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Research Article

Understanding the nexus between traditional brick-making, biophysical and socio-economic environment of Goma Division, Mukono Municipality, Central Uganda

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Abstract

This study aimed to evaluate the environmental and socio-economic impact of traditional brick-making in Goma Division. The research methods included semi-structured questionnaires, key informant interviews, field observation, and focused group discussions. The results indicated that traditional brick-making is causing harm to the biophysical environment in the form of the degradation of wetland vegetation and deforestation (100%), landscape deformation (85%), air and water pollution, whereby DO had reduced by 19.8%, BOD, pH, TSS, TDS, EC and turbidity had increased by 3.8±0.9 ppm, 1.2±0.1, 89.4±0.1 mg/L, 18±0.9 ppm, 70±0.7 µS/cm, and 264±44 NTUs, respectively. Water pollution loads varied from point to point of sampling significantly at $p<0.05$, with the highest loads found at the tail end or downstream of the site but lowest at a point upstream of the clay mining site. The socio-economic analysis showed that the benefits of brick-making outweigh the costs in terms of magnitude, except for the frequency of responses. All respondents indicated that brick-making had created employment, while 87% reported an improvement in their standard of living. However, the activity is associated with accidents that can result in loss of life or bodily injury. It was concluded that Mukono Municipal Environmental Officers should monitor brick-making mines and site activities to prevent the creation of open pits and caves. The environment should be treated as a borrowed asset to ensure sustainability. The study suggests that financial support and awareness should be available to clay miners and brickmakers to ensure sustainability.

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Introduction

Wetlands of Mukono, formerly dominated by forest and farmland cover, today have been turned into clay mines and brick-making sites (Kayamba et al., 2017). Many clay mining and brick-making activities in Mukono wetlands have resulted in land surface deformation with the landscape now dominated by puddles and pits. In addition, after the mining activity is completed, many of the lands are left without a good restoration process (Nyakairu et al., 2002). Many of top soils are disposed off during the mining process, yet top soils should be separated and stored in the protected area along the overburden excavation prior to the clay extraction, and then these would be used as material for post-mining land reclamation (Turyahabwe et al., 2021). Generally, artisanal and small-scale clay mining in Mukono Municipality, Mukono District of Uganda, is undertaken with little or no environmental care (Kayamba and Kwesiga, 2017). Another problem that can also be generated is the removal of vegetation that exposes bare land to soil erosion, which runs downslope into streams. This not only compromises agricultural land quality but also comes with a reduction in water quality and the destruction of respective aquatic ecosystems.

Research has shown the deterioration of soil physicochemical properties and increases in greenhouse gas emissions due to brick-making operations (Nyakairu et al., 2002; Hashemi et al., 2015; Kayamba and Kwesiga, 2017). These studies have focused on unfired bricks mostly in East Africa, and no attention has been given to the impact of clay mining and brick operations on water quality and other biophysical and socio-economic environmental components in Mukono Municipality, Mukono District of Central Uganda. For example, Hashemi et al. (2015) found poor organic matter and bulk density closer to brick kilns in Kenya. Loss of nutrients and environmental degradation resulted from brick burning in the eastern region of Tanzania (Kayamba and Kwesiga, 2017)

Humans have lived in natural environments since ancient times (Mahdjoub et al., 2021). During the Stone Age, they inhabited both natural and man-made caves due to environmental determinism, as explained by Anaikaiye et al. (2021). As populations grew, caves became less popular (Mahdjoub et al., 2021), and people learned to construct homes using locally available materials such as grass, rocks, and tree poles (Ngbolua et al., 2018). Housing facilities have improved over time with the use of various materials. Bricks are made of clay that is commonly mined in the wetlands.

Bricks are currently the most popular building material in many parts of the world due to their availability and ease of production (Hashemi et al., 2015; Asante-Kyei and Addae, 2016). Moreover, due to the growing need for building materials to support rapid urbanization in many parts of the world, bricks have become a viable alternative for masonry (Mahdjoub et al., 2021). Brick-making is widespread in many countries and is carried out at various levels of technological advancement (Das et al., 2017; Bhattacharya, 2018). For example, developed countries such as India and America utilize energy-efficient technology, while African countries like Ghana, South Africa, Uganda, and Tanzania have been found to lag behind in this regard (Nyakairu et al., 2002; Mukwevho et al., 2014; Kayamba and Kwesiga, 2017; Akanwa, 2018; Aniyikaiye et al., 2021).

Some Asian countries, including Bangladesh and Indonesia, have implemented modern technology for mining and firing bricks. However, as mentioned by Das et al. (2017), other countries still rely on traditional methods that can have a negative impact on the environment like impact on groundwater and aquifers, landfilling, grading, destruction of vegetation, and construction activities that result in the change of water levels and drainage patterns (Anju and Jaya, 2022).

Regardless of the level of technology used, brickmakers take pride in being responsible for providing readily available building materials. Brick-making provides employment opportunities for energetic youth and improves housing standards worldwide (Mukwevho et al., 2014; Aniyikaiye et al., 2021). Regardless of the level of technology used, brickmakers take pride in being responsible for providing readily available building materials. Regardless of the level of technology used, brickmakers take pride in being responsible for providing readily available building materials. However, it is important to note that although brick supplies are contributing to improving housing conditions for humans, little attention has been paid to the environmental impact of the bricks' origin. In many African countries, such as South Africa, Ghana, and Nigeria, brick-making is predominantly carried out in wetlands due to the low technology (Nyakairu et al., 2002; Mahdjoub et al., 2021). In countries without regulations, wetlands, forest cover, and other non-forest vegetation have been significantly lost due to brick firing and grass burning, resulting in a loss of biodiversity (Asante-Kye and Addae, 2016). Brick firing emits dust, smoke, and greenhouse gases into the atmosphere, causing pollution (Packe and Kingsnorth, 2016; Aniyikaiye et al., 2021).

In Uganda, building with bricks is a common practice, but the environmental impact of brick production and the source of materials used are often overlooked. It is important to consider the environmental impact of brick production and the source of materials used. The presence of clay and other materials in Goma Division could kickstart socio-economic development. However, it is necessary first to identify the impacts of current traditional brick-making activities on the biophysical environment and socio-economic development of the area to fully understand this. This study aims to provide information for improving and sustaining clay brick production in Goma Division. Identifying challenges in brick-making will enable the development of measures to enhance positive impacts and mitigate negative ones. The study examines the relationship between traditional brick-making, socio-economic factors, and biophysical aspects.

Materials and Methods

Description of the study area

Goma Division is a subdivision of Mukono Municipality located in the western region of Mukono

Municipality, Mukono District. It shares boundaries with Mukono Central Division to the east, Kayunga to the northeast, and Wakiso District to the west, south, and north (Figure 1). Goma Division and Mukono Municipality, Mukono District, are situated in the greater Lake Victoria-Kyoga basin in Central Uganda. Goma Division comprises five parishes and 115 villages. The drainage of Goma is characterized by several valleys and swamps. It is drained by several permanent streams, mainly Nakiyanja, which flows into River Ssezibwa and ultimately ends in the Lake Kyoga basin.

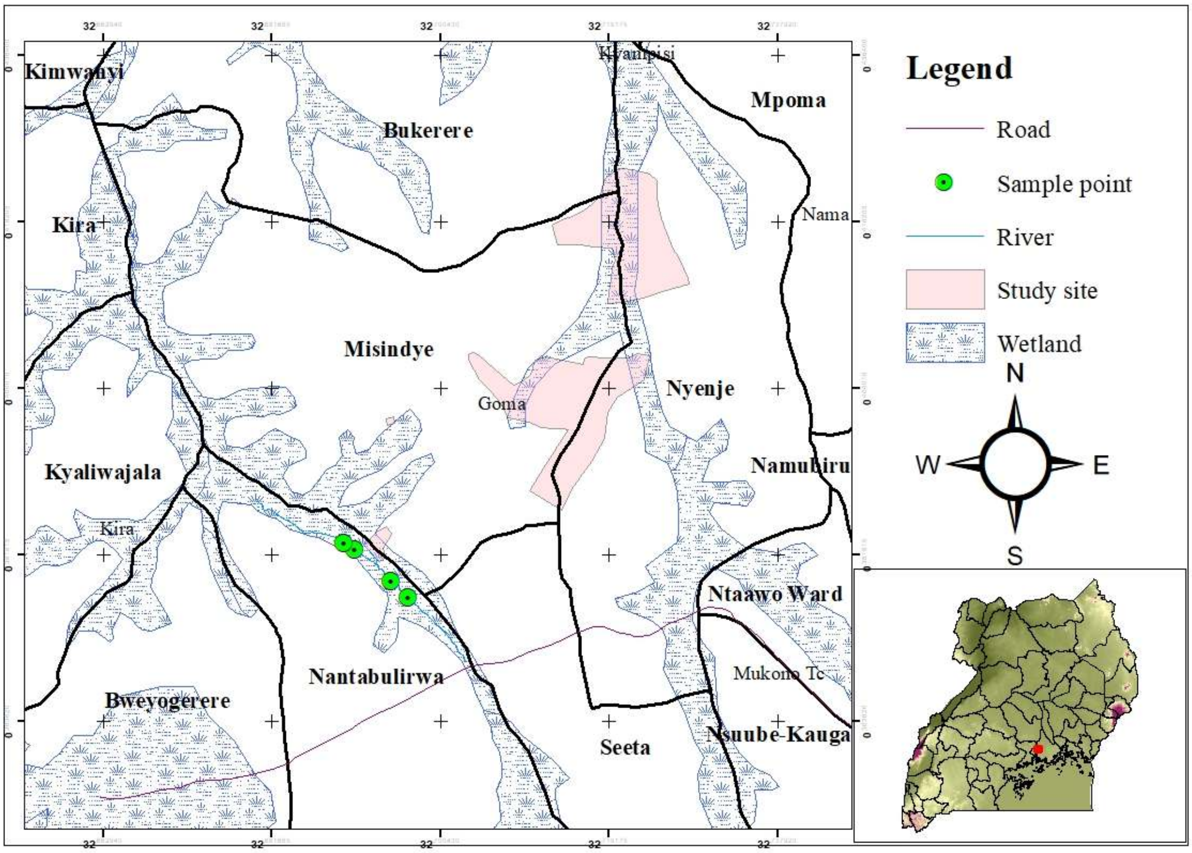


Figure 1. A map of Goma Division and the surrounding areas showing the study sites.

The area is also drained by other smaller and seasonal streams. The valleys have clay soils that are suitable for the production of clay bricks. Human activities such as agriculture and brick-making are dominant, and they have severely impacted the wetland biodiversity in these areas. Goma Division alone has six micro wetlands and nine large-scale brick-making sites.

Sampling

The study employed purposive, clustered, and random sampling techniques to select participants from four brick-making sites (Table 1). The sample sizes varied based on the size of the sites and the number of workers in each cluster. Specifically, the study sampled 40 respondents from Joggo cluster, 60 from Lumuli cluster, 80 from Namyooya, and 20 from Bajjo cluster. Participants were selected randomly from households and individuals at the sites using simple random sampling. Eight key informant interviews and eight focus group discussions were conducted to gain insights into the impact of traditional clay brick-making on the biophysical environment and socio-economic development of the area. Observations were used to confirm and triangulate the accuracy of the information obtained from the semi-structured questionnaire, key informant interviews, and focus group discussions. Between October 2023 and January 2024, this study conducted questionnaires, interviews, and discussions with 120 respondents. This study translated responses from the local language (Luganda) into English. This study selected households located within a radius of 5-10 km from the perimeter of the brick-making sites. This study conducted structured interviews with one representative from each local village council, one community development officer from the visited ward, head teachers from nearby schools, and workers at the brick-making sites.

Physio-chemical water quality sampling

Four sampling campaigns were undertaken in both wet and dry seasons. At Lumuli clay mining and brick-making site, water samples were drawn from three different points on Nakiyanja stream that crossed the site. That is, at 5 m upstream of the mining site, inside the mining site, and 10 metres downstream of the clay mining site to reveal the influence of the clay mining and brick-making activities on water quality.

Data collection

Data was collected from primary and secondary sources. The secondary sources included environmental reports, journal articles, and online resources. Primary data was collected from workers at the brick-making sites and surrounding local households through questionnaires, interviews, and field observations. The purpose was to gain insights into the impacts of traditional brick-making on the biophysical environment and socio-economic development of Goma Division, Mukono Municipality. Local assistants, five per site, were recruited and trained to administer questionnaires to respondents who were over 18 years old and had lived in the area for at least one year. The questionnaires collected information on socio-demographic data, job description, area of origin, working conditions (including pay and occupational health and safety), and marital status. The questionnaire collected information on the socio-economic and biophysical impacts of clay mining, as well as strategies for maximizing benefits and minimizing costs. The data collected from structured interviews was corroborated with that obtained from questionnaire surveys and observations.

On each sampling occasion, physio-chemical water quality variables were measured in triplicate. Electrical conductivity (EC), pH, and total dissolved solids (TDS) were measured (in situ) using a combined conductivity/TDS/pH/temperature meter (HANNA Hi 991300 Model). Dissolved oxygen (DO) was measured using a multi-parameter analyzer (Consort C3010/C3030 Model), and turbidity was measured using a turbidity meter (AL 450T-IR Model). Biochemical oxygen demand (BOD) and total suspended solids (TSS) were analysed in the laboratory (x-situ) following APHA (1998) protocols. GPS coordinates were recorded using GPS-Germin Oregon e-60 type.

Data analysis

Data obtained from questionnaires, focus group discussions, key informant interviews, and field observations were analysed qualitatively and quantitatively. Statistical analyses took the form of simple descriptive statistics, that is, frequencies and percentages, with the findings presented in tables. To compare the differences in physicochemical water quality at the three sampling points, parametric (ANOVA) statistics were used. Before the comparison, a normality test using Shapiro-Wilk was applied to ecological health variables and physicochemical water quality variables. All the data having passed the normality test, one-way ANOVA was performed to assess the differences between means of dependent variables from the two study sites. For those models where it was found to be significant under ANOVA, a post hoc test using Turkey's Honestly Significant Difference (HSD) test was done all generated from STATA version 14.01

Results

Traditional clay brick-making and biophysical environmental nexus in Goma Division

The relationship between traditional brick-making and the biophysical environment of Mukono is summarized in Table 1. Data presented in Table 1 show that all respondents (100%) agreed that the process of brick-making begins with clearing the vegetation before excavating the clay. This involves removing the top layer of vegetation, including papyrus, spear grass, and trees of all sizes, from a larger area than the one to be excavated. This has led to erosion and negatively impacted the health of the wetland and other terrestrial ecosystems. During the process of brick drying, laying, and stacking at the foundation, the grass is required to cover the bricks and protect them from rain (Figure 2; Plate B, C, and D). Spear grass is commonly harvested from the adjacent mine area or several kilometers away from the brick-making site for this purpose. Similarly, the final stage of the brick-making process, known as brick firing in the brick clamp kiln, requires a significant cutting of nearby trees or from distant areas to provide the fuel wood. This has led to deforestation and thus contributed to climate change, as a significant amount of wood is extracted without replacement.

