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RESEARCH ARTICLE

CONDITIONS OF HYDRAULIC STRUCTURES IN THE BIRNI N'KONNI REGION (NIGER) DURING LOW-WATER PERIODS AND THEIR POSSIBLE IMPROVEMENTS

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ABSTRACT

The Birni N'Konnihydro-agricultural structures are hydraulic works utilized for agricultural purposes in this region of Niger. They play a pivotal role in the country's economy. In recent years, these hydraulic infrastructures have been subjected to a multitude of degradation factors, both physical and chemical in nature. The physical factors include erosion, sedimentation, and fatigue, while the chemical factors encompass corrosion and pollution. Additionally, biological factors, particularly the impact of vegetation, have also contributed to the deterioration of these structures. Anthropogenic factors, such as overuse, inadequate maintenance, and design flaws, have also played a role in the observed degradation. For this reason, the primary objective of this study is to conduct a diagnostic analysis of the Konni hydraulic structures with the aim of proposing strategies for enhancing their performance and mitigating their deterioration, particularly during periods of low water levels. The approach adopted is that the integration of computational and design models, in conjunction with protection and maintenance measures, can extend the lifespan of the structures. This will undoubtedly lead to an improvement in irrigation efficiency and a reduction in the frequency of food shortages for local residents and economic losses for producers.

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INTRODUCTION

Hydraulic structures are an essential component of modern infrastructure, playing a crucial role in water resource management, power generation, flood protection and river transport. Since ancient times, man has sought to dominate and use waterways to meet his vital needs and development ambitions. Permanent hydraulic structures (canal dykes and dams) can fulfil a number of functions (crop irrigation, storage for drinking water distribution, etc.). Temporary hydraulic structures (river flood protection dikes, flood protection dams) protect people and their property in the event of flooding. Dams are massive structures designed to hold back water and create reservoirs. They are used for a variety of purposes, including irrigation, hydropower generation, flood management and drinking water supply. The main types of dam include earth dams, concrete dams and arch dams. Canals, on the other hand, are man-made waterways used for river transport, irrigation and stormwater management. They can be built of earth, concrete or masonry, are often equipped with gates and generally work in conjunction with dams to control water flow. Canals play a crucial role in irrigating farmland and transporting goods. These structures are often exposed to internal erosion, which is one of the main causes of failure [1]. These erosive failures can be promoted by mechanisms such as structural ageing, poor design and construction, and faulty maintenance. Niger currently has 85 hydro-agricultural projects, covering some 16,000 hectares and providing employment for over 40,000 farmers. By 2030, a further 45,000 hectares should be developed [2] The Konni department has a perimeter of 3,000 hectares, of which 2,452 are exploitable. Hence its importance for the country's food self-sufficiency.

Infrastructures are subject to progressive deterioration throughout their lifetime, which can affect their performance as well as their environmental and social impact. According to Deroo et al [3], the erosive factor, which can be divided into four types (internal, contact regressive and diffusion regressive), is a major factor in deterioration. These degradations are caused by aspects inherent to these structures, such as ageing, poor design/implementation or faulty maintenance. These are the main elements that can influence the appearance of a deterioration mechanism caused by internal erosion: the geometry of the structure, its geotechnical characteristics, its hydraulics and its "biological" environment (type of vegetation, degree of decomposition, presence of burrowing animals, etc.). Mériaux et al [4] analyzed the presence of arborescent vegetation on or near the structure as part of their research. They discovered that this vegetation poses a number of problems, as it can encourage the development of short-, medium- and long-term deterioration mechanisms, in particular internal erosion due to root development. This phenomenon can affect both the structures backfill and its foundations. Depending on the nature of the soil, the tree's root extensions and decomposition can either create conduits through the structure that can initiate internal erosion, or increase the overall permeability of the embankment zone concerned by the decomposition of a large root volume.Further on, Zannedi et al [5] carried out a root characterization that enabled them to understand the impact of these shrub roots in the fill. Indeed, these shrubs can be more or less detrimental to the internal erosion mechanism when their woody roots decompose. These long horizontal roots can potentially cross the embankment from downstream to upstream in search of water, posing a risk of cracking the structure's surface. Decomposition of this type of root is likely to create a conduit through the embankment, depending on the type of material.

