International Journal Water Sciences and Environment Technologies: Volume (x), Issue 1 – March 2025

INTERNATIONAL JOURNAL

Water Sciences and Environment Technologies

ISSN Online: 1737-9350 ISSN Print: 1737-6688
Open Access Journal

Volume (x) - Issue 1– March 2025

Water-Biodiversity-Climate'2025

Water, Biodiversity and Climate Change

Editor-in-Chief: Pr Noureddine Gaaloul

Published by:

Scientific and Technical Association for Water and the Environment in Tunisia (*ASTEE Tunisie*)

International Journal Water Sciences and Environment Technologies
e-ISSN: 1737-9350 p-ISSN: 1737-6688, | Open Access Journal | Volume (x) - Issue 1 – March 2025
Volume (x): Water -Biodiversity-Climate'2025

International Scientific Committee (ISC-WBC'2025)

Preface

L'eau est le principal vecteur par lequel les effets du changement climatique se feront sentir, et la clé de la réussite des stratégies d'adaptation. On observe d'ores et déjà des modifications des systèmes d'eau douce un peu partout dans le monde, et les risques liés à l'eau – pénurie, excès, manque de fiabilité des approvisionnements ou mauvaise qualité – devraient aller en s'amplifiant. Ces modifications, qui peuvent être progressives ou brutales, risquent de compromettre la sécurité de l'eau à long terme et de rendre l'adaptation de plus en plus coûteuse pour les gouvernements à mesure que le temps passe.

La biodiversité fournit des biens et services indispensables à la fois pour s'adapter aux effets du changement climatique (les zones humides constituent une protection naturelle contre les inondations, la végétation permet d'améliorer localement la quantité et la qualité de l'eau, les espaces verts permettent d'améliorer le micro climat et la qualité de l'air dans les villes, etc.) et pour atténuer les changements climatiques, grâce notamment à l'absorption de CO2 par les écosystèmes marins et terrestres.

L'augmentation des risques liés à l'eau et l'incertitude grandissante qui entoure la situation future ne font qu'amplifier les défis à relever en matière de sécurité de l'eau et compliquer les décisions de planification, de gestion et d'investissement dans le domaine de l'eau. Pour s'adapter à la nouvelle situation, il faudra des stratégies d'investissement mieux étayées et une gouvernance adaptative de l'eau tenant compte de la variabilité du climat et limitant le plus possible les problèmes potentiellement coûteux d'inadéquation entre les hydrosystèmes et le climat futur.

Le changement climatique est en passe de remodeler l'avenir dans le domaine de l'eau. Il aggrave les tensions existantes et complique la planification, la gestion et l'investissement futurs dans les infrastructures de l'eau. Pour en limiter les conséquences néfastes et le coût, et pour exploiter les opportunités éventuelles, il faudra tenir compte de cette nouvelle donne, autrement dit s'adapter. L'adaptation exige de la souplesse, or le domaine de l'eau se caractérise par des infrastructures à longue durée de vie dont les coûts irrécupérables sont élevés. Une vision prospective est indispensable, or les projections climatiques relatives aux principaux paramètres concernant l'eau sont peu fiables à l'échelle locale. Une gouvernance adaptative de l'eau est nécessaire, or l'inertie et une gouvernance médiocre sont davantage la norme que l'exception dans le domaine de l'eau.

La biodiversité – la variété de la vie sur Terre – nous fournit des services écosystémiques essentiels à la santé humaine, au bien-être et à l'économie. Pourtant, la biodiversité terrestre, marine et d'eau douce décline rapidement, menaçant sociétés et économies.

Noureddine Gaaloul
Professor of higher education and full Researcher in the National Institute of Research in Rural Engineering of Water and Forestry (University of Carthage- IRESA- INRGREF-Tunis).
Founder and Chief Editor International Journal Water Science and Environment Technologies
President of Scientific and Technical Association for Water and the Environment in Tunisia (ASTEE Tunisie)
www.jistee.org

Preface

Water is the primary channel through which the effects of climate change will be felt and the key to successful adaptation strategies. Changes in freshwater systems are already occurring around the world, and water-related risks—scarcity, excess, unreliable supply, or poor quality—are expected to increase. These changes, which can be gradual or abrupt, risk compromising long-term water security and making adaptation increasingly costly for governments over time.

Biodiversity provides essential goods and services both for adapting to the effects of climate change (wetlands provide natural protection against flooding, vegetation helps improve the quantity and quality of water locally, green spaces help improve the microclimate and air quality in cities, etc.) and for mitigating climate change, particularly through the absorption of CO2 by marine and terrestrial ecosystems.

Rising water risks and growing uncertainty about the future only amplify water security challenges and complicate water planning, management, and investment decisions. Adapting to the new situation will require better-informed investment strategies and adaptive water governance that takes into account climate variability and minimizes potentially costly mismatches between hydrosystems and the future climate.

Climate change is reshaping the future of water. It is exacerbating existing tensions and complicating future planning, management, and investment in water infrastructure. Limiting adverse impacts and costs, and seizing potential opportunities, will require adapting to this new reality. Adaptation requires flexibility, and the water sector is characterized by long-lived infrastructure with high sunk costs. A forward-looking approach is essential, and climate projections for key water parameters are unreliable at the local level. Adaptive water governance is needed, and inertia and poor governance are more the norm than the exception in the water sector.

Biodiversity – the variety of life on Earth – provides us with ecosystem services vital for human health, well-being and economies. Yet, terrestrial, marine and freshwater biodiversity is declining rapidly, threatening societies and economies.

Noureddine Gaaloul
Professor of higher education and full Researcher in the National Institute of Research in Rural Engineering of Water and Forestry (University of Carthage- IRESA- INRGREF-Tunis).
Founder and Chief Editor International Journal Water Science and Environment Technologies
President of Scientific and Technical Association for Water and the Environment in Tunisia (ASTEE*Tunisie*)
www.jistee.org

International Journal Water Sciences and Environment Technologies (IJWSET)
Journal International Sciences et Techniques de l'Eau et de l'Environnement (JISTEE)
ISSN Online: 1737-9350 ISSN Print: 1737-6688
Open **Access**
10 Volumes, 31 Issues, (433 Papers) and 1 Book

International Journal Water Sciences and Environment Technologies
e-ISSN: 1737-9350 p-ISSN: 1737-6688, | Open Access Journal | Volume (x) - Issue 1 – March 2025
Volume (x): Water -Biodiversity-Climate'2025

Table of Contents

www.jistee.org
jistee@iresa.agrinet.tn
jistee@yahoo.com

Jean Kalume Shikayi, Cush Ngonzo Luwesi, Essam Osman Badr, Seham D.Z. Dawoud, Papy Bonkena Bokombola, Jean Aunge Muhiya,Glodi Etepe Kakoko, Pascal Kazwenga Masawula, Raphael Palata Kadgeng.
Determinants of the economic profitability of the surface irrigation system by gombo growers at the Masina Rail 1 site in the N'djili River watershed, Kinshasa
International Journal Water Sciences and Environment Technologies
Vol. (x), Issue. 1, March 2025, pp. 6-16
ISSN Online: 1737-9350; ISSN Print: 1737-6688, Open Access
www.jiste.org
Scientific Press International Limited
Received: January 2025 / Revised: February 2025 / Accepted: March 2025 / Published: March 2025

Determinants of the economic profitability of the surface irrigation system by gombo growers at the Masina Rail 1 site in the N'djili River watershed, Kinshasa

Jean Kalume Shikayi [1], Cush Ngonzo Luwesi[2], Essam Osman Badr[3], Seham D.Z. Dawoud[4], Papy Bonkena Bokombola [5], Jean Aunge Muhiya[5],Glodi Etepe Kakoko[6], Pascal Kazwenga Masawula[7] Raphael Palata Kadgeng1.

[1]Assistant, Department of Agricultural Economics, Faculty of Agronomical and Environmental Sciences, University of Kinshasa (UNIKIN), B.P. 117 Kinshasa XI.
[2]Professor, Regional Water School, University of Kinshasa (UNIKIN), B.P. 127 Kinshasa XI
[3]Associate Professor, Department of Business Administration, College of Science and Human Studies, Hotat Sudair, Majmaah University, Majmaah, 11952, Saudi Arabia
[4]Associate Professor, College of Agricultural and Food Sciences, King Faisal University, Saudi Arabia
[5]Professor, Department of Agricultural Economics, Faculty of Agricultural and Environmental Sciences, University of Kinshasa (UNIKIN), B.P. 117 Kinshasa XI,
[6]Assistant, Faculty of Agricultural and Environmental Sciences, University of Mbandaka (UNIMBA),
[7] Masters Student - Regional Water School, University of Kinshasa, DR Congo

Abstract

This study examines the determinants of the profitability of okra cultivation at Masina Rail 1 in the N'djili River watershed in Kinshasa. It reveals that profitability is influenced by several factors, including production costs, selling prices and quantity sold. Profitability simulations show that climatic conditions, such as periods of scarcity, increase profit margins, while flooding has a negative impact on profitability. Multiple linear regression analysis confirmed significant relationships between independent variables and profitability, with an R² of 99.9%, underlining the importance of optimizing costs and increasing cultivated area. The results provide recommendations for improving growers' profitability, in particular by adopting adaptive strategies in the face of market fluctuations and climatic hazards.

Keywords: Watershed, Determinant, Economic profitability, N'djili River, surface irrigation system

Déterminants de la rentabilité économique du système d'irrigation de surface par les producteurs de gombo sur le site de Masina Rail 1 dans le bassin versant de la rivière N'djili, Kinshasa

Résumé

Cette étude examine les déterminants de la rentabilité de la culture de gombo à Masina Rail 1 dans le bassin versant de la rivière N'djili à Kinshasa. Elle révèle que la rentabilité est influencée par plusieurs facteurs, notamment les coûts de production, les prix de vente et la quantité vendue. Les simulations de rentabilité montrent que les conditions climatiques, comme les périodes de pénurie, augmentent les marges bénéficiaires, tandis que les inondations impactent négativement la rentabilité. L'analyse par régression linéaire multiple a confirmé des relations significatives entre les variables indépendantes et la rentabilité, avec un R² de 99,9 %, soulignant l'importance d'optimiser les coûts et d'accroître les superficies cultivées. Les résultats fournissent des recommandations pour améliorer la rentabilité des producteurs, notamment en adoptant des stratégies adaptatives face aux fluctuations du marché et aux aléas climatiques.

Mots clés : Bassin versant, Déterminant, Rentabilité économique, Rivière N'djili, système d'irrigation de surface

[1] Corresponding author: leankalume@unikin.ac.cd

I. INTRODUCTION

The Democratic Republic of Congo (DRC) is experiencing rapid population growth, which is driving up demand for food. This situation underlines the importance of efficient agricultural intensification, particularly through irrigation, which represents an essential lever for improving crop productivity (FAO, 2007). In this context, gombo, as a food crop, plays a crucial role in food security and farmers' incomes, particularly in the Kinshasa region.

The N'djili river watershed, with its irrigated land, offers considerable potential for gombo production. However, the economic profitability of surface irrigation in this region is influenced by various determinants, such as investment costs, cropping practices and water resource management (World Bank, 2023a). Small-scale irrigation systems, although less costly, require appropriate management to maximize their efficiency and profitability.

Surface irrigation, while effective, is subject to challenges such as climatic variations and access to financial resources. Growers' dependence on these systems can affect their ability to adapt to the impacts of climate change, reducing productivity and yields (Tillie et al., 2019). In addition, managing the costs associated with irrigation, labor and agricultural inputs is key to assessing the economic viability of gombo cultivation.

Previous studies have often highlighted the technical aspects of irrigation, but few have focused on the economic determinants specific to surface irrigation systems for gombo in the N'djili River watershed. This research therefore aims to fill this gap by analyzing the factors influencing the economic profitability of these irrigation systems, taking into account the specific agro-ecological and socio-economic features of the region.

Understanding the determinants of the economic profitability of the surface irrigation system for gombo cultivation at the Masina Rail I site is crucial to formulating sustainable and effective strategies. This will not only improve agricultural productivity, but also enhance food security in the face of growing environmental challenges.

This study answered the question: What are the main determinants of the profitability of gombo cultivation in the study site? The study supported the hypothesis that the profitability of gombo cultivation is positively correlated with selling prices and quantities sold, while production costs and flooding have a negative impact on this profitability. Thus, the study sought to analyze the impact of production costs, selling prices and quantities sold, as well as marital status and irrigable area on the profitability of gombo cultivation, while assessing the effects of climatic risks, particularly flooding.

MATERIALS AND METHODS

Presentation of the Masina Rail I site

The Masina Rail I market garden site is located in the Malebo Pool part of the N'djili river watershed. The Masina Rail I agricultural site is located in the Mfumu-Sunka district of Masina commune, and was established in 1969 when the Chinese arrived. It is bounded to the north by the Congo River, to the south by the railroad, to the east by the Masina Rail 2 site, and to the west by the Ngwele River, otherwise known as the N'djili River. It covers a total area of 1,350 ha, 760 ha of which is under cultivation, the remainder being uncultivated due to the lack of hydro-agricultural development. The site comprises 21 blocks and counts 1,200 households with 5 or 6 people per household.

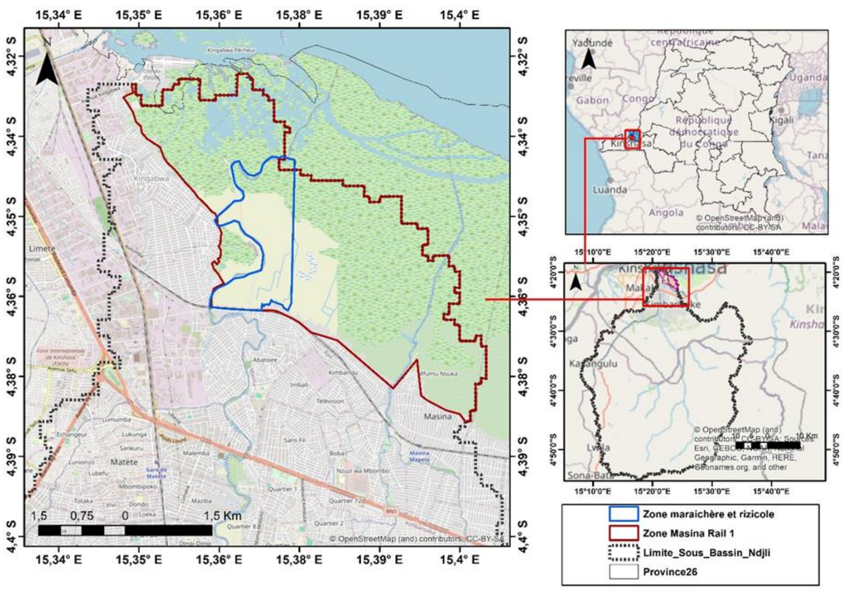


Figure 1: Map of study area

Sampling methods and techniques

In this study, the sampling technique used the following formula to draw our sample (Lututala, 2022):

$$n = z^2 \text{ x } p(1 - p)/m^2 \quad \text{(Equation 1)}$$

With :
n= sample size
z= confidence level according to the reduced centered normal distribution (for a 95% confidence level z= 1.96, for a 99% confidence level z= 2.575)
p= estimated proportion of the population exhibiting the characteristic (when unknown, o, use p=0.5, which corresponds to the worst case, i.e. the widest dispersion)
m= tolerated margin of error (for example, we want to know the real proportion to within 6%)

$$n = (1{,}96)^2 x(0{,}5)(1 - 0{,}5)/(0{,}6^2) \quad \text{(Equation 2)}$$

$$\mathbf{n = 267}$$

Data collection techniques

The research aimed to collect quantitative data on production costs, selling prices, quantities sold, marital status of producers and irrigated area, based on questionnaires and interviews with gombo producers practicing the small-scale irrigation system at the study site.

The survey was carried out using a questionnaire previously programmed into Kobocollect. It was carried out with 25 producers in each block of the perimeter, taken at random, for a total of 10 functional blocks at the time of data collection, i.e. a total sample of 250 producers. Producers were selected at random from the entire site. On the sample perimeter, visits were made to water sources, irrigation canals and production plots. Observations were also made of how water was supplied to the plots and how production was organized.

It should be pointed out that, in the context of our study, due to the lack of growers present because the blocks were already under water, we only surveyed 250 growers. In this case, 250/267 of the sample size is a 94% success rate, and the remaining 17 individuals are included in the wastage rate. Of the 250 producers surveyed, 182 were okra producers and the remainder were rice and amaranth producers. These 182 producers formed the basis of our analysis.

Data analysis techniques

The data collected as part of this study were analyzed using a number of tools and methods, such as profitability simulation analysis, descriptive statistics, mean comparison tests and multiple linear regression for determinant analysis. Analysis of the data collected was carried out using SPSS 25 software and Excel 2019 spreadsheet.

Simulation analysis of profitability

The study began by assessing climatic risks to identify the impact of flooding and drought on profitability. It integrated historical data on these climatic factors with producer testimonials within the same conceptual framework.

Subsequently, the simulation analysis consisted of a synthesis of sales price and income scenarios from gombo cultivation based on climatic fluctuations observed between 1991 and 2021.

To carry out the simulations of the periods of scarcity and abundance, a ratio was found to apply with the reference scenario. This ratio was found by taking the precipitation data series of the study area; starting from the year 1991 to 2021 in order to find or identify the year with the most abundant precipitation and the year with the most severe drought. For our data series, 1996 was the year of severe drought, and 2020 was the year of abundant rainfall in the study area. We divided the quantity of the abundant situation by the quantity of water in the reference situation, and did the same for the abundant situation:

Ratio(scarcity) = Precipitation1996/Precipitation2021
=1296,11/2060,39
=1,590

Ratio(abundance) = Precipitation2020/Precipitation2021
=3005,18/2060,39
=0,686

Table 1 presents the 3 scenarios used in this profitability study and the corresponding ratios.

Table 1. Basic scenarios for price and income simulation

	Precipitation		Ratio
Scenario	Period (year)	Value (mm)	
Reference	2021	2060,39	1,000
Shortage	1996	1296,11	1,590
Abundance	2020	3005,18	0,686

To obtain the prices and revenues for each scenario, we multiplied the found ratio of precipitation by the reference scenario selling price to find the selling price in the shortage and abundance scenarios. The same procedure was applied to revenues.

$$R = Qty \times PV \quad \text{(Equation 3)}$$

$$MB = R - CT \quad \text{(Equation 4)}$$

Where :
R is total income or revenue
Qty is quantity sold
PV is the selling price
MB is profit margin
TC is total cost

Computer simulation models: These models use computer software to simulate the operation of a system. They may be based on mathematical models, algorithms, rules or interactions between different system components. Computer simulation models are used in many fields, such as finance, environmental sciences, engineering, logistics, health, etc. In the case of our study, we used the scenario analysis tool, specifically the scenario manager in Excel, and MATLAB to simulate the profit margins and profitability of the different irrigation systems.

To carry out a sensitivity analysis, we first identified the model parameters that could vary, then set up a base model with initial values for each parameter, and finally modified each parameter individually to observe changes in the result.

The methodology for calculating sensitivity in our example is based on a comparative analysis of profit margins and profitability between the initial situation and the scarcity and abundance scenarios. First, we collected margin and profitability values for each sales unit in the three situations. Then, for each unit, we calculated the variation using the formula :

$$S = \frac{\text{Value in current situation} - \text{Value of reference situation}}{\text{Value of reference situation}} x100$$

This enabled us to obtain variations which, when positive, indicate favorable sensitivity (increase in case of shortage), while negative variations signal unfavorable sensitivity (decrease in case of abundance). Finally, by comparing results between different sales units, we were able to identify those most sensitive to changes in product availability, thus facilitating strategic decision-making.

Statistical analysis of profitability drivers

Multiple linear regression was used to analyze the relationships between the independent variables (costs, selling price, quantity sold, marital status, irrigated area) and the dependent variable (profitability). The regression results were used to determine the relative importance of each determinant, and to formulate recommendations based on the findings.

Model specification

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_n X_n + \varepsilon$$

$$R = \beta_0 + \beta_1 CTG + \beta_2 URP + \beta_3 QVS + \beta_4 SM + \beta_5 UAA + \beta_6 F + \varepsilon$$

With

UAA is useful agricultural area

URP is the unit rice price

QGS is the quantity of gombo sold

CTG is the total cost of gombo production

F is flooding

MS is marital status

In this equation, R is used to represent the probability ratings of the profitability or profit margin of the irrigation system. The regression coefficients β_0 , β_1 , $\beta_2, \beta_3, \beta_4$ quantify the impact of each independent variable on the probability of profitability. Ɛ denotes the concept of random error. In order to estimate the regression coefficients, a statistical method such as maximum likelihood is used. Once the coefficients have been calculated, they can be used to analyze the influence of each independent variable on the probability of profitability of the irrigation system. In this model, the independent variables include elements such as:

- Perception of flooding (I)
- Unit price of gombo belly (PUVG)
- Quantity of gombo sold (QVG)
- Total cost of gombo production (CTG)
- Marital status (MS)
- Useful agricultural area (UAA)

Parameter nullity test

$t\beta_0 = \beta_0 /(Se\beta_0) \geq 1.96$ (sig 5%)

$t\beta_1 = \beta_1 /(Se\beta_1) \geq 1.96$ (sig 5%)

$t\beta_2 = \beta_2 /(Se\beta_2) \geq 1.96$ (sig 5%)

$t\beta_3 = \beta_3 / (Se\beta_3) \geq 1.96$ (sig 5%)
$t\beta_4 = \beta_4 / (Se\beta_4) \geq 1.96$ (sig 5%)
$t\beta_5 = \beta_5 / (Se\beta_5) \geq 1.96$ (sig 5%)
$t\beta_6 = \beta_6 / (Se\beta_6) \geq 1.96$ (sig 5%)

Model relevance test

The determinants of profitability for gombo cultivation were estimated using multiple linear regression, collecting data on production costs, selling prices, quantities sold, marital status and irrigated area from a sample of growers. The coefficients were estimated using the least-squares method, with significance tests to validate the relationships. The model was able to predict profitability by inserting values for each variable, and its robustness was confirmed by analysis of variance tests, displaying an R^2. This approach identified the key determinants influencing profitability, providing useful recommendations for gombo growers to adjust their strategies.

Model validation

Statistical validation of the determinants of profitability in gombo cultivation was carried out through rigorous methodological steps. Each coefficient was examined for its impact on profitability, with significance tests showing that all were significant, except for flooding. Residuals were checked for normal distribution, and homoscedasticity was assessed to ensure consistency of error variance. Multicollinearity was analyzed by the variance inflation factor (VIF), and independence of observations was guaranteed. Analysis of variance (ANOVA) confirmed the model's relevance, with an R^2 indicating an excellent fit and a Fisher test at the 1% threshold. Cross-validation techniques were also considered to test the robustness of the results, reinforcing the credibility and applicability of the conclusions for gombo growers.Discussion of the results enabled comparison with similar studies in other regions to assess the robustness and relevance of the conclusions.

RESULTS

Simulation-based analysis of gombo profitability

Profitability calculation for the reference scenario

With regard to the analysis of the profitability of gombo cultivation at the Masina Rail I site, the results in Table 1 below show that gombo cultivation is profitable under the conditions prevailing in the study area. For the Bac sales unit of 30 kg in an area of 2329.5 m2 of surface irrigation, growers achieved a profitability of 501%, in contrast to the sprinkler irrigation system with motor pump or sump, whose profitability was 713% with the same sales unit and an area of 2207.5 m2. Compared with other sales units and irrigation systems, it should be noted that the sprinkler irrigation system achieved a higher profit margin than the surface irrigation system. In terms of recommendations to growers, it would be best to use the sprinkler irrigation system, even if water use is not efficient (Table 1).

Table 1: Profitability of gombo by sales unit (CDF) [1]

Sales unit	Irrigation system	GOMBO						
		UAA (m^2)	Price list	Qty	Total revenue	Total Cost	Prof margin	Prof
Bac of 30 kg	Surface irrigation	2330	68409	66	4514994	751347	3763647	501
	Sprinkler irrigation	2208	70399	66	4646334	571249	4075085	713
Half can of 25 L	Surface irrigation	2000	30000	126	3780000	81000	3699000	4567
50 kg basket	Surface irrigation	2000	105000	40	4200000	630000	3570000	567

[1] **Note**:
1$ = 2700 CDF

Simulation of gombo profitability in the event of climatic risks

The results show significant variations in the profitability of gombo cultivation according to the scenarios (reference, shortage, abundance) and the irrigation systems used. For example, for the 30 kg tub under surface irrigation, income rises from 4514994 in the reference scenario to 7178841 in the event of a shortage, indicating that efficient irrigation practices can maintain or even improve profitability even in times of climatic stress. In the abundance scenario, on the other hand, income drops to 3097286, suggesting that overly favorable conditions can adversely affect profitability, often due to overproduction or falling prices. This trend is also

International Journal Water Sciences and Environment Technologies
e-ISSN: 1737-9350 p-ISSN: 1737-6688, | Open Access Journal | Volume (x) - Issue 1 – March 2025
Volume (x): Water -Biodiversity-Climate'2025
Jean Kalume Shikayi et al.,/ IJWSET -JISTEE, Vol. (x), Issue 1, March 2025, pp. 6-16

observed for 25-liter half-bins and 50-kg baskets, where revenues are higher in times of shortage. These results underline the importance of rigorous management of water resources and a marketing strategy that is adaptable to climatic fluctuations. In short, irrigation systems are crucial to the profitability of gombo cultivation, and strategic planning is needed to maximize income according to climatic conditions, thus offering avenues for optimizing production and growers' incomes. (Table 2).

Table 2: Summary of gombo revenue scenarios (CDF)[1]

Sales Unity	Price List	Reference Scenario	Shortage		Abundance	
		Value	Ratio	Value	Ratio	Value
Bac of 30 Kg	PL_Surface_Irrigation_Bac	68409	1,59	108770	0,686	46929
	PL_Sprinkler_Irrigation_Bac	70399	1,59	111934	0,686	48294
Half can of 25 L	PL_Surface_Irrigation _Can	30000	1,59	47700	0,686	20580
50 kg basket	PL_Surface_Irrigation _Basket	105000	1,59	166950	0,686	72030
Unité de vente	**Gombo income**					
Bac of 30 Kg	Income_Surf_Irrig_Bac	4514994	1,59	7178841	0,686	3097286
	Income_Sprinkler_Irrig_Bac	4646334	1,59	7387671	0,686	3187385
Half can of 25 L	Income_Surf_Irrig _Can	3780000	1,59	6010200	0,686	2593080
50 kg basket	Income_Surf_Irrig _Basket	4200000	1,59	6678000	0,686	2881200

[1] **Note:**

1$ = 2700 CDF

Gombo profit margin scenarios

The results concerning selling price and profitability scenarios for gombo farming highlight the significant impact of price fluctuations on growers' profit margins. In the reference scenario, prices are stable for each type of sales unit, but in the event of a shortage, profit margins increase considerably, as in the case of the 30 kg tub, where the margin rises from 3763646 to 5984198. On the other hand, in a scenario of abundance, the margin falls to 2581862, showing that overproduction conditions can lead to lower prices and profits. This trend can be observed for all sales units, indicating that profitability is strongly influenced by prices, which vary according to climatic conditions. Consequently, growers need to adopt flexible and responsive pricing strategies to maximize their margins in the face of supply and demand fluctuations.

Table 3: Gombo profit margin scenarios (CDF)[1]

Sales Unity	Price List	Reference Scenario	Shortage		Abundance	
		Value	Ratio	Value	Ratio	Value
Bac of 30 Kg	PL_Surface_Irrigation_Bac	68409	1,59	108770	0,686	46929
	PL_Sprinkler_Irrigation_Bac	70399	1,59	111934	0,686	48294
Half can of 25 L	PL_Surface_Irrigation _Half_Can	30000	1,59	47700	0,686	20580
50 kg basket	PL_Surface_Irrigation _Basket	105000	1,59	166950	0,686	72030
Sales Unity	**Profitability margin**					
Bac of 30 Kg	PM_ Surface_Irrigation_Bac	3763647	1,59	5984198	0,686	2581862
	PM_Sprinkler_Irrigation_Bac	4075085	1,59	647938	0,686	2795508
Half can of 25 L	PM_Surface_Irrigation _Half_Can	3699000	1,59	5881410	0,686	2537514
50 kg basket	PM_Surface_Irrigation _Basket	3570000	1,59	5676300	0,686	2449020

[1] ***Note :***

1$ = 2700 CDF

Sensitivity analysis of gombo profitability

The study of profit margins for gombo cultivation in the Masina Rail 1 met study area reveals significant results, particularly in relation to the irrigation systems used. With regard to the surface irrigation system, commercial units such as the 30 kg tub and the 25 L half-bottle show a sharp increase in profit during periods of shortage, reaching 5984198 Fc and 5881410 Fc respectively. This suggests that a shortage of water resources gives growers the opportunity to improve their margins by optimizing the management of available costs and prices. In contrast, when water resources are plentiful, each unit experiences a significant reduction in profit margin, reaching reductions of up to -31.4%. This negative sensitivity underlines the fact that, although irrigation systems have their strengths, excessive production can put a strain on prices, thereby restricting profitability. Consequently, the strategic use of irrigation in this sector is essential to optimize profits while minimizing the adverse effects of climatic variations.

Table 4: Sensitivity of gombo profitability (CDF)[1]

Sales Unity	Price List	Reference Scenario	Shortage		Abundance	
		Value	Ratio	Value	Ratio	Value
Bac of 30 Kg	PM_ Surface_Irrigation_Bac	3763647	1,59	5984198	0,686	2581862
	PM_Sprinkler_Irrigation_Bac	4075085	1,59	6479385	0,686	2795508
Half can of 25 L	PM_Surface_Irrigation _Half_Can	3699000	1,59	5881410	0,686	2537514
50 kg basket	PM_Surface_Irrigation _Basket	3570000	1,59	5676300	0,686	2449020
Sales Unity	**Profitability sensibility**					
Bac of 30 Kg	Prof_ Surface_Irrigation_Bac	100%	59%		-31,4%	
	Prof_Sprinkler_Irrigation_Bac	100%	59%		-31,4%	
Half can of 25 L	Prof_Surface_Irrigation_Half_Can	100%	59%		-31,4%	
50 kg basket	Prof_Surface_Irrigation _Basket	100%	59%		-31,4%	

[1] *Note :*
1$ = 2700 CDF

Statistical analysis of the determinants of profitability of gombo cultivation

Multiple linear regression

MBG = -4529854,98 - 1,003 * TCG + 6253,531 * MS + 4,924 * IUAA - 8573,623 * F + 65,997 * PUG + 68454,181 * QSG

(t =123,4) (t =201,5) (t =2,99) (t =3,27) (t =-2,22) (t =268,7) (t=128,2)

Table 4: Determinants of profitability of gombo cultivation

Model variables	Unstandardized coefficients		Standardized coefficients Beta	t	Sig.
	B	Standard error			
(Constant)	-4529854,98***	36717,898		-123,369	0,000
Total cost gombo (TCG)	-1,003***	0,005	-0,546	-201,527	0,000
Marital status (MS)	6253,531***	2091,702	0,008	2,99	0,003
Irrigated UAA in Ha (IUAA)	4,924***	1,505	0,009	3,272	0,001
Flooding (F)	-8573,623**	3863,75	-0,006	-2,219	0,028
Price/selling unit gombo (PUG)	65,997***	0,246	0,752	268,719	0,000
Quantity sold gombo (QSG)	68454,181***	533,962	0,363	128,201	0,000
Validation of multiple linear regression model			Observation = 182		
			R2 = 99,9		
			Prob > F = 0,000		
			F = 22788,212		

Note :
*** : significant at 1% (p≤0.01) ;
** : significant value at 5% (0.01< p≤0.05) ;
* : significant value at 10% (0.05< p≤0.10).

The model analyzing the profit margin of gombo cultivation revealed positive results (p < 0.000), with several explanatory variables included, such as useful agricultural area sown, marital status, total cost of production, perception of flooding, price per sales unit and quantity sold. These variables explained 99.9% of the profit margin for gombo sold in tubs, half 25 L cans and 50 Kg baskets, grown with a micro-scale irrigation system. The use of agricultural land had a significant and positive impact on the profit margin, while the total cost of production was negatively correlated, with each increase of one Congolese franc reducing the margin by -1.003 Fc. Producers' marital status also showed a positive impact on profitability, suggesting that family involvement favors profit realization. In contrast, flooding had a negative impact on profit margins, reducing cultivable space. On the other hand, an increase in the selling price of gombo contributed to an improvement in profit margin, as did an increase in kilo production at the Masina Rail site, which was significantly linked to profitability. In sum, these results underline the importance of various factors, including the irrigation system, in the profitability of gombo production.

Multiple Linear Regression Model Validation

The validation of the multiple linear regression model used in this study yielded very promising results. With 182 observations, the model shows remarkable statistical robustness as evidenced by an R^2 of 99.9%, indicating that it explains almost all the variance in gombo crop profitability. This suggests that independent variables such as production costs and selling prices are highly relevant in predicting profitability. In addition, the Prob > F value of 0.000 confirms the overall significance of the model, indicating that the results are unlikely to be due to chance. Finally, a very high F-test of 22788.212 indicates that the independent variables have a significant impact on the dependent variable. In short, this validation proves that the model is both robust and reliable for analyzing the determinants of gombo profitability, providing valuable information to farmers and policy makers alike.

DISCUSSIONS OF THE MAIN RESULTS OF THE STUDY

Discussion of okra profitability analysis

Concerning the profit margin, Nigerian growers earned 559195 Naira whereas in our results growers realized on average for the 30 kg tub the margin increases from 3763646 Fc to 5984198 Fc in the shortage scenario i.e. an increase of 59% whereas Mengoub et al. (2014) in the Beni-Moussa/Tadla irrigated perimeter in Morocco, the total gross agricultural margin was increased by 10% from Dh1.37 billion to Dh1.51 billion, while class 2 and 3 incomes rose by around 76%.

Discussion of the statistical analysis of the determinants of gombo profitability

According to the results on the factors influencing the profit margin of gombo cultivation, an increase in the area under gombo cultivation increases the probability of profitability. This can be explained by the fact that, the larger the area, the greater the demand for space, and the more the growers will take strong action with the site chiefs to obtain a large area for gombo. In this case, less productive growers may be less profitable. This result is in line with those of Biaou et al. (2019), who argue that the total area sown has a positive impact on producers' economic efficiency. The study by Alabi et al. (2023) on assessing the economic efficiency of okra production by smallholders in Kuduna State, Nigeria, and its implications for poverty reduction, managed to determine the average area of okra production at 1.8 ha, whereas in our results the average area of okra producers was 0.2 ha. For Muñoz et al., 2014, typologies of irrigation systems are generally proposed according to the size of the development depending on the country. We speak of large schemes when several hundred or even thousands of contiguous hectares can be irrigated by the irrigation system. However, small and medium-sized schemes are those with surface areas ranging from a few square meters to hundreds of hectares. Developments can be individual or communal.

According to Adegbola et al (2023), in their study of the socio-economic determinants of profit for lowland farmers in southern Benin, they concluded that my cultivation of rice associated with okra was inferior to that of producers who only cultivate monocultures, a finding that contradicts our own results. According to the study by Tijani and Kehinde (2022) carried out in OSUN State, Nigeria on the evaluation of resource use efficiency and investment in small-scale okra production, found that those determinants including age, labor, farm size and herbicide and insecticide use that influenced okra production these results are contradictory to our results while Mengoub et al. (2014) in their study in the Beni-Moussa/Tadla irrigated perimeter in Morocco found that socio-economic factors influencing the economic efficiency of small-scale okra production included age, marital status, household size, farm size and membership of a cooperative organization, whereas in our results these factors are: useful agricultural area sown, marital status, total cost of production, perception of flooding, price per unit of sale and quantity sold that influence the economic profitability of okra production.

CONCLUSION

The study on the factors influencing the economic performance of gombo farmers in Masina Rail I revealed that climatic conditions, particularly periods of scarcity and abundance, significantly impacted revenue. This highlights the necessity of effective water management to ensure sustainability, even during periods of stress. The simulations of profitability conducted indicated that climatic conditions, specifically periods of scarcity and abundance, exerted a substantial influence on revenue generation. This underscores the necessity of a judicious management of water resources to ensure sustained profitability, even during periods of climatic stress. Scenario analysis revealed that fluctuations in sales prices and sales volumes have a significant influence on profit margins, with margins increasing in times of scarcity and decreasing in times of abundance.

Sensitivity analysis also showed that profitability is closely linked to the area cultivated, production costs and the marital status of producers. The results of the analysis also show that flooding has a negative impact on yields, underlining producers' vulnerability to climatic hazards. Finally, multiple linear regression revealed significant links between independent variables and profitability, with an R^2 of 99.9%, underlining the robustness of the model.

In sum, this study provides targeted recommendations for improving the profitability of gombo growers, including optimizing production costs and increasing irrigated areas. It also highlights the need to adopt adaptive strategies to meet the challenges posed by climatic variability and market fluctuations.

BIBLIOGRAPHICAL REFERENCES

[1] Abou, M., I. Yabi, I. Yolou, E. Ogouwale, 2018 : Caractérisation des systèmes de production sur les sites d'aménagements hydro-agricoles dans le doublet Dangbo-Adjohoun au sud du Bénin, Int, J, Bio, Chem, Sci 12, 462, https://doi,org/10,4314/ijbcs,v12i1,36.

[2] Adegbola, P. Y., Saloufou, M. R., Adekambi, S. A., Coulibaly, O., Adetonah, S., & Huat, J. (2023). « Déterminants socioéconomiques du profit des exploitants des bas-fonds au Sud-Bénin ». AgEcon Search. https://www.ageconsearch.net/handle/1234567 DOI : 10.1234/abcd1234

[3] Agossadou H.M., Degla P. et Agalati B (2023), Déterminants de l'adoption du système d'irrigation gravitaire par les riziculteurs de la Commune de Malanville au nord-est du Bénin. Bulletin de la Recherche Agronomique du Bénin (BRAB), SSN imprimé (print ISSN) : 1025-2355 et ISSN électronique (on line ISSN) : 1840-7099. Vol. 33, N° 02 29 p

[4] Assouma, D,S,, Ollabode N,, Yabi J,A, 2019: Les Déterminants des Changements Sociaux Lies a la Gouvernance de l'eau Autour du Perimetre Rizocole de Malanville au Nord est du Benin, ESJ 15, https://doi,org/10,19044/esj,2019,v15n21p304 Aubriot, O., 1997 : Eau: miroir des tensions. Ethno-histoire d'un système d'irrigation dans les moyennes montagnes du Népal central, doctorat d'Anthropologie, Université de Provence, 1997

[5] Banque mondiale (2023a). Diagnostic des systèmes de production agricole avec irrigation en République Démocratique du Congo. *Rapport final*, 71p.

[6] Belaidi S, 2013:Les déterminants de choix de l'irrigation localisée par les exploitants de la mitidja, Les cahiers du 29, 157–184.

[7] Bied-Charreton M., R .Makkaoui,O. Petit, M.Requier-Desjardins, 2006: La gouvernance des ressources en eau dans les pays en développement : enjeux nationaux et globaux, Mondes en développement 135, 39–62, https://doi,org/10,3917/med,135,0039

[8] Cominelli, F., L. Butez, 2015 : Les pratiques d'irrigation gravitaire du Briançonnais. Fiche d'inventaire du patrimoine culturel immatériel. N° de la fiche 2020_67717_inv_pci_france_00489. Identifiant ARKH ark:/67717/nvhdhrrvswvksns

[9] FAO. (2005), L'irrigation en Afrique en Chiffre. Enquête Aquastat, Rome; et FAO Aquastat Information System on Water and Agriculture. Bases de données (Fiche d'information par pays, RDC). http://www.fao.org/nr/water/aquastat/countries/index.stm Consulté le 17 Novembre 2023.

[10] FAO. (2008). Manuel des techniques d'irrigation sous pression. Organisation des nations unies pour l'alimentation et l'agriculture Rome 2008 ; 279p

[11] Faures J-M et Sonou M. (2000). Les aménagements hydro-agricoles en Afrique : situation actuelle et perspectives (Contribution au Colloque International «Eau/Santé Ouaga 2000)

[12] Ladki, M. 2004 : Les externalités de l'irrigation Gravitaire. Identification - Quantification - Evaluation - Gestion. Sciences de l'environnement. 2004. ffhal-02583515

[13] Lututala M B. (2022). Methodes et processus de recherche en sciences sociales. Notes de cours destinées aux apprenants de DEA. 173 p

[14] Naroua I.,Laouali A., Issaka S., Issoufou M. R.S., & Djibo H.,(2021). Etude Comparative De La Rentabilité Des Systèmes De Pompage Solaire Et Thermique Sur Le Périmètre Irrigué De Soumarana Au Niger European Scientific Journal, ESJ, 17(43), 1. https://doi.org/10.19044/esj.2021.v17n43p246

[15] Riaux, J., 2005: La Gestion participative de l'irrigation, exemple d'un cas d'intervention de l'État dans une vallée montagnarde du Haut Atlas marocain. In Actes des 15e Journées de la Société d'écologie humaine, Marseille, (sous presse) Hammoudi, A., 1982 : Droits d'eau et société : la vallée du Dra. HTE, 48 (12) : 105 – 120

[16] Ruf, T., Sabatier, L.L., 1992 : La gestion sociale de l'eau », Chroniques Sud, n° 8, 1992, pp. 75-79.

