

Impact of Human Activities and Climate Change on the Flow and Fish Fauna of the Milo River, Urban Commune of Kankan, Republic of Guinea

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Abstract: The Milo River, the main tributary of the Niger River, is a vital resource for the urban commune of Kankan. However, it is subject to increasing pressure from human activities, exacerbated by the effects of climate variability (rainfall, drought, and bank erosion). This study aims to analyze the effects of anthropogenic factors on the hydrological regime and environmental quality of the Milo River. A combination of quantitative and qualitative methods was used, including satellite data analysis, field observations, fish sampling, and socio-environmental surveys conducted with riverside communities (fishermen, farmers, brickmakers, and sand miners). The study's results confirm a considerable drop in the water level in the Milo Riverbed, leading to a depletion of fish stocks. Agriculture, clay extraction from the riverbanks, sand quarrying, and brickmaking are the main human activities that negatively impact the river. Several fish species (*Malapterurus electricus*, *Brycinus longipinnis*, *Parachanna obscura*, and *Polypterus senegalus*) have been driven to extinction. Flow rate monitoring showed that during the rainy season, the average flow rate is 19.28 m³/s at station 1 and 11.83 m³/s at station 2, while during the dry season, the average flow rate is 4.88 m³/s at station 1 and 0.88 m³/s at station 2. The increase in human activities, combined with the effects of climate change, is intensifying the pressure on the Milo River. This situation manifests itself through a disruption of the hydrological regime, a degradation of water quality, and an impact on aquatic ecosystems. It becomes imperative to implement integrated and sustainable water resource management policies involving riparian communities.

Key words: Human impact, climate change, fish, flow rate, Milo, Kankan.

1. Introduction

Water is an irreplaceable common good, essential to the life of humans and all animal and plant species [1, 2]. Aquatic ecosystems cover 70% of the Earth's surface, including a significant 2.5% freshwater [3].

Over the past century, global water use has increased sixfold and continues to accelerate, with an approximate annual increase of 1%, driven by population growth, economic development, and changing consumption patterns. Climate change, coupled with a more fluctuating and uncertain supply, will exacerbate water scarcity in

already affected areas while creating water pressure in regions where water is currently abundant. Physical water insufficiency is often seasonal rather than persistent, but climate fluctuations can influence the amount of water available throughout the year in different areas [4].

Social interactions and ecological factors related to living in urban and rural areas significantly influence access to water. In many developing countries, especially in sub-Saharan Africa, the most spatially and socially marginalized groups face difficulties in obtaining safe drinking water. Extreme weather events such as droughts, floods, and storms can exacerbate these

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inequalities in access to water by disproportionately affecting vulnerable communities. This can lead to environmental disparities [5].

However, due to the intensification of human activities and urbanization, some rivers are suffering significant damage, especially in the lower reaches of their course [6].

Guinea possesses a rich and diverse hydrological potential. Many rivers in the sub-region originate there. The hydrographic network comprises 1,161 rivers, organized into 23 drainage basins. Fourteen rivers of international importance flow through the country, including the Niger river, whose basin is shared by nine countries in the sub-region. Unfortunately, water resources are currently threatened by various human activities (extensive farming, open-pit mining, illegal fishing, brush fires, brickmaking on riverbanks, etc.) as well as by the detrimental consequences of climate change. Furthermore, the population's lack of awareness of institutional and legal frameworks hinders the sustainable management of water resources [7].

The Milo River, a tributary of the Niger River, is vital to the urban municipality of Kankan. It provides water for agriculture, ensures the supply of drinking water, and supports numerous economic activities. However, it is subject to human pressures from agriculture, sand mining, deforestation, brickmaking, large-scale household waste production, the production of plastics for water bags, and increasing, uncontrolled urbanization. All of this has negative impacts on water quality and the river's aquatic ecosystems, which are extremely important to the local communities.

In the urban municipality of Kankan, the human impact on the Milo River is already evident, particularly regarding water quality, aquatic biodiversity, and aquatic ecosystems. Activities such as large-scale agriculture, uncontrolled urbanization, sand extraction, small bag water production, the construction of garages on riverbanks, brick production, and waste management can lead to river contamination, a reduction in the amount of accessible water, degradation of natural

ecosystems, and an increase in water temperature, among other consequences. These impacts can have detrimental repercussions on the health of aquatic ecosystems and the human communities that rely on the river for various purposes.

In the context of climate change, human actions can be amplified, leading to an intensification of extreme events such as floods, droughts, and storms. Analyzing and measuring these effects is essential for developing adaptation measures to ensure the sustainability of the Milo River and the communities that depend on it.

