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RESEARCH ARTICLE

CONTRIBUTION TO THE SOLUTION OF THE FOUNKAMA MICRO-DAM PROBLEM IN THE FARANAH MUNICIPALITY, GUINEA

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Abstract

As part of efforts to ensure the rational use of the Founkama Plainan objective of Pillar 1, “Agriculture, Food Industry, and Trade,” of the SINANDOU 2040 program, initiated by the Guinean government, which aims for food sovereignty, the modernization of supply chains, and the development of local processing, this study proposes the rehabilitation of the existing Founkama micro-dam, built on the Niger River bed in 1981, by constructing a new modern micro-dam with a side spillway and fixed sill at the same site and elevation as the existing structure, to supplement the existing dam and address the scarcity of water resources during the dry seasona critical issue for the development of agro-pastoral activities in the Niger River plain area of Faranah. In this context, climatic, topographic, hydrographic, and pedological data were collected and analyzed for the study area. The results of the analyses showed a maximum average monthly rainfall of 325.7 mm, with maximum and minimum average monthly temperatures recorded around March (approximately 36°C) and around January (approximately 13°C), respectively, and a clay-loam soil texture.The design flood discharge (100-year return period) at the watershed level is estimated at 41 m³/s, while that at the spillway is 4.8 m³/s. Topographic data were used to determine the alignment of the new micro-dam and to confirm that the bottom of the reservoir basin is approximately flat. The results of these analyses were used to define the characteristics of the new micro-dam to be constructed, including its height (5.60 m), length (250.032 m), crest width (3.75 m), the slopes of the upstream (m_1=2.5) and downstream (m_2=2) embankments, and the total volume of compacted fill (16,500 m³). The reservoir volumes at Normal Water Level (NWL) and High-Water Level (HWL) are 412,000 m³ and 450,000 m³, respectively, which will enable the development of 180 ha of land for rice cultivation out of the 260 ha currently comprising the estate. The intake structure includes a 300-mm-diameter pipeline 280 m long.As for the spillway structure, it includes a gate 2 m wide and 1.50 m high, capable of discharging a flow rate of 4.8 m³/s into the 9.35 m long stilling basin. The rehabilitation of the existing micro-dam, through the construction of a new structure meeting the aforementioned specifications, could make this resource available year-round for the development of agricultural and pastoral activities in the Founkama plain, within the urban municipality of Faranah.

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Introduction: -

Dam construction has been one of the oldest and most fascinating activities known to humankind, as water has always been the most cherished and precious element of life. Building dams on a river disrupts the natural ecosystem. This new situation leads to harmful problems both upstream and downstream of the structures (Remini et al., 2019). Added to this is climate change, which is one of the most pressing global challenges. Its impacts have become increasingly visible, ranging from rising global average temperatures to the intensification of natural disasters (floods, prolonged droughts, wildfires, etc.). Drought and water stress have become one of the most visible and devastating consequences of climate change on a global scale. According to (El Ghazlani, Benaabidate, &Zemzami, 2023), "the vulnerability of water resources to climate change is inevitable," and the UN predicts that by 2025, one-third of the global population will be affected by water stress. Hence, understanding climate change and its impact on water resources is now a critical necessity.

In West Africa, agriculture forms the backbone of the economy in most countries. As in many other countries, agricultural activities play a key role in the economic and social development of the Republic of Guinea. In Guinea, approximately 70% of the population practices rain-fed agriculture. In Upper and Middle Guinea, more than 75% of the land consists of lowlands and plains, but unfortunately, these areas are poorly developed (PANA, 2007). In the Faranah Prefecture, the existing Founkama micro-dam was built in 1980. The primary objective of this structure at the outset was to irrigate 150 hectares of the Founkama plain, with the aim of meeting the food needs of students at the Valery Giscard d'Estaing Higher Institute of Agronomy and Veterinary Medicine in Faranah (ISAV-VGE/F) at the time, while also serving as a practical application site for theoretical courses. The structure was built along the road connecting the urban municipality of Faranah to that of Dabola. To provide a sufficient volume of water capable of irrigating the entire area at the time (150 ha), it was necessary to construct a structure with a crest height of at least 10 m.This would require the construction of a dike extending from the farm on the north side to the foot of Dandaya Hill (in the Faranah urban district) on the south side. The water from the reservoir would flood the surrounding homes (nearly 30 families at the time) and, worse, would have a negative impact on the bridge over the Founkama River. For these socio-legal and administrative reasons, the Authority at the time had asked the Institute to build a structure without displacing the population and without affecting the bridge. Thus, the Institute opted to construct a micro-dam, meeting the Authority's conditions and capable of serving educational purposes, as well as irrigating an area of 8 ha during the dry season. However, since 1982, the Institute has embarked on a comprehensive program of analysis and solution-seeking for the development and operation of the entire area at that time (150 ha) throughout all seasons, in order to resolve the mismatch between the reservoir's capacity and the irrigation water needs across the entire estate and to ensure the development of agro-pastoral activities in the Founkama plain in Faranah. It should be noted that the data to date has changed due to the strong population growth recorded in recent years. The entire estate now has a total area of 260 ha, of which 180 ha are to be developed.

This focus of the Institute (ISAV-VGE/F) aligns well with Pillar 1, "Agriculture, Food Industry, and Trade," of the SINANDOU 2040 program launched by the Guinean government, which aims to achieve food sovereignty, modernize supply chains, and develop local processing. This justifies the relevance of this study titled "contribution to the solution of the Founkama micro-dam problem in the Faranah municipality, Guinea." The objective of this study is the year-round hydro-agricultural development and utilization of 180 ha out of the 260 ha currently comprising the Founkama plain. Thus, as a first step, climatic, topographic, hydrographic, and pedological data were collected and then analyzed for the study area. The results of these analyses were used to define the characteristics of the new micro-dam planned for construction as part of the rehabilitation of the existing structure, with the aim of achieving the objective of this study.

Presentation of the study area: -

This study is being conducted in the Republic of Guinea, in the Faranah Prefecture.

Presentation of the Faranah Prefecture: -

The prefecture is located between 10° 0' 00'' north latitude and 10° 49' 60'' west longitude. It is situated in the central-eastern part of the country, 460 km from the capital, Conakry. With an elevation ranging from 300 to 600 m, the Faranah Prefecture covers an area of 13,000 km² and has a population of 211,115, resulting in a population density of 16 people per square kilometer (Faranah Prefectural Health Directorate, 2010). It is bordered by:

- to the east by the Kouroussa Prefecture;
- to the west by the Mamou Prefecture and the Republic of Sierra Leone;
- to the north by the Dabola Prefecture; and

- to the south by the Kissidougou and Gueckedou Prefectures.

