concern, being the region with the world highest annual urbanization rate (about 4.1%), not to mention the largely inadequate waste management infrastructure and poor land use planning bedevilling the region (Onibokun and Kumuyi, 1999; Saghir and Santoro, 2018).

Leachate contains a myriad of chemical constituents' consequent from the solubilisation of in-place waste as well as chemical cum biochemical reactions occurring

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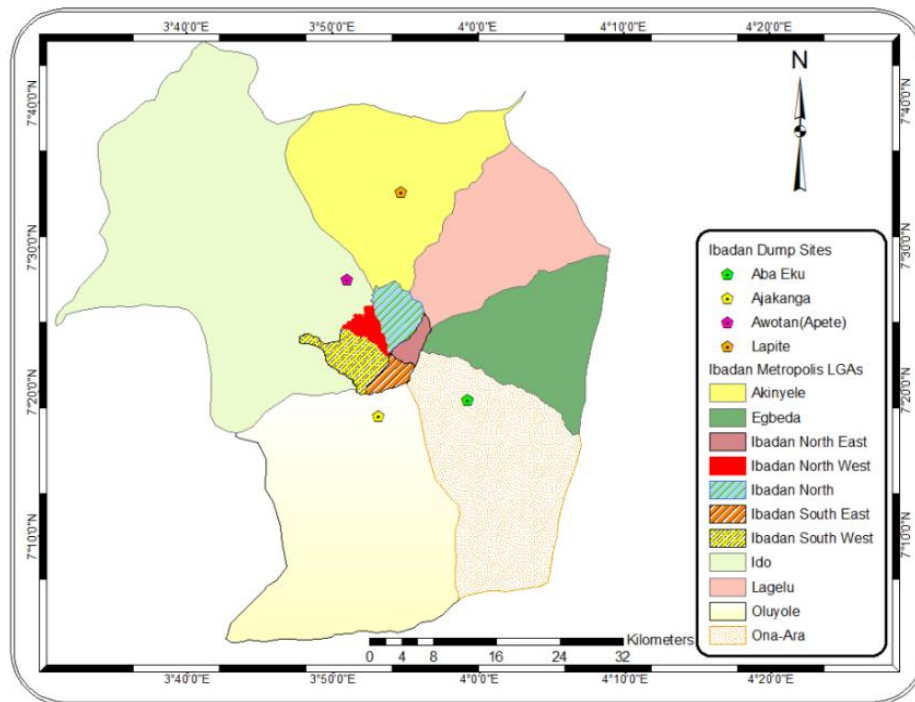


Figure 1. Map of Ibadan metropolis showing the approved landfills.

within the landfill system, the composition of which varies throughout the lifespan of the landfill (Santoro, 2018). Leachate production rate is largely dependent on the precipitation, the in-place moisture content of waste, run-on cum run-off, evapotranspiration and the level of water table relative to the base of the landfill unit (Klinck and Stuart, 1999), water table level is of concern because shallow water table can be easily polluted, while deep water table may not because of natural soil purification process.

It is necessary to have a uniform scale assessment of leachate pollution data of various landfill facilities (or even same facility at different instants) are assessed. In fact, it was in response to this necessity that a quantitative tool (Leachate Pollution Index, LPI), based on Rand Corporation DELPHI Technique was developed for measuring leachate pollution potential of landfills (Kumar and Alappat, 2003). It is also relevant in providing guide as to what leachate treatment option to adopt; LPI is useful in landfill ranking, landfill trend analysis, public awareness campaigns and budgetary planning *Vis à-vis* site remediation. Manimekalai and Vijayalakshmi (2012) opine that result of leachate trend analysis for a particular landfill site can be used in the design of leachate treatment facilities for other sites having analogous conditions.

Though much energy have been geared towards characterization of landfill leachates and the assessment of their impacts, leachate pollution index data from landfills are still very limited despite their relevance. In Ibadan metropolis for instance, only one dumpsite has

such empirical data (Aromolaran et al., 2019); this is very disturbing considering the fact that the metropolis, which has four approved dumpsites and more than a few illegal open dumps, is the largest in Sub-Saharan Africa and third most populous in Nigeria. This research endeavors to assess the contamination potential of leachate from two major landfill sites in Ibadan metropolis through leachate pollution index modelling.

Study area

Ibadan Metropolis is the largest settlement (approximately 3123km²) in tropical Africa, south of the Sahara. With an estimated population of 3.4 million, Ibadan ranked third most populous Nigerian city (IUFMP, 2014; Lapworth et al., 2019). It has a tropical climate, having two distinct seasons: wet season (April to October) and dry season (November to March). It has a mean annual rainfall of about 1150 mm. Situated in Oyo State, South-Western Nigeria; Ibadan consists of eleven Local Government Areas (Figure 1). Four approved dumpsites, all located in the suburbs, receive commingled waste from the entire metropolis: Aba-Eku landfill, Ajakanga landfill, Awotan landfill and Lapite landfill. The unsanitary manner, in which they are managed, is one of the major reasons for Ajakanga and Awotan landfills (South and North of Ibadan urban respectively) to have been chosen.

Ajakanga landfill is a legal dumpsite lying approximately on latitude 7.3114N and longitude 3.8414E

in close proximity with River Ona (only separated by Odo Ona Elewe Road) near Arapaja in Oluyole LGA (Omonigho, 2020). Situated in a rapidly developing community, a sizeable lot of the 10.03-hectare landfill has been allegedly encroached by adjacent human settlement. The government-owned landfill is operated by the Oyo State Waste Management Authority (OYWMA) and has been active since 1996. The dumpsite receives an average annual waste of about 205,000 tonnes (Falusi et al., 2016).

Awotan landfill (also called Apete landfill) is located on latitude 7.463N and longitude 3.849E, along the deplorable Apete-Awotan-Akufo Road in Awotan, Ido Local Government Area of Oyo State. Awotan community plays host to a number of institutions, commercial outfits and residential settlements close to the landfill. The facility, which is owned by Oyo State Government and operated by same through the OYWMA, takes delivery of approximately 78,000 tonnes of waste annually (Falusi et al., 2016). Established in 1998, the second largest landfill (20.26 hectares) in the metropolis made the list of *The World's 50 Biggest Dumpsites* (Waste Atlas, 2014).

MATERIALS AND METHODS

There was field reconnaissance of all four major landfills in Ibadan metropolis after a familiarization visit to the Oyo State Waste Management Authority to obtain access to the facilities. Then stratified, purposeful selection base on records of propensity randomly selection of two landfill sites for the study: Ajakanga landfill and Awotan landfill, South and North of Ibadan urban respectively was carried out. Measurements of the geographical coordinates of the landfills with the aid of a handheld Global Positioning System (GPS) device were undertaken.

Samples were obtained between December 2019 and January 2020 when the harshest effects of leachate could be felt. It is during this time that leachate effects are felt more in relation to health as rural people often embark on rain harvesting during the raining season and result to ground water harvesting during dry season. The seasonal physicochemical analysis of the leachates showed that rainfall events increase the decomposition rate of the waste and affect pollutant concentration of the leachate (Falusi et al., 2016).

Composite leachate samples were obtained from three purposefully selected points from each dumpsite. The samples were collected into thoroughly pre-washed sterile 75 cl bottles on ice.

The pH and electrical conductivity (EC) were recorded on site at the time of sampling with digital pH meter and digital EC meter, respectively. For heavy metal analyses, samples were separately collected in pre-washed polypropylene containers of 50 cl capacity and acidified onsite to avoid precipitation of metals.

Analytical methods

The parameters were selected based on their relative importance in municipal landfill leachates composition, and their pollution potential on groundwater resource in particular (Bagchi 2004). The physicochemical parameters such as total dissolved solids (TDS), total alkalinity (TA), total hardness (TH), major cations such as calcium (Ca^{2+}) and magnesium (Mg^{2+}), major anion such as chlorides (Cl^-) of the leachate and groundwater samples were

analyzed by titrimetric methods. Chloride was included in the water quality assessment because of its measure of extent of dispersion of leachates in groundwater body (Chapman 1992). Sulfates (SO_4^{2-}) in the groundwater samples were analyzed by nephelometric turbidity method (APHA, 1998). Nitrates (NO_3^-) and total organic carbon (TOC) determination in the groundwater samples were carried out by DR 2700 spectrometer. Estimation of chemical oxygen demand (COD) was done by closed reflux titrimetry method, while biochemical oxygen demand (BOD) was calculated using oxygen determination by Winkler titration for the preserved leachate sample. All the analyses in this study were repeated two or three times until concordant values were obtained, and all the tests were carried out according to the standard methods (APHA, 1998; APHA, 2005). The heavy metals such as Cd, Cu, Mn, Pb and Zn concentrations in the leachate and ground water samples were analyzed using atomic absorption spectrophotometer (AAS) supplied by Thermo Fisher Scientific, USA with D2 background correction lamp. Standard solutions of heavy metals viz. copper (Cu), cadmium (Cd), manganese (Mn), lead (Pb) and zinc (Zn) were prepared with distilled water using copper sulfate ($\text{CuSO}_4\cdot 5\text{H}_2\text{O}$), cadmium sulfate ($\text{CdSO}_4\cdot 8\text{H}_2\text{O}$), manganese sulfate ($\text{MnSO}_4\cdot 7\text{H}_2\text{O}$), lead nitrate [$\text{Pb}(\text{NO}_3)_2$], and zinc nitrate [$\text{Zn}(\text{NO}_3)_2\cdot 6\text{H}_2\text{O}$].

Their wastewater discharge limits were then compared with the laboratory results to determine their level of compliance. Calculation of pollution indices using leachate characterization results based on DELPHI technique using the linear weighted sum aggregation method given thus (Kumar and Alappat, 2005):

$$\text{Overall LPI} = 0.232\text{LPI}_{\text{org}} + 0.257\text{LPI}_{\text{in}} + 0.511\text{LPI}_{\text{hm}} \quad (1)$$

Where, LPI is the acronym for Leachate Pollution Index; LPI_{org} is the sub-leachate pollution index organic component value; LPI_{in} is the sub-leachate pollution index inorganic component value; and LPI_{hm} is the sub-leachate pollution index heavy metal component value.

Each sub-LPI is given by the expression:

$$\text{LPI}_x = \frac{\sum_{i=1}^m w_i p_i}{\sum_{i=1}^m w_i} \quad (2)$$

Where w_i = weight factor and p_i = sub - index value of the applicable analytes

RESULTS AND DISCUSSION

Characterization of landfill leachates

The mean values obtained from the physicochemical and microbiological examination of the leachate samples compared with the WHO wastewater discharge limits are in Table 1. The result of leachate characterization presented shows high concentration of a myriad of physicochemical and microbial parameters, with the following exceeding the discharge limits stipulated by the World Health Organisation: TDS, DO, BOD, Na^+ , Cr^{++} , Cu^{++} , Ag^{++} (Table 1).

The pH values of the leachate in Ajakanga and Awotan landfills are 7.6 and 8.3 respectively, revealing old leachates under steady state. These values are in line with the pH value of 8.03 reported in Aba-Eku in Ibadan by Aluko et al., 2003. The pH range of 7.15 to 7.80 reported in Soluos 1 and Soluos 2 landfills in Lagos

Table 1. Characterization of landfill leachates from Ajakanga and Awotan landfills.

Parameter	Ajakanga	Awotan	WHO wastewater discharge limit
pH	7.6	8.3	6-9
TDS	1953	1360	1500
DO	0.13	0.13	<0.1
BOD	945.0	1343.7	60
Na ⁺	345.0	375.0	200
Cl ⁻	48.5	42.6	350
Ammonia	9.3	16.3	<1
Cr ⁺⁺	0.040	0.080	0.02
Cd ⁺⁺	0.017	0.060	0.1
Pb ⁺⁺	0.080	0.093	0.2
Ni ⁺⁺	0.043	0.047	0.2
Mn ⁺⁺	0.100	0.070	0.2
Zn ⁺⁺	1.267	0.833	5
Fe ⁺⁺	0.633	1.100	5
Cu ⁺⁺	0.467	0.833	0.2
Ag ⁺⁺	0.060	0.057	0.05
Total coliform bacteria count (TCB)	3.10 x 10 ⁵	7.20 x 10 ⁵	400* ^a
Total fungal count	3.50 x 10 ⁶	6.30 x 10 ⁶	

All parameters are measured in mg/L, save for pH (no unit) and Total Coliform/ Fungal Count (CFUs/ml); concentrations values that do not conform to the stipulated standard are italicized; ^a indicates FEPA permissible limit for discharge into surface water as adapted from Salami and Susu (2019).

(Salami and Susu, 2019) and pH value of 8.97 observed in Sarbah landfill in Accra–Ghana (Sackey and Meizah, 2015); though in sharp contrast with the 5.11 pH value recorded in Olososun landfill in Lagos (Ogunyemi et al., 2018). The alkaline pH observed is expected because of the over two decade old landfills. Abbas et al. (2009) had posited that old leachate have pH higher than 7.5, whereas young leachates have acidic pH due to the overwhelming organic acids produced during such stage. This may be attributed to the decrease in the concentration of free volatile acids due to anaerobic decomposition, as fatty acids can be partially ionized and contribute to higher pH values. Alkaline pH is normally encountered at landfills, 10 years after disposal (El-Fadel et al., 2002).

The high BOD values recorded in leachates from both landfills is expected of landfills that receives such high proportion of food (organic) waste. Several reports validate the observation made on the landfill sites regarding their waste composition (Palczynski, 2002; CPE, 2010; Ogunbuyi, 2013). Similar BOD values (912 and 1396mg/L) were reported in LFL from Soluos 3 landfill in Lagos, Nigeria (Salami and Susu, 2019). High BOD of leachate suggests the leachates have high biodegradable organic load, indicative of potentially great microbiological activities and consequential depletion in the oxygen content of the leachate, as observed in the values of total coliform, total fungi and DO in Table 1. If the leachates from these landfills continue to find their

way to nearby surface water, particularly River Ona which is barely 50 m from the Ajakanga landfill (Omonigho, 2020), it will be difficult to realize the agenda of Agenda 14's *Life below Water* of the Sustainable Development Goal. Ammoniacal nitrogen content of the LFL is attributable to the biological degradation of amino acids and other nitrogenous organic component of the waste (predominantly food and animal waste). The values of the parameter in this study are akin to those obtained from Soluos 2 and Soluos 3 landfills in Lagos, which ranged between 26.3 to 36.30 mg/L and 7.98 to 8.77 mg/L respectively (Salami and Susu, 2019), and Aba-Eku landfill in Ibadan, which ranged between 98.01mg/L to 134.01mg/L (Aromolaran et al., 2019). Although its concentration is low when compared with results (exceeding 1000mg/L) obtained elsewhere (Wichitsathian et al., 2004; Robinson, 2007; Visvanathan et al., 2007; Aloui et al., 2009; Hasar et al., 2009; Svojitka et al., 2009; Puszczalo et al., 2010; Chiemchaisri et al., 2011), the need for treatment of the leachate cannot be overemphasized. This is because NH₄-N has been identified as a priority parameter responsible for the toxicity of LFL and could have harmful effect even as an air pollutant upon its volatilization from the leachate when it exceeds 0.50 mg/l (Cameron and Koch, 1980; USEPA, 1984, 1989).

The 0.63 and 1.10 mg/L iron contents in both leachates examined fall within the WHO permissible limit for discharge to the environment. Leachate value of

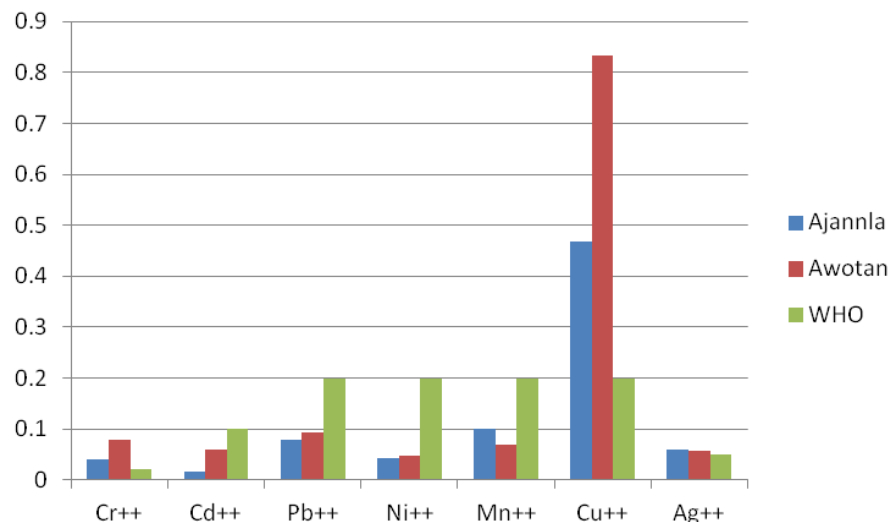


Figure 2. Heavy metal concentration AT Ajanla and Awotan.

2.08 mg/L has been reported by Aromolaran et al. (2019) in Aba-Eku while value of 1.20 mg/L has been reported by Salami and Susu (2019) in Soluos 1, Lagos Aromolaran et al., 2019; Salami and Susu, 2019 had reported values of 2.08 and 1.20 mg/L in Aba-Eku and Soluos 1 respectively. The presence of iron in the leachate is attributable to the presence of ferrous metal scrap in the waste stream; left of after scavengers had rummaged through the in-place waste. The oxidation of the ferrous iron to the ferric hydroxide colloid and other ferric forms is partly responsible for the depleted dissolved oxygen and the characteristic darkish brown colour of the leachates so obtained in this research.

The concentrations of heavy metals in the leachate from both landfills studied are generally low and are only very marginally higher than obtained by Nubi et al. (2008) from Aba-Eku landfill, except for cadmium where Ajakanga has a somewhat lower value as graphically represented in Figure 2. Aromolaran et al. (2019) and Salami and Susu (2019) also reported analogous heavy metal concentrations for Aba-Eku and Soluos 1 landfills respectively. The level of heavy metals in the decreasing hierarchy in Ajakanga is Zn > Fe > Cu > Mn > Pb > Ag > Ni > Cr > Cd and Awotan (Fe > Zn > Cu > Pb > Cr > Mn > Cd > Ag > Ni). Heavy metals have bioaccumulation and biomagnifying tendencies and are therefore particularly toxic. The possible source of chloride is food wastes. The presence of high BOD indicates the high organic strength. Fe in the leachate sample suggests that steel scraps are also dumped in the landfill. The dark brown color of the leachate is mainly attributed to the oxidation of ferrous to ferric form and the formation of ferric hydroxide colloids and complexes with fulvic/humic substance. The concentration of Zn in the leachate shows that the dumping site receives waste from

batteries and fluorescent lamps. The possible source of lead may be batteries, chemicals for photograph processing, older lead-based paints and lead pipes disposed at the landfill.

Figure 2 indicate that Cr⁺⁺, Cu⁺⁺ and Ag⁺⁺ are the only heavy metal analytes that did not satisfy wastewater discharge guideline having values greater than 0.02, 0.5 and 0.05 stipulated respectively by WHO. Copper can lead to increased corrosion of galvanized iron and steel plumbing fittings, staining of sanitary wares and laundry as well as bitter taste in water if the leachates find their way to water supplies. The corrosion process may have accelerated due to the galvanic effect between copper and galvanized iron and also the dampness of the environment. Health-wise, Wilson's disease gastrointestinal distress and jaundice may result (Gossel and Bricker, 1990). In addition, arsenic-contaminated water supplies can cause damage to the vital organs as well as the circulatory system; nasal ulcers; peripheral vascular disease; dermal lesions; peripheral neuropathy may also result (WHO, 2008).

High total coliform and total fungal values recorded in both landfills is an attestation of the poor sanitary condition of the metropolis (Ologuneru, 2019), especially the low income slums like Adeoyo, Beere and Sabo, where residents resort to defecating indiscriminately due to grossly inadequate sewage disposal facilities – only to be inadvertently evacuated commingled with solid waste by waste collectors. Isolates of TCB identified include *Enterobacter sp.*, *Aeromonas sp.*, *E coli*; *Proteus sp.* and *Salmonella sp.*, while those of total fungi identified include *Aspergillus sp.*, *Geotricum sp.*, *Rhizopus sp.* and *Penicillium sp.* The higher TCB recorded in leachate from Awotan landfill may not be unconnected with the higher volume of health care waste (containing beddings,

Table 2. Leachate pollution index of selected landfills in Ibadan Metropolis.

Parameter	Ajakanga				Awotan			
	C _i	w _i	p _i	$\frac{\sum_{i=1}^m w_i p_i}{\sum_{i=1}^m w_i}$	C _i	w _i	p _i	$\frac{\sum_{i=1}^m w_i p_i}{\sum_{i=1}^m w_i}$
Organic (LPI _{org})								
BOD	945	0.263	27	14.58	1343.7	0.263	32	17.28
TCB	3100	0.224	78	35.88	7200	0.224	88	40.48
		0.487		50.46		0.487		57.76
Inorganic (LPI _{in})								
pH	7.6	0.214	5	1.35	8.3	0.214	5	1.35
Ammonia	9.3	0.198	5	1.25	16.3	0.198	6	1.50
TDS	1953	0.195	6	1.47	1360	0.195	5.5	1.35
Cl ⁻	48.5	0.187	5	1.18	42.6	0.187	5	1.18
		0.794		5.25		0.794		5.37
Heavy metals (LPI _{hm})								
Cr ⁺⁺	0.04	0.125	5	0.82	0.08	0.125	5	0.82
Pb ⁺⁺	0.08	0.123	5	0.80	0.093	0.123	6	0.96
As ⁺⁺	0.06	0.119	5	0.78	0.057	0.119	5	0.78
Zn ⁺⁺	1.267	0.11	5	0.72	0.833	0.11	5	0.72
Ni ⁺⁺	0.043	0.102	5	0.67	0.047	0.102	5	0.67
Cu ⁺⁺	0.467	0.098	6	0.77	0.833	0.098	7	0.90
Fe ⁺⁺	0.633	0.088	5	0.58	1.1	0.088	5	0.58
		0.765		5.13		0.765		5.42
Overall LPI				15.67				17.55

Unit of Total Coliform Bacterial (TCB) is CFUs/ml; pH has no unit; other parameters are measured in mg/L. The significance, pollutant weight (w_i) and sub-index values (p_i) for each parameter in Table 2 were adapted from Kumar and Alappat (2005).

swaps, pads and the likes that may be soiled with faecal discharges and urine of in-patients) deposited in Awotan landfill. TCB values obtained in Aba-Eku landfill, Ibadan (8.7×10^5 CFUs/ml) and Sarbah landfill, Accra-Ghana (2.6×10^5 CFUs/ml) Aromolaran et al., 2019; Sackey and Meizah, 2015). The impact of the LFL on the underlying aquifer and nearby surface water can be better-imagined (WHO, 1996, 2008).

Computation of leachate pollution indices

Deploying the leachate pollution index (LPI) hazard identification tool, the leachate pollution data is as summarized in Table 2. Although all three sub LPIs computed are higher in Awotan landfill than Ajakanga landfill, the difference is somewhat significant in the sub LPI–organic component LPI_{org}, attributable largely to the conspicuously higher total coliform bacterial count TCB in Awotan leachate. In addition, of all three sub pollution indices, the organic modules are the highest ranking – suggesting high organic load and microbial load in both LFLs.

The low values of heavy metals sub-LPIs (LPI_{hm}) are consistent with the findings in Harewood Whin Landfill in

UK (Kumar and Alappat, 2005). The observed higher value of the calculated LPI_{hm} in Awotan, can be attributed to slightly higher concentration of all the individual heavy metal analytes studied (excepting manganese and zinc) as shown in Figure 2. The observable difference could be traceable to the comparatively larger volume of hazardous waste constituents deposited in Awotan landfill, predominantly laboratory, pharmaceutical and health care wastes (HCW) from the University College Hospital (UCH), University of Ibadan and The Polytechnic–Ibadan. Lamentably, Coker and Sridhar (2010) had described the proliferation of health care facilities in the metropolis as a “technological paradox” that could promote the spread of diseases; the continued co-disposal of these laboratory and HCW with municipal waste portends dire health consequences for not just for those living close by, but for an unimaginably greater population. The significance, pollutant weight (w_i) and sub-index values (p_i) for each parameter in Table 2 were adapted from Kumar and Alappat (2005).

The high values of LPI_{org} are indicative of acetogenic processes (Kumar and Alappat, 2005). Meanwhile, high pH does not promote the solubilisation and mobility of inorganic constituent, and is conceivably responsible for the low computed values of the inorganic and heavy

Table 3. Comparison of pollution indices of landfills from various locations.

Ranking	Location	Computed LPI	References
1	Pallikaranai landfill (Chennai, India)	37.11	Naveen and Malik (2019)
2	Pallikaranai landfill (Chennai, India)	37.01	Manimekalai and Vijayalakshmi (2012)
3	Guanajuato (Mexico)	34.84	Guerrero-Rodríguez et al. (2014)
4	Dhapa (Kolkata, India) [active]	34.02	De et al. (2016)
5	Brahmapuram landfill (Kochi, Kerala, India)	31.99	Arunbabu et al. (2017)
6	Dhapa (Kolkata, India) [closed]	31.80	De et al. (2016)
7	Mavallipura landfill (Bangalore, India)	30.10	Naveen and Malik (2019)
8	Dhapa landfill (Kolkata, India)	28.90	Naveen and Malik (2019)
9	Ghazipur landfill (Delhi, India)	28.41	Naveen and Malik (2019)
10	Jamalpur landfill (Punjab, India)	26.45	Bhalla et al. (2014)
11	Turbhe landfill (Maharashtra, India)	25.10	Naveen and Malik (2019)
12	Ikhueniro dumpsite (Benin, Nigeria)	22.31	Ibezute and Erhunmwunse (2018)
13	Harewood Whin landfill (North Yorkshire, UK)	19.67	Kumar and Alappat (2005)
14	Toluca (Mexico)	18.46	Guerrero-Rodríguez et al. (2014)
15	Awotan landfill (Ibadan, Nigeria)	17.55	Present study
16	Don-Parkar landfill (Warri, Nigeria)	16.57	Odia et al. (2016)
17	Niger Cat landfill (Warri, Nigeria)	15.72	Odia et al. (2016)
18	Ajakanga landfill (Ibadan, Nigeria)	15.67	Present study
19	Aba-Eku landfill (Ibadan, Nigeria)	14.46	Aromolaran et al. (2019) – wet season
20	Aba-Eku landfill (Ibadan, Nigeria)	12.70	Aromolaran et al. (2019) – dry season
21	Orhuwhorun landfill (Warri, Nigeria)	12.13	Odia et al. (2016)

metal components of the LPI. These conditions suggest that faster methanogenic processes are running concurrently with the acetogenic processes within the methane fermentation phase (Kjeldsen et al., 2002; Kamaruddin et al., 2017). The low LPI_{hm} support the thriving of microorganisms and thereby supports biological leachate treatment. The low inorganic sub-LPI (LPI_{in}) values further lend support to this wastewater treatment option.

The LPI values obtained from the landfills in this research are greater than the recommended standard by Kumar and Alappat (2003) in their studies. The overall LPI values of both landfills studied exceed in the standard LPI value of 7.378 (Kumar and Alappat, 2003), portending grave multifaceted environmental impact that transcends beyond the surrounding soil and water resources. These indices are comparable with those obtained elsewhere: Table 3 outlines the LPI data of various landfills across different geographical locations as computed by various researchers. The ranking of these landfills shows that landfills within a geographical area tend to have similar pollution indices and are somewhat different from those outside their region. To illustrate, apart from the observed skew in Ikhueniro landfill in Benin metropolis, all identified landfills in Nigeria (Southern Nigeria) rank 15th to 22nd position (with LPI range of 12 to 18); just as all the landfill sites in India rank 1st to 11th. This observed cluster is expected because of the peculiarity of the region in terms

of climatic condition, geologic settings, and demographics, level of technological advancement, lifestyle of the people, socio-economic activities and the existing solid waste management strategies.

The LPI of Awotan (17.55) was found to be greater than that of Ajakanga (15.67), with both values obtained from the present study greater than an already existing LPI for Aba-Eku landfill (12.70 and 14.46). Based on available data, with three of the four landfills in Ibadan falling within this cluster, it is very likely that the LPI of the fourth (Lapite landfill) would be within 12 and 18, *ceteris paribus*.

Conclusion

Leachate pollution index (LPI) is a quantitative tool used in measuring the contamination potential of landfill leachate (LFL). This work examines the leachate from two major unlined landfills in Africa's largest settlement (Ibadan metropolis) with a view to informing necessary decision. The LPI of Ajakanga and Awotan landfills were found to be 15.67 and 17.55 respectively. Both landfills have the capacity of altering the ecological balance of the nearby ecosystem and unimaginable wider population as they exceed the 7.378 standard LPI value. Results of LPI sub group's reveals that biological waste treatment is the best for the treatment of the LFLs. All four landfills are

recommended for closure in line with international best practices. LPI is a very useful tool that gives an unambiguous reportage of the environmental status of landfill leachates.

CONFLICTS OF INTEREST

The authors have not declared any conflict of interest.

REFERENCES

- Abbas AA, Jingsong G, Ping LZ, Ya PY, Al-Rekabi WS (2009). "Review on Landfill Leachate Treatments". *American Journal of Applied Sciences Research* 5(5):534-545.
- Aloui F, Fki F, Loukil S, Sayadi S (2009). Application of combined membrane biological reactor and electro-oxidation processes for the treatment of landfill leachates. *Water Science and Technology* 60(3):605-614.
- Aluko OO, Sridhar MKC, Oluwande PA (2003): Characterization of leachates from a municipal solid waste landfill site in Ibadan, Nigeria. *Journal of Environmental Health Research* 2(1):45-54.
- APHA (1998). *Standard Methods for the Examination of Water and Wastewater*, 20nd Edition; American Public Health Association, Washington.
- APHA (2005). *Standard Methods for the Examination of Water and Wastewater*, 21st Edition; American Public Health Association, Washington.
- Aromolaran O, Fagade OE, Aromolaran OK, Faleye ET, Faerber H (2019). Assessment of groundwater pollution near Aba-Eku municipal solid waste dumpsite. *Environmental Monitoring and Assessment* 191(12):1-25.
- Arunbabu V, Indu KS, Ramasamy EV (2017). Leachate pollution index as an effective tool in determining the phytotoxicity of municipal solid waste leachate. *Waste Management* 68:329-336.
- Bhalla B, Saini MS, Jha MK (2014). Assessment of municipal solid waste landfill leachate treatment efficiency by leachate pollution index. *Assessment* 3(1):8447-8454.
- Cameron RD, Koch FA (1980): Toxicity of landfill leachates. *Water Pollution Control* 52:760-769.
- Chiemchaisri C, Chiemchaisri W, Nindee P, Chang CY, Yamamoto K (2011). Treatment performance and microbial characteristics in two-stage membrane bioreactor applied to partially stabilized leachate. *Water Science and Technology* 64:1064-1072.
- Coker AO, Sridhar MKC (2010). "Increase in healthcare facilities and rapid environmental degradation: A technological paradox in Nigeria's urban centres". *African Journal of Environmental Science and Technology* 4(9):577-585.
- CPE (2010). *Landfill Recovery and Use in Nigeria (Pre-feasibility studies of using LFGE)*. Centre for People and Environment, Ibadan, Nigeria.
- De S, Maiti SK, Hazra T, Debsarkar A, Dutta A (2016). Leachate characterization and identification of dominant pollutants using leachate pollution index for an uncontrolled landfill site. *Global Journal of Environmental Science and Management* 2(2):177-186.
- El-Fadel M, Bou-Zeid E, Chahine W, Alayli B (2002). Temporal variation of leachate quality from pre-sorted and baled municipal solid waste with high organic and moisture content. *Waste Management* 22(3):269-282.
- Falusi BA, Odedokun OA, Abubakar A, Agoh A (2016). Effects of dumpsites air pollution on the ascorbic acid and chlorophyll contents of medicinal plants. *Cogent Environmental Science* 2(1):1170585.
- Gossel TA, Bricker JD (1990). *Principles of Clinical Toxicology*. 2nd Ed.: Raven Press Ltd New York, USA.
- Guerrero-Rodríguez D, Sánchez-Yáñez JM, Buenrostro-Delgado O, Márquez-Benavides L (2014). Phytotoxic effect of landfill leachate with different pollution indexes on common bean. *Water, Air and Soil Pollution* 225:1-7.
- Hasar H, Ipek U, Kinaci C (2009). Joint treatment of landfill leachate with municipal wastewater by submerged membrane bioreactor. *Water Science and Technology* 60:3121-3127.
- Ibezute AC, Erhunmwunse O (2018). Assessment of leachate characteristics and pollution index of Ikhueniro dumpsite in Benin City, Edo State, Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)* 12(6):38-44.
- IUFMP (2014). *Environmental and social management framework*. "Ibadan Urban Flood Management Project", World Bank.
- Johannessen LM, Boyer G (1999). *Observations of Solid Waste Landfills in Developing Countries: Africa, Asia, and Latin America*. Urban Development Division, Waste Management Anchor Team, The International Bank for Reconstruction and Development/The World Bank, Washington, DC.
- Kamaruddin MA, Aziz HA, Alrozi R, Jaafar MH (2017). "Exploring Municipal Solid Waste and Landfill Management". In *Environmental impacts, assessment and management*, Chandler N. (2ed.):151-192. Hauppauge, New York: Nova Science Publishers.
- Kjeldsen P, Barlaz MA, Rooker AP, Baun A, Ledin A, Christensen TH (2002). Present and long term composition of MSW landfill leachate. *Critical Reviews in Environmental Science and Technology* 32(4):297-336.
- Klinck BA, Stuart ME (1999). Human health risk in relation to landfill leachate. Final report to DFID, British Geological Survey Technical Report, WC/99/17.
- Kumar D, Alappat BJ (2005). Analysis of leachate pollution index and formulation of sub-leachate pollution indices. *Waste Management and Research* 22:230-239.
- Kumar D, Alappat BJ (2003): Analysis of leachate contamination potential of a municipal landfill using leachate pollution index. *Workshop on Sustainable Landfill Management, India* 3(5):147-153.
- Lapworth DJ, Stuart ME, Pedley S, Nkhuwa DCW, Tijani MN (2019). A review of urban groundwater use and water quality challenges in Sub-Saharan Africa. *British Geological Survey Open Report*, OR/17/056.
- Manimekalai B, Vijayalakshmi P (2012). Analysis of leachate contamination potential of a municipal landfill using leachate pollution index. *IOSR Journal of Environmental Science, Toxicology and Food Technology* 2(1):16-39.
- Naveen BP, Malik RK (2019). Assessment of contamination potential of leachate from municipal solid waste landfill sites for metropolitan cities in India. *Pollution* 5(2):313-322.
- Nubi OA, Osibanjo O, Nubi AT (2008): Impact assessment of dumpsite leachate. *Science World Journal* 3(3):17-20.
- Odia M, Nwaogazie IL, Nwachukwu EO, Avwiri GO (2016). Modelling Leachate Pollution Index and Potential for Selected Municipal Solid Waste Dump Sites: A Case Study. *British Journal of Applied Science and Technology* 18(6):1-16.
- Ologuneru A (2019). *Waste To Wealth: Oyo govt launches project to clean up Ibadan*. <https://ogbomosotoday.com/waste-to-wealth-oyo-govt-launches-project-to-clean-up-ibadan/> (accessed on 27th November, 2019).
- Ogunbuyi K (2013). *Ibadan Urban Flooding Management Project - Baseline Report on Solid Wastes Management Component*. Environmental Harmony Ltd.
- Ogunyemi AK, Samuel TA, Amund OO, Ilori MO (2018): Genotoxicity evaluation of landfill solid waste leachates from a waste dumpsite in Lagos State, Nigeria using the *Allium cepa* assay. *Plant and Animal Research Journal* 1(3):68-76.
- Omonigbo BO (2020). *A geo-spatial information based approach to municipal solid waste landfill site selection in Ibadan Municipality, Oyo State*. Unpublished M.Sc. Thesis Department of Civil Engineering, University of Ibadan, Ibadan.
- Onibokun AG, Kumuyi AJ (1999). Ibadan, Nigeria. 49-101. In *Managing the Monster: Urban Waste and Governance in Africa* Onibokun, A.G. (ed). IDRC.
- Palczynski RJ (2002). *Study on Solid Waste Management Options for Africa. Project Report, Final Draft Version*. African Development Bank ADP-PSDU, Côte d'Ivoire.
- Puszczalo E, Bohdziewicz J, Świerczyńska A (2010). The influence of percentage share of municipal landfill leachates in a mixture with synthetic wastewater on the effectiveness of a treatment process with use of membrane bioreactor, Desalin. *Desalination and Water*

- Treatment 14:16-20.
- Rafizul IM, Alamgir M, Shahed SM (2012). Analysis and Selection of Appropriate Aggregation Function for Calculating of Leachate Pollution Index of Landfill Lysimeter. *Iranica Journal of Energy and Environment* 3(4):370-379. DOI: 10.5829/idosi.ijee.2012.03.04.12.
- Robinson T (2007). Membrane bioreactors: Nanotechnology improves landfill leachate quality, *Filtration and Separation* 44(9):38-39.
- Sackey LN, Meizah K (2015). Assessment of the quality of leachate at Sarbah landfill site at Weija in Accra. *Journal of Environmental Chemistry and Ecotoxicology* 7(6):56-61.
- Saghir J, Santoro J (2018). Urbanization in Sub-Saharan Africa: Meeting Challenges by Bridging Stakeholders. Center for Strategic and International Studies (CSIS), Washington, DC.
- Salami L, Susu AA (2019). A Comprehensive Study of Leachate Characteristics from Three Soluos Dumpsites in Igando Area of Lagos State, Nigeria. *Greener Journal of Environmental Management and Public Safety* 8(1):01-14.
- Svojitka J, Wintgens T, Melin T (2009). Treatment of landfill leachate in a bench scale MBR, *Desalin. Water Treatment* 9:136-141.
- USEPA (1984). Ambient Water Quality Criteria for Ammonia 440/5-85-001; US Environmental Protection Agency, Criteria and Standards Division: Washington, DC, USA.
- USEPA (1989). Ambient Water Quality Criteria for Ammonia (Saltwater) 440/5-88-004; US Environmental Protection Agency, Criteria and Standards Division: Washington, DC, USA.
- Visvanathan C, Choudhary MK, Montalbo MT, Jegatheesan V (2007). Landfill leachate treatment using thermophilic membrane bioreactor. *Desalination* 204(1-3):8-16.
- Waste Atlas Report (2014). World's fifty biggest dumpsites. <http://www.d-waste.com/Atlasreport2014/Waste-Atlas-report-2014-webEdition.pdf>. (Accessed on 27th November, 2019).
- WHO (1996). World Health Organization. Guidelines for Drinking Water Quality, 2nd ed. Health Criteria and Other Supporting Information, Vol. 2, WHO, Geneva, Switzerland.
- WHO (2008). World Health Organization. Guidelines for drinking-water quality: incorporating 1st and 2nd addenda, Vol.1, Recommendations. 3rd ed. WHO, Geneva, Switzerland.
- Wichitsathian B, Sindhuja S, Visvanathan C, Ahn KH (2004). Landfill leachate treatment by yeast and bacteria based membrane bioreactors. *Journal of Environmental* 39:2391-2404.

Full Length Research Paper

A community perspective of flood occurrence and weather forecasting over Kampala City

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Weather and climate issues have become increasingly recognized among the global challenges especially in the era of climate change. Kampala city has faced a number of flooding events in the past that have led to serious damages in many low lying areas of the city. A study was conducted in one of the flood prone areas in Kampala city to understand the community perspectives on flood occurrence and weather forecasting in the area. The main objective was to understand community perceptions on flood occurrence as well as use of weather information for early warning. Data was collected from 400 respondents using a structured questionnaire as well as focused group discussions. Results from the survey revealed that 99.8% of the respondents reported rainfall intensities to have increased in the last 5 years and as a result, 96% of these respondents stated floods as the main climate risk in the area. The most common impacts of floods in the community included loss of property, lack of safe and clean water and disease outbreaks among others. In response to floods, the community identified use of raised tables or stands and use of stones in the compound as the main coping mechanisms employed in the community. In terms of weather alerts, only 22% of respondents reported receiving the weather alerts issued by the Uganda National Meteorological Authority (UNMA). Of those who receive the alerts, 91% hear the information mainly on television. Therefore, the study proposes strengthening of collaboration between UNMA and the local leaders through the Kampala Capital City Authority (KCCA) for provision of earlier weather forecasts that help reduce the negative flood impacts among communities.

Key words: Weather alerts, flood forecasting, changing climate and community perspectives.

INTRODUCTION

Weather and climate are key environmental challenges especially in the developing countries that depend on

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natural resources for most of their economic activities (Noack et al., 2019; Foster and Brozovic, 2018). For example, Uganda is dependent on agriculture that is mainly rain fed contributing 22% to the total GDP and employs 78% of the total population (UBOS, 2019). With the increasing irregularity and unpredictability of seasonal rainfall, rural communities that depend on rain fed agriculture are vulnerable to climatic hazards such as droughts and floods (Noack et al., 2019; Ogwang et al., 2016). These normally lead to crop failures and thus exacerbating food insecurity and famine. Therefore availability of timely climate information for communities to make better farming decisions is pivotal in insulating them from climatic vagaries.

Meteorological information, especially weather and climate forecasts, is essential in planning not only agricultural production activities but also business related activities especially for city dwellers (Jordan, 2020; Osuret et al., 2016). For instance, the following decisions should not be made without knowing climatic conditions: land use and management, selecting plants and breeds of animals and crop production practices such as irrigation, pest and disease control and crop-weather relationships (Elias et al., 2019). The success and failure of agricultural farming is generally related to the prevailing weather conditions. Weather plays an important role in crop production from germination of a seed to the maturity of the crop (Foster and Brozovic, 2018). The timing of sowing of a given seed of a particular crop, transplanting, scheduling of irrigation water application, timing of fertilizer application, using of pesticides to control the diseases and pests of the crops should all be pegged on weather conditions of the area to maximize agricultural production (Guo et al., 2020; Foster and Brozovic, 2018).

The cities especially in the developing countries are equally affected by changes in weather and climate because their activities like sports, business and travel also depend on weather conditions (Ogwang et al., 2016; Jordan, 2020; Lu et al., 2020; Akampumuza and Matsuda, 2017). The weather changes are exacerbated by the planning challenges mainly due to poor drainage channels that normally induce flood during the rainy seasons (Kwiringira et al., 2016; Isunju et al., 2016). Over Kampala city, flooding events have been reported to be on an increase affecting the city dwellers (Twinomuhangi et al., 2021; Kiyengo et al., 2020; Sliuzas et al., 2017). Heavy rainfall events in the city usually led to increased traffic jams in the different parts of the city due to flooding on the major roads.

One of the critical factors in managing flooding is improved weather prediction. However, accurate quantitative rainfall prediction is often a challenge to national hydro meteorological services (Mugume et al.,

2016). So, for managing floods especially in Kampala city, improving the prediction of heavy rainfall is very important for the communities living in the city. This enables them to have sufficient early warning messages and be in position to implement early actions especially in the flood prone areas. The purpose of this study was mainly to understand the impacts of heavy rainfall that normally causes flooding in a flood prone area of Kampala city as well as understanding the dissemination of weather and climate information in the same community.

MATERIALS AND METHODS

Study area

Kampala city, located in the central region is the capital and largest city of Uganda. It is located on latitude 0.35°N and longitude 32.58°E. The city occupies an estimated area of 189 km² of which 176 km² is land area and 13 km² is water. The city is divided into five divisions; Makindye, Kawempe, Nakawa, Central and Rubaga (Figure 1). Generally, Kampala city has a bimodal rainfall regime with two major rainfall seasons of March to May (MAM) and September to November (SON). However, the city being closer to Lake Victoria receives rainfall in almost all months of the year due to land and Lake Breeze effects.

The study was conducted in the areas of Kyebando-Nsoba, Bwaise and Makerere III wards in Kawempe division, one of the flood prone divisions in Kampala City under the Kampala Capital City Authority (KCCA). The division was chosen because of the recurrent flooding events that have been observed in the area. In addition, the study areas are among the slums in Kampala City.

Selection of respondents

Household surveys (HHS)

The respondents were purposively selected from communities along the Kyebando-Lubigi channel because of their high vulnerability to floods in the division compared to other areas. A total of 400 respondents were sampled from four wards (100 households from each Ward) along the channel following guidance from the Environmental officer of Kawempe Division, Kampala Capital City Authority (KCCA) and local council chairpersons. Only residents who had been in the area for more than 5 years qualified to be interviewed.

Data collection

Both primary and secondary data were used in this study to understand community perspectives on floods and weather forecasting in the flood prone area of Kampala city.

Primary data

A questionnaire was designed to capture the community perceptions in relation to heavy rainfall (storms) and its impacts on their livelihoods. The questionnaire was pre-tested among 20

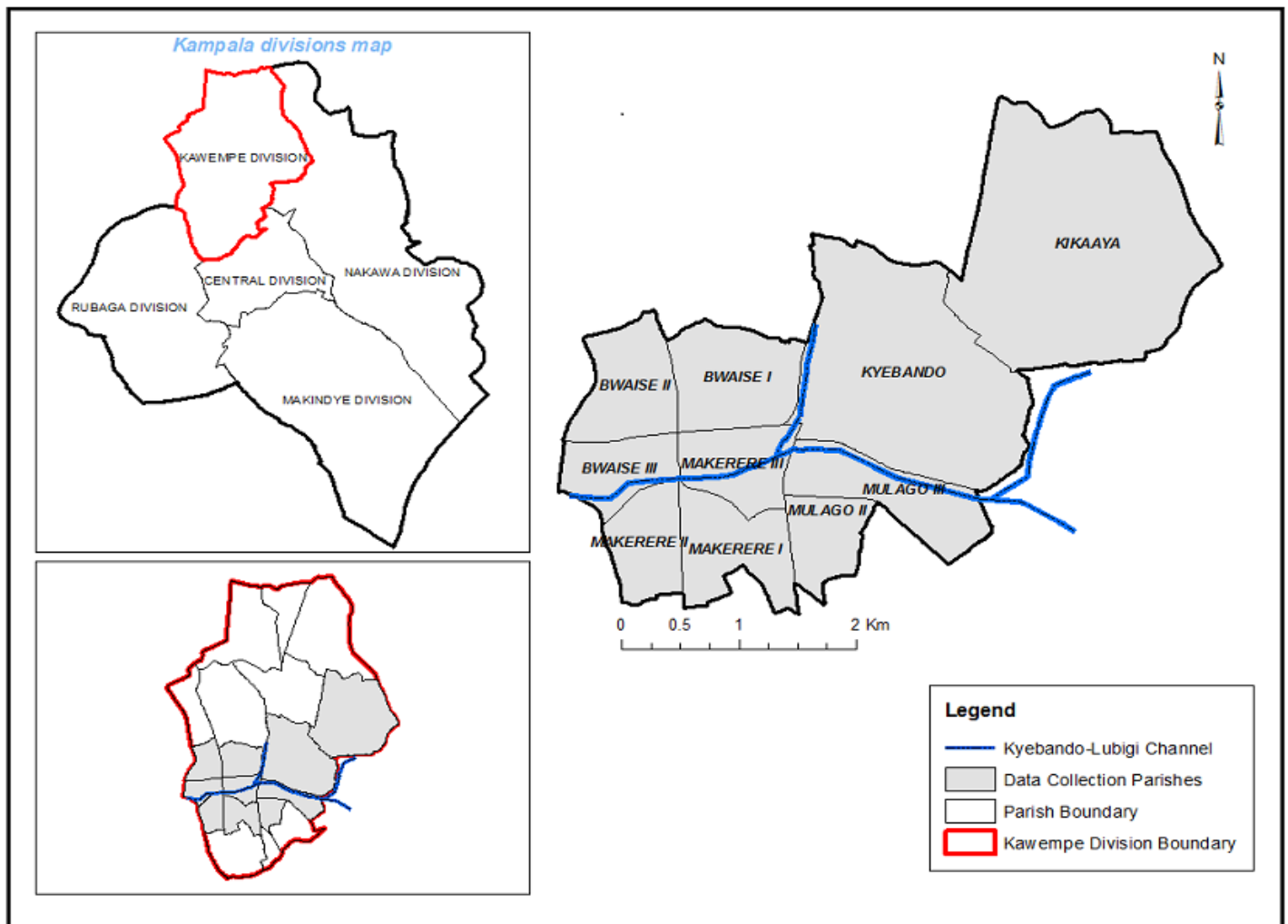


Figure 1. Study area map showing Kawempe division and the Kyebando – Lubigi Channel.

residents in Makerere III ward to confirm its reliability and validity before it was administered to the communities. In addition, four focus group discussions were conducted from both males and females in the same area to further understand the nature of the problem and also to explain the missing links from the household survey. Two focus groups consisted of mixed men and women while the other two consisted of males and females only respectively. The groups were chosen following the guidance of the local council chairpersons of people who had lived in the area for a period of at least five years.

Secondary data

This consisted of historical data mainly on rainfall from 1981 to 2019. Kampala synoptic weather station was selected mainly to understand the trends of extreme rainfall events at both seasonal and annual scales. This data was obtained from the Uganda

National Meteorological Authority in the Ministry of Water and Environment.

Data analysis

Primary data

The questionnaires from the Household Survey (HHS) were coded and results entered using epi-data software which was later exported to SPSS for further analysis. Graphs, and tables and cross tabulations of variables of specific interest are then presented for discussion.

Secondary data

The data was checked and quality controlled using WMO (1983)

Table 1. The respondent's characteristics.

Variable	Frequency (n=400)	%
Gender		
Male	177	44.2
Female	223	55.8
Age		
18-25	5	1.3
26-35	179	44.8
36-50	193	48.3
Above 50	23	5.8
Education level		
None	4	1.0
Primary	24	6.0
Secondary	339	84.8
Tertiary	33	8.3
Marital status		
Single	59	14.8
Married	285	71.3
Divorced	28	7.0
Widowed	28	7.0

guidelines. Trend analysis on seasonal and annual extreme rainfall trends in the study area was then performed. Extreme rainfall considered here was daily rainfall greater than 20 mm (R20 mm) (ECTCD).

RESULTS

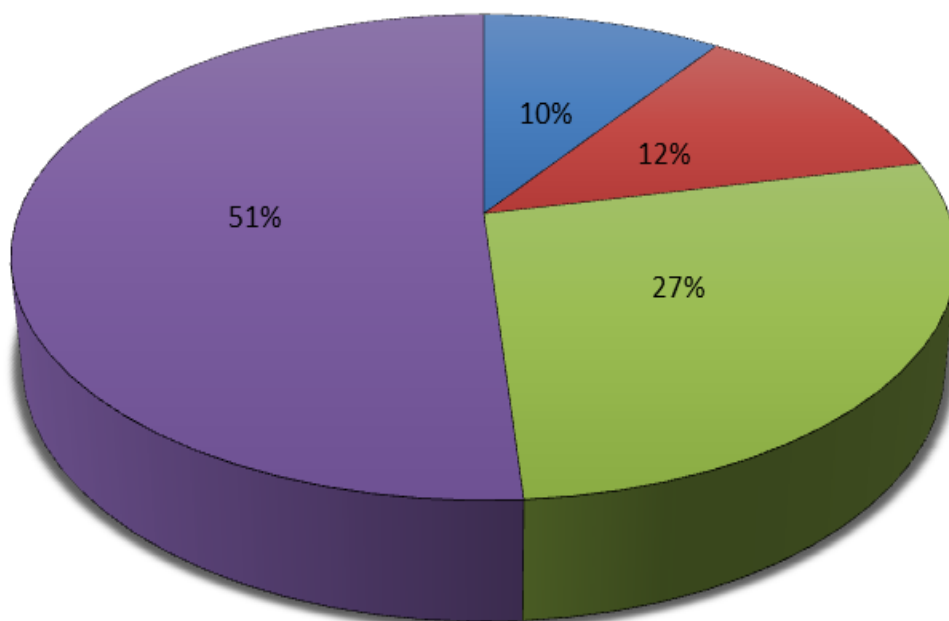
Bio data of the respondents

Table 1 shows the characteristics of the sampled respondents in terms of gender, age, education level and marital status. This is key to understanding their responses and how they adapt in various situations. From the survey, 55.8% were females and 44.2% were males. Whilst this may be attributed to the nature of the occupation of the residents in the area where males are always working outside their residences during the day to support their families, the study supports the narrative that women and children are more vulnerable to floods and storms. Over 98% of respondents were greater than 26 years who are expected to understand the impacts of floods in their communities since 2010 (ACPF, September 2013). 84% of the respondents completed secondary education which meant that they could easily respond to the given questions. However those who did

not understand English were interviewed through interpreters who were recruited from the communities. The education level is not surprising because this is a peri-urban and most people who come to live there have some formal education training compared to a rural setting (UBOS, 2017). Of the respondents, 71.3% were married compared to 14.7% that were single, 7% widowed and 7% divorced.

Length of stay in the area

Figure 2 shows the duration the respondents had resided in the area. It can be seen that 27% of the respondents interviewed have stayed in the area for more than 5 years (between 6 and 10 years) while 51% of the respondents had stayed in the area for more than 10 years. This serves to provide good information from the two categories of respondents whose length of stay in the area is long enough and very important in relation to information sharing pertaining to the impacts of floods and storms along the selected areas. It was considered that respondents who have stayed in the area for more than 5 years, that is, 78% (51% for over 10 years and



■ Less than 1 year ■ Between 1 and 5 Years ■ Between 6 and 10 Years ■ More than 10 years

Figure 2. Respondents' length of stay in the area.

27% for over 5 years) have a richer experience with the environment.

Changes in the rainfall amounts and intensity in the area over the last 10 years

From Figure 3, it is clearly seen that about 99.8% of the respondents interviewed agreed that they have observed changes in the rainfall amounts and intensity and only 0.2% of the respondents have not observed changes in rainfall amounts and intensity in the study areas for the last 10 years. The changes in rainfall amounts and intensities are attributed to changes in flood incidences that are occurring in Kawempe division since there are no proper channels that have been constructed to accommodate the flood waters. This was further confirmed in focus group discussions that captured the actual facts from the communities as reported by some members.

In the last years (before 2010), the rains were moderately received but for long hours compared to 2019 where it was heavily received for short hours. In 2017, there was more sunshine than rains contrary to 2019 where rain

has been too much. Also, rains of those days could prepare (okubindabinda), that is to say you would see the rainy clouds forming in the sky giving people notice and time to prepare, unlike these days where rains come abruptly.

Times of the day when they normally receive heavy rainfall events

From Figure 4, the areas usually receive heavy rainfall events in the afternoon (48%), the evening takes (34%), and night time (10%) and rarely in the early morning (8%). The biggest percentage of time, the day goes to afternoon since this is the time of the day when there is convective rainfall events that usually result in flooding events. It can be argued that these results, especially the timing, are expected as these areas experience the convective effects of Lake Victoria.

Rates of occurrence of floods within the seasons in the last 10 years (2010-2019)

From Figure 5, it is observed that floods occur mostly in

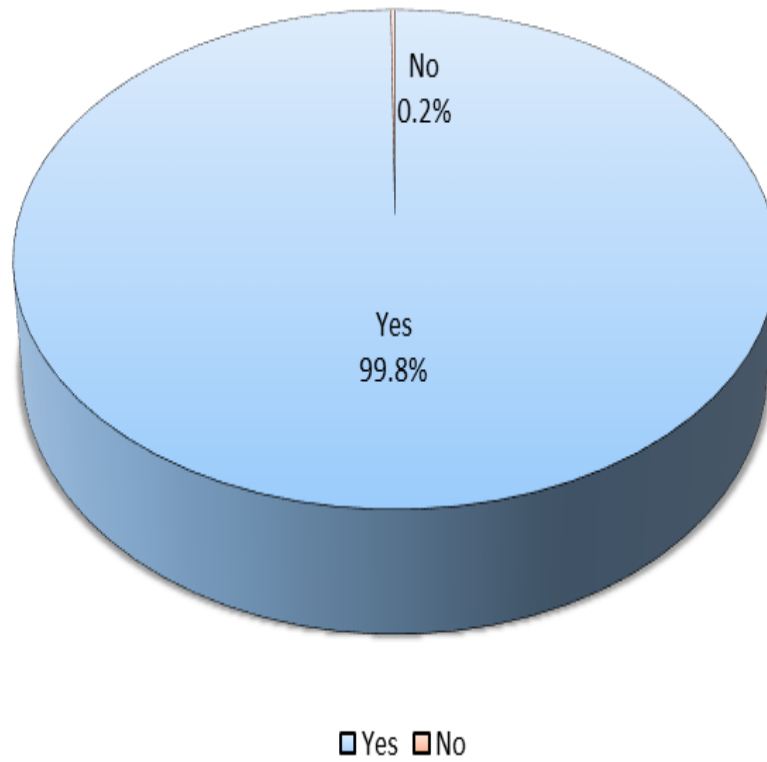


Figure 3. Perceptions on rainfall amounts and intensity.

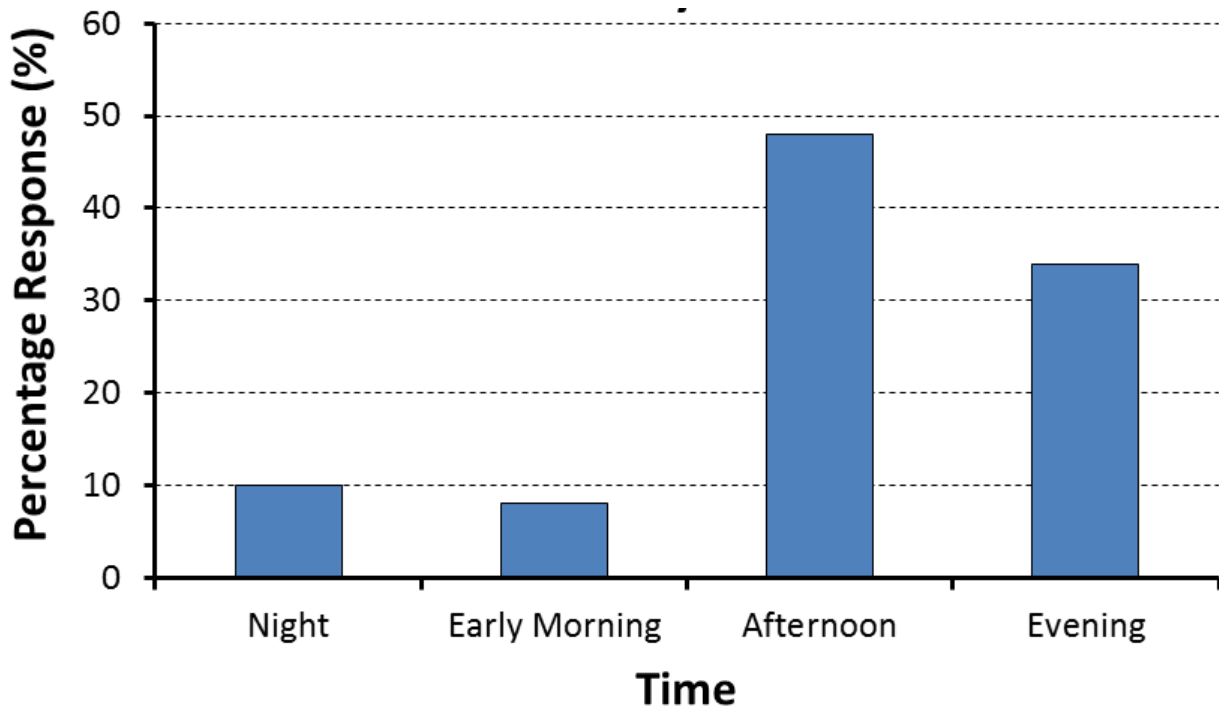


Figure 4. Time when heavy rainfall events are received.

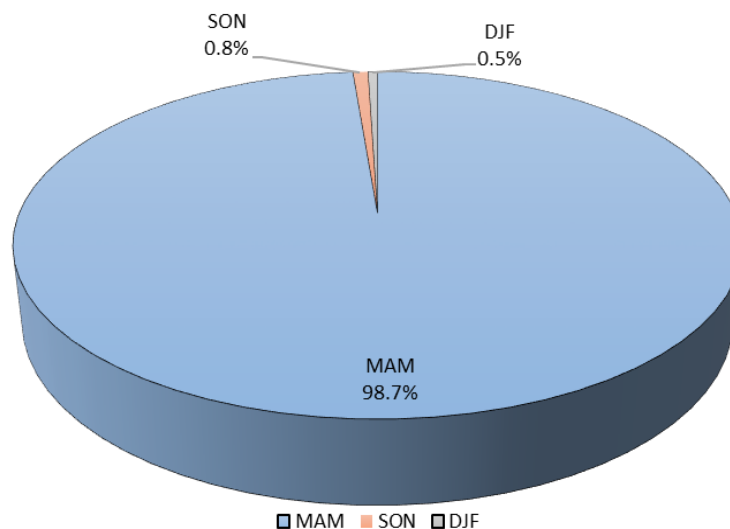


Figure 5. Seasonality occurrence of floods.

the MAM season (98.7%), followed by SON season (0.8%) and lastly in the DJF season (0.5%). Flood occurrence in the MAM season is attributed to the fact that it is long rainfall season experienced in the area. Analysis of secondary data from seasonal rainfall of Kampala weather station show that extreme rainfall (daily rainfall greater than 20 mm) has been increasing especially in the MAM season (Figure 6).

Climate risk event that has/have affected people most

The climatic risk events that affect the residents in the chosen study area are drought, floods and water related human diseases (Figure 7). With these climatic risk events, floods are ranked as number one with a percentage effect of 96%, followed by water related human disease and drought with the same ranking (2%). Floods are ranked number one as this is attributed to the heavy rainfall intensities received in the area and the informal settlement patterns of the local people who usually block the existing drainage channels of the flowing waters leading to enormous cases of floods.

Effects of floods on the community

From the Figure 8, loss of property (23.4%), lack of clean and safe water (22.1%) and disease outbreaks (17.6%) take the biggest percentage of the effects of floods, followed by, blockage of drainage systems (14.7%), loss

of lives (10.3%), children missing school (5.9%), increased traffic jam (4.4%) and others that mainly included reduced customers and increased crime activities. The high effects associated with floods are majorly attributed to the poor informal settings, heavy rainfalls and poor drainage systems in the area.

Coping strategies used by the local people

Table 2 shows the common coping mechanisms/strategies employed by the communities in the study area during heavy rainfall or flooding events.

Results from the coping strategies used by local community indicate that raised tables/stands takes the biggest percentage of about (32%), followed by use of stones in the compounds and use of soil bags (16%) while the least mechanism was scooping out water using basins (1%). Figure 9 shows these mechanisms have proved not to be sustainable during heavy floods, since they cannot withstand the strength of the flood waters; some have been reported to be expensive while others are time consuming and labour intensive, requiring a lot of energy like scooping out water from houses using basins. The communities were asked the challenges they face in trying to cope with the floods and mentioned the high cost of materials used for controlling floods as a major challenge since their level of incomes are very low to afford the purchase of the required materials. They also reported lack of modern technologies to control such floods and also having no alternative places to live in.

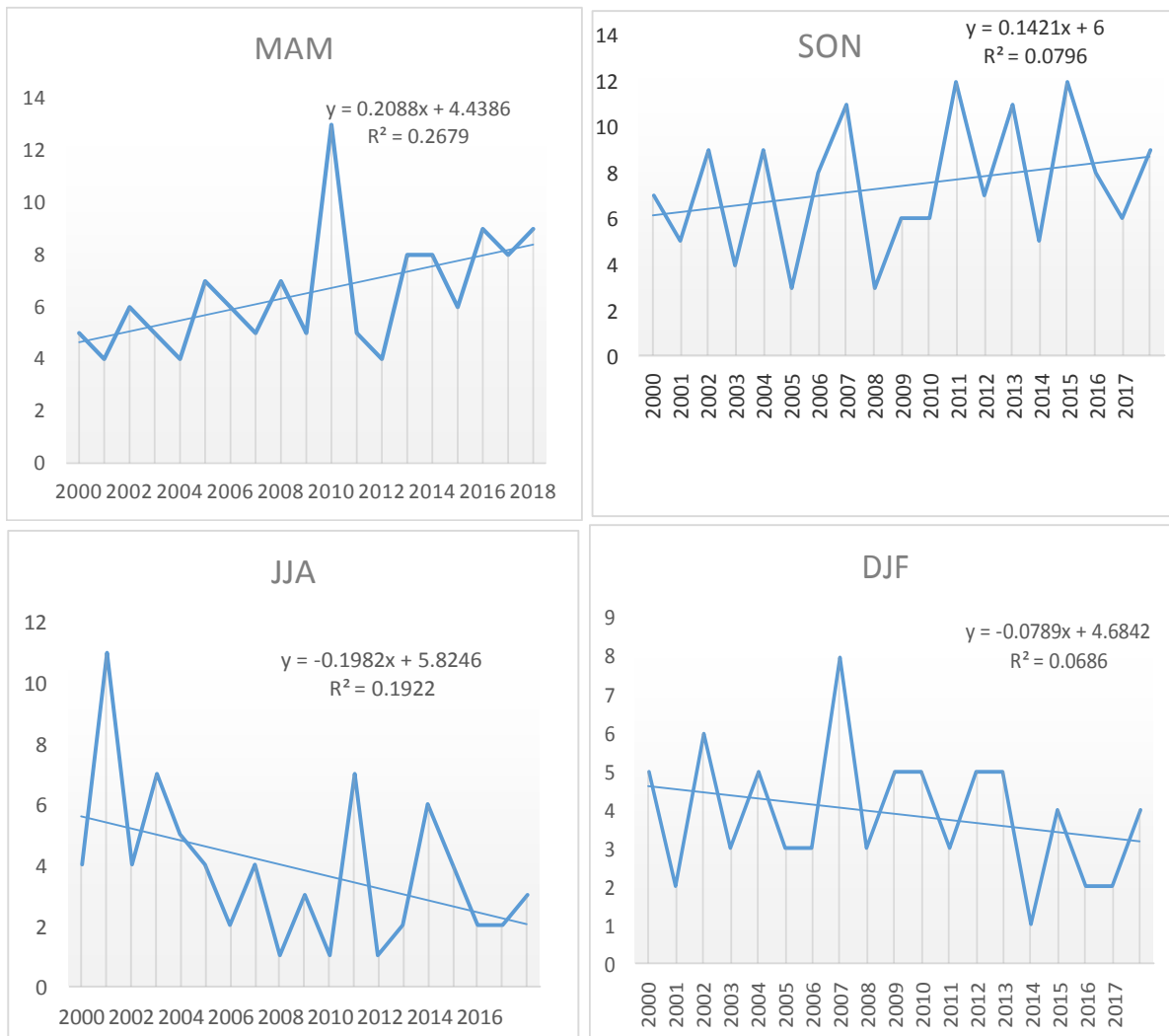


Figure 6. Trends in extreme rainfall over Kampala from 2000 to 2017 for the four seasons.

Reception of weather alerts

Respondents were also asked about receiving weather alerts regarding the forecasted heavy rainfall events that normally cause flooding. About 78% of the respondents interviewed have not been receiving weather alerts and forecasts in the last ten years while only 22% of the respondents have been receiving weather alerts and forecasts (Figure 10). This increases the vulnerability of the communities since they cannot plan based on the weather alerts. Of those who receive the alerts, 91% reported getting the messages through television, 5% normally through radio while others receive it from friends as well as social media (Figure 11). However, television

being the biggest source of weather information is not sustainable since it involves monthly subscription charges, monthly electricity bills, poor signal strength coupled with poor arrangement of programs where weather forecasts are usually given at the end of the news forcing some people to miss out on weather alerts and forecasts.

Challenges associated with weather alerts and forecasts

Survey results show that the biggest challenge associated with weather alerts and forecasts is that 63%

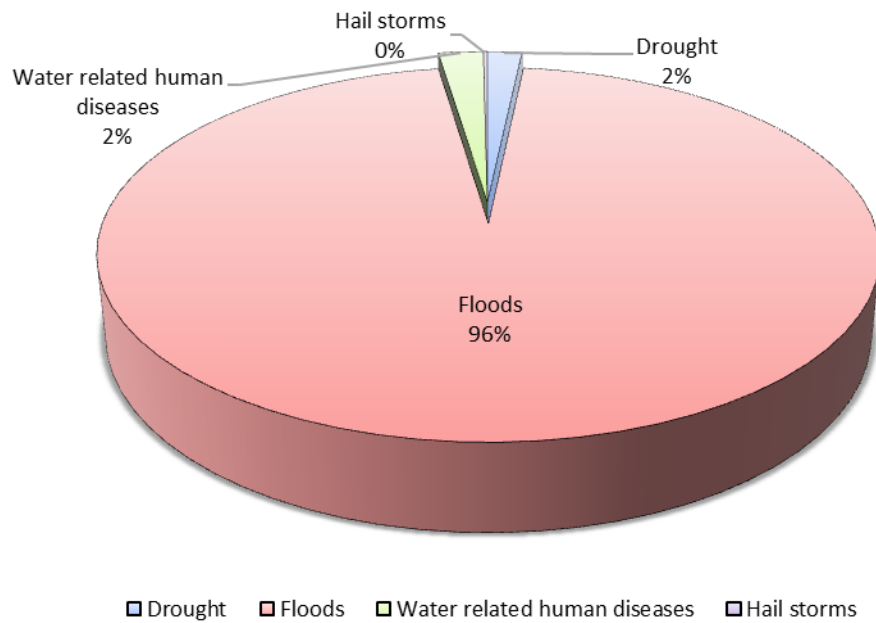


Figure 7. Climate risk event that affect the people.

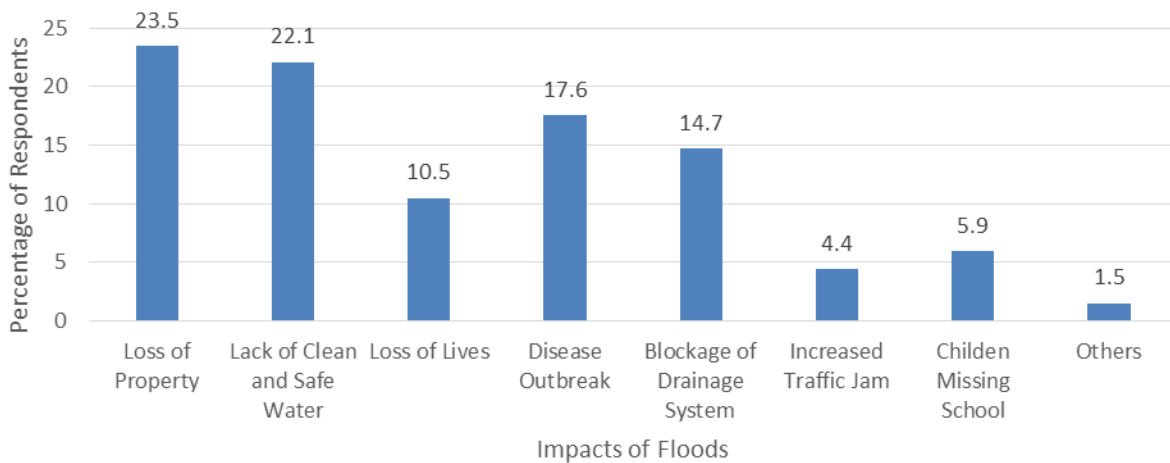


Figure 8. Effects of floods to surrounding communities.

do not reach the communities in the study area, 17% are not broadcasted in time, 11% are not accurate and 9% are as a result of language barrier (Figure 12). This information obtained from the survey study portrays the level at which the people are missing out on weather alerts and forecasts. They reported that the most of these forecasts are always broadcasted in English which some of them do not comprehend easily and therefore they normally loose interest even when they know the

importance of such information.

Among the suggestions given by the community to improve access and use of weather information was to involve local leaders in the process of disseminating weather alerts and forecasts (37%), the use of local radio stations (26%), translating the alerts and forecasts in local languages (16%), use of social media (11%) and lastly that alerts should be disseminated in time (Table 3). Involving local leaders emerged the best alternative as

Table 2. Major coping strategies to flooding employed by the communities.

Coping Strategy	Percentage of Respondents
Using raised tables/ Stands at house entrance	32
Use of stones in the compound	16
Use of soil bags	16
Seek financial help	11
Building raised verandas	7
Leaving houses for some time	4
Unblocking trenches around the home	2
Rely on business	2



(a)



(b)



(c)

Figure 9. Some of the coping strategies employed by the communities including (a) Raised stands at house entrance, (b) Raised veranda and (c) Use of soil bags.

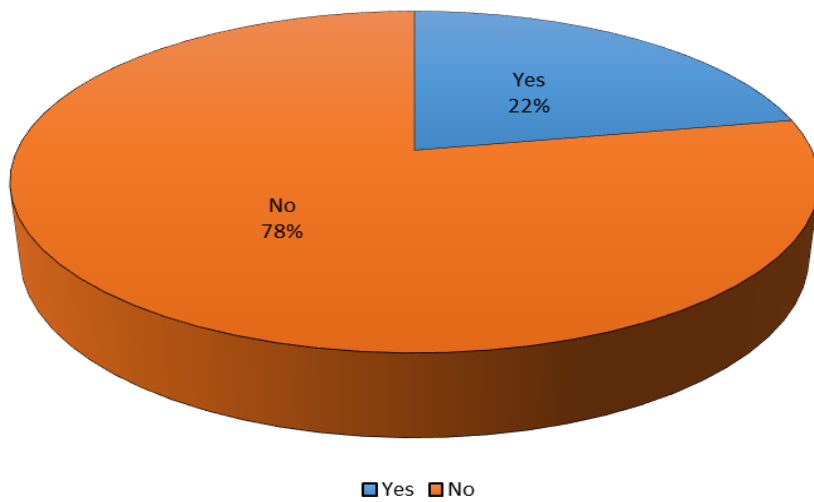


Figure 10. Reception of weather alerts.

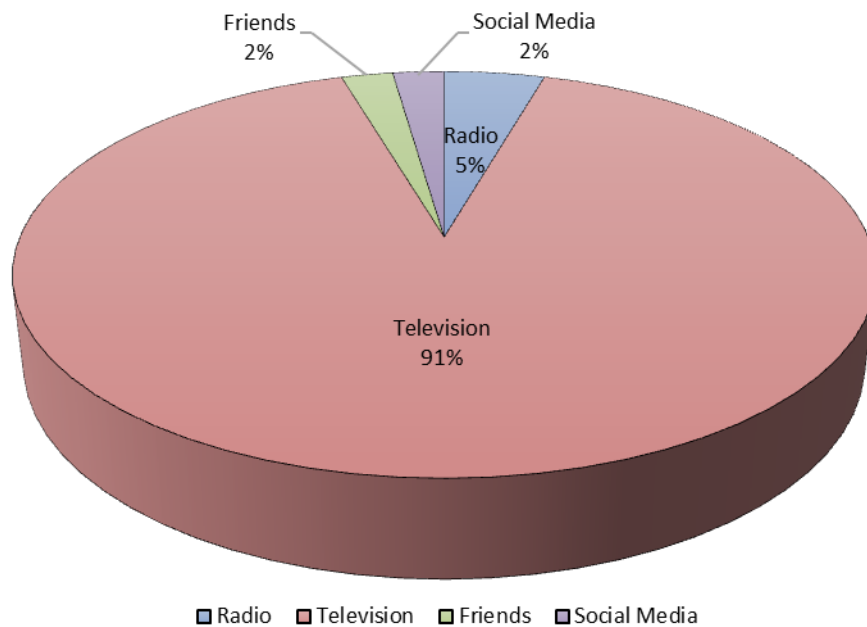


Figure 11. Sources of weather alerts and forecasts.

people think that these local leaders can easily and directly talk to them any time of the day and they are always with them.

DISCUSSION

Table 4 shows the perception of the various variables in

relation to the social demographic characteristics.

The perceptions to changes in rainfall (amount and intensity) were significantly associated to the respondent's level of education ($p = 0.011$) and membership ($p = 0.015$) (Table 4). For instance, the majority of the respondents who were aware of changes in rainfall had attained secondary and tertiary education (85 and 8.0%, respectively) and were members in the

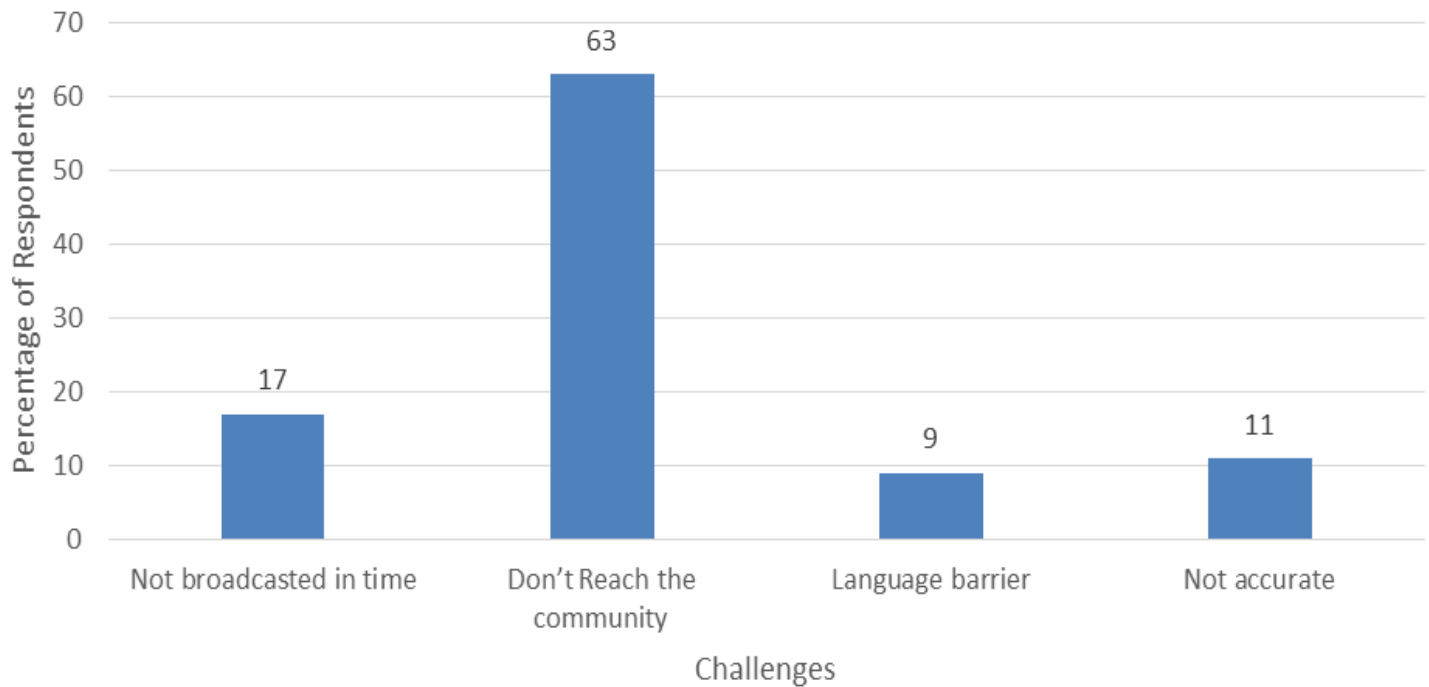


Figure 12. Challenges associated with weather alerts and forecast.

Table 3. Suggestions to improving the dissemination of weather forecasts and alerts.

Suggestion	Percentage of respondents
Involving local leaders	37
Use of local radio stations	26
Translated in local language	16
Use of social media	11
Alerts given in time	10

Table 4. Perceptions of flood occurrences in Kawempe division.

Socio-demographic characteristics	Perceptions											
	Change in rainfall (amount and intensity)			Occurrence of floods			Effects of floods			Reception of weather forecasts and alerts		
	X ²	df.	Sig.	X ²	df.	Sig.	X ²	df.	Sig.	X ²	df.	Sig.
Sex	1.263	1	0.261	0.796	1	0.372	0.006	1	0.940	2.568	2	0.277
Marital status	0.405	3	0.939	0.405	3	0.939	2.299	3	0.513	6.675	6	0.352
Age of respondent	1.075	3	0.783	79.198	3	0.000*	1.709	3	0.635	30.665	6	0.000*
Education level	11.149	3	0.011*	15.706	3	0.001*	11.482	3	0.009*	10.780	6	0.095
House ownership	0.474	3	0.925	0.474	3	0.925	0.546	3	0.909	4.610	6	0.595
Membership	5.962	1	0.015*	0.169	1	0.681	4.685	1	0.030*	1.051	2	0.591
Length of stay in area	7.508	3	0.057	7.508	3	0.057	2.891	3	0.409	93.374	6	0.000*

*Significant at 95%.

different groups (14.2%). The perceptions on occurrence of floods were significantly associated to the respondent's age ($p = 0.000$) and level of education ($p = 0.001$). It should be noted that majority of the respondents who were aware of occurrence of floods fall in age group categories (36-50 and 26-35) (48.4 and 44.9%, respectively).

Effects of floods were significantly associated to respondent's level of education ($X^2=11.485$, d.f. =3, $p = 0.009$) and membership ($X^2= 4.685$, d.f. = 1, $p = 0.030$). Insights on the reception of weather forecasts and alerts were significantly associated to the respondent's age ($X^2=30.665$, d.f. =6, $p = 0.000$) and length of stay in an area ($X^2=93.374$, d.f. =6, $p = 0.000$). Results indicated that respondents who receive weather forecasts and alerts fall in age group categories (36-50 and 26-35 years) (56.5 and 40%, respectively) and while for the length of stay in an area, majority of the respondents had stayed in the area (more than ten years and less than one year) (48.2 and 30.6%) respectively.

Like many cities in sub-Saharan Africa, this study findings are in agreement with several studies indicating that Kampala city experiences recurrent floods that have occurred over years (Kiyengo et al., 2020; Osuret et al., 2016; Pérez-Molina et al., 2015). Coupled with population projections, climate change is also likely to worsen Kampala's flooding problems (Isunju et al., 2016; Sliuzas et al., 2017).

The study area is low lying and has a high water table, making it vulnerable as observed by Dimanin (2012) that floods are common in low lying areas mainly occupied by the urban poor and distracting their livelihoods (Shatkin, 2019). According to Isunju et al. (2016), occupation of flood-prone areas happens in dry seasons, among population that are always on the move hence the vulnerability. Empirical evidence similar to study findings suggest that extreme/intense rainfalls during the high peak MAM season result in high flooding (Jacobs et al., 2016). As such, the effects of floods reportedly include destruction of property, damage to houses, blockage of drainage channels, disease outbreaks and pollution of water sources. This is also in line with other previous studies which points out that floods have a negative impact on human health and livelihoods (Isunju et al., 2016).

In relation to coping strategies, similar ones have been adopted elsewhere; elevating the ground level before the construction of their houses, barriers in front of doors or small dyke around the house and small levee around drainage channels (Habonimana, 2014); filling the flooded parts of their houses with soil, building raised houses and clearing the drainage channels of soil and rubbish (Bagonza, 2014); use of indigenous knowledge in weather forecasting and preparedness (Osuret et al.,

2016). This is achieved partly because most of the community members in the area have attained at least a secondary level education (84.8%) which enables them to understand and apply the indigenous knowledge. Despite the above improvised strategies adopted, the communities are still vulnerable to flood events due to their income status and less capacity to cope more especially for the women who are the majority (55.8%) and are mainly engaged in informal livelihood strategies that are prone to flood events.

A study by Asfaw and Maggio (2018) suggest that weather shocks tend to negatively impact both husbands and wives though more on female headed households due to lack of access to productive resources and opportunities including land and credit (Akampumuza and Matsuda, 2017).

On the other hand, Bagonza (2014) argues that the coping capacity of the women and children is somehow enhanced by the agencies in charge of management of the flood hazard, in this case, Kampala Capital City Council Authority.

Conclusion

Floods were ranked as the highest climate risk events in the study area. This has been attributed to changes in rainfall amounts and intensity (extreme rainfall) and underlying human activities that affect the water channels. The heavy rainfalls mainly occur in the afternoon and evening especially in the MAM season. Consequentially, loss of property, lack of clean and safe water and disease outbreak are common impacts affecting the vulnerabilities of the poor urban men and women in the study. Whilst the communities have devised coping strategies, strengthening capabilities of these efforts is required. Since a small percentage of the respondents receive weather alerts, there is need for local leaders to be actively involved in dissemination of weather information as well as the use of local vernacular radio stations with translated weather information in their local language. The linkages between UNMA (producers of weather information) and KCCA staff that interact with communities at the grass roots should be strengthened for better use and uptake of weather information.

ABBREVIATIONS

DJF, December, January, February season; **ECTCD**, Expert Team on Climate Change Detection; **GDP**, Gross domestic product; **HHS**, Household survey; **JJA**, June, July, August season; **KCCA**, Kampala Capital City Authority; **MAM**, March, April, May season; **UBOS**,

Uganda Bureau of Statistics; **UNMA**, Uganda National Meteorology Authority; **WMO**, World Meteorological Organisation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

- ACPF (2013). The African Child Policy Forum. Minimum age of sexual consent: International and Regional Laws. Retrieved from http://www.africanchildforum.org/cfr/Harmonisation%20of%20Laws%20in%20Africa/other-documents-harmonisation_7_en.pdf
- Akampunguza P, Matsuda H (2017). Weather shocks and urban livelihood strategies: The gender dimension of household vulnerability in the Kumi District of Uganda. *The Journal of Development Studies* 53(6):953-970.
- Asfaw S, Maggio G (2018). Gender, weather shocks and welfare: Evidence from Malawi. *The Journal of Development Studies* 54(2):271-291.
- Bagonza RA (2014). Gender and vulnerability to disasters and disaster/climate risk management in Uganda: a participatory characterization.
- Dimanin P (2012). Exploring livelihoods of the urban poor in Kampala, Uganda. An institutional, community, and household contextual analysis ACF.
- Elias EH, Flynn R, Idowu OJ, Reyes J, Sanogo S, Schutte BJ, Sutherland C (2019). Crop vulnerability to weather and climate risk: analysis of interacting systems and adaptation efficacy for sustainable crop production. *Sustainability* 11(23):6619.
- Foster T, Brozovic N (2018). Simulating crop-water production functions using crop growth models to support water policy assessments. *Ecological Economics* 152:9-21.
- Guo T, Confesor JrR, Saleh A, King K (2020). Crop growth, hydrology and water quality dynamics in agricultural fields across the Western Lake Erie Basin: Multi-site verification of Nutrient tracking tool (NTT). *Science of the Total Environment* 726:138485.
- Habonimana HV (2014). Integrated flood modeling in Lubigi catchment Kampala (Master's thesis, University of Twente).
- Isunju JB, Orach CG, Kemp J (2016). Hazards and vulnerabilities among informal wetland communities in Kampala, Uganda. *Environment and Urbanization* 28(1):275-293.
- Jacobs L, Maes J, Mertens K, Sekajugo J, Thiery W, Van Lipzig N, Dewitte O (2016). Reconstruction of a flash flood event through a multi-hazard approach: focus on the Rwenzori Mountains, Uganda. *Natural Hazards* 84(2):851-876.
- Jordan P (2020). The international conference on climate services 6: Advancing the knowledge and practice of climate services for climate resilience. CGIAR Research program on climate change, agriculture and Food Security (CCAFS).
- Kiyengo R, Majaliwa M, Twinomuhangi R, Waswa H (2020). Spatio-temporal flood trends & settlement choice in flood-prone areas. A case study of Lubigi micro-catchment, Kampala City. *International Journal of Environmental Studies* 77(3):480-491.
- Kwiriringira J, Atekyereza P, Niwagaba C, Kabumbuli R, Rwabukwali C, Kulabako R, Günther I (2016). Seasonal variations and shared latrine cleaning practices in the slums of Kampala city, Uganda. *BMC Public Health* 16(1):1-10.
- Lu H, Chen M, Kuang W (2020). The impacts of abnormal weather and natural disasters on transport and strategies for enhancing ability for disaster prevention and mitigation. *Transport Policy* 98:2-9.
- Mugume I, Michel DS, Mesquita CB, Yazidhi B, Joachim R, Alex N, Daniel W, Godfrey M, Sulin T, Triphonia JN (2016). Patterns of Dekadal Rainfall Variation Over a Selected Region in Lake Victoria Basin, Uganda. *Journal of Atmosphere* 11:150.
- Noack F, Riekhof MC, Di Falco S (2019). Droughts, biodiversity and rural incomes in the tropics. *Journal of the Association of Environmental and Resource Economics* 6(4):823-852.
- Ogwang BA, Ongoma V, Gitau W (2016). Contributions of Atlantic Ocean to June-August Rainfall over Uganda and Western Kenya. *Journal of the Earth and Space Physics* 41(4):131-140.
- Osuret J, Atuyambe LM, Mayega RW, Ssentongo J, Tumuhamy N, Bua GM, Bazeyo W (2016). Coping strategies for landslide and flood disasters: a qualitative study of Mt. Elgon Region, Uganda. *PLoS Currents*, p. 8.
- Pérez-Molina E, Sliuzas R, Jetten VG, Van Maarseveen MFAM (2015). Simulating flood impacts in Kampala, Uganda: when do land patterns matter. In 13th International Conference on GeoComputation Geospatial Information Sciences, pp. 337-342.
- Shatkin G (2019). Futures of crisis, futures of urban political theory: Flooding in Asian coastal megacities. *International Journal of Urban and Regional Research* 43(2) 207-226.
- Sliuzas R, Kuffer M, Kemper T (2017). Assessing the quality of Global Human Settlement Layer products for Kampala, Uganda. In 2017 Joint Urban Remote Sensing Event (JURSE) (pp. 1-4). IEEE.
- Twinomuhangi R, Sseviiri H, Mulinde C, Mukwaya PI, Nimusiima A, Kato AM (2021). Perceptions and vulnerability to climate change among the urban poor in Kampala City, Uganda. *Regional Environmental Change* 21(2):1-13.
- UBOS (2017). Uganda Bureau of Statistics. A report on Education as a means of population transformation based on National population and housing census 2014.
- UBOS (2019). Uganda Bureau of Statistics; statistical abstract. The Republic of Uganda.
- WMO (1983). Guide to climatological Practice. Available at: <https://www.amazon.com/Guide-Climatological-Practices-W-M/dp/9263121001>

Full Length Research Paper

Impact of mining on environment: A case study of Taita Taveta County, Kenya

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Research on the impacts of mining on the environment was conducted on nine purposive selected mining sites in Kamtonga and Mkuki, Taita Taveta County, Kenya. The FOLCHI method was adopted to quantify the environmental impact of mining activities in gemstone mining sites. The affected environment surrounding the pits was broken down into three components such as Topography, Vegetation and Air. The effect of the three components impacting factors, both directly and indirectly, from the mining activities was then calculated for each Environmental Component and computed averages (magnitude) presented in table format. The findings showed that mining activities contributed to environmental and landscape changes, leading to loss of indigenous-trees, shrubs, grassland, forests, natural ecosystems and agricultural and grazing land. Mining activities contributed to air pollution. Even with the existence of environmental regulations and policies, the environment is still abused in Kenya, as a result, the country has lost considerable amount of forest cover due to mining activities. Government and non-governmental organizations should advocate for afforestation, re-afforestation and restoration of forests. Environmental Impact Assessment and Environmental Audit should be conducted in line with mining regulations in Environmental Management and Coordination act 1999 (amended 2019) in Kenya.

Key words: Mining activities, environmental elements, waste piles, sustainable livelihoods, air pollution, forest restoration.

INTRODUCTION

Mining is a major economic activity in most developing countries (Kitula, 2006), particularly in rural sub-Saharan Africa. But the extraction and mining of these natural

resources lead to some adverse effect on the environment. In many developing countries, unregistered and illegal small-scale mining is widespread leading to

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environmental deterioration (Bush, 2009; Hilson, 2009). The study areas were Kamtonga and Mkuki in Taita Taveta County (TTC), located in the Coastal region of Kenya. The population of Taita Taveta County is 340,671 (KNBS, 2019) having grown from 284,657 in 2009. Mwatate Sub County population has an estimate of 1.95% of the county population which has grown to 81659 people partly because of people migrating to town to establish businesses especially trading in precious stone called Tsavorite, found plentifully around Mkuki and Kamtonga areas. The county has become popular because of its gemstone minerals. With this knowledge, this study whose specific objective was to observe the impact of mining on the environment was conducted focusing on three elements namely; topography, air and vegetation. The research question was: What is the state of the environment in mining areas?

The literature on this subject revealed that mining has adverse impacts on societies and their cultural heritage (Sinnott, 2019). Vast land usage through mining has impacted the environmental standards of the county resulting in land degradation, famine and poverty. Other impacts concern health and safety of mineworkers and communities close to operations, including displacement, marginalization, and oppression of local people (Mwakumanya et al., 2016). Mining activities contribute to soil erosion, the formation of sinkholes, loss of biodiversity, soil and water chemical contamination. Mining activities also cause noise, dust and visual pollution (Cuba et al., 2014; Naja and Volesky, 2009).

Mining is an economic process that begins with exploration for and discovery of mineral deposits and continues through extraction and processing to closure and remediation of exploitation sites (Hoskin et al., 2000). Different forms of mining methods are used depending on the type of mineral being extracted. These methods have varying impacts on the environment. Four popular surface mining methods include open cast mining, open pit, quarrying and augering. All these involve the extraction of mineral material from the surface to underground mining where mines are accessed through shafts and tunnels; recovery of minerals through boreholes and underwater mining (Klop, 2009). Therefore, a working definition of mining could simply be "the extraction of minerals from the Earth".

On the one hand, mining generates wealth for companies, communities and countries. But at the same time, social vices such as prostitution, substance abuse, gambling, and incest have increased, including general destabilisation of families and livelihood (Akabzaa and Darimani, 2001; Gualnam, 2008). Mining has socio-economic impacts which include generating huge amounts of waste and pollution, disrupting indigenous livelihood, local economies and communities, destroying natural habitat and maybe leaving toxic legacy-acid mine drainage (AMD). Other major consequences include the

loss of Flora and fauna, affected and destabilized ecosystem due to infected water, soil and loss of habitat. Some negative environmental impacts may persist for hundreds of years (Gosar, 2004).

Mining affects vegetation, farmlands, livestock and aquatic activities through pollution leading to effects in agriculture and food security (Hayes and Wagner, 2008). Mining tends to drive people away from sustainable livelihoods, for instance, farming to other livelihoods which may result in possible destruction of productive land resources. Such alternative changes lead to further destruction of the environment and expose peoples' livelihoods to unsustainable risk (Hilson and Banchirigah, 2009). Mined land remains unsuitable for industrial and agricultural purposes. Mining operations have devastating effects on nearby streams, rivers and surrounding vegetation. Consumption of contaminated toxic water and soil or plants cause diseases in people and animals and can result in death. Collecting runoff water using ponds would help but the problem would persist (Gupta and Gupta, 1998). Other environmental impacts of mining activities recorded in the literature include permanent scarring of land surfaces where wastes are dumped. Dangerous old deep mine holes which may subside vertically or horizontally, and damage buildings, roads and farmland, as well as alter the surface drainage patterns. More disturbances to residents and wild-life are caused by noise from blasting and transport in the mining areas (Bell et al., 2000).

Small – Scale mining activities are not confined to Africa but throughout the developing world. In Africa however, small –scale mining operations have been responsible for a wide range of environmental impacts. Because of the lack of advanced technology, operations are rudimentary and concern for environment minimal. This has resulted in constant and persistent environmental problems (Hilson, 2002). Mining activities have similar impacts on the environment in various countries. For example, in Ghana, despite all the legal measures put in place by the government, environmental degradation around most of the communities remains a major threat and concern (Mensah et al., 2015). In Kenya, large and small-scale mining activities are cited in most parts of the country such as in Migori, Kwale, Vihiga District and Lake Victoria to mention a few. Mining activities in Kenya have been associated with serious environmental impacts such as metal contamination in soil, health implications on human and animals, poverty and land conflicts (Okang'Odumo et al., 2014; Abuya, 2016).

Information about mining in Taita Taveta County generated a lot of attention as a location of minerals, particularly gemstones even though the economic impact of the vast existing natural resources extraction on local people and its effects on the environment has not been researched (Taita Taveta County, 2013). Natural

resources can provide poor counties with large revenue streams that can be used to alleviate poverty, and result in enhanced the much-needed peace and co-existence with other communities in the counties, who up to now are regarded as exploiters of community resources (Pegg, 2006). The absence of this might invite restlessness and conflict with outsiders, which the country would have to contend with sooner or later (Mghanga, 2011).

One of the necessary pre-conditions for sustainable development is a sustainable peace. Articles 43, 69 and 72 of the Kenya constitution record that inclusive policies and measures that ensure communities fully participate in conserving and deriving benefits from their local natural resources needed to be developed. The Republic of Kenya (2010), states that every person has social, economic and environmental rights including equitable sharing of accruing benefits from natural resources. This is also engraved in the Kenya Vision 2030 which encourages the sustainable exploitation of natural resources for National Development (Vision, 2007). In 2013 the Kenya government established the Mining and Petroleum Ministry which repealed the previous Act (1940). Later in 2016, a new bill (the Mining Act 2016) was created as a mining law that would meet the current mining requirement. One such requirement involved engaging Taita Taveta University (TTU) and Jomo Kenyatta University of Agriculture and Technology (JKUAT) personnel to conduct regular on-site training of miners on protective measures. Training on proper mining methods has helped to reduce the negative impacts of mining, particularly, the artisanal miners who are provided with technical and professional assistance to improve their production and reduce environmental degradation.

The general objective aimed at investigating and interrogating the impacts of extensive mining activities on communities' livelihoods to find ways of improving their living standards. Specifically, the content of the paper is to observe the environmental impact of mining on topography, air and vegetation and the state of the environment in mining areas. When dealing with extractive industries, it was important to consider and identify ways of maximizing positive effects on the lives of people while minimizing the negative effects (Obiri et al., 2016).

MATERIALS AND METHODS

Study area

This study was done in Taita Taveta County, located in the Coastal region of Kenya (Figure 1). The observations were made in Mwatate sub-county's minefields of Kamtonga, and Mkuki, on the geographical coordinates of 3°30'0" S, 38°23'0" E. These minefields were purposively selected as representative samples of the mining

industry in Taita Taveta because they were easily accessible, unlike those of Kasigau in Tsavo West. The county is divided into three major topographical zones. The upper zone, suitable for horticultural farming comprises of Taita, Mwambirwa and Sagalla hills region with altitudes ranging between 304 and 2,208 m above sea level. Mining takes place in the lower zones consisting of plains, where ranches and national game parks are placed. The third topographical zone covers Taveta region which although with volcanic features, has a potential for underground water and springs from Mt. Kilimanjaro. By a geological point of view, the Taita region is covered by the Mozambique belt, while the Taveta region is covered by the Tertiary Volcanic belt. The complex rocks of this belt underlie most of the Eastern African region between Ethiopia to the north and Mozambique to the South. The County is the main source of Tsavorite and ruby minerals.

Samplings

The observation was carried out in nine mining sites of Kamtonga and Mkuki areas of Taita Taveta County in Kenya. These purposively selected mines included; Shah mines, Ray mines, Shadrack (individual digger), International Mines, Mama Fatuma mines, Surface mining (group), Hardrock mines, Chawia Mining Community Based Organization (CBO) and Classic 1 Gemstone Mines. Purposive sampling method was used to focus on environmental characteristics around Kamtonga and Mkuki mining areas. These included nine mines comprising of large, semi and fully mechanized mining groups, Small artisanal mining groups and individuals doing manual mining and surface mining in Kamtonga and Mkuki areas of Mwatate sub-county. The researcher conducted the observational research in a real-life situation which yielded valuable insights on the issues of vegetation, topography and air around the mining sites.

Research approaches and data collection

The study used a structured observation approach to get information on the state of three environmental elements namely vegetation, topography and air. The focus was mainly on mining approaches, their characteristics and proximity to the urban infrastructure and neighbouring communities. In structured observation method, data is not collected using typical research methods like surveys and interviews. Instead, data is coded, and in this case, the researcher prepared record sheets or structured matrix with a listed preliminary list of issues to be observed at the selected mining areas. This method has both advantages and disadvantages. On the positive side, it is an easier and more systematic approach and likely to produce quantitative data which makes it easier to analyse and compare results at segmented times. For example, this study was done in August. The same areas could be observed quarterly and results compared. Therefore, it is a method that allows progressive research. Also, observer bias risk is smaller. The method, however, has its shortcomings in that the results may not be detailed and some data collected may not be useful for the research and therefore the results may not be detailed. Nevertheless, the advantages outweigh the negative outputs and the valuable information was obtained in this study.

Structured matrix of the impacting factors against the environmental components formed the data collection tool in the nine selected mining sites. The matrix was used to record the observations made in the affected environment surrounding the mining areas which was broken down into three components that included; topography, vegetation and air. The FOLCHI method was adopted to quantify the environmental impact of mining activities in

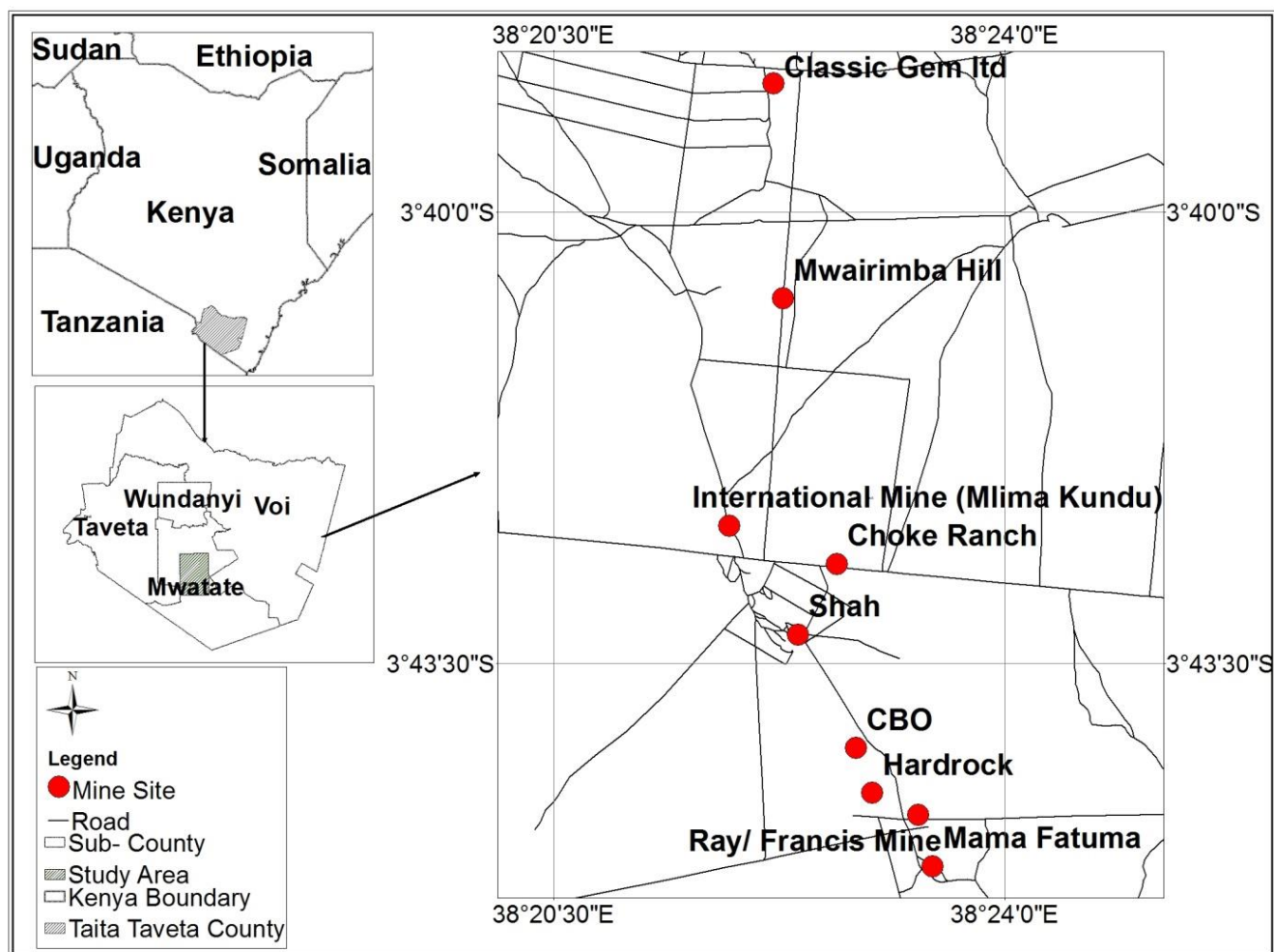


Figure 1. Map of the study area.
Source: Author.

gemstone mining sites (Folchi, 2003). The effect of the three components impacting factors, both directly and indirectly, from the mining activities was then calculated for each environmental component and computed averages (magnitude) presented in table format.

RESULTS AND DISCUSSION

Mining approaches and characteristics

Popular mining approaches used included excavation and removal of overburden (layers) in the underground and open-pit surface mining. The process negatively impacted soil structure and composition. Different processes of mining consequently rendered the soil infertile and barren to accommodate wildlife or flora and fauna. The mining activities revealed characteristics such as open pits below groundwater level, horizontal tunnels

and shafts, strip mining and deep in the ground (Figures 2 to 5 and Table 1). Wherever these mining activities were conducted they resulted in deforestation and great damage around the pits on soil, vegetation, and grassland hence altering the topography of the area.

Mining in Kenya is mainly open-pit, a process that has created many large pits. Figures 2, 4 and 5 demonstrated the negative impact on the soil structure, its composition, fertility and landscape. There was complete biodiversity loss and wildlife activity had diminished. Open-pit mining often involved the removal of natively vegetated areas, rendering it as one of the most environmentally destructive types of mining method. This observation was the same wherever minerals are extracted. For example, gypsum extraction is done through open cast and quarrying methods as well. These methods like earlier indicated involved removing topsoil up to bedrock and make the mining areas bare and devoid of vegetation.



Figure 2. Open pit.



Figure 3. Horizontal tunnels and shafts.

The landscape is heavily impacted by drilling of holes, blasting, transportation and usage of heavy machines in the initial stages of the mining process (Brahma, 2007).

Mining operations proximity to urban infrastructure

Mining operations proximity to urban infrastructure was

measured in Kilometers and it emerged that most livelihood centres were quite far from the mining areas and its communities. At the mining site, there was no water reticulation system. Therefore, water is bought and delivered to those in the mining fields. The residential areas to the mining sites are about 20-40 km while the water sources ranged between 40-42 km. The distance from various mines in Kamtonga and Mkuki to the main shopping centres in Mwatate and Voi is 20-40 km (Table 2). There is a lot of activity in Mkuki and growth of the shopping Centre due to mining activities attracting selling and buying of the valuable gemstones.

Impacts of mining activity on topography

Mining activity influence on topography was observed on all the nine mine sites on a scale of 1-5 (none, damaged, moderately damaged, highly damaged and extensively damaged). Observation focused on valleys, plains, damp sites/piles, natural water head, hills and wetlands. Around all the mines there were no valleys, plains, hills and wetlands (Table 3). Dump piles were an eyesore in most of the mines. Most of the mining sites observed had dump piles causing moderate damage while others had highly damaged areas especially surface mining which caused extensive damages (Figure 1). Mining has interfered with water beds and rivers have dried up. Water resources have been adversely affected, as a result of forest destruction during mining, and have caused other water bodies to disappear.

Mining activities generate unique effects on landforms, shapes, structure and stream headwaters (Lechner et al., 2016). Only hydro-seeded grass and non-native tree species were found on the alkaline soils of reclaimed mining areas. Native plants did not grow again once removed for mining operations (Figures 6 to 9). This resulted in permanent loss of valuable land for agricultural activities and degradation lead to poverty for the current and future generations. Respondents in the study area depend on agriculture as the major source of food and income. Mining potentially causes serious land degradation. Rahimsouri et al. (2011) observed that mining and natural sources contributed significantly to soil pollution that in turn reduced agricultural productivity because of the toxicity of the chemical compounds which adversely affected biological functions. The impact of mining on the quality of soils around the mines cannot, therefore, be ignored as the cumulative effects of pollution loads on the soil and water resources alter the land use in the host communities (Omoti et al., 2016).

Mining activity influence on vegetation

In this study, the impact of mining activity on vegetation was also observed. Aspects of vegetation observed



Figure 4. Strip mining.



Figure 5. Deep in the ground.

included general categories of trees, shrubs and grass. Also, animal life around the mining area was observed. Observation from all the nine mining sites revealed similar characteristics where trees, shrubs and grass were sparsely populated (Figures 7 and 8 and Table 4). In surface and open pits mining, there was no grass as the method involved the removal of the topsoil that was fertile and supported the growth of land cover. Livestock life

was distributed all over the mining areas, located in variously owned ranches, but with moderate to dense distribution in some mining sites (Figure 4).

The natural habitation and indigenous trees were cleared. Mining activities had negative impacts on vegetation which included, deforestation, destruction of habitats, soil erosion, disruption of watersheds and pollution. The tendency of clearing the vegetation was to prepare trenches and pits to remove the minerals (Figures 2 and 7). Adjei (2007) also observed similar mining destruction of reserves upon which thousands of people depended for their food and livelihoods. Ogola et al. (2002) explained gold mining resulted in increased removal of vegetation in Migori County in Kenya.

Global Forests Atlas (GFA) and World Wide Fund for Nature (WWF) reports state that mining is the cause for 7% of the deforestation in sub-tropics including 6,100 km² of Amazon forests. It is recorded that as Ghana got its independence, its forest estate was 8.3 million hectares, but mining activities reduced the cover to only 1.2 million hectares (Hilson, 2004).

According to Ross et al. (2016), it is revealed that mining affects environmental systems including water quantity and quality degradation and burying of streams headwater. After removal of vegetation, the bare ground remaining loses water through evaporation. Besides, destruction of natural land topography and landscapes, negatively affect water movement thus leading to either diversion or disappearing of such streams in the areas.

Impact of mining on air

Another aspect observed in this study was the mining effects on air. The study focussed on the levels of noise and dust as a result of blasting, transportation, tailing (mine dump) stockpiles, haul roads, exhaust emissions (car trucks, heavy equipment) and Gas emissions (Table 5). At the time of collecting this data most of the listed activities were sporadically performed. This posed as a limitation to the researcher regarding the consistency of the matrix used to record the observations made. For example, some mining sites conduct their blasting activity at night or early hours while some carry out theirs in the afternoons.

The dust from the blasting, transportation of materials, Exhaust Emissions (Cars, trucks, and heavy equipment) and gas emissions in surface mining was very thick, because of open mining methods used, and wind. The blasting observed during this study was done at 11 a.m and 6 p.m in some mines while the transportation of materials time was between 2 and 3 p.m. Gas emissions from trucks and heavy types of equipment like generators were unnoticeable during blasting where the mines were fully or semi-mechanized. Both dust and noise also depended on the horizontal tunnels shafts of the mining

Table 1. Types of mining approaches, techniques and characteristics.

Mine characteristics	Mining type (number of mines observed)			Total
	Mechanized	Surface mining	Open pit	
Pits below groundwater level	4	0	1	5
Horizontal tunnels and shafts	0	0	1	1
Strip mining	0	1	0	1
Deep in the ground	0	0	2	2
Total	4	1	4	9

Table 2. Mining operations proximity to urban infrastructure.

Distance	Mining type proximity, (Km)			Total
	Mechanized	Surface mining	Open pit	
Between residential area and mine (Km)	31.0	21.0	30.5	29.7
Between water sources and mines (Km)	30.8	1.0	20.5	22.9
Between shopping centres and mines (Km)	21.3	21.0	30.5	25.3

Table 3. Subjective assessment of the impact of the type of mining activity on topography.

Topography	Mining approach			Total
	Mechanized	(Specify)	Open pit	
Valleys	1.0	1.0	1.0	1.0
Plains	1.2	1.0	1.5	1.4
Dump piles	2.4	3.0	2.6	2.6
Natural Water Heads	1.1	1.0	1.0	1.1
Hills	1.0	1.0	1.0	1.0
Wetlands	1.0	1.0	1.0	1.0

Scale of 1-5 (1=none, 2=damaged, 3=moderately damaged, 4=highly damaged, 5=extensively damaged).

pits which stretched to between 200-400 m long. Increased activities of surface and underground mining led to increased dust production. The busy and speedy traffic in and out of the mining areas for mineral trading also resulted in a lot of dust and air pollution. Soils left unprotected during the removal of vegetation led to the production of intensive dust and wind erosion.

Air is polluted during excavation because small particles are easily dispersed by the wind (Fugiel et al., 2017). The quality of the air is reduced, resulting in poor human health, and diminished vegetation close to the mining areas (Ghorani-Azam et al., 2016). Fine and coarse particulate matter can reach the lungs leading to respiratory problems. Heavy dust plume production also affected visibility and the chemicals, from dust, released into the atmosphere killed the Flora and Fauna and also polluted the air, water and land.

Impact of mining activity on noise and earth vibrations

Noise and earth vibrations were produced during excavation activities. Vibrations were associated with many types of equipment used in mining operations, but blasting was considered a major source of the more disturbing noise and vibration. Vibrations affected the stability of infrastructures and homes of people living near mining operations. Most of the noise was caused by loading and unloading of rocks, power generations, shovelling, drilling, blasting, transport, and stockpiling (Tables 6 and 7). Only four of the mining sites had powered tractors and power generators. None of the mining sites owned a steel dumper or carried out such activities as chutting, ripping, and crash grinding. Nevertheless, there was no control of noise and vibration



Figure 6. Dump piles.



Figure 7. Abandoned mining trenches

effects, which could negatively affect the workers in the mining sector.

The effects of noise and vibrations can directly affect the health of the miners and their neighbours. Even so, miners observed were not protected against these mining hazards. There was a display of ignorance and negligence concerning the use of protective gears. It

could also be due to inadequate law enforcement by government agencies. A study by Chen et al. (2018) on coal and gas outburst hazards in Henan, China, revealed that lack of knowledge among people working in coal mining areas was blamed for their failure to use protective gear, which exposed them to injuries on heads, legs, hands and backs. Ignorance has led most miners to expose themselves to danger, sometimes even to the extent of losing their lives due to lack of protective gears (Friend and Kohn, 2018). Then there is an element of risk to nature, especially to wildlife. Therefore, environment and wildlife safeguard agencies, have an urgent need to be more proactive in policy and law formulation and also in their enforcement. Reluctance on the part of the authoritative governmental body has resulted in lack of their visibility. The two sectors can play a very important role in ensuring that forests do not critically face adverse impacts during mining. Also, enforcement of Environmental Impact Assessment (EIA) requirements is critical in predicting and planning for mitigation of impacts likely to emerge due to mining. This study goes hand in hand with that of Mwangi and Mutiso (2018); all of whom explain that there is need to develop a complete regulation in the forest and environment department to increase sufficient capacity for monitoring and enforcing various laws and regulations to ensure forests and the whole environment is well managed.

Conclusion

This study specifically observed the environmental patterns as affected by mining activities, and data collected was to answer the research question on how mining activities impacted the environment. The specific objective of the study was to observe the mining impact on the environment on three elements namely; topography, air and vegetation. Observation of approaches and characteristics of all nine mining areas revealed similarity of the sparsity of trees, shrubs and grass because of removal of fertile soil. Deforestation, damaged vegetation, destruction of habitats, disruption of watersheds and pollution was also noticed. The study results revealed that clearing of trees, shrubs and grassland during mining preparations destroyed the top fertile soil which led to land degradation, groundwater contamination, persistent noise and air pollution. Opencast mining as observed in the study area has severely altered the landscape. It has suppressed and prevented vegetation. Dump piles were an eyesore in most of the mines observed. Forests have been converted into grasslands and most of the natural habitation and indigenous trees have been eliminated. Farmlands have not been spared. Native plants, once removed for mining operations, do not grow again, resulting in permanent loss of valuable land for



Figure 8. Damaged vegetation cover.



Figure 9. Abandoned mining pits.

Table 4. Impact of mining activity on vegetation within proximity of mines between 0-1 km.

Vegetation	Mechanized	(Specify)	Open pit	Total
Trees	2	2.5	2.6	2.3
Shrubs	2.5	2.5	2.3	2.4
Grass	3	1	1.8	2.2
Animal life	3.7	3.5	3.5	3.6

(Scale 1-5)1=none (ground is bare) 2=sparse 3=moderate and lush 4= dense and lush 5= very dense and green.

Table 5. Excavation activities.

Excavation	Mechanized	(specify)	Open Pit	Total
Blasting	2.0	5.0	2.7	2.6
Transportation of materials	3.5	5.0	4.3	4.0
Wind erosion	3.3	4.0	3.0	3.3
Fugitive dust from tailings facilities	2.0	2.0	3.7	2.6
Stockpiles	1.0	2.0	1.3	1.3
Waste dumps	2.8	4.0	3.7	3.3
Haul roads	2.8	3.0	3.7	3.1
Exhaust emissions (cars, trucks, heavy equipment)	3.8	5.0	3.7	3.9
Gas Emissions	2.8	5.0	2.5	3.4

The scale of 1-5 (1=none 2=Very thin 3= Thin 4=Thick 5= Very thick).

Table 6. Mining activities that produce noise.

Activities	Mechanized	(Specify)	Open Pit	Total
Transport	2.0	4.0	3.0	2.7
Vehicle engines	2.0	3.0	2.8	2.4
Drilling	1.8	4.0	2.8	2.4
Blasting	2.3	4.0	1.8	2.2
Ripping	2.0	1.0	2.0	1.9
Power generations	1.3	3.0	2.3	1.9
Stock pilling	1.3	1.0	1.5	1.3
Shovelling earth	1.3	1.0	1.3	1.2
Loading and unloading into steel dumpers	1.0	1.0	1.0	1.0
Chutes	1.0	1.0	1.0	1.0
Crash grinding	1.0	1.0	1.0	1.0

Scale 1-5 (1=none 2=minimum 3=moderate 4=loud 5=very loud).

agricultural activities which leads to poverty for the current and future generations. The respondents from the study area depended on agriculture as the major source of food and income. There was a loss of plant biodiversity which directly affected domestic and wild animals. There were many abandoned open pits which endangered both human and wildlife. Little administrative and legal sanction has been instituted to contain the pollution, despite uncontrolled dust in the air and the fact that

miners are not protected against mining hazards. Efficient monitoring mechanisms on mining activities by large and small miners are lacking in Kenya hence the environment is not protected. Even though there are many environmental regulations and policies on paper, the environment is still abused in Kenya, as a result, the country has lost forest cover due to mining activities.

This study recommends that relevant administration personnel could oversee the rehabilitation and restoration

Table 7. Mining activities that cause earth vibrations.

Activities	Mechanized	(Specify)	Open pit	Total
Drilling earth	4	4	3.5	3.8
Power generation earth	2	3	2.5	2.3
Blasting earth	1.5	4	1.8	1.9
Transport earth	1.8	2	2	1.9
Vehicle engines earth	1	1	1	1
Loading and unloading into steel dumpers earth	1	1	1	1
Chutes earth	1	1	1	1
Shovelling earth	1	1	1	1
Crash grinding earth	1	1	1	1
Stockpiling Earth	1	1	1	1

Scale 1-4 (1=none 2=minimum 3=moderate 4=very loud).

of areas degraded by mining are restored by making sure pits are backfilled, soil piles are removed and re-forestation and waterways sources are restored for sustainable environmental protection. Environment and wildlife safeguard agencies have an urgent need to be more proactive in policy and law formulation and also in their enforcement. Reluctance on the part of the authoritative governmental body has resulted in lack of their visibility. The two sectors can play a very important role in ensuring that forests do not critically face adverse impacts during mining. It is suggested that the concerned government departments, put in place mining regulations that will secure wildlife and their habitat during mining and enforce subsequent restoration of the excavated areas to original status. Environmental legal instruments such as Environmental Social and Impact Assessment, Environmental Audit and Social and Environmental Assessment should be conducted in line with mining regulation, Environmental Management and Coordination act 1999 (amended 2019) in Kenya. These regulations should be enforced jointly by the ministries of environment, water and health.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Adjei E (2007). Impact of Mining on Livelihood of Rural Households: A case study of Farmers in Wassa Mining Region, Ghana. MS thesis. Geografisk institutt.
- Abuya WO (2016). Mining conflicts and corporate social responsibility: titanium mining in Kwale, Kenya. *The Extractive Industries and Society* 3(2):485-493.
- Akabzaa T, Darimani A (2001). Impact of mining sector investment in Ghana: A study of the Tarkwa mining region. Third World Network.
- Bell FG, Stacey TR, Genske DD (2000). Mining subsidence and its effect on the environment: some differing examples. *Environmental Geology* 40(1-2):135-152.
- Brahma KC (2007). A study on the application of strategic planning models and operations research techniques in opencast mining. Rourkela, Orissa: Thesis submitted to the National Institute of Technology.
- Bush R (2009). 'Soon there will be no-one left to take the corpses to the morgue': Accumulation and abjection in Ghana's mining communities. *Resources Policy* 34(1-2):57-63.
- Chen L, Wang E, Ou J, Fu J (2018). Coal and gas outburst hazards and factors of the No. B-1 Coalbed, Henan, China. *Geosciences Journal* 22(1):171-182.
- Cuba N, Bebbington A, Rogan J, Millones M (2014). Extractive industries, livelihoods and natural resource competition: Mapping overlapping claims in Peru and Ghana. *Applied Geography* 54:250-261.
- Folchi R (2003). Environmental Impact statement for mining with explosives: a quantitative method". In: I.S.E.E 29th Annual Conference Explosives and Blasting Technique, Northville Tennessee, U.S.A. February 2-5.
- Friend MA, Kohn JP (2018). Fundamentals of occupational safety and health. Rowman & Littlefield. (Vol.3). African Development Bank.
- Fugiel A, Burchart-Korol D, Czaplicka-Kolarz K, Smoliński A (2017). Environmental impact and damage categories caused by air pollution emissions from the mining and quarrying sectors of European countries. *Journal of Cleaner Production* 143:159-168.
- Fugiel A, Burchart-Korol D, Czaplicka-Kolarz K, Smoliński A (2017). Environmental impact and damage categories caused by air pollution emissions from mining and quarrying sectors of European countries. *Journal of cleaner production* 143: 159-168.
- Ghorani-Azam A, Riahi-Zanjani B, Balali-Mood M (2016). Effects of air pollution on human health and practical measures for prevention in Iran. *Journal of Research in Medical Sciences: The Official Journal of Isfahan University of Medical Sciences*, p. 21.
- Gosar M (2004). Environmental impacts of metal mining= Vplivi kovinskih rudnikov na okolje. *RMZ-Materials and Geoenvironment* 51(4):2097-2107.
- Gualnam C (2008). Mining: Social and environmental impacts.
- Gupta UC, Gupta SC (1998). Trace element toxicity relationships to crop production and livestock and human health: implications for management. *Communications in Soil Science and Plant Analysis* 29(11-14):1491-1522.
- Hayes K, Wagner F (2008). Artisanal & small-scale mining and livelihoods in Africa. Common Fund for Commodities. Prepared for International Seminar: "Small-scale Mining in Africa-A Case for

- Sustainable Livelihood.
- Hilson G (2009). Small-scale mining, poverty and economic development in sub-Saharan Africa: An overview. *Resources Policy* 34(1-2):1-5.
- Hilson GM (2004). Structural adjustment in Ghana: Assessing the impacts of mining-sector reform. *Africa Today*, pp. 53-77.
- Hilson G (2002). Small-scale mining in Africa: Tackling pressing environmental problems with an improved strategy. *The Journal of Environment and Development* 11(2):149-174.
- Hilson G, Banchirigah SM (2009). Are alternative livelihood projects alleviating poverty in mining communities? Experiences from Ghana. *The Journal of Development Studies* 45(2):172-196.
- Hoskin W, Bird G, Stanley T (2000). Mining—facts, figures and environment. *Industry and Environment* 23:4-8.
- Kitula AGN (2006). The environmental and socio-economic impacts of mining on local livelihoods in Tanzania: A case study of Geita District. *Journal of Cleaner Production* 14(3-4):405-414.
- Klop P (2009). Minerals and pro-poor growth. R. Woodward (Edi.), *Natural resources and pro-poor growth* pp. 135-144.
- KNBS (2019). Kenya Population and Housing Census Volume I: Population by County and Sub-County. <https://www.knbs.or.ke/?wpdmpro=2019-Kenya-population-and-housing-census-volume-i-population-by-county-and-sub-county>.
- Lechner AM, Baumgartl T, Matthew P, Glenn V (2016). The impact of underground longwall mining on prime agricultural land: a review and research agenda. *Land Degradation and Development* 27(6):1650-1663.
- Mensah AK, Mahiri IO, Owusu O, Mireku OD, Wireko I, Kissi EA (2015). Environmental impacts of mining: a study of mining communities in Ghana. *Applied Ecology and Environmental Sciences* 3(3):81-94.
- Mghanga M (2011). Mining in Taita Taveta County: Prospects & Problems. Nairobi: Heinrich Boll Stiftung.
- Mwakumanya MA, Maghenda M, Juma H (2016). Socio-economic and environmental impact of mining on women in Kasigau mining zone in Taita Taveta County. *Journal of Sustainable Mining* 15(4):197-204.
- Mwangi MR, Mutiso J (2018). Influence of stakeholder involvement on the performance of mining projects in Taita Taveta County in Kenya. *Journal of International Business, Innovation and Strategic Management* 1(6):167-190.
- Naja GM, Volesky B (2009). Toxicity and sources of Pb, Cd, Hg, Cr, As, and radionuclides in the environment. *Heavy Metals in the Environment* 8:16-18.
- Ogola JS, Mitullah WV, Omulo MA (2002). Impact of gold mining on the environment and human health: a case study in the Migori gold belt, Kenya. *Environmental Geochemistry and Health* 24(2):141-157.
- Okang'Odumo B, Carbonell G, Angeyo HK, Patel JP, Torrijos M, Martín JAR (2014). Impact of gold mining associated with mercury contamination in soil, biota sediments and tailings in Kenya. *Environmental Science and Pollution Research* 21(21):12426-12435.
- Omoti K, Kitemu J, Keriko JM (2016). An assessment of the impacts of extractive industries on the landscape: a case study of gypsum mining in Kajiado, Kenya. *Kabarak Journal of Research and Innovation* 4(1):75-90.
- Pegg S (2006). Mining and poverty reduction: Transforming rhetoric into reality. *Journal of Cleaner Production* 14(3-4):376-387.
- Rahimsouri Y, Yaghubpur A, Modabberi S, Alipour S (2011). Environmental impacts of natural contaminants and mining activities on the surface and agricultural soils in the Aq-Darreh River watershed, Takab, West Azerbaijan Province, NW Iran.
- Ross MR, McGlynn BL, Bernhardt ES (2016). Deep impact: Effects of mountaintop mining on surface topography, bedrock structure, and downstream waters. *Environmental Science and Technology* 50(4):2064-2074.
- Sinnott D (2019). Going to waste? The potential impacts on nature conservation and cultural heritage from resource recovery on former mineral extraction sites in England and Wales. *Journal of Environmental Planning and Management* 62(7):1227-1248.
- Taita Taveta County Government (2013). County Integrated Development Plan. County Government of Taita Taveta. Nairobi: Government Printers.
- The Republic of Kenya (2010). Constitution of Kenya.
- Vision K (2007). 2030. Nairobi: Government of the Republic of Kenya.

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