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Vulnerability Assessment of the Town of Bekily to Flash Floods of the Menarandra River (Southern Madagascar)

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ABSTRACT

Bekily is one of the towns in the Great South of Madagascar. This town has a semi-arid climate characterized by a long dry season (April to October) and a short rainy season (November to March). The Menarandra River flows through the town, and its hydrological regime often becomes violent during periods of heavy, sudden rainfall, reaching a maximum flow velocity of 7.09 m/s at the main bridge. This situation, combined with the lack of urban flood protection infrastructure and upstream vegetation cover, exposes the population to a high risk of flash floods. Out of approximately 1,937 households, 399 households (20.59%) located on the riverbanks within a 250-meter radius, spread across three fokontany (villages), are identified as highly vulnerable to flooding. This study aims to assess the physical and social vulnerability to flash floods and to propose integrated measures to strengthen urban resilience. To analyze this, a mixed-methods approach was adopted, combining literature review, the V-index vulnerability method, and field data collection to analyze the exposure, sensitivity, and adaptive capacities of dwellings. The results show that intense rainfall variability, the city's topography, low levels of protection, and anthropogenic pressures are the main contributing factors. These results highlight the need to implement integrated interventions to reduce vulnerability and strengthen urban resilience to flash floods. Therefore, this study aims to provide a solid knowledge base on the degree of vulnerability, given the lack of in-depth studies on Bekily.

Keywords: Anthropogenic factors, Flash floods, Urban vulnerability, Menarandra River, Semi-arid climate, Urban resilience.

1 INTRODUCTION

Geographically, the town of Bekily is located in the Androy region in the far south of Madagascar. This region has a semi-arid to arid climate, characterized by high rainfall variability, a long dry season, and a short rainy season (Battistini et al., 1969; Monograph of the Androy Region, 2014). This type of climate strongly influences the hydrological regime of the region's watercourses, particularly that of the Menarandra River, which flows through the town of Bekily. The high variability in rainfall, marked by intense and sudden downpours, leads to rapid hydrological responses in the river and can result in sudden and violent floods. During the rainy season, its upper reaches receive torrential rains; it is then a raging river, eroding its banks, especially in the Ampotaka region (Riquier et al., 1952). Conversely, during the dry season, which lasts approximately seven to eight months per year, the river's flow decreases considerably. Hydrological data show that the maximum flow velocity can reach 7.09 m/s at the bridge (Aldégheri, ORSTOM). During the ten-year floods observed between 1971 and 1972, peak flows reached up to 1,710 m^3/s (Chaperon et al., 1993). This vulnerability is also exacerbated by several anthropogenic and institutional factors, including the progressive occupation of floodplains by housing, the use of riverbanks for agriculture, brickmaking on the banks, the degradation of vegetation around the river, as well as inadequate flood protection infrastructure and the absence of a suitable urban development plan. Faced with this situation, the city of Bekily is confronted with an often-unpredictable flood threat, linked to both rainfall variability and the river's hydrological dynamics. According to Naess (2006), "urban vulnerability can be understood as the susceptibility of urban systems to damage caused by hazards, depending on exposure, sensitivity, and adaptive capacity." Coleman and Clarke (2025) emphasize that vulnerability to flash floods in urban areas results from the interaction between physical exposure, urbanization dynamics, and social vulnerability. The results of this study show that nearly 399 out of 1,937 households living within 250 meters of the riverbanks, spread across three fokontany (villages), are identified as vulnerable to flash floods. This vulnerability affects poor households due to their limited financial resources, fragile housing conditions, and low adaptive capacity. It particularly affects people with reduced mobility, such as elderly people, persons

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with disabilities, pregnant women, and children, who are among the most vulnerable groups and often the first victims of these natural hazards. The objective of this study is to identify households exposed, or even highly exposed, to flash floods, and then to analyze the main factors contributing to the vulnerability of urban households in the city of Bekily. To conduct this analysis, the study adopts a mixed-methods approach combining document review, vulnerability indicator analysis, and participatory surveys. This study underscores the importance of implementing targeted interventions to reduce flood risks in Bekily.