Other researchers such as Serre et al [6, 7, 8] have focused their research on methods and tools that can first assess and improve the performance of embankment dams and river dikes.For Courivaud et al [9], the prediction of overtopping erosion of flood protection dykes and embankment dams is one of the major difficulties in the safety analysis of these structures. Although it has been identified as the dominant failure mechanism in almost half of all river dyke failures, the methods and tools used in the past remain very limited. In particular, the characterization of the erosion process, in geometric and temporal terms, taking into account the behavior of the materials constituting the embankment and its foundation, as well as the specificities of hydraulic stresses on dikes, is not yet within the reach of any numerical modeling tool validated to the required level. The ultimate aim is to significantly improve the reliability and accuracy of erosion prediction tools in relation to dike overtopping failures, based on a highly advanced multi-scale experimental approach. In addition, Piraud [10] investigated the Malpasset arch dam failure (Var, France), which occurred in 1959. Alongside the technical causes of the failure, which are now well elucidated, he re-examined the organizational and human factors that contributed to this catastrophe, in the light of today's conceptions of the responsibilities of the various actors involved. At the same time, he conducted research into old hydroelectric and nuclear power plants, and presented their malfunctions with a view to situating responsibilitiesNevertheless, other researchers have conducted studies on matters pertaining to rural development and the administration of pastoral hydraulic infrastructures [11, 12, 13, 14]. These studies have elucidated the consequences of such structures on the socio-economic activities of farmers, as well as on their livestock and the surrounding environment.

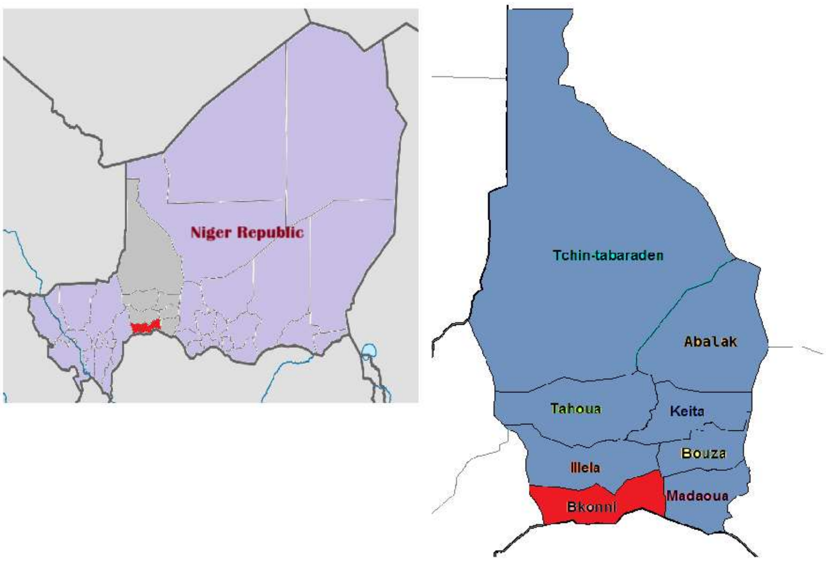

Figure 1. Geographical location of Konni department on a national map of Niger

Table 1. Global data for Konni dams

	Mozagué dam	Zongo dam	Thierassa reservoir (for regulation)
Storage capacity (m^3)	30 million	12 millions	2.5 million
Length of structure (m)	653	392	----------
Height of structure (m)	9.85	7.45	----------

Table 2. Data for the main canals and the major dike

	A supply canal (from Zongo to Thierassa)	4 Primary canals	23 Secondary canals	Protective dike
Flow (m^3/s)	3.5	---------	----------	---------
Length of structure (m)	15000	25115	26660	15000

Overview of the study area: Konni or BirniNkonni is located in Niger Republic, about 120 km from Niamey the capital. It belongs to the Tahoua region. It is bordered to the west by the Dogondoutchi department, to the east by the Bouza and Madaoua departments, to the north by the Illéla department, and to the south by Nigeria Konni lies on a vast plateau dominated by the Ader-Doutchi, through which the Magia flows from east to west. Water resources are abundant, with a water table varying in depth from 1.5 to 8 m. Konni has an irrigated perimeter, created in the mid-70s and early 80s. It covers a gross area of 3000 ha, of which 2452 ha are exploitable, divided into 0.75 ha plots. The dimensions of the largest parts of these hydro-agricultural structures are shown in the following tables. Although these tables are not exhaustive, the main structures around the Konni perimeter are listed here, along with trapezoidal (159) and rectangular (79) tertiary canals. In addition, there are drainage networks and tracks all around the perimeter. The Konni irrigation network is like a mesh that supplies the different sectors of the perimeter. The hydro-agricultural scheme is subdivided into 34 mutual production groups, including 15 for Konni 1 and 19 for Konni 2, and is operated by 3,150 families from 12 villages and 8 districts of Konni. Each group manages its own sector and is subdivided as shown in the following figure.

The current status of the hydro-agricultural infrastructure during low-water periods: Climate change over the past 50 years has caused upheavals both worldwide and in the Sahel in particular [16, 17]. This has led to high variability and reduced rainfall in this part of Africa. This region of Niger is therefore no exception, and has been hit by the same effects of climate change that have altered its rainfall. This has caused watercourses to dry up, particularly in the months of April, May and June 2024. Water is generally lacking in hydro-agricultural schemes during low-water periods, due to infiltration losses, excessive evaporation caused by sunshine, and unregulated use of water by farmers. This lack of water contributes to the disorganization of fish production and other food crops. It can also lead to mud piling up on the perimeters, making maintenance work difficult. The wind also blows plastic waste into the perimeters, clogging the pores that allow water to pass through.

Possible solutions to the problems besetting these hydro-agricultural infrastructures

In terms of design and execution: For infrastructures of this scale, and given the socio-economic role they play for Niger and the Konni region in particular, academic research expertise must accompany the entire process of designing and building or rehabilitating these hydraulic structures. As science evolves, design software is pushed to the very limits of state-of-the-art technology. This is where HEC-RAS software, whose full name is Hydrologic Engineering Centers River Analysis System, (or other) comes in. It covers the whole field of hydraulics and hydrology, and is designed to simulate flow in rivers and canals.

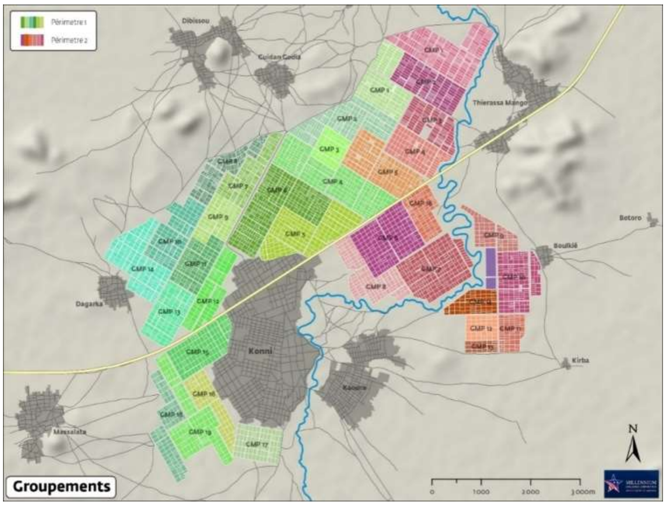

Figure 2. Map of the perimeter and its division into groups [15]

Figure 3. Zongo Dam during low water period

Figure 4. Primary canal silted up and covered in grass during low water periods

Furthermore, it is important to note that most of the canals are not in good condition; they are in a state of almost total disrepair, and their efficiency is almost non-existent. This prevents water from reaching its intended destination. When it comes to construction, a poorly executed structure means a loss of money from the moment it is built, and a further loss in terms of maintenance. It's vital that structures are designed and built with the utmost rigor and attention to detail, to make them durable and effective over time. And that means choosing the right technical personnel and materials.