2. Materials and Methods

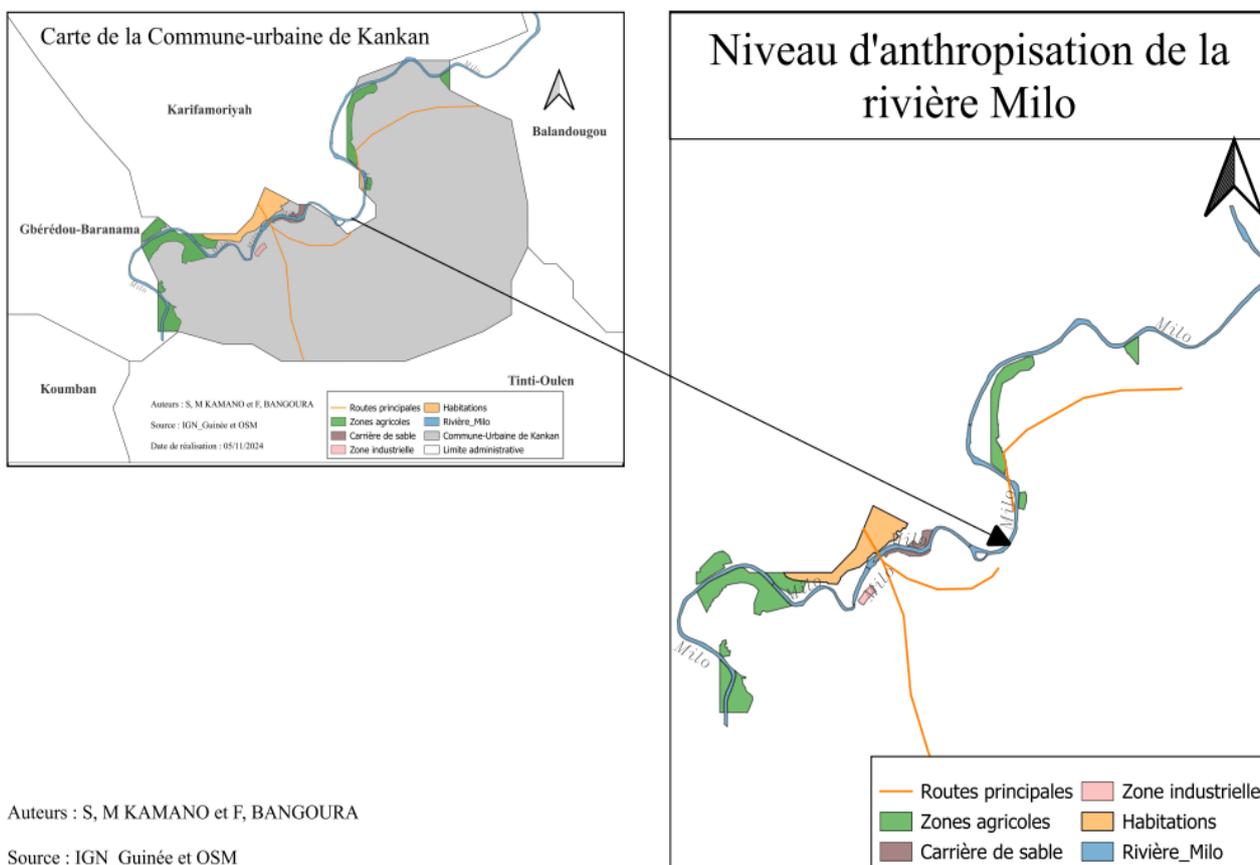
2.1 Presentation of the Study Area

Kankan, the capital of the administrative region and the chief town of the prefecture of the same name, covers an area of 334 km² and is home to approximately 195,002 inhabitants. This welcoming city, often referred to as "Nabaya", is located between 10°7'15.323" north latitude and 9°32'42.349" west longitude (RGPH, 2014).

2.2 Methods

This study adopted a mixed approach (quantitative and qualitative) combining documentary and satellite data analysis, field observation, fish sample collection, and socio-environmental surveys of riverside populations.

Following the literature review, an inventory of ecosystem services was carried out through direct observation (visual identification of human activities taking place along the river) followed by surveys. Surveys were conducted with local officials and various stakeholders (fishermen, farmers, brickmakers, sand extractors, river residents, etc.). Sampling targeted, within each category, those with several years of experience in their respective activities. The Sphinx software enabled the creation of a data collection space for each stakeholder and the processing of post-collection data. Single-answer, multiple-answer, scaled, and numerical questions, among others, yielded quantitative data, while text-based questions provided primary qualitative data. These



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Source : IGN_Guinée et OSM

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Fig. 1 Study area and levels of human impact on the river.

questions related to socio-demographic information, activities carried out, perceptions of changes, polluting practices, and knowledge of the effects of climate on the Milo River. These developed questionnaires facilitated individual and focus group interviews with the different stakeholders.

Next, an analysis of satellite imagery of vegetation cover over a decade (2014-2023) along the Milo River was conducted. Using Google Earth, detailed information on vegetation cover was obtained. Areas heavily impacted by degradation were randomly selected, and the distance between impact zones was measured over time. This data enabled QGIS to generate a map highlighting the impacts of human activities on the Milo River.

To determine the flow rate during both the dry season (January) and the rainy season (September), two

stations (A and B) along the river profile were selected. A rope, divided into three main sections, was deployed according to a specific sequence to determine the wetted cross-section and measure the water flow velocity. To determine the width, a marked rope was deployed perpendicular to the water current between two trees, followed by precise measurement of the distance between the two marked points on the rope using a measuring tape. The depth was estimated using a large stone attached to one end of the rope, submerged vertically to the riverbed, and the submerged portion of the rope was measured with a measuring tape.

The speed was obtained by averaging several measurements taken at different levels along the bank. A weighted plastic bottle painted in a bright color was used as a float. The float was thrown upstream. Upon

sighting the float, the stopwatch was immediately started and stopped when it passed the marker located downstream. After three successive measurements, the surface speed (V_s) was calculated using the following formula:

$$V_s \text{ (m/s)} = \frac{\text{distance} \times 3}{\text{temps} 1 + \text{temps} 2 + \text{temps} 3}$$

The current speed is faster at the surface, and therefore a correction factor of 0.6 is used to calculate the average speed (V_m) from the surface speed (V_s): $V_m = V_s \times 0.6$

Two parameters contributed to determining the cross-sectional area: width and depth. The flow rate of a river is calculated using two parameters: the wetted cross-sectional area and the current velocity. The general formula is as follows: $Q = S \times V \times 0,85$ [8] With Q = river flow rate; S = wetted cross-section of the river and V = river flow velocity.