It comprises eleven (11) rural municipalities, namely: Banian, Beindou, Hèrèmakono, Nialya, Songoya, Tiro, Tindo, Marella, Passaya, Sandenia, Kobikoro, and the urban municipality. Figure 1 shows the geographical location of Faranah.

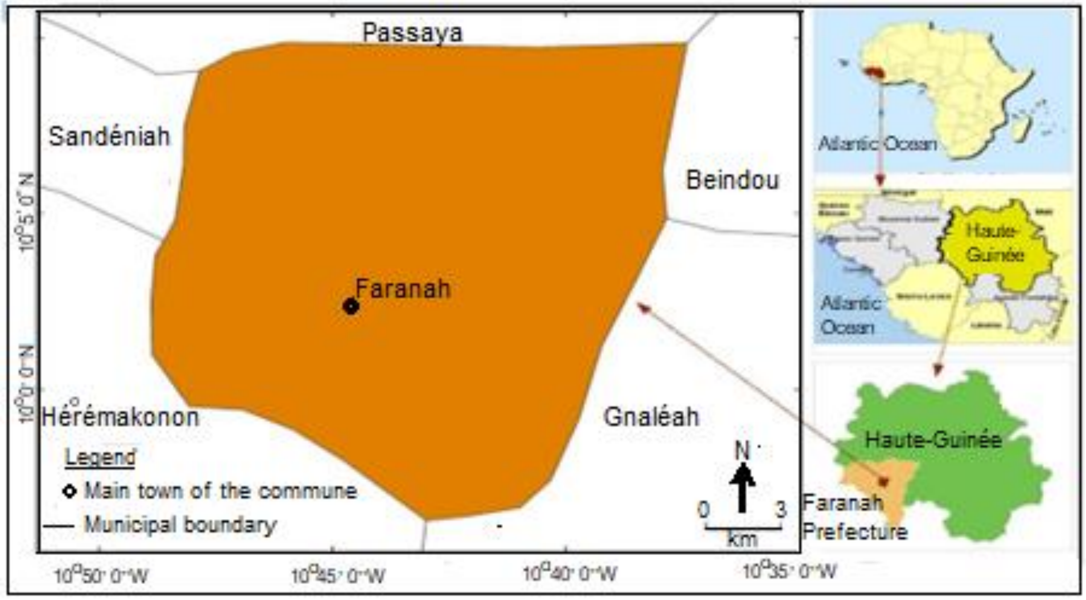

Figure 1: - Geographic location of Faranah (Agrhymet Regional Center, 2014)

Climate: -

According to the Köppen climate classification, these areas have a savanna climate, while according to the World Bank's Climate Change Knowledge Portal, the rainy season runs from May to October and the dry season from November to April. The climate in the vicinity of the urban municipality of Faranah is shown in Figure 2.

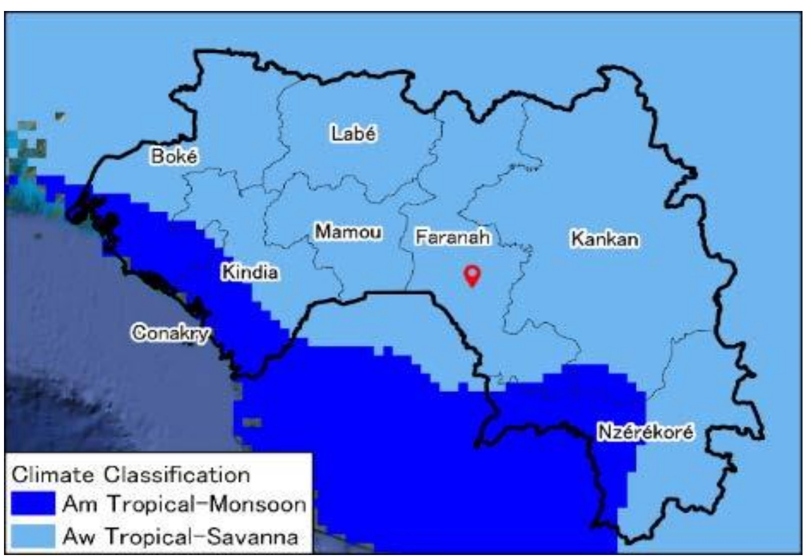

Figure 2: - Climate in the vicinity of the urban municipality of Faranah (World Bank, 2023).

Annual precipitation: -

Figure 3 shows precipitation levels between 1981 and 2019 at the Faranah weather station. The annual average is 1,529 mm, with precipitation of approximately 2,025.2 mm in wet years and approximately 979.1 mm in dry years. Annual rainfall data do not indicate an increase in precipitation resulting from climate change.

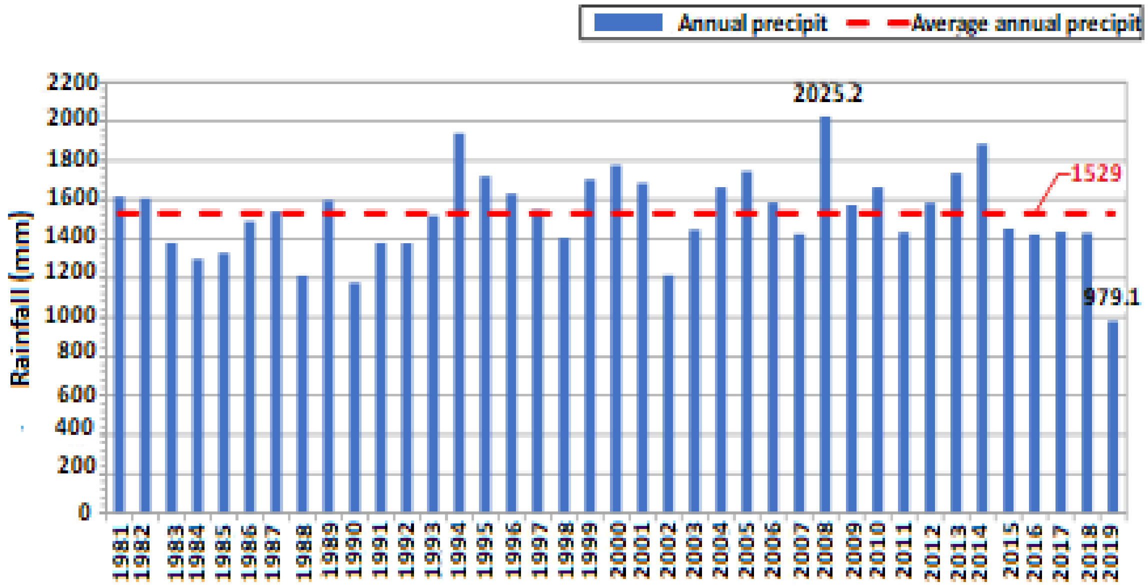

Figure 3: - Annual precipitation in the vicinity of the urban municipality of Faranah (Guinean National Meteorological Service).