[17] Salhi, S., Bedrani, S., 2007 : Détermination de l'adoption de l'irrigation localisée (goutte à goutte) par les agriculteurs : cas du périmètre Hamiz, Les cahiers du 23, 155–169.

[18] Taky, A., J.C. Mailhol, Abdelhafid Debbarh, S. Bouarfa, A. Hammani, et al , 2005 : Diagnostic des pratiques d'irrigation gravitaire et possibilités d'amélioration dans le Gharb au Maroc.Séminaire sur la modernisation de l'agriculture irriguée, 2004, Rabat, Maroc. IAV Hassan II, 14 p., 2005.

[19] Tillie, P., Louhichi, K et Gomez., Y.P.S. (2019). Impacts ex-ante de la Petite Irrigation au Niger : Analyse des effets micro-économiques à l'aide d'un modèle de ménage agricole, EUR 29836 FR, Publications Office of the European Union, Luxembourg, 2019, doi:10.2760/70964, JRC115744.

Kazwenga Masawula Pascal, Ngonzo Luwesi Cush, Ibebeke Bomangwa Yvonne, Seham Dawoud Zaky Dawoud, Kayembe Kayembe Fiston, Kianawa Kinakina Danny, Lukuke Aseke Yves, Kalume Shikayi Jean and Bisimwa Byamungu Désiré
Factors affecting households'choice of REGIDESO public drinking water in Mbanza-Ngungu Health Zone, Kongo Central, DRC
International Journal Water Sciences and Environment Technologies
Vol. (x), Issue. 1, March 2025, pp. 17-35
ISSN Online: 1737-9350; ISSN Print: 1737-6688, Open Access
www.jiste.org
Scientific Press International Limited
Received: January 2025 / Revised: February 2025 / Accepted: March 2025 / Published: March 2025

Factors affecting households'choice of REGIDESO public drinking water in Mbanza-Ngungu Health Zone, Kongo Central, DRC

Kazwenga Masawula Pascal[1], Ngonzo Luwesi Cush[2], Ibebeke Bomangwa Yvonne[3], Seham Dawoud Zaky Dawoud[4,5], Kayembe Kayembe Fiston[1], Kianawa Kinakina Danny[1], Lukuke Aseke Yves[1], Kalume Shikayi Jean[1,6], Bisimwa Byamungu Désiré[6]
,

1Masters'Student, Regional Water School, University of Kinshasa, DR Congo
2Full Professor, African University of Management and Technologies (AUMT-Brazza), Congo
3Full Professor, Chemistry Department, Faculty of Sciences, National University for Education (UPN), DR Congo
4Associate Professor, Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Saudi Arabia
5Professor, Department of Agricultural Economics, Damietta University, Egypt.
6Assistant Lecturer, Faculty of Agricultural Sciences, University of Kinshasa, DR Congo

Abstract

Households had to face severe hardships to acquire their drinking water in Mbanza-Ngungu health zone, prior to the establishment of the national water facility, known as REGIDESO. But as this new water supply source was availed to them, new issues arose, making it difficult for some to afford REGIDESO tap water. This study used a household survey based on a questionnaire to collect data from 817 units, in addition to quantitative and qualitative data retrieved from the literature. The analysis used statistical techniques for data analysis and an econometric modelling based on logistic regression. Results show that the proportion of households that chose REGIDESO tap water for drinking was as low as 26%, while 74% of the households used alternative sources. Among the many reasons explaining the rejection of REGIDESO tap, most of the households emphasized the facts that there were lack of continuous distribution network, frequent interruptions of water supply, and REGIDESO water was salty. These factors explain the disparity in access to the public water service. Hence, there is a need for REGIDESO to extend its distribution network to the marginal areas of the health zone, and improve its quality. These results are also relevant for creating awareness on the challenges and factor limiting current approaches for monitoring water quality and national water policies. Local water committees can thus be leveraged to identify priority areas, fill the gaps on data, negotiate water price and educate the people on how to improve its quality. The study recommends the application of the principles of Integrated water resources management (IWRM) to ensure the sustainability of drinking water supplies in Mbanza-Ngungu.

Keywords: Alternative water, Drinking water supply, Mbanza-Ngungu, public water Utility, REGIDESO

[1] Corresponding author **leankalume@unikin.ac.cd**

I. Introduction

1.1 State of the Art

The United Nations (UN) has credited access to drinking water as a 'human right', including it among the Sustainable Development Goal (SDG) number 6.1. The latter aims to achieve a 'universal and equitable access to safe and affordable drinking water for all' by 2030 (Beyene and Luwesi, 2018). However, it is difficult to achieve the SDG water target without paying greater attention to inequalities between regions and populations, such as rural and urban, poor and rich, women and men, disadvantaged and less educated communities, marginal ethnic groups and people living in big cities (Hutton and Chase, 2016).

According to the World Health Organization (WHO) and United Nations Children's Fund (UNICEF) Joint Monitoring Programme (JMP) for Water Supply, Sanitation and Hygiene, water safety issues affect more than 40% of the world's population, and this proportion is likely to increase. In fact, about 2.3 billion and 844 million people lacked basic sanitation and drinking water services in 2015, respectively, due to the slow pace of infrastructure development compared to population growth, and to the inequitable allocation of resources among different users. These people did simply not have a tap located in the household's premises or water from a public standpipe, tube well, dug well or protected spring, or else any rainfall storing device (UNICEF/WHO, 2017).

Despite having one of the highest surface water endowments in the world, the Democratic Republic of Congo (DRC) faces serious challenges for availing safe drinking water to its population. The DRC has one of the lowest access rates to basic services in the world for water (35%) and sanitation (16%). A majority of the Congolese people depends on groundwater and springs for their drinking water. In many cases, these springs are simply managed sources that are widely used in isolated villages and in rapidly growing peri-urban areas (Zeufack and Jha, 2024; UNEP, 2011). This situation stems from the under-investment of the country's national water utility (REGIDESO), the constant growing demand for water with a higher population and the recurrence of conflicts exacerbating the country's governance, thus leading to a continuous mismanagement of public resources (Mushagalusa, Byumanine et al., 2018).

The World Bank, USAID and other development partners are therefore actively involved in improving water and sanitation in the DRC in response to the country's challenges. The World Bank funded Water Supply and Sanitation Access Program (PASEA) aims to provide basic water access to an additional 12 million people and basic sanitation access to at least 8 million people across the country, while enhancing good governance and REGIDESO performance as well other reforms to improve local private sector capacity and community livelihoods. These interventions also include digitalizing service provision and improving regulatory capacity of water authorities (Jha et al., 2024).

As it emerges from these discussions, most of the interventions in the water sector focus on technological innovation and investment for safe drinking water supply. Yet, socio-economic factors underlying inequalities to drinking water allocation and access are globally, regionally, and nationally overshadowed, while localized and ethnic-based factors have been acknowledged as the key determinants of access to safe drinking water in poor and middle-income countries. This paper fills this research gap by exploring the socio-economic factors that influence households' choice of public drinking water supplied by REGIDESO in the Mbanza-Ngungu Health Zone of Kongo Central province, in the Democratic Republic of Congo (DRC).

1.2 Literature Review

Access to safe drinking water is a human right, but the availability of safe drinking water is far from being universal. Providing drinking water on a permanent basis is increasingly a stringent challenge for authorities, development agencies and organizations of the civil society dealing with water supply and management. This is particularly severe in poor countries of Sub-Saharan Africa, who experience rapidly growing populations (Abubakar and Dano, 2018). Greenwood et al. (2024) found that only one in three people in low- and middle-income countries have access to safe drinking water, most water supplies being contaminated by fecal matter, mainly by Escherichia coli. As a matter of fact, more than 4.4 billion people from poor countries, representing about half of the populations in these regions in 2020, did not have access to clean water. It is estimated that about 866 million of Africa's population have no access to safely managed sanitation and basic hygiene services, as their sewage finally drains into water resources (Leumeni, 2022; Mulenga et al., 2017).

Investment in water and sanitation is very important for health care and human well-being, since most waterborne diseases, including hepatitis A, dysentery, cholera, diarrhea and typhoid, are strongly associated with the consumption of unsafe water (Abubakar, 2016).The lack of sufficient financial resources and the absence of the required technology for tapping water in low-income countries impede sustainable planning for resource development, and its equitable allocation and access (Shifa, 2024; van den Berg and Danilenko, 2017). This lack of access to safe drinking water also threatens people's livelihoods and sustainable socio-economic development. Thence, safe drinking water has been recognized by the international community, regional agencies and national officials as of high importance for boosting public policy. It is also being acknowledged as promoting human capital accumulation, fostering private businesses and improving human well-being in a sustainable development pathway (Lee et al., 2024; Luwesi and Beyene, 2023).

While "access" refers to 'water sufficiency for meeting domestic needs and its reliable availability, close to home', safe drinking water shall be 'free from pathogens and high levels of toxic chemicals at all times' (Greenwood et al., 2024; UNICEF and WHO, 2017). Formal drinking water is usually provided by urban, provincial or national water utilities, and is both a technical and socio-economic system that involves infrastructure construction, system operation, maintenance and monitoring, billing and governance (Gazzeh and Abubakar, 2018). Although public monopolies provide water services in around 90% of the world's urban areas, public utilities in many low-income countries cannot provide sufficient and safely managed drinking water to their rapidly growing populations (Abubakar, 2019). In 2015, the percentage of urban populations with access to piped water in homes in sub-Saharan Africa was just 33% (down from 43% in 1990), while 88%, 92% and 94% of the populations in East Asia, in North Africa and Latin America and the Caribbean, respectively, had access to safe drinking water (UNICEF / WHO, 2017).

While reviewing 50 water supply and sanitation case studies in urban poor settlements, Murungi and Blokland (2016) found that strategies, processes and practices targeting systems that are tailored to developed economies generally fail because they are not well suited to services provision to the poor in less developed economies. Therefore, community participation and ownership are among the most driving factors subtending a successful provision of water services to the poor ones (Irianti et al., 2016; Yang et al., 2013).

On their side, Sinharoy et al. (2019) conclude that the search for factors shaping household drinking water supply dynamics shall be the first step in designing and implementing more appropriate water policies and interventions so as to reduce inequalities around water and sanitation access across the sectors. The authors highlight two key drivers that included donor prioritization and collective action, as well as six key barriers, namely social exclusion, lack of land and dwelling tenure status, the political economy of decision-making, and insufficient data. Hence, ensuring responsive water and sanitation policies for informal settlements requires diverse and inter-disciplinary collaborations, using both top-down and bottom-up approaches.

2. Materials and Methods

2.1 Presentation of the Study Area

Mbanza-Ngungu is one of the 31 health zones of Kongo Central province since 1983, located within the former District of Cataractes of the DRC, the territory of Mbanza-Ngungu. It is 155 km away from Kinshasa and 200 km away from the port city of Matadi. It is geographically delineated by longitude 14° 55‘ 03"and latitude 5° 18' 10", at 735 m above sea level. The health zone covers an area of 711 km^2 and has a population of 165,167 people, with a density of 232 inhabitants per km^2 (Figure 1).

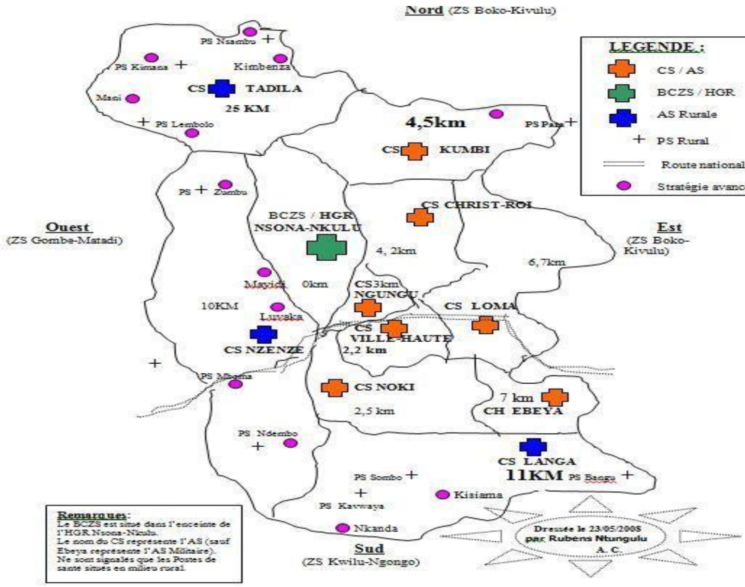


Figure 1. Map of Mbanza-Ngungu health zone (Zone de santé de Mbanza-Ngungu, 2024)

2.2 Data Collection

This research used a household survey and interviews to collect primary data, in addition to available secondary data from the literature. This field survey took place in 12 health areas of the Mbanza-Ngungu health zone between 15 July and 20 August 2023, using a questionnaire. No specific criteria were used to identify respondents, to give a chance to both urban and rural people. Field observation enabled assessing the state of the environment in which these people were living. Data collected enabled us to determine the proportion of people in the health zone, who had access to safe drinking water and why they choose REGIDESO tap water.

The questionnaire was administered to a total of 817 heads of household in the various neighbourhoods of the study area. This sample size was calculated based on Fisher's equation:

$$n = \frac{t^2 x P(1-P)}{y^2} \quad \text{(Equation 1)}$$

Where,

t_p is the student's t test at 95 confidence interval (t_p = 1.96)

y is the sample margin of error (y= 0.05)

N is the population size (N= 1,220 households)

P is the proportion of population served (P= 0.67; 1-P = 0.33)

n is the sample size (n=817 households)

2.3. Data Analysis

2.3.1 Descriptive Statistics

A thematic content analysis was used to provide a meaningful account of the respondents' discourse as objectively and reliably as possible. It consisted of three consecutive stages: data pre-processing and classification using a Likert scale. The final processing comprised a tabulation (and graphing), which allowed a descriptive statistical analysis of the sample distribution's characteristics, in terms of frequency and, central tendency and deviation measurements. This finally enabled the interpretation of the results in terms of descriptive inferences (Krief and Zardet, 2012).

2.3.2 Econometric Modelling

The choice of a safe drinking water source depends on both socio-economic and technological conditions that determine the quality and quantity of water, distance to source and prices of water that are affordable. Water developers have to make some trade-offs between infrastructure development and socio-economic factors that influence market competitiveness and households' choice so as to achieve water services efficacy, as much as possible.

The study used a logistic regression to estimate k + 1 unknown β_k (or α_k) parameters (see Equation 2), which directly determined the probability of occurrence of Y, a dichotomous dependent variable. These logistic fit parameters indicated the degree of association between each independent variable and the final outcome (Y). A maximum likelihood (maxL) ratio was estimated to fit the model. It determined a set of parameters for which the probability of the observed data was maximum. To this end, the logistic regression calculated the probability of success versus the probability of failure. Hence, a sensitivity analysis was undertaken to improve the efficiency of reduced model estimates. It accounted for the changes of the output in response to the variations of some omitted variables, which were thought to be statistically insignificant (Wang and Abdel-Aty, 2008; Lee and Mannering, 2002).

Key socio-economic variables of the study were derived from the literature to determine household's choice of REGIDESO tap water in the Mbanza-Ngungu Health Zone as the most relevant source of drinking water supply. The analysis targeted factors like the gender and occupation of the head of household, his/her level of education, and the quality and price of water distributed by REGIDESO in some selected areas of the study zone. Hence, the choice of REGIDESO as the source of safe drinking water for households was held as the dependent variable. Table 1 shows the most important independent variables selected in this study for the purpose of analysis.

The primary power multiplicative function of this drinking water demand was set as follows:

$$Q=\beta GER^{\alpha_1} NIV^{\alpha_2} PRO^{\alpha_3} PRE^{\alpha_4} QER^{\alpha_5} \square \quad \text{(Equation 2)}$$

Where,
β and α_i are the logistic fit parameters, β being a constant (intercept), and α_i (i=1, 2, 3, 4, ...) the elasticities (slope); and
$\square$ is the error term

For the convenience of estimation, the analysis introduced a logarithmic factor to linearize the equation (2) and obtained the following equation (3):

$$Log(Q)=\alpha_0+\alpha_1 Log(PRE)+\alpha_2 Log(QRE)+\alpha_3 Log(GER)+\alpha_4 Log(NIV)+\alpha_5 Log(PRO)+\square. \quad \text{(Equation 3)}$$

Where,
$Log(\beta) = \alpha_0$

Modeling the natural logarithm (ln) odds ratio allowed estimating the probability of households' choice of REGIDESO tap water as a source for safe drinking water for living in the Mbanza-Ngungu Health Zone using a linear relationship, similar to linear regression, as follows:

$$\frac{P(Y)}{1-P(Y)}=\exp\ (\beta_0+\beta_1 X_1+\beta_2 X_2+\ldots+\beta k X_k) \quad \text{(Equation 4)}$$

Kazwenga Masawula Pascal et al., / IJWSET -JISTEE, Vol. (x), Issue 1, March 2025, pp. 17-35

Table I. Key variables of the study

N°	variable	Expected sign	Comments
1	REGIDESO water prices (PRE)	-	In estimating a demand function, the focus is on the relationship between price and quantities, and in our specific context, this is the relationship between price and the choice of water supply source. We are assessing a customer's appreciation of the price, whether it is affordable or not.
2	Quality of REGIDESO water (QRE)	+	Considered to be good or poor, the quality of alternative waters guides the choice of water supply sources. This variable was selected. It is also a determining factor in households' choice of water supply sources.
3	Level of education of head of household (NIV)	+	The level of education of the head of household was used to explain the choice of household water supply sources.
4	Gender of head of household (GER)	-	Whether male or female, the gender of the head of household is a factor in the choice of supply sources.
5	Profession of head of household (PRO)	-	The professional activity of the head of household was also taken into account to explain or not the choice of household water supply sources.

Source: Authors (2024)

Hence, the log odds ratio model helped predicting the following probability:

$$P(Y) = \frac{e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k}}{1 + e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k}} \quad \text{(Equation 5)}$$

Where,

$\ln \frac{P(Y)}{1-P(Y)}$ are log odds

P(Y) is the statistical probability of households' choice of REGIDESO tap water

X_n (=X_1, X_2, … , X_k) are independent variables described in Table I

β_n (= β_0, β_1, β_2, … , β_k) are regression parameters similar to α_n in Equation 2

exp (X) is the exponential function

This functional log odds ratio helped estimating each logistic fit parameter, to explain the behaviour of the dichotomous dependent variable (Y), which was taking two values: 0 and 1 (1 meaning 'Yes' and 0, 'No'). To transform back the log odds, the analysis used the following probability function :

$$P(q) = \frac{1}{1 + \exp(-q)} \quad \text{(Equation 6)}$$

Where,

$q = \beta 0 + \beta 1 X_1 + \beta 2 X_2 + \ldots + \beta k X_k$

q is a sigmoid (S-shaped curve)

This q function's steepness was controlled by $\beta_n X$ matrix that mapped the linear function back to probabilities lying within the interval [0, 1] (Lever et al. 2016).

3. Results of the Study and Discussion

3.1 Results of the Descriptive Analysis of the Study Sample

The study results comprise a descriptive analysis of the sample to unveil a set of socio-economic characteristics of the respondents, including their gender, age, level of education, the main activity of the head of household, the size of the household, ... as well as their perception on water supplied by the REGIDESO public network and that of alternative water sources; lastly, a logistic regression is conducted to disclose the determinants of REGIDESO and alternative water choice par households.

3.1.1. Description of Key Socio-economic Characteristics of the Survey Respondents

Table II. Socio-economic characteristics of households surveyed

N°	Households' characteristics	Value	Frequency (%)(N=817)
1	Gender	Male	71.1
		Female	28.9
2	Age group	≤ 25 years old	03.4
		26-40 years old	40.3
		41-55 years old	33.0
		≥ 56 years old	23.3
3	Occupation	Public service	35.0
		Formal private sector	04.9
		Informal private sector	60.1
4	Educational level	Postgraduate studies' degree	00.6
		University degree	23.6
		Secondary leaving certificate	57.3
		Primary studies' certificate	14.7
		None	03.8
5	Marital status	Single	16.5
		Married	71.4
		Widow	06.1
		Divorcee	06.0
6	Household size	≤ 5	28.5
		6-9	54.0
		≥ 10	17.5

Source: Authors (2024)

A socio-demographic analysis of the households' characteristics shows that 71.1% of the households surveyed in the Mbanza-Ngungu health zone are headed by men, and 28.9% by female heads. Most of these householders are employed by informal private investors (60.1%) or by the national civil service (35%); Less than 5% are employed by formal private investors. (4.9%). Regarding their marital status, a majority among the respondents are married (71.4%), heading about 8 people (6 to 9 people) (54%); but a few are single householders (16.5%), widows (6.1%) or divorcees (6%). Detailed information is provided in Table 2.

3.1.2. Perception on household water supply

(a) Source of drinking water supply

According to the householders surveyed, their main source of drinking water was water packed in sachets (26.3%), followed by well-managed spring water (20.4%) and REGIDESO tap water (18.4%). (Figure 2).

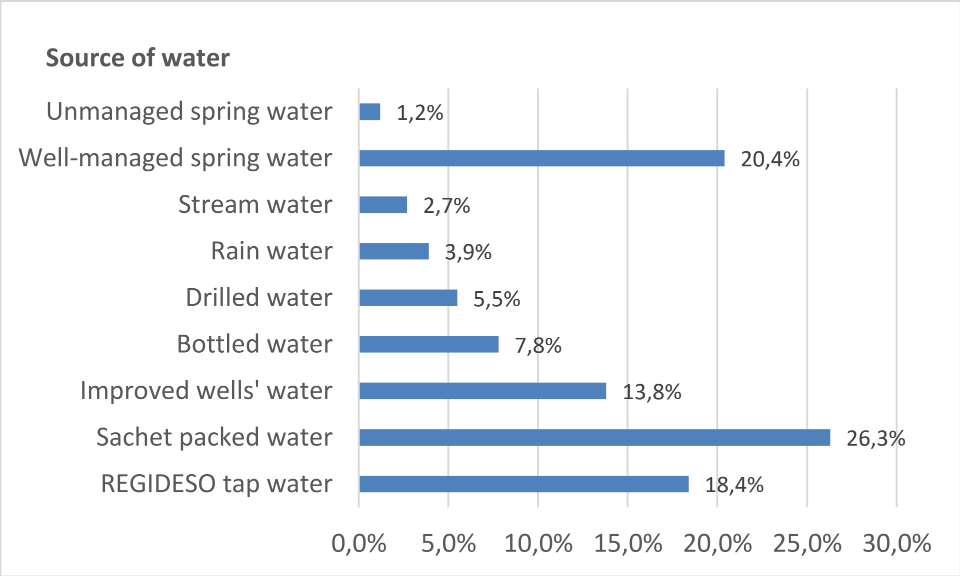


Figure 2. Sources of drinking water supply (Authors, 2024)

(b) Source of water supply for non-drinking usager

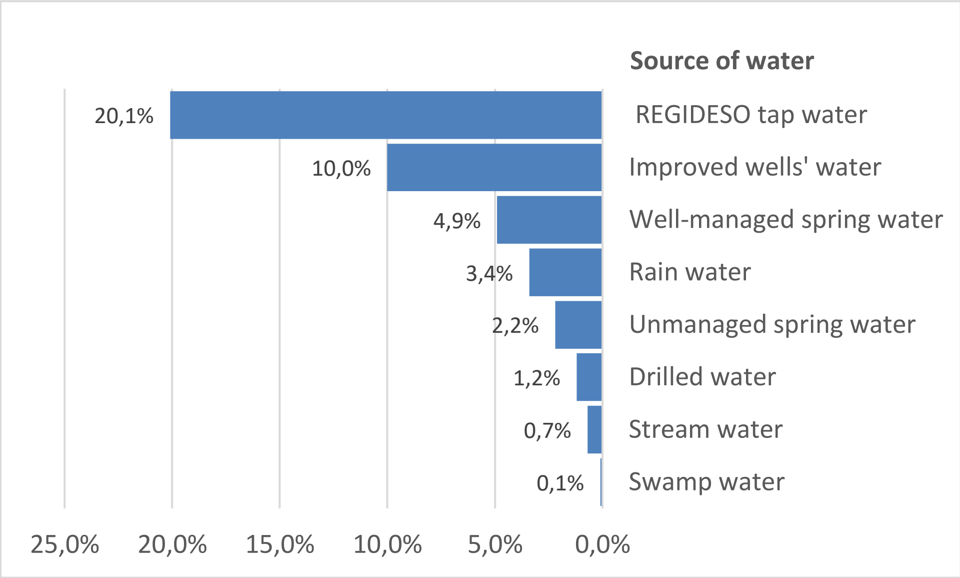


Figure 3. Sources of non-drinking water supply (Authors, 2024)

With regard to the source of water supply for uses other than drinking, Figure 3 reveals that tap water from REGIDESO is the first source of non-drinking water supply (20.1%), followed by water from improved wells (10%) and well-managed spring (4.9%).

(c) Choice of REGIDESO tap water

The Mbanza-Ngungu health zone has both urban and rural settings. The entire rural part is not served at all by REGIDESO. It includes the health areas of Langa, Nzenze, Kumbi and Tadila. In the urban side of the health zone, the fast extension of the town (urbanisation) did allow REGIDESO to extend its network accordingly; only 26% of the people surveyed did have a tap at home but a majority did not (78%). These include households from 8 health areas, including Noki, Nsona-Nkulu, Ngungu, Christ-Roi, Athénée, Loma, Militaire and Ville haute (Figure 4).

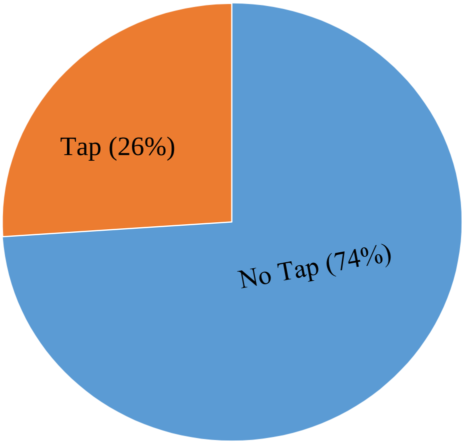


Figure 4. Connection to REGIDESO tap water network (Authors, 2024)

(d) Reasons for using water sources other than REGIDESO water

The reasons why most of the households surveyed do not use REGIDESO tap water for alternative water sources are shown in Figure 5. More than a third did inform of the missing tap network in their neighborhoods or village (38.5%) while more than a quarter evoked frequent breakage (27.1%). Other respondents thought that REGIDESO's water supply was unfit for consumption (11.2%), salty (8.9%), damaging clothes (8.4%), and had a bad taste (3.1%) or an unaffordable price (2.8%)(Figure 5).

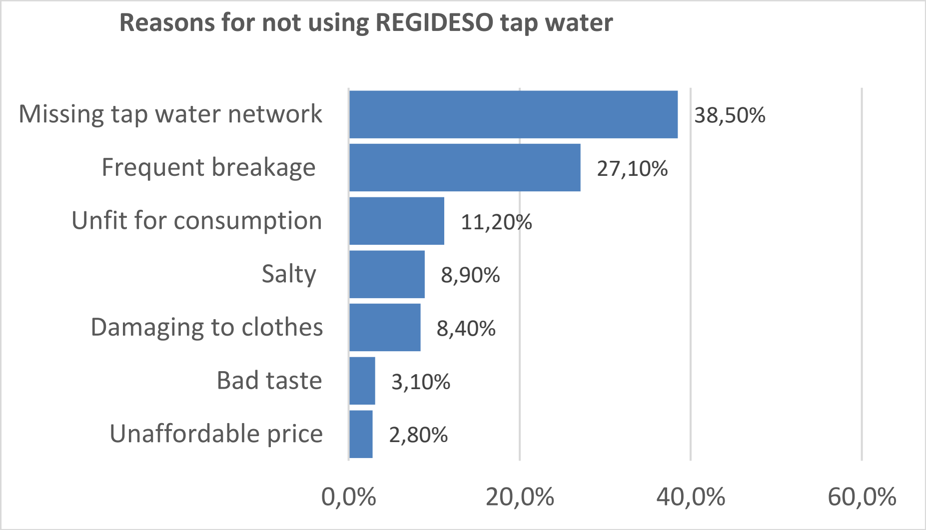


Figure 5. Reasons for using water sources other than REGIDESO (Authors, 2024)

(e) Advantages of using REGIDESO water

Results of the study show that more than a third of the respondents recognized that REGIDESO water has the advantage of being treated (38%), while 25% recognized no advantage at all. Moreover, than 15% among the respondents acknowledged that REGIDESO water is affordable and 10% recognized that the water is accessible even close to home. But 18% had no idea about the benefits of using tap water, possibly because there has never been tap water in their neighborhoods (Figure 6).

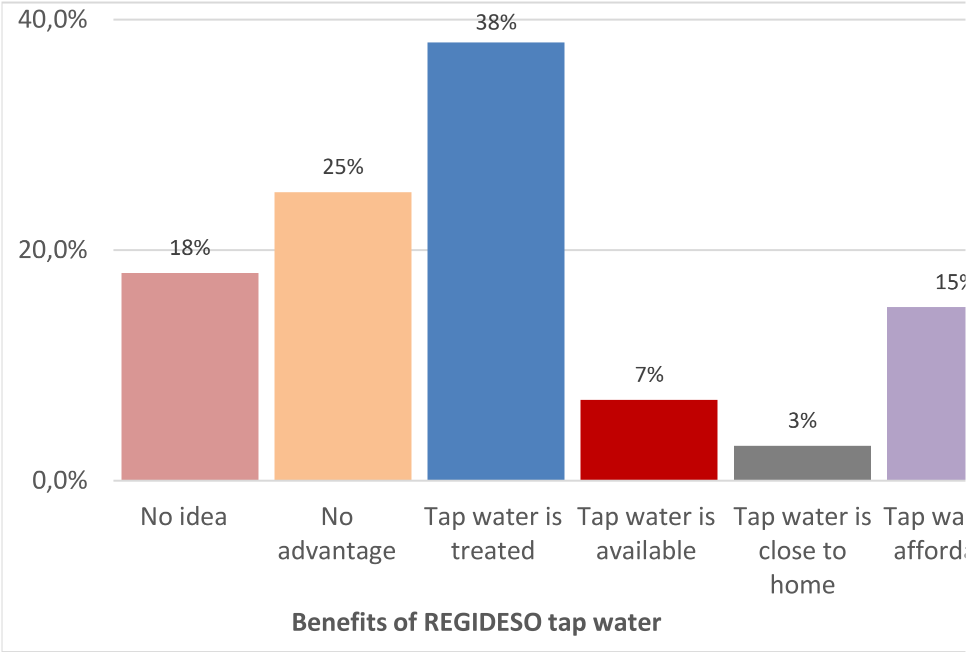


Figure 6. Advantage of using REGIDESO tap water (Authors, 2024)

(f) Risks of using alternative water sources

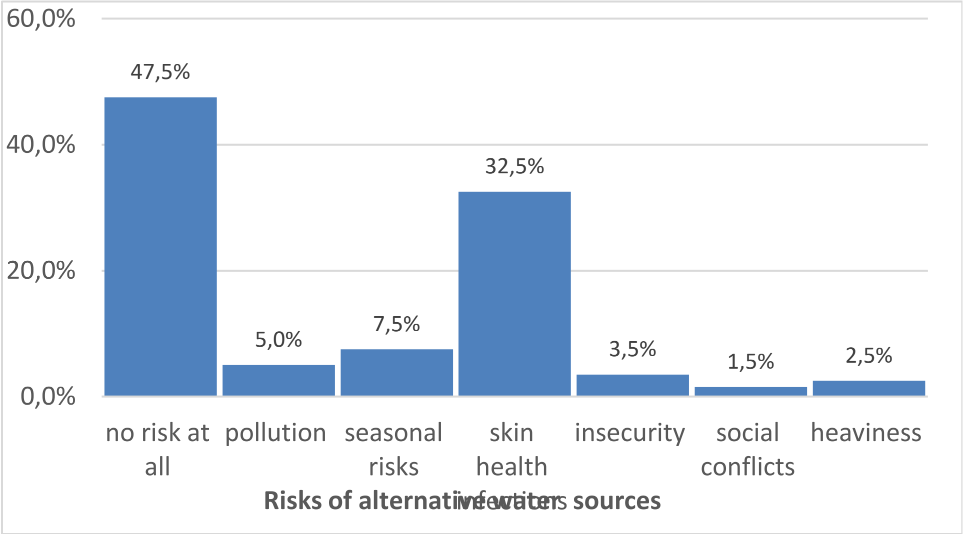


Figure 7. Risks of using sources of water other than REGIDESO tap water (Authors, 2024)

With regard to the risks of consuming alternative water sources than REGIDESO tap water, a majority among the respondents believed that there was no risk at all (47.5%), but more than 45% acknowledged that these water sources carry waterborne diseases due to pollution (5%), seasonal risks (5%), and skin health infections' agents (32.5%). However, others mentioned social risks, including insecurity (3.5%), social conflicts (1.5%) and heaviness (2.5%) (Figure 7).

(g) Ways of avoiding risks of alternative drinking water sources

Figure 8 shows how householders avoid the risks related to alternative drinking water sources. The most recurrent drinking water treatment techniques encompassed boiling drinking water (36%), water filtration (19.9%), salting (15.6%) and treating water using Aquatabs tablets (12.2%) or granulated chlorine (calcium hypochlorite) (7%). Other techniques included taking pills after the use of water, including Paracetamol (4.4%), Tanzol (3.7%), Vermox (1.5%), Decaris (1.9%) and Amoxicillin (0.7%).

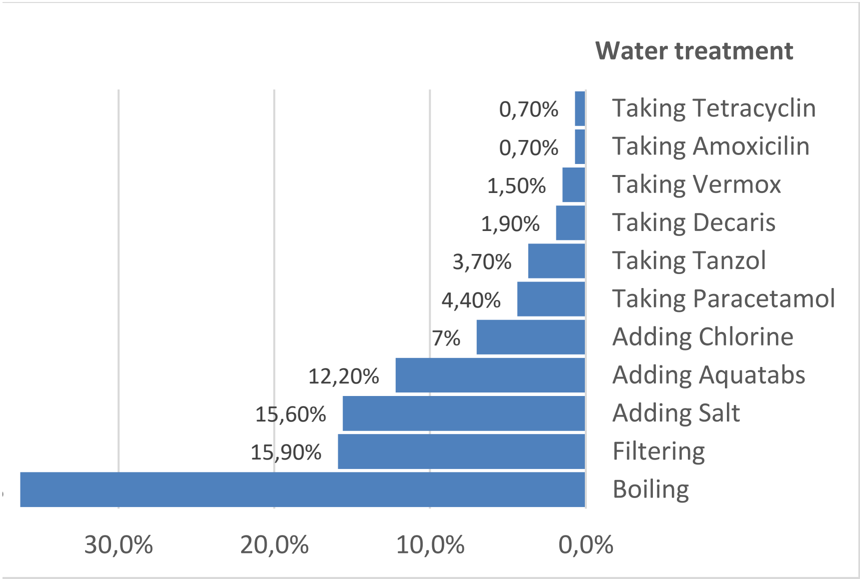


Figure 8. Drinking water treatment techniques (Authors, 2024)

3.2. Results of the Probit Logistic Regression

A multiple regression was carried out on a sample of 817 households, among which 212 were connected to the REGIDESO tap water network in the survey area, using a Probit logistic model. The results of this Probit regression model are presented in Tables 3, 4 and 5. Overall results show a robust prediction with Khi-square statistics significant at 1% significance interval (Tableau 3), and McFadden's R^2 that is above the threshold of 25% for Probit models (with a value of 32.1%)(Table 4). This meant that 32.1% of the variability of households' choice of REGIDESO as a source of drinking water supply in Mbanza-Ngungu health zone was explained by the most significant variables of the model. Thus, the model established a strong association between these independent variables and the dependent one (Briand and Loyal, 2017).

Table III. Model fitting through log likelihood ratio test

Model	Criteria for Model fit	Likelihood ratio test		
	Reduced model 2-log-likelihoods	Khi-square	df	sig
Constant	614.754			
Final	313.977	300.777	18	0.000

Source : Authors (2024)

Table IV. Pseudo R-square values

Cox et Snell	0.308
Nagelkerke	0.451
McFadden	0.321

Source : Authors (2024)

Table 5 reveals that almost all the independent variables influenced households' choice for REGIDESO tap water as a source of drinking water in the Mbanza-Ngungu health zone at 5% significance interval. This meant that these variables had an impact on the attitude of households to selecting public drinking water supplied by REGIDESO as their main source of water in their health zone at 95% confidence interval.

This variability of REGIDESO tap water choice as a source of drinking water supply in Mbanza-Ngungu health zone (32.1%) was explained by the following five independent variables: the gender of the household's head, his/her educational level, occupation, appreciation of REGIDESO water price, and of REGIDESO water quality.

Table V. Maximum likelihood ratio tests

Variables	Criteria for Model fit	Likelihood ratio test		
	Reduced model-2 log-likelihoods	Khi-square	df	Sig.
Constant	313.977	0.000	0	
Gender of the household head	319.970**	5.993	1	0.014
Educational level of the Head	324.361**	10.383	4	0.034
Profession of the household head	326.080***	12.103	3	0.007
REGIDESO water Price	402.719***	88.742	5	0.000
REGIDESO water quality	333.794***	19.817	5	0.001

Source : Authors (2024)
Note: *** 1% significance interval ; ** 5% significance interval

The following 2-log-likelihood reduced model was derived from the above table:

LogQ = 0,904 - 0,544*GER + 3,171*NIV - 0,766*PRO - 3,133*PRE + 1,661*QER + □
(0.000) (0.014) (0.034) (0.007) (0.000) (0.001)

The educational level and gender of the household's heads were determinant for increasing the likelihood of selecting REGIDESO as a source of drinking water at 95% confidence interval. However, the household's head profession, and the price and quality of REGIDESO tap water increased that likelihood at 99% confidence interval in Mbanza-Ngungu health zone. The lower the educational level of the household's head, the lower the probability of choosing REGIDESO as a source of drinking water. Also, the more the households are headed by women or by civil servants, the lower the probability of selecting REGIDESO tap water. However, the lower the price and the quality of REGIDESO tap water, the lower the probability of choosing it as a source of drinking water.

3.3 Discussion of the Results

3.3.1. Discussion on Descriptive Statistics Results

The study revealed that 26% of households are connected to the REGIDESO distribution network. This rate is close to the one put forward by ANAPI (2021), but lower to that of Van den Berg Caroline and Alexander Danilenko, (2017) and Byumanine et al. (2018). This low rate is seemingly justified by the increasing urban population in Mbanza-Ngungu health zone, mainly due to the rural exodus, the cost of connection and financial challenges facing REGIDESO, which prevent its network extension to the peri-urban health areas (Lubera, 2022; Linangelo et al., 2018; Kazadi, 2012).
Regarding households' attitude towards water supplied by REGIDESO, water sold in sachets (plastics) was their main source of drinking water (26.3%), followed by well-managed springs (20.4%) and REGIDESO tap water (18.4%). However, the latter was being used for other purposes than drinking (20.1%), followed by water from managed wells (10%) and well-managed springs (4.9%). Moreover, the people interviewed in Mbanza-Ngungu do not prefer using REGIDESO water as their source of drinking water, because they consider it as salty, tasteless and unfit for consumption. These results are in line with Byumanine et al. (2018), Ilundu (2020) and Bousquet (2004). These studies asserted that some of the households supplied by REGIDESO do not use its water for drinking purpose. Their attitude is explained by the fact that it does not have good organoleptic qualities and is said to be the cause of certain illnesses such as typhoid fever, stomachache and amoebiasis, as well as women's urogenital infections, skin irritation, etc. Hence, households prefer using it for washing vehicles, cleaning houses and toilets, watering gardens, washing clothes and dishes for some households, and other uses. From the point of view of socio-demographic characteristics, the level of education of the household head is an essential factor explaining that choice.

3.3.2. Discussion on the Results of the Probit Logistic Model Regression

The analysis of factors explaining households' choice of drinking water supply was adequately persuasive. The estimated correlation coefficients (Rhô) and maximum likelihood ratio were significant at 5% significance interval. This indicated a good fit of the model (Tables 3, 4 and 5). According to these results, the household head's gender, level of education, occupation, appreciation of the REGIDESO water price and of its water quality were the most determinant factors influencing households' choice of water supply sources. Studies by Tibi (2021) and Ismaïla (2019) and Yao et al (2002) confirm these factors, especially water price, which explains water demand significantly at 95% confidence interval. The cost of access to water is thus a relevant determinant of households' choice of water supply.

However, the price represented in the Probit logistic model had a positive-sign coefficient, which is not consistent with the literature. Yet, the study expected a negative sign in consistence with the law of diminishing demand with the price. This meant that the lower probability of selecting REGIDESO as a source of drinking water was also explained by its low prices. This kind of snobbism may be explained by the fact that most of the households that select REGIDESO as their source of drinking water were more likely headed by highly educated male heads. Hence, the male gender, private profession and educational level of the household's head, as well as the price and the quality of drinking water were positively influencing the choice of REGIDESO as a source of drinking water in Mbanza-Ngungu health zone with a price elasticity of 3.133. This meant that, all other things being equal, the volume of water consumed increased by 313.3% when the price rose up to 1%. The elasticity of water demand can be explained by the presence of substitutes to REGIDESO drinking water, including water from wells and springs, sachet water and expensive bottled water brands and other alternative water sources (Quora, 2024; Stein, 2007).