1.1 Study Area Location

The city of Bekily as shown in Figure 1, also known as Morafeno-Bekily, is the administrative center of the Bekily district in the Androy region, southern Madagascar. It is crossed from north to south by the Menarandra River, which has a torrential regime and highly irregular hydrological behavior.

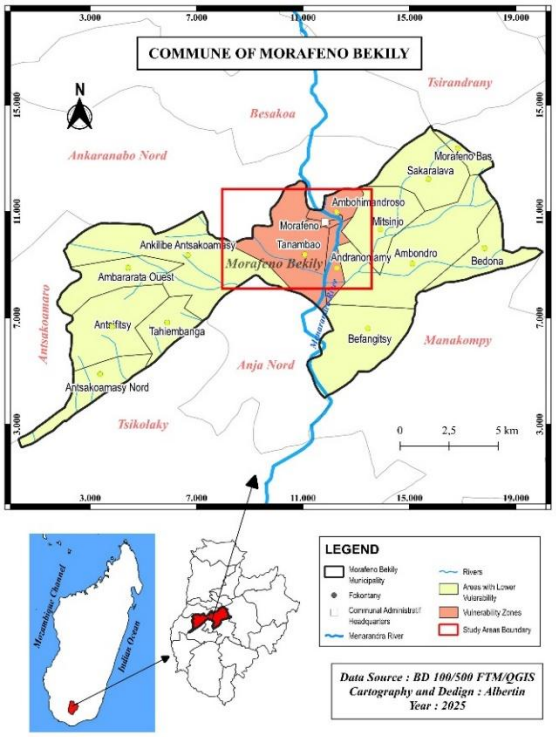


Figure 1. Location map of the study area: the city of Bekily

Bekily has an estimated population of 20,915 inhabitants, including 10,637 women and 10,278 men, living in 22 fokontany and distributed over an area of 400 km². The population is predominantly rural, relying on a subsistence economy based on livestock breeding and crop cultivation adapted to the semi-arid climate (RGPH3, 2018). The Antandroy ethnic group represents 65 % of the population (13,595 inhabitants), while the Antanala account for 4,183 people and the Antanosy represent 2,092 people (approximately 10 % of the total population). The study area includes the fokontany most exposed to flash floods, notably Tanambao Morafeno, Ambohimandroso, and Andranomamy.

2 LITERATURE REVIEW / RELATED WORK

Flash floods in semi-arid regions have been widely studied due to their destructive impacts on communities and infrastructure. The Menarandra River in southern Madagascar is described as a "violent river," exhibiting abrupt discharge variations during intense rainfall events (Riquier, Moureaux & Ségalen, 1952, 1953). Its hydrological behavior is influenced by local topography, soil permeability, and upstream vegetation degradation (Billon, 1969; Guo et al., 2021). Human activities, such as unplanned urban expansion and riverside agriculture, further increase exposure and amplify flood impacts (Chaperon et al., 1993; RGPH3, 2018). Most previous studies have focused on hydrological measurements, with limited attention to institutional and community factors that determine vulnerability. Recent research emphasizes the importance of combining field surveys, participatory approaches, and hydrometeorological data to assess urban flood vulnerability (Creswell, 2014). However, few studies have addressed the localized vulnerability of Bekily, where natural, socio-economic, and institutional factors interact. This study fills this gap by providing an integrated assessment of Bekily's vulnerability to Menarandra flash floods, aiming to support more resilient urban planning and risk management.

3 METHODOLOGY

This section presents the three complementary methods used in this study to analyze household vulnerability in Bekily.

3.1 CONCEPTUAL FRAMEWOREK

In this article, we rely on two definitions recognized by scientific sources to establish the basis for vulnerability analysis. These two definitions emphasize that exposure, sensitivity, and adaptive capacity are considered the main determinants of vulnerability. According to UNDP (2004), "Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of hazard."

Naess (2006) states, "Urban vulnerability can be understood as the susceptibility of urban systems to damage from hazards, as a function of exposure, sensitivity, and adaptive capacity." These two definitions serve as the conceptual foundation for our study, guiding the analysis of natural, anthropogenic, and institutional factors.