Figure 5. Tertiary canal degradation

The use of geosynthetics to improve the quality and sustainability of hydraulic structures: A geosynthetic is a product that contains at least one component derived from a synthetic polymer (such as polyethylene, polyamide, polyester, or polypropylene) or a natural polymer. It can take the form of a sheet, strip, or three-dimensional structure and is utilized in contact with soil or other materials within the domains of geotechnics and civil engineering.Geosynthetic materials (mainly geotextiles and geomembranes) are playing an increasingly important role in the design and construction of hydraulic structures. They offer numerous advantages due to their unique properties, notably in terms of durability, efficiency and cost reduction.Geosynthetics generally fall into 2 main groups: geotextiles and geomembranes. They can be combined to form geocomposites. In effect, geomembranes are impermeable sheets, generally made of high-density polyethylene (HDPE) or polyvinyl chloride (PVC), designed to resist chemical and biological degradation. In accordance with the standards set forth by the ASTM D4439-00 [18], a geomembrane can be defined as an essentially impermeable membrane utilized in conjunction with a foundation, soil, rock, earth, or any other geotechnical engineering-related material as an integral component of a man-made project, structure, or system. Additionally, geomembranes assist in the prevention and mitigation of water leakage and structural damage through the provision of waterproofing and sealing or bridging of cracks and joints. They serve as a protective layer against the mechanical and chemical actions of corrosive water or against deterioration and contamination of chemical origin. They offer several advantages over traditional barriers, including durability, rapid installation, cost-effectiveness, high deformability, minimal maintenance requirements, and enhanced hydraulic efficiency [19,20,21,22]

Figure 6. Laying a geomembrane along a canal in Spain [23]

Figure 6 illustrates how the geomembrane protects the pipe walls against erosion, thereby ensuring the longevity of the structure. This would be ideal for rehabilitating the canals of the Konni hydro-agricultural scheme. As for geotextiles, these are non-woven or woven textiles designed to be permeable to water while offering tensile strength. They can be used as separators, filters and reinforcements. They are used to reinforce structures by preventing them from falling or collapsing, and at the same time to avoid erosion that could result from such collapses.

Figure 7. A dike strengthened with geotextiles [24]

The formation of revetments of soil, rockfill or concrete can control the erosion of exposed surfaces. Geosynthetics make it possible to combine these materials, based on their high strength and durability, to create durable, versatile and cost-effective structures, such as geotextile-reinforced embankments. Geosynthetics can also be used to protect the walls of structures against perforation and wear.This technology could also be applied to the protection dike and dam dikes of the Konni hydraulic works.

Enhanced maintenance and rehabilitation of hydro-agricultural facilities by operators and the Nigerien government: This part of the proposed solutions is particularly important, as regular, well-maintained structures require very little costly rehabilitation, and operators should regularly weed the canals, clean the tracks and other ancillary structures, and clear the undergrowth from the dams. On the other hand, it's incumbent on the Niger government to perform large-scale maintenance work with the participation of its financial and technical partners, providing them with the necessary machinery and other resources. It would be important to make use of any new technology aimed at improving the performance of these structures.

CONCLUSION

The hydraulic structures used for hydro-agricultural purposes in the department of Konni play a vital role, with more than 37 groups operating over a perimeter of 2,452 ha. Water supply is most difficult during periods of low water. Water storage and transport infrastructures are almost all in an advanced state of deterioration. This deterioration is caused by poor design or construction, lack of maintenance or inadequate repairs. The use of modern software and new technologies, such as the use of geotextiles and geomembranes on structures, helps to remedy the situation. It is also worth noting the negligence of the primary beneficiaries in maintaining these structures, such as lack of weed control, mortar joint repairs and blockages. The Niger government should take the initiative in using drones to monitor dams and related structures, so that a solution can be found quickly in the event of a leak, or any other emergency repair.

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