To measure the impact of the river's water level, several observations were made with fishermen. This approach allowed us to understand Endangered species and those that disappeared from the area during the investigation period were identified. An inventory of all human activities having a direct impact on the river was compiled.

2.3 Statistical Analysis of Data

The collected data was entered into an Excel spreadsheet, which served as the basis for processing and generating graphical representations. QGIS

software was used to map human activities and their impacts on the Milo River.

3. Results

3.1 Field Investigation

3.1.1 Population Growth in the Urban Municipality from 2014 to 2023

The population of the urban commune increased from 195,002 to 250,607 inhabitants between 2014 and 2023. This population growth is affecting the water quality of the Milo River.

3.1.2 Intensification of Rainfall

Over the last decade, the amount of rain has varied greatly, with the highest peak recorded in 2018 (2083 mm) and the lowest amount of rain recorded in 2017 with 1107.8 mm (Fig. 3).

3.1.3 Quantity of Sand Extracted per Day

Fifteen (15) actors are involved in the sand sector, with a daily production that varies from 100 to 1,000 m^3 . Depending on the workforce and their technical and financial resources, the lowest production (100 m^3) was recorded by three actors and the highest was observed in two sand extractors (1,000 m^3).

3.1.4 Quantity of Bricks Produced

This figure shows a disparity in the quantity of bricks produced per day and per actor, ranging from 500 to 10,000 bricks. Two out of eight actors, with greater technical and financial resources, employ a large workforce with a daily production capacity of 10,000 bricks.

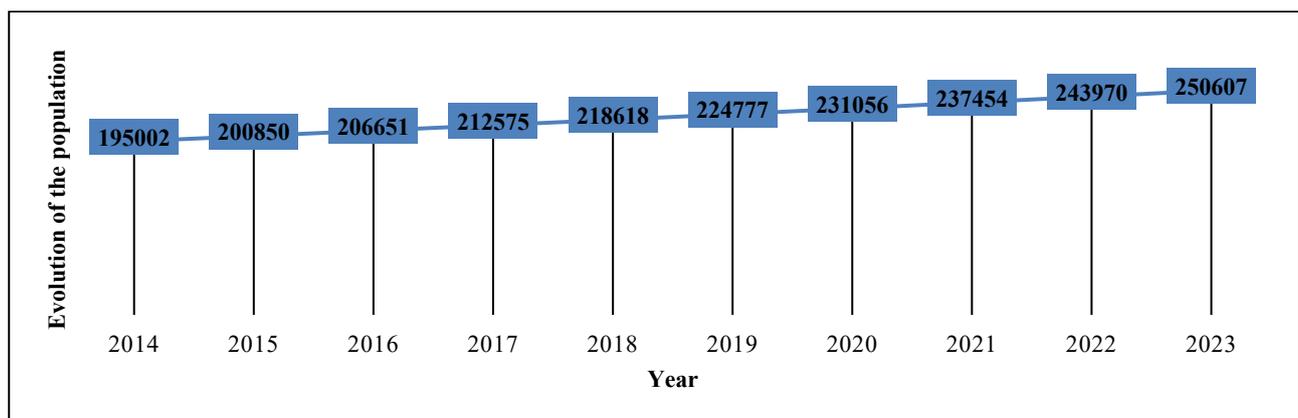


Fig. 2 Population growth of the urban commune of Kankan (Archives of the Governorate of Kankan 2025).

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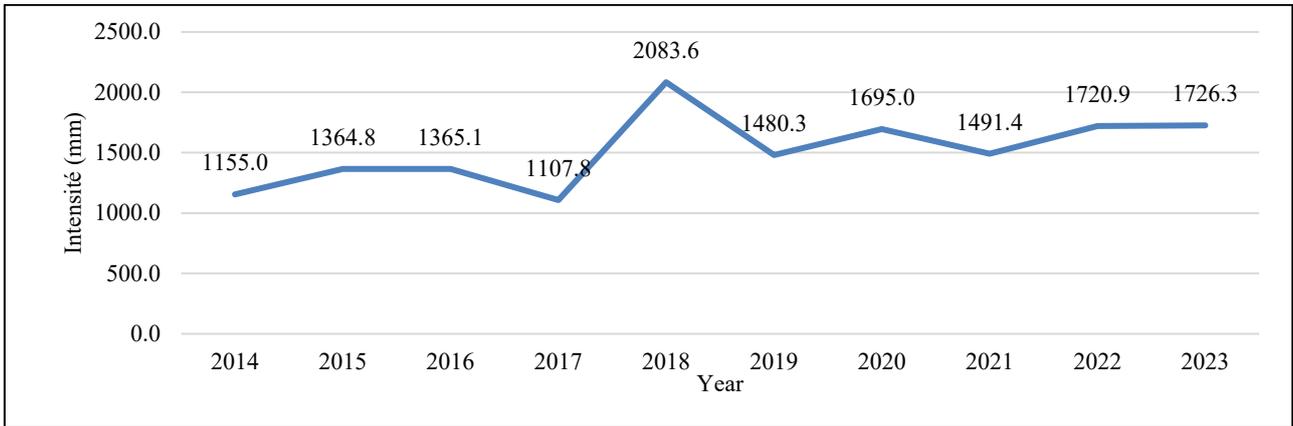


Fig. 3 Rainfall intensity in the urban commune of Kankan.

