Inundation risks and habitat vulnerability in the commune of Kolleram, Zinder's Region-Niger.

ABSTRACT

Inundations are becoming increasingly frequent and disastrous in Niger. This study aims to analyze inundation risk factors and habitat vulnerability in the village of Kolleram, Zinder Region. Following a survey on community perceptions of the inundation phenomenon, the frequency, consequences, and adaptation strategies developed by the population of Kolleram were documented. Particular attention was given to habitat vulnerability.

A topographic survey and sampling of clay geomaterials used in the construction of houses in Kolleram were conducted. The collected samples were analyzed from physicochemical and geotechnical perspectives. Rainfall data analysis and mapping were also used to explain the causes of the inundations observed by the local population.

The findings reveal that the recurrence of inundations in Kolleram is linked to local morphology, the presence of numerous ponds, exceptional rainfall events, and the lack of a rainwater drainage system. The clay geomaterials used in Kolleram are primarily kaolin deposits. Their geotechnical parameters, along with the presence and proportions of Fe_2O_3, C, Ti, and K_2O, were assessed. The results indicate that the clay materials used for construction in Kolleram are structurally fragile and highly vulnerable to flooding.

In response, the population of Kolleram has developed various coping strategies to manage flooding and reduce their vulnerability.

***Keywords*:** Flood risk, Habitat vulnerability, Clay geomaterials, Kolleram, Zinder

1. Introduction

In the current context of climate change and rapid population growth, inundations are among the most frequent natural hazards worldwide (E. Fiorillo et al., 2015; Mamadou and Abdou, 2016; OCHA, 2021, 2022). The damage is often extensive, and the losses associated with these events are estimated at several hundred billion US dollars (Descroix et al., 2013). Like other Sahelian countries, Niger also experiences recurrent inundations (Mamadou et al., 2019). These floods occur almost every year in urban centers as well as in rural areas (Mamadou et al., 2019).

Large-scale inundations with disastrous consequences for crops, housing, infrastructure, and human health are observed throughout the country, often resulting in significant loss of life. This highlights the importance of analyzing the inundation phenomenon in order to better understand it and to provide decision-makers with appropriate tools for effective risk and disaster management (Eba et al., 2021; Brou et al., 2022; Babaye et al., 2023).

This study contributes to that effort by examining inundation risk factors and habitat vulnerability in the village of Kolleram in the Zinder region.

2. Materials and Methods

2.1. Presentation of the Study Site

The rural commune of Kolleram is located in the southwestern part of the Mirriah Department, in the Zinder region (Figure 1). It lies between latitude 13°42′53.7″ N and longitude 9°05′18.5″ E. The commune covers an area of 437 km² and has a Sahelian climate. Geologically, Kolleram belongs to the Korama Basin, an ancient tributary of Lake Chad.

Chad basin (Amadou Malam et al., 2021).

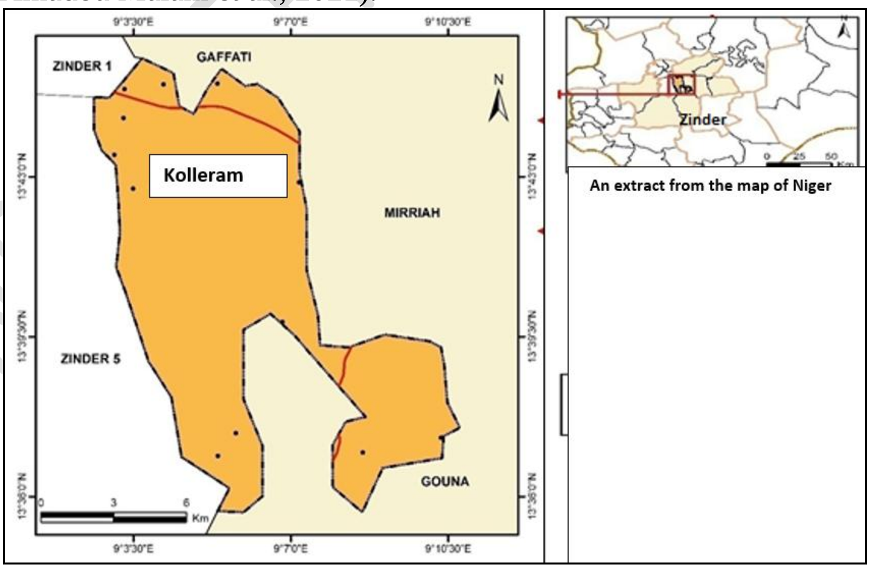

Figure 1 : Localisation of the study site

Quaternary granitic, clayey-sandstone, and sandy formations can be observed. The population of the rural commune of Kolleram was estimated at 16,250 inhabitants in 2008 (projection based on the results of the RGP/H 2001).