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3.2 DOCUMENTARY RESEARCH

The first step involved an in-depth documentary research conducted in several university libraries and documentation centers in Madagascar, as well as in national and international digital databases (University of Toliara, Regional University Center of Androy, IRD, National Library of France, etc.). This review covered general works on physical and human geography, as well as specialized documents on hydrology, climatology, natural hazards, and flood management in semi-arid areas. Reports from local and international organizations, such as ADRA, ACF, WFP, UNICEF, and BNGRC, were also consulted to obtain up-to-date socio-economic, institutional, and environmental data.

3.3 METHOD FOR ASSESSING VULNERABILITY

Specifically, household vulnerability to flash floods was assessed using the conceptual approach to socio-economic vulnerability, which is based on three main components: exposure, sensitivity, and adaptive capacity, according to the definition proposed by Naess (2006). This approach has been developed in research on climate vulnerability and natural hazards, such as Adger (2006), and has been adopted in several studies on flood vulnerability (Balica et al., 2012). This approach is based on the formula:

$$V = E + S - CA \quad (1)$$

Where:

***V*:** Vulnerability Index

***E*:** Exposure to Flash Floods

***S*:** Household Sensitivity

***CA*:** Adaptive Capacity

Exposure was calculated from the proportion of households exposed and highly exposed to flooding:

$$E = \frac{N\ highly\ exposed + 0.5 * N\ exposed}{N\ total} \quad (2)$$

Where:

N exposed: number of households exposed to flooding

N total: total number of households

Sensitivity was estimated from the percentage of houses built with mud bricks, considered vulnerable to flooding:

$$S = \frac{\%\ of\ the\ houses\ built\ with\ mud\ bricks}{100} \quad (3)$$

Adaptive capacity was assessed based on the existence of protective infrastructure, early warning systems, and community organization (scale 0 to 1).

i. Protective infrastructure: score of 0.1 (non-existent in Bekily),

ii. Early warning system: score of 0.3 (Low/Informal),

iii. Community organization: score of 0.4 (exists in the form of mutual aid, fokonolona),

iv. Access to information (weather/radio): score of 0.4 (exists on average).

$$CA = \frac{0.1 + 0.3 + 0.4 + 0.4}{4} = 0.3 \quad (4)$$

These formulas were used to quantify the level of household vulnerability in Bekily. The approach highlighted that household vulnerability increases with the level of exposure and sensitivity, but decreases when household adaptive capacity is high. To comply with the standard published in scientific literature, this study uses vulnerability indices on a scale of 0 to 2. In this case, the indices are divided into four levels as follows:

i. 0 to 0.5: Low,

ii. 0.5 to 1: Medium,

iii. 1 to 1.5: High,

iv. 1.5 to 2: Very High

3.4 DATA COLLECTION AND ANALYSIS

Following the documentation work, which allowed us to acquire a good understanding of the physical and human environment of the town of Bekily, a field visit was conducted. During this visit, we collected preliminary data from the three fokontany chiefs targeted by the study, including demographic and social information, as well as data on infrastructure and building materials.

Once the total number of households per fokontany was obtained, a direct census of riverside households was carried out in two stages. The first stage consisted of counting the total number of households located within 250 meters of the riverbed, which are considered exposed. The second stage focused on counting households located within 50 meters of the riverbanks, which are considered highly exposed (more vulnerable). Subsequently, the collected data were entered into an Excel file to categorize it and generate tables and graphs. This method allowed us to link field observations to quantitative analyses, providing a solid foundation and enabling us to conduct the analyses.

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4 RESULTS

This section explains the results of the study conducted in Bekily. It focuses on presenting quantitative and narrative results concerning household vulnerability index levels by Fokontany, as well as the various associated factors.