Average monthly precipitation: -

Figure 4 shows the average monthly rainfall at the Faranah weather station. The rainy season runs from May to October, with a particularly rainy period during the three months from July to September, when rainfall is especially heavy. Maximum rainfall of 325.7 mm was recorded in August, and there is virtually no rain between early November and early May, a period that corresponds to the dry season.

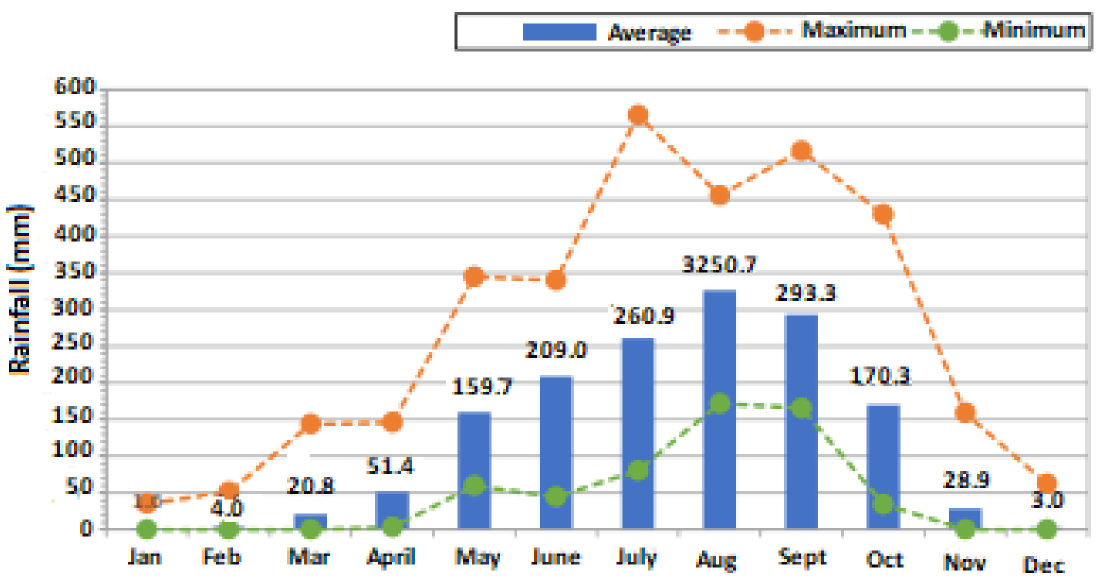

Figure 4: - Average monthly precipitation in the vicinity of the urban municipality of Faranah (Guinean National Meteorological Directorate).

Annual maximum daily precipitation: -

Figure 5 shows the annual maximum daily rainfall between 1981 and 2019 at the Faranah observation station. The maximum daily rainfall recorded was 152.3 mm in 2008. The 246.2 mm recorded in 2019 indicates that approximately 16% of the annual average fell in a single day, representing a sharp increase, even from a statistical standpoint. However, this value can be considered an anomaly, given that no notable changes were observed in water level and flow rate data for the period in question. Annual maximum daily precipitation over the past 20 yearsreached historic highs in 2008 and 2011, and shows a slight upward trend under the influence of climate change. (The 2019 value is an anomaly.)

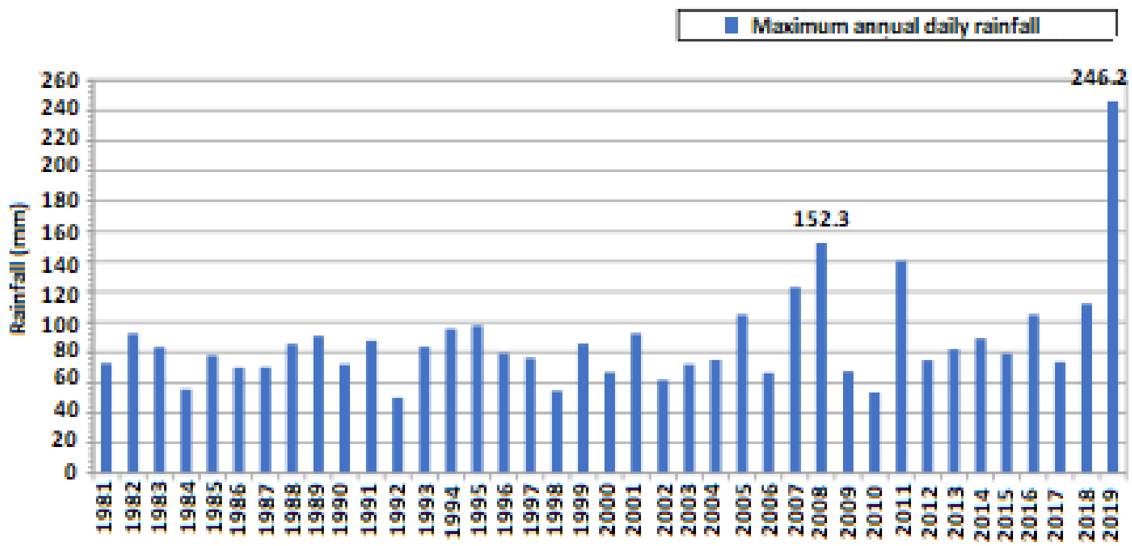

Figure 5: - Annual maximum daily precipitation in the vicinity of the urban municipality of Faranah(Guinean National Meteorological Directorate).

Temperatures: -

Observational data from the World Meteorological Organization (WMO) covering the past 30 years (1991–2020) show that the highest and lowest temperatures are recorded around March (approximately 36°C) and around January (approximately 13°C), respectively. The temperature in the vicinity of the urban municipality of Faranah is shown in Figure 6.