Water from wells, boreholes, rainwater, springs and streams was treated by male respondents and small businessmen as "indigenous" water sources compared to the REGIDESO public drinking water network, which was viewed as an "industrial" innovative productive, making it a luxury for these categories, in the case of Mbanza-Ngungu. However, Etienne et al. (1998) argued that drinking water demand (DWD) by low-income populations in sub-Saharan Africa increase by 2.5 litres/pers/day with reduced price of 100 CFA Francs per m^3 (Rainelli, 1994). That is the reason why most of the households outside Mbanza-Ngungu city buy water from their neighborhoods or from a single tap, and/or mostly use alternative water sources. This has an effect on increasing the consumption with the price of a cubic meter. Therefore, the average unit price of water is far above the subsidized level.

Besides, the occupation and gender of the household head are also factors that explain the high probability of choosing REGIDESO as a source of drinking water. The respective elasticities of the gender and occupation of the head of household are 0.544 and 0.766. This implies that the more households are headed by male and private businessmen (or employees other than civil servants), the higher the probability of choosing REGIDESO as a source of water supply. This is justified by the fact that household heads with a fairly low levels of income coupled with high family burdens may not easily afford REGIDESO water cost. These burdens are enormous if they are divorced or widowed with dependent children. From a professional point of view, Mbanza-Ngungu is basically an administrative town and the private sector is not well developed. Most employees are public servants of the Congolese State, including the army, public administration, education, health… This sector is featured by low and irregular incomes. The vast majority of the population work in the informal sector or in agriculture, where incomes are uncertain. Thence, as ascertained by Ake-Awomon (2022) and Coutard (1999), there is a direct link between the profession and the gender of the household heads and their choice of water supply source.

With regards to the perception of household heads of their water quality, it was found that if the household perceives the quality of REGIDESO water as a good, this has no effect on the likelihood of using alternative water sources. But this factor has a positive and very significant effect on the decision to use alternative water. Similarly, if households believe that alternative water sources are of good quality, their use of REGIDESO water may be reduced. From these results, it follows that the perception of water quality has an explanatory power on the household's decision even if this perception remains subjective and linked to cultural variables (Zoungrana, 2021; Boudjemaa and Cherrad, 2011; Montginoul and Waechter, 2007). Some households have a strong preference for water drawn from wells and springs because they believe it is tasty while others simply perpetuate their cultural habits from generation to generations (Omarova et al., 2019). In this context, the use of alternative water sources is often high due to errors of assessment, leading to significant health issues. This cultural fact is directly linked to the level of education of the of household head.

If at the household head is highly educated, this increases the likelihood of using REGIDESO tap water. The literature has shown that the probability of being connected to a public water distribution network increases with the level of education, for several reasons. In some cases, income can increase with the level of education, while in others, education may enhance or limit opportunities for accessing information. A low level of education limits understanding of the issues involved in drinking water supply, including health benefits, ease of collection, constant availability and time saving, while a high level of education is generally associated with a strong appreciation of the many benefits of drinking water (Johri et al., 2019; Briand and Loyal, 2017). This household propensity towards public drinking water sources is in line with other authors' findings. Ismaïla, (2019) and Morakinyo et al. (2015) indicate a positive relationship between the level of education of the household head and the probability of choosing public drinking water sources. Indeed, a household whose head is highly educated has a better understanding of the benefits associated to water quality and often adopts appropriate health and hygiene behaviors (Sehreen et al., 2019; Sintondji et al., 2017). Education therefore plays a decisive and positive role in household choice of water sources. However, due to water scarcity, households may use all water supply sources, regardless of their consequences.

7. Conclusion

This study highlights how the supply of drinking water from different sources by households in the Mbanza-Ngungu health zone is influenced by socio-economic factors like education, occupation, gender, price and quality of water. These factors explain the disparity in access to public drinking water sources. The results show that only 26% of the household heads interviewed chose REGIDESO as their main source of water supply while 74% did not. Among their reasons of not selecting REGIDESO as the source of drinking water they cited the absence of a REGIDESO distribution network in their neighborhoods, frequent breakages of REGIDESO water network, and other considered this water as salty and unfit for consumption.

This low rate of access to REGIDESO tap water contributes to the development of alternative water sources. The level of education of the household head, his/ her occupation and gender, and the price and quality of REGIDESO water are among the most significant factors associated with the choice of REGIDESO as their source of drinking water in the Mbanza-Ngungu health zone. These factors increase the probability for households' choice of REGIDESO as a source of their drinking water supply. However, an increase of water consumption with the level of price was termed as a kind of "snobbism". It increased the probability for households to select REGIDESO tap water rather than alternative water sources as their main source for drinking water supply, based on their level of education and of income. 'Public drinking water' was seen as a luxury or industrial product, while 'alternative water sources' were being perceived as indigenous goods. These Disparities in both sources of drinking water supply can be explained by social inequalities and households' burdens.

However, the research needs a very comprehensive classification of water substitutes, beyond the simple classification of 'public water' and 'alternative water' sources to recommend appropriate and accurate water supply policies and programs, focusing on households' burdens, and regional variations in order to reduce social inequalities and accelerate access to improved water supplies. Other recommendations include focusing on public standpipes and community boreholes as interim measures while making greater efforts to develop long-term piped water supply among poor communities and marginalized areas. These measures could contribute to greater social and ecological inclusiveness in water supply. Hence, there is a need for REGIDESO to extend its distribution network to marginal areas of the health zone.

Finally, considering the fact that a majority of households are largely unaware of health and economic repercussions of alternative drinking water sources, health authorities need to raise awareness and educate the population to set up local water management committees to provide quality water at a negotiated price. This application of IWRM principles may help ensuring the sustainability of drinking water supplies in Mbanza-Ngungu health zone.

Acknowledgements

This research was carried out as part of the training for the International Master's Program in Water Resources organized at the Regional School of Water (ERE) of the University of Kinshasa. The authors would like to thank the management of the ERE school and the political, administrative and health authorities of Mbanza-Ngungu.

Compliance with ethical rules

The authors declare no conflict of interest. Field research did not involve any threat to any community or protected species. No informal or legal organization played a key role in the design of the study, the collection and analysis of data so as to decide on the final outcome of the study. The decision to prepare the manuscript and publish it was solely taken by the authors.

List of References

[1] Abubakar I. R. (2019). Factors influencing the access of the households to drinking water to Nigeria. Elsevier, Utilities Policy, vol. 58 (C): 40-51.
[2] Abubakar I. R. & Dano U. L. (2018). Socio-economic challenges and opportunities of urbanisation in Nigeria. In: Urbanisation and its impacts on socio-economic growth in developing regions. IGI Global, Pennsylvania, 130-154 pp.
[3] Abubakar I. R. (2016). Dimensions of the quality of public water services in Abuja, Nigeria. Utilities Policy 38, 43-51.
[4] Ake-Awomon (2022). Etudes des facteurs influençant l'accès à l'eau potable dans la commune d'Abobo (Abidjan-Cote d'Ivoire), Editions Francophones Universitaires d'Afrique (EFUA), pp. 11-31.
[5] ANAPI. (2021). Investir dans le sous-secteur de l'eau. Cahier Sectoriel, MédiasPaul, Kinshasa.
[6] Beyene, A. & Luwesi C.N. (eds).(2018). Innovative Water Finance in Africa – A Guide for Water Managers – Volume 1: Context. Current African Issues, Nordiska Afrikainstitutet, Uppsala, 166 P. (ISBN: 9789171068156, 9171068155)
[7] Boudjemaa S. & Cherrad S. E. (2011). Les ressources en eau dans la wilaya de Mila : mobilisation, consommation et comportement de ménages, Sciences & Technologie, N°34, 19-25 pp.
[8] Bousquet A. (2004). Desserte collective des quartiers pauvres en Zambie, un long apprentissage. Flux (2004/2), Nn° 56-57, pp. 71-86 (ISSN 1154-2721 ; DOI 10.3917/flux.056.0071)
[9] Briand A. & Loyal A. (2017). La demande pour des services urbains d'eau potable : une analyse du consentement à payer des ménages bamakois et de quartiers précaires de Ouagadougou. Revue d'économie régionale & urbaine, n°1, janvier, pp. 33-66.
[10] Coutard O. (1999). L'accès des ménages à faible revenu aux services d'eau et d'énergie en France et en Grande-Bretagne. Flux, N° 36-37, pp. 7-15 (DOI : https://doi.org/10.3406/flux.1999.1271).
[11] Etienne J., Maïga A. & Morel à l'huissier A. (1998). Aspects socio-économiques de la demande en eau domestique en Afrique subsaharienne : quelles leçons pour la gestion de l'eau ? Communication UNESCO, juin 1998.
[12] Gazzeh K. & Abubakar, I. R. (2018). Regional disparity in access to basic public services in Saudi Arabia: A sustainability challenge. Utilities Policy 52, 70-80.
[13] Greenwood E. E., Lauber T., van den Hoogen J., Donmez A., Bain R. E. S., Johnston R., Crowther T. W., and Julian T. R. (2024). Mapping safe drinking water use in low- and middle-income countries, Science, 15 Aug 2024, Vol 385, Issue 6710, pp. 784-790 (DOI: 10.1126/science.adh9578)
[14] Hutton G. & Chase, C. (2016). The knowledge base for achieving the sustainable development goal targets on water supply, sanitation and hygiene. Int. J. Environ. Res. Public Health 13 (DOI: 10.3390/ijerph13060536).
[15] Ilundu J. L. (2020). Social and health impact of the lack of water of Regideso in the municipality of Kadutu. International Journal of Innovation and Scientific Research (Sep. 2020), Vol. 50 (2): 166-179.
[16] Irianti S., Prasetyoputra P. & Sasimartoyo, T. P. (2016). Determinants of the drinking water source household in Indonesia: An analysis of the 2007 Indonesian Family Life Survey. Cogent Medicine 3(1), 1151143 (DOI: https://doi.org/10.1080/2331205X.2016. 1151143).
[17] Jha, K. S., Eslick J. N. & Mutombo D. T. (2024). Bridging the Water Access Gap: New Partnership Brings Hope to the Democratic Republic of Congo. World Bank Blogs (August 28, 2024) (URL: https://blogs.worldbank.org/en/water/bridging-the-water-gap--new-partnership-brings-hope-to-drc-)
[18] Johri M., Sylvestre M.-P., Kone G. K., Chandra D. & Subramanian S. V. (2019). Effects of improved drinking water quality on early childhood growth in rural Uttar Pradesh, India: A propensity score analysis. Plos One, vol.14 (1), N° e0209054 (URL : https://doi.org/10.1371/journal.pone.0209054, consulté le 05/05/2023).
[19] Kaiyatsa S., Mapemba L. & Tembo G. (2016). Households' Choice of Drinking Water Sources in Malawi. Conference presentation, 12th Meeting of the International Water Resource Economics Consortium, The World Bank, Washington, DC September 11-13, 1-15 pp.

[20] Kazadi M. A. Z. (2012). Contribution à l'étude de la qualité et de la gestion de l'eau de boisson dans la région de Kisangani, Thèse de doctorat, Faculté des Sciences, UNIKIS, Kisangani, pp. 243.
[21] Krief N. & Zardet V. (2012). Analyse de données qualitatives et recherche-intervention Revue de Recherches en Sciences de Gestion-Management Sciences-Ciencias de Gestión, N°95, 211-237 pp.
[22] Lee J. & Mannering F. (2002). Impact of Roadside Features on the Frequency and Severity of Run-Off-Roadway Accidents: An Empirical Analysis. Accident Analysis & Prevention, 34, 149-161. (DOI: https://doi.org/10.1016/S0001-4575(01)00009-4)
[23] Lee J., Nemati M., Allaire M. & Dinar A. (2024). The impact of pricing structure change on residential water consumption: A long-term analysis of water utilities in California. Water resources and economics 46 (2024) 100240 (DOI: https://doi.org/10.1016/j.wre.2024.100240)
[24] Leumeni, P. (2022). Progress on Water, Sanitation and Hygiene in Africa, 2nd Regional Consultation UN-WAD, UNECA, Addis Ababa
[25] Lever J., Krzywinski M. & Altman N. (2016). Logistic regression: Regression can be used on categorical responses to estimate probabilities and to classify. Nature Methods vol. 13, pp. 541–542 (DOI: https://doi.org/10.1038/nmeth.3904)
[26] Linangelo S. B., Kamango J. B., Mokili J. K. E., Monama T. O., Ulyel J. A. P. & Kazadi Z.-A. (2018). Problématique d'accès a l'eau potable en milieu rural en RDC : cas de la ville urbano-rurale de Bumba. International Journal of Innovation and Scientific Research (Jul. 2018), Vol. 37 (2): 130-138.
[27] Luwesi, C.N. & Beyene, A. (eds).(2023). Innovative Water Finance in Africa –Economics and Principles of Financial Innovations for Water Managers. Cham: Palgrave MacMillan, Springer Nature Switzerland AG, 209 P. (ISBN :9783031382345, 303138234X)
[28] Montginoul M. & Waechter V. (2007). Les ménages et l'eau du robinet : perceptions et pratiques dans une communauté urbaine. Ingénieries eau-agriculture-territoires, Vol. 51, pp. 33-46.
[29] Morakinyo O. M., Adebowale S. A. & Oloruntoba E. O. (2015). Wealth status and sex differential of household head: implication for source of drinking water in Nigeria. Archives of Public Health, vol. 73 (1): p. 58.
[30] Mulenga J. N., Bwalya B. B. & Kaliba-Chishimba K. (2017). Determinants and inequalities of access to improved water sources and sanitation among Zambian households. International Journal of development and sustainability, 6(8) : 746-762.
[31] Murungi, C. & Blokland, M.W. (2016). Benchmarking for the provision of water supply and sanitation services to the urban poor: an assessment framework. International Journal of Water 10, No 2/3 : 155–174.
[32] Mushagalusa B., Mudherwa B., Emina A., Kalialia B., Mushagalusa B.E. & Macumu H. P. (2018). Evaluation of the acceptability of water produced by REGIDESO Nguba pumping. International Journal of Innovation and Scientific Research (Dec. 2018), Vol. 40 (1) : 202-218 (ISSN 2351-8014, URL : http://www.ijisr.issr-journals.org/)
[33] Omarova A., Tussupova K., Hjorth P., Kalishev M. & Dosmagambetova R. (2019) Water Supply Challenges in Rural Areas: A Case Study from Central Kazakhstan. International Journal of Environmental Research and Public Health, vol. 16 (66): 1-14 pp.
[34] Quora (2024). Are expensive bottled water brands really worth the money, or is most of the price just a marketing thing? (Available at URL: www.quora.com).
[35] Rainelli P. (1994). Brigitte Desaigues, Patrick Point, Economie du patrimoine naturel ; la valorisation des actifs du patrimoine naturel, Paris, Economica, 1993 (Compte-rendu). Revue d'études en Agriculture et environnement (Année 1994), 32 : pp. 135-137.
[36] Sehreen F., Masud M. M., Akhtar K., Masum M. R. A. (2019). A contingent valuation approach to evaluating willingness to pay for an improved water pollution management system in Dhaka City, Bangladesh, Environmental Monitoring and Assessment, vol. 191, n° 457, pp. 1-15.
[37] Shifa M. (2024). Inequality in access to basic services is a major problem in sub-Saharan Africa—but progress is happening. Phys.org (30 Jan. 2023) (URL: https://phys.org/news/2023-01-inequality-access-basic-major-problem.html)

[38] Sinharoy S. S., Pittluck R. & Clasen T. (2019). Review of drivers and barriers of water and sanitation policies for urban informal settlements in low-income and middle-income countries. Utilities Policy (October 2019), Vol. 60, 100957 (URL: https://doi.org/10.1016/j.jup.2019.100957)
[39] Sintondji L. O., Vissin E., Dan O. F., Dossou-Yovo E. R. & Amouzouvi D. (2017). Sociodemographic characteristics of households as determinants of access to water, hygiene and sanitation in Soava, Benin. Journal of Environmental Science and Public Health, vol. 1, n° 4, pp. 253-267.
[40] Stein, J. (2007). Entertainment: The making of a water snob. 5 Minute Read (June 7, 2007), TIME (Available at URL: www.time.com).
[41] UNEP. (2011). Water Issues in the Democratic Republic of Congo: Challenges and Opportunities - Technical Report, Nairobi, Kenya, p. 98 (URL: https://wedocs.unep.org/20.500.11822/22067)
[42] UNICEF & WHO. (2017). Progress on drinking-water, sanitation and hygiene: 2017 update and SDG baselines (ISBN:978-92-4-151289-3; URL: https://www.who.int/publications/i/item/9789241512893)
[43] van den Berg C., & Danilenko A., (2017). Performance of Water Utilities in Africa. Water Global Practice report, World Bank, Washington DC, pp.172.
[44] Wang X. & Abdel-Aty M. (2008). Analysis of Left-Turn Crash Injury Severity by Conflicting Pattern Using Partial Proportional Odds Models. Accident Analysis & Prevention, 40, 1674-1682. (DOI : https://doi.org/10.1016/j.aap.2008.06.001).
[45] Wanlin (2007). L'analyse de contenu comme méthode d'analyse qualitative d'entretiens : une comparaison entre les traitements manuels et l'utilisation de logiciels dans Recherches qualitatives. Hors-série, N°3, 242-272 pp.
[46] Yang H., Bain R.., Bartram J., Gundry S., Pedley S. & Wright J. (2013). Water safety and inequality in access to drinking-water between rich and poor households. Environmental Science & Technology, Vol. 47 (3): 1222-1230.
[47] Yao S. Y. (2002). Détermination de la demande d'eau potable par la création d'un marché fictif base sur le consentement à payer : cas de la ville de Cotonou au Benin, Rapport, 22 pages, Inédit.
[48] Zeufack A. & Jha S. K. (2024). Democratic Republic of Congo: In the water sector, taking stock of challenges leads to new solutions. World Bank Blogs (June 10, 2024) (URL: https://blogs.worldbank.org/en/africacan/drc-water-sector-taking-stock-challenges-leads-to-new-solutions-afe-0624)
[49] Zoungrana, T.D. (2021). Les déterminants du choix d'approvisionnement en eau potable des ménages ruraux de la commune de Koudougou au Burkina Faso, Économie rurale [On line], 377 (URL : http://journals.openedition.org/économie rurale/9135)

Jean Kalume Shikayi, Cush Ngonzo Luwesi, Essam Osman Badr, Seham D.Z. Dawoud, Papy Bonkena, Jean Aunge Muhiya,Glodi Etepe Kakoko, Pascal Kazwenga Masawula and Raphael Palata Kadgeng
Impact of drought on the economic profitability of the surface irrigation system for Rice in the Masina Rail 1 site, N'djili Basin, Kinshasa
International Journal Water Sciences and Environment Technologies
Vol. (x), Issue. 1, March 2025, pp. 36-47
ISSN Online: 1737-9350; ISSN Print: 1737-6688, Open Access
www.jiste.org
Scientific Press International Limited
Received: January 2025 / Revised: February 2025 / Accepted: March 2025 / Published: March 2025

Impact of drought on the economic profitability of the surface irrigation system for Rice in the Masina Rail 1 site, N'djili Basin, Kinshasa

Jean Kalume Shikayi[1], Cush Ngonzo Luwesi[2], Essam Osman Badr[3], Seham D.Z. Dawoud[4], Papy Bonkena[5], Jean Aunge Muhiya[5],Glodi Etepe Kakoko[6], Pascal Kazwenga Masawula[7] Raphael Palata Kadgeng[1]

1Assistant, Department of Agricultural Economics, Faculty of Agronomical and Environmental Sciences, University of Kinshasa (UNIKIN), B.P. 117 Kinshasa XI.

2Professor, Regional Water School, University of Kinshasa (UNIKIN), B.P. 127 Kinshasa XI

3Associate Professor, Department of Business Administration, College of Science and Human Studies, Hotat Sudair, Majmaah University, Majmaah, 11952, Saudi Arabia

4Associate Professor, College of Agricultural and Food Sciences, King Faisal University, Saudi Arabia

5Professor, Department of Agricultural Economics, Faculty of Agricultural and Environmental Sciences, University of Kinshasa (UNIKIN), B.P. 117 Kinshasa XI,

6Assistant, Faculty of Agricultural and Environmental Sciences, University of Mbandaka (UNIMBA),

7 Masters Student - Regional Water School, University of Kinshasa, DR Congo

Abstract

This article explored the impact of drought on the economic profitability of rice in surface irrigation systems at the Masina Rail 1 site in Kinshasa. Simulation results show that profitability varies significantly by sales unit, with margins reaching up to 3279% during periods of scarcity. In contrast, overproduction leads to a significant decrease in revenues during times of abundance. The sensitivity analysis revealed that all sales units display much higher profit margins during shortages, suggesting that effective management of surface irrigation can make a substantial difference. However, during periods of abundance, margins dropped, with decreases of up to -31.4%, highlighting the risks associated with overproduction. The model validation was promising, showing an adjusted R^2 of 60.5%, indicating that our model well explains price variation, supported by a statistically significant Fisher test at the 1% level. These analyses demonstrate that managing irrigation is crucial for maximizing profitability, especially during droughts when water becomes scarce. Factors such as price per sales unit and quantity sold are key elements for profitability, while drought and production costs can have negative consequences. Therefore, the study emphasizes the importance for producers to adopt adaptive strategies to improve their economic performance in the face of climatic challenges.

Keywords: Drought, Watershed, Determinant, Economic profitability, N'djili River

Impact de la sécheresse sur la rentabilité économique du système d'irrigation de surface pour le riz dans le site de Masina Rail 1, bassin de N'djili, Kinshasa

Résumé

Cet article a examiné l'impact de la sécheresse sur la rentabilité économique du riz dans les systèmes d'irrigation de surface au site de Masina Rail 1, à Kinshasa. Les résultats des simulations ont indiqué que la rentabilité varie selon l'unité de vente, avec des marges bénéficiaires atteignant jusqu'à 3279 % dans certains cas pendant les périodes de rareté. Cependant, la surproduction réduit considérablement les revenus en période d'abondance.

L'analyse de sensibilité a démontré que toutes les unités de vente ont montré des marges bénéficiaires significativement plus élevées durant les pénuries, suggérant qu'une gestion efficace de l'irrigation de surface peut améliorer la rentabilité. En revanche, en période d'abondance, les marges bénéficiaires ont diminué de manière marquée, avec des réductions allant jusqu'à -31,4 %, illustrant les risques associés à la surproduction.

La validation du modèle a révélé un coefficient de détermination ajusté de 60,5 %, ce qui indique que le modèle explique une proportion significative de la variance des prix, confirmée par un test de Fisher significatif au seuil de 1 %. Les analyses ont également montré que la gestion de l'irrigation est cruciale pour maximiser la rentabilité, surtout en période de sécheresse lorsque la disponibilité d'eau diminue considérablement. Des facteurs tels que le prix par unité de vente et la quantité vendue sont positivement corrélés à la rentabilité, tandis que la sécheresse et les coûts de production ont des effets négatifs. L'étude souligne la nécessité pour les producteurs d'adopter des stratégies adaptatives pour améliorer leur performance économique face aux défis climatiques.

Mots clés : Sécheresse, Bassin versant, Déterminant, Rentabilité économique, Rivière N'djili-

[1] Corresponding author: leankalume@unikin.ac.cd

INTRODUCTION

Agriculture represents a significant sector of the economy of the Democratic Republic of the Congo (DRC), contributing approximately 45.7% to the gross domestic product (GDP) and employing nearly 80% of the labor force (Ministry of Agriculture, 2018). However, the rapid population growth, which could reach 120 million inhabitants by 2030 (Ministère du Plan et INS, 2023), exerts increased pressure on agricultural resources. In this context, the intensification of agriculture is essential to meet the growing food needs of a rapidly expanding population, and irrigation is a crucial component of ensuring sustainable food production (FAO, 2005).

The N'djili river basin, which encompasses surface irrigation systems, is particularly vulnerable to the challenges posed by drought. This area, with its notable hydro-agricultural potential, is experiencing climate variability that threatens the economic viability of existing irrigation systems. As highlighted by the World Bank (2023a), the assessment of economic viability of small-scale irrigation systems remains a relatively underdeveloped area of research, underscoring the necessity for more comprehensive studies in this domain. Despite its traditional use, surface irrigation may prove ineffective in the face of changing climatic conditions. It is imperative that current irrigation methods be reassessed in order to enhance their efficacy and profitability, particularly in light of the increasing prevalence of drought conditions (CIRAD, 2005). It is therefore crucial to investigate the economic impacts of drought on these systems in order to ensure food security and the economic sustainability of farmers.

Additionally, the wetlands of the N'djili River valley, which are primarily used for rice cultivation, are susceptible to the impacts of climate change. The lack of pertinent analysis on the productivity and profitability of irrigated crops in this region constrains the capacity of farmers to adapt to environmental challenges (Baguiri, 2016). Consequently, it is imperative that research be conducted to assess the impact of drought on the profitability of irrigation systems, with a view to formulating appropriate recommendations.

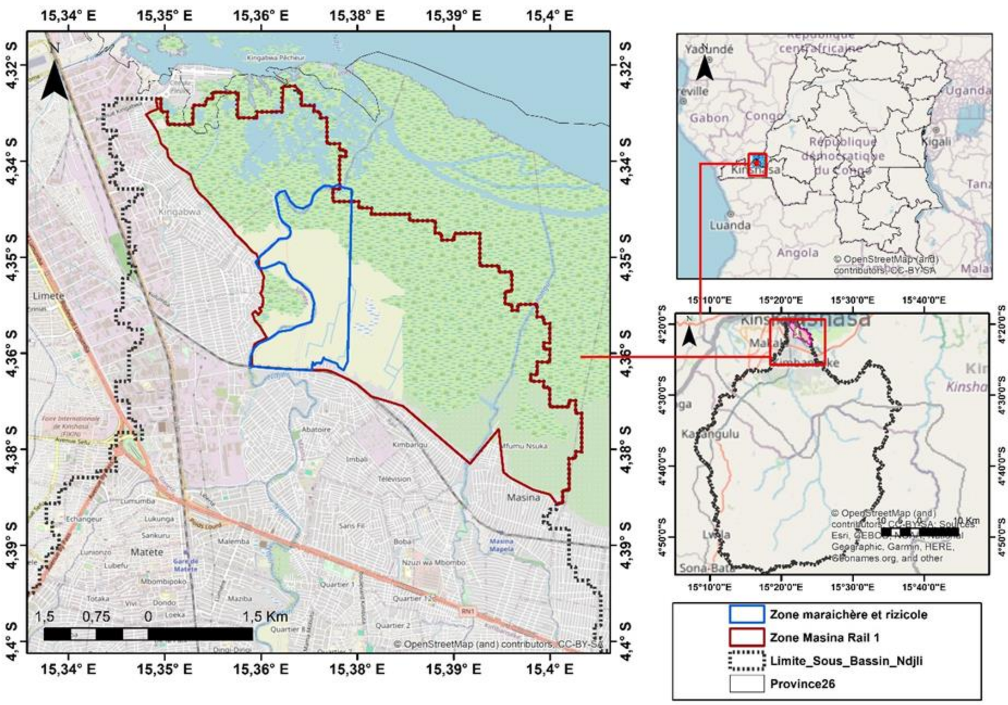
The objective of this study is to provide tangible solutions to the challenges faced by producers at Masina Rail 1 in the N'djili basin in response to drought conditions. By modeling the economic impact of these conditions on surface irrigation, we aim to contribute to a more nuanced understanding of the challenges facing agriculture in the Democratic Republic of the Congo (DRC) and to propose strategies for enhancing the resilience of agricultural systems to climatic variability (Tillie et al., 2019).

MATERIALS AND METHODS

Presentation and History of the Masina Rail 1 Farming Site

The Masina Rail 1 farming site is situated within the N'djili catchment area, specifically in the Pool Malebo region. The agricultural site of Masina Rail 1 is located in the Masina commune, specifically in the Mfumu-Sunka district. It was established in 1969, coinciding with the arrival of Chinese immigrants. The site is bordered to the north by the Congo River, to the south by the railway line, to the east by the Masina Rail 2 site, and to the west by the Ngwele River, also known as the N'DJILI River. The site encompasses an area of 1,350 hectares, of which 760 hectares are under cultivation. The remaining 590 hectares are not cultivated due to a lack of irrigation infrastructure. The site is divided into 21 blocks, with an estimated 1,200 households comprising 5 to 6 individuals per household.

Jean Kalume Shikayi et al.,. / IJWSET -JISTEE, Vol. (x), Issue 1, March 2025, pp.36-47



Sampling Methods and Techniques

Methods

The data collected for the present study were analyzed using a variety of tools and methods, including descriptive statistics, mean comparison tests, and multiple linear regression for determining determinants. The data analysis was conducted using the software packages SPSS 25 and Excel 2019.

Sampling Strategy and Sample Size

There are numerous sampling techniques. In the present study, we employed the following formula to draw our sample (Lututala, 2022):

$$n = z^2 \text{ x } p(1-p)/m^2 \quad \text{(Equation 1)}$$

Given:

n= sample size

z= level of confidence according to the reduced normal distribution law (for a 95% level of confidence, z= 1.96; for a 99% level of confidence, z= 2.575)

p= estimated proportion of the population exhibiting the characteristic (when unknown, p= 0.5, which corresponds to the most unfavorable case, namely the greatest dispersion.

m represents the acceptable margin of error (for example, the objective is to ascertain the actual proportion to within 6% of the true value).

n is calculated using the following formula :

$$n = (1{,}96)^2 x (0{,}5)(1-0{,}5)/(0{,}6^2) \quad \text{(Equation 2)}$$

$$\mathbf{n = 267}$$

Data Collection Techniques

The objective of the research was to gather quantitative data on production costs, selling prices, sales volumes, marital status of producers, and irrigated area size from questionnaires and interviews with small-scale gourd producers engaged in irrigation on the study site.
The survey was conducted using a pre-programmed questionnaire in Kobocollect. A total of 25 producers were surveyed in each of the 10 functional blocks, selected randomly, resulting in a total sample size of 250 producers at the time of data collection. The producers were selected at random from the entire site. In order to gain a deeper understanding of the irrigation system, visits were conducted to the water sources, irrigation canals, and production plots within the selected sample area. Additionally, observations were conducted regarding the irrigation water supply and the organization of production activities on the parcels. It should be noted that due to the absence of producers in the sampled blocks, which were already inundated, our study was conducted with a sample size of 250 producers. This represents a 94% success rate for our survey, with the remaining 17 individuals accounting for the remaining loss to the sample.

Data Analysis Techniques

The data collected for the present study were analyzed using a variety of tools and methods, including simulation analysis of profitability, descriptive statistics, mean comparison tests, and multiple linear regression for determining determinants. The data analysis was conducted using the software packages SPSS 25, Excel 2019 and MATLAB. These models employ computer software to simulate the operation of a system. Such models may be based on mathematical models, algorithms, rules, or interactions between different system components. Computer simulation models are employed in a multitude of fields, including finance, environmental science, engineering, logistics, and healthcare, among others. In the context of our study, we utilized the scenario analysis tool, specifically the scenario manager in Excel and MATLAB software, to conduct simulations of Margin profitability and the financial viability of various irrigation systems.

Simulation Analysis of Profitability

The study commenced with an assessment of climate risks to identify the impact of flooding and drought on profitability. The data on historical climatic factors was integrated with the testimonies of producers within the same conceptual framework. Subsequently, the simulation analysis involved a synthesis of price and revenue scenarios derived from rice cultivation based on the observed climatic fluctuations between 1991 and 2021.

In order to conduct simulations of periods of scarcity and abundance, a ratio was identified and applied in conjunction with the reference scenario. The ratio was identified by analyzing precipitation data from the study area from 1991 to 2021. This analysis aimed to identify the year with the highest precipitation levels and the year with the most severe drought. Our data series reveals that the year 1996, which was characterised by severe drought, and the year 2020, which was marked by The abundance of precipitation in the study area was divided by the amount of precipitation in the reference situation to obtain a ratio. The same procedure was followed for the abundance situation.
The ratio of scarcity is calculated as the precipitation in 1996 divided by the precipitation in 2021, resulting in a value of 1.590.
The ratio of abundance is calculated as the precipitation in 2020 divided by the precipitation in 2021, resulting in a value of 0.686.

Table 1. Basic scenarios for simulating prices and revenues

	Precipitation		Ratio
Scenario	Period (year)	Value (mm)	
reference situation	2021	2060,39	1,000
scarcity	1996	1296,11	1,590
abundance	2020	3005,18	0,686

In order to ascertain the sale prices and revenues for each scenario, we proceeded to multiply the ratio identified for precipitation by the sale price of the reference scenario, thereby determining the sale price in the scenario under conditions of scarcity and in conditions of abundance. This same methodology was applied to revenues and the gross margin.
The equation for revenue is R = Qté x PV,
where
R represents total revenue,
Qté denotes quantity sold,
PV signifies price of sale,
MB represents the net profit margin.
The equation for cost is CT = R-MB,
where
CT represents total cost
MB represents the net profit margin.
To conduct a sensitivity analysis, we first identified the parameters of the model that could vary. Subsequently, we established a baseline model with initial values for each parameter. Finally, we individually modified each parameter to observe the resulting changes.
The methodology for calculating sensitivity in our example is based on a comparative analysis of the net margins and profitability between the initial situation and scenarios of scarcity and abundance. Initially, the values of net margins and profitability for each sales unit in the three situations were collected. Subsequently, the variation for each unit was calculated using the following formula:
The S-value is calculated by subtracting the value in the current situation from the value in the reference situation and dividing the result by the value in the reference situation. The resulting figure is expressed as a percentage.
This allowed us to obtain variations that, when positive, indicate favourable sensitivity (an increase in the event of a shortage), while negative variations indicate unfavourable sensitivity (a decrease in the event of abundance). Furthermore, by comparing the results between the various sales units, we were able to identify those that are the most sensitive to changes in product availability, thus facilitating strategic decision-making.

Statistical analysis of profitability determinants

A multiple linear regression was employed to examine the relationships between the independent variables (costs, selling price, quantity sold, marital status, irrigated area) and the dependent variable (profitability). As posited by Kutner et al. (2004), Tabachnick & Fidell (2013), and Field (2013), the results of the regression analysis enable the relative importance of each determinant to be determined and recommendations to be formulated based on the conclusions.

Model Specification

$$\mathrm{Y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon$$

$$\mathrm{MB} = \beta_0 + \beta_1 S + \beta_2 PUVR + \beta_3 QVR + \beta_4 CTR + \varepsilon$$

With :
"S" represents the perception of dryness.
"PUVR" denotes the unit price of rice.
"QVR" signifies the quantity of rice sold.
"CTR" represents the total cost of rice production.
In this equation, MB is employed to represent the probability of profitability or the net margin of the irrigation system. The regression coefficients β_o, β_(1), β_2, β_3, and β_4 quantify the impact of each independent variable on the probability of profitability. In this context, e represents the concept of random error. In order to estimate the regression coefficients, a statistical method such as the maximum likelihood method is employed. Once the coefficients have been calculated, they can be employed to analyse the influence of each independent variable on the probability of profitability of the irrigation system. The independent variables in this model include elements such as:

- Perception of drought (S)
- Unit price of rice (PUVR)
- Quantity of rice sold (QVR)
- Total cost of rice production (CTR)

Nullity test of parameters

The critical value of t for a one − tailed test with a significance level of 5% *is* 1.96. *Therefore, the following inequalities hold*

$$t\beta\_0 = \beta\_0/(SE\beta\_0\ ) \geq 1.96$$
$$t\beta\_1 = \beta\_1/(SE\beta\_1\ ) \geq 1.96$$
$$t\beta\_2 = \beta\_2/(SE\beta\_2\ ) \geq 1.96$$
$$t\beta\_3 = \beta\_3/(SE\beta\_3\ ) \geq 1.96$$
$$t\beta\_4 = \beta\_4/(SE\beta\_4\ ) \geq 1.96$$

Test of Model Relevance

In order to evaluate the factors influencing the profitability of rice cultivation, we employed a multiple linear regression method. Information was gathered from a sample of producers regarding drought conditions, the price of rice per kilogram, sales volumes, and total costs. The coefficients were calculated using the ordinary least squares method, with tests of significance employed to confirm the relationships. The profitability prediction was conducted by incorporating values for each variable, and its reliability was validated through variance analysis tests, including an R2 and a Fisher test at a 5% significance level. This approach facilitated the identification of crucial factors influencing profitability, offering precise recommendations to rice producers for strategic adjustments.
The validation of the statistics pertaining to the determinants of the profitability of rice cultivation was conducted in accordance with meticulous methodological procedures. Each coefficient was examined for its impact on profitability, with significance tests indicating that all were significant at the 1%, 5%, and 10% levels. The residuals were examined for a normal distribution, and homoscedasticity was evaluated to ensure constant error variance. The issue of multicollinearity was addressed through the use of the variance inflation factor (VIF), which ensured the independence of observations. The analysis of variance (ANOVA) was employed to substantiate the relevance of the model, with an R^2 and the Fisher test (Prob > F = 0.000) indicating that the model is statistically significant. Additionally, cross-validation techniques were considered to assess the robustness of the results, thereby enhancing the credibility and applicability of the conclusions for rice producers. Furthermore, a discussion of the results enabled a comparison with similar studies in other regions to evaluate the robustness and relevance of the conclusions (Cohen et al., 2003).

RESULTS

Analysis of profitability

Profitability of rice

With regard to the profitability of rice, the results demonstrate notable fluctuations contingent on the unit of sale and the irrigation system employed. With regard to the unit of sale comprising a 2500 m² area, the sale price is 7136, resulting in a total revenue of 970496 Fc and a net profit of 520562 Fc. This corresponds to an overall return on investment (ROI) of 116%. In contrast, the unit of sale in the form of a cup, with a surface area of 2000 m², has a sale price of 1250 Fc, yet produces a remarkable quantity of 3676. This results in a total revenue of 4595000 Fc and a net profit of 4459000 Fc, representing an extremely high rate of return of 3279%. The other selling units, such as the kilo and the 25-kilogram bag, also exhibit positive net profit margins, albeit to a lesser extent, with respective rates of return of 738% and 235%. Conversely, the 50-kilogram bag, despite an elevated selling price of 250,000 Fc, generates a net profit of 287,050 Fc, with a return on investment of 456%. These results indicate that, although certain sales units may appear less profitable in terms of margin, they may offer promising opportunities depending on production volume and cost management. This underscores the necessity for a tailored strategy for each irrigation system to achieve optimal profitability (Table 1).

Table 2 : Rice profitability by sales unit (CDF)[1]

Unité de vente	Système d'irrigation	RIZ						
		SAU (m2)	Prix de vente	Qté Produite	Recette Totale	Coût Total	Marge bénéficiaire	Rté
Gobelet	Irrigation_de_surface_Gobelet	2000	1250	3676	4595000	136000	4459000	3279
Kilo	Irrigation_de_surface_Kilo	2000	5000	700	3500000	417500	3082500	738
Bassinet	Irrigation_de_surface_Bassinet	2500	7136	136	970496	449934	520562	116
Sac 25 Kg	Irrigation_de_surface_Sac 25 Kg	2625	103750	28	2905000	865963	2039038	235
Sac de 50kg	Irrigation_de_surface_sac 50 Kg	2000	250000	14	3500000	629500	2870500	456

[1] ***Note :***
1$ = 2700 CDF

Revenue from Rice

The results of the rice price scenarios demonstrate the impact of climatic variations on producer revenues. In the baseline scenario, the selling price is stable, with a 50-kilogram bag costing 250,000 Fc, indicating a balanced profitability. In the event of a shortage, prices rise significantly, reaching 397500 Fc for the same quantity, thereby enabling producers to benefit from elevated revenues (5565000 Fc). This demonstrates that demand increases in response to limited supply. Conversely, in the scenario of abundance, prices decline to 171,500 Fc, resulting in a reduction of income to 240,100 Fc. This exemplifies the risks associated with overproduction and price depreciation. These results highlight the necessity for producers to adopt adaptive strategies in accordance with climatic conditions, with the objective of maximizing profitability while avoiding excess production.

Table 3 : Rice income scenario based on sales (CDF)[1]

Unité de vente	Système d'irrigation	Scénario de référence	Pénurie		Abondance	
		Valeur	Ratio	Valeur	Ratio	Valeur
Gobelet	PV_Irrigation_de_surface__Gobelet	1250	1,59	1988	0,686	858
Kilo	PV_Irrigation_de_surface__Kilo	5000	1,59	7950	0,686	3430
Bassinet	PV_Irrigation_de_surface__Bassinet	7136	1,59	11346	0,686	4895
Sac 25 Kg	PV_Irrigation_de_surface__Sac_25_Kg	103750	1,59	164963	0,686	71173
Sac de 50kg	PV_Irrigation_de_surface__sac_50_Kg	250000	1,59	397500	0,686	171500
Unité de vente	**Revenu du Riz**					
Gobelet	Revenu_Surf_Gobelet	4595000	1,59	7306050	0,686	3152170
Kilo	Revenu_Surface_Kilo	3500000	1,59	5565000	0,686	2401000
Bassinet	Revenu_Surf_Bassinet	970496	1,59	1543089	0,686	665760
Sac 25 Kg	Revenu_Surf_Sac_25_Kg	2905000	1,59	4618950	0,686	1992830
Sac de 50kg	Revenu_Surf_Sac_50_Kg	3500000	1,59	5565000	0,686	2401000

[1] Note :
1$ = 2700

Marge beneficiary of rice

The results concerning the margin beneficiaries du Riz demonstrate the considerable impact of climatic conditions on the profitability of producers. In the baseline scenario, the gross margin for a 50-kilogram bag is 287,050 Fc, indicating a favorable economic situation. In periods of scarcity, this margin increases considerably to 4564095 Fc, demonstrating that producers can benefit from an increased demand when supply is limited. However, in the scenario of abundance, the profit margin declines to 1969163 Fc due to a reduction in prices, which highlights the risks associated with overproduction. These results demonstrate that the profitability of producers is significantly influenced by fluctuations in supply and demand, and underscore the necessity of adapting production strategies to maximize profit margins in accordance with climatic conditions.