4.1 DISTRIBUTION OF HOUSEHOLDS EXPOSED AND SEVERELY AFFECTED BY FLASH FLOODS ACCORDING TO DISTANCE FROM THE MENARANDRA RIVER

Table I shows the distribution of household and severely affected by flash floods in the town of Bekily

TABLE 1. DISTRIBUTION OF HOUSEHOLDS EXPOSED AND SEVERELY AFFECTED BY FLASH FLOODS IN THE TOWN OF BEKILY

Village	Tanambao Morafeno	Ambohimandroso	Andranomamy	TOTAL
Total number of populations	4904	2675	2106	**9685**
Total number of households (average size 5 people per household)	981	535	421	**1937**
Households exposed (less than 250m)	181	123	95	**399**
% of households exposed (less than 250m) in %	18,45	22,99	22,56	--
Households exposed (less than 50m)	92	55	41	**188**
% of households exposed (less than 50m) in %	9,38	10,28	9,74	--

Source : SDSP Bekily and field survey, October 2025

According to this table, out of a total of 1,937 households surveyed in the three fokontany studied, 399 households, or 20.60%, are exposed to flash floods of the Menarandra River, while 188 households, or 9.71%, are highly exposed due to their immediate proximity to the riverbed. This result proves that one in five households in Bekily is exposed to the risk of flooding. Among the three fokontany studied, Tanambao-Morafeno has the highest proportion of households exposed to flooding, with 18.44% of households located within 250 meters of the river and 9.39% of highly exposed households within 50 meters. This high exposure is linked to the higher density of housing along the riverbanks. The fokontany (village) of Ambohimandroso accounts for 22.99% of households at risk and 10.28% of households at very high risk. Similarly, the fokontany of Andranomamy has 22.57% of households at risk and 9.74% of households at very high risk. Figure 2 below confirms this analysis. It shows the flooding (in blue) of the Tanambao-Morafeno neighborhood following Cyclone Honde on February 28, 2025. Therefore, the high vulnerability of the Tanambao-Morafeno fokontany results from its significant exposure to flooding from the Menarandra River.



Figure 2. Aerial view of the city of Bekily after Cyclone Honde, February 28, 2025.

In this Malagasy context, studies on urban vulnerability in Antananarivo also indicate that a significant portion of the urban population, often exceeding 20%, is exposed to flooding due to the occupation of low-lying and marshy areas (Ramiaramanana and Teller, 2021). Comparatively, research on African cities indicates that 15 to 30% of urban populations live in areas exposed to flooding, particularly in alluvial plains and near waterways (Douglas et al., 2008; Adelekan, 2011).

Table II describes the distribution of vulnerability levels in the three Fokontany studied. Among them, the Andranomamy Fokontany has a higher index, with a value of 0.80, indicating high vulnerability compared to the others. This situation is linked to the very high percentage of households built with mud bricks (72%), which has increased the susceptibility of dwellings to flooding. Houses built with mud bricks are often fragile in the face of flooding. In contrast, the Ambohimandroso Fokontany remains moderately vulnerable, with a vulnerability index of 0.61, and Tanambao-Morafeno has a vulnerability index of 0.57. The percentage of households built with bricks is still low (45%). In short, these results show that vulnerability is the result of the interaction between exposure, susceptibility, and adaptive capacity, and not solely of proximity to the river.

TABLE II: VULNERABILITY INDEX NORMALIZED BY FOKONTANY FOR HIGHLY EXPOSED HOUSEHOLDS

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Village	Tanambao Morafeno	Ambohimandroso	Andranomamy	TOTAL
Total number of populations	4904	2675	2106	**9685**
Total number of households (average size 5 people per household)	981	535	421	**1937**
% of households in earth brick buildings (in %)	45	51	72	--
Sensitivity (S)	0,45	0,51	0,72	--
Exposure (E)	0,42	0,40	0,38	--
Adaptive Capacity (CA)	0,30	0,30	0,30	--
Index V	0,57	0,61	0,80	--
Vulnérability level	**Medium**	**Medium**	**Strong**	