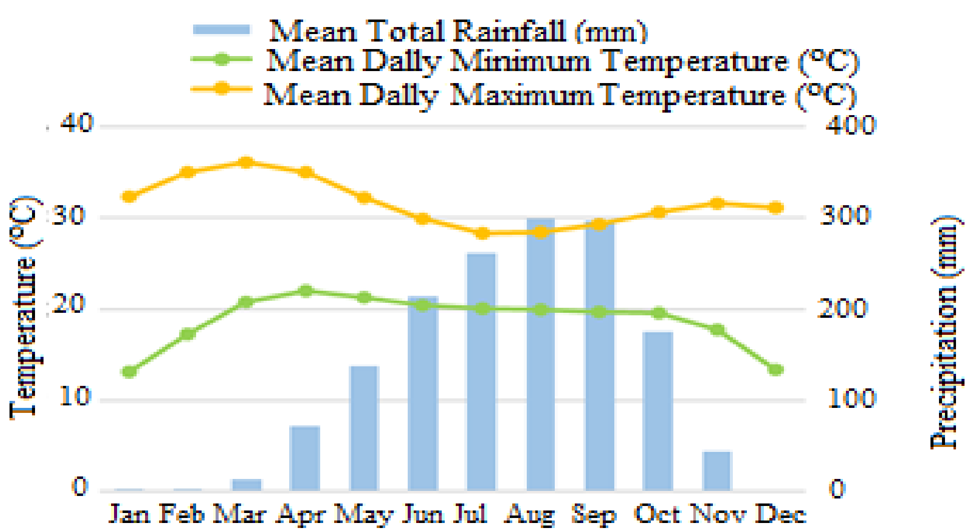

Figure 6: -Temperatures in the vicinity of the urban municipality of Faranah (WMO, 2023, World Meteorological Information Service)

Wind: -
Due to a lack of observations, wind conditions remain unknown, but an extremely dry trade wind known as the "harmattan," laden with sand, blows from the Sahara toward the Gulf of Guinea, generally between November and April, bringing the dry season to the region.

Soils: -
According to the National Soil Service (SENASOL, 2012), the main soil types found there are:
• Ferralitic soils (FAO Ferrasols, 1989): covering more than 62% of the prefecture's total area, they are suitable for cereal farming and arboriculture;
• Recent fluvial alluvial soils (FAO Fluvisols, 1989): These are suitable for floating rice cultivation and vegetable farming;
• Hydromorphic soils (FAO Histosols, Gleysols, 1989): These are suitable for flooded rice cultivation;
• Underdeveloped soils (Arenosols and Leptosols, FAO, 1989): These soils have a low organic matter content and warrant protection. They are not well-suited for agriculture;
• Lithic skeletal soils on scree (Regosols and Leptosols, FAO, 1989): These are found on mountain slopes and are intended for reforestation.

Vegetation: -
The Faranah Prefecture is a transitional zone between three natural regions of Guinea. Its vegetation consists of woody species such as Khaya senegalensis (A. Juss), Parkia biglobosa (J. Benth), Ceiba pentandra (S), Daniella oliverii (H), Albizia gygia (N); grasses: Echinochloacolona (L), Echinochloa pyramidalis (L), Pennisetum purpureum (L), Pennisetum subangustum (Schumps), Imperata cylindrica (Beauv), Rottboeliaexaltata (L), Urena lobata (L); Cyperaceae: Cyperus rotundus (L), Cyperus difformis (L); and Fabaceae: Calopogoniummucunoides (Desv).

Hydrographic network: -
The main waterways flowing through this prefecture are: the Niger River and its tributaries (Mafou, Falikou, Balen, Banian, Farakoba, and Koffi).

Knowledge of the study site: -

The Founkama Plain is located on the right bank of the Niger River, 500 meters from the Valery Giscard d'Estaing Higher Institute of Agronomy and Veterinary Medicine in Faranah (ISAV-VGE/F). It is bounded to the east by the micro-dam reservoir, to the west by the Niger River, to the north by the Zootechnical Research Center, and to the south by the Institute's experimental farm (ISAV-VGE/F).

The reservoir basin widens around the beds of the Foukama and Tourakose backwaters, located 1,235 m from the Faranah-Dabola national highway. It is bounded to the north by the land reserved for the Faranah Cemetery, to the south by the Bendou Road, to the east by the Karamoko CISSE estate, and to the west by the Dandaya neighborhood. Figure 7 shows a partial view of the geographical location of the study site, indicating the reservoir basin and the Founkama micro-dam.

The site's soil is hydromorphic with a clay-loam texture and a vegetation cover composed of wild grasses and sedges. The structures occupy 4% of the total area, or 6 hectares. The Founkama plain is divided into two (02) main parts:
• **High-risk zone:** This zone has not benefited from any adequate development;
• **Non-risk zone:** This zone has undergone significant development for over 30 years but is currently subject to the harmful effects of erosion and flooding.

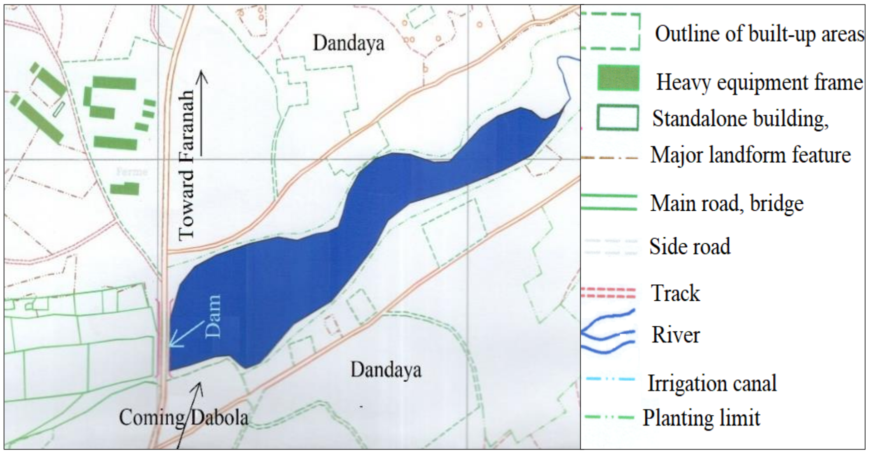

Figure 7: -Partial map showing the geographic location of the study site(ISAV-VGE/F, 2023).

Materials and Methods: -

Study data: -

The data used pertain to the hydrography, topography, geological and geotechnical conditions of the study area, and the characteristics of the reservoir of the existing Founkama micro-dam.

Hydrography of the study area: -

Originating in a mountainous region (at an elevation of approximately 610 meters) in southeastern Guinea, near the northeastern border with Sierra Leone, the Niger River flows northeastward before entering the Republic of Mali. It then turns southeastward, flowing through Niger and Nigeria, before emptying into the Gulf of Guinea, forming a large delta. Approximately 4,200 km long, with a watershed of about 2.1 million km², it is the third-longest river on the African continent. Figure 8 shows the study site's watershed. Upstream of the Founkama micro-dam in the urban municipality of Faranah, the watershed covers an area of approximately 3,100 km², with a river length of about 128 km and an average gradient of around 0.144%.

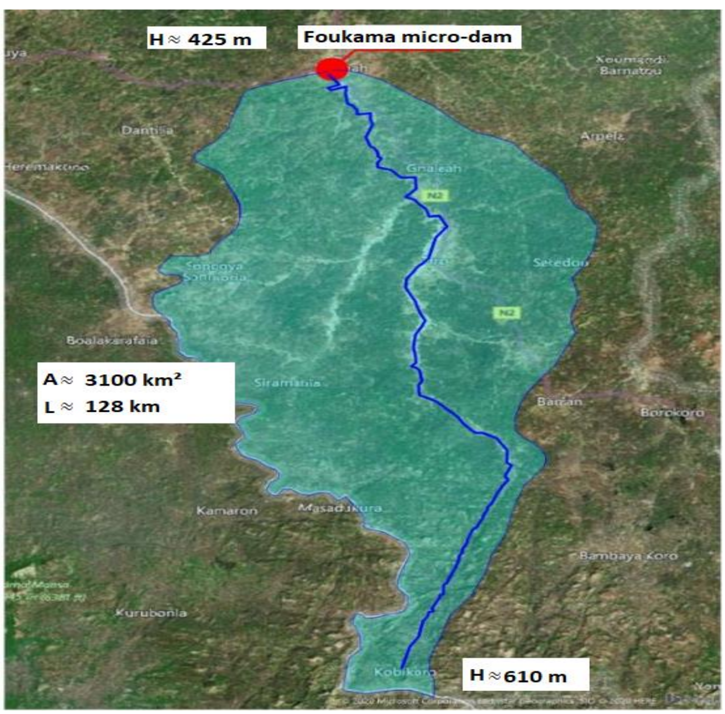

Figure 8: - Watershed of the Founkama site in the urban municipality of Faranah (JICA, 2023).

Topography of the study area: -
The topography around Faranah is characterized by valleys at an elevation of approximately 420 to 430 meters, carved into plateaus at an elevation of approximately 470 meters. It is characterized by the presence of a large valley traversed from southeast to northwest by the main channel of the Niger River, with the formation of numerous small-scale valleys that run perpendicular to it. The Niger River channel winds through the valley floor, thus exhibiting a characteristic of topography in the senile stage. For the study site, existing topographic surveys show that the valley floor is roughly flat and surrounded by hillsides. Figure 9 shows the topographic map of the area surrounding the urban municipality of Faranah.

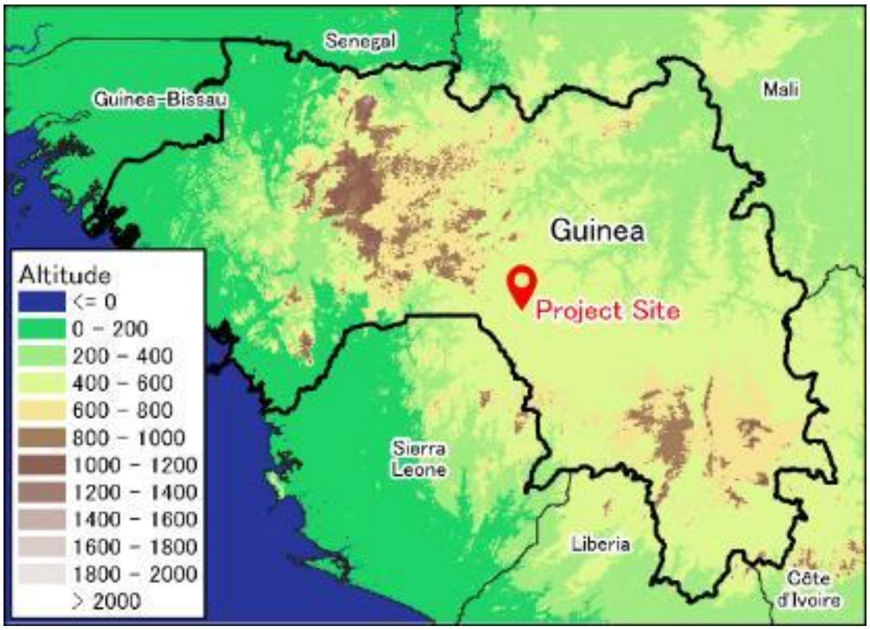

Figure 9: - Topography of the area surrounding the urban municipality of Faranah (JICA, 2023).

Geological and geotechnical conditions: -
The foundation soil of the existing micro-dam is impermeable (clay-loam). This soil can be used as construction material for building the proposed new micro-dam. Site visits revealed that there are no rocks in the immediate vicinity of the site, but large quantities are available behind the eastern hill at a distance of approximately 1 km, and sand is available 4 km away on the bed of the Niger River. These site visits detected no signs of landslides. There are no areas where natural stability could be compromised by the impoundment of the dam, by subsequent drainage, or by construction earthworks**.**

Characteristics of the reservoir of the existing Founkama micro-dam: -
The existing irrigation system in the Founkama Plain consists of a 117,529-cubic-meter reservoir, a 1,529-meter drainage canal, two ring canals (542 meters), 42 distribution canals, two dividers, and a network of embankments separating the plots.

Methodological Approach: -
The technical analysis of these various studies allowed us to verify our hypotheses and draw a sound conclusion from our research. The various studies conducted for the Founkama site are as follows:
Once the documentation was gathered and the information collected, a synthesis was performed; subsequently, the compilation of results from the diagnostic studies we conducted allowed us to identify the benefits demonstrating the necessity of constructing the new micro-dam, on the one hand, and the means for its implementation, on the other. Data processing initially involved prioritizing the various data collected according to their importance and grouping them based on their usefulness. We then extracted directly actionable information from this data as follows:
• Assessment of needs and losses: The functions of the reservoir were selected based on socioeconomic data, and the needs were calculated for each function in terms of cubic meters of water. The same calculation was performed for losses based on meteorological data obtained from the Guinean National Meteorological Directorate, and the

recommendations in the manuals"Small Dam Engineering in Sahelian and Equatorial Africa" and "Dam Engineering in Rural Development." Thus, rainfall and temperature data from the station near the Niger Basin were utilized;
• Topographic studies: the reservoir capacity was calculated using the mean surface area method. These studies were used to determine the alignment of the new micro-dam to be constructed;
• Hydrological studies: the design flood was determined using the ORSTOM and CIEH methods, and annual inflows were estimated using the runoff coefficient estimation method.
The data analysis was conducted after processing in order to identify the steps needed to rehabilitate the existing micro-dam and construct the proposed one.Given the information regarding the materials and soils in the lowlands, and although no formal geotechnical studies have been conducted, the following is proposed:
•Subject to confirmation of the quality and quantity of site materials through various laboratory tests, it would be efficient to use a large portion (80%) of local material for the backfill.
• The remaining proportion (20%) could therefore consist of imported materials.
With regard to hydraulic design, the dimensions of the structure capable of discharging the flood flow must be determined. In this part of the study, the various structures are identified based on defined criteria, and the dimensions of each structure are then derived.

Types of flood discharge structures: -
Among the range of spillways, the choice fell on the thick-crested (fixed) spillway, due to its structural robustness, its ability to handle high flow rates, and its resistance to erosion. It offers greater mechanical stability and requires less maintenance, making it ideal for small hydraulic structures. In summary, for a micro-dam, the thick-crested weir is a reliable and economical solution, prioritizing strength over extreme measurement precision. Figure 10 below shows the type of weir adopted for the new Founkama micro-dam, which is planned for construction.

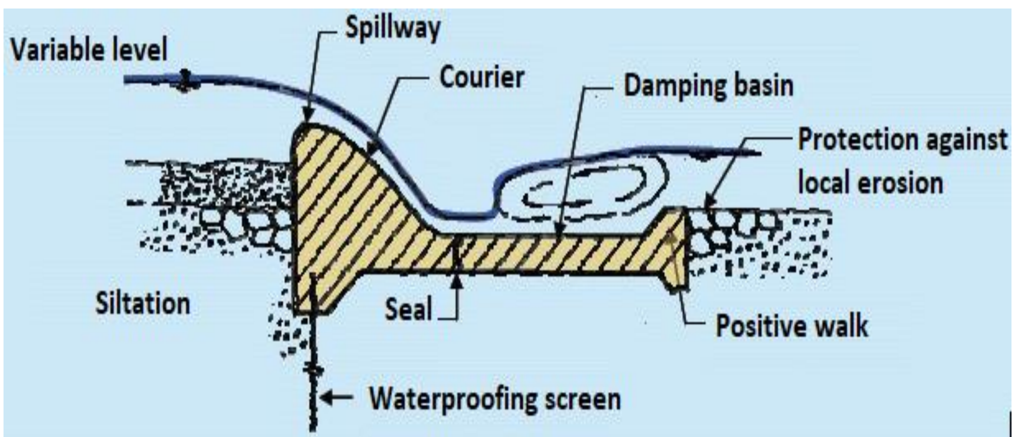

Figure 10: -Fixed-weir spillway to be used for the new Founkama micro-dam planned for construction (Hountondji, 2026).

Location of the spillway: -
The spillway will be positioned on the side to safely discharge excess water (floodwaters), thereby protecting the structure from submersion and failure. This configuration directs the discharge water away from the main body of the levee, reducing erosion at the toe of the micro-dam.

Dike: -
The height of the levee is equal to the normal water level (NWL) plus the maximum overflow at the spillway and the clearance height. The crest width of the weir must be sufficient to prevent significant water flow over it near the crest when the reservoir is full. It must also allow for the movement of equipment for the completion of the structure and, subsequently, for its maintenance. The embankment is homogeneous, and the slope values for the upstream and downstream slopes will be determined using the table of standard values for slope design.

Slope protection: -
The upstream slope will be protected by hand-laid riprap with a retaining wall installed at the base of the slope. The riprap layers must be between 0.20 m and 0.30 m thick. The downstream slope will be protected by a 40-cm-thick

layer of topsoil sourced from the natural ground during the excavation of the trenches. Periodic maintenance is necessary to fill in any gullies as soon as they appear. Care must be taken to remove trees or shrubs whose roots could create areas where water flows.

Anchor trench: -

It is excavated beneath the future seawall and backfilled with waterproof materials (selected clay) that are carefully compacted. Its depth mustreach the bedrock to ensure the base is watertight.

Foot drain: -

To prevent seepage through the levee, a single-layer drainage mat approximately 30 cm thick is planned. A toe ditch is also planned to collect water downstream.

Footrest: -

The toe wall of the upstream face serves, on the one hand, to anchor the toe of the riprap in the natural ground and, on the other hand, to bear part of the thrust generated by the weight of the stones that make up the riprap. The toe wall shall have a triangular cross-section and a depth of 0.60 m, which is at least twice the largest dimension of the stones, with a minimum of 0.30 m, and a length of 1.5 m from the natural ground.

Results and Discussion: -

Results: -

In this section, the results of the technical study for the new Founkama micro-damplanned for construction in the urban municipality of Faranahare presented in the form of a technical data sheet in Table 1. The dam will be homogeneous, constructed of ungraded clay materials found in the project area. For construction purposes, it is necessary to excavate an anchor trench with a depth ranging from 1 to 5 meters, depending on whether the location is at the inter-river level or the minor riverbed level. Based on the topographic survey of the study site, the axis of the proposed structure has been marked. Figure 11 shows a partial view of the study site's topography, indicating the axis and channel of the new Founkama micro-dam planned for construction.

Table 1: - Technical Specifications for the Proposed New Founkama Micro-Dam

TechnicalSpecifications of the Founkama Micro-Dam	
Bowl	
Volume	450,000 m^3
Dike	
Nature	Homogène
Length	184 m
Crest width	3.75 m
Width at the base	28.95 m
Maximum height	5.60 m
Volume of the dike	12,000 m^3
Spillway	
Type	Thick threshold (fixed)
Position	Lateral
Length	66 m
Length of the dissipation basin	9.35 m
Plug	
Position	Connected to the spillway
Pipe diameter	300 mm
Length	280 m
Drainage structure	
Valve position	Central
Valve size	2.00 m x 1.50 m
Perimeter	
Surface	180 hectares
Aptitude	Rice cultivation

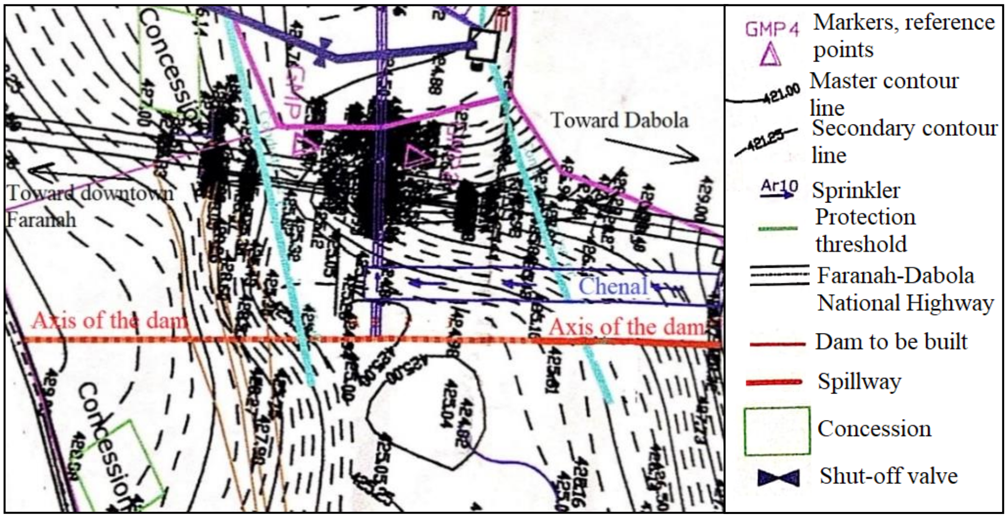

Figure 11: -Topographic view of the site showing the alignment of the proposed new micro-dam

Discussion: -

The socio-economic significance of the structure's development within the community: -

The majority of the population in the urban municipality of Faranah relies on agriculture for their livelihood. Therefore, promoting agriculture is the key to reducing poverty and contributing to economic growth. The objective of constructing micro-dams is to meet food needs while creating better production conditions and generating benefits for both urban and rural populations (Berton, 1988).Thus, the development of the Founkama plain through the rehabilitation of the existing micro-dam and the construction of a new one will provide the population with sources of income through vegetable farming, fish farming, irrigated rice cultivation, and livestock raising. According to a study conducted by (Kpera et al., 2012), the presence of micro-dams is a consistently recognized benefit, given the wide range of activities they support. The development of the Founkama plain will therefore be of great benefit to the development of the urban municipality of Faranah. The presence of water in the reservoir throughout the year will raise the water table across the entire area, thereby facilitating the construction of boreholes and traditional wells. These findings are consistent with those reported by Napon (2013) regarding small water reservoirs and their effects on living conditions.Furthermore, the development of 180 hectares out of a total of 260 hectares in the Foukama Plain presents a significant employment opportunity for young people, thereby helping to curb rural migration. The proposed project will help retain the workforce in the municipality of Faranah.

Description of the structure to be built: -

The structure examined in this study is a micro-dam that creates a water reservoir upstream of the impoundment. The water retained upstream of the micro-dam will be used for a period that is longer the larger the resulting reservoir is. The upstream slope of the dam will be reinforced with hand-laid riprap, and the downstream slope will be vegetated (Adomahou, 1999). The spillway is therefore made of reinforced concrete.

Functioning of the structure: -

The presence of the structure on the riverbed will disruptthe natural flow regime of the water. This will cause a rise in water levelupstream. Two types of hydraulic operation will be observed depending on the water level at the structure: submerged and unsubmerged conditions. Submerged operation means that the water level at the structure's immediate outlet exceeds the upper edge of the spillway. Water will therefore flow downstream under the spillway.In contrast, the unregulated flow regime is one in which the flow rate over the sill depends on the downstream water level. The downstream water level is therefore determined by the flow conditions upstream of the structure. Unflooded operation is therefore the condition in which the flow rate upstream of the mini-dam's spillway is unaffected by the water level downstream of the structure. The flow is unflooded as long as $H_{(downstream)} \leq 0.8\ H_{(upstream)}$ but flooded otherwise.

The structure positioned above the spillway sill is designed to dischargehigh flows and thus generally protects the structure against exceptional floods. It must operate in the non-submerged regime to avoid anyrisk. Since the reservoir's surface area is relatively large (35 hectares) and thedetermined length of the spillway is 66 m, it is now evident that the flood attenuation will be very significant. This aligns with the work of Durand (1995), who states that the larger the reservoir, the greater the flood attenuation.

Proposed plans for the new Founkama micro-dam: -

In the urban municipality of Faranah, we recommend using the following maps (Figures 12–15):