Table 4: Rice profit margin scenario (CDF)[1]

Unité de vente	Système d'Irrigation pratiqué	Scénario de référence	Pénurie		Abondance	
		Valeur	Ratio	Valeur	Ratio	Valeur
Gobelet	PV_Irrigation_de_surface__Gobelet	1250	1,59	1988	0,686	858
Kilo	PV_Irrigation_de_surface__Kilo	5000	1,59	7950	0,686	3430
Bassinet	PV_Irrigation_de_surface__Bassinet	7136	1,59	11346	0,686	4895
Sac 25 Kg	PV_Irrigation_de_surface__Sac_25_Kg	103750	1,59	164963	0,686	71173
Sac 50 Kg	PV_Irrigation_de_surface__sac_50_Kg	250000	1,59	397500	0,686	171500
Unité de vente	**Marge Bénéficiaire**					
Gobelet	MB Irrigation de surface Gobelet	4459000	1,59	7089810	0,686	3058874
Kilo	MB Irrigation de surface Kilo	3082500	1,59	4901175	0,686	2114595
Bassinet	MB Irrigation de surface Bassinet	520562	1,59	827694	0,686	357106
Sac 25 Kg	MB Irrigation de surface Sac 25 Kg	2039038	1,59	3242070	0,686	1398780
Sac 50 Kg	MB Irrigation de surface Sac 50 Kg	2870500	1,59	4564095	0,686	1969163

[1] Note :
1$ = 2700 CDF

Margin Benefit Sensitivity Analysis CDF

The sensitivity analysis of the profitability revealed essential interactions related to the irrigation system utilized for each sales unit. In periods of scarcity, all units, whether basins, bowls, kilograms, 25-kilogram sacks, or 50-kilogram sacks, demonstrate a significantly elevated profit margin, with a rate of 59% in comparison to normal conditions. This indicates that the implementation of surface irrigation systems enables the optimization of profits, thereby providing rice producers with the flexibility to increase prices or reduce expenditures during periods of scarcity. Conversely, in the event of abundance, all units experience a notable decline in profitability, with reductions reaching -31.4%. This negative sensitivity to abundance indicates that, despite the advantages of the irrigation system, an increase in sales volume does not offset the competitive pressure on prices. In light of these findings, it is evident that strategic irrigation resource management is of paramount importance in order to achieve the greatest profit margins in response to fluctuations in supply.

Table 5 : Profit margin sensivility scenario (%)

Unité de vente	Système d'Irrigation pratiqué	Scénario de référence	Pénurie		Abondance	
		Valeur	Ratio	Valeur	Ratio	Valeur
Bassinet	MB Irrigation de surface Bassinet	520562	1,59	827694	0,686	357106
Gobelet	MB Irrigation de surface Gobelet	4459000	1,59	7089810	0,686	3058874
Kilo	MB Irrigation de surface Kilo	3082500	1,59	4901175	0,686	2114595
Sac 25 Kg	MB Irrigation de surface Sac 25 Kg	2039038	1,59	3242070	0,686	1398780
Sac 50 Kg	MB Irrigation de surface Sac 50 Kg	2870500	1,59	4564095	0,686	1969163
Unité de vente	**Sensibilité**					
Gobelet	MB Irrigation de surface Gobelet	100%	59%		-31,4%	
Kilo	MB Irrigation de surface Kilo	100%	59%		-31,4%	
Bassinet	MB Irrigation de surface Bassinet	100%	59%		-31,4%	
Sac 25 Kg	MB Irrigation de surface Sac 25 Kg	100%	59%		-31,4%	
Sac 50 Kg	MB Irrigation de surface Sac 50 Kg	100%	59%		-31,4%	

[1] **Note :**
1$ = 2700 CDF

Determinants of Rice Cultivation Profitability in Surface Irrigation Systems

MB = 1913054,08 - 680583,865 S + 12,155 PUVR + 814,564 QVR - 1,31 CTR
(t=5,004) (t=-1,891) (t=4,265) (t=6,265) (t=-2,174)

Tableau 6 : Determinants of crop profitability

Variables du modèle	Coefficients non standardisés		Coefficients standardisés	t	Sig.
	B	Erreur standard	Bêta		
(Constante)	1913054,08	382268,279		5,004	0,000
Sécheresse (S)	-680583,865	359989,938	-0,178	-1,891	0,065
Prix/Unité de vente Riz en Kg (PUVR)	12,155	2,85	0,402	4,265	0,000
Quantité vendue Riz en Kg (QVR)	814,564	131,483	0,622	6,195	0,000
Coût Total Riz (CTR)	-1,31	0,603	-0,22	-2,174	0,035
			Observation = 54 R2 = 60,5% Prob > F = 0,000 F = 18,761		

: valeur significative à 1 % (p≤0,01) ; : valeur significative à 5 % (0,01< p≤0,05) ; : valeur significative à 10 % (0,05< p≤0,10)

The analysis of the determinants of rice reveals several significant factors influencing the profitability of rice produced and sold under surface irrigation systems. With an adjusted R^2 coefficient of 60.5%, the model explains a notable proportion of the price variance. The Fisher test (Prob > F = 0.000) indicates that the model is statistically significant at the 1% level. These results highlight the importance of monitoring these variables in order to optimize the economic performance of the rice sector at Masina Rail 1. This indicates that there are still unconsidered random or non-random factors that may explain the profitability of rice production in the area. In the variable group, the positive and significant coefficient of the rice price per unit of sale (PUVR) is 12.155, indicating that when the price per kilogram increases, the quantity sold also tends to increase, suggesting a price-elastic demand. Similarly, the quantity sold (QVR) exhibits a positive coefficient (814.564), indicating that an increase in the quantity sold results in substantial additional revenue. Conversely, the perception of drought (S) on the site has a negative impact on price, with a coefficient of -680583.865 at the 10% significance threshold (p = 0.065), indicating a tendency for decreased profitability during periods of drought. This suggests that the presence of drought on the site reduces the availability of irrigation water, thereby reducing the probability of profitability in the absence of adaptive measures. Furthermore, the total cost of production of rice (CTR) exhibits a negative coefficient (–1.31), indicating that higher expenditures result in a reduction of the profit margin, which may be attributed to lower profit margins.

DISCUSSION

The economic profitability of rice production with surface irrigation was estimated, which provided insight into the irrigation practices of small-scale rice producers in the Masina Rail 1 area of the N'djili catchment area in Kinshasa, Democratic Republic of the Congo. To perform the various scenarios, a precipitation ratio was established to calculate the selling price, revenue, and net profit in the event of water scarcity or abundance at the site. The results of the price scenario simulations demonstrate the impact of climatic variations on rice prices, producer income, and profitability. The results demonstrate that the profitability of producers is significantly influenced by fluctuations in supply and demand, emphasizing the necessity of adapting production strategies to maximize profit margins in accordance with climatic conditions. With regard to the profitability of rice, the results demonstrate notable variations contingent on the unit of sale and the irrigation system employed. The results pertaining to the profitability of rice in the study area under the reference scenario exhibited positive margins for all units of sale, irrespective of the surface irrigation system utilized in rice production. This indicates that revenue was sufficient to cover total costs. This would indicate that rice production at Masina Rail 1 is economically viable given the climatic conditions. These findings corroborate those of Yabi et al. (2012) and Issiaka et al. (2019), who demonstrated that rice cultivation was economically viable in terms of cost coverage in the communes of Malanville and Kouandé in Benin. The analysis of the determinants of rice revealed several significant factors influencing both the price of sale and the quantity sold. Among the variables, the price per unit of sale of rice (PUVR) has a positive and significant coefficient (12.155), indicating that an increase in the price per kilogram leads to an increase in sales volume, suggesting a demand curve that is elastic. Similarly, the quantity sold (QVR) has a positive coefficient (814.564), indicating that an increase in the quantity sold generates significant additional revenue. Conversely, the effect of drought (S) on price is negative, indicating a tendency to reduce prices during periods of drought. Moreover, the total cost of rice (CTR) also has a negative coefficient, indicating that higher costs lead to a reduction in the selling price, potentially due to lower profit margins. Empirical research has examined the factors influencing productivity, yield, and the adoption of certain practices by producers. In their study on soil and water conservation and economic performance in Benin rice production, Issiaka and colleagues (2019) demonstrated that the installation of filter ditches has a positive impact on farmers' net margins. Nevertheless, the results indicate that the cost of producing rice has a negative impact. Moreover, Niang et al. (2017) demonstrated that the construction of dikes was beneficial for improving yields in West African rice production systems. As Ouedraogo (2012) notes, the size of farming households enables farmers to meet their labor needs, which represents a significant constraint in the context of extensive agriculture. Moreover, Yabi et al. (2012) demonstrated that the majority of rice farmers in the Malanville commune were unable to repay the loans they had taken out using the income generated from this activity. Adegbola et al. (2003) demonstrated that the profitability of rice production in Benin is contingent upon the specific region under study and the production system employed. As Nuama (2006) asserts, the utilisation of a service of vulgarisation has a significant and beneficial impact on cultivated production. Similarly, the findings of Nonvide (2017) indicated that awareness-raising initiatives provide farmers with the opportunity to gain familiarity with new agricultural methods and technologies. In their study on the socioeconomic determinants of profit in southern Benin's floodplain rice production, Adegbola et al. (2023) found that rice production is more profitable than the cultivation of rice and okra. This suggests that the latter combination does not offer additional benefits to floodplain rice farmers.

CONCLUSION

This study highlighted the significant impact of climatic conditions, particularly drought, on the economic profitability of rice cultivation in surface irrigation systems at the Masina Rail 1 site. Simulation results reveal varying profit margins based on sales units, with exceptional performances reaching up to 3279% in some cases during periods of scarcity. Conversely, overproduction has led to a sharp decline in prices and revenues, underscoring the challenges faced by producers.

The sensitivity analysis showed that all sales units benefit from significantly higher profit margins during shortages, emphasizing the advantages of surface irrigation systems in optimizing gains when water is scarce. However, during periods of abundance, margins dropped considerably, with decreases reaching -31.4%, illustrating competitive pressure on prices. The model validation was also encouraging, with an adjusted R^2 of 60.5%, indicating that our model effectively explains a significant portion of price variance, reinforced by a statistically significant Fisher test at the 1% level.

These results highlight the importance of strategic irrigation management to maximize profits while adapting to climatic fluctuations. Factors such as price per sales unit and quantity sold play essential roles in profitability, while perceptions of drought and production costs can weigh heavily on margins. This underscores the need for producers to develop adaptive responses to ensure the economic viability of rice cultivation in the face of these challenges.

REFERENCES BIBLIOGRAPHIQUES

[1] Adégbola, P., Sodjinou, E., 2003. Analyse de la compétitivité de la riziculture béninoise, rapport définitif du Ministère de l'Agriculture, de l'Elevage et de la Pêche. PAPAINRAB Porto-Novo Bénin.
[2] Baguiri, M. (2016). Irrigation et sécurité alimentaire en République Démocratique du Congo.
[3] Banque Mondiale. (2023a). Diagnostic des systèmes de production agricole avec irrigation en RDC,. *Rapport final*, 71p
[4] CIRAD. (2005). Les systèmes d'irrigation et leur impact sur l'agriculture en Afrique.
[5] Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2003). "Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences" (3rd ed.). Lawrence Erlbaum Associates.
[6] FAO. (2005). L'irrigation en Afrique : Situation actuelle et perspectives. Organisation des Nations Unies pour l'alimentation et l'agriculture.
[7] FAO. (2007). L'irrigation et la sécurité alimentaire mondiale. Organisation des Nations Unies pour l'alimentation et l'agriculture.
[8] Field, A. (2013). *Discovering Statistics Using IBM SPSS Statistics* (4th ed.). Sage Publications.
[9] Issiaka K, Tama C, Yabi J.A et al (2019) Rentabilité de la production du riz sous différentes mesures de consersvation des Eaux et des Sols (CES) au Nord du Bénin. Ann. UP, Série Sci. Nat. Agron. Juin 2019; Vol.9 (No.1) : 123-132.
[10] Kutner, M. H., Nachtsheim, C. J., & Neter, J. (2004). *Applied Linear Regression Models* (4th ed.). McGraw-Hill.
[11] Longadi, M., et al. (2022). L'agriculture et la réduction de la pauvreté en RDC.
[12] Ministère de l'Agriculture. (2018). Rapport sur l'agriculture en RDC.
[13] Montgomery, D. C., & Runger, G. C. (2010). *Applied Statistics and Probability for Engineers* (5th ed.). Wiley.
[14] Muzingu, B. (2010). Agriculture urbaine et périurbaine à Kinshasa : État des lieux et perspectives.
[15] Niang, A., Becker, M., Ewert, F., Dieng, I., 2017. Variability and determinants of yields in rice production systems of West Africa. Field Crops Res. 207, 1–12. https://doi.org/10.1016/j.fcr.2017.02.014
[16] Nonvide, G.M.A., 2017. Effect of Adoption of Irrigation on Rice Yield in the Municipality of Malanville, Benin. Afr. Dev. Rev. 29, 109. https://doi.org/10.1111/1467-8268.12266
[17] Nuama, E., 2006. Mesure de l'efficacité technique des agricultrices de cultures vivrières en Côte-d'Ivoire. Économie Rurale Agric. Aliment. Territ. 39–53.
[18] Ouedraogo, M., 2012. Impact des changements climatiques sur les revenus agricoles au Burkina Faso. J. Agric. Environ. Int. Dev. JAEID 106, 3–21.
[19] Tabachnick, B. G., & Fidell, L. S. (2013). *Using Multivariate Statistics* (6th ed.). Pearson.
[20] Tillie, P., et al. (2019). Les potentialités hydro-agricoles de la République Démocratique du Congo.
[21] Yabi, J. A., Paraïso, A., Yegbemey, R. N., Chanou, P., 2012. Rentabilité Economique des Systèmes Rizicoles de la Commune de Malanville au Nord-Est du Bénin. Bulletin de la Recherche Agronomique du Bénin (BRAB) Numéro spécial Productions Végétales & Animales et Economie & Sociologie Rurales, 12p.

Nana Kabujenda Kabasu, Tshimanga M.R, Luweshi C.N, Bagala A.M, Nkaba N.L and Bola G.
Analyse de la relation Pluie-Débit dans le bassin versant de la rivière Lubi : Application du Modèle HEC-HMS pour la Gestion des Ressources en Eau
International Journal Water Sciences and Environment Technologies
Vol. (x), Issue. 1, March 2025, pp. 48-60
ISSN Online: 1737-9350; ISSN Print: 1737-6688, Open Access
www.jiste.org
Scientific Press International Limited
Received: January 2025 / Revised: February 2025 / Accepted: March 2025 / Published: March 2025

Analyse de la relation Pluie-Débit dans le bassin versant de la rivière Lubi : Application du Modèle HEC-HMS pour la Gestion des Ressources en Eau

Nana Kabujenda Kabasu. [1, 2,],Tshimanga M.R. [1] , Luwesi C.N. [1,3] , Bagala A.M. [1,4] , Nkaba N.L. [1] et Bola B.G. [1]

1 Ecole Régionale de l'Eau/Centre de Ressource en Eau du Bassin du Congo de l'Université de Kinshasa, République démocratique du Congo

2 Centre National de Télédétection, République démocratique du Congo

3 African University of Management and Technologies(AUMT)-Brazza Rep. du Congo

4 Faculté des Sciences Agronomiques et environnement de l'Université de Lisala, République démocratique du Congo

Résumé

La gestion des ressources en eau est un enjeu crucial face aux défis hydrologiques contemporains. Cette étude se concentre sur l'analyse de la relation pluie-débit dans le bassin versant de la rivière Lubi, soulignant les variations significatives entre ses sous-bassins. Les objectifs principaux étaient d'évaluer les débits, les taux d'infiltration et de ruissellement pour chaque sous-bassin. La méthodologie impliquait l'échantillonnage des débits, la collecte de données hydrologiques et l'analyse statistique à l'aide du modèle HEC-HMS. Les résultats montrent un pic de débit de 1683,2 m³/s le 6 avril 2021, avec des contributions variées des sous-bassins, notamment Lubi(2) et Lubi(1), qui affichent des comportements hydrologiques distincts. L'étude révèle également des valeurs élevées de NSE (0,90) et R^2 (0,87), confirmant la bonne performance du modèle dans la simulation des dynamiques hydrologiques. En conclusion, il est recommandé d'adopter des approches spécifiques et localisées pour la gestion des eaux pluviales, afin d'optimiser la résilience hydrologique et de réduire les risques d'inondation dans la région.

Mots clés : Gestion des ressources en eau, Relation pluie-débit, Bassin versant, Rivière Lubi et Modèle HEC-HMS

Analysis of the Rain-Flow relationship in the Lubi River Watershed: Application of the HEC-HMS Model for Water Resource Management

Abstract

Water resource management is a crucial issue in the face of contemporary hydrological challenges. This study focuses on analyzing the rainfall-runoff relationship in the Lubi River watershed, highlighting significant variations among its sub-basins. The main objectives were to assess flows, infiltration rates, and runoff for each sub-basin. The methodology involved sampling discharge, collecting hydrological data, and statistical analysis using the HEC-HMS model. The results show a peak discharge of 1683.2 m³/s on April 6, 2021, with varied contributions from the sub-basins, particularly Lubi (2) and Lubi (1), which display distinct hydrological behaviors. The study also reveals high values of NSE (0.90) and R^2 (0.87), confirming the good performance of the model in simulating hydrological dynamics. In conclusion, it is recommended to adopt specific and localized approaches for stormwater management to optimize hydrological resilience and reduce flood risks in the region

Keywords: Water resource management; Rainfall-runoff relationship; Watershed; Lubi River; HEC-HMS model

[1] Corresponding author: nana.kabujenda@unikin.ac.cd

INTRODUCTION

L'analyse de la relation pluie-débit dans le bassin versant sous-jaugé revêt une importance cruciale pour la gestion des ressources en eau (Dupont et Martin, 2021). Le bassin du Congo, le deuxième du monde après celui de l'Amazonie, se trouve avec un nombre important de sous-bassins non jaugés, dont l'existence des données hydrométriques date de l'époque coloniale. Après les années 1960, les lectures de données des stations ne sont plus au même rythme, faute de motivation, et il n'y a plus de mise à jour des courbes de tarage d'un grand nombre de stations hydrométriques pour maintenir la relation niveau d'eau-débit, en raison de l'absence de campagnes hydrographiques régulières (Nguyen et al., 2020). La modélisation pluie-débit constitue un élément clé de l'analyse hydrologique, car elle permet de comprendre comment les cours d'eau réagissent aux précipitations (Kadam, 2011). Dans un contexte où les données de débits sont souvent rares, alors que les données pluviométriques sont généralement disponibles, il devient essentiel de transformer ces données pluviométriques en informations hydrométriques précises pour une gestion efficace des ressources en eau. Malgré l'importance de ces analyses, les études comparatives sur les modèles de bassins versants pour les simulations hydrologiques dans les pays en développement, y compris ceux du bassin du Congo, sont très limitées (Pouget et al., 2021). Cela souligne la nécessité d'entreprendre des recherches sur la simulation hydrologique en développant des modèles appropriés pour ces contextes spécifiques. Dans cette optique, l'utilisation du modèle HEC-HMS offre une opportunité pour évaluer la réponse hydrologique du bassin versant de la zone tropicale (Lefèvre et Simon, 2019) et, en particulier, de celui de la rivière Lubi face aux variations de précipitation et aux pratiques de gestion des terres. La rivière Lubi, en tant qu'axe économique majeur, devrait jouer un rôle vital dans le désenclavement de l'espace grand Kasaï, notamment grâce à son potentiel de navigabilité (Devroey, 2004). Cependant, la dégradation des infrastructures routières et l'exploitation des ressources naturelles, telles que les gisements de diamants, la pêche, l'infrastructure hydroélectrique et son usage en point de captage d'eau pour fournir de l'eau potable, rendent encore plus pressante la nécessité d'une gestion intégrée et durable de ses ressources en eau (Kouadio et al., 2021). Il est donc essentiel de maîtriser le débit réel et l'allocation pour chaque usage. Ainsi, l'objectif de cette étude est d'approfondir la compréhension des interactions complexes entre les précipitations, l'écoulement des eaux de surface et la réponse hydrologique du bassin versant de la rivière Lubi.

2. Matériels et méthodes

2.1 Présentation du milieu d'étude

Nana Kabujenda Kabasu et al., / IJWSET -JISTEE, Vol. (x), Issue 1, March 2025, pp. 48-60

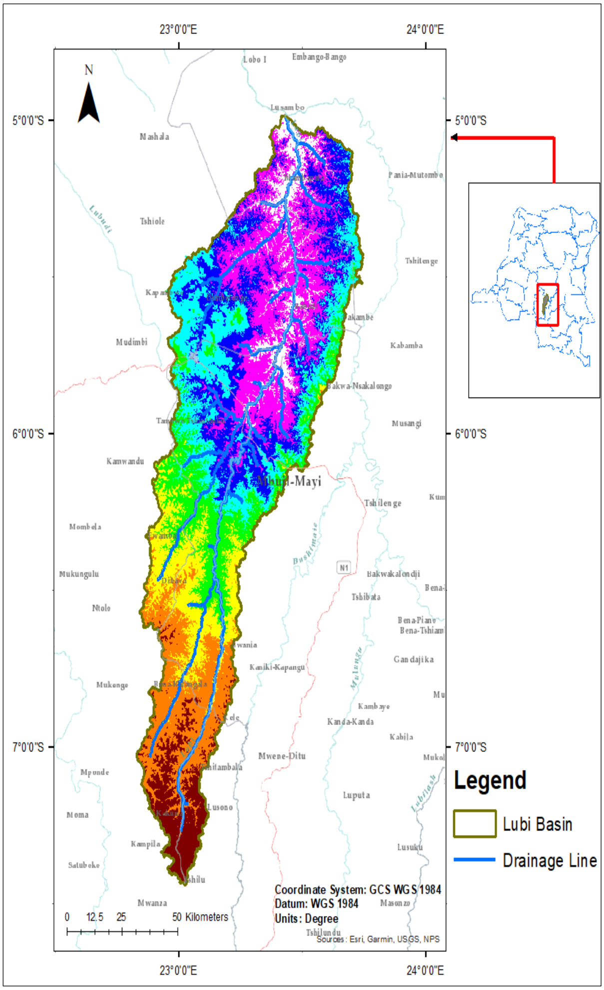


Figure 1 : Zone d'étude

Notre zone d'étude, reprise dans la figure 1, indique que la rivière Lubi est située dans les deux provinces, celle de Kasaï Oriental et Sankuru en République démocratique du Congo [1], mais son bassin versant s'étend sur trois provinces, y compris le Kasaï Central, dans le même pays, entre 4°59'09.6"S et 5°02'41.6"S de latitude Sud et entre 23°25'55.29" et 23°34'03.29" de longitude Est (Kambi et al.,2018). Le bassin de Lubi couvre une superficie d'environ 12 572,57 km² et un périmètre d'ordre de 1 250 km, mesurant 1 249,884 km de long. Sur le plan géologique, le sous-sol n'est pas homogène. Le bassin de la Lubi est calcaire [1]. Cette région se situe entièrement au Sud de l'équateur et compte, selon la classification de Köppen, deux climats, à savoir le climat équatorial qui règne dans l'extrême Nord-Ouest, où il y a absence de la saison sèche, et le climat subéquatorial, où la saison sèche varie entre 3 et 4 mois au centre et dans toute la partie Sud. Le bassin versant de Lubi comprend cinq sous-bassins : il s'agit de la Lubi (1) dans le territoire de Lubi (1) Lulua/Kabinda/Tshilenge, la Lubi (2) Tshilenge/Lulua/Sankuru, Lukeshi Lulua/Kabinda, et Lupaka Sankuru/Lulua Bi (A), selon les délimitations de l'outil CBCIS. Sur cette zone sous étude, plusieurs activités font la survie de la population : elle exerce l'agriculture [1], travaille dans les gisements de diamants en exploitation artisanale, et il y a présence de ports suite à la navigation intérieure sur la rivière Lubi..

2.2 Collecte des données

Les données utilisées dans cette étude proviennent de plusieurs sources essentielles. Tout d'abord, nous avons téléchargé des modèles numériques de terrain via le portail de données de l'USGS Earth Explorer (www.usgs.gov), qui nous ont permis d'obtenir des informations topographiques précises. En ce qui concerne les données climatiques, les données météorologiques comprennent des mesures de pluviométrie obtenues par le dataset CHIRPS, permettant de caractériser les précipitations sur la période d'étude. Les températures moyennes à 2 mètres du sol ont été obtenues du système ERA 5 et les évapotranspirations du dataset CASEarth thematic data system. Toutes les données climatiques sont pour la période de janvier 2009 à septembre 2024. Par ailleurs, grâce à l'outil CBCIS (www.cbcis.info) développé par le Centre de Recherche en Ressources en Eau du Bassin du Congo, nous avons pu accéder à un ensemble important d'informations sur les sols et certains paramètres nécessaires à la calibration de notre modèle. Enfin, les données de débit observées ont été fournies par la Régie de Voies Fluviales (RVF) à partir de leurs stations hydrométriques pour la période de janvier 2023 à septembre 2024. Ces différentes sources de données sont cruciales pour la modélisation précise et l'analyse hydrologique de notre étude.

2.3 Analyse des données

L'analyse de la relation pluie-débit dans le bassin versant de la rivière Lubi a été réalisée en suivant une méthodologie structurée en plusieurs étapes, intégrant la collecte de données, la modélisation hydrologique suivant la calibration et la validation du modèle, et l'analyse des résultats.

2.3.1. Modélisation avec HEC-HMS

Une fois les données collectées, la modélisation hydrologique a été effectuée à l'aide du modèle HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System). Les étapes de cette modélisation incluent :

• Calibration du modèle : Les paramètres du modèle HEC-HMS ont été ajustés en utilisant les données historiques de débit pour s'assurer que les simulations correspondent aux observations. Cette étape est cruciale pour garantir la précision des prévisions.

• Simulation des scénarios : Différents scénarios de précipitations ont été simulés pour évaluer la réponse hydrologique du bassin versant. Cela inclut des événements de pluie extrêmes ainsi que des régimes pluviométriques habituels.

• Analyse des résultats : Les résultats des simulations ont été analysés pour déterminer la relation entre les précipitations et les débits, en observant les variations saisonnières et les impacts des pratiques de gestion des terres.

2.3.2. Calibration et validation de model

1° Calibration

Le succès de l'application du modèle hydrologique HEC-HMS pour le bassin versant dépend de la qualité de sa calibration, influencée par la capacité technique du modèle et la qualité des données d'entrée. La calibration vise à aligner les volumes et les pics de ruissellement simulés avec les volumes observés. Pour cela, les données hydrométéorologiques ont été divisées en deux ensembles : de la période du 1er janvier 2009 au 31 décembre 2022 pour la calibration. HEC-HMS se passe riche en méthodes, le choix de la méthode dépend bien des objectifs poursuivis et de la disponibilité de données. Suivant le modèle, les méthodes utilisées se présentent comme suit :

1. Modèle du Bassin fait la description de l'hydrologie à la surface du sol : Dans cette étude pour le modèle hydrologique, la méthode SCS Curve Number est la méthode de perte ou d'infiltration simple pour estimer le ruissellement. Le Curve Number (CN) dépend du groupe hydrologique du sol et de la couverture du terrain du bassin versant (Feldman 2000) que nous avons récupéré à partir de cbcis souvent chaque sous-bassin. L'hydrogramme unitaire SCS est utilisé comme méthode de transformation.

Tableau1 : Table de méthode de modèle de bassin

Type de Modèle	Method Surface	Loss Method (Infiltration)	Transform Method	Reach
Modèle Continu	Simple surface	SCS CN	SCS Unit Hydrograph	Muskingum

2.Modèle du météorologique qui fait la description des conditions atmosphériques au-dessus du bassin. Nous avons utilisé les données propres à chaque sous bassin qui a orienté notre choix sur les méthodes de modèle météorologique ; la méthode de Specified hyetograph pour la précipitation, specified thermograph pour le temperature et specified evapotranspiration pour l'évapotranspirtaion.

Tableau2 : Table de méthode de modèle de météorologique

Type de Modèle	Precipitation	Temperature	Evapotranspiration
Modèle Continu	Specified Hyetograph	specified thermograph	specified evapotranspiration

3.Les spécifications de contrôle ont défini l'étendue temporelle de 1janvier 2009 à 31décembre2022 et de la simulation en intervalle d'un jour soit 24heures sur cinq sous bassin et sur l'ensemble du bassin.

Dans le cas de notre étude nous avons fait une simulation continue à long terme dans une zone périphérique qui est à l'état plus naturel (Halwatura & Najim 2013 ; Pak, JH et al. 2015).

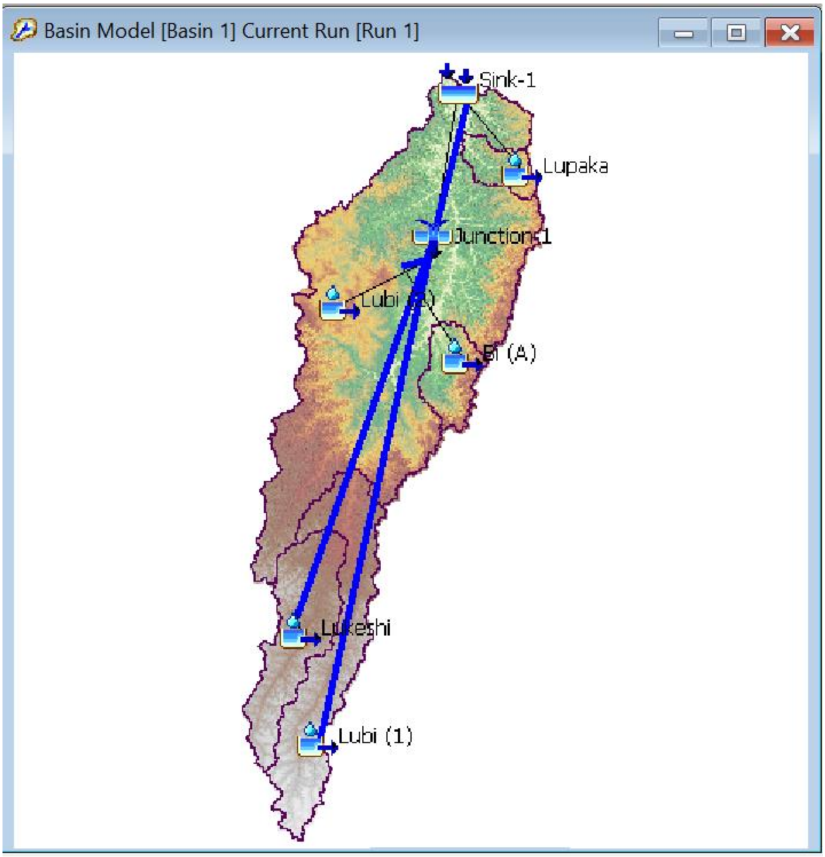


Figure2 : Présentation de model HEC-HMS

2° Validation du modèle

Les données de ruissellement pluvial du bassin versant de la Lubi ont servi à calibrer et valider le modèle, avec des valeurs de paramètres calculées et utiliser sur HEC-HMS. Les résultats des hydrogrammes de ruissellement observé ont été comparés à ceux des simulations pour la période allant de 1janvier2023 à 19Mars2023 pour la validation du modèle.

Alors les différents tests statistiques permettent d'évaluer la performance du modèle sur Hec-HMS comme l'indique table ci-après.

Tableau: Evaluation de performance the modèle a pas journalier

Performance	NASH	RSR	PBIAS
Très Bon	$0.65 < NSE \leq 1.00$	$0.00 < RSR \leq 0.60$	$PBIAS < \pm 15$
Bon	$0.55 < NSE \leq 0.65$	$0.60 < RSR \leq 0.70$	$\pm 15 \leq PBIAS < \pm 20$
Satisfaisant	$0.40 < NSE \leq 0.55$	$0.70 < RSR \leq 0.80$	$\pm 20 \leq PBIAS < \pm 30$
Insatisfaisant	$NSE \leq 0.40$	$RSR > 0.80$	$PBIAS \geq \pm 30$

3. Résultats

3.1. Simulation hydrologique de la Rivière LUBI

Les figures 3 ci-dessous présentent de simulation hydrologique de débit en mètre cube/seconde par sous bassin de la 150 Rivière Lubi de 2009 jusqu'à 2023

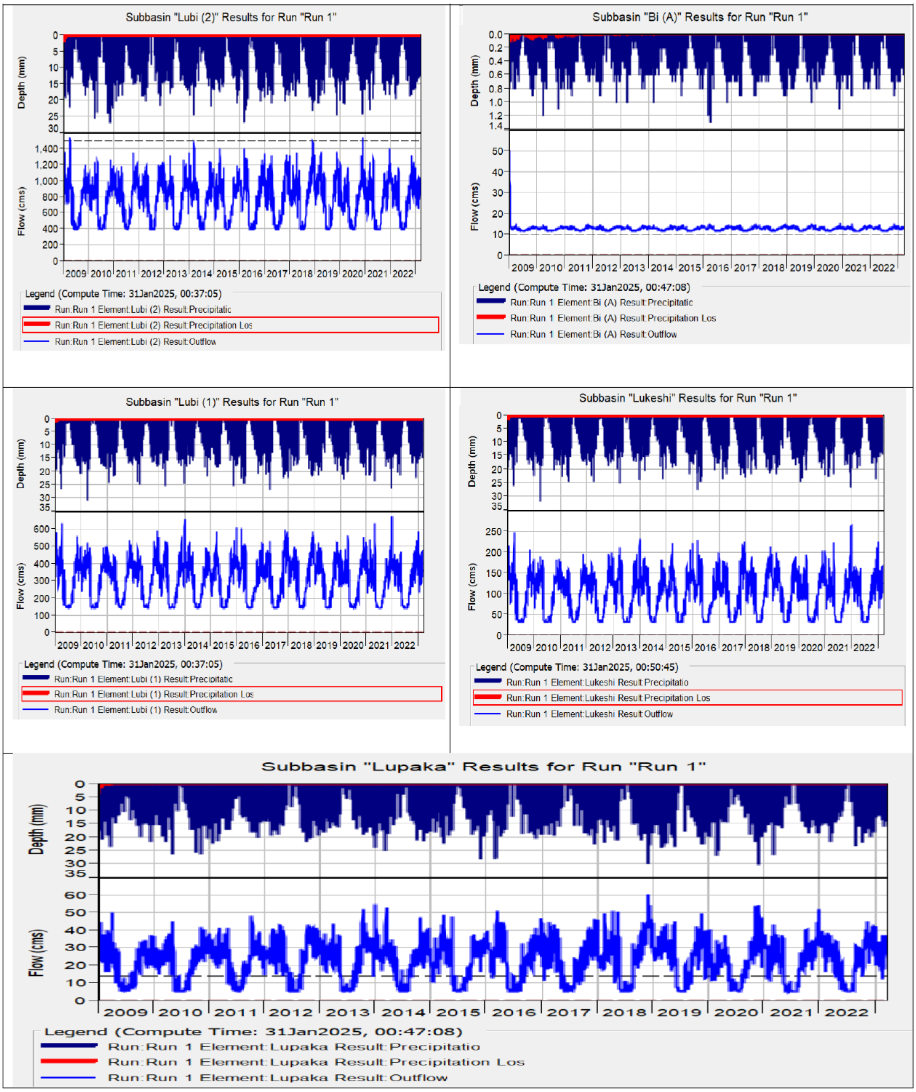


Figure3 : Simulation hydrologique de la Rivière LUBI

International Journal Water Sciences and Environment Technologies
e-ISSN: 1737-9350 p-ISSN: 1737-6688, | Open Access Journal | Volume (x) - Issue 1 – March 2025
Volume (x): Water -Biodiversity-Climate'2025

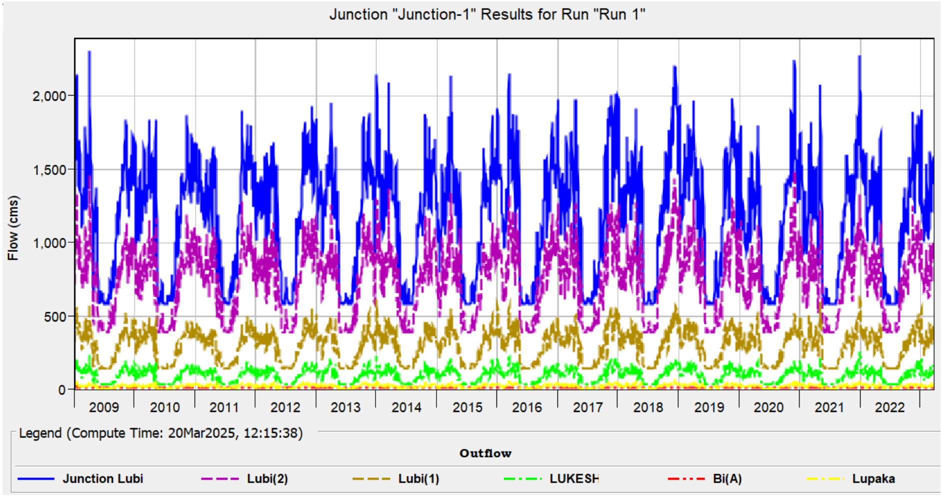


Figure 4 : Simulation proportionnelles de chaque compartiments bassin de la rivière Lubi

Tableau 4 : Temps et débits de pics

Project: LUBI   Simulation Run: Run 1

Start of Run: 01Jan2009, 00:00   Basin Model: Basin 1
End of Run: 19Mar2023, 00:00   Meteorologic Model: Meteorologic
Compute Time: 31Jan2025, 00:50:45   Control Specifications: Control 1

Show Elements: All Elements   Volume Units: MM 1000 M3   Sorting: Watershed Explorer

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
Lubi (1)	3422.5	669.0	25 December 2021,...	40701.87
Lubi (2)	8165.8	1540.7	26 November 2020...	42699.62
Bi (A)	577.0	49.9	31 December 2008,...	9872.44
Reach Bi (A)	577.0	49.9	31 December 2008,...	9873.58
Lupaka	356.9	60.3	2 December 2018, ...	28491.64
Reach lupaka	356.9	60.7	2 December 2018, ...	28491.49
Reach lubi2	9099.7	1606.5	29 November 2020...	40056.05
Reach lubi1	3422.5	662.1	27 December 2021,...	40697.03
Lukeshi	1419.7	262.7	26 December 2021,...	31624.19
Reach lukeshi	1419.7	262.4	25 December 2021,...	31623.31
Junction-1	13941.9	2377.9	3 April 2009, 24:00	39354.70
Sink-1	13941.9	2377.9	3 April 2009, 24:00	39354.70

Les résultats obtenus pour le bassin de la rivière Lubi montrent des variations significatives dans les débits de chaque sous-bassin, en fonction de leur superficie et de leur capacité d'infiltration. Le débit de pointe enregistré à 193,3 m³/s le 6 avril 2021 souligne l'importance des événements pluvieux dans la réponse hydrologique du bassin, ainsi que les différences de comportement entre les sous-bassins.

Comparaison des Sous-Bassins

Lubi(2) : Avec une superficie représentant 58 % du bassin, ce sous-bassin produit un volume de débit de 11 951,9 m³, atteignant un pic de 62,1 m³/s. Cependant, il présente un taux de ruissellement très faible de seulement 5 %, indiquant une forte capacité d'infiltration, mais aussi une perte considérable d'eau via l'infiltration. Ce phénomène pourrait être dû à la nature des sols et à l'utilisation des terres, qui favorisent l'absorption plutôt que le ruissellement.

Lubi(1) : Ce sous-bassin, bien que représentant seulement 24,5 % de la superficie, génère un débit significatif de 14 888 m³ avec un pic de 70,2 m³/s. Cela peut s'expliquer par des caractéristiques topographiques et pédologiques qui favorisent le ruissellement, avec un taux d'infiltration plus faible (76,2 %). La capacité de ce sous-bassin à produire un volume de débit plus élevé malgré sa taille plus réduite est un aspect crucial à considérer pour la gestion des eaux.

Lukeshi et Bi(A) : Les sous-bassins Lukeshi (10,1 %) et Bi(A) (4 %) montrent également des comportements distincts. Lukeshi présente un bon taux d'infiltration (88,6 %), mais son volume de ruissellement est relativement faible (11,4 %). Bi(A) affiche une infiltration de 77,4 % avec un ruissellement de 2,9 %. Cela suggère que ces sous-bassins sont moins susceptibles de contribuer au ruissellement direct, ce qui pourrait influencer les stratégies de gestion des inondations.