The preferred tree species to provide wood include Mango (*Mangifera indica)*, Mahogany (*Khaya anthotheca*), Musizi (*Measopsis eminii*), Jackfruit (*Artocarpus heterophyllus*), and Eucalyptus (*Eucalyptus saligna)* (Figure 2; Plate D). The price of this fuel wood is determined based on the size/tonnage of the truck used for transportation, such as Isuzu-Fuso, Forward-truck, or other lorry types. Firing, or burning, is a process used to harden and increase the durability of dried bricks. According to the respondents, the amount of fuel wood required for firing bricks varies depending on the size of the clamp kiln, the season, and the extent of drying of the bricks to be fired. All of the respondents (100%) indicated that firing bricks has resulted in the loss of some indigenous grass and tree species, which previously provided other benefits to the community. This has consequently reduced the ecosystem services and values of the wetlands. Based on interviews with 148 respondents (74% of the total), it was found that brick-making is associated with air pollution. It is important to note that this process has been identified as a significant contributor to air pollution. This was particularly evident at the Namyooya site (Table 1). The traditional brick-making process involves five stages: excavation, preparation, moulding, drying, and firing.

Table 1. Traditional clay brick-making and biophysical environmental nexus in Goma Division.

Response	Community responses from four brick-making sites (wards) in Goma Division				Total	%
	Joggo	Lumuli	Namyooya	Bajjo		
Costs						
De-vegetation	40	60	80	20	200	100
Air pollution	32	42	57	17	148	74
Water quality deterioration	14	19	47	17	97	49
Flooding	27	19	12	00	58	29
Drying up of wells and streams	9	17	12	00	38	19
Scenery deformation	36	38	77	19	170	85
Soil and land degradation	18	27	52	18	115	58
Loss of natural habitats	29	30	18	14	91	46
Benefits						
Formation of new habitats	6	41	13	9	69	35
Creation of new local ponds for breeding *Clarias* fish species	00	60	39	20	119	60

During firing, five additional sub-stages are followed: hacking, laying a protective layer, firing, cooling, and de-hacking. During the firing, hacking, and de-hacking processes, a significant amount of dust particles are released from the bricks. This dust can compromise the health of workers and others in the vicinity. The dust from red bricks is carried by the wind and can be inhaled by brickmakers on-site as well as people off-site. During the firing sub-process, a clamp kiln is constructed and filled with wood of varying sizes and lengths (Figure 2; Plate D). Fast-burning materials, such as grass, small wood, and plastics, are strategically placed between the logs to aid in the ignition of larger pieces and to prolong burning until the bricks are fully ready. During this process, various greenhouse gases are produced and emitted into the atmosphere, reducing air quality. Brickmakers are particularly affected as they are at the source and inhale the highest concentration of these gases. The greenhouse gases produced include carbon, carbon dioxide, and methane.

Clay mining for brick-making resulted in the clearance of swamp vegetation, which has deprived Namyooya of its wetland ecosystem services, including flood water filtering and absorption (Figure 2; Plate B). As a result, Namyooya ward currently experiences heavier floods than ever before, as the wetland that used to absorb these shocks was completely cleared for brick-making. This is ecologically dangerous, as evidenced by the observation of dead fish fingerlings and young fish on the ground as the flood recedes.

According to Table 1, 19% of respondents reported that brickmakers dig deep pits to store water for use during drought spells (Figure 2; Plate B). This provided a suitable breeding ground for mosquitoes, thus increasing the incidence of malaria fever in the vicinity. This practice was also reported to affect the biophysical environment in that it reduced the water table, dried up wells in the vicinity, and reduced or dried up small streams in wetlands, leading to a reduction in water availability for the community. The process of excavating the ground using the open-cast method to obtain soil/clay for brick-making caused deformation of the scenery, resulting in the loss of scenic beauty (Figure 2; Plate A). This was the second most commonly reported problem, with 85% of respondents citing it. Brickmakers extract clay soil until it reaches an undesired quality level, at which point the mine is abandoned for another location. It is important to consider the long-term impact of this activity on the environment. These abandoned mines are often left unfilled, resulting in collapsed pits and unsightly landscapes that are no longer suitable for agricultural activities and the consequent loss of many ecosystem services.

According to Table 1, 58% of respondents reported that brick-making was linked to soil and land degradation. Brickmakers who did not use clay soil resorted to using topsoil (black/horizon A), which, once excavated, leaves behind infertile soil that cannot be used for agriculture. Additionally, when clay soil was mined and piled on top, its sticky nature and texture sealed soil pores (Figure 2; Plates A and F). The piles put in the area limited the rates of biogeochemical cycles. Additionally, the heat generated from the clamp kiln killed soil organisms, which are a vital part of the soil's habitat. The heat from the firing process also destroyed surrounding vegetation, affecting flora and fauna communities and soil formation processes, leading to land and soil degradation.

Brick-making is associated with the loss of natural habitats for living organisms. During brick-making process, as the swamp vegetation is cleared (Figure 2; Plate B), the water levels reduce, and animals that thrive in swamps, like fish, reptiles, amphibians, tortoises, guinea fowls, etc., either migrate or and others die. It was also reported that, as clay or soil mining for brick-making starts, all the ant hills become devoid of ants, crickets, and termites. Some brickmakers indicated that ant hills have better soils for brick-making, so most people prefer starting with those to make bricks. One of the brickmakers in Joggo Ward reported that they used to enjoy flying ants/termites, but since they started making bricks from here, all the ants have migrated, and now all anthills are dormant. This is an indicator that this activity is a threat to the habitat of these organisms in the environment, yet they are free and edible by man, reptiles, and birds during their season.

Excavated pits left after clay mining can become habitats for aquatic animals such as reptiles, amphibians, and fish. Streams adjacent to brick-making sites connect to abandoned pits during the rainy season, allowing water to flow freely and the organisms to spread throughout. As the flood recedes, some organisms recede back with the stream, but others remain in the new habitat - the clay pits filled with water. Certain fish species, particularly *Clarias leocephalus* and *Clarias carsonii*, have thrived more successfully in pit habitats than their counterparts in streams. They have grown larger in these deeper and muddier pits than those in streams. Three brickmakers in Lumuli site reported that they learned from this scenario that the pits were better fish ponds, and as such, they domesticated four pits as their personal fish ponds.

Reptiles, fish, and amphibians all coexist in this new ecosystem. In Lumuli, brick-making was found to be associated with the highest level of water pollution, particularly in Nakiyanja stream, due to the large number of people on the site and its size (Table 1). During the preparation stage, clay was extracted and piled on the ground, where it was left for some time. Some of this soil was eroded downslope during the rainy season and ended up in the nearby stream called Nakiyanja, leading to its silting, yet the community uses this stream for domestic water abstraction. On this site, brickmakers used muddy and dirty buckets to abstract water for brick-making, contaminating the water that people also use for domestic purposes.

In the Bajjo site, brickmakers diverted part of the small stream to ensure a water supply for brick-making during the dry season. During the wet season, the stream floods, and the water from the brick-making pits mixes with the stream water, causing contamination. This results in increased water turbidity, nutrient levels, and bio-oxygen demand while reducing light penetration and dissolved oxygen. These changes in chemical water conditions lead to the death of pollution-sensitive aquatic organisms such as macroinvertebrates and fish in the streams. Since water is a bloodstream of the planet, based on this finding, this study went ahead to quantify the extent of pollution these clay mining and brick-making activities infringed on the water quality, and results were summarised in Table 2.

The clay mining and brick-making activities increased degradation of the water quality by increasing all the parameters as shown in Table 2. For example, apart from DO, all other parameters increased from upstream to downstream. Water in the Nakiyanja stream entering the Lumuli clay mining and brick-making site was cleaner than at the point it was leaving the site (Table 2).

Table 2. Influence of clay mining and brick-making activities on physicochemical water quality values (mean ± standard deviation) of water stream adjacent to Lumuli clay mining and brick-making site for all four sampling campaigns (twice in the wet season and twice in the dry season).

Sampling points on the Nakiyanja stream on the Limuli clay mining and brick-making site	**Average values of physio-chemical water quality parameters from three sampling points on the Nakiyanja stream on the Lumuli clay mining and brick-making site**						
	BOD (ppm)	**DO (ppm)**	**pH**	**TSS (mg/L)**	**TDS (ppm)**	**EC (µS/cm)**	**TURB (NTUs)**
5 m before site	22.3±0.2a	11.1±0.1a	7.6±0.1c	74.6±0c	126±1.2a	54±2.8a	110±0.8c
Inside on site	26.0±2.2ab	9.2±1b	8.4±0.2b	107±1.8a	132.0±6.1b	83.2±1.9a	245±6.2b
1 m at end of site	26.1±1.1c	8.9±0.2c	8.8±0.1ac	162±0.1b	144±0.3c	124±2.1c	374±4.5a
Effect by range (↑↓)	3.8±0.9 ↑	2.2±0.1 ↓	1.2±0.1 ↑	89.4±0.1↑	18±0.9 ↑	70±0.7 ↑	264±44 ↑
% effect	16.3	19.8	16.7	123	14.5	134.6	242

NOTE: ↑↓ Mean increase and decrease in the physio-chemical water quality parameters, respectively. Mean values with the different letters (a, b, c, and d) in the same column are significantly different One Way ANOVA at p≤ 0.05.

At the end point of the site, the pollution loads had accumulated and concentrated to levels that were >14% (Table 2). DO have reduced by 19.8%, BOD, pH, TSS, TDS, EC, and turbidity had increased by 3.8±0.9 ppm, 1.2±0.1, 89.4±0.1 mg/L, 18±0.9 ppm, 70±0.7 µS/cm and 264±44 NTUs respectively. Based on the One-way ANOVA, water pollution loads varied from point to point of sampling significantly at p<0.05, with the highest loads found at the tail end or downstream of the site but lowest at a point upstream of the clay mining site (Table 2).

Traditional clay brick-making and socio-economic nexus in Goma Division

Data about the relationship between traditional brick-making and socio-economic environment of Goma

Division, Mukono Municipality, is summarized in Table 3. According to Table 3, 25% of the respondents stated that traditional brick-making was risky due to accidents. Care must be taken during the loading of sun-dried bricks into a clamp kiln to avoid accidents. Before loading the dried bricks, the firing area must be prepared by arranging the bricks on dry, level ground. The size of the clamp kiln depends on the number of available dried bricks. The bricks were usually piled, leaving rectangular openings, called firing boxes, through the clamp kiln to the opposite side of the kiln, with a size of approximately 1 m x 1 m in 2 to 3 parts of the kiln, depending on its dimensions (Figure 2; Plate B).

Table 3. Traditional clay brick-making and socio-economic nexus in Goma Division.

Response	Responses from different clay brick-making sites in Goma Division				Total	%
	Joggo	Lumuli	Namyooya	Bajjo		
Costs						
Accidents (death trap)	9	17	12	12	50	25
Disease vector habitats	36	31	77	19	163	82
Child labour and school dropouts	18	27	50	10	105	53
HIV escalation	29	30	18	14	91	46
Hectic work with low pay that comes with Long-term health deterioration e.g., chest pains, respiratory diseases	20	30	50	10	110	55
Economic losses when floods happen and destroy unburnt bricks	32	22	57	17	128	64
High rate of wetland renting	14	47	19	17	97	49
Benefits						
Employment opportunities	40	60	80	20	200	100
Local revenue generation	32	22	57	17	128	64
Start of small-scale business	14	47	19	17	97	49
Improved standards of living enhancement	36	41	77	19	173	87

Inexperienced brickmakers who were uncooperative or did not seek guidance made mistakes in hacking the clamp kiln. If the firing boxes were made with incorrect dimensions, when the bricks were stacked too high, the weight caused the kilns to collapse. This resulted in numerous fatalities and injuries among clamp kiln hackers. Additionally, abandoned clay mines often leave open cast pits that fill with rainwater during the wet season. The community has reported incidents of the accidental drowning of children and domestic animals in the ditches and pits, which they referred to as 'death traps'. Additionally, some children lost their lives while attempting to swim in these pits.

Reservoirs of stagnant water, created by excavated pits left after clay mining, become breeding grounds for disease vectors such as mosquitoes and snails during the rainy season (Figure 2; Plates E and B). This increased the risk of morbidity and mortality due to diseases such as malaria and bilharzia. This was the second most commonly reported social effect, with 82% of respondents mentioning it (see Table 3 and Figure 2). The respondents highlighted that brick-making had led to an increase in school dropout rates and absenteeism from schools. According to their argument, the income generated from brick-making activities attracted pupils and students from communities in the brick-making areas, resulting in school absenteeism. Prolonged absenteeism ultimately leads to dropping out. This was revealed by 105 respondents, accounting for 53% of the total respondents. The study found that clay mining led to the use of child labour, with many children under the age of 18 being exposed to tedious work that puts their growth and development at risk. According to the study, 9% of workers were children under the age of 18 years, indicating that child labour was widespread in the brick-making area.

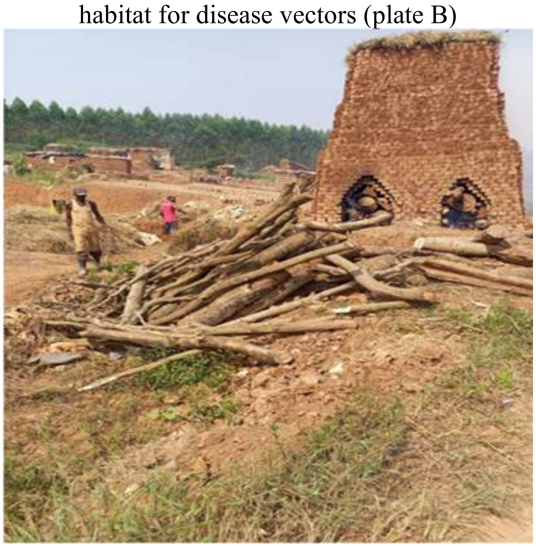
Brick-making also increased prostitution, resulting in an increased prevalence of HIV/AIDS in the surrounding sites among the brickmakers, vendors, and villagers. The respondents reported an increase in the prevalence of HIV/AIDS due to the establishment and expansion of brick-making sites in the study areas. The increase in HIV/AIDS orphans and single mothers in these areas also indicates the aforementioned problem. Some brick-making workers came from distant locations such as Jinja, Wakiso, Kayunga, Mpigi, and Masaka, leaving their families behind. Sixty-six percent of the interviewed workers were not previously residents of the area and came from outside Mukono Municipality, Mukono District and re-married in the new site and had left their spouses behind. Such separation exposes people to infidelity, thereby increasing the spread of HIV/AIDS.

Brick-making is a laborious process that can have negative long-term health effects, such as chest pains and respiratory diseases, due to the many laborious processes. The production of a single brick requires a significant amount of energy. Workers typically begin their days' work from 9 am in the morning and complete a substantial amount of work by the time by 7 pm. Mining and preparing clay dough is physically demanding job that is typically performed by men, but the pay is so low and costed maximum of Ug Shs10,000 (approx. 2.6 USD) per day (Figure 2, Plate C and F).

Land deformation (plate A)

Pools of stagnant water are a risk to children and a habitat for disease vectors (plate B)

Youth employment (Plate C)



Brick-making process produces a lot of smoke and causes deforestation (Plate D)

Abandoned clay mining pits (Plate E)

Process of clay mining using manual labour (Plate F)

Figure 2. Field photos.

Brick-making was associated with significant economic losses, as reported by 64% of the respondents (Table 3). For instance, during the dry season, if the clay dough was not molded into bricks within three days of preparation, it dries out and would need to be re-prepared. In the rainy season, when floods occur, the newly made bricks dissolve and are washed away by the running water. The fired bricks require tight security to prevent theft. Poorly baked bricks break down during the de-hacking process. Brick-making is a challenging activity due to the associated high cost of wetland rent for clay extraction. Most brickmakers rented wetlands to extract the clay soil. Sometimes, the clay in the hired pieces may not be economically viable, but this cannot be determined from the surface. Clay mines consist of plots owned by individuals renting them out for clay extraction and brick-making. These landlords viewed the plots as a source of income. Other people earned income by selling fuel wood, and grass to fire bricks. The women involved in the brick-making activity reported employing labour for various tasks, including extracting clay/soil, preparing clay dough, molding bricks, cutting/collecting and carrying grass for brick covering, and performing clamp kiln hacking, de-hacking, and firing.

The price of bricks depends on the season and production inputs, with the cost of fuel wood being a principal factor in determining the price. According to respondents, a clay brick costs 350 Uganda Shillings (approx. 0.09 USD) on-site, while a loam-soil brick costs 250 Uganda Shillings (approx. 0.07 USD) on-site. All these economic activities earned income for the workers, which they used to improve their standards of living. Local government council officials also moved to the brick-making sites to register and collect local revenues/taxes from brickmakers. This is a source of revenue to the government, which the bricklayers paid regularly, although the majority admitted to evading tax payments.

The study found that brick-making in the municipality has contributed to the development of trade and commerce. The respondents agreed that the market established from the brick-making sites to supply the workers sustained the trading centres within the mine fringes, such as Joggo, Lumuli, and Namyooya trading centres. Small-scale vendors from various parts of the municipality sold merchandise, including clothing and food items such as half-cakes (locally known as 'mandazi'), ripe bananas, fried cassava, and cooked food, at the clay mine/brick-making sites. These activities helped to broaden the income base of the people and reduce poverty levels. According to the survey, 45% of the interviewed villagers reported being involved in vending activities at the brick-making sites.

The study revealed that 87% of respondents believed that brick-making in Goma Division has led to increased development of infrastructure, including low and storied houses, perimeter walls, and bridges. It was also found that those who plan to build a house consider purchasing bricks and often make bookings in advance or opt to buy ready-made bricks at the brick-making sites. The respondents expressed pride in their responsibility to contribute bricks to all the buildings in the nearby and far trading centres/municipalities. This contributed to an improved standard of living for people in both rural and urban areas.

Discussion

In Goma Division's brick-making process, a substantial amount of wood is necessary to fire the bricks. Regrettably, this has led to the felling of trees both inside and outside forests. This practice not only contributes to global climate change but also results in the loss of valuable fruit tree species, such as Mango and Jackfruit trees, in the surrounding community and environment. Ngbolua et al. (2018) and Saha (2023) found that brick-making has led to the destruction of forest resources and the loss of nutritious fruit tree species, such as Marula, in Gbado-Lite city, Democratic Republic of Congo (DRC). Similarly, other areas have lost plum trees, which are rich in antioxidants, vitamin A, potassium, and iron (Sarkodie et al., 2014; Asante-Kyei and Addae, 2016).

Traditional brick-making in Goma has been associated with air pollution due to the use of plastics to sustain the fire in the clamp kilns during firing. This emits greenhouse gases such as carbon, carbon dioxide, and methane, which reduce the air quality and can cause or trigger respiratory diseases. This finding is in agreement with Anaikaiye et al. (2021) who stated that atmospheric emissions were a significant problem in both developing and developed countries where brick-making relies on crude fuel technology and coal, respectively. This is because the wood and coal used in brick firing emit greenhouse gases (Standing, 2014; Hashemi et al., 2015; Das et al., 2017). Therefore, brick-making is a development project that is closely linked to air quality deterioration.

The use of dirty and muddy containers by brickmakers to fetch water from wells results in the pollution of water sources that are also used by other members of the community for domestic purposes. This practice not only increases water turbidity and reduces dissolved oxygen but also poses a risk of disease transmission to the rest of the community who share the same water sources. This observation is similar to the findings of Abdalla's (2015), Packey and Kingworth (2016), and Akanwa (2018) that both active and inactive clay mines can potentially contaminate water sources if not properly managed. To avoid this scenario, it is suggested that separate dams be constructed specifically for brickmakers to reduce contamination and water mixing from the groundwater seepages to the other clean water sources.

Brickmakers often dig deep pits to store water for use during long drought spells, which lowers the water table and causes nearby wells to dry up. This practice has also had a negative impact on the continuous and steady flow of small streams in wetlands, resulting in reduced water levels or even complete drying up. This observation is in line with the findings of Sarkodie et al. (2014) and Anju and Jaya (2022) that harvesting sites located near water bodies caused the streams near the sites to dry up easily during dry seasons due to reduced underground water volume. This can have ecological consequences, such as suffocation and extinction of aquatic organisms (Bhattacharya, 2018).

The open pits left after abandoning the clay mines in Joggo ward of Goma Division made the overall landscape unsightly and rendered the land unsuitable for agricultural activities. This has resulted in a decline in the ecosystem's service value and health. Similar findings were reported by Sarkodie et al. (2014) in Ghana, where communities faced challenges in using mined wetlands for agriculture. Artificial fertilizers had to be applied after reclaiming the land before it could be suitable for agriculture.