3.1.5 Position of the Fields in Relation to the Riverbank

The majority of farmers (40 out of 47), or 85.11%, operate directly on the riverbank, within 50 meters of the shore, while 14.89% have their fields more than 50 meters from the riverbank (Fig. 6). The presence of most fields in the immediate vicinity of the river aims

to facilitate access to water for crop irrigation. This proximity is associated with unsustainable practices such as excessive tree cutting, frequent bushfires, and the overuse of agricultural inputs. These factors contribute significantly to erosion, pollution, and eutrophication of the aquatic environment, with consequences for aquatic life.

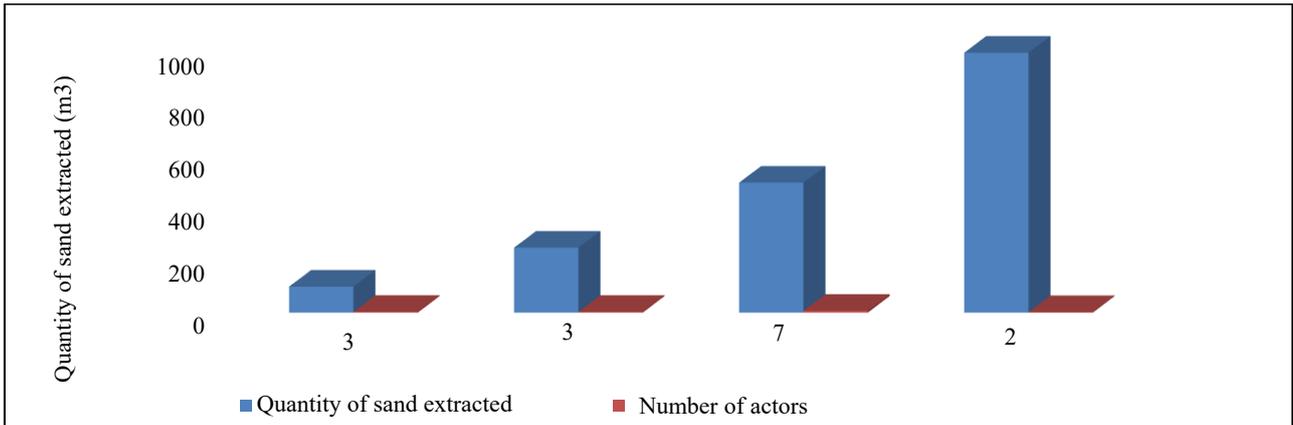


Fig. 4 Quantity of sand extracted per day and per actor.

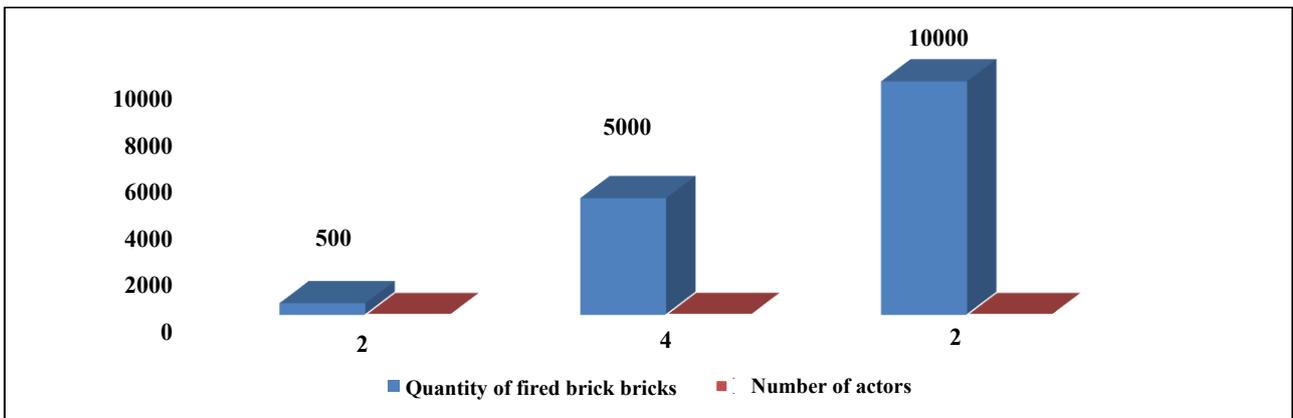


Fig. 5 Quantity of bricks produced per day and per actor.