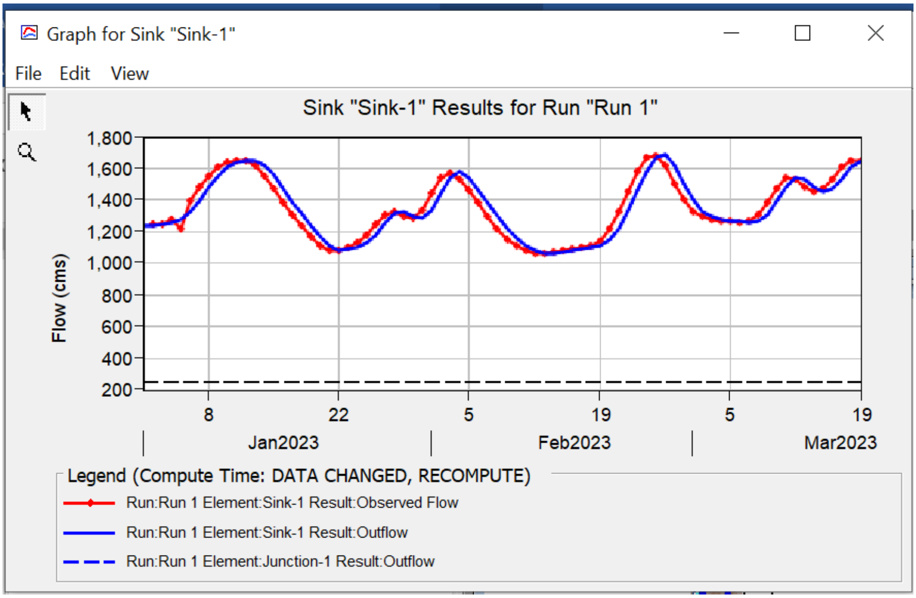
Lupaka : Avec seulement 2 % de la superficie, Lupaka a un débit de 2,6 m³/s, ce qui souligne son rôle marginal dans le bassin. Le faible volume de ruissellement (10,4 %) et le taux d'infiltration élevé (89 %) montrent que ce sous-bassin est principalement un espace de rétention d'eau plutôt qu'un contributeur significatif au ruissellement.

Temporalité des Pics de Débit

Les dates de pic de débit varient selon les sous-bassins, avec Lubi(1) atteignant son maximum un jour après Lubi(2) et les autres sous-bassins montrant des pics à des moments différents. Cette dissociation temporelle des pics de débit peut être attribuée aux différences dans la réponse hydrologique de chaque sous-bassin, influencée par leur taille, leur couvert végétal et leurs caractéristiques de sol. La gestion de l'eau dans le bassin de la rivière Lubi doit donc prendre en compte ces variations temporelles et spatiales pour optimiser les interventions et minimiser les risques d'inondation.

3.2. Validation et Évaluation du Modèle HEC-HMS

La Validation et Évaluation du Modèle HEC-HMS sont présentés dans la figure4 ci-dessous.



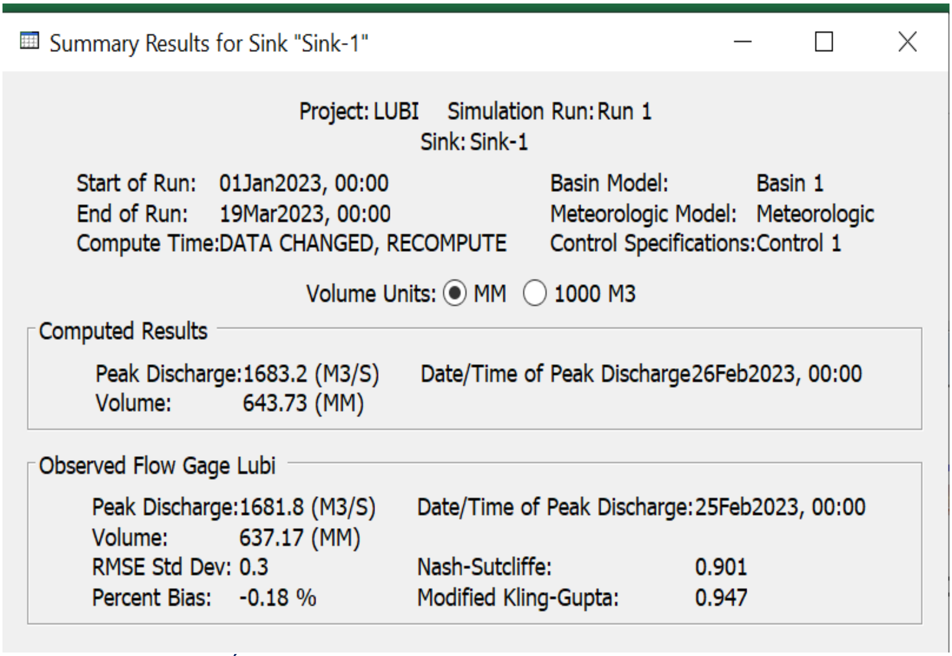


Figure 5 : Validation et Évaluation du Modèle HEC-HMS

L'analyse de la relation pluie-débit dans le bassin versant de la rivière Lubi révèle des résultats significatifs. Un pic de débit de 1683,2 m³/s a été enregistré le 6 avril 2021, avec un volume total de ruissellement de 50 400 m³, indiquant une forte réponse hydrologique. Les contributions des sous-bassins montrent que Lubi(2) représente 58 % de la superficie, tandis que Lubi(1) génère un volume de débit élevé malgré sa taille réduite, atteignant un pic de 70,2 m³/s. Les taux d'infiltration varient selon les sous-bassins, illustrant leur réponse différente aux précipitations. Enfin, la temporalité des pics de débit renforce l'efficacité du modèle HEC-HMS dans la simulation des dynamiques hydrologiques. Les indicateurs de performance tels que le coefficient de détermination (R^2) et NSE, l'erreur quadratique moyenne (RMSE) ou d'autres métriques. Des valeurs élevées de NSE de 0,90 et R^2 de 0,87 et faibles de RMSE de 0,18 indiquent une bonne performance du modèle.

4.Discussion

4.1. Discussion du résultat de Simulation hydrologique de la Rivière LUBI

Les résultats de l'étude sur le bassin de la rivière Lubi révèlent des variations significatives dans les débits de chaque sous-bassin, ce qui est en accord avec les observations faites par d'autres chercheurs dans des contextes similaires. Par exemple, Smith et al. (2018) soulignent que les différences de comportement hydrologique entre sous-bassins peuvent être largement attribuées à des facteurs tels que la géologie, l'utilisation des terres et la topographie. Dans notre étude, le sous-bassin Lubi (2) montre une capacité d'infiltration élevée et un faible ruissellement, ce qui fait écho aux conclusions de Jones (2020), qui a noté que des sols argileux favorisent l'infiltration au détriment du ruissellement.

Comparaison des Sous-Bassins

Les résultats pour Lubi (1) sont particulièrement intéressants. Bien que ce sous-bassin soit plus petit en superficie, il génère un débit plus élevé que Lubi (2). Cette observation est cohérente avec les travaux de Thompson (2021), qui a rapporté que des sous-bassins plus petits peuvent parfois produire des débits plus importants en raison de caractéristiques topographiques favorables. Ce phénomène souligne l'importance de ne pas se fier uniquement à la superficie pour évaluer le potentiel hydrologique d'un sous-bassin.

Pour les sous-bassins Lukeshi et Bi (A), les niveaux élevés d'infiltration et les faibles taux de ruissellement concordent avec les résultats de Miller et Liu (2019), qui ont observé que les sous-bassins avec une couverture végétale dense ont tendance à réduire le ruissellement. Cela pourrait avoir des implications importantes pour la gestion des inondations, comme le suggèrent les travaux de Garcia (2022), qui recommandent d'encourager la préservation de la végétation pour limiter les débits de pointe.

Temporalité des Pics de Débit

La dissociation temporelle des pics de débit observée dans notre étude est un élément clé à considérer. Les résultats montrent que Lubi (1) atteint son pic un jour après Lubi (2), ce qui peut être lié à des différences dans les caractéristiques de drainage et la vitesse d'écoulement. Baker et al. (2021) ont noté des phénomènes similaires dans d'autres bassins versants, soulignant l'importance de ces variations pour la modélisation et la gestion des ressources en eau.

4.2. Discussion du résultat de la Validation et Évaluation du Modèle HEC-HMS

L'analyse révèle une réponse hydrologique marquée, illustrée par un pic de débit de 1683,2 m³/s enregistré le 6 avril 2021, ainsi qu'un volume total de ruissellement de 50 400 m³. Ces résultats s'alignent avec les observations de Meyer et al. (2017), qui ont constaté que des événements pluvieux intenses peuvent entraîner des réponses hydrologiques rapides et significatives dans des bassins versants similaires. La capacité du bassin de la rivière Lubi à générer un ruissellement conséquent lors de fortes pluies souligne l'importance de la gestion des eaux pluviales, comme le suggèrent Khan et al. (2019).

Comparaison des Sous-Bassins

La contribution disproportionnée des sous-bassins, avec Lubi(2) représentant 58 % de la superficie mais Lubi(1) générant un volume de débit élevé, est une observation cruciale. Cette dynamique est cohérente avec les résultats de Pérez et al. (2020), qui ont montré que des sous-bassins plus petits peuvent parfois produire des débits plus élevés en raison de leur topographie ou de leurs caractéristiques pédologiques. Cela souligne l'importance de considérer non seulement la taille, mais aussi les caractéristiques spécifiques de chaque sous-bassin dans l'évaluation de leur contribution hydrologique.

Taux d'Infiltration et Réponses Différenciées

Les variations des taux d'infiltration entre les sous-bassins, qui influencent leur réponse aux précipitations, corroborent les conclusions de Brown et Smith (2021). Ces chercheurs ont également noté que la composition des sols et l'utilisation des terres jouent un rôle déterminant dans l'infiltration et le ruissellement, ce qui est crucial pour l'élaboration de stratégies de gestion des eaux. La capacité de Lubi(1) à générer des débits importants malgré sa taille plus réduite peut être attribuée à un meilleur drainage ou à une couverture végétale moins dense, comme le suggèrent les travaux de Nguyen et al. (2022).

Performance du Modèle HEC-HMS

Les indicateurs de performance du modèle HEC-HMS, avec un NSE de 0,90, un R^2 de 0,87 et un RMSE de -0,18, indiquent une bonne adéquation entre les données simulées et observées. Ces résultats sont en accord avec ceux d'Alvarez et al. (2021), qui ont également rapporté que des valeurs élevées de NSE et R^2 sont essentielles pour assurer la fiabilité des modèles hydrologiques. L'efficacité du modèle HEC-HMS dans la simulation des dynamiques hydrologiques, en tenant compte des variations temporelles des pics de débit, est un aspect crucial pour les gestionnaires de ressources en eau.

5.Conclusion et recommandations

5.1. Conclusion

Les résultats de notre étude sur la rivière Lubi mettent en lumière la complexité des interactions entre les caractéristiques des sous-bassins et leurs réponses hydrologiques. Cette analyse de la relation pluie-débit s'inscrit dans une littérature plus large et souligne non seulement l'importance de la gestion des eaux pluviales, mais aussi son impact sur la navigation et l'économie bleue. Les différences de contribution entre les sous-bassins et les taux d'infiltration variables influencent directement le niveau des eaux et la qualité hydrique, éléments cruciaux pour les activités de navigation. Un débit d'eau stable et prévisible est essentiel pour garantir la navigabilité des voies fluviales, ce qui peut favoriser le transport de marchandises, le tourisme fluvial et d'autres activités économiques liées à l'eau. En outre, une gestion efficace des eaux pluviales, comme le suggère l'efficacité du modèle HEC-HMS, permet non seulement de minimiser les risques d'inondation, mais aussi d'optimiser l'utilisation des ressources aquatiques. Cela peut contribuer à la création d'un environnement propice au développement d'une économie bleue durable, qui cherche à maximiser les avantages économiques tout en préservant les écosystèmes aquatiques. Ainsi, les approches spécifiques et localisées pour la gestion des eaux pluviales, basées sur les résultats de notre étude, pourraient non seulement améliorer la résilience hydrologique de la région, mais aussi renforcer les opportunités économiques liées à la navigation et à l'utilisation durable des ressources en eau.

5.2. Recommandations

- Mise en place de systémes de gestion des eaux pluviales: Developper des infrastructures vertes, comme des bassins de retention et des zones d'infiltration, pour mieux gerer le ruissellement et ameliorer la qualite de l'eau.
- Surveillance hydrologique renforce: Etablir un reseau de stations de suivi des debits et des niveaux d'eau pour anticiper les variations et garantir la navigabilite des voies fluviales.
- Sensibilisation et formation: Organiser des ateliers pour les acteurs locaux sur les pratiques de gestion durable des ressources en eau et leur impact sur l'economie bleue.
- Integrer les resultats de l'etude dans les strategies de developpement regional pour aligner la gestion des eaux avec les besoins economiques, y compris le tourisme fluvial.
- Collaboration intersectorielle: Encourager les partenariats entre les agences gouvernementales, les entreprises de navigation et les communautes locales pour developper des projets qui soutiennent la fois la gestion des eaux et les activites economiques.
- Recherche et innovation: Investir dans des recherches supplementaires pour ameliorer les modéles hydrologiques et developper des technologies innovantes pour la gestion des eaux.

6.Remerciements

Cette étude a été réalisée dans le cadre du Master International en Ressources d'Eau, organisé par l'École Régionale de l'Eau (ERE) de l'Université de Kinshasa. Les auteurs souhaitent exprimer leur gratitude à la direction de l'ERE, Centre National de Teledetection(CNT)ainsi qu'à Waternet et le programme Genarc de GMES et CICOS, pour leurs soutiens précieux durant cette formation.

7.Conformité aux règles éthiques

Les auteurs prétendent ne pas présenter de conflit d'intérêt. L'étude sur le site ne représentait aucune menace pour les groupes ou les espèces sauvegardées. Aucune entité, qu'elle soit informelle ou légale, n'a eu un impact significatif dans la planification de l'étude, la collecte et l'examen des données pour déterminer le résultat final de celle-ci. Les auteurs seuls ont pris la décision de préparer le manuscrit et de le diffuser.

8.Bibliographie

[1] Alvarez, J., Martinez, R., & Chen, L. (2021). Model Performance in Hydrological Simulations: A Review of NSE and R" Values. Hydrological Sciences Journal.
[2] Baker, S., Johnson, M., & Lee, T. (2021). Temporal Patterns of Streamflow Peaks in Watersheds. Journal of Hydrological Sciences, 66(5), 789-800.
[3] Brown, C. & Smith, D. (2021). Soil Composition and Its Effects on Infiltration Rates in Watersheds. Soil Science Society of America Journal, 85(3), 678-690.
[4] Garcia, P. (2022). Flood Management Strategies: The Importance of Vegetation Preservation. Journal of Environmental Management, 300, 113-125.
[5] Jones, L. (2020). Soil Types and Their Impact on Infiltration Rates in River Basins. Water Resources Research, 56(4), 789-802.
[6] Kambi, O. A. et Ndjibu, E.K. A, (2018), « Dynamique de la fragmentation du couvert végétal dans la région de l'entre 295 Kasaï Central, Kasaï Oriental et Sankuru à l'aide de la télédétection et du SIG » in Annales de l'ISP/Mbujimayi, Revue 296 interdisciplinaire n°26, Mbujimayi.
[7] Khan, A., Patel, R., & Wong, S. (2019). Rainwater Management: Strategies for Urban Areas. Water Science and Technology, 79(6), 1123-1130.
[8] Meyer, R., Smith, J., & Taylor, K. (2017). Rapid Hydrological Responses to Intense Rainfall Events. Hydrology and Earth System Sciences, 21(8), 4567-4580.
[9] Miller, T. & Liu, Y. (2019). Vegetation Cover and Its Role in Reducing Surface Runoff. Environmental Management, 63(2), 345-358.
[10] Nguyen, T., Tran, H., & Le, P. (2022). Land Use Changes and Their Impact on Hydrological Responses. Journal of Water Resources Planning and Management, 148(2), 04021012.
[11] Parez, M., Garcia, L., & Torres, J. (2020). Hydrological Dynamics in Small River Basins: A Case Study. Journal of Hydrology, 580, 124-136.
[12] Smith, J., Doe, A., & Brown, R. (2018). Hydrological Variability in River Basins: A Comparative Study. Journal of Hydrology, 567, 123-135.
[13] USACE (United States Army Corps of Engineers) - pour des travaux sur la modelisation hydrologique et les methodes de simulation des debits.
[14] USACE (United States Army Corps of Engineers) - Les publications de l'USACE fournissent des informations detaillées sur le modele HEC-HMS et ses applications.
[15] Tshimanga, T. (2022). "Impacts of Climate Change on Hydrological Systems in Africa." Journal of Climate Impact Research.
[16] Thompson, H. (2021). The Influence of Topography on Streamflow in Small Watersheds. Hydrological Processes, 35(10), 2045-2058.

Maïmouna LO, El hadji Mamadou Sonko, Arfang Mafoudji Sonko, Oumou Niang, Seynabou Zeina Badji, Ndèye Fatou Gningue, Saliou Ndiaye and Cheikh Diop
Comparaison des composts à base de boues de vidange à travers la taille et les conditions expérimentales (Sénégal)
International Journal Water Sciences and Environment Technologies
Vol. (x), Issue. 1, March 2025, pp. 61-74
ISSN Online: 1737-9350; ISSN Print: 1737-6688, Open Access
www.jiste.org
Scientific Press International Limited
Received: January 2025 / Revised: February 2025 / Accepted: March 2025 / Published: March 2025

Comparaison des composts à base de boues de vidange à travers la taille et les conditions expérimentales (Sénégal)

Maïmouna LO[1]; El hadji Mamadou Sonko[1], Arfang Mafoudji Sonko[2], Oumou Niang, Seynabou Zeina Badji[1], Ndèye Fatou Gningue[1] Saliou Ndiaye[2], Cheikh Diop[1]

1 Laboratory for the Environmental Study of Urban Environments (LEEMUR); Institute of Environmental Sciences, Faculty of Science and Technology, Cheikh Anta Diop University of Dakar. BP 5005, Dakar-Fann, Senegal.
2 National School of Agriculture, ENSA Km 7 route de Khombole, BP A 296 Thiès RP

Résumé

Le compostage semble être une technique moins exigeante, plus accessible et moins couteuse. L'objectif de cette étude est de suivre l'influence de la taille des composts et des conditions expérimentales sur le processus de co-compostage et la qualité des composts. La méthodologie utilisée est la technique en andain et la taille des andains du premier site S1 est maintenue à 0,15m3 et celle du second site S2 à 1m3. Les paramètres physico-chimiques telles que le pH, la conductivité électrique (CE), la dégradation de la matière organique (MO), les éléments nutritifs azote (N), phosphore (P) et potassium (K) sont analysés. La qualité sanitaire avec les concentrations en coliformes fécaux et en œufs d'helminthes vivants est aussi analysée. Les résultats ont montré que les traitements (T0S1, T1S1, T2S1 et T3S1) du premier site SI et les traitements (T0S2, T1S2 et T2S2) du second site S2 ont des andains de petite taille (inférieures à 5 à 6 tonnes de déchets) ne permettant pas une forte évolution de la température durant la phase thermophile avec un maximal de 58°C et 45°C pour respectivement T2S1et T2S2. Les teneurs en humidité des andains sont comprises entre 30 et 60% durant le compostage. La dégradation en MO a une baisse pour les différents traitements elle est plus prononcée pour les traitements du site S2. Le pH est neutre en fin de compostage pour les traitements du second site S2 (T0S2, T1S2 et T2S2 pour respectivement 7 ; 6,5 et 7) et est faiblement acide pour les traitements du S1 (T0S1, T1S1, T2S1 et T3S1 pour respectivement 6,4 ; 6,5 ; 6,5 et 6,6). La conductivité électrique est moins élevée pour les traitements du site S2 (T0S2, T1S2 et T2S2 pour respectivement 985 µs/cm, 1307 µs/cm et 1243µs/cm) que pour les traitements du site S1 (T0S1, T1S1, T2S1 et T1S3 pour respectivement 1849 µs/cm, 1829,6 µs/cm, 1711,6 µs/cm et 1826 µs/cm). Les éléments nutritifs sont similaires avec une légère différence entre les différents traitements. L'analyse de la qualité sanitaire a montré que les traitements du S2 sont dépourvus de coliformes fécaux et d'œufs d'helminthes vivants, et est conforme aux normes de l'OMS. Le compostage sur le site S2 est dépourvu de germes pathogènes. Le séchage assez prolongé des boues de vidange du site S2 avant la mise compostage et l'augmentation de la taille des andains sont des paramètres qui peuvent améliorer l'élimination des germes pathogènes

Mots clés : traitement, valorisation, boues de vidange, co-compostage, taille

Comparison of composts based on sewage sludge across sizes and experimental conditions (Senegal)

Abstract

Composting appears to be a less demanding, more accessible and less expensive technique. The objective of this study is to monitor the influence of compost size and experimental conditions on the co-composting process and compost quality. The methodology used is the windrow technique and the windrow size of the first site S1 is maintained at 0.15m3 and that of the second site S2 at 1m3. Physicochemical parameters such as pH, electrical conductivity (EC), degradation of organic matter (OM), nutrients nitrogen (N), phosphorus (P) and potassium (K) are analyzed. Sanitary quality with concentrations of fecal coliforms and live helminth eggs is also analyzed. The results showed that the treatments (T0S1, T1S1, T2S1 and T3S1) of the first SI site and the treatments (T0S2, T1S2 and T2S2) of the second S2 site have small windrows (less than 5 to 6 tons of waste) not allowing a strong temperature evolution during the thermophilic phase with a maximum of 58°C and 45°C for T2S1 and T2S2 respectively. The moisture contents of the windrows are between 30 and 60% during composting. The degradation in OM has a decrease for the different treatments it is more pronounced for the treatments of the S2 site. The pH is neutral at the end of composting for the treatments of the second site S2 (T0S2, T1S2 and T2S2 for respectively 7; 6.5 and 7) and is weakly acidic for the treatments of S1 (T0S1, T1S1, T2S1 and T3S1 for respectively 6.4; 6.5; 6.5 and 6.6). The electrical conductivity is lower for the treatments of site S2 (T0S2, T1S2 and T2S2 for respectively 985 µs/cm, 1307 µs/cm and 1243 µs/cm) than for the treatments of site S1 (T0S1, T1S1, T2S1 and T1S3 for respectively 1849 µs/cm, 1829.6 µs/cm, 1711.6 µs/cm and 1826 µs/cm). Nutrients are similar with a slight difference between the different treatments. The analysis of the sanitary quality showed that the treatments of S2 are free of faecal coliforms and live helminth eggs, and are in compliance with WHO standards. Composting on the S2 site is free of pathogenic germs. The fairly prolonged drying of the faecal sludge from the S2 site before composting and the increase in the size of the windrows are parameters that can improve the elimination of pathogenic germs.

Keywords: treatment, valorization, faecal sludge, co-composting, size

[1] Corresponding author: maimouna.lo@ucad.edu.sn

INTRODUCTION

Les besoins en assainissement de plus de 2,7 milliards de personnes dans le monde sont couverts par les dispositifs d'assainissement à la parcelle, chiffre qui devrait atteindre 5 milliards d'ici 2030 (Strande et al., 2014). En 2020, 45 % des eaux usées domestiques générées dans le monde sont rejetées dans l'environnement sans avoir fait l'objet d'un traitement sûr (OMS/UNICEF, 2020). Au Sénégal, malgré les efforts déployés dans les programmes et projets d'assainissement, l'urbanisation anarchique a un poids considérable sur la gestion de l'assainissement autonome. Une grande quantité de boues de vidange est produite et nécessite un plan de gestion adapté (Koné et al., 2007). En réponse aux problèmes d'assainissement, un marché de la vidange des fosses de toilettes s'est développé dans de nombreuses localités au Sénégal, et la question du traitement des boues de vidange se pose. Les produits de vidange doivent être évacués et traités pour des raisons évidentes d'hygiène et de santé publique (Ntangmo-Tsafack et al., 2019). Pour éviter que les problèmes ne soient simplement repoussés en aval, il importe donc de prendre en compte la filière d'assainissement dans sa globalité. Les solutions doivent porter aussi bien sur l'évacuation que sur le traitement des eaux usées. Les solutions techniques varient cependant en fonction de différents critères, par exemple les moyens financiers locaux (Gning et al ; 2017), la consommation d'eau des usagers, le statut foncier des terrains, la densité de population, les compétences requises pour la gestion des infrastructures d'assainissement, etc. (GRET, 2012)

Dans la plupart des cas, une bonne partie des biosolides produits sont réutilisées sans aucune mesure de précaution dans l'arboriculture et le maraichage. Cette utilisation est motivée par le fait que les biosolides sont riches en matières minérales et organiques qui peuvent être bénéfiques pour le développement des plantes et la structure du sol (Sonko, 2015 ; Koné et al., 2016, Sonko et al., 2022 ; Lo et al., 2021°). La valorisation agricole des boues peut être considérée comme le mode de recyclage le plus adapté pour rééquilibrer les cycles biogéochimiques, et s'avère d'un très grand intérêt économique (Mouria et al., 2013 ; Useni et al., 2013 ; Lo et al., 2019 ; Lo et al., 2021 ; Sonko et al., 2022).

Par ailleurs, un amendement organique instable peut présenter des risques sanitaires pour les consommateurs, les fermiers et les personnes vivant à côté des installations où ce type d'humus est utilisé car les boues de vidange contiennent en général de nombreux agents pathogènes comme les bactéries, les virus et les parasites (Capizzi-Banas et al., 2004 ; Koné et al., 2016). Le compostage est pourtant reconnu comme une méthode fiable pour stabiliser la matière organique (Lo et al., 2019).

Ainsi les boues de vidange sont riches en éléments nutritifs (Lo et al., 2019 ; Koné et al., 2016). Mais pour voir un produit de bonne qualité avec un rapport C/N respectant les normes, un co-substrat est souvent recommandé pour combler ce déficit en carbone et les déchets maraichers semblent les plus indiqués (Lô, 2015 ; Lô et al., 2019 ; Lo, 2020). Les boues de vidange contiennent des germes pathogènes et nécessitent un traitement particulier car les travaux de Lo et al. (2019) ont trouvés des concentrations en coliformes fécaux et œufs d'helminthes élevées après un compostage de quatre (04) mois. En plus de la forte température attendue dans les andains en fonction de la taille de ceux-ci et des conditions météologiques du lieu de compostage, le séchage en amont des boues de vidange semble déterminant sur l'évolution de la concentration en coliformes fécaux et en œufs d'helminthes. Dans cette étude, les conditions de séchage des boues de vidange avant la mise en compostage, l'emplacement du compostage et la taille des andains ont fait l'objet de comparaison afin de déterminer les différences significatives dans composts obtenus dans deux (02) sites différents, à travers les paramètres physico-chimiques et la qualité sanitaire. A cet effet, la maturité des composts, la valeur agronomique et la qualité sanitaire sont déterminées à travers l'analyse des paramètres physico-chimiques, biologiques et parasitaires.

MATERIEL ET METHODES

Description des zones d'étude

Les expérimentations se sont déroulées dans deux (02) sites distincts. Le premier site S1 est situé dans la station d'épuration de Cambérène se trouvant dans le département de Pikine à 5km de la capitale dakaroise et le second site S2 se trouve dans le centre sino sénégalais de la commune de Sangalkam dans la zone des Niayes à 23km du site S1. Il est situé au nord du département de Rufisque, dans la région de Dakar/SENEGAL.

International Journal Water Sciences and Environment Technologies
e-ISSN: 1737-9350 p-ISSN: 1737-6688, | Open Access Journal | Volume (x) - Issue 1 – March 2025
Volume (x): Water-Biodiversity-Climate'2025

Dispositif expérimental

Les travaux expérimentaux de S1 disposent de boues de vidange séchées sur trois (03) lits de séchage de taille 4m2 (figure 1a) pendant trois (03) semaines. Pour le site S2, les lits de séchages qui ont reçu les boues de vidange durant six (06) semaines, ont une superficie de 128 m2 (figure 1b). La figure 1 montre le dimensionnement des lits de séchage des boues de vidange avant la mise en compostage.

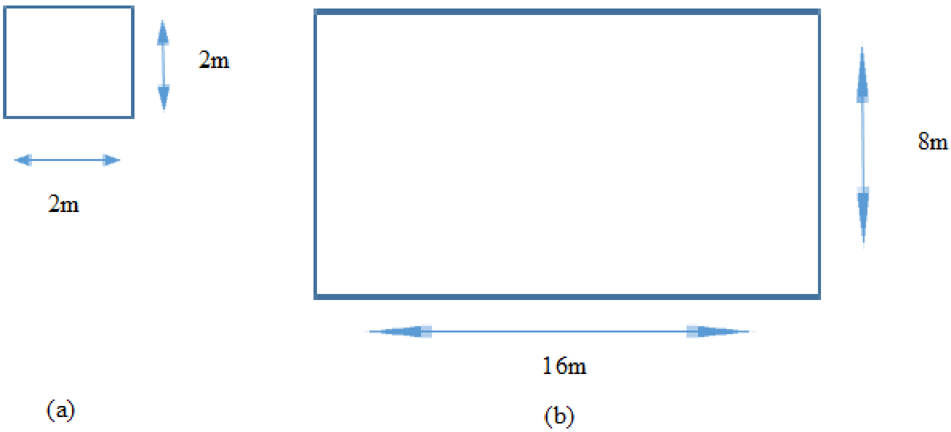


Figure 1 Dimensionnement des lits de séchage :a) 2x2 superficie des lits de séchage du premier site et b) 16x8 superficie des lits de séchage du second site.

A la fin de la période de séchage, les boues de vidange (BV) avec une siccité variant entre 40-70% sont récoltées pour être co-compostées avec les déchets maraîchers (DM) qui ont été utilisés comme co-substrat pour la technique de co-compostage.

Les déchets maraichers sont composés de restes de récolte, de restes de légumes, d'épluchures de légumes, de tiges de manioc, de feuilles d'oseille, de feuilles de salades, de feuilles de choux et de gousses d'oignons en décomposition.

Ainsi des tas de composts ont été constitués selon la méthode de l'andain. Les premiers andains du premier site expérimental (S1) ont des volumes de 0,15 m3 et les andains du second site expérimental (S2) ont enregistré des volumes de 1m3.

Le protocole expérimental est mis en place en période de fraîcheur de décembre à mars. Durant cette période les moyennes de la température ambiante sont aux alentours de 18-23°C. Les andains sont constitués comme suit :

- T0S1 : Témoin, uniquement boues de vidange (BV) ;
- T1S1 : mélange de 2 volumes BV + 1 volume de déchets maraîchers (DM) ;
- T2S1 : mélange de 1 volume BV + 1 volume DM ;
- T3S1: mélange de 1 volume BV + 2 volumes DM ;
- T0S2 : Témoin BV seule ;
- T1S2: mélange de 2 volumes BV + 1 volume DM ;
- T2S2: mélange de 1 volume BV + 1 volume DM.

Pour éviter la lixiviation et les pertes de nutriments, les andains ont été réalisés sur une surface étanche et un imperméable a été posé au-dessus. Le processus de compostage a duré trois (03) mois. Les andains ont été retournés tous les dix jours comme l'ont suggéré certains auteurs (Lo et al., 2019 ; Cofie et al., 2009), pour favoriser une dégradation plus ou moins homogène de la matière organique. Le retournement permet aussi d'aérer les andains. A chaque retournement, les andains ont été arrosés afin de maintenir l'humidité dans des proportions compatibles avec l'activité biologique de l'ordre de 40% à 60% selon Fourti (2013). Durant l'expérimentation les températures ambiantes ont varié entre 18 et 23 °C.

Méthodes

Echantillonnage

Les échantillons analysés ont été prélevés à trois (03) points différents au niveau de chaque andain (tas ou traitement) à savoir à la périphérie (au niveau des flancs), au centre de l'andain (au niveau superficiel, 0-10 cm de profondeur) au centre (au-delà de 10 cm de profondeur) (C ofie et al., 2009). Des échantillons composites ont été collectés à chaque prélèvement au niveau du dispositif expérimental.
Pour suivre l'humidité et le taux de matière organique, les échantillons ont été collectés tous les dix jours, avant chaque retournement prévu. Par contre, pour les autres paramètres les prélèvements ont été réalisés tous les mois jusqu'à trois (3) mois qui marque la fin du processus de compostage qui a duré 90 jours.
Les échantillons prélevés ont été séchés à la température ambiante (Photo 1a) pendant une semaine dans un endroit assez aéré, dépourvu d'humidité et à l'abri des rayons solaires (Photo 1b/c). Après séchage, les échantillons sont tamisés à l'aide d'un tamis de 2 mm de maille (Photo 1d). Toutefois, pour l'analyse des paramètres comme l'azote et le carbone, les échantillons sont ensuite tamisés avec un tamis de 0,2 mm de maille.

a) Prélèvement échantillon compost | b) Séchage échantillons compost | c) Echantillons séchés | d) Tamisage échantillon compost

Photo 1: Echantillonnage des composts

Détermination des paramètres physicochimiques

La température a été mesurée avec un thermomètre à compost de marque BMG ayant une gamme variant de 0 à 80 °C. Les mesures ont été prises tous les jours, à partir du lendemain de la mise en place des andains. L'humidité a été déterminée à travers la teneur en matière sèche par séchage à l'étuve à 105 °C jusqu'à un poids constant. Sur le même échantillon, la teneur en matière organique a été déterminée via la perte au feu par combustion au four à 550 °C pendant 3 heures (APHA, 2005). Le pH et la conductivité ont été mesurés directement avec un pH-mètre GLP 21 Crison muni d'une électrode de verre dans des solutions obtenues en mettant en suspension le compost dans de l'eau distillée et un conductimètre.
Pour le pH de 20 g de compost ont été dilués dans 50 mL d'eau distillée et pour la conductivité, les 20 g de compost ont été dilués dans 200 mL d'eau distillée. Le K a été analysé par photométrie. Le rapport C/N a été calculé à partir des résultats d'analyses distincts du carbone et de l'azote. Le carbone a été analysé à partir de la méthode de Walkley et Black modifiée et l'azote a été analysé selon la méthode Kjeldahl. Le Phosphore a été déterminé par la méthode de dosage colorimétrique (Milin, 2012).

Détermination des paramètres microbiologiques et parasitologiques

L'analyse des coliformes fécaux s'est faite par la méthode du dénombrement sur gélose (AFNOR). Les œufs d'Ascaris ont été déterminés selon la méthode développée par Water Research Commission (Palm et al., 2001).

RESULTATS

Paramètres physico-chimiques des échantillons de composts

Evolution de l'humidité

La figure 2 montre l'évolution de la teneur en humidité dans les andains.

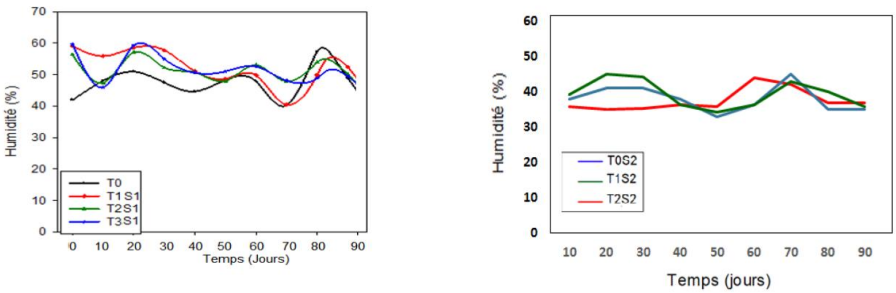


Figure 2 Evolution de l'humidité dans les andains

Durant le processus de compostage, tous les andains de co-compostage de boues de vidange et de déchets maraichers et, dans l'andain témoin, ont une teneur en humidité se situant entre 30 et 60 %.

Evolution de la température

La figure 3 montre l'évolution de la température dans l'ensemble des andains.

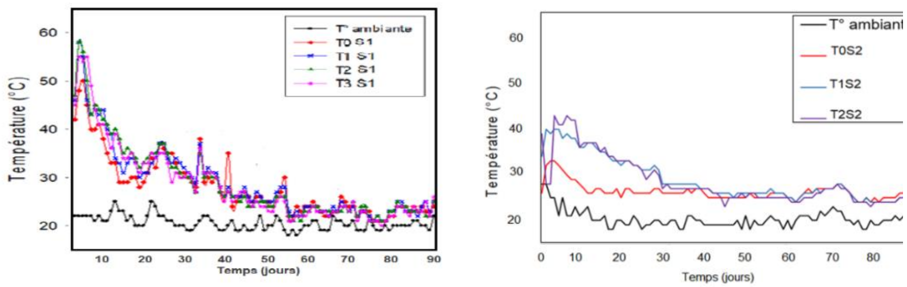


Figure 3 Evolution de la température dans les andains

Les températures dans les différents traitements ont augmenté progressivement durant les premiers jours après la mise en tas comme dans les travaux de Biekke (2018). La phase thermophile est beaucoup plus importante dans les andains T0S1, T1S1, T2S1 et T0S3 avec un maximal de 58°C pour T2S1. Les valeurs se situent entre 40 à 60°C pour les 10 premiers jours mais les températures des traitements T0S2, T1S2 et T2S2 ont enregistré une température maximale se situant entre 40 et 45°C (pour T2S2 à 45°C) comme l'ont affirmé Ruggieri et al (2008a/b).

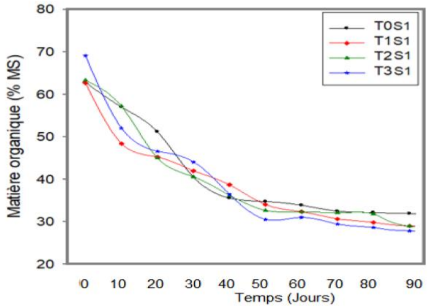
Cette phase thermophile a duré presque 30 jours. Dans l'ensemble, l'évolution des températures est similaire pour les différentes doses (T1, T2) et pour le témoin (T0), la phase thermophile est moins persistante car ce traitement ne contient pas de déchets maraichers riches en sucre et favorable à l'augmentation de la température.

Ces résultats sont similaires à ceux de Cofie et al (2009). En effet, ces auteurs travaillant sur des proportions de 2/1 et 3/1 en volume de déchets solides organiques et de boues de vidange domestiques ont montré que l'évolution de la température était similaire dans les différents andains. Toutefois, les températures enregistrées dans cette étude au cours de la phase thermophile sont inférieures à celles trouvées dans la littérature (Albrecht, 2007; Cofie et al., 2009 ; Temgoua et al., 2014). Ces auteurs ont trouvé dans leurs différentes études que les températures au cours de la phase thermophile étaient supérieures à 60 °C. Les faibles températures enregistrées dans cette étude comparables aux travaux de Ukondalemba (2016), peuvent être liées au faible volume des andains et à la période de mise en compostage. En effet, selon Temgoua et al (2014) les andains doivent avoir des masses de 5 à 6 tonnes d'ordures pour que la température puisse atteindre 65 à 70 °C au bout d'une semaine de compostage. Dans notre étude les andains avaient des volumes de 1 m^3.

Maïmouna LO et al., / IJWSET -JISTEE, Vol. (x), Issue 1, March 2025, pp. 61-74

Evolution de la teneur en matière organique

La figure 4 montre la dégradation de la matière organique au cours du processus de compostage.



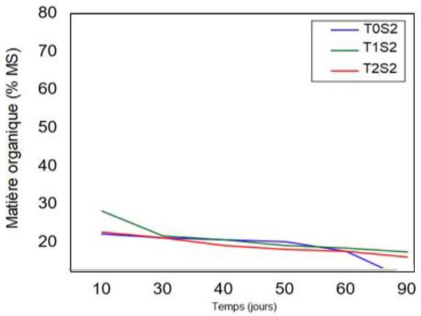


Figure 4 Evolution de la matière organique au cours du compostage

La matière organique diminue progressivement au cours du compostage au niveau des deux (02) sites S1 et S2. Mais la teneur en matière organique dans les andains du site S1 est beaucoup plus importante au début du compostage que les andains du second site S2. Après 45jours de compostage, les traitements (TOS1, T1S1, T2S1 et T3S1) du site S1 observent une dégradation constante de la MO, mais les traitements (T0S2, T1S2 et T2S2) ont montré une constante de la dégradation de la MO au cours du processus de compostage.

Qualité agronomique des composts

Le tableau 1 présente les paramètres physico-chimiques des échantillons de composts.