Source : SDSP Bekily and field survey, October 2025

5 DISCUSSION

According to the results of this study, it is clear that the vulnerability of households in Bekily varies from one Fokontany to another, depending on the observed level of vulnerability. This variability is largely determined by the degree of exposure, the quality of housing, and the households' capacity to adapt. In this study area, the Tanambao-Morafeno Fokontany has the highest number of households directly exposed to flooding. There are 92 households considered highly exposed and 181 households considered exposed, placing this Fokontany at a medium level of vulnerability. It is followed by the Ambohimandroso Fokontany, which 55 households considered highly exposed and 123 households considered exposed, with a medium level vulnerability. In contrast, the Andranomamy Fokontany, with 41 households considered highly exposed and 95 households considered exposed, recorded a high level of vulnerability. This vulnerability is explained by the increased sensitivity of dwellings, linked to the high proportion of mud-brick construction (72%), as well as a low adaptive capacity (0.30). in the total, 188 households at high risk and 399 households at risk in this flood zone require the implementation of effective and sustainable protection strategies to reduce the risk of loss of life and property in the event of a surprise flood. These strategies include improving housing types and constructing dikes to protect the local population.

This vulnerability is exacerbated by natural factors such as rainfall variability, which strongly influences the rivers's hydrological regime, anthropogenic factors related to population growth and riverbank development, and institutional factors, notably the lack of protective infrastructure and early warning systems, which limits the populations adaptive.

5.1 VULNERABILITY FACTORS OF THE CITY OF BEKILY

5.1.1 NATURAL FACTORS

i. Rainfall variability

The town of Bekily is located in the semi-arid region characterized by high rainfall variability and concentrated rainfall over à short period (Nicholson, 2011). During the rainy season, intense rainfall on dry, vegetation free soils promote runoff and rapid rises in watercourses (Lebel and Ali, 2009). Furthermore, Riquer et al. (1952), describe the Menarandra river as a torrential and violent watercourse, characterized by rapid flooding after heavy rainfall. This climatic variability is one of the major natural factors contributing to the vulnerability of households in Bekily. This rainfall pattern, which promotes rapid flooding of the Menarandra river, leads to considerable material and human damage during cyclones. For example, cyclone Honde on February 28, 2025, damaged approximately 4.000 houseoulds and caused three deaths in the town of Bekily (BNGRC). The victims were buried under the rubble of homes destroyed by the storm.

In 2020 as shown in Table III and Figure 3, the municipality received a total annual rainfall of 520.48 mm distributed over 90 days. The wettest months were January (95.67 mm) and February (124.78 mm), accounting for nearly 42% of the annual rainfall. Rainfall was very unevenly distributed, with nearly dry months such as September (2.96 mm) and August (6.74 mm), reflecting the semi-arid nature of the local climate.

TABLE III: MONTHLY RAINFALL DISTRIBUTION AT BEKILY STATION, YEARS 2020 AND 2022

	2020		2022	
Month / Precipitation (mm)	**Rain**	**Number of days**	**Rain**	**Number of days**
January	95,67	9	109,12	9
February	124,78	13	108,74	6
March	57,45	11	62,26	3
April	51,60	9	52,63	5
May	13,38	6	1,76	1
June	29,59	8	0	0
July	13,82	5	0	0
August	6,74	2	1,15	0
September	2,96	1	0	0
October	36,07	8	25,7	5
November	22,79	7	68,68	12
December	65,63	11	241,33	18
Annual total	520,48	90,00	671,38	59,00

Source : Regional Meteorological Service of Androy, October 2025

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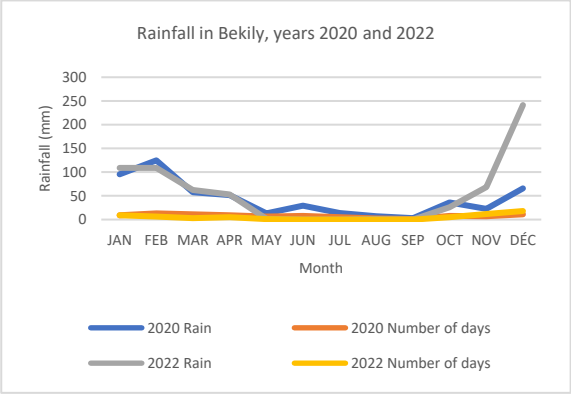


Figure 3. Monthly rainfall trends at Bekily station, 2020 and 2022

In 2022, the annual precipitation was higher, reaching 671.38 mm, but distributed over only 59 days. This indicates more intense but less frequent rainfall events. For example, January (109.12 mm) and February (108.74 mm) remained the wettest months, while several months, such as June, July, and September, were almost dry.

ii. Topography of the town of Bekily

In this town, houses are primarily located along the riverbanks. This location directly exposes the houses to flooding, especially since the town lacks a protective dike or hydraulic infrastructure to limit the river's overflows. The Menarandra River flows through a geological zone characterized by alluvial deposits of sand and silt along its bed, evidence of sediment accumulation over time in the surrounding plain during floods (Staël, 2013). These sedimentary deposits create low-lying, flat areas that are easily flooded during flash floods. Furthermore, the unstable alluvial soils increase the risk of collapse for houses built with mud bricks. Alluvial deposits often exhibit low bearing capacity and high compressibility when saturated with water, increasing the vulnerability of traditional buildings to ground movement during floods (FAO, 2013).

iii. Flash flood dynamics of the river and household vulnerability

The Menarandra River's fluvial dynamics result in rapid and often unpredictable floods. Riquier et al. (1952) described this river as having an irregular hydrological regime, characterized by flash floods linked to intense thunderstorms in the watershed. These floods frequently lead to bank erosion, flooding of low-lying areas, and the destruction of infrastructure located near the riverbed. The presence of remains of former infrastructure, including a swimming pool and a now-abandoned hotel on the riverbank, testifies to the violence of the Menarandra's floods. This proves that the vulnerability of households in Bekily is not only linked to climatic conditions, but also to the fluvial dynamics of the Menarandra River and the occupation of floodplains by the population. Braud et al., 2016 explained in the Journal of Hydrology (2016) that flash floods are generally linked to intense rainfall, rapid runoff, and low soil infiltration capacity, particularly in semi-arid environments.



Figure 4. Remains of a swimming pool (colored blue inside) and a hotel devastated by Cyclone Enawo, 2017 (concrete dal remaining)

In hydrology (Chaperon et al., 1993), the following empirical ratios are often appliedas indicted in Table IV:

i. Dry years: 0.5 to 0.6 of the interannual mean
ii. Wet years: 1.5 to 1.6 of the interannual mean

Applying these coefficients to 220 mm:

i. Decennial dry height (H): 220 × 0.55 ≈ 120 mm
ii. Decennial wet height (H): 220 × 1.55 ≈ 340 mm
iii. Runoff coefficient (C): (220 mm / 820 mm) × 100 ≈ 27 %

TABLE IV: WATER DEPTH DISCHARGED IN THE MENARANDRA RIVER

Station	**Menarandra**
Interannual discharged water depth H (mm)	220
Decennial dry H (mm)	120
Decennial wet H (mm)	340
Runoff coefficient **(%)**	27

Source : Chaperon et al., 1993.

The average flow of the Menarandra River at Bekily exhibits significant seasonal variability, directly reflecting the semi-arid climatic conditions characteristic of the Androy region (see Table V). During the rainy season (Chaperon et al., 1993), the river experiences rapid and violent floods, with peak discharges reaching 1,710 m^3/s during the decennial floods of 1971–72. These floods, often triggered by intense storm rainfall on the slopes of the Tsikofiky massif, generate strong runoff and significant sediment mobilization. The high runoff coefficient (K_3 = 0.35) reflects the rapid hydrological

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response of the basin, facilitated by sparse vegetation cover and the impermeable nature of the soils.

TABLE V: FLOW OF THE MENARANDRA RIVER DURING FLOOD AND LOW-FLOW PERIODS

Flow [Q (m^3/s)]	Flood	Low-Flow
Median	220	12
Five-year	1140	5
Decennial	1710	2
K^3(Runoff d'écoulement)	0.3	0.8

Source : Chaperon et al., 1993.

In contrast, during the long dry season, low-flow discharges become extremely low, dropping to 2–5 m^3/s, or barely 1–2% of the values observed during flood periods. This situation is explained by the near-total disappearance of surface runoff and the predominance of infiltration into the sandy alluvium of the floodplain. The runoff coefficient then drops to 0.08, indicating that only a small fraction of precipitation reaches the main channel. These variations reflect a strongly marked seasonality, typical of southern Madagascar's river basins. The Menarandra River thus demonstrates a contrasting hydrodynamic behavior, alternating between sudden water surges and prolonged deficits, posing a major challenge for sustainable water resource management. Field observations revealed remnants of a swimming pool and a hotel destroyed by Cyclone Enawo in 2017, located in the immediate vicinity of the Bekily bridge.

5.1.2 DEMOGRAPHIC AND ANTHROPOGENIC FACTORS

Bekily's vulnerability to sudden floods of the Menarandra River is further exacerbated by major demographic and anthropogenic factors. Indeed, the total urban population of Bekily-Morafeno has grown rapidly, increasing from approximately 10,000 inhabitants in 2001 (Wikipedia) to 20,915 inhabitants in 2018 (RGPH 3, 2018). This significant demographic growth exerts increased pressure on urban space, leading to more intensive occupation of areas near the riverbanks. Historically, before 2015, few constructions were established immediately along the Menarandra's banks. However, recent photos show urban development marked by housing built directly on the riverbanks. Moreover, this demographic pressure is accompanied by intensive use of the banks for subsistence farming, particularly maize and sweet potato cultivation, and for the production of mud bricks for construction due to the scarcity of wood resources in Bekily. These practices lead to the degradation of natural vegetation cover along the banks, which plays a crucial protective role by stabilizing soils and limiting erosion. The gradual disappearance of this vegetation intensifies bank erosion and further reduces the soil's capacity to absorb rainfall, exacerbating the risk of violent runoff and flooding.

5.1.3 INSTITUTIONAL FACTORS

In Bekily, there is no reliable protection system, such as a concrete levee or retention basin, and no local flood management policy is effectively in place. As a result, the risk of flooding remains high, and the population continues to be exposed to both material and human damages. As Pelling (2003) emphasizes, *"the reduction of urban vulnerability strongly depends on local governance and proactive planning."* This lack of governance is concretely reflected in the absence of flood zone mapping, an effective early warning system, and maintenance of existing infrastructure. Consequently, institutional weakness amplifies the vulnerability of Bekily's residents, particularly those living in precarious housing along the riverbanks.



(a) (b)

Figure 5: Agricultural activities (a) Cattle crossing on the Menarandra Riverbed (b) Residential house in Bekily for poor households

6 CONCLUSION

The analysis of Bekily's vulnerability to sudden floods of the Menarandra River shows that this exposure results from a combination of natural, anthropogenic, and institutional factors. Torrential river flows, rugged upper-watershed topography, low soil permeability, and upstream deforestation amplify flood intensity and speed. Human pressures, such as unplanned urbanization, intensive agriculture, and mudbrick production, further increase population exposure, while the lack of protective infrastructure and coordinated institutional planning exacerbates risk. To reduce vulnerability, an integrated approach is needed: riverbank stabilization, upstream reforestation, improved soil permeability, controlled urban expansion, public awareness campaigns, and strengthened drainage and levee infrastructure. Effective coordination among local and regional stakeholders is essential. Addressing natural, demographic, and institutional factors together can significantly protect populations and infrastructure and support sustainable development in this semi-arid region. Future studies should focus on detailed hydrological modeling and long-term monitoring to improve risk prediction and management. By combining interventions on natural, demographic, and institutional levels, it is

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possible to significantly reduce Bekily's vulnerability, protect its population and infrastructure, and promote sustainable urban and rural development in this semi-arid region of Madagascar.

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ABBREVIATION

- ACF: Action Against Hunger
- ADRA: Adventist Development and Relief Agency
- BNGRC: National Bureau for Risk and Disaster Management (Madagascar)
- FAO: Food and Agriculture Organization
- IPC: Integrated Food Security Phase Classification
- NGO: Non-Governmental Organization
- RPE: Education Promotion Relay
- SDSP: District Health Service
- UNDP: United Nations Development Programme
- UNICEF: United Nations Children's Fund
- WFP: World Food Programme