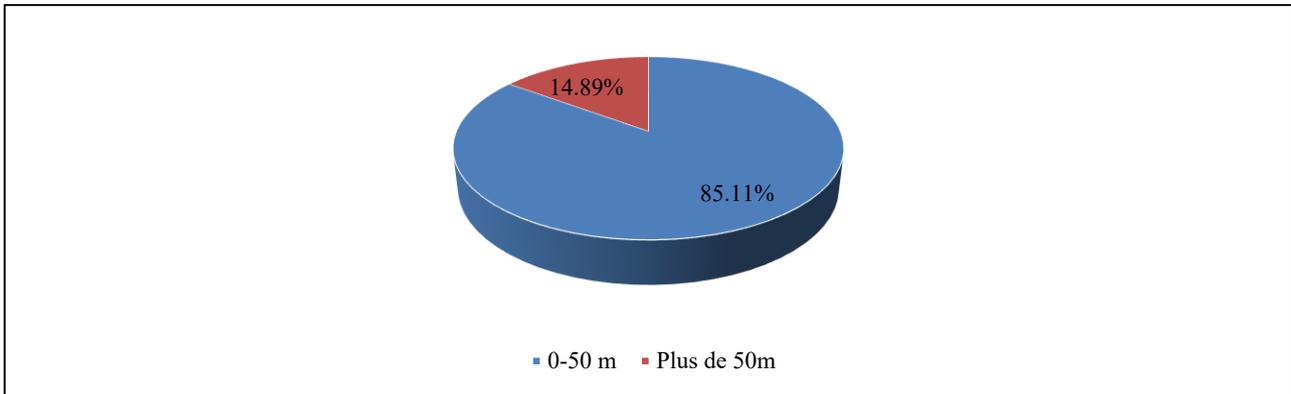


Fig. 6 Distance of agricultural fields from the riverbank.

3.1.6 Household Waste Management Methods

Among those surveyed, 50% throw their waste near the river, while 22% incinerate it during the dry season, and 28% dump garbage in gutters and other inappropriate places to eventually be washed into the watercourse (Fig. 7).

3.2 Impact of Human Activities on the River

To measure the level of anthropization and the consequences on the river ecosystem and the river population, the interpretation of satellite images (Fig. 8), the evolution of the flow of the watercourse (Table 1), the abundance of fish fauna (Table 2) and the inventory of human activities were recorded in the tables and figure below.

The Milo River underwent significant transformations between 2014 and 2023. In 2014, it was primarily used for agriculture, covering 41 hectares, with a floodplain of 53.1 hectares, a small forest of 0.86 hectares, and no sand mining or brickmaking. By 2023, a marked

change was observed with the introduction of sand mining (7.56 hectares) and brickmaking (34.2 hectares), while the area dedicated to agriculture decreased to 17 hectares. The floodplain disappeared, indicating significant changes in the landscape and the deformation of the riverbed. Although household pollution linked to the advance of the built-up area has increased slightly in terms of area, from 0.02 kilometre in 2014 to 0.1 hectare in 2023, these changes underline a major shift in land use, with potential implications for the local environment and agricultural practices.

During the rainy season, stations A and B had average depths and average flow rates of 12.07 m and 19.28 m³/s, and 9.02 m and 11.84 m³/s, respectively, while during the dry season, they were 4.25 m and 4.88 m³/s at station A and 2.5 m and 0.88 m³/s at station B (Table 1). This variation is likely due to increased human activity at both stations, contributing to channel deformation, excessive water level drops, bank erosion, and variations in rainfall intensity.

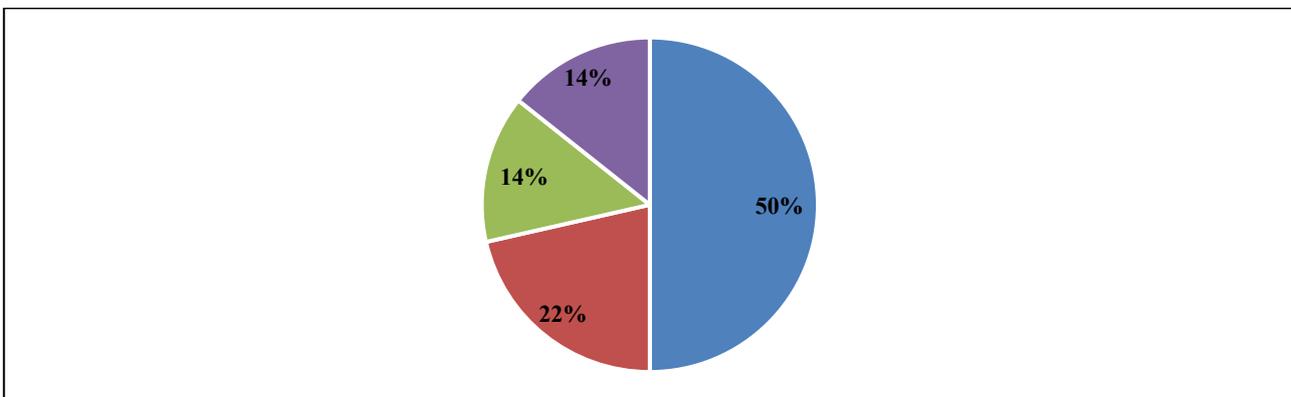


Fig. 7 Waste management methods.



Map of the Milo River in 2014

Map of the Milo River in 2023

Fig. 8 Spatiotemporal distribution of vegetation cover along the river between 2014 and 2023.

Table 1 Evolution of the water flow of the Milo.

Body of water	Periods	Station	Average depth (m)	Average speed (m/s)	Width (m)	Average flow rate (m ³ /s)
MILO River	RAINY SEASON (September)	Station A	12.07	0.0232	81.03	19.29
		Station B	9.02	0.0226	68.25	11.84
	DRY SEASON (January)	Station A	4.25	0.0146	74.25	4.88
		Station B	2.5	0.0117	30.5	0.88

Table 2 Fish fauna of the Milo River.

Families	Scientific names	Names in French	Local names (Maninka)
Predominant species			
Hepsetidae	<i>Hydrocynis forskalii</i>	Tigerfish	Waran
Osteoglossidae	<i>Heterotis niloticus</i>	Nile heteros	Fandan
Mochokidae	<i>Synodontis schall</i>	Schall de wahrindi	Konkon
Mormyridae	<i>Petrocephalus bane</i>	Scourge	Nana
Clariidae	<i>Clarias gariepinus</i>	Catfish	Mano
	<i>Clarias anguilaris</i>	Senegal catfish	
	<i>Heterobranchus longifilis</i>	Vundu or catfish	Kandan
Cichlidae	<i>Oreochromis niloticus</i>	Nile tilapia	Tèbengbè
Bagridae	<i>Bagrus bajad</i>	Sudanese catfish	Sanfi
Rare species			
Centropomidae	<i>Lates niloticus</i>	Nile perch	Salen
Cyprinidae	<i>Labeo senegalensis</i>	African carp	Bama
Gymnarchidae	<i>Gymnarchus niloticus</i>	Gymnastics of the Nile	Kolon
Citharinidae	<i>Citharinus latus</i>	Vavi	Tanka
Extinct species			
Gymnotidae	<i>Malapterurus electricus</i>	African electric catfish	Miri miri
Alestidae	<i>Brycinus longipinnis</i>	African long-finned tetra	Tinani
Channidae	<i>Parachanna obscura</i>	Snake-headed fish	Soukoudén
Protopteridae	<i>Protopterus senegalus</i>	Protopter	Mawondén

Table 5 Impacts of human activities on the Milo.

Human activities	Causes	Consequences
Fishing	<ul style="list-style-type: none"> Abandonment of nets in the water Illegal fishing Use of nets not authorized 	<ul style="list-style-type: none"> Ghost fishing for resources Filling in of the river Degradation of the riverbed Scarcity of resources Destruction of aquatic habitats Alteration of the riverbed Decline in fish populations Imbalances in the aquatic ecosystem
Sand extraction	<ul style="list-style-type: none"> Construction of infrastructure (houses, huts, bridges, etc.); Poverty ; Lack of employment; Ease of obtaining raw materials (sand and clay); 	<ul style="list-style-type: none"> Water quality deterioration Shoreline erosion Alteration of hydrological regimes Waste management problems. The excessive exploitation of clay Environmental pollution during brick firing
Making fired bricks		<ul style="list-style-type: none"> Water consumption Degradation of water quality and riverbanks Hydrological changes Deterioration of water quality The loss of natural habitats
Market gardening activities	<ul style="list-style-type: none"> Easy access to water (for irrigation or brick making...) The pipeline, the elimination of meanders; 	<ul style="list-style-type: none"> Pollution from agricultural inputs such as pesticides and fertilizers The modification of the hydrological regime Increased sedimentation Modification of physico-chemical parameters
Riverside activities		<ul style="list-style-type: none"> Pollution from discharges of chemical substances, solid waste or wastewater; Reduction in the length of the watercourse; Oversized riverbed; Denaturation of the substrate at the bottom of the bed; Introduction of exotic species

Table 2 shows that certain species persist in the Milo ecosystem and are subject to periodic fishing, a phenomenon attributable to fluctuating water levels. This is evidenced by the presence of some rare species (4 species) in the river, while 4 fish species have disappeared. This problem is intrinsically linked to the deterioration of riparian zones, spawning grounds, and the resting areas of aquatic species, as well as to an intensification of pollutants and a significant variation in water quality caused by human activities.

4. Discussion

Aquatic ecosystems provide many goods and services that are often undervalued [9], particularly through its fish fauna, which provides a source of protein and income for riverside communities [10]. However, human activities, such as overfishing and pollution, degrade water quality and threaten the biodiversity of these ecosystems. Freshwater ecosystems, in particular, are experiencing greater biodiversity declines than

terrestrial ecosystems [11].

Along the Milo River, urbanization, marked by population growth, appears to be the main factor responsible for the degradation of the riverbanks and fish fauna. This observation supports the assertion of Kilingwa, Mutanda, Swana, Tabou, Nseu, and Kiamfu [12] who asserted that the negative impacts of human activities on water bodies can be classified into three categories: physical alteration of habitats, chemical degradation of water, and changes in species assemblages. Sand extraction, brickmaking, agriculture practiced at river level, and poor waste management have significant consequences not only for the health of living organisms but also for their environment. All of this represents a threat that jeopardizes the capacity of aquatic ecosystems to adapt to the effects of human actions and even environmental changes [13].

The Milo River underwent significant transformations between 2014 and 2023. In 2014, the main activity was agriculture, occupying 41 hectares, with a floodplain of

53.1 hectares. However, by 2023, a marked change was observed with the establishment of sand extraction operations (7.56 hectares) and fired brick manufacturers (34.2 hectares). At the same time, the area of agricultural land decreased by 17 hectares. The floodplain disappeared, indicating significant changes to the landscape and deformation of the riverbed. Although household pollution related to urban sprawl increased in area in 2023, these changes highlight a major shift in land use, with potential implications for the local environment and agricultural practices. These results differ from those found by AMEC [14], who observed a 61-hectare forest loss between 2000 and 2014, due to agricultural expansion and urbanization, with an average annual deforestation rate of 4.06 hectares. Satellite observation of vegetation cover along the Milo River between 2014 and 2023 confirms environmental changes driven by several constraints, the main ones being climatic and anthropogenic, thus affecting both natural and human systems [13]. This marked change could be explained by the intensification of human activities such as brickmaking and sand extraction, followed by the disappearance of the floodplain, as well as urbanization in the river's vicinity.