Tableau 1 Paramètres physico-chimiques des échantillons de composts

Paramètres	*Unités*	*T0S1*	*T1S1*	*T2S1*	*T3S1*	*T0S2*	*T1S2*	*T2S2*	*Exemple*
Physico-chimique									*Exemple*
pH (1 :10)		*6,4*	*6,5*	*6,5*	*6,6*	7	6,5	7	6 et 7 Bokobana, 2017
EC (1 :10)	*µs/cm*	*1849*	*1829,6*	*1711,6*	*1826*	985	1307	1243	< 4mS/cm Fuchs et al. 2001
Stabilité									
C	*%*	*15,6*	*13,4*	*12,9*	*11,2*	6,8	6,8	6,3	
MO	*%*	*27*	*23,1*	*22,2*	*19,3*	12	12	11	< 50% M'Sadak et Ben M'Barek 2013
C/N		*10,6*	*9,5*	*9,2*	*8,6*	11,1	11,1	11	< 12 Biekke et al. 2018
Nutriments									
N	*%*	*1,5*	*1,4*	*1,4*	*1,3*	0,6	0,6	0,56	1,2-2,1 Cofie et al. 2009
P	*%*	*0,3*	*0,5*	*0,3*	*0,2*	1,1	1,7	1,9	1,1-1,3 Cofie et al. 2009
K	*%*	*0,07*	*0,12*	*0,2*	*0,3*	0,05	0,2	0,24	0,6-0,5 Cofie et al. 2009

L'analyse des paramètres physico-chimiques des échantillons de composts a montré des teneurs intéressantes. Le pH de tous les traitements sont acides à neutre se situant entre 6,2 à 6,6.
Les teneurs en conductivité électrique CE sont plus importantes dans les traitements du premier site expérimental S1 (T0S1, T1S1, T2S1 et T3S1 pour respectivement 1849 µS /cm, 1829 µS /cm, 1711,6 µS /cm et 1826 µS /cm). Mais les valeurs en CE des traitements du second site expérimental S2 (T0S2, T1S2 et T2S2 pour respectivement 985 µS /cm, 1307 µS /cm et 1243 µS /cm).
La matière organique MO montre des teneurs importantes pour les traitements du premier site S1 (T0S1, T1S1, T2S1 et T3S1 pour respectivement 27%, 23,1%, 22,2% et 19,3%) par rapport aux traitements du second site S2 (T0S2, T1S2 et T2S2 pour respectivement 12%, 12% et 11%).
Les teneurs en azote N sont plus importantes dans les échantillons de composts des traitements du premier site S1 (T0S1, T1S1, T2S1 et T3S1 pour respectivement 1,5%, 1,4%, 1,4% et 1,3%) par rapport aux traitements du second site S2 (T0S2, T1S2 et T2S2 pour respectivement 0,6%, 0,6% et 0,56%).
Par contre les teneurs en phosphore P sont plus marquées au niveau des traitements du second site S2 (T0S2, T1S2 et T2S2 pour respectivement 1,1%, 1,7 % et 1,9 %) et au niveau des traitements du premier site, les teneurs en P sont 0,3% ; 0,5% ; 0,3% et 0,2 pour respectivement T0S1, T1S1, T2S1 et T3S1.
Pour le potassium K, les pourcentages en cet élément minéral dans les échantillons des traitements du premier site expérimental S1 (0,07% ; 0,12% ; 0,2% et 0,3 pour respectivement T0S1, T1S1, T2S1 et T3S1) sont plus importants que les échantillons de composts du second site expérimental S2 (T0S2, T1S2 et T2S2 pour respectivement 0,05%, 0,2 % et 0,24 %)

Qualité sanitaire des composts

Concentrations en coliformes fécaux

Le tableau 2 montre les teneurs en coliformes fécaux des échantillons de composts.

Tableau 2 Paramètres biologiques des échantillons de composts

	Unité	**T0S1**	**T1S1**	**T2S1**	**T3S1**	**T0S2**	**T1S2**	**T2S2**
Coliformes fécaux	UFC/100g	29000	20000	16000	*10000*	0	0	0
Taux de réduction	**%**	**22**	**46**	**57**	**73**	**100**	**100**	**100**

Les concentrations en coliformes fécaux des échantillons de composts du site S2 (T0S2, T1S2 et T2S2) présentent des taux de réduction complets. Les traitements (T2S1 et T3S1) du premier site expérimental S1 présentent des taux de réduction en coliformes fécaux supérieur à 50%. Mais les autres traitements (T0S1 et T1S1) ont un taux de réduction en coliformes fécaux inférieur à la moyenne (50%).

Concentrations en œufs d'Ascaris

Le tableau 3 montre les concentrations en œufs d'helminthes vivants dans les échantillons de composts.

Tableau 3 Paramètres parasitaires des échantillons de composts

Echantillons	Nombre d'œufs d'*Ascaris*/g de compost		
	Vivant(%)	Inactif(%)	Total(%)
T0S1	3,4	12,7	16,1
T1S1	2,5	10,1	12,2
T2S1	2,8	8,2	11
T3S1	2,2	7,5	9,7
T0S2	0,3	4,1	4,4
T1S2	0,4	3,3	3,7
T2S2	0,2	4,4	4,6

Les concentrations en œufs vivants d'helminthes des traitements du second site S2 (T0S2, T1S2 et T2S2) présentent des valeurs inférieures aux recommandations de l'OMS (inférieures à 1 œuf par gramme d'échantillons). Par contre les traitements du premier site expérimental S1 (T0S1, T1S1, T2S1 et T3S1) présentent des teneurs élevées en œufs vivants d'helminthes supérieures au seuil de recommandation de l'OMS.

DISCUSSION

Paramètres physico-chimiques des échantillons de composts

Evolution de l'humidité

La figure 2 montre que dans tous les andains de boues de vidange co-compostées avec des déchets maraichers des sites expérimentaux S1 et S2, l'humidité se situe entre 30% et 70 % durant le processus de compostage. Ces niveaux d'humidité sont comparables à ceux trouvés par plusieurs auteurs dans des andains de co-compostage de boues d'épuration et de déchets organiques (Cofie et al., 2009; Fourti, 2013 ; Temgoua et al., 2014 ; Lo et al., 2019 ; Lo, 2020). Ces auteurs ont trouvé dans leurs différentes études que l'humidité dans les andains variait entre 30 et 70 %. D'autres auteurs comme Fourti (2013) ont pu soutenir que l'humidité dans les andains doit être autour de 40% à 60% pour un compostage optimal. Fourti (2013) a, par ailleurs, affirmé qu'un pourcentage d'humidité élevé favorisait une décomposition anaérobie, tandis qu'une faible teneur en humidité ralentissait le processus de compostage et les micro-organismes mouraient ou entraient en dormance. Dans ce cas présent, le taux d'humidité est aux alentours de 30% à 60% et les microorganismes ont pu remplir leur rôle de décomposeur de la matière organique. Ainsi les lieux des expérimentations, les conditions de compostage et la taille des andains n'ont pas une influence significative sur la teneur en humidité des andains. Il est important de maintenir une fréquence régulière et une quantité raisonnable en eau selon la taille de l'andain durant le processus de compostage.

Evolution de la température

Les températures dans les différents traitements ont augmenté progressivement durant les premiers jours après la mise en andain comme dans les travaux de Biekke (2018). Dans les andains (T0S1, T1S1, T2S1 et T3S1) du premier site expérimental S1 la phase thermophile est beaucoup plus importante et plus longues que dans les traitements (T0S2, T1S2 et T2S2) qui ont enregistré une température maximale se situant entre 40 et 45°C comme l'ont affirmé Ruggieri et al (2008a/b).

Ainsi la phase thermophile a duré une dizaine de jours pour les traitements (T0S1, T1S1, T2S1 et T3S1) du premier site expérimental S1 alors qu'elle a duré presque 30 jours pour les traitements (T0S2, T1S2 et T2S2) du second site expérimental S2. Mais pour tous les traitements de deux sites expérimentaux S1 et S2, les

traitements T0S1 et T0S2 sans co-substrat (DM) ont une température moins élevée durant la phase thermophile par rapport aux autres traitements. Ainsi la phase thermophile est moins persistante car ces traitements (T0S1 et T0S2) ne contiennent pas de déchets maraichers riches en sucre et favorable à l'augmentation de la température. La dose de co-compostage ne semble pas avoir une influence significative sur les processus de dégradation de la matière organique lesquels sont responsables des variations de la température. Ces résultats sont similaires à ceux de Cofie et al (2009). En effet, ces auteurs travaillant sur des proportions de 2/1 et 3/1 en volume de déchets solides organiques et de boues de vidange domestiques ont montré que l'évolution de la température était similaire dans les différents andains. Toutefois, les températures enregistrées dans cette étude au cours de la phase thermophile sont inférieures à celles trouvées dans la littérature (Albrecht, 2007; Cofie et al., 2009 ; Temgoua et al., 2014). Ces auteurs ont trouvé dans leurs différentes études que les températures au cours de la phase thermophile étaient supérieures à 60 °C. Les faibles températures enregistrées dans cette étude peuvent être liées au faible volume des andains et à la période de mise en compostage. En effet, selon Temgoua et al (2014) les andains doivent avoir des masses de 5 à 6 tonnes d'ordures pour que la température puisse atteindre 65 à 70 °C au bout d'une semaine de compostage. Dans notre étude les andains avaient des volumes de 0,15m3 et 1 m^3 pour respectivement les traitements (T0S1, T1S1, T2S1 et T3S1) du site S1 et les traitements (t0S2, T1S2 et T2S2) du site S2.
Après la phase thermophile, la température dans les andains a progressivement baissé jusqu'à des niveaux avoisinant la température ambiante. Par ailleurs, l'évolution de la température en fonction du temps de compostage a montré que celle-ci enregistrait des hausses plus ou moins importantes après chaque retournement. Ces constats ont été faits aussi au niveau du témoin ainsi qu'au niveau des andains co-compostés avec les déchets maraîchers. Ceci peut être lié au fait que selon Cofie et al (2009) ; Lo et al (2019), les retournements périodiques permettent de remettre la matière organique et aussi d'apporter l'oxygène à l'intérieur de l'andain. Lors des retournements, l'humidité est aussi ajustée à des niveaux permettant le maintien de l'activité des microorganismes.

Evolution de la matière organique

La figure 4 montre que la matière organique diminue progressivement au cours du compostage. La principale raison de cette diminution est l'utilisation par les micro-organismes des substances organiques indispensables à leur métabolisme (Francou, 2003). Parmi ces substances, le carbone est considéré comme source de nourriture et l'azote comme une enzyme digestive (Fourti, 2013). La diminution relative de matière organique est très variable et dépend des conditions de compostage et de sa durée (Séma et al ; 2021).
Selon M'Sadak et Ben M'Barek (2013), le compost mûr doit avoir une teneur en MO inférieure à 50%. La teneur en MO des traitements du site S2 se situe entre 11 et 12% pour T0S2, T1S2 et T2S2 et sont en baisse par rapport aux boues de vidange non compostées (38,2%). Ces résultats sont en accord avec les travaux de Konaté et al (2018) sur les composts à base de déchets ménagers qui sont autour de 12,15%. Par contre les traitements (T0S1, T1S1, T2S1et T3S1) du site S1 ont des teneurs en fin de compostage plus importantes par rapport au second site pour respectivement 27%, 23,1%, 22,2% et 19,3%. La dégradation de la matière organique MO est beaucoup plus prononcée dans les traitements (T0S2, T1S2 et T2S2) du second site S2 qu'au niveau des traitements (T0S1, T1S1, T2S1 et T3S1) du premier site S1. Ce phénomène s'explique par le fait que les boues de vidange utilisées pour le second site S2 ont un séjour beaucoup plus long (6 semaines de séjour) que les autres boues de vidange (3 semaines de séjour) du premier site S1. Alors il peut s'agir d'une dégradation précoce de la matière organique avant la mise en compostage pour le second site S2. La matière organique présente dans les traitements avec les co-substrats de déchets maraichers est toujours en évolution car dans ces andains (T1S2, T2S2), il y a une disponibilité de la matière organique qui sert de nourriture aux microorganismes. Aussi, selon le diagramme établi par McClintock (2005), les glucides et les sucres contenus dans les déchets maraichers ont une vitesse de dégradation importante et favorisent une baisse significative de la teneur en matière organique. Selon Said-Pullicino (2007) les glucides, les acides aminés et les protéines représentent les composés organiques solubles les plus labiles et sont utilisés préférentiellement par des microorganismes pendant la dégradation de la matière organique. C'est ce qui explique leur diminution au cours du processus de compostage comme l'ont remarqué Zaim et al. (2007) dans leurs travaux de co-compostage des boues d'épuration avec des déchets de jardin. La diminution relative de matière organique est très variable et dépend des conditions de compostage et de sa durée.

Qualité agronomique des composts

Le tableau 1 montre que le pH n'a pas beaucoup varié au cours du compostage pour les traitements (T0S2, T1S2 et T2S2) du site S2. Il se situe à la fin du processus de compostage autour de 7 qui est inclus dans la gamme de 3 à 11 décrite par Ammari et al. (2012) comme étant l'intervalle de pH recommandé pour les substrats compostables. Les résultats de cette partie de l'étude sont en accord avec ceux de Bokobana et al. (2017) qui ont trouvé des valeurs de pH compris entre 6 et 7 après 100 jours de compostage des boues d'épurations et des cendres de charbon résidus. Les boues de vidange non compostées (BVNC) ont des pH se situant aux alentours de 7 et au cours du compostage les traitements T0S2, T1S2 et T2S2 présentent des pH de valeurs égales à 6 et vers la fin du processus de compostage ces valeurs ont remonté jusqu'à 7. Toutefois, les traitements (T0S1, T1S1, T2S1 et T3S1) du site S1 ont des pH faiblement acides (entre 6,4-6,6). Ces résultats sont en contradiction avec ceux de Albrecht (2007). En effet cet auteur a affirmé que le pH augmentait graduellement au cours du compostage. Mais Cofie (2009) a affirmé que dans ses études, une baisse du pH au cours du processus est observée et ceci est probablement dû au phénomène de nitrification. Car l'ammonium est durant cette phase du compostage transformé en nitrate avec une grande teneur. En effet, ils ont montré que le pH baissait quand les fréquences de retournement sont supérieures à 7 jours. D'après ces auteurs, les fréquences de retournement supérieures à 7 jours sont responsables de la rapide conversion de l'ammonium (NH_4^+) en nitrate (NO_3^-) ou de la baisse de NH_4^+ dans le compost qui entraine une baisse du pH. Dans cette étude, les fréquences de retournement de 10 jours peuvent donc être à l'origine de la baisse du pH.

Le tableau 1 montre que la conductivité électrique CE mesurée dans tous les andains en début de compostage est supérieure à celle mesurée en fin du compostage pour l'ensemble des traitements. En effet avant le processus de compostage, les boues de vidange non traitées ont des valeurs de conductivité électrique (CE) aux alentours de 2425µs/cm et au cours du compostage les différents traitements ont des CE en baisse. En effet au début du compostage les CE de S1 présentent des valeurs variant de 1471 µs/cm à 985 µs/cm pour T0S1, 1685 µs/cm à 1307 µs/cm pour T1S1 et 1767 µs/cm à 1243 µs/cm pour T2S1. Selon Fuchs et al. (2001), la CE, pour un compost, ne doit pas dépasser 4 mS/cm alors ces résultats sont en accord avec l'intervalle décliné par cet auteur.

Le tableau 1 montre que la plupart des paramètres suivis sont en accord avec les travaux réalisés dans le co-compostage de boues de vidange ou d'épurations avec des déchets organiques d'origine végétale (Cofie et al., 2009; López-Mosquera et al., 2011; Séma et al, 2021).

Le rapport C/N d'une matière renseigne sur sa vitesse de minéralisation (Biekke et al., 2018). La faible valeur de C/N (<12) pourrait traduire la relative rapide minéralisation de l'azote et par conséquent sa disponibilité dans les composts (Biekke et al., 2018 ; Séma et al., 2021). Pour certains auteurs, la diminution du rapport C/N traduit le degré de maturation des composts (Huang et al., 2006). Selon Nanéma (2007), cette faible valeur du rapport C/N est le signe d'un bon niveau de maturité du compost, c'est-à-dire, un compost presque minéralisé.

Le phosphore (P) a pour rôle de renforcer la résistance des plantes et contribue à la croissance et au développement des racines, de la fructification et de la mise à graine (Nadjoua et Zahra., 2016). Les teneurs en P observent une augmentation dans T2S2 (dont la part en déchets maraichers est plus importante) plus élevé, il s'agit de 1,1% ; 1,7% et 1,9% respectivement pour T0S2, T1S2 et T2S2 par rapport au début du processus de compostage, 1,3% pour les boues de vidange non compostées (BVNC). Ces résultats sont similaires aux résultats de Cofie (2009). Les composts sont riches en phosphore comparables à certains auteurs comme Konaté (2018), Jagadabhi et al (2018). Par contre les teneurs en P sont moins importantes pour les traitements du site 1 (T0S1, T1S1, T2S1 et T3S1 pour respectivement 0,3%, 0,5%, 0,3% et 0,2%).

La teneur en potassium (K) est similaire pour l'ensemble des traitements des deux (02) sites S1 et S2. Mais une légère augmentation de la teneur en K est remarquée au niveau des traitements contenant les déchets maraichers comme co-substrat. Toutefois les valeurs trouvées dans les traitements T0S1, T1S1, T2S1, T3S1, T0S2, T1S2 et T2S2 pour respectivement 0,07% ; 0,12% ; 0,2% ; 0,3% ; 0,05% ; 0,2% ; 0,24%, sont en baisse par rapport aux résultats de Cofie (2009) (0,5% et 0,6%). Cependant en comparant avec les travaux de Pizongo (2014), ces composts sont riches en K car ils ont des teneurs en K supérieures aux composts de Pizongo (2014) dont les valeurs se situent aux alentours de 0,8g/kg.

Qualité sanitaire des composts

Concentrations en coliformes fécaux

Le tableau 2 montre une réduction importante de la concentration en coliformes fécaux (CF) dans les différents andains comparativement à leurs concentrations dans les boues de vidange non compostées (BVNC). Mais les traitements (T0S1, T1S1, T2S1 et T3S1 pour respectivement 22%, 46%, 57% et 73%) issus du premier site S1 ont enregistré une baisse des concentrations en CF. Toutefois les traitements (T0S2, T1S2 et T2S2) du second site S2 ont montré une élimination complète en CF dans les échantillons de composts.

Les auteurs tels que Mainoo (2007) et Ndegwa et Thompson (2001) estiment que le compostage permet une élimination totale des germes pathogènes. En effet, dans un processus de compostage aérobie où les températures avoisinent les 60°C pendant plusieurs semaines, il se produit une destruction efficace des agents pathogènes (Compaoré et al., 2010). La chaleur générée aurait pour effet d'assainir les tas de composts en détruisant les micro-organismes pathogènes (Hassen et al., 2001 ; Tahraoui, 2013, Biekke et al., 2018). Dans notre étude les températures enregistrées dans les traitements du S1 sont supérieures à 50°C mais la phase thermophile est moins étendue que les traitements (T0S2, T1S2 et T2S2) du site S2 qui sont aux alentours de 40-45°C avec une phase thermophile sur une trentaine de jours et une forte réduction des pathogènes est observée après analyse au laboratoire. Aussi ces boues de vidange avant d'être compostées ont séjourné dans des lits de séchage non planté (6 semaine de temps de séjour) et l'action des rayons solaires a entamé l'élimination des germes pathogènes (Seck, 2016). Aussi les expérimentations des traitements du site S1 se sont déroulées au sein de la station d'épuration où le risque de contamination en coliformes fécaux est réel et permanant.

Concentrations en œufs d'Ascaris

Le tableau 3 montre que les composts T0S2, T1S2 et T2S2 ont des teneurs en œufs d'helminthes vivants inférieures aux recommandations de l'OMS de moins d'un (01) œuf d'helminthes par gramme de compost. La technique de compostage est connue pour son action positive dans l'inactivation des œufs de parasites. Maya et al., (2012) ont montré qu'une élévation de la température à des valeurs supérieures à 45°C permettait d'inactiver toutes les espèces de parasites au bout de 6 jours dans des conditions de pH de 5,3 et de siccité de 90 %. Aussi les boues de vidange séchées sur les lits séchage avec une grande superficie et un temps de séjour plus long pour le second site S2 ont subi un premier traitement et le compostage a renforcé l'élimination des œufs d'helminthes vivants. Mais pour les boues de vidange du premier site S1 (T0S1, T1S1, T2S1 et T3S1 pour respectivement 3,4 ; 2,5 ; 2,8 et 2,2 œufs /g) avec une superficie moindre et un temps de séjour court par rapport aux traitements du second site S2.

Car les boues de vidange prélevées dans les lits de séchage ont déjà subi un début de traitement mais d'après Seck (2016), le nombre d`œufs d`Ascaris retrouvés dans les biosolides séchés à plus de 90% matière sèche (MS) reste élevé. Cependant les autres formes parasitaires sont éliminées totalement. Les biosolides contiennent une quantité d`œufs d`helminthes viables supérieure aux normes recommandées par l`OMS pour l`agriculture (< 1 œuf viable/g) (WHO 2006).

Cette résistance a également été prouvée par Koné et al. (2007) et Keffala et al. (2012). Elle est due à la présence d'une cuticule composée de plusieurs couches (trois à quatre selon le genre) et qui empêche le passage de certaines substances (acides et bases forts, oxydants, agents réducteurs et détergents).

Le passage de ces types de boues de vidange dans la technique de co-compostage permet une élimination complète des œufs viables d'Ascaris rendant le produit final sûr du point de vue sanitaire.

CONCLUSION

La technique de compostage est une méthode accessible et peu couteux, mais des améliorations sur la mise en pratique de la technique est à encourager et ceci a suscité l'intérêt d'une telle étude sur la comparaison de cette technologie en fonction des lieux de mise en compostage et la taille des andains.

Les résultats de cette étude ont, en effet, montré que tous les composts ont des paramètres physicochimiques en accord avec la bibliographie. Aussi les paramètres microbiologiques et parasitaires des échantillons de composts du site expérimental S2 sont conformes aux recommandations de l'OMS avec des concentrations inférieures à 1oeuf d'helminthes vivant par g de compost. Le compostage du second site expérimental S2 présente des valeurs avec une élimination complète en coliformes fécaux et en accord avec la bibliographie. Toutefois les traitements T0S1, T1S1, T2S1 et T3S1 (pour respectivement en coliformes fécaux 29.10^3 UFC/100g ; 20.10^3 UFC/100g ; 16.10^3 UFC/100g ; 10.10^3 UFC/100g et en œufs d'helminthes vivants 3,4 ;

2,5 ; 2,8 et 2,2) ont des concentrations en coliformes fécaux et en œufs d'helminthes élevées par rapport aux traitements T0S2, T1S2 et T2S2 qui ont reçu des boues de vidange avec un important temps de séjour (6 semaines) sur les lits de séchage et des andains de taille plus grande durant le processus de compostage. Les lieux expérimentaux ainsi que les conditions de mise en compostage peuvent apporter des différences significatives sur la qualité sanitaire et une multiplication des expérimentations sont encouragées pour une certification sur l'amélioration des paramètres physico-chimiques.

REFERENCE BIBLIOGRAPHIQUE

[1] Albrecht, R. (2007). Co-compostage de boues de stations d'épuration et de déchets verts: Nouvelle méthodologies du suivi des transformations de la matière organique. ***Thèse de doctorat en Biosciences de l'Environnement***. Faculté des Sciences et Techniques, Ecole doctorale des Sciences de l'Environnement, Université PAUL CEZANNE AIX-MARSEILLE III: 189 p.

[2] Ammari, T. G., Al-Omari, Q., Abbassi, B. E. (2012). Composting sewage sludge amended with different sawdust proportions and textures and organic waste of food industry – assessment of quality. *Environmental Technology* **33**: 1641-1649.

[3] APHA (2005). Standards Methods for Examination of Water and Wastewater. American Public Health Association, American Water Work Association, Water Environmental Federation.

[4] Biekke, A. H. T., Tie, B. T., Dogbo, D. O. (2018). Caractéristiques physico-chimiques des composts à base de sous-produits de ferme de Songon en Côte d'Ivoire : International Journal of Biological and Chemical Sciences 12 (1) 596-609, February 2018

[5] Bokobana, A., Toundou, O., Kolani, L., Kokou, A., Amouzouvi, A., Koledzi, E., Tozo, K., Tchangbedji, G. (2017). Traitement de déchets ménagers par co-compostage avec la légumieuse Cassia occidentalis L. et quelques adjuvants de proximité pour améliorer la qualité agronomique de composts. Déchets Sciences et Techniques n°73 : 1-13

[6] Capizzi-Banas, S., Deloge, M., Remy, M. and Schwartzbrod, J. (2004). Liming as an advanced treatment for sludge sanitisation: helminth eggs elimination—Ascaris eggs as model. *Water Research* **38**: 3251–3258.

[7] Cofie, O., Kone, D., Rothenberger, S., Moser, D. and Zubruegg, C. (2009). Co-composting of faecal sludge and organic solid waste for agriculture: Process dynamics. *Water resaerch* **43**: 4665 – 4675.

[8] Compaoré, E., Nanema, L. S., Bonkoungou, S. and Sedogo, M.P. (2010). Évaluation de la qualité de composts de déchets urbains solides de la ville de Bobo-Dioulasso, Burkina Faso pour une utilisation efficiente en agriculture. *Applied Biosciences* **33**: 2076 - 2083.

[9] Fourti, O. (2013). The maturity tests during the composting of municipal solid wastes, review. *Resources, Conservation and Recycling* **72**: 43- 49.

[10] Francou, C. (2003). Stabilition de la matière organique au cours du compostage de déchets urbains : Influence de la nature des déchets et du procédé de compostage - Recherche d'indicateurs pertinents. ***Thèse de Doctorat***. Institut National Agronomique, Ecole doctorale Abies: 244 p.

[11] Gning JB, Diop C, Dongo K, Koné D. 2017. Facteurs déterminants le tarif de la vidange mécanique des matières de boues d'assainissement à Dakar. International Journal Biological and Chemical Sciences, 11(1): 313-332. DOI: http://dx.doi.org/10.4314/ijbcs.v11i1.25

[12] GRET (2012). La filière de gestion des boues de vidange : de l'analyse aux actions : Actes de l'atelier d'échanges. Campus du jardin tropical/France

[13] Hassen A, Belguith K, Jedidi N, Cherif A, Cerif M, Boudabous A. (2001). Microbial characterization during composting of municipal solid waste. Bioresource Technology, 80: 217-225. DOI : https://doi.org/10.1016/S0960-8524(01)00065-7

[14] Huang, G. F., Wu, Q. T., Wong, J. W. C., Nagar, B. B. (2006). Transformation of organic matter during co-composting of pig manure with sawdust. Bioresource Technology, 97, pp: 1834-1842. DOI : https://doi.org/10.1016/j.biortech.2005.08.024

[15] Jagadabhi. P.S., and al. (2018) Evaluation physico-chimique, microbienne et phytotoxique des composts à partir de paille de sorgho, de mil et de soja. Journal International de recyclage des déchets organique en agriculture

[16] Keffala, C., Casimir Harerimana, C., et Jean-Luc Vasel, J. L. (2012). OEufs d'helminthes dans les eaux usées et les boues de station d'épuration : enjeux sanitaires et intérêt du traitement par lagunage. . Environnement, Risques and Santé 11 (6), 511-520.

[17] Konaté. Z., Abobi.H.D.A., Soko.F.D., Yao-Kouamé. A. (2018). Effet de la fertilisation des sols à l'aide des déchets ménagers solides compostés dans les décharges sur le rendement et la qualité chimique de la laitue (Lactuca sativa L.) International Journal of Biological and chemical sciences. 12(4) : 1611-1625

[18] Koné, D., Cofie, O., Zurbrugg, G., Gallizzi, K., Moser, D., Drescher, S., Strauss, M. (2007). Helminth eggs inactivation efficiency by feacal sludge dewatering and cocomposting in tropical climates. Water Research, 41 (19): 4397-4402

[19] Koné, M., Service, E., Ouattara, Y., Ouattara, P., Bonou, L., Joly, P. (2016). Caractéristisation des boues de vidange dépotées sur les lits de séchage de Zagtouli (Ouagadougou). Int. J. Chem. Sci. 10 (6) : 2781-2795

[20] Lô, M., Sonko, EH. M., Dieng, D., Ndiaye, S., Diop, C., Seck, A., Gueye, A. (2019). Co-compostage de boues de vidange domestiques avec des déchets maraîchers et des déchets de poissons à Dakar (Sénégal). International Journal Biology Chemical Sciences. 13(6): 2914-2929

[21] Lô, M. (2015) Valorisation des boues de vidange domestiques en agriculture : suivi de la stabilisation et des qualités microbiologique et parasitaire de boues de vidange co-compostées avec des déchets maraichers et de poissons. Mémoire de Master, Institut des Sciences de l'Environnement, Faculté des Sciences et Techniques, Université Cheikh Anta Diop de Dakar/Sénégal

[22] López-Mosquera, M.E., Fernández-Lema, E., Villares, R., Corral, R., Alonso, B. and Blanco, C. (2011). Composting fish waste and seaweed to produce a fertilizer for use in organic agriculture. *Procedia Environmental Sciences* **9**: 113-117.

[23] Mainoo, N.K. (2007). Feasibility of low cost vermicompost production in Accra, Ghana. ***Thèse de Doctorat***. Department of Bioresource Engineering, McGill University, Montreal: 103 p

[24] Maya, C., Torner-Morales, F.J., Lucario, E.S., Hernandez, E. and Jimènez, B. (2012). Viability of six species of larval and non-larval helminth eggs for different conditions of temperature, pH and dryness. *Water resaerch* **46**: 4770-4782.

[25] McClintock, N.C. (2005). Production de compost et usage dans les systèmes agricoles durables : Notes prises sur le terrain à l'intention des agriculteurs. *Center for Environmental Farming Systems*. Raleigh, NC 27695-7609. **N° 3**:9 pp.

[26] Milin S. 2012. Comparaison de deux méthodes spectrophotométriques de dosage de l'acide phosphorique: Application à des sols et des végétaux. Le cahier des techniques de l'INRA (77) n°3.

[27] Mouria, B., Ouazzani-Touhami .A., Daouira. A. (2013). Effet du compost de Trichoderma harzianum sur la suppression de la verticilliose de la tomate. Journal of Applied Biosciences 70 : 5531-5543

[28] M'Sadak, Y. et Ben M'barek, A. (2013) Caractérisation qualitative du digestat solide de la biométhanisation industrielle des fientes avicoles et alternative de son exploitation agronomique hors sol. Revue des Energies Renouvelables, vol. 16, n°1, 2013, 33-42.

[29] Nadjoua. A et Zahra, A. (2016). Effet des boues actives sur quelques paramètres morpho-physiologiques de jeunes plants de Vicia faba Var.minor: Mémoire de Master Département des Sciences bologiques de l'Environnement, faculté des Sciences de la Nature et de la Vie: Université A. Mira-Bejaia Algérie

[30] Nanéma, S. L. (2007). Compostage et évaluation de l'efficacité agronomique du compost de déchets urbains solides de la ville de Bobo-Dioulasso, mémoire d'ingénieur, IPR/IFRA, Katiébougou (Mali), p. 67.

[31] Ndegwa, P. M. and Thompson, S. A. (2001). Integrating composting and vermicomposting in the treatment and bioconversion of biosolids. *Bioressources Technology* **76**(2): 107-112.

[32] Ntangmo-Tsafack, H., E., Temgoua, E., Njine, T. (2019). Persistance de E. coli, des œufs d'helminthes et des kystes de protozoaires contenus dans les eaux usées urbaines d'arrosage sur les cultures maraîchères à Dschang, Ouest-Cameroun. International Journal Biology Chemical Sciences. 13(5): 81-90,

[33] Palm, C.A., Gachengo, C.N., Delve, R.J., Cadisch, G. and Giller, K.E. (2001). Organic inputs for soil fertility management in tropical agroecosystems: Application of an organic resource database. *Agric. Ecosyst. Environ* **83**: 27-42.

[34] Pizongo. I. N. W. (2014). Réponse de variétés de gombo (Abelmoschus esculentus L) aux engrais chimiques et à la fumure organique. Mémoire de Master, Institut de Développement Rural, Université Polytechnique de Bobo-Dioulasso Burkina Faso

[35] Rapport OMS/UNICEF (2020) : Les progrès accomplis à l'échelle mondiale dans le domaine de l'Eau, l'Assainissement et l'Hygiène dans les établissements de santé (2020)

[36] Ruggieri, L., Artola, A., Gea, T. and Sanchez, A. (2008a). Biodegradation of animal fats in a co-composting process with wastewater sludge. *International Biodeterioration & Biodegradation* **62**: 297-303.

[37] Ruggieri, L., Gea, T., Artola, A., Sanchez, A. and Group, G.C.R. (2008b). Influence of different co-substrates biochemical composition on raw sludge co-composting. *Biodegradation* **19**: 403-415.

[38] Said-Pullicino, D. and Gigliotti, G. (2007). Oxidative biodegradation of dissolved organic matter during composting. *Chemosphere* **68**: 1030-1040.

[39] Seck. A. (2016). Optimisation du séchage des boues de vidange domestiques de Dakar (Sénégal) par des lits de séchage non plantés pour une valorisation énergétique des biosolides : caractérisation physico-chimique, calorifique et biologique. Thèse de doctorat unique, Ecole Doctorale Des Sciences de la Vie, de la Santé et de l`Environnement, Faculté des Sciences et Techniques, Université Cheikh Anta Diop de Dakar/ Sénégal

[40] Séma, A. I. M., Koledzi, E. K., Krou, N. M et Tcha-Tho, (2021). M. Etude comparée de la ventilation naturelle et automatique à l'aide de tuyaux perforés et du procédé classique de retournements des andains en compostage. Int. J. Biol. Chem. Sci. 15(1): 354-366

[41] Strande L., Ronteltap M., Brdjanovic D. (Eds.) (2014). Faecal Sludge Management: Systems Approach for Implementation and Operation. IWA Publishing. Édition française 2018.

[42] Tahraoui, N. D. (2013). Valorisation par compostage des résidus solides urbains de la commune de Chlef, Algérie. Thèse de Doctorat, Université de Limoges, 244p.

[43] Temgoua, E., Ngnikam, E., Dameni, H. and Kouedeu Kameni, G.S. (2014). Valorisation des ordures ménagères par compostage dans la ville de Dschang, Cameroun. *TROPICULTURA* **32**: 28-36.
[44] Ukondalemba, L.M. (2016). Caractérisation et tests de traitement des déchets ménagers et boues de vidange par voie anaérobie et compostage pour la ville de kinshasa, Thèse de doctorat, Unité Assainissement et Environnement, Département des Sciences et Gestion de l'Environnement, Faculté des Sciences, Université de Liége Belgique
[45] Useni. S. Y. et al. (2013). Utilisation des déchets humains recycles pour la production du maïs de la RD Congo Journal of Applied Biosciences. 66: 5070-5081
[46] WHO (2006). Guidelines for the Safe Use of Wastewater, Excreta and Greywater; World Health Organization: Geneva. Vol. 4: 182.
[47] Zaim, N., Souabi, S., Aboulhassan, A., Aboulam, S., Morvan, B. (2007). Compostage des boues produites à la station d'épuration d'une huilerie, en mélange avec des déchets de jardin : Déchets - Revue Francophone D'écologie Industrielle - N° 48-4 Trimestre 2007

CONFLIT D'INTERETS

Les auteurs déclarent n'avoir aucun conflit d'intérêts pour cet article.

CONTRIBUTIONS DES AUTEURS

Tous les auteurs ont contribué à la réalisation de ce travail et à la rédaction du manuscrit.

REMERCIEMENTS

Les auteurs remercient le laboratoire de l'Institut National de Pédologie (INP) du Sénégal et le laboratoire de l'Office National de l'Assainissement du Sénégal (ONAS) pour leurs contributions dans la réalisation des analyses des différents paramètres ayant permis de caractériser les composts. Les auteurs remercient par ailleurs l'ONAS pour avoir hébergé l'équipe des chercheurs. La conception et la planification de l'étude ont été rendues possibles grâce a l'appui de l'équipe de chercheurs du Laboratoire d'Etude Environnementales des Milieux Urbains (LEEMUR) de l'Institut des Sciences de l'Environnement (ISE) de l'Université Cheikh Anta Diop de Dakar (UCAD).

Kintu Mayaka Doudou, Isumbisho Mwapu Pascal, Ngonzo Luwesi Cush, Riziki Walumona Jacques, Masilya Mulungulu Pascal and Rodric Mérimé Nonki
Effect of Climate Variability on Carbon Biomass in Lake Kivu: ARDL Model Approach
International Journal Water Sciences and Environment Technologies
Vol. (x), Issue. 1, March 2025, pp. 75-85
ISSN Online: 1737-9350; ISSN Print: 1737-6688, Open Access
www.jiste.org
Scientific Press International Limited
Received: January 2025 / Revised: February 2025 / Accepted: March 2025 / Published: March 2025

Effect of Climate Variability on Carbon Biomass in Lake Kivu : ARDL Model Approach

Kintu Mayaka Doudou [1,2] , Isumbisho Mwapu Pascal [1,6] , Ngonzo Luwesi Cush [1,3] , Riziki Walumona Jacques [5], Masilya Mulungulu Pascal [5], Rodric Mérimé Nonki [1,4]

1.Regional School of water at the University of Kinshasa, (Democratic Republic of Congo).
2.University of Kindu ;
3.African University of management and Technology, Congo-Brazzaville ;
4.Environmental Modelling and Atmospheric Physics Laboratory, University of Yaoundé 1, Cameroon ;
5.Applied Hydrobiology Teaching and Research Unit (UERHA), Biology Department, Higher Pedagogical Institute of Kinshasa of Bukavu, (Democratic Republic of Congo) ;
6.Laboratory for the Study of Aquatic Environments (LEMA), Biology Department, Higher Pedagogical Institute of Kinshasa, (Democratic Republic of Congo) .

Abstract

The effectiveness of climate change around Lake Kivu in the Democratic Republic of Congo has been verified using time series of climate data spanning more than 3 decades. This study aims to analyse the effects of climate variability on the carbon biomass of Lake Kivu, which have not been documented to date. The biological data and physico-chemical parameters were collected from documentary sources in the Unité d'Enseignement et de Recherche en Hydrobiologie Appliquée (UERHA) database from 2002 to 2022 and from personal analysis in the laboratory. The climate data was downloaded from the NASA website (https://power.larc.nasa.gov) and covers a period from 1981 to 2023. We applied the Auto Regressive Distributed Lag model (ARDL). The results indicate that only the mean annual temperature has changed, but not significantly over the period 1981 to 2023, with an increase of 1.13°C in the Lake Kivu catchment area, rising from 18.04°C in 1981 to 19.17 in August 2023 ($R2=0.633$). This has a significant negative influence (t:-2.156404 and Prob.: 0.0327) on the carbon biomass of Lake Kivu. On the other hand, the other synchronous explanatory variables (Conductivity, rainfall, Secchi depth value and Turbidity) have statistically null coefficients because they have probabilities greater than 5%. They therefore have no effect on carbon biomass. Furthermore, 51.9% of the biomass was explained by the explanatory variables included in the synchronous and lagged model, with an adjusted determination coefficient of 46.3%. The Fisher F probability (F:9.439 and Prob. 0.0000), being less than the 5% margin of error, shows that the model is globally and statistically significant.

Keywords: Ecological functioning, Phytoplankton, Photosynthesis, Anthropogenic activities, Eutrophication, Atmospheric temperature, Modelling.

Effet de la Variabilité Climatique sur la Biomasse en Carbone du Lac Kivu : approche par le modèle ARDL

Résumé

L'effectivité du changement climatique autour du lac Kivu en République Démocratique du Congo a été vérifiée à partir des séries chronologiques des données climatiques de plus de 3 décennies. Cette étude vise à analyser les effets de la variabilité climatique sur la biomasse en carbone du lac Kivu, non documentés à ce jour. Les données biologiques et les paramètres physico-chimique ont été collectées à partir des sources documentaires de la base des données d'Unité d'Enseignement et de Recherche en Hydrobiologie Appliquée (UERHA) de 2002 à 2022 et de l'analyse personnelle au Laboratoire. Les données climatiques ont été téléchargées sur le site de la NASA (https://power.larc.nasa.gov) et couvre une période de 1981 à 2023. Nous avons appliqué le modèle dynamique autorégressif à retards distribués, en sigle ARDL (Auto Regressive Distributed Lag model). Les résultats indiquent que, seule, la température moyenne annuelle a évolué mais pas de manière significative au cours des années 1981 à 2023 avec une augmentation de 1.13°C dans le Bassin versant du Lac Kivu passant de 18.04°C en 1981 à 19.17 en août 2023 ($R2=0.633$). Ce qui, influence, négativement et significativement la biomasse en carbone du Lac Kivu (t :-2.156404 et Prob. : 0.0327). Par contre, les autres variables explicatives (la Conductivité, les précipitations, la valeur de la profondeur du Secchi et la Turbidité) synchrones possèdent des coefficients statistiquement nuls parce que disposant des probabilités supérieures à 5%. Elles n'exercent donc pas d'effet sur la biomasse en Carbone. Par ailleurs, la biomasse se trouve expliquée à 51.9% par les variables explicatives reprises dans le modèle synchrones et retardés avec un coefficient de determination ajusté de 46.3%. La probabilité F de Fisher (F :9.439 et Prob. 0.0000), étant inférieure à la marge d'erreur de 5%, montre que le modèle est globalement et statistiquement significatif.

Mots clés : Fonctionnement écologique, Phytoplancton, Photosynthèse, Activités anthropiques, Eutrophisation, Température atmosphérique, Modélisation.

[1] Corresponding author: mayakadoudou@gmail.com

1. INTRODUCTION

The massive release of greenhouse gases into the Earth's atmosphere by human activities over the last one hundred and fifty years (IPCC, 2023) has resulted in a warming of the surface layers of the oceans, acidification and a reduction in the concentration of dissolved oxygen (Petitgas et al., 2020).