2.2. Surveys

The experiences and perceptions of local people regarding inundation and its consequences were investigated. These surveys constituted the first phase of the study. A questionnaire and interviews were administered to the population of Kolleram. The questionnaire was individual and administered to a randomly selected sample of 100 people, chosen according to geomorphological position.

The interviews involved several key local stakeholders, including the Mayor of the commune, the Chief of Kolleram village, and the Head of the Mirriah Civil Protection Department.

The information collected was processed and analyzed using SPINX and Excel software.

2.3. Topographical Survey and Analysis of Rainfall Data

The topographical survey was conducted using a cartographic approach. This method was applied to produce a topographical profile of the village of Kolleram based on a recent Google Earth image. The profile, drawn from west to east over a distance of 1.33 km, made it possible to assess the site's morphology and determine slope variations.

Photo-interpretation of the same Google Earth image was used to identify areas at high risk of inundation.

Rainfall, the main driver of inundation in Kolleram, was analyzed using daily rainfall data from the town of Zinder, located 11 km away and considered representative of Kolleram's climatic conditions. These data were obtained from the National Meteorological Office. Intra- and inter-annual variability were analyzed, and the rainfall threshold likely to trigger flooding was calculated using the method applied by M.S. Moustapha (2016) for the town of Zinder.

This threshold corresponds to a rainfall level whose probability of non-exceedance (Hazen frequency) is set at 5%. The formula used is:

$$F(xi) = (r - 0.5) / N$$

Where:
$F(xi)$ = frequency of non-exceedance
N = total number of rainfall event values
r = rank of the value
0.5 = constant

After this step, the probability of non-exceedance was calculated using:

$$\text{Probability of non-exceedance} = 1 - F(xi)$$

2.4. Sampling and Characterization of Clay Geomaterial Samples

The vulnerability of habitats to inundation in Kolleram was evaluated based on the types of geomaterials used in construction. To determine their level of vulnerability, the materials were sampled and characterized. Two quarries were selected, and ten samples were collected and analyzed from chemical and geotechnical perspectives.

a. Sampling

The sampling operation focused on the quarries most frequently used by the villagers of Kolleram. One quarry per type of clay geomaterial was selected, resulting in two quarries:

- A red clay geomaterial quarry located on the Precambrian basement (Zinder site)
- A black clay geomaterial quarry located on Quaternary formations (Kolleram site)

At each quarry, five (05) sampling points were identified and collected from different sides of the quarry. In the laboratory, a representative composite sample for each quarry was prepared by mixing equal proportions (500 g) from each of the five samples.

The ten samples collected were labeled as follows:

- ZDR1, ZDR2, ZDR3, ZDR4, ZDR5 (Zinder quarry)
- KOL1, KOL2, KOL3, KOL4, KOL5 (Kolleram quarry)

In addition, two composite samples representative of each quarry (ZDR and KOL) were prepared.

All samples were sent to the laboratory for chemical analysis.

a. Experimental Methods

After preliminary crushing using an agate mortar and pestle (20 mm in diameter and 70 mm in height), the chemical composition of the raw samples was determined by X-ray fluorescence spectrometry (Philips PW 2400 XRF). The mass percentages of the major oxides and certain simple chemical elements, such as carbon, were quantified.

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b. Geotechnical Analysis

Geotechnical tests were conducted to evaluate the vulnerability of constructions made from clay materials extracted from these quarries. The tests were carried out at the National Public Works and Construction Laboratory in Zinder.

Sampling

Six (6) samples were collected for geotechnical analysis from the two quarries. These samples were taken from different sides of each quarry in sufficient quantities to allow test repetition and validation.

c. Experimental Methods (Geotechnical Tests)

Two geotechnical tests were performed:

1. **Atterberg limit tests** to determine and compare the plasticity of the materials and to assess their behavior in the presence of water.
2. **Compressive strength (crushing) tests** to evaluate the mechanical resistance of the clay materials.

3. Results

3.1. Population Experience and Perception of Inundation in Kolleram

3.1.1. Population Perception of Inundation Periods

In the study area, inundation is primarily pluvial in origin. Its occurrence is therefore closely linked to rainfall recorded during the rainy season. According to the surveyed population, there is unanimous agreement that inundations occur only during the rainy season, from June to October.

For 86% of respondents, inundation occurs in the middle of the rainy season, particularly during July and August. Meanwhile, 11% reported that inundation occurs toward the end of the season. In contrast, only 3% believed that inundation occurs at the beginning of the season (Figure 2).

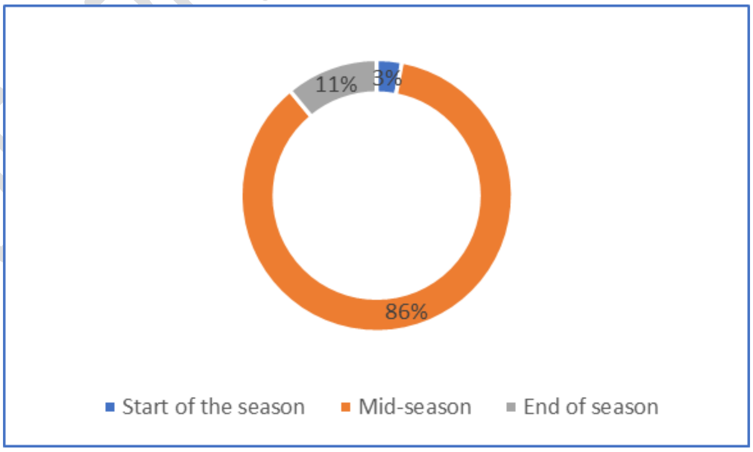

Figure 2: Population perception of inundationperiods in Kolleram

3.1.2. Population Perception of the Causes of Inundation in Kolleram

To explain the causes of inundation in their village, the interviewed population of Kolleram identified several factors. The most relevant causes were retained for analysis. In order of frequency of response, these included: absence of a rainwater drainage system, heavy rainfall, topography, poor quality of building materials, expansion of housing, degradation of vegetation cover, divine will, and occupation of flood-prone areas (Figure 3).

The survey results indicate that three of these factors are perceived as the primary causes of flooding. The absence of a rainwater drainage system was cited by 63% of respondents, making it the most frequently mentioned cause. Heavy rainfall was identified by 54% of respondents as a major contributing factor. Finally, 43% of the surveyed population attributed flooding to the village's topography (Figure 3).

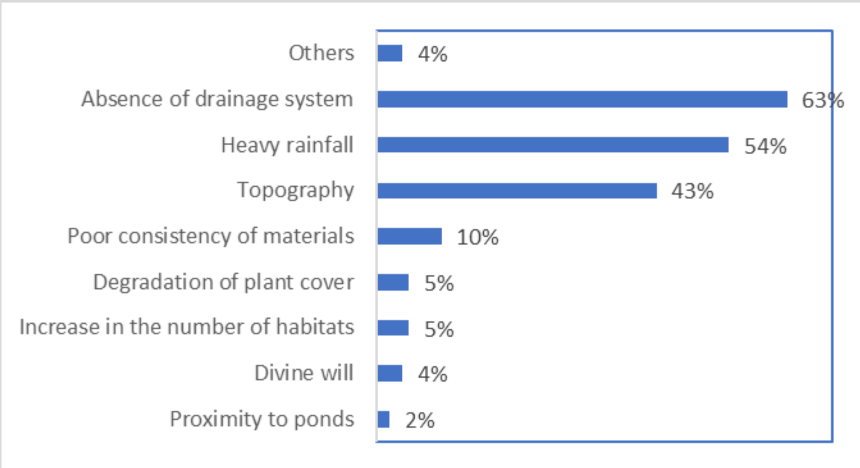

Figure 3: Survey population's perception of the causes of inundation in Kolleram

3.2. Types of Habitat in Kolleram

The extent of inundation damage can be assessed according to the type of housing. In the study area, three main types of habitat were identified during field visits and confirmed by survey results: clay houses, straw houses, and cement houses.

According to the survey, 90% of respondents live in clay-built houses. These structures are reported to have suffered the greatest flood-related damage in Kolleram. Straw houses account for 7% of the surveyed homes and are also highly vulnerable to flooding, as they are constructed from straw and tree branches.

Cement-built houses and infrastructure are relatively rare in the study area, representing only 2% of respondents' dwellings (Figure 4).

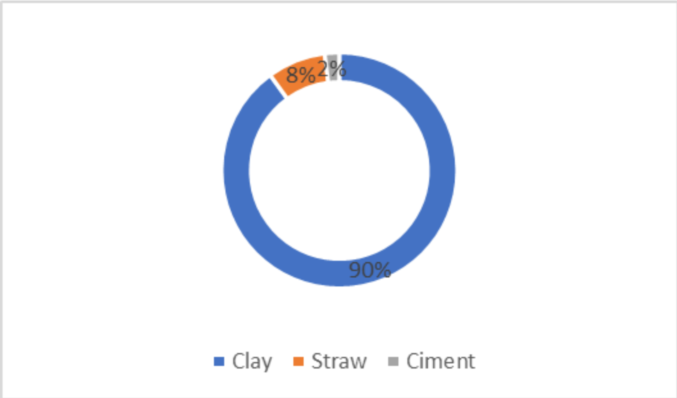

Figure 4: Type of habitat at Kolleram

3.3. Types of Clay Materials Used in the Construction of Clay Houses

Regarding construction materials, survey results indicate that 84% of respondents living in clay houses use black clay extracted locally from quarries in the village of Kolleram. Only 3% reported that their houses were built using red clay sourced from the town of Zinder.

In contrast, 13% of respondents reported mixing the two types of clay to improve the resistance of their houses to heavy rainfall and inundation (Figure 5).

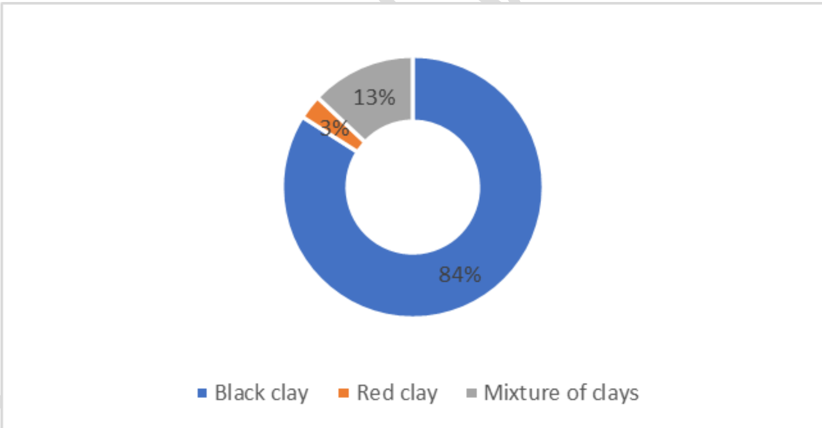

Figure 5 : Types of claymaterialsused in clay habitat construction

3.4. Experience and Description of Inundation Damage

Regarding the damage caused by inundations, respondents reported human, animal, and material losses. Material damage was mentioned by all respondents (100%) and primarily concerned the destruction of houses and school infrastructure (Figure 6).

According to the inundation report prepared by the Mirriah Civil Protection Department, 69 houses and four secondary school classrooms collapsed in Kolleram in 2019 due to flooding. In 2020, following heavy rainfall recorded on 6 and 7 September, 93 houses collapsed.

The number of affected people was 626 in 2019 and 527 in 2020, corresponding to 69 and 67 affected households, respectively. The death and weakening of livestock were also reported by 48% of respondents.

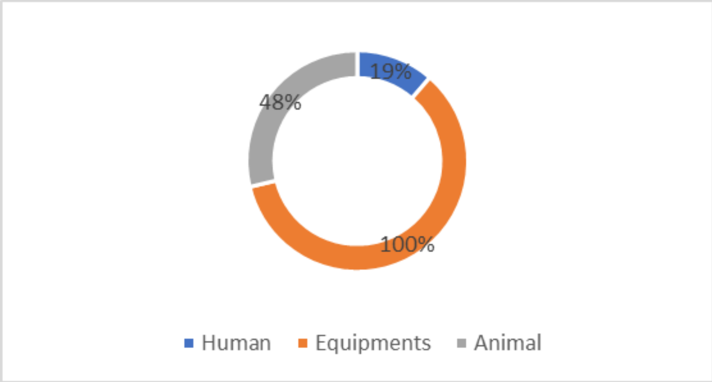

Figure 6 : Type of inundation damage experienced by victims

3.5. Inundation Risk Factors in Kolleram

3.5.1. Rainfall Variability in Kolleram

Figure 7 shows that the rainy season in Kolleram lasts approximately six (6) months. Monthly rainfall ranges from 0 mm (November, December, January, and February) to 164.42 mm (August). The average monthly rainfall was 29.79 mm for the period 1984–1990 and 35.54 mm for 1990–2018.

The highest average monthly rainfall amounts occur in July, August, and September. These three months account for 75.65% of the cumulative seasonal rainfall. Inundations in Kolleram are mainly observed during this period, particularly in July and August, which correspond to the middle of the rainy season—an observation consistent with the perception of 86% of surveyed respondents.

Inter-annual rainfall variability is also evident in Kolleram. Analysis of daily rainfall data from the Zinder meteorological station (representative of Kolleram) shows that annual cumulative rainfall between 1984 and 2018 fluctuates markedly from year to year, following a jagged or sawtooth pattern (Figure 8).

To assess the rainfall threshold capable of triggering inundation, a probability of non-exceedance (Hazen frequency) of 5% was applied. The calculated threshold corresponds to rainfall events of at least 35 mm (Figure 9).

Applying this threshold to the 1984–2018 period indicates that 82 rainfall events equal to or exceeding 35 mm were recorded in Kolleram. The trend analysis suggests an increasing frequency of rainfall events likely to cause inundation (Figure 9).

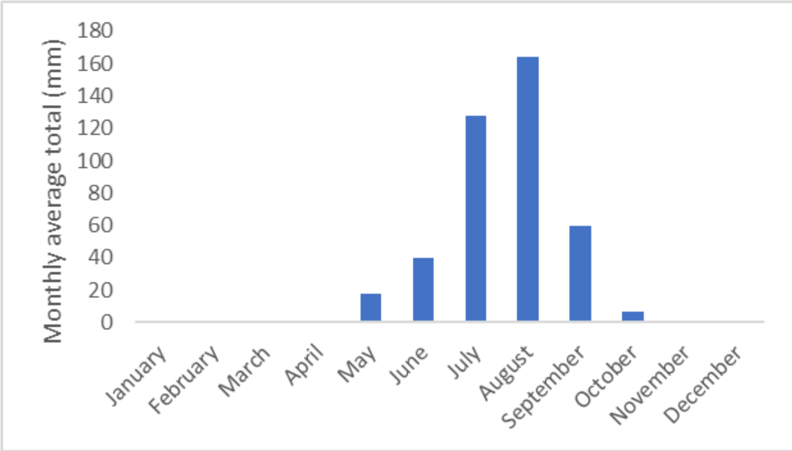

Figure 7: Variation of averagemonthlyrainfallfrom 1984 to 2018 at Kolleram

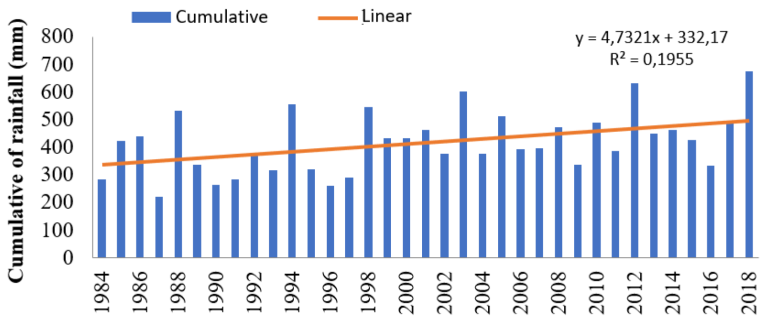

Figure 8 : Interannual variation of cumulative rainfallfrom 1984 to 2018 at Kolleram

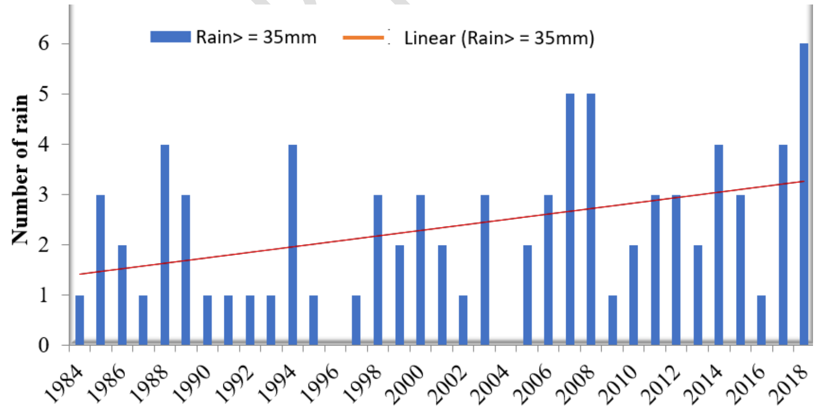

Figure 9: Variation of the number of raineventswiththreshold>= 35 mm

3.5.2. Topography and Typology of Areas at Risk of Inundation in Kolleram

The topographical morphology of the village of Kolleram is characterized by a dune system composed of elevated areas and low-lying depressions (Figure 9). The elevated zones correspond to dune crests, while the low-lying areas form depressional corridors that cross the village from north to south (Figure 10).

Analysis of the topographical profile, conducted from west to east over a distance of 1.33 km using a Google Earth image, indicates that land elevation ranges from 445 m in the low-lying areas to 454 m in the elevated zones, representing a total relief difference of 9 m. The average altitude of the site is 449 m.

Maximum slope gradients vary between 4.6% and 5.4%, while average slopes range from 2.2% to 2.5%.

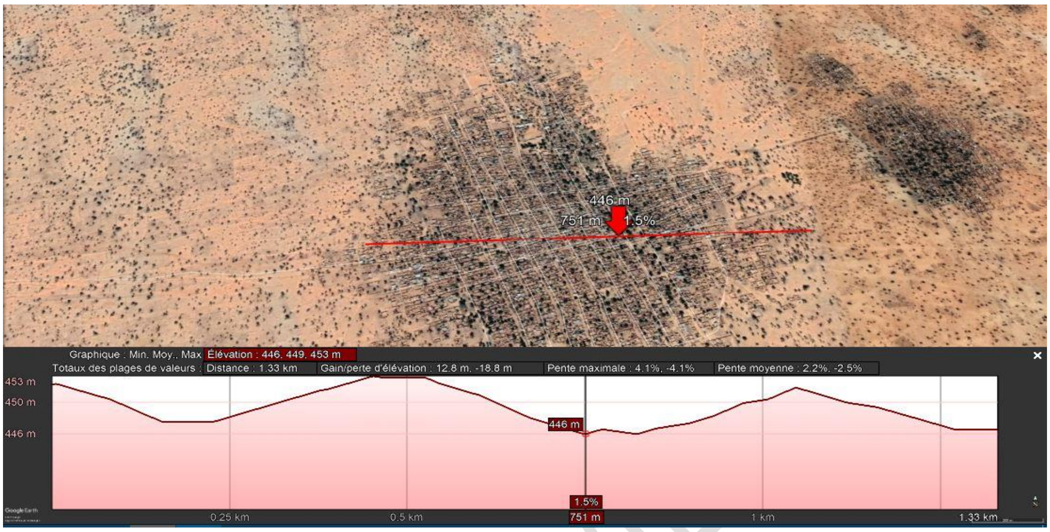

Figure 10: West-East topographical profile of the village of Kolleram

Further analysis of the general topography of Kolleram made it possible to identify three main types of areas at risk of inundation within the village:

- Low-lying areas
- Areas located near ponds
- Areas located near large ravines

Kolleram contains two major low-lying zones that cross the locality from north to south. The village also has six (6) temporary ponds, around which the population extracts materials used for brick production. In addition, gully erosion is highly active in several parts of the village due to the fragility of the dominant dune soils. This process has led to the formation of large gullies throughout the area.

Because of their relatively low elevation, these three types of zones (low-lying areas, areas near ponds, and areas near gullies) function as primary drainage and/or water stagnation zones for rainwater within the village.

3.6. Characterisation of Geoconstruction Materials

3.6.1. Chemical Characterisation

Tables 1 and 2 present the results of the chemical analysis of samples collected from the two quarries (Kolleram and Zinder), focusing on major constituent elements. These elements account for more than 98% of the total mass in each sample, indicating that they are sufficient for reliable material characterization.

Overall, all twelve (12) samples from the two sites are primarily composed of silica (SiO_2) and alumina (Al_2O_3). This confirms that the materials are aluminosilicates and therefore belong to the clay mineral family. However, variations were observed in the silica-to-alumina ratios, as well as in the presence and relative proportions of certain elements such as iron oxide (Fe_2O_3) and carbon (C).

Table 1: Chemical analysis (% by mass) of rawsamplesfrom the Kolleramquarries (black clay)

Sample	SiO_2	Al_2O_3	Fe_2O_3	C	CaO	MgO	K_2O	**Totals**
KOL1	41,453	22,008	7,836	19,982	3,62	1,898	1,51	**98,307**
KOL2	41,498	22,039	7,918	19,933	3,629	1,962	1,521	**98,5**
KOL 3	41,497	22,026	7,916	19,961	3,621	1,862	1,519	**98,402**
KOL 4	41,468	22,007	7,895	19,907	3,608	1,957	1,561	**98,403**
KOL 5	41,403	22,028	7,918	19,968	3,638	1,927	1,521	**98,403**
Standard deviation	**0,0390602**	**0,0137949**	**0,0352392**	**0,0300283**	**0,0111669**	**0,0419011**	**0,0198696**	
KOL	**41,138**	**22,816**	**7,952**	**19,592**	**3,712**	**1,912**	**1,864**	**98,986**

Analysis of the results presented in Tables 1 and 2 indicates that the materials from both Kolleram and Zinder are predominantly composed of silica (SiO_2) and alumina (Al_2O_3), confirming their aluminosilicate nature.

The silica-to-alumina (SiO_2/Al_2O_3) ratio differs between the two quarry sites. The Zinder quarry samples show a relatively higher ratio (1.80) compared to the Kolleram quarry samples (0.41).

The presence of CaO, MgO, and K_2O is particularly notable in the Kolleram samples, while titanium (Ti) is more distinctly observed in the Zinder samples. Iron oxides (Fe_2O_3) are significantly more abundant in the Zinder samples (32.1%) than in the Kolleram samples (7.95%).

In contrast, carbon content is considerably higher in the Kolleram samples (19.59%) compared to the Zinder samples (1.12%).

Table 2: Chemical analysis (% by mass) of rawsamplesfrom the Zinder quarry (Red clay)

Sample	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**C**	**Ti**	**Totals**
ZDR1	18,626	45,081	32,358	1,281	1,741	**99,087**
ZDR 2	18,555	45,098	32,348	1,301	1,798	**99,1**
ZDR 3	18,691	45,088	32,353	1,305	1,661	**99,098**
ZDR 4	18,696	45,071	32,354	1,155	1,824	**99,1**

ZDR 5	18,576	45,091	32,381	1,101	1,847	**98,996**
Standard deviation	**0,064**	**0,010**	**0,012**	**0,094**	**0,074**	
ZDR	**18,628**	**45,398**	**32,108**	**1,128**	**1,742**	**99,004**

3.6.2. Geotechnical Analysis

a. Atterberg Limit Tests on Clay Materials

Atterberg limit tests were carried out on four (4) samples collected from the two quarries (Kolleram and Zinder), with two samples tested per quarry.

Comparative analysis of the results presented in Tables 3 and 4 shows clear differences between the materials from the two sites in terms of liquid limit (LL), plastic limit (PL), and plasticity index (PI). Overall, these parameters are significantly higher for the Zinder samples than for the Kolleram samples.

Similarly, the average natural water content is higher in the Zinder samples (40.45%) compared to the Kolleram samples (18.97%).

These results indicate that the Zinder materials are more plastic and, therefore, richer in clay minerals than the Kolleram materials. Consequently, their behavior in the presence of water is expected to differ, depending not only on their plasticity but also on their swelling potential. Higher plasticity generally suggests greater susceptibility to volumetric changes when exposed to moisture.

b. Strength Test on Clay Materials

To assess the mechanical strength of the materials and estimate the load-bearing capacity, test bricks were manufactured and subjected to compression using a CBR press.

The results of the compressive strength tests for materials from the Kolleram and Zinder quarries are presented in Tables 5 and 6. Analysis of Table 5 shows that bricks made from black clay materials extracted from the Kolleram quarries failed under compressive stresses ranging from 5.55 to 6.66 bar, with an average compressive strength of 6.16 bar.

In comparison, bricks made from red clay materials sourced from the Zinder quarries exhibit higher compressive strength, indicating greater mechanical resistance. This explains why some villagers prefer Zinder materials for construction. These materials are perceived as more consistent and are often used to reinforce locally available black clay materials (Figure 6).

Table 3: Atterberg limit test results for Kollerammaterials

WL (%)	18,5%	20,5%	19,5%
WP (%)	14,66%	14,3%	14,48%
IP (%)	3,84%	6,20%	5,02%

Table 4: Atterberg limit test results for Zinder materials

WL (%)	39,95%	44%	41,97%
WP (%)	27,11%	26,12%	26,61%
IP (%)	12,84%	17,88%	15,36%

Table 5: Test of resistance on black claymaterials of Kolleram

N° Brick	**Measuring (mm)**	**Resistivityweight (KN)**	**Contraint (bars)**	**average contraint (bars)**
KOL1	0.60	13,33	6,665	6,16
KOL2	0.55	12,22	6,11	
KOL3	0.50	11,11	5,555	
KOL4	0.57	12,67	6,335	

Table 6: Test of resistance on redclay of Zinder

N° Brick	**Measuring (mm)**	**Resistivityweight (KN)**	**Contraint (bars)**	**average contraint (bars)**
ZDR1	0.81	18	9	12,305
ZDR2	1.32	29,33	14,665	
ZDR3	1.07	23,78	11,890	
ZDR4	1.23	27,33	13,665	

4. Discussion

4.1. Trends in Inundation Factors in Kolleram

In Kolleram, flooding is predominantly rain-fed and closely linked to rainfall variability during the rainy season. According to local respondents, the main causes of inundation include the absence of a drainage system, high rainfall intensity, unfavorable topography, and the low consistency of building materials. Similar factors have been reported in other Sahelian cities. For example, studies conducted in Ouagadougou highlighted the role of geological and geomorphological conditions in increasing flood risk (Bani & Yonkeu, 2016).

Rainfall trends in Kolleram indicate a return to wetter conditions since the 1990s, characterized by increasing cumulative annual rainfall and a higher number of rainy days. Between 1990 and 2018, the frequency of extreme rainfall events ($\geq$ 35 mm) also increased, enhancing flood potential. This pattern is consistent with broader climatic observations across the Sahel, where a partial recovery of rainfall has been accompanied by an increase in extreme precipitation events.

Topographically, Kolleram is situated in a basin-shaped depression with variable slopes, a configuration that naturally favors water accumulation. Similar findings were reported in Kantché, located within the Korama catchment area, where basin morphology significantly contributed to recurrent flooding. Settlements located in such depressions often face major constraints in stormwater evacuation, thereby amplifying flood hazards.

Despite these known risk factors, a substantial proportion of dwellings in Kolleram are located in low-lying zones and near temporary ponds. This spatial occupation pattern significantly increases the exposure and vulnerability of households and infrastructure during heavy rainfall events.

4.2. Vulnerability of Clay-Based Habitats to Inundation

Clay-based housing dominates in Kolleram, representing approximately 90% of surveyed dwellings. The widespread use of clay in rural West Africa is well documented, particularly in countries such as Burkina Faso and Niger, where clay is commonly used for residential construction, pottery, and ceramics.

In Kolleram, most houses are built with locally extracted black clay (84%), while red clay from Zinder is used less frequently.

Geochemical Characteristics

Chemical analyses indicate that silica (SiO_2) and alumina (Al_2O_3) together account for more than 63% of the materials from both quarries. However, their proportions differ significantly between sites. The silica/alumina (SiO_2/Al_2O_3) ratio—an indicator of clay mineral content—was estimated at 1.8 for Kolleram samples and 0.41 for Zinder samples.

The higher ratio observed in Kolleram materials suggests a greater proportion of free quartz and a lower clay mineral content. These materials are therefore relatively poor in binding clay fractions and structurally less cohesive. In contrast, the lower ratio in Zinder samples indicates a higher clay mineral content and greater mineralogical maturity.

Mineralogical and Geotechnical Behavior

Mineralogical analysis shows that both materials are dominated by kaolinite associated with quartz. Kaolinite is a non-expansive clay mineral, meaning it exhibits limited shrink–swell behavior during wetting and drying cycles. This was confirmed by Atterberg limit tests, which indicated relatively low swelling potential for both materials.

However, significant differences were observed in plasticity. Zinder materials exhibit higher liquid limits, plastic limits, and plasticity indices compared to Kolleram materials. Their higher natural water content (40.45% versus 18.97%) further reflects their greater clay fraction. Increased plasticity generally enhances cohesion and resistance to mechanical degradation under wet conditions.

Mechanical Strength and Structural Implications

Compression tests revealed that bricks made from Kolleram clay exhibit relatively low compressive strength (average 6.16 bar), whereas bricks made from Zinder clay demonstrate higher mechanical resistance. This confirms local perceptions that Zinder clay produces more consistent and durable bricks. Consequently, some households use Zinder clay to reinforce local materials.

The low clay fraction and reduced mechanical strength of Kolleram materials make them particularly vulnerable to prolonged water exposure. During inundation events, these materials lose cohesion more rapidly, increasing the likelihood of wall cracking, erosion, and structural collapse.

Thus, while climatic and topographic conditions create flood hazards, the intrinsic properties of locally used geomaterials significantly amplify structural vulnerability.

5. Conclusion

This study demonstrates that inundation is a recurrent phenomenon in Kolleram and causes substantial damage to housing and livelihoods. Flood occurrence is driven by a combination of factors, including increasing rainfall intensity, basin-shaped topography, absence of drainage infrastructure, and settlement expansion into flood-prone zones.

Beyond environmental drivers, the nature of construction materials plays a decisive role in determining the extent of damage. Laboratory analyses reveal that locally used black clay from Kolleram quarries possesses lower clay content, reduced plasticity, and weaker mechanical strength compared to red clay from Zinder. These properties increase the susceptibility of buildings to water-induced degradation and collapse.

Therefore, flood risk in Kolleram results from the interaction between climatic variability, geomorphological constraints, settlement patterns, and material vulnerability.

To enhance resilience, priority actions should include:

- Development of basic drainage infrastructure
- Regulation of settlement in flood-prone zones
- Promotion of improved or stabilized earth construction techniques
- Community awareness and capacity-building programs

Strengthening both environmental management and construction practices is essential to reduce vulnerability and promote sustainable habitat development in Kolleram.

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