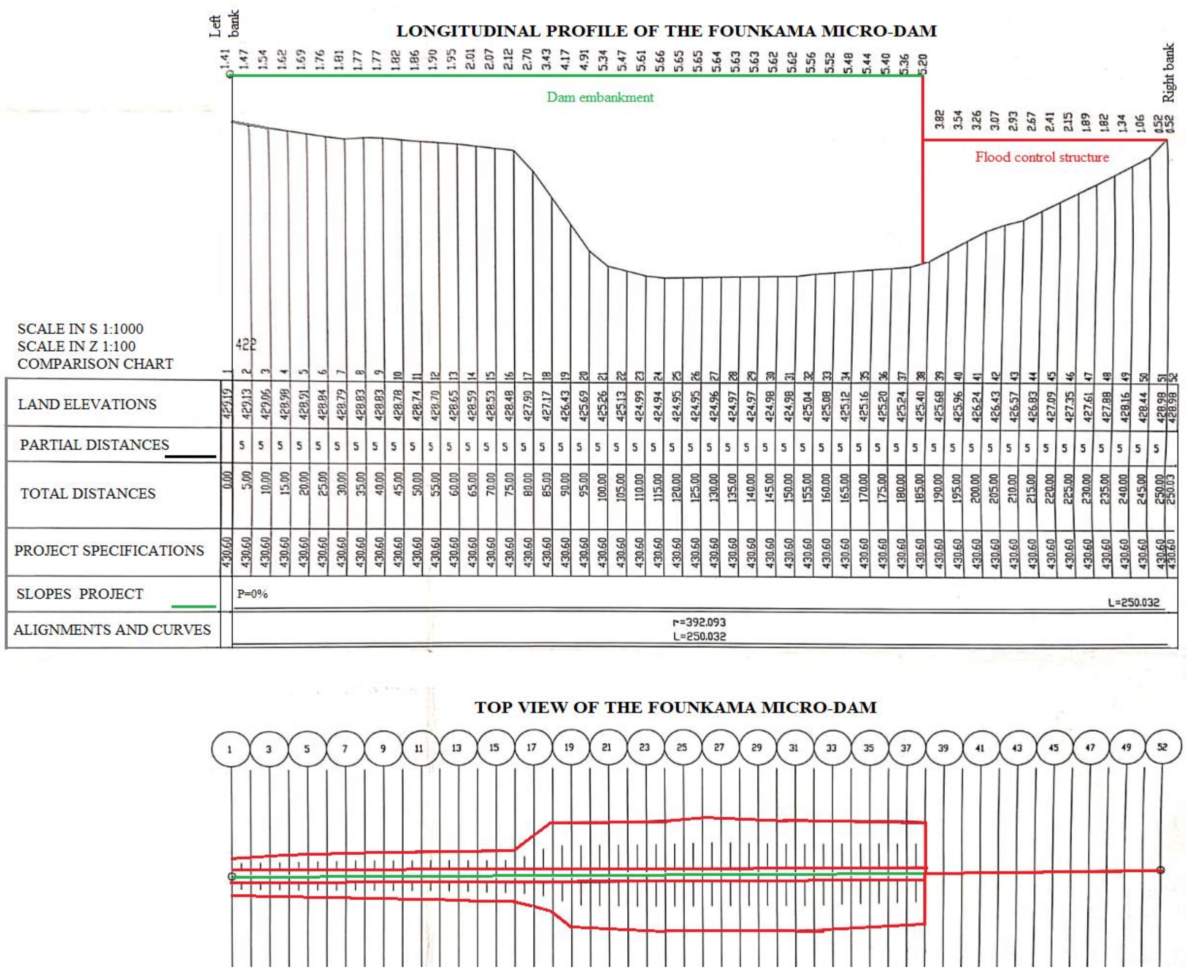

Figure 12: - Longitudinal and cross-sectional profiles of the structure

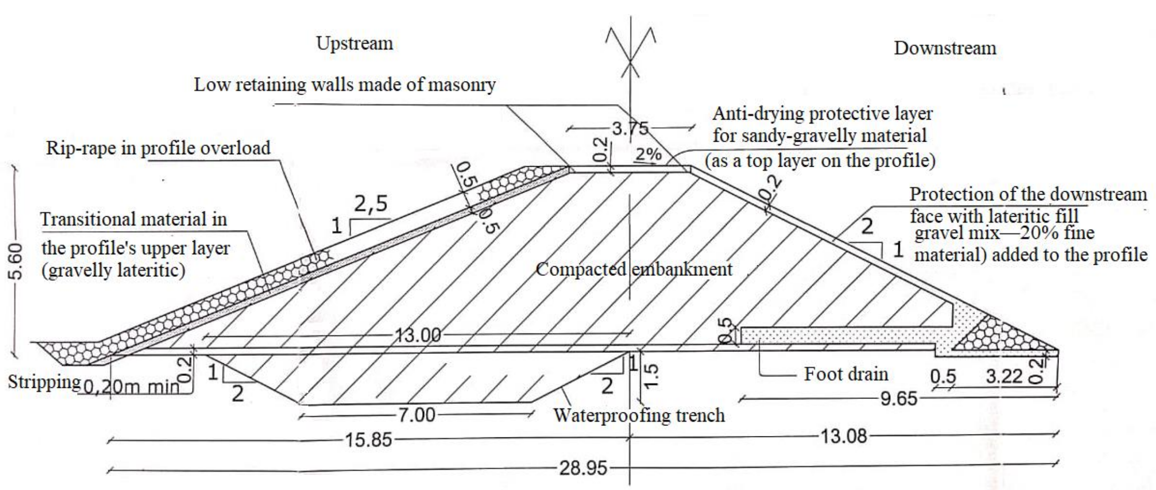

Figure 13: - Typical cross-sectional profile of the seawall

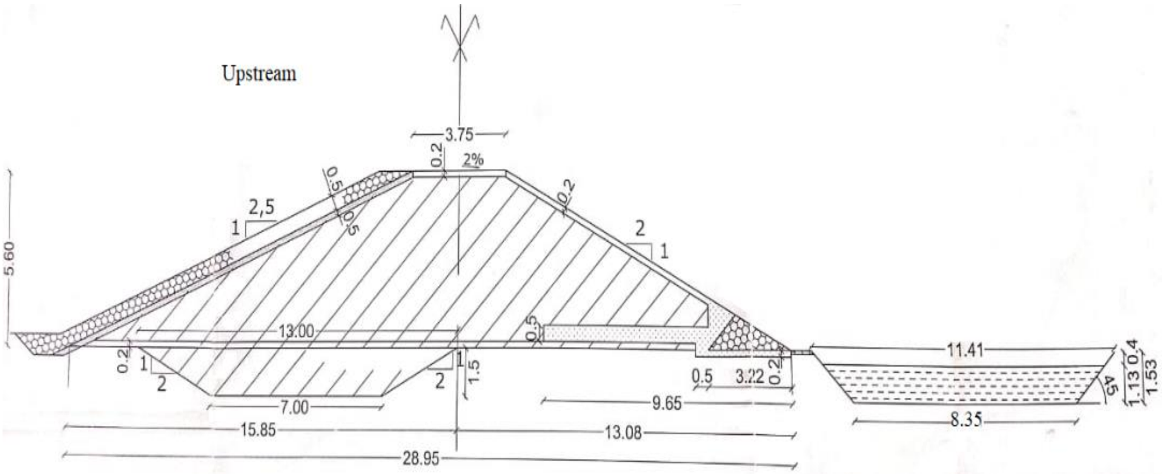

Figure 14: - Typical cross-sectional profile of the levee with the energy dissipation basin

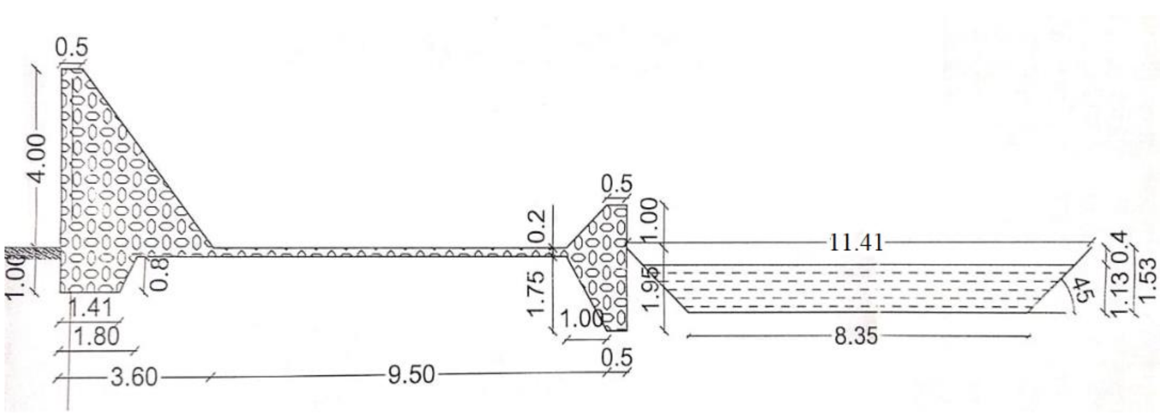

Figure 15: -Cross-sectional profile of the spillway

Conclusion: -

The key finding of this study is that the rehabilitation of the Founkama micro-dam through the construction of a new structure will contribute to the well-being, fulfillment, and improved living conditions of the students at ISAV-VGE/F and the population throughout the surrounding plain, specifically in terms of food needs for both groups and the practical application of theoretical coursework for the students. Indeed, meeting the agro-pastoral water needs of the local communities will enable them to generate more income. The environmental and social analysis has highlighted the impacts of the new structure planned for construction, most of which are positive and significantly outweigh the negative impacts, which have been minimized. Field observations, reinforced by the results of the analyses, strongly support the feasibility of developing the 180 hectares of the downstream section of the micro-dam, which constitutes the Founkama plain.

Conflicts of interest: -

The authors declare that they have no conflicts of interest regarding the data published in this article.

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