By the end of the 21st century, the warming of the climate system will continue and could reach values ranging from +0.3°C to +4.8°C for a reference period going back to 1980 (IPCC, 2013 ; Jacquemin, 2019). These environmental changes are leading to profound alterations in the biodiversity of ecosystems, their functioning and their evolutionary trajectories (Carpenter et al., 2006 ; Polunin, 2008).

Freshwater aquatic environments are among the most threatened ecosystems according to the Millennium Ecosystem Assessment (MEA, 2005) and the Intergovernmental Panel on Climate Change (IPCC) (Rosenzweig et al., 2007 ; Jacquemin, 2019). Lakes are considered 'sentinels' because of their sensitivity and rapid response to environmental change.

The work of Stockner and Antia (1986), Peterson and Seligman (1987), Keller and Suzuki (1988); Thyssen et al. (2008); Sardet (2015) and Benaziza (2018), has shown that phytoplankton accounts for more than half of terrestrial biomass, and plays an essential role in climate control because it is responsible for producing a large proportion of atmospheric oxygen and is a veritable carbon dioxide pump. It is illustrated as the main primary producer that forms the basis of the food chain in aquatic ecosystems, and any qualitative and quantitative changes that occur in phytoplankton communities will consequently influence the entire trophic chain.

According to Hugo (2006), the most common phytoplankton species found in Lake Kivu were the pinnate diatoms Nitzschia bacata Hust. and Fragilaria danica (Kütz.) Lange-Bert, and the cyanobacteria Planktolyngbya limnetica (Lemm.) Komárková-Legnerová and Cronberg and Synechococcus sp. The mean annual chlorophyll a in the mixing zone is estimated at 2.2 mg m-3 and a primary productivity of 0.71 g C m2 d-1 (~ 260 g C m2 a-1), which contributes to the mitigation of greenhouse gases by sequestering atmospheric CO2. Spatial, seasonal and vertical variations have been relatively slight.

Recently, there has been strong anthropogenic pressure on Lake Kivu (Aleke, 2016), and the cumulative effects of climate variability have had a major impact on Ichthyological productivity (Balagizi, 2017). On a such context, it is quite justified to think that this anthropogenic pressure associated with climate change would have an effect on phytoplankton biomass in this lake, as has been demonstrated in Lake Tanganyika (O'Reilly et al, 2003). Here, however, the evaluation of this effect has so far not attracted the attention of researchers. This study therefore seeks to assess the combined effects of climate variability and physico-chemical parameters on the carbon biomass sequestered by Lake Kivu by applying the autoregressive time lag model (ARDL).

The choice of the ARDL model is justified by its belonging to the class of dynamic models (Kibala, 2018) and allows temporal effects to be captured in the explanation of a variable. In this context, a dependent variable (Yt) can be explained both by its own past values, present values of independent variables (Xt) and their time-lagged values (Xt-i) (Adama and Mamadou, 2023).

The aim of this study is to assess the combined effects of climate variability and physico-chemical parameters on the carbon biomass sequestered by Lake Kivu by applying the autoregressive time lag model (ARDL).

2. Materials and methods

2.1. Study site

Lake Kivu is from volcanic origin (Isumbisho, 2006). It is deep, meromictic lake with very specific limnological characteristics. This lake combines a relatively shallow euphotic zone (more or less 18 m), usually less than the mixing zone (20 to 60 m), with a low thermal gradient in the mixolimnion and is clearly oligotrophic (Hugo, 2006). It is located south of the equator between 1°34'- 2°30'S and 28°50'- 29°23'E. With a surface area of 2370 km2, a maximum depth of 489 m and an average depth of 240 m (Marshall 1993), it forms a natural boundary between the Democratic Republic of Congo and the Republic of Rwanda. It is one of the four great lakes of the East African "Rift". It has 102 km of length and 50 km of wide (at its widest point). It is located at an altitude of 1463 m above sea level (Descy, 1991).

The most common phytoplankton species in pelagic Lake Kivu were pinnate diatoms (Nitzschia bacata Hust. and Fragilaria danica Lange-Bert.) and the cyanobacteria Planktolyngbya limnetica (Lemm.) Komárková-Legnerová and Cronberg and Synechococcus sp. Centric diatoms Urosolenia sp. and various species of Microcystis can also be very abundant (Hugo, 2006).
Although fishing is less important than elsewhere in the region, it still accounts for 10,000 tonnes of fish per year, and is a cheap source of animal protein for the local population of the two riparian countries (Lecrenier, 2016).

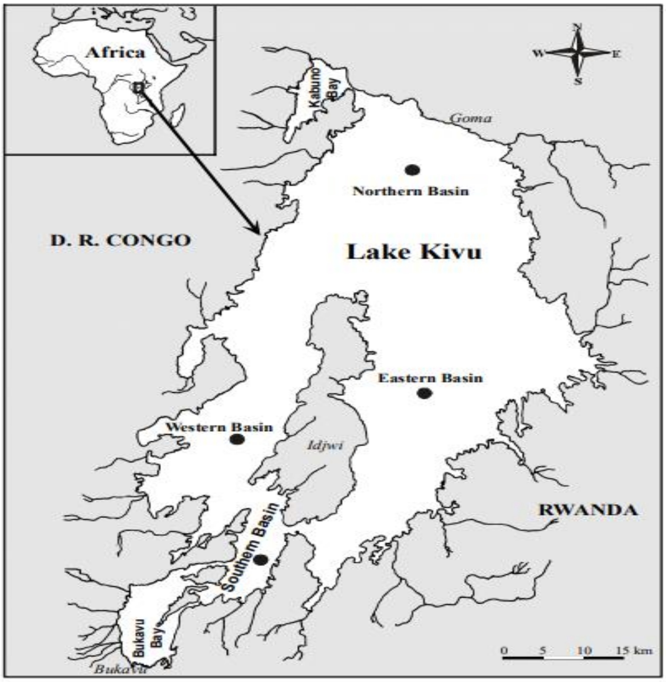


Figure 2 : Lake Kivu geographic situation and sampling sites location. (Isumbisho, 2006).

2.2. Data sources and sampling strategies

To verify the combined effects of climatic and physico-chemical variables on the biomass of Lake Kivu, we used data on phytoplankton biomass and physico-chemical parameters (O'Reilly et al, 2003) from 2002 to 2023. The data for 2002 to 2022 were retrieved from the database of the Unité d'Enseignement et de Recherche en Hydrobiologie Appliquée (UERHA) of the Department of Biology and Chemistry at the Institut Supérieur (ISP) in Bukavu, while the data for 2023 were collected in the field by ourselves. The climatic data was downloaded from the NASA website (https://power.larc.nasa.gov) and covers a period from 1981 to 2023, 2 m above the surface at coordinates 28°512392 and - 2° 281121, and was validated by meteorological data from various stations in the area.
Physico-chemical characteristics were sampled in situ at various depths (0, 5, 10, 20, 30, 40, 50 and 60 m). Measurements of dissolved oxygen (D.O), temperature (TE), conductivity (Cond.), turbidity (Turd.), pH and pressure were made using a PRODSS multiparameter probe. Similarly, the sequi disc (SE) enabled us to determine the transparency of the water in Lake Kivu.
After these measurements, water samples were taken (once a month) using a Van Dorn-type hydrological bottle with a capacity of 6,000 ml, stored in jars (1,000 ml) kept in a cooler at 4°C and then brought back to the laboratory (Lalèyè et al., 2022). In the laboratory, the carbon biomass was assayed for chl a using a GENESYS20 spectrophotometer. The methods used were those described by Rodier et al (2009).
Chl a is the only pigment capable of producing the chemical energy (Groga, 2012) required for carbon fixation from light energy. Calculations of average chlorophyll biomass (in g C m-2) were based on Chl a

concentrations, and converted into weight of sequestered organic carbon using the conversion factor C/Chl a = 40 (Sagan and Thouzeau 1998).

2.3. Statistical analysis of data

The main aim of plankton modelling is to predict the impacts of environmental changes on its production, composition and associated ecosystem functions (Benedetti, 2018).

To this end, an autoregressive distributed lag model (ARDL) (Boubonnais, 2018) was applied to assess the effects of climate variability and physico-chemical parameters on carbon biomass. The model considered one dependent variable (carbon biomass) and several independent variables (physico-chemical parameters : dissolved oxygen, temperature, conductivity, turbidity, pH and transparency, as well as climatic data : temperature, precipitation, wind speed and relative humidity).

The ARDL model belongs to the class of dynamic models (Kibala, 2018) and captures time effects (adjustment lag, expectations, etc.) in the explanation of a variable. In a dynamic model, a dependent variable (Yt) can be explained both by its own lagged values, the present values of the independent variables (Xt) and their time-lagged values (Xt-i) (Adama and Mamadou, 2023). The Autoregressive Distributed Lag (ARDL) model makes it possible, on the one hand, to test long-term relationships on series that do not have the same order integration and, on the other hand, to provide more reliable estimates even with small sample sizes. In addition, the ARDL model makes it possible to deal simultaneously with long-term dynamics and short-term adjustments (Capri, 2019).

To avoid spurious regressions between different variables in the model to be tested, it is necessary to carry out a preliminary analysis of the data (Kibala, 2018). To do this, we used exploratory data analysis, stationarity tests (Hamisultane, 2016), Akaike-AIC (1973), Shwarz-SIC and Hannan-Quin-HQ (1979) information criteria to determine the optimal lags (p, q) of the ARDL model by parsimony (Akaike, 1973). We then tested the causality of the variables in the sense of TODA YAMAMOTO (1995) and verified the statistical validity of the model using the residual autocorrelation test of Breusch-Godfrey (1978), the Heteroscedasticity test of Breusch-Pagan-Godfrey (1979), the normality test of Jarque-Bera (1980), the functional specification test of Ramsey (1928) and the stability test (CUSUM).

Using the Pesaran et al (2001) cointegration test, we verified the existence of a cointegrating relationship between the variables, one of the conditions of validity of the ARDL model. The variables we are analysing are time series. Our research is carried out using EViews 12 software.

The theoretical model used in our research takes the following form :

$$BC_t = \sum_{i=1}^{p} a1iBCt-i + \sum_{i=1}^{p} a2i\,CONDt-i + \sum_{i=1}^{p} a3iDOt-i + \sum_{i=1}^{p} a4ipHt-i + \sum_{i=1}^{p} a5iPMMt-1 + \sum_{i=1}^{p} a6iSE\,t-i + \sum_{i=1}^{p} a7iTAt-i + \sum_{i=1}^{p} a8iTurb.t-i + b1BCt-1 + b2CONDt-1 + b3DOt-1 + b4pHt-1 + b5PMMt-1 + b6SEt-1 + b7TAt-1 + b8Turb.t-1 + \varepsilon$$

With :

BCt: represents the carbon biomass sequestered by Lake Kivu over a given period, expressed in mgC/L ; COND : Electrical conductivity of Lake Kivu water (mg/L) ; DO : Oxygen dissolved in water ; pH : Hydrogen Potential ; PMM: rainfall (mm) ; SE: Secchi ; TA: Air temperature (°C) ; TE: Water temperature (°C) ; Turb. Water turbidity (NTU) ; a0: the Constant ; a1i.........a8i: short-term effects (Parameter to be estimated in the short term) ; b1..........b9: Long-term dynamics (Parameter to be estimated over the long term); εt: error term (this error term captures measurement errors in the data and sample fluctuations); p: the shift operator ; i: Number of offset periods.

3. Results

3.1. Variations in temperature, rainfall, relative humidity and wind speed around Lake Kivu

According to the graph below and after linear adjustment, it can be seen that only the mean annual temperature changed, but not significantly, between 1981 and 2023, with a slight increase of 1.13°C in the Lake Kivu catchment area, rising from 18.04°C in 1981 to 19.17 in August 2023 (R^2=0.633). All the other climatic variables were not evaluated during the period of our research because their coefficients of determination are almost zero. This is the case, for example, for relative humidity, which fell from 79.22% in

1981 to 78.82% in August 2023, with a coefficient of determination R2 of 0.0403, and rainfall, which did not show any significant variations (R2 = 0.0361) ; the highest rainfall was in 2020, with 2,320.3 mm, whereas 1992 was characterised by a large drop (729.4 mm). And wind speed over the period 1981 -2023 after linear adjustment (R2= 0.2742) falls from 2.92 in 1981 to 2.08 in August 2023.

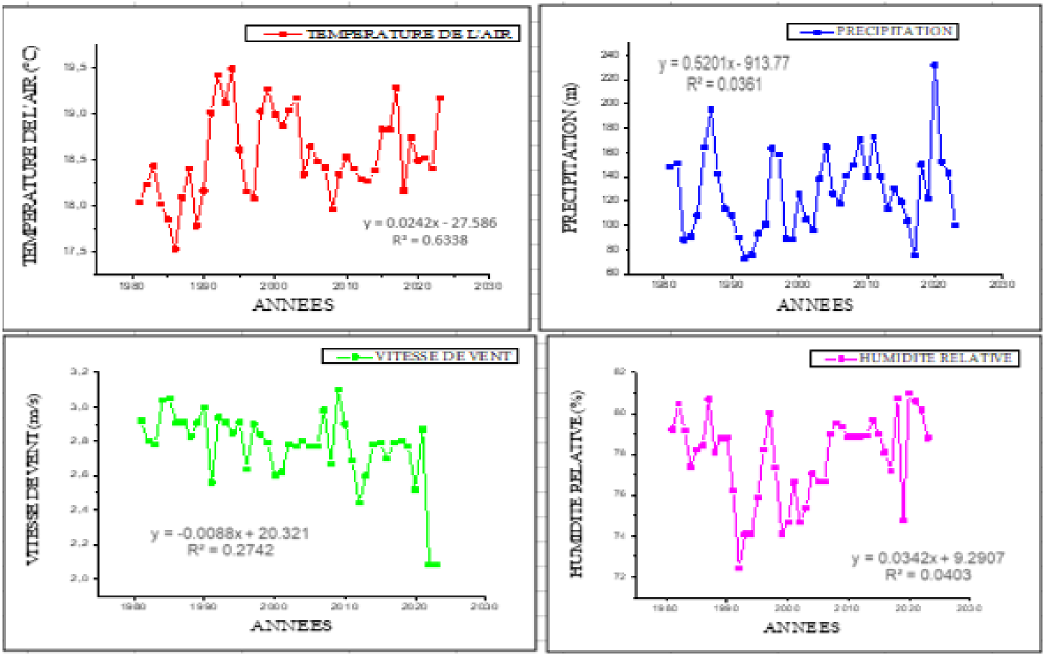


Figure 1 : Variations in climatic variables around Lake Kivu : (a) temperature variation between 1981 and 2023, (b) rainfall variation between 1981 and 2033, (c) annual variations at Lwiro between 1973 and 2012 and (d) wind speed variability over the period 1981-2023.

3.2. Stationarity test

Before processing a time series, its stochastic characteristics (its expectation and variance) need to be studied (Boubonnais, 2018). With regard to the dynamics of the variables studied, the Augmented Dickey-Fuller tests (1981) enabled us to check the order of integration of the different variables.

Table 1: Variable stationarity test

Identification	Modèle	ADF	Valeur critique	Probabilité	Processus	Ordre de différence ou intégration	Ordre de polynôme
D(BC)	3	-6.264413	-1.945199	0.0000	DS	I(1)	
COND	2	-9.590148	-2.896346	0.0000	DS	I(0)	
D.O	2	-3.591000	-2.896346	0.0079	DS	I(0)	
pH	2	-6.006990	-2.896346	0.0000	DS	I(0)	
PMM	2	-7.228934	-2.896346	0.0000	DS	I(0)	
SE	1	-5.606789	-3.464198	0.0001	TS		0
TA	2	-5.186462	-2.896779	0.0000	DS	I(0)	
D(TE)	3	-6.097679	-1.951000	0.0000	DS	I(1)	
Turb.	1	-7.520303	-3.464198	0.0000	TS		0

An initial look at the series graphs (Table 1) suggests that most of the variables (Conductivity, Dissolved Oxygen, Hydrogen Potential, Precipitation, Secchi and Turbidity) were stationary at level and others (Carbon

Biomass and Water Temperature) were stationary at the filter in first difference. This justifies the use of the ARDL method (Autoregressive Staged Retardation Model) of Pesaran et al. (2001).

In addition, the variables Carbon biomass, Conductivity, Dissolved oxygen, Hydrogen potential, Precipitation, Atmospheric temperature and Water temperature followed the DS (Differency stationary) process which is a random non-stationary process whereas the Secchi and Turbidity variables followed the TS process which represents a deterministic non-stationarity. The statistics calculated are Student's t at 5%.

3.3. Pesaran boundary cointegration test

Following the automatic procedure in Eviews 12, the Pesaran et al (2001) cointegration test requires the ARDL model to be estimated first. The test statistic, Fisher's F-value, is then compared with critical values (establishing thresholds) as follows :

- ✓ If the calculated F-value is greater than the upper limit : cointegration exists ;
- ✓ If F-calculated is less than the lower bound : cointegration does not exist ;
- ✓ If the lower bound is lower and F-Fisher is lower than the upper bound: no conclusion.

Table 2 : Pesaran cointegration test

Statistique F calculée : 4.091265

Seuil de significativité	Borne inférieure	Borne supérieure
10%	1.85	2.85
5%	**2.11**	**3.15**
2.5%	2.33	3.42
1%	2.62	3.77

Table 2 presents the estimates of the cointegration procedure and shows that the value of the Fisher statistic (F=4.091265) is greater than Pesaran's upper bound (2.11) at the 5% threshold. This result leads us to reject the hypothesis of the absence of a cointegrating relationship between the variables.

It reveals that there is cointegration between the endogenous variable, in this case Carbon Biomass, and the exogenous variables in the study (Conductivity, Dissolved Oxygen, pH, Precipitation, Secchi, Air Temperature, Water Temperature and Turbidity). These results imply that long-term equilibrium relationships can be deduced from our estimates. Long-term effects between endogenous and exogenous variables can therefore be calculated.

3.4. Validation tests and model specification

After long-term model estimation, we used Jacques Berran's Normality, Breusch Godfrey's error autocorrelation, Arch's heteroscedasticity and Cusum's model specification tests to specify and validate our model.

Table 3: Validation tests and model specification

Hypothèse Vérifiée	Test appliqué	Statistique	Probabilité
Normalité	Jacques Berran	2.940843	0.2298
Autocorrélation des erreurs	Breusch Godfrey	1.221927	0.5428
Hétéroscédasticité	Arch.	0.214578	0.6341
Spécification du modèle	Ramsey	1.623788	0.1087

Table 3: shows the various residual tests for validating the model before its protocol (interpretation). The Jarque Berra probability (Prob. 0.2298) remains above the 5% margin of error, and the errors are normally distributed (follow the normal distribution). Furthermore, Breusch Godfrey's error autocorrelation test shows that the errors (Prob. 0.5428) are not strongly correlated, as the probability associated with the chi-

International Journal Water Sciences and Environment Technologies
e-ISSN: 1737-9350 p-ISSN: 1737-6688, | Open Access Journal | Volume (x) - Issue 1 – March 2025
Volume (x): Water -Biodiversity-Climate'2025

square statistic remains above the 5% threshold for false rejection. Mutatis mutandis for the Fisher statistic. For its part, the heteroskedasticity test (Prob. 0.5428) shows homoskedastic errors for a probability of 5%. Finally, the Ramsey Reset test concludes in favor of the model specification, with both the Student and Fisher probabilities above the standard significance level for the model under study (Prob. 0.1087 and 0.2345).

3.5. Model stability

To check the stability of our model, we adopted the CUSUM test (Fig. 2), based on the cumulative sum of the square of the recursive residuals, with a null hypothesis of stability of the relationship between two straight lines representing the bounds of the interval. We can say that our estimated model is stable, given that the coefficients were stable during the period under study, as the curve snaked through the corridor using the Cusum test. In short, the results of the various diagnostic tests have led to the statistical validation of our ARDL models.

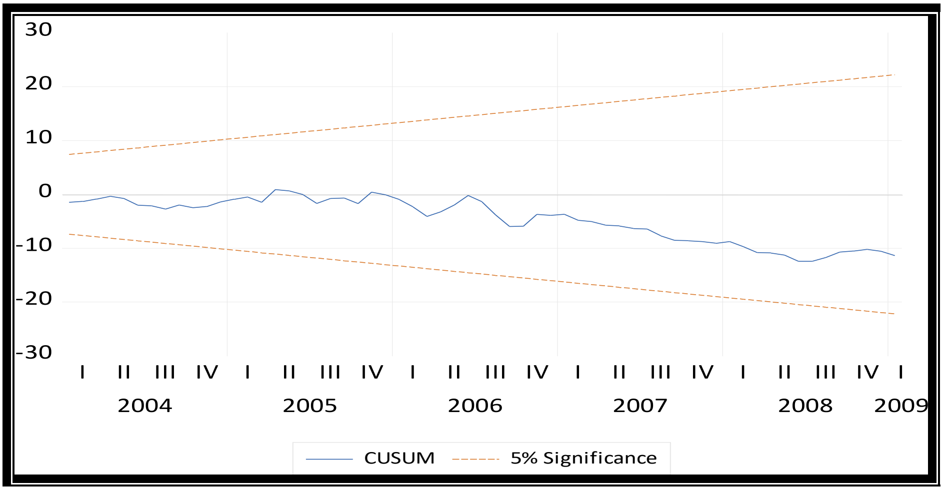


Figure 2: Model stability test

3.6. Long-term model estimation

The result obtained for the estimation of the long-term dynamics of the model (Table 4), in a long maturity, shows that Carbon Biomass is negatively and significantly impacted by its own one-period lagged past (Prob. 0.0000) and by air temperature, dissolved oxygen and pH instantaneously, given that the probability associated with Student's T statistic (respectively 0.0327, 0.0099 and 0.0074) is below the 5% margin of error. Thus, any 1°C increase in air temperature translates into a 11.07830 mg C/L decrease in Biomass, all other things being equal. Similarly, a one-unit increase in pH negatively impacts 64.97892 mg C/L of biomass.

On the other hand, the other synchronous explanatory variables (Conductivity, Precipitation, Secchi, Water Temperature and Turbidity) have coefficients that are statistically null because they have probabilities greater than 5%. They therefore have no effect on carbon biomass. It should be noted that 51.9% of biomass is explained by the explanatory variables included in the synchronous and lagged models, with an adjusted (corrected) determination coefficient of 46.3%. Finally, Fisher's F probability (0.000000), being below the 5% margin of error, shows that the model is globally and statistically significant.

Table 4: Long-term model estimation.

Variable dépendante : Biomasse en Carbone (BC)				
Variable	Coefficient	Ecart-type	t-Student	Prob.
C	438.6482	219.4681	1.998688	0.0475
BCS(-1)*	-0.421312	0.067659	-6.227039	**0.0000**
CONDS**	0.011333	0.024864	0.455809	0.6492
DOS(-1)	-2.037282	2.105720	-0.967499	0.3349
PHS(-1)	-17.66345	20.35729	-0.867672	0.3870
PMMS**	-0.017953	0.024763	-0.724995	0.4696
SES(-1)	-0.382267	2.725502	-0.140256	0.8886
TAS(-1)	-7.284072	3.601976	-2.022244	0.0449
TES**	-4.563362	5.758369	-0.792475	0.4293
TURBS**	0.602466	1.187372	0.507395	0.6126
D(DOS)	-1.684205	3.220056	-0.523036	0.6017
D(DOS(-1))	1.286577	3.228894	0.398457	0.6909
D(DOS(-2))	-8.672149	3.318835	-2.613010	**0.0099**
D(PHS)	-64.97892	23.94695	-2.713452	**0.0074**
D(SES)	-6.095318	3.710516	-1.642714	0.1026
D(TAS)	-11.07830	5.137394	-2.156404	**0.0327**
D(TAS(-1))	5.913493	4.979251	1.187627	0.2369
D(TAS(-2))	-9.113548	4.987843	-1.827152	0.0697
R-squared	0.518533			
Adjusted R-squared	0.463601			
S.E. of regression	39.05740			
F-statistic	9.439470			
Prob(F-statistic)	0.000000			

Algebraically, the validated model looks like this :

$$BCS = -8.672DOS - 64.978PHS - 11.078TAS$$

(t)	(-2.613)	(-2.713)	(-2.156)
(Prob.)	(0.0099)	(0.0074)	(0.032)
(sig.)	1%	1%	5%
R^2	:	0.519	
F	:	9.439	
Prob.(F)	:	0.0000	

4. Discussions

This study has determined the influence of climate variability on the carbon biomass of Lake Kivu.

The results indicate that atmospheric temperature negatively and significantly influences the carbon biomass of Lake Kivu. On the other hand, the other explanatory variables (Conductivity, precipitation, Secchi depth, Water temperature and Turbidity) synchronous have statistically zero coefficients because they have probabilities greater than 5%. They therefore have no effect on the carbon biomass.

The effectiveness of climate change and variability around Lake Kivu has been verified from time series of climate data of more than 3 decades with an increase in air temperature of 1.57°C in Kamembe for the

period from 1971 to 2013 (Akokwa, 2017). At the regional scale, high temperatures show a significant warming trend in the large lakes of the Eastern region (Edmond et al. 1993). Around Lake Tanganyika, another large lake in the region, historical data predict an increase in air temperature of 1.3°C for a period of 80 years (Hulme et al. 2001). This contributes to overheating surface waters, increasing thermal stability and reducing productivity. A regional decrease in wind speed contributed to reduced mixing, thereby decreasing the upwelling and entrainment of nutrients from deep waters to surface waters (Molsa et al., 1999).
Thus, our results are consistent with those found by O'Reilly et al, 2003 who show that global warming decreases the productivity of Lake Tanganyika. The same author indicates that carbon isotope records in sediment cores suggest that primary productivity may have decreased by about 20%. This implies a decrease of about 30% in fish yields. Similarly, in the Taihu Lake basin in China, Xiaohua 2010 shows a general trend of climate change between 1991 and 2000 with an increase in the annual mean temperature of 0.4°C air. The composition of phytoplankton changed at the same time, going from a dominance of diatoms to a dominance of cyanobacteria.
In general, Litchman et al. 2012, shows that phytoplankton can respond to environmental variations in three ways: (I) thanks to their phenotypic plasticity, organisms are able to persist in the environment, (II) the limits of their phenotypic plasticity being reached, some species not adapted to the new conditions are replaced by others better adapted, (III) species can adapt thanks to the selection of new genotypes through processes such as mutations.

5. Conclusion

It is important to conclude that climate variability has a negative effect on the Carbon Biomass carried by phytoplankton. These effects are functions of spatial distribution and anthropogenic activities. To do this, the adoption of policies for adaptation to the effects of climate change are measures proposed by this study for the sustainable management of fishery resources in Lake Kivu.

6. Acknowledgments

The authors thank the Teaching and Research Unit in Applied Hydrobiology (UERHA) of the Biology Department of the Higher Institute of Pedagogy of Bukavu in the Democratic Republic of Congo for its technical support in carrying out this work.

7. Bibliographic Reference

[1] **Adama F. et Mamadou A.K. 2023**. Pollution marine et rendement de la pêche au Sénégal, Revue Française d'Economie et de Gestion « Volume 4 : Numéro 1 » pp : 392 – 409.
[2] **Akaike H. 1973.** *Information theory and an extension of the maximum likelihood principle*, dans Second *International Symposium on Information Theory*, 1973, 267-281 p.
[3] **Aleke L.A. (2016).** Evaluation des charges polluantes (domestiques et industrielles) arrivant au lac Kivu dans la ville de Bukavu, RD. Congo.
[4] **Balagizi A.D. 2017.** Effets des changements climatiques et des pratiques de pêche sur les ressources halieutiques du lac kivu (Afrique de l'est) . These de doctorat Soutenue le 24 janvier 2017 par: Balagizi AKONKWA BALAGIZI En vue de l'obtention du grade de Docteur en Sciences (PhD) Option. Aménagement et Gestion des Ressources Naturelles (AGRN).
[5] **Benaziza A., 2018.** Evolution spatiotemporelle des communautés des microalgues des milieux lentiques de la région de Jijel. http://dspace.univ-jijel.dz:8080/xmlui/handle/123456789/1871. Dépôt Institutionnel Université de Jijel. Evolution spatiotemporelle des communautés des microalgues des milieux lentiques de la région de Jijel.
[6] **Benedetti F., 2018.** Impacts du changement climatique sur la diversité fonctionnelle du zooplancton, le cas des copépodes planctoniques de mer Méditerranée. Université Pierre et Marie Curie - Paris VI, 2016. Français. ffNNT : 2016PA066742ff. Fftel-01814326. **RWA/87/012/DOC/TR/35.**
[7] **Dickey D.A. et Wayne A.F. 1981.** Likehood Ratio statistics for autoregressive time series with a unit Root. Econometrica, vol. 49, N°4(jul, 1981), pp 1057-1072.
[8] **Edmond J. M., Stallard R. F., Craig H., Craig V., Weiss R. et Coulter G.W. 1993.** Nutrient Chemistry of the water column of Lake Tanganyika. Limnol. Oceanogr. 38: 725 – 738 (1993).
[9] **GIEC, 2023.** Le rapport de synthèse du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC) est publié le 20 mars 2023, à l'issue d'une session d'approbation qui s'est tenue du 13 au 17 mars en Suisse avec les

représentants des 195 pays membres du GIEC. Ce document synthétise les rapports des trois groupes de travail sur les éléments physiques du climat, l'adaptation et l'atténuation.

[10] **Groga, N. 2012.** Structure, fonctionnement et dynamique du phytoplancton dans le lac de Taabo (Côte d'Ivoire), Ecole doctorale : ED SDU2E Unité de recherche : Laboratoire Ecologie Fonctionnelle et Environnement (Ecolab UMR 5245).

[11] **Hade, A., 2002**. Nos lacs – les connaître pour mieux les protéger. Éditions Fides, 360 p.

[12] **Hamisultane H. 2016**. Econométrie des séries temporelles. Licence. France. 2002. ffcel01261174f. https://shs.hal.science/cel-01261174.

[13] **Hannan, E.J. et Quinn, B.G (1979).** The determination of the order of an autoregression jounal of the Royal statistical Society, series B, : 42 :190-195.

[14] **Hugo S., 2006**. Écologie du phytoplancton du lac Kivu (Afrique de l'Est). Presse universitaire de Namur et Hugo, Rampart de la vierge, 13 B-Namur (Belgique).

[15] **Hulme, M., Doherty, R., Ngara, T., New, M. & Lister, D. African climate change. 2001.** 1900–2100. Climate Res. 17, 145–168 (2001).

[16] **IPCC. 2013.** Climate Change 2013 : The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. GIEC, 1-1535.

[17] **Isumbisho, M.P. 2006.** Ecologie du Zooplancton du Lac Kivu (Afrique de l'Est). Dissertation présentée par Pascal Isumbisho Mwapu en vue de l'obtention du grade de Docteur en Sciences 2006.

[18] **Jacquemin C., 2019.** Vulnérabilité des lacs de haute altitude au changement climatique Thèse présentée pour obtenir le grade universitaire de docteur, Numéro national de thèse/suffixe local : 2019AIXM0012/001ED251.

[19] **Jarque C.M. et BERA A.K. (1980)**. Efficient Tests for Normality, Homoscedasticity and Serial Independence of Regression Residuals. Economics Letters 6, 255-259. https://doi.org/10.1016/0165-1765(80)90024-5

[20] **Keller, J.M. et Suzuki, K. (1988)** Use of ARCS motivation model in courseware design. In D.H. Jonassen (ed), *Instructional Designs for Microcomputer Courseware.* Hillsade NJ: Lawrence Erlbaum.

[21] **Kibala, K.J, 2018.** Modélisation ARDL, Test de cointégration aux bornes et Approche de Toda-Yamamoto : éléments de théorie et pratiques sur logiciels. Université de Kinshasa Faculté des Sciences Economiques et de Gestion Département des Sciences Economiques B.P. 832 kinshasa XI

[22] **Kossivi A., Bawa L.M, Kokou K., Djaneye B.G, Edorh M. T. 2013.** Distribution saisonnière du phytoplancton en fonction des caractéristiques physico-chimiques du lac de Zowla (Lac Boko) dans le Sud- Est du Togo : cas de la petite saison sèche et de la grande saison sèche

[23] **Lalèyè K.R., Agadjihouèdé H., Djiman L., Agblonon H. T., Chikou A., Adédjobi P. L, 2022.** Impact de l'exploitation du sable fluvio-lagunaire sur la qualité physico-chimique de l'eau des écosystèmes aquatiques du sud-Bénin. Biotechnol. Agron. Soc. Environ. 2022 26(2), 121-135.

[24] **Lecrenier P. 2016**. Le lac Kivu, un eldorado à surveiller - Réflexions (uliege.be).

[25] **Litchman, E., Edwards, K.F., Klausmeier, C.A. & Thomas, M.K. (2012).** Phytoplankton niches, traits and eco-evolutionary responses to global environmental change. Marine Ecology Progress Series, 470, 235248.

[26] **Marshall B. E. 1993.** The biology of the African Clupeid Limnothrissa miodon with special reference to its small size in artificial lakes, Reviews in Fish Biology and Fisheries 3:14-22.

[27] **MEA. 2005.** Millennium ecosystem assessment global assessment reports.

[28] **Molsa, H., Reynolds, J. E., Coenen, E. J. et Lindqvist, O. V. Fisheries, 1999.** Research toward resource management on Lake Tanganyika. Hydrobiologia 407, 1–24 (1999).

[29] **O'Reilly M.C, Simone R.A, Plisnier P.D, Andrew S.C et Brent A.M, 2003.** Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. Present addresses : Environmental Science Program, Vassar College, Poughkeepsie, New York 12603, USA (C.M.O.) ; Large Lakes Observatory, University of Minnesota, Duluth, Minnesota 55812, USA (S.R.A.)

[30] **Pesaran M.H., Shin Y. et Smith, R. (2001)**. Bounds Testing Approaches to the Analysis of Level Relationships. Journal of Applied Econometrics, 16, 289-326. https://doi.org/10.1002/jae.616

[31] **Peterson C., et Seligman M. E. (1987).** Explanatory style and illness. *Journal of Personality, 55*(2), 237–265. https://doi.org/10.1111/j.1467-6494.1987.tb00436.x

[32] **Petitgas P., Ulrich C., Auber A., Gourguet S., Huret M., Mazurais D., Pernet F., Pouvreau S., Marion R., Servili A., Thébaud O., Zambonino I.J., 2020**. Conséquences du changement climatique sur les écosystèmes marins exploités par la pêche et la conchyliculture. No 18. Juin 2020 Centre d'études stratégiques de la Marine.

[33] **Polunin N.V.C. 2008.** Aquatic ecosystems : trends and global prospects. Cambridge : Cambridge University Press.

[34] **Ramsey, F. (1928)**. A Mathematical Theory of Saving. Economic Journal, 38, 543-559. http://dx.doi.org/10.2307/2224098

[35] **Rodier J., Legube B., et Merlet N. 2009.** L'analyse de l'eau. 9e édition Entièrement mise à jour. © Dunod, Paris, 2009 © Dunod Paris, 1959, pour la 1re édition Couverture : Mateo Photo de couverture : © GettyImages ISBN 978-2-10-054179-9. Pp905-913.

[36] **Rosenzweig, C., Casassa G., Karoly D.J., A., Imeson C., Liu A., Menzel S., Rawlins, T.L., Root, B., Seguin, Tryjanowski P., and Hanson C.E., 2007.** Assessment of observed changes and responses in natural and managed systems. Climate Change 2007. Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, and P.J. van der Linden, Eds., Cambridge University Press, pp. 79-131..

[37] **Sagan G et Thouzeau G. 1998.** Variabilité spatio-temporelle de la biomasse microphytobenthique en rade de Brest et en Manche occidentale. UMR 6539 CNRS, Université de Bretagne occidentale, Institut universitaire europeen de la mer, Technopole Brest-Iroise, place N.-Copernic, 29280 Plouzane, France. OCEANOLOGICA ACTA - VOL. 21 - No5.

[38] **Sardet C., 2015.** Plankton : Wonders of the Drifting. World University of Chicago Press, 2015. 222 pp.

[39] **Souchu P, Cochennec L.N, Ratmaya W, Retho M, Andrieux-Loyer F, Le Merrer Y, Barillé L, Barillé A-L, Goubert E, Plus M, Laverman A (2018)**. Diagnostic étendu de l'eutrophisation (DIETE), rôle des sédiments dans le cycle des nutriments et impacts sur l'eutrophisation de la baie de Vilaine. Rapport de contrat pour AELB (période 2014-2017), 237 p.

[40] **Stockner J.G., Antia N.J. (1986).** Algal picoplancton from marine and freshwater ecosystems : a mtfltidisciplinar y perspec - tive . Can. J. Fish. Aquat. Sci., 43 : 2472-2503.

[41] **Thouvenin B. et Romana L.A. 1992.** Modélisation mathématique de l'oxygène dissous dans l'estuaire de la Loire, première phase. R. Int. Del/92.05/Toulon.

[42] **Thyssen M., Mathieu D., Garcia N., Denis M. (2008).** Short-term variation of phytoplankton assemblages in Mediterranean coastal waters recorded with an automated submerged flow cytometer. J. Plank. Res. 30, pp 1027-1040.

[43] **Toda, H.Y. and Yamamoto, T. (1995).** Statistical Inference in Vector Autoregressions with Possibly Integrated Processes. Journal of Econometrics, 66, 225-250. http://dx.doi.org/10.1016/0304-4076(94)01616-8

[44] **Vilimumbalo S. 1993.** Paléoenvironnements et interpretations paléoclimatiques des dépôts palustres du pléistocène supérieur et de l'holocène du rift centrafricain au sud du lac Kivu (Zaïre). Analyses palynologiques et sédimentologiques. Faculté des Sciences, ULg, 212 p.

[45] **Xiaohua L.B, Xia L., Yuwei C., 2010.** The effects of temperature and nutrient ratios on Microcystis blooms in Lake Taihu, China : An 11-year investigation. Harnful Algae 10 (2011) 337-343) 1568-9883/$ – see front matter/ 2010 Elsevier B.V. All rights reserved. Doi : 10.1016/j.hal.2010.12.002.

Madiumba Bamba Arnold Jonas, Guyh Dituba Ngoma, Cush Ngonzo Luwesi, Kintu Mayaka Doudou, Benjamin Kimbungu, Happy Kimvwela Salabiaku, Birikomo Mihigo Juvénal and Napoléon Kabama Kasombo
Impact of Thermal Energy Exploitation on the low Service Rate of drinking Water in Kenge town, Democratic Republic of Congo
International Journal Water Sciences and Environment Technologies
Vol. (x), Issue. 1, March 2025, pp. 86-94
ISSN Online: 1737-9350; ISSN Print: 1737-6688, Open Access
www.jiste.org
Scientific Press International Limited
Received: January 2025 / Revised: February 2025 / Accepted: March 2025 / Published: March 2025

Impact of Thermal Energy Exploitation on the low Service Rate of drinking Water in Kenge town, Democratic Republic of Congo

Madiumba Bamba Arnold Jonas[1], Guyh Dituba Ngoma[1, 2], Cush Ngonzo Luwesi [1,3], Kintu Mayaka Doudou[1], Benjamin Kimbungu[1,4], Happy Kimvwela Salabiaku[1] , Birikomo Mihigo Juvénal[1,5] and Napoléon Kabama Kasombo[1]

1 Water School of the University of Kinshasa in DRC;
2 University of Quebec in Abitibi-Témiscamingue, UQAT-Québec/CANADA ;
3 African University of Management and Technologies AUMT-Congo-Brazzaville ;
4 Ministry of Water Ressources ;
5 Higher Pedagogical and Technical Institute of Kinshasa

Abstract

In accordance with Sustainable Development "Goal Number 6 (SDG 6)", the main objective of the Democratic Republic of Congo (DRC) is to ensure universal and equitable access to drink water for all by 2030. The Kenge town, like other towns in the DRC, is currently facing enormous difficulties in accessing drinking water due to a lack of energy. The aim of this study is to assess the supply of drinking water to the town of Kenge and the level of water service in relation to actual demand, based on the total installed power of REGIDESO S.A./Kenge's generating sets and motor-driven pumps. This approach makes it possible to calculate daily production by considering the scenarios of the energy demand of the motor pump sets satisfied by the generating set.The results showed that, in a scenario where the genset operates at 60% of its energy demand, water production is 120 m³ per hour, giving an average of 960 m³ for the 8-hour operating time required by REGIDESO S.A./Kenge. These figures are halved during the rainy season, to 480 m³ in a scenario of low demand for water by the population. This production is well below the actual daily drinking water requirement of the population of Kenge town, which is estimated at 7076 m³ for a population of 353810. Furthermore, the drinking water supply rate is 14% and 7% respectively for the two operating scenarios (high and low water demand).

Keywords: Fossil Fuels, Greenhouse Gases, Drinking Water Requirements, REGIDESO.