During the rainy season, stations A and B had average depths and average flow rates of 12.07 m and 19.28 m³/s, and 9.02 m and 11.84 m³/s, respectively, while during the dry season, they were 4.25 m and 4.88 m³/s at station A and 2.5 m and 0.88 m³/s at station B. This variation is likely due to the intensification of human activities in the study area, contributing to channel deformation, excessive water level drops, bank degradation, and variations in rainfall intensity over the years. These results differ from those found by AMEC [14] who obtained flow rates of 1100 m³/s and 1000 m³/s in the same areas during the flood period, compared to 10.83 m³/s and 9.72 m³/s during the low-water period. This discrepancy in results is attributed to the assessment method, the excessive degradation of the river due to the advanced destruction of riparian

vegetation, the significant increase in human activity, soil impermeability caused by the presence of gravel, and the scarcity of rainfall. Furthermore, rainfall fluctuated considerably between 2014 and 2023. These results differ from those found by Shukla et al. [15] in the Punjab region, Pakistan. This situation is partly due to increased human activity and shorter rainy seasons. This variation in rainfall in the Kankan commune could have negative impacts on the Milo River. It should be noted that periods of reduced rainfall could decrease river flow, threatening water availability for the ecosystem and human activities, thus compromising water quality and the health of the aquatic ecosystem.

The fish fauna of the Milo River remains rich and diverse. Nine predominant species belonging to seven fish families have been identified, along with four rare species belonging to the families Cyprinidae, Centropomidae, Gymnarchidae, and Citharrinidae, and finally, four extinct fish species: *Malapterus electricus*, *Brycinus longipinnis*, *Parachanna obscura*, and *Protopterus annectens*. Therefore, the Milo River exhibits a richness and diversity of fish fauna, as confirmed by Kilingwa, Mutanda, Swana, Tabou, Nseu, and Kiamfu [12]. At the Mpieme River (Kinshasa, Democratic Republic of Congo), 18 fish species were recorded. The presence of rare or extinct fish species could be misleading regarding the river's health (improved environmental quality) or could be explained by riparian degradation, the effects of climate change, or changes in the hydrological regime observed in the environment, such as alterations in water temperature, flow rate, or water level, or changes in connectivity during floods. However, this study highlights the decline in fish production over time, which could be attributed to low water levels, a phenomenon caused by increased human activity along the river, leading to the migration and extinction of certain fish species.

Furthermore, human activities related to fishing, sand extraction, brickmaking, market gardening, and others have significant detrimental consequences on

the dynamics and life of organisms in this ecosystem. Indeed, illegal fishing and the use of unauthorized fishing gear lead to increased pressure on the environment and resources, resulting in decreased catch levels, degradation of the riverbed, and even silting up of the river. The destruction of aquatic habitats, uncontrolled urbanization, the discharge of pollutants (chemical, solid, liquid, etc.), and the use of agricultural inputs such as chemical fertilizers and pesticides have caused an imbalance in the aquatic ecosystem, a degradation of water quality, a modification of the hydrological regime, sedimentation, and alteration of riparian vegetation, with the consequent destruction of spawning grounds and biological resting areas. These activities, over the years, have significant consequences for the ecosystem in general and could be a driver of extinction for threatened or endemic species of the Milo River, as highlighted [16] at the level of the N'zè river in the tropical forest zone (Taï National Park in Ivory Coast).

Furthermore, a certain disparity was observed in the quantity of sand extracted per day and per operator, varying from 100 to 1000 m³. This difference is attributed to the composition of the riverbed (sandy, muddy, mixed, etc.), the advanced degradation of certain sections of the river, and the types of substrate (sand, gravel, etc.), as well as the extraction methods used in each area. These results differ from those found by Reddy K., and Shanmugam A. (2006) [17] who recorded volumes of 10-50 m³ and between 100 and 500 m³ per day, respectively, depending on the stations studied along the Ponnaiyar River in Tamil Nadu, India. Regarding brick production, daily output was estimated at 500 to 10,000 bricks. This figure could be explained, in part, by siltation of the riverbanks limiting access to clay, insufficient equipment, fluctuating demand, resource depletion, and a lack of suitable labor, as well as by the level of demand itself. As for agriculture, particularly market gardening, the majority of those surveyed (78%) use chemical agricultural inputs to increase crop yields. This agricultural practice

promotes the appearance of nitrates, nitrites, and phosphates in the river (Milo), thus leading to eutrophication. These results, however, differ significantly from those found by Chantre E. [18] who report that all the farmers surveyed use chemical inputs.

5. Conclusion

This study assessed the impacts of human activities on the fish fauna of the Milo River in the Kankan commune of Guinea. Fishing, sand mining, brickmaking, agriculture, and other riverside activities are all human activities carried out along the Milo River that affect the health of this ecosystem. These anthropogenic activities, coupled with the effects of climate change (variations in temperature, rainfall intensity, and flow rate), have significant negative impacts on the abundance and diversity of aquatic organisms, such as fish, and on the physicochemical quality of the river water. The predominance of certain fish species can be an indicator of living conditions within the ecosystem, in addition to the various polluting activities carried out in its vicinity. The drastic decrease in the river's flow rate, particularly during periods of low water, combined with the physicochemical conditions of the water and the destruction of riparian vegetation, could explain the migration of some aquatic species and the disappearance of others. It is therefore essential to take appropriate measures for the better preservation and management of this waterway, which is under significant human pressure. This can be achieved through an assessment of the hydrological dynamics and bioecological pollution indicators of the Milo River (urban commune of Kankan) within the context of climate change.

References

- [1] Mimouni, Y. 2020. *Evaluation of the Physico-Chemical and Bacteriological Quality of Surface Waters in Three Sub-Basins of Tensift*. University of Liège, Scientific Research Publishing." Accessed November 7, 2025, available online at: <https://www.scirp.org/reference/referencespapers?referenceid=3448311>.
- [2] Denier-Pasquier, F. 2013. "Water Management and Use in Agriculture." Economic, Social and Environmental

- Council, France, accessed November 7, 2025.
- [3] Sow M. A. 2018. "Hydrology and Geochemistry of Dissolved and Particulate River Transport in the Milo River Basin, Republic of Guinea." Ph.D. thesis, National Polytechnic Institute of Toulouse (INPT), accessed June 19, 2025, available online at: <https://theses.hal.science/tel-04200980>.
- [4] UNESCO 2020. "United Nations World Water Development Report 2020: Water and Climate Change." Accessed 19 June 2025.
- [5] Diouf, K., Hellier, E., AN Fall, Taibi, A., Kane, A., and Ballouche, A. 2024. "Environmental Inequalities in Access to Water in Rural Areas: Flaws in Resource Governance or a Problem of Spatial Justice? The Case of the Gorom Lampsar Axis (River Delta), Senegal." *Vertig O - Rev. Électronique En Sci. Environ.* 24-2. doi: 10.4000/11qkz.
- [6] Mimouni, Y. 2020. "Evaluations of the Physico-Chemical and Bacteriological Quality of Surface Waters in Three Sub-Basins of Tensift." University of Liège, Liège, Belgium, accessed November 5, 2025, available online at: <http://hdl.handle.net/2268.2/10128>.
- [7] Camara, S., and Bangoura, A. 2017. "Valorisation des ressources en eau en Guinée pour la vue un développement économique et social durable." *J. Wat. Env. Sci.* 1: 106-114.
- [8] Mukrimaa, S. S., Nurdyansyah, E. F., Fahyuni, and Yulia Citra A. 2016. "Flow Measurement in Hydrology", *J. Penelit. Pendidik. Guru Sekol. Dasar* 6 (August) 128.
- [9] Brummett, R. E., Lazard, J., and Moehl, J. Oct. 2008. "African Aquaculture: Realizing the Potential." *Food Policy* 33 (5): 371-385. doi: 10.1016/j.foodpol.2008.01.005.
- [10] Yao, S. S. 2006. "Study of the Biological Diversity and Feeding Ecology of the Ichthyofauna of a West African Hydrosystem: The Case of the Comoé Basin, Côte d'Ivoire." Cocody-Abidjan University, Côte d'Ivoire, accessed November 7, 2025, available online at: <https://dicames.online/jspui/handle/20.500.12177/1737>.
- [11] Kamelan, T. M., Yao, S. S., Kouamé, K., Gervais, K. N., and Kouamelan, E. P. 2013. "Ichthyofauna of the Dodo River, Ivory Coast, West Africa: Update and Influence of Environmental Variables on Species Distribution", *J. Appl. Biosci.* 71: 5773-5785.
- [12] Kilingwa, C. M., Mutanda, S. K., and Swana, W. L., Tabou, T. T., Nseu, B. M., and Kiamfu, V. P. 2025. "Influence of Environmental Factors on the Ichthyofauna of the Mpieme River, Kinshasa, Democratic Republic of Congo." *ESI Prepr. Eur. Sci. J. ESJ* 21 (21): 185-185. Doi: 10.19044/esj.2025.v21n21p185.
- [13] Suski, C. D., and Cooke, S. J. 2007. "Conservation of Aquatic Resources Through the Use of Freshwater Protected Areas: Opportunities and Challenges." *Biodiversity and Conservation* 16: 2015-2029.
- [14] AMEC. 2014. Lower Columbia River Sculpin and Dace Life History Assessment (CLBMON-43). Year 5 Technical Report. Report Prepared for BC Hydro, Burnaby, BC. Prepared by: AMEC Environment & Infrastructure Ltd. 117 p. + 8 App.
- [15] Shukla A. K. *et al.* 2018. "Population Growth, Land Use and Land Cover Transformations, and Water Quality Nexus in the Upper Ganga River Basin", *Hydrology and Earth System Sciences*: 4745-4770.
- [16] N'Guessan, A., Berté, S., Kamelan, T., and Kouamelan, E. 2021. "Impacts of Anthropogenic Activities on the Ichthyofauna of the N'zè River in the Tropical Forest Zone, Taï National Park, Ivory Coast", *REB-PASRES* 6 (2): 25-36.
- [17] Reddy, K., and Shanmugam, A. 2006. "Environmental Impacts of Sand Mining: A Study in the Ponnaiyar River Basin, Tamil Nadu, India." *Environmental Geology* 6: 50.
- [18] Chantre, E. 2021. "Farmers' Learning Towards Input Reduction in Field Crops: Case of the Champagne Berrichonne of Indre in the Years 1985-2010.", 398p.