Excavated pits left after clay mining have become new habitats for aquatic animals, such as reptiles, amphibians, and fish. Three brickmakers at the Lumuli site reported that they used the pits to make fish ponds, which form an additional source of income for their family. This is similar to the reasoning given by Turyahabwe et al. (2021, 2023). However, this contradicts Aniyikaiye et al.'s (2021) findings. They observed that rural communities in Southern African countries destroy many anthills/mounds during all winter seasons to make clay bricks for sale or for their own consumption in building infrastructure. This practice leads to the destruction of natural ecological habitats for ants and crickets (Aniyikaiye et al., 2021) in terrestrial habitats, and a similar observation was made in this study, which focused on aquatic habitats. However, it is important to note that this may affect not only ants and crickets but also humans and other natural predators, as they miss out on these protein-rich delicacies that are popular, as reported in Zambia (Figueirêdo et al., 2015; Aniyikaiye et al., 2021).

Traditional brick-making and socio-economic nexus in Goma Division

Human injury caused by the collapsing of kilns which have incorrect dimensions of the firing boxes, caused hackers to fall with collapsing bricks. Unfortunately, this has led to numerous fatalities and injuries among clamp kiln hackers. Similar accidents have been reported by Bhattacharya (2018) and Turyahabwe et al. (2021), who indicated that improperly managed clay pits and kilns can cause serious injuries to workers. Excavated pits left after clay mining have become reservoirs for stagnant water during the rainy season. This has increased human morbidity and mortality due to diseases such as malaria and bilharzia, as they have become breeding grounds for disease vectors like mosquitoes and snails. This finding is in line with studies by Corral-Avitia and Mora-Covarrubias (2012) and Mukwevho et al. (2014), which reported that the proximity of clay harvesting pits to residential areas had led to an increase in mosquito breeding and, consequently, a rise in malaria cases within the community. Malaria is the most commonly reported disease in the Mukono Municipality, Mukono District, as reported by the district health directorate. This may be due to the creation of breeding habitats for mosquitoes in the district, which is caused by the popular brick-making business.

The respondents reported that brick-making has resulted in higher rates of school dropouts and absenteeism. They explained that the income generated from brick-making attracts pupils and students from nearby communities, leading to prolonged absenteeism and eventual dropping out. Additionally, parents often involve their children in this activity at a young age, exacerbating the problem. Aigbedion and Iyaji (2007) also reported a similar observation that brick-making is often a family-owned cottage industry in Africa, Asia, and other parts of the world.

Brick-making in Goma Division has created numerous employment opportunities. The process involves extracting clay or soil, preparing clay dough, moulding bricks, cutting and collecting grass to cover the bricks, clamping kiln, hacking and de-hacking, and firing. Additionally, transportation businesses have also benefited from this industry. Those employed in these activities earn income that they use to improve their standard of living. Some respondents specialize in certain activities within the mines. The process of making bricks is lengthy and arduous, requiring the employment of specialized workers to complete the task. This confirms the findings of Standing (2014) and Asante-Kyei and Addae (2016) that there were over 1,000 informal brick-making industries in South Africa and South Africa, respectively, employing more than 5,000 workers.

Brick-making has emerged as a significant source of income for various groups in the Goma Division. These groups include those who rent clay mines, sell firewood, make bricks, sell them, and sell the loaders and transporters. This finding is consistent with the conclusions of Das et al. (2017) and Anaikaiye et al. (2021), who found that brick-making businesses were often established to generate income for jobless and unskilled laborers to support their families.

Conclusions

Based on the study's results, this study concluded that the wetland biophysical environment is a valuable natural resource that was negatively impacted by brick-making activities in the Gombe area. It is the responsibility of all citizens to act as guardians and promote the sustainable use and conservation of fragile habitats, such as wetlands and forests. The technology used in brick-making was still rudimentary, resulting in air and water pollution. Therefore, the government needs to promote improved technology for extracting, using, and managing the after-effects of developing clay resources for brick-making. Bricklaying is important for socio-economic development due to its association with employment opportunities and the improvement of living standards. The brick industry has a significant impact on the biophysical environment. This impact includes the elimination of wetlands and their ecosystem services, pollution of air and water sources, and the creation of pits during clay mining that become habitats for disease vectors.

Clay mining has caused pollution in most water bodies in the community due to the lack of regulation and policy by mandatory agencies such as the Environmental Protection Agency (EPA). Furthermore, extensive farmland has been destroyed due to clay mining, and there has been no effort to restore the land without proper training and monitoring by the EPA. To prevent water pollution, the study suggests that community leaders prohibit clay harvesting near sources of drinking water. Additionally, the EPA should enhance its supervisory role at clay mining sites in these areas to prevent disease outbreaks in Goma Division. District by-laws should be introduced to regulate land acquisition for clay mining and the reclamation of land after harvesting. More efforts are needed to find sustainable solutions to the problems associated with clay harvesting in Mukono Municipality and other parts of the country where it is prevalent. The government, through the local council, should regularly organise awareness programmes on the impacts of clay mining in the community. Future research will focus on the impact of clay mining and brick-making on water quality and soil quality in Uganda as this is an area with limited literature.

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