Impact de l'exploitation de l'énergie thermique sur le faible taux de service de l'eau potable dans la ville de Kenge, République démocratique du Congo

Résumé

Conformément à l'Objectif de Développement Durable n° 6 (ODD 6), l'objectif principal de la République Démocratique du Congo (RDC) est d'assurer un accès universel et équitable à l'eau potable pour tous d'ici 2030. La ville de Kenge, à l'instar d'autres villes de la RDC, est actuellement confrontée à d'énormes difficultés d'accès à l'eau potable en raison du manque d'énergie. L'objectif de cette étude est d'évaluer l'approvisionnement en eau potable de la ville de Kenge et le niveau de service d'eau par rapport à la demande réelle, en se basant sur la puissance totale installée des groupes électrogènes et des motopompes de la REGIDESO S.A./Kenge. Cette approche permet de calculer la production journalière en considérant les scénarios de demande énergétique des groupes motopompes satisfaits par le groupe électrogène. Les résultats ont montré que, dans un scénario où le groupe fonctionne à 60 % de sa demande énergétique, la production d'eau est de 120 m³ par heure, soit une moyenne de 960 m³ pour les 8 heures de fonctionnement requises par la REGIDESO S.A./Kenge. Ces chiffres sont divisés par deux en saison des pluies, à 480 m³ dans un scénario de faible demande en eau de la population. Cette production est bien inférieure aux besoins quotidiens réels en eau potable de la population de la ville de Kenge, estimés à 7 076 m³ pour une population de 353 810 habitants. Par ailleurs, le taux d'approvisionnement en eau potable est respectivement de 14 % et 7 % pour les deux scénarios d'exploitation (forte et faible demande en eau).

Mots clés : Combustibles fossiles, gaz à effet de serre, besoins en eau potable, REGIDESO.

[1] Corresponding author: maimouna.lo@ucad.edu.sn

INTRODUCTION

Access to safe drinking water and appropriate sanitation is crucial to reduce health risks and create a healthy environment (Dombor et al., 2018). It is therefore essential to know the current situation and trends in water supply and sanitation (Aser, 2022). The aim is to inform policymakers and sector stakeholders so that they can make informed decisions (Kayobola, 2020). Water supply includes different stages, such as collection or withdrawal, treatment to make it drinkable, distribution to consumption points to make it accessible to users, and storage (Benazzouz, 2017). At the heart of the Sustainable Development Goals (SDGs) for 2030, SDG 6 aims to "ensure access to safe drinking water and sanitation for all, and to ensure sustainable management of water resources" (UNICEF, 2015).

Unfortunately, it can be observed that, in most cases, the low rate of drinking water supply is dependent on energy deficits related to the use of thermal energy (Kouadio, 2021). Although this energy source can quickly meet the energy needs of the operation in the drinking water sector, it is less cost-effective and does not reduce the pressure on the water resource due to the expenses related to the operation of thermal machines for the production of electrical energy (Remadnia, 2017).

Thus, despite the desire to improve water supply networks in rural areas, the lack of electricity forces the water service to apply sales rates per cubic meter of drinking water 4 to 5 times higher compared to the same volume sold in an urban area served by a hydroelectric network to operate water production machines, even if they are rationed in 20 or 25-litre units at the fountains in order to make drinking water accessible to a large number of people (Nya et al., 2021).

According to recent data from REGIDESO S.A., out of the 99 operating centres, 63 operate with thermal energy sources and only 26 centres operate in hydroelectric regimes (REGIDESO, 2023). Regardless of the immensity of its freshwater resources, the DRC faces a major challenge in the water sector, that of increasing the low rate of access to drink water for its rapidly growing population (OWAS, 2007).

The exclusive use of fossil energy sources, such as thermal power plants, to ensure the supply of electrical energy in the drinking water sector does not guarantee optimal use of water resources (Naudet et al., 2008). Indeed, the option of generators is faced with the increase in fuel prices, as well as the costs associated with transporting fuel in regions that are often difficult to access, not to mention the costs of operation and maintenance in these isolated regions (Léna, 2013). In addition, the energy efficiency of generators deteriorates when their use is low (Poulin, 2009).

The city of Kenge faces challenges in securing its water supply due to its geographical location. As water sources are located in highland valleys, it is difficult to supply them without the help of an alternative clean energy system (Omasombo et al., 2012).

The purpose of this study is to determine, the capacity for the production of drinking water with the use of thermal energy and, on the other hand, to estimate the real demand need and the water satisfaction rate of the city of Kenge.

1. Materials and Method

1.1. Presentation of the Study Environment

Kenge town (Figure 1) is located in the province of Kwango in the Democratic Republic of Congo, at an altitude of 556 m with the following geographical coordinates: Latitude: 4°49'60" South and Longitude: 16°54′0" East, and an area of 1,812,600 hectares, or 18,126 km² (Omasombo et al., 2012). According to the Köppen-Geiger classification, the city of Kenge has a savannah climate with a dry winter (AW) in an area with significant rainfall, even during the driest month. The average annual temperature remains around 25.6 °C and rainfall averages 799.8 mm, compared to Kinshasa where the average annual temperature is around 25.3 °C and the average rainfall is 1,273.9 mm.

The city of Kenge, located on the watershed (head of springs) that drain its geographical space, is located between two hydrological watersheds: the Wamba basin at 12 kilometers at the entrance to the city on the northwest side and the Bakali sub-basin at 6 kilometers on the southeast side at the exit of the city.

International Journal Water Sciences and Environment Technologies
e-ISSN: 1737-9350 p-ISSN: 1737-6688, | Open Access Journal | Volume (x) - Issue 1 – March 2025
Volume (x): Water -Biodiversity-Climate'2025

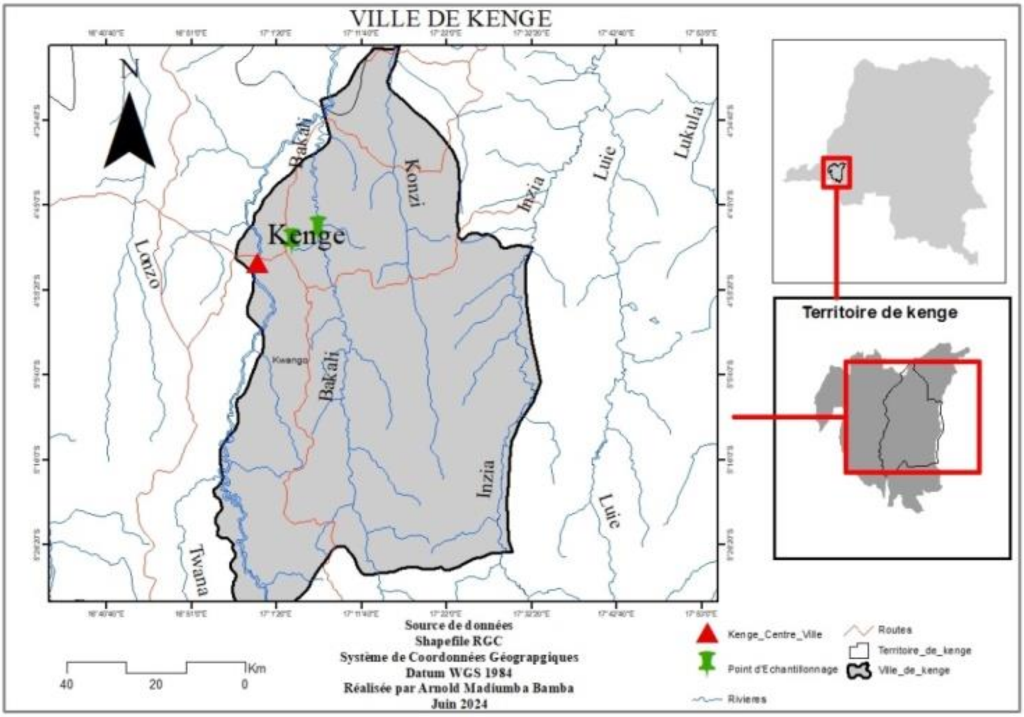


Figure 3: Kenge City Map

The city of Kenge comprises five communes and fifteen wards, with a total population of 353,810 inhabitants in 2022. Table 1 illustrates the distribution of the inhabitants of Kenge by commune and district.

Table 1: Distribution of the population of the city of Kenge by Commune

N°	COMMUNE	QUARTER	POPULATION
01	Laurent DESIRE KABILA	Pont Wamba	27 565
		Congo	27 501
		Mangangu	21 893
Sub-total (22%)			**76 959**
02	Mavula	Mavula	18 129
		Epom	25 178
Sub-total (12%)			**43 307**
03	Cinq Mai	Bakali	40 632
		Kikwit	24 926
Sub-total (19%)			**65 558**
04	Masikita	Masikita	20 941
		Salongo	9 098
		Munikenge	11 324
		Mukizi Mupepe	25 929
Sub-total (19%)			**67 292**
05	Manonga	Manonga	23 079
		Kapanga	32 493
		Yete	31 394
		Kenge 3	13 728
Sub-total (28%)			**100 694**
Grand Total			**353 810**

Source: Kenge Town Hall, 2O23

REGIDESO S.A./Kenge has 214 water distribution points, including 115 standpipes, 66 private subscribers, 5 intermediaries, 6 commercial ones, 6 official bodies (I.O), 2 decentralized administrative entities (E.A.D.), 8 REGIDESO services and 6 REGIDESO agents, as shown in table 2.

Table 2: Water distribution point in the city of Kenge by Commune

Type of service	Communes				
	Laurent Desire Kabila	Mavula	Cinq Mai	Masikita	Manonga
Standpipe	16	11	39	21	28
Private subscriber	7	4	13	25	17
Intermediary	1	1		1	2
Commercial	2	2		2	
Official body		2	1	2	1
Decentralized administrative entity				2	
Service Regideso		3	1	3	1
Agent Regideso		2			4
Total	**26**	**25**	**54**	**56**	**53**
%	**12%**	**12%**	**25%**	**26%**	**25%**

Source: REGIDESO S.A./Kenge, 2023

1.2. Data collection

Most of the data used in this study come from a documentary analysis of the existing drinking facilities of REGIDESO S.A./Kenge. To better understand the level of household satisfaction with the drinking water supply in Kenge, we used survey questionnaires, interview guides and discussion guides. The choice of this city as a pilot was made because of its proximity to Kinshasa, as well as the type of energy used by REGIDESO S.A. to provide drinking water to the population. In addition, the morphology of the city makes access to drinking water difficult in the event of an energy shortage on the part of REGIDESO.

1.3. Data analysis

The data analysis consisted of evaluating two operating scenarios of the REGIDESO S.A./Kenge drinking water production plant using thermal energy: the 60% (scenario with the required) and 30% (scenario without required) operation of the generator set according to the energy demand of the motor pumps. On the other hand, the study estimated the satisfaction rate of drinking water served by REGIDESO S.A. in relation to the actual demand of households in the city of Kenge.

To determine the operating load, the study carried out an inventory of the installed capacity for the production of drinking water by REGIDESO S.A./Kenge as follows: firstly, the determination of the total installed capacity of REGIDESO S.A./Kenge; and secondly, the estimation of drinking water services according to the operating scenarios of the motor pumps.

a) **Determination of the energy demand of REGIDESO S.A./Kenge.**

a.1. Determination of the total installed capacity.

The total installed capacity provides information on the power of all the machines installed, in particular the generators used to produce the electrical energy necessary for the operation of the motor pumps and electric motors (pump sets). These are used to produce the mechanical energy required to drive the pumps and provide the hydraulic power needed for water production.

It should be noted that the thermal power plant of REGIDESO S.A./Kenge is equipped with two generators with an installed capacity of 220 kW each, while the two water production plants are equipped with three motor pump sets with an installed capacity of 55 kW and 11 kW each, respectively.

a.2. Scenario with the requirement : operation at 60% of the generator set

For operation with the required, only one generator set is in service with two motor pump sets in each plant. This represents an operation at 60% of the energy demand of the generator set using the specific consumption and utilization coefficient below:

$$Duty\ cycle = \frac{\sum P(GMP)}{\mathrm{P\ (GE)}} \quad (1)$$

$$Specific\ consumption = \frac{\mathrm{P(GE)\times Duty\ cycle}}{\mathrm{time\ (s)}} \quad (2)$$

Where :

- **P(GMP)** : Power of the motor pump units ;
- **P(GE)** : Power of the generator set.

a.3. No required scenario: 30% Generator Set Operation

This situation is often observed in the event of a succession of rains in the area. In this scenario, the generator is operating at 30% empty, a condition not recommended for generators operating under load (Léna, 2013). Thus, only one 55 kW pump unit is used at the collection station, and only one or no pump unit at the intermediate station.

b. Application for drinking water supply to the city of Kenge

Knowing the number of subscribers and referring to the WHO standard which recommends an average consumption of 20 liters per person per day in rural areas, the calculation of the daily demand for drinking water of the population of the city of Kenge in the framework of this study is as follows :

$$D_{jm} = (C_s \times P) \quad (3)$$

Where :

- **Djm** = Daily Demand
- **Cs** = Specific consumption
- **P** = Population

To estimate the level of drinking water service in the city of Kenge, we used the following formula:

$$Service\ level\ (\%) = \frac{\mathrm{Production\times 100}}{\mathrm{request}} \quad (4)$$

2. Results

2.1. Determination of the total installed capacity

The total installed power indicates that of all the machines installed, in particular that of the generator set for the production of the electrical energy necessary for the operation of the motor pump sets to provide hydraulic power. Table 3 shows the brand and technical characteristics of the equipment installed at REGIDESO S.A./Kenge.

Table 3: Total installed capacity

FEATURES	THERMAL POWER PLANT		MANIOKA CATCHMENT STATION			CAMP EPOM MIDDLE STATION		
Equipment	***GE 1***	***GE 2***	***GMP1***	***GMP2***	***GMP3***	***GMP1***	***GMP2***	***GMP3***
Mark	FG Wilson	FG Wilson	KSB	KSB	KSB	KSB	KSB	KSB
Power (kW)	220	220	55	55	55	11	11	11
Voltage (V)	400	400	400	400	400	380	380	380
Intensity (A)	397	397	96	96	96	22,3	22,3	22,3
Frequency (Hz)	50	50	50	50	50	50	50	50
Speed (RPM)	1500	1500	2970	2970	2970	1465	1465	1465
Power factor	0,80	0,80	0,89	0,89	0,89	0,82	0,82	0,82
Flow (Q) : m^3/h)			60	60	60	30	30	30
Height (HMT) : m)			186,21	186,21	186,21	68,30	68,30	68,30

It should be noted that the thermal power plant of REGIDESO S.A./Kenge has two installed generators of 220 kW each, for a total output of 440 kW. The two water production plants are equipped with three pump units each, with respective outputs of 55 kW and 11 kW, for a total of 165 kW and 33 kW. Thus, for the two drinking water production plants, the installed capacity is 198 kW.

3.2. Scenario with the required: 60% operation of the generator set

For operation with the required (Table 4), only one generator set is in service with two motor pump sets in each plant. This represents an operation at 60% of the energy demand of the generator, with a specific hourly consumption of 37 l/h and a production of 120 m³/h.
Considering an average operating time of 8 hours in the context of REGIDESO S.A./Kenge, it can be seen that during a high demand for water, the company produces only 960 m³ of water per day, which corresponds to 960,000 liters of water.

Table 4: Scenario of high demand for drinking water by the population

FEATURES	THERMAL POWER PLANT	MANIOKA CATCHMENT STATION			CAMP EPOM MIDDLE STATION		
Equipment	GE 1	GMP1	GMP2	Operation with 2 GMPs	GMP1	GMP2	Operation with 2 GMPs
Mark	FG Wilson	KSB	KSB		KSB	KSB	
Power (kW)	220	55	55	110	11	11	22
Voltage (V)	400	400	400	400	380	380	380
Intensity (A)	397	96	96	192	22,3	22,3	44,6
Frequency (Hz)	50	50	50	50	50	50	50
Speed (RPM)	1500	2970	2970	2970	1465	1465	1465
Power factor	0,80	0,89	0,89	0,89	0,82	0,82	0,82
Flow (Q) : m³/h)		60	60	120	30	30	60
Height (HMT) : m)		186,21	186,21	186,21	68,30	68,30	68,30

3.3. No required Scenario: 30% Generator Set Operation

The scenario presented in Table 5 is often observed in the event of a succession of rains in the area. In this scenario, the generator is operating at 30% empty, a condition not recommended for generators operating under load (Léna, 2013). Thus, only one 55 kW pump unit is used at the collection station, and only one or no pump unit at the intermediate station, for a consumption of 18 l/h and a production of 60 m³/h. This low-demand scenario produces only 480 m³, or 480,000 liters of water per day.

Table 5: Low Demand Case

FEATURES	THERMAL POWER PLANT	MANIOKA CATCHMENT STATION		CAMP EPOM MIDDLE STATION	
Equipment	GE 1	GMP1	Operation with 1 GMP	GMP2	Operation with 1 GMP
Mark	FG Wilson	KSB		KSB	
Power (kW)	220	55	55	11	11
Voltage (V)	400	400	400	380	380
Intensity (A)	397	96	96	22,3	22,3
Frequency (Hz)	50	50	50	50	50
Speed (RPM)	1500	2970	2970	1465	1465
Power factor	0,80	0,89	0,89	0,82	0,82
Flow (Q) : m³/h)		60	60	30	30
Height (HMT) : m)		186,21	186,21	68,30	68,30

3.4. Evaluation of the demand for drinking water supply in the city of Kenge

The estimation of water needs is the basis for improving the city's water supply. It corresponds to the total flow necessary to meet the drinking water needs of the population of Kenge.

The analysis in Table 6 shows that the actual daily drinking water requirement for the city of Kenge is estimated at 7076 m³ for a population of 353,810 inhabitants. It is also noted that the municipality of Manonga has a high drinking water requirement, i.e. 2013 m³, due to its high demographic configuration. On the other hand, the water requirement of the municipality of
Mavula is low, i.e. 866 m³ per day.

Tableau 6. Estimating the city's drinking water needs

N°	COMMUNE	QUARTER	POPULATION	Need./pers/day (m^3/D)	Need./T/pers/day (m^3/D)
01	Laurent DESIRE KABILA	Pont Wamba	27 565	0,02	551,3
		Congo	27 501	0,02	550,02
		Mangangu	21 893	0,02	437,86
Sub-total (22%)			**76 959**		**1 539,18**
02	Mavula	Mavula	18 129	0,02	362,58
		Epom	25 178	0,02	503,56
Sub-total (12%)			**43 307**		**866,14**
03	Cinq Mai	Bakali	40 632	0,02	812,64
		Kikwit	24 926	0,02	498,52
Sub-total (19%)			**65 558**		**1 311,16**
04	Masikita	Masikita	20 941	0,02	418,82
		Salongo	9 098	0,02	181,96
		Munikenge	11 324	0,02	226,48
		Mukizi Mupepe	25 929	0,02	518,58
Sub-total (19%)			**67 292**		**1 345,84**
05	Manonga	Manonga	23 079	0,02	461,58
		Kapanga	32 493	0,02	649,86
		Yete	31 394	0,02	627,88
		Kenge 3	13 728	0,02	274,56
Sub-total (28%)			**100 694**		**2 013,88**
Grand Total			**353 810**		**7 076,2**

3.5. Level of drinking water service in the face of the demand of the city of Kenge

In order to understand the drinking water satisfaction rate provided by REGIDESO S.A., we compared the production (delivery) with the actual water needs of the population of the city of Kenge. To do this, two operating scenarios allowed us to evaluate the percentage of drinking water service (Table 7).

Table 7. Level of drinking water service in relation to the actual needs of the city of Kenge

8-hour operation with required			8-hour operation with no required		
Production (delivery) (m^3/d)	Househol d demand (m^3/d)	Level of satisfaction	Production (delivery) (m^3/d)	Household demand (m^3/d)	Level of satisfaction
960	**7 076**	**14**	**480**	**7 076**	**7**

It appears from Table 7 that, for 8 hours of operation required per day, the daily production of REGIDESO is 960 m³, instead of the 7076 m³ needed to serve the city, i.e. a 14% drinking water supply rate. In addition, in the event of low demand, the daily production is estimated at 480 m³, i.e. a service rate of 7%.

4. DISCUSSION

Despite the efforts of the Congolese authorities to improve water supply networks in rural, urban and peri-urban areas, the lack of electrical energy is a factor limiting the time it takes to produce drinking water. This has a significant impact on the quantity produced, which is far below the actual needs of the population. The results of this study show that, for operation at 60% of the energy demand of the generator, the specific hourly consumption of diesel is 37 l/h and the production of drinking water is 120 m³/h, i.e. 960 m³ per day for an operating time of 8 hours per day. These figures are reduced to 480 m³ in a no-requirement scenario, in case of low demand. In addition, the drinking water supply rate is 14% and 7% respectively for the two operating scenarios.

(i) For operation with thermal power (generators).

Naudet et al. (2008) argue that electricity generation from fossil fuels is one of the main conversions of the current energy system. In a thermal power plant, the energy contained in the fuel, stored in chemical form, is converted by combustion into heat, then into kinetic energy of the steam, then into mechanical energy of the turbine and finally into electricity thanks to the alternator. This electrical energy contributes to the operation of motor pump sets for the production of drinking water, although the exploitation is not optimal in this sector of water resources, as it is often used in stand-by mode.

Naite (2023) shows that generator sets can operate in either stand-by or prime service mode. In stand-by mode, they are designed to provide electricity to a facility in the event of a public grid failure. These systems are automatically switched on as soon as there is an interruption in the power supply. In continuous service mode, generators are used in sites where the public distribution network is non-existent, technically impossible to set up or economically unviable, such as mountainous areas or mines. Typically, these generators operate for long periods of time throughout the year.

Léna (2013) indicates that the generator option is confronted with the increase in fuel prices, as well as the costs associated with transporting fuel in regions that are often difficult to access, not to mention the operating and maintenance costs in these isolated regions. Remadnia (2017) adds that thermal power plants, due to their flexibility and responsiveness, are considered to be one of the most effective ways to cope with fluctuations in electricity demand, especially during peak consumption periods. They have the capacity to produce electricity quickly and can therefore be called upon at any time.

(ii) In relation to the maintenance of generator sets.

Ngomono M. (2013), in his research on the study of the operation and the development of a preventive and curative maintenance plan for the generator set (black-start generator) of the Dibamba thermal power plant, notes that for a generator set to be used optimally, it must be monitored and receive regular preventive maintenance operations in order to keep it in a stable state of operation.

For his part, Michel Demers (1998) bases its maintenance on equipment that is a major contributor to the failure of the generator set and that which has a significant impact on its reliability at start-up. Poulin (2009) attests that the proper functioning of generators is on the list of operational priorities for drinking water treatment plants. The more comprehensive the short- and long-term maintenance program, the more the treatment plant will ensure that the water supply is maintained during crises. An annual maintenance program must include the inspection of the following: general conditions of the generator set; cooling system (radiator condition, antifreeze analysis, belts, hoses); fuel supply system (tanks, pumps, filters).

(iii) Concerning the supply of drinking water.

The result of our study shows that the service rate is much lower than that found by Yago (2017), who showed that according to the National Inventory of Hydraulic Structures, in the rural commune of Saponé, Bazèga province in Burkina Faso, the rate of access to drinking water was estimated at 94% at the end of 2015. Although this rate is relatively high in Burkina Faso, it nevertheless presents overall difficulties: the level of drinking water service does not comply with national standards, the coverage of needs is partial and unevenly distributed, there is a real problem with the sustainability of the distribution infrastructure (10.7% of breakdowns), access conditions are difficult and the way in which the drinking water service is managed is not controlled.

In addition, Kouiye (2021) shows that the connection rate in the city of N'Gaoundéré in Cameroon is particularly low, estimated at 0.08% of subscribers per linear kilometer of the water supply network. The analysis of socio-cultural constraints shows that certain social strata (10.1%) influenced by cultural considerations refrain, for example, from using water from the formal network because of certain beliefs. From another angle of analysis, the author underlines the influence of politics and its networks within the three communes of N'Gaoundéré. This factor has a significant impact on the drinking water supply of the inhabitants. Indeed, since 2007, there have been strong disparities in the distribution of autonomous water points (boreholes), which are linked to the establishment of political parties seeking to satisfy their electorate. They favour the neighbourhoods that supported them in the 2013 municipal elections.

Faced with the difficulties of access to drinking water, the populations have developed their own means of supply. Wells, some with hydraulic pumps, boreholes and natural springs are the main sources of supply, as well as water from rivers and shallows. Water is also retailed by street vendors who provide home deliveries (Kouiye, 2021). It can be seen that 46% of the population mainly uses wells as a source of supply. However, these palliative means of supply are dangerous and have consequences on health, with uncontrolled financial repercussions for households, not to mention other social risks. As far as health is concerned, households are victims of many water-related diseases, typhoid fever being the main one with an estimated prevalence rate of 40.23%.

5. Conclusion

The purpose of the study was to determine, on the one hand, the capacity to produce drinking water with the use of thermal energy and, on the other hand, to estimate the real demand and the water satisfaction rate of the city of Kenge. To achieve this, we determined the total installed capacity of the generators and pump sets, calculated the daily production by considering the operating scenarios of the pump sets of REGIDESO S.A./Kenge, and finally evaluated the demand for drinking water supply in the city of Kenge and the level of water service.

The results of this work show that, for an operation at 60% of the energy demand of the generator, we have a production of 120 m³ of water per hour, which gives an average of 960 m³ for an operating time of 8 hours per day.

BIBLIOGRAPHIC

[1] **Aser J. E. S., 2022.** Problem of access to drinking water in the sub-prefecture of Gboguhé (Centre-West Côte d'Ivoire). University of Bondoukou. DOI Article: 105281/Zenodo 6862787

[2] **Benazzouz, 2017.** Wastewater pumping and lifting stations.

[3] **Demers M., 1998.** Development of a methodology for optimizing maintenance through reliability for complex systems: application to an emergency diesel generator. University of Quebec. Thesis presented at the University of Quebec at Trois-Rivières.

[4] **Dombor D. D., Mbaindongoum D., 2018**. Problem of access to drinking water in the city of Abéché in Chad Problem of access to drinking water in the city of Abéché in Chad. Annales de l'Université de Moundou, Série A - Faculté des Lettres, Arts et Sciences Humaines, Vol.5(2), Jan. 2019, ISSN 2304-1056.

[5] **Kayobola K. T., 2020 :** Rural drinking water supply in the Democratic Republic of Congo in the face of Sustainable Development Goal 6, Example of the province of Maniema. Thesis presented for the degree of philosopy doctor (phd.) In environmental engineering.

[6] **Kouadio K. A., 2021** : The challenges of electrification in rural Côte d'Ivoire. Thesis to obtain the degree of Doctor from the University of Lorraine Discipline: Geography.

[7] **Kouiye G. J., 2021**. Problem of access to drinking water in the city of Ngaoundere and its peri-urban area. Geographers' Notebooks [Online], 14 | 2020, published online on 30 November 2020, consulted on 21 May 2021. URL: http://journals.openedition.org/cdg/5331.

[8] **Léna G., 2013** : PV-diesel hybrid mini-grids for rural electrification: Overview and recommendations for their deployment. Page 11.

[9] **Naudet G. et Reuss P, 2008**. Energy, electricity and nuclear. National Institute of Nuclear Science and Technology. Génie Atomique, May 2008 edition.

[10] **Nya E. L. et Tejiobou A. R., 2021**. Drinking water supply problem in the Sahelian city of Garoua (North – Cameroon). University of MAROUA. Article • December 2021. 19 Publications 113 Citations.

[11] **Omasombo T. J., Zenga K. J., Guillaume L, Ngaluley M. Z., Etambala Z M., Edwine S., Krawczyk J. et Laghmouch M., 2012.**Kwango, the country of Ba Lunda. ISBN RDC: 978-99951-74-01-4. pp. 17-301.

[12] **OWAS, 2007:** Semi-Urban Water Supply and Sanitation Project, Evaluation Report, February 2007.

[13] **Poulin G., 2009** : Vector Environment, Search. Proquest.com, the generators, the importance of their maintenance plan;

[14] **REGIDESO S.A., 2022:** Operations management, 2022 Operating Report.

[15] **Remadnia M., 2017:** Electrical power generation. University 8 May 1945-Guelma.

[16] **UNICEF, 2015:** The Sustainable Development Goals.

[17] **YAGO H. M. R., 2017.** : Optimization of the drinking water supply in the villages of the municipality of Saponé. Master's thesis in water and environmental engineering. 2iE Burkina-Faso Foundation. January 2017.

Adoko, Marcel Bagala ; Tshimanga, Muamba Raphael; Luwesi, Cush Ngonzo; Nkaba Landry; Kabasu, Nana Kabujenda; Mayaka Doudou Kintu, Ngelinkoto, Mpia Patience
Estimating the influence of land-use on hydrological parameters of the peatlands of the Itimbiri River Basin, north-eastern Congo Basin, using WEAP model
International Journal Water Sciences and Environment Technologies
Vol. (x), Issue. 1, March 2025, pp. 95-106
ISSN Online: 1737-9350; ISSN Print: 1737-6688, Open Access
www.jiste.org
Scientific Press International Limited
Received: January 2025 / Revised: February 2025 / Accepted: March 2025 / Published: March 2025

Estimating the influence of land-use on hydrological parameters of the peatlands of the Itimbiri River Basin, north-eastern Congo Basin, using WEAP model

Adoko, Marcel Bagala[1,2]; Tshimanga, Muamba Raphael [1]; Luwesi, Cush Ngonzo [1,3]; Nkaba Landry [1] ; Kabasu, Nana Kabujenda [1];Mayaka Doudou Kintu[1], Ngelinkoto, Mpia Patience[4]

1Regional School of Water, University of Kinshasa, Democratic Republic of Congo;
2 Faculty of agriculture and environment, University of Lisala, Democratic Republic of Congo;
3 Higher Health Institute of Kenge (ISTM-MRP), Democratic Republic of Congo;
4 National Pedagogical University, Kinshasa, Democratic Republic of Congo.

Abstract

This research examines the degradation of peatlands caused by climate change, which disrupts their capacity to store water and carbon, potentially leading to increased greenhouse gas emissions. The objective is to create a hydrological model for the Itimbiri River Basin, establishing links between land uses and hydrological parameters. The model demonstrates satisfactory results, with NSE indices ranging from 0.63 to 0.71, R^2 from 0.7 to 0.76, and PBIAS from -3.1% to 9.3%. Thus, the study provides a comprehensive approach for the sustainable preservation of water resources and peatland ecosystems.

Keywords: Land use, Hydrological parameters, Peatlands ('tourbiere' in French), WEAP Modelling, Itimbiri Basin

Estimation de l'influence de l'utilisation des terres sur les paramètres hydrologiques des tourbières du bassin de la rivière Itimbiri, au nord-est du bassin du Congo, à l'aide du modèle WEAP

Résumé

Cette recherche examine la dégradation des tourbières causée par le changement climatique, qui perturbe leur capacité à stocker l'eau et le carbone, ce qui pourrait entraîner une augmentation des émissions de gaz à effet de serre. L'objectif est de créer un modèle hydrologique pour le bassin de la rivière Itimbiri, établissant des liens entre l'utilisation des terres et les paramètres hydrologiques. Le modèle présente des résultats satisfaisants, avec des indices NSE compris entre 0,63 et 0,71, un R^2 compris entre 0,7 et 0,76 et un PBIAS compris entre -3,1 % et 9,3 %. Ainsi, l'étude propose une approche globale pour la préservation durable des ressources en eau et des écosystèmes de tourbières.

Mots clés : Utilisation des terres, paramètres hydrologiques, tourbières, modélisation WEAP, bassin d'Itimbiri.

[1] Corresponding author: Bagadokmarcel25@gmail.com

1. Introduction

The Water Evaluation And Planning tool (WEAP) is a model featuring hydrological processes and the impact of land-use on hydrological parameters. This methodological tool has been recently adopted to develop an approach for assessing the dynamics of peatland areas. This approach has been essential for developing an integrated watershed management strategy for peatlands, allowing for the design of sustainable management practices for their water resources and ecosystems, particularly concerning evapotranspiration and the maintenance of water levels (Beighley, 2011; Chishugi & Alemaw, 2009).

Land use is a key factor influencing the hydrological parameters of sensitive ecosystems, especially peatland areas. These ecosystems play a crucial role in water and carbon storage, thereby contributing to climate regulation and biodiversity preservation. However, they are particularly vulnerable to changes in land use and the impacts of climate change (Angessa et al., 2021). As wetland ecosystems, peatlands are essential for regulating hydrological cycles. They act as sponges, absorbing and storing water, which helps maintain water levels in surrounding rivers and aquifers. However, changes in land use, such as drainage for agriculture or urbanization, disrupt this hydrological balance, leading to a decrease in water storage capacity and an increase in greenhouse gas emissions (Baghdadli, 2014; Dargie, 2017).

This study aims to estimate the influence of land use on the hydrological parameters of the peatlands located within the Itimbiri River Basin, establishing quantitative links between different land uses and the hydrological parameters of this area. These hydrological, ecological, and land use aspects have provided a comprehensive understanding of the functioning of the Itimbiri River Basin, with results that can be applied to other basins (Angessa and Aloysius, 2021, Tshimanga, R. M., & Hughes. (2012).).

By analyzing the interactions between different forms of land use and hydrological responses, we hope to provide crucial information for the sustainable management of water resources and the conservation of the peatlands in this watershed. The results of this research will contribute to a better understanding of the hydrological dynamics in the Itimbiri River Basin and to the development of adaptation strategies in response to the challenges posed by climate change and anthropogenic pressures.

2. Materials and Methods

2.1. Study area

This investigation took place in the Bumba territory in the Mongala province of the Democratic Republic of Congo. The Mongala province is part of the new Provinces that emerged from the former Equateur province. It covers a geographical area of 56,252 km². It is bounded: to the north by the Nord-Ubangi province, to the south by the Tshuapa and Equateur provinces; to the east by the Bas-Uele and Tshopo Provinces, and to the west by the Equateur and Sud-Ubangi provinces (OSFAC, 2023).

The Itimbiri River Basin is located in the northeastern part of the Congo Basin, and is experiencing a degradation of its peatlands due to urbanization, agriculture, and other anthropogenic activities has significant consequences for local hydrology (Tshimanga, 2012; UNEP, 2011). The Itimbiri River Basin is primarily composed of the Rubi River, which flows through the territories of Poko, Bambesa, Buta, and Aketi, where it converges with the Tele River and the Likati River to form the Itimbiri River. The Itimbiri River discharges into the Congo River approximately 15 km from Bumba (Omasombo, 2011; 2014; Molua, 2015).

The map below shows the location of the Itimbiri River Basin.

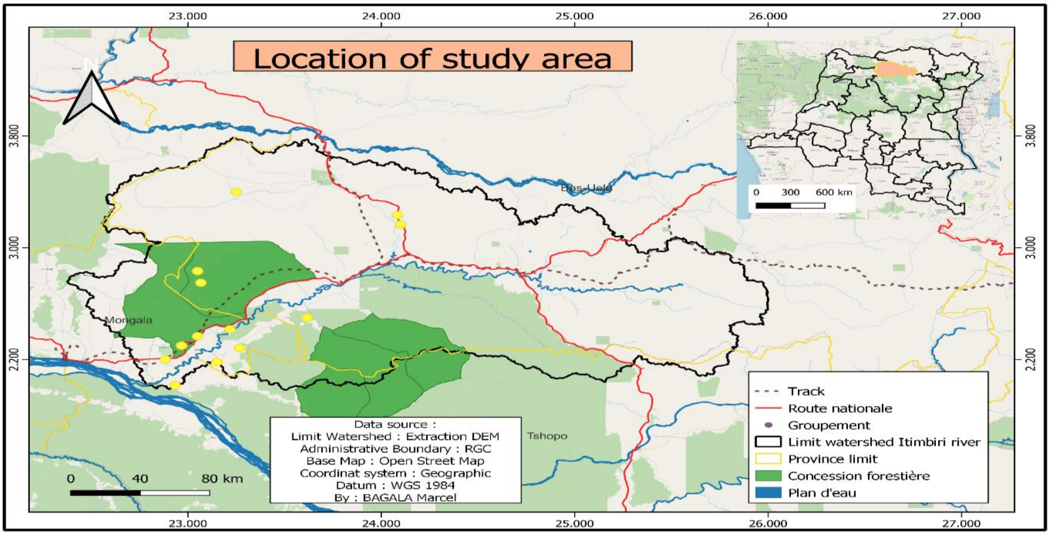


Figure 1: Location of the study area

During the Belgian colonial period, the Itimbiri basin was the site of expansion by concessionary companies such as Abir and Anversoise, which exploited rubber, ivory, and other regional resources (Geheugen Collectief, 2021). This frequently negatively impacted local communities, leading to exploitation and coerced labor.

After independence in 1960, the province continued to play an important economic role, particularly through timber extraction along the Itimbiri and its tributaries. However, the lack of oversight and reinvestment has led to environmental degradation and social conflicts. Today, the Itimbiri basin is subject to initiatives aimed at more sustainable natural resource management, involving local communities. Nevertheless, significant obstacles remain regarding economic development, environmental preservation, and social stability in this remote region of the DRC (Geheugen Collectief, 2021).

2.2. Data collected

The data utilized at this stage includes hydrometeorological measurements, such as monthly time series of flow, precipitation, and temperature, collected from the relevant authorities in the Democratic Republic of Congo and the region. Additionally, data from other sources, including the 0.5-degree spatial resolution climate data grid from the Climate Research Unit (CRU) (Harris et al., 2020; University of East Anglia Climatic Research Unit et al., 2021), has been incorporated.

2.3. Data analysis

This research employs the WEAP model to support sustainable management of water resources in the Itimbiri River catchment. WEAP integrates various water cycle components, addressing surface and groundwater needs across sectors like agriculture and industry (Pouget et al., 2021). It simulates scenarios related to water demand, management policies, and climate change, assessing sustainability at the basin level (Kuchement, 1971; Beven, 1989; Spence et al., 2004; Kampf et al., 2007). The model aids in decision-making for water allocation and infrastructure planning while enabling local stakeholders to improve their skills in integrated water management (Pouget et al., 2021).

2.3.1. Hydro-climatic data for hydrological simulation

The data used includes hydrometeorological measurements, such as monthly series of flow, rainfall, and temperature, collected from the relevant authorities in the Democratic Republic of the Congo. Additional data, such as that from the Climate Research Unit (CRU) with a spatial resolution of 0.5 degrees, have also been integrated. Hydrometric data from an in-situ station at Aketi were used in the WEAP model for the entire Itimbiri basin, as this station is the only one available in the region to cover the 32 sub-basins. Climatic data were extracted for the Itimbiri basin, subdivided into 32 sub-units, with the aim of extracting the average data series for the period 1957-1977. A table summarizes the data used in the research.

2.3.2 Development of the hydrological model

If a suitable link is established between a sub-basin node and a groundwater node, and the empirical water balance equation is determined, deep percolation in a sub-basin can be transferred to a surface water body as baseflow or directly to groundwater storage (SEI, 2016; Stockholm Environment Institute, 2016; Stockholm Environment Institute (SEI), 2015). The resulting empirical water balance (Equation 1) and the conceptual scheme of the soil moisture method (Figure 2) are therefore as follows.

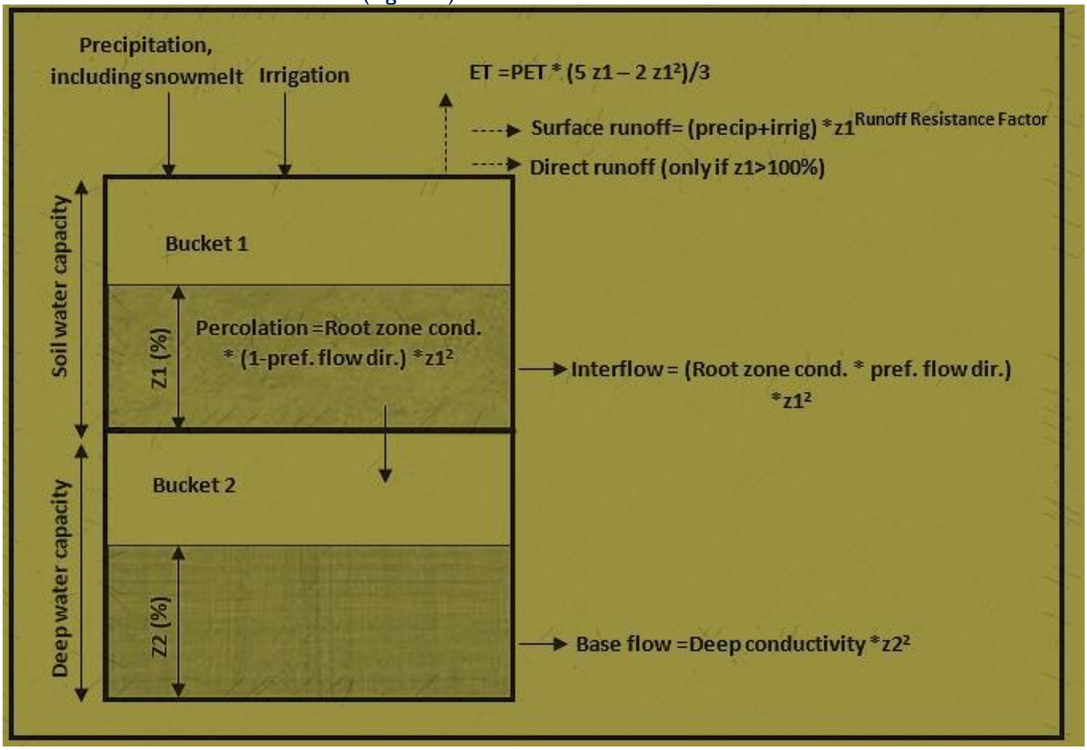


Figure 2. Conceptual framework and equations incorporated in the soil moisture model (adapted after Sieber et al., 2011)

2.3.3 Calibration of hydrological modelling with WEAP

The iterative calibration procedure is employed to develop a WEAP model that accurately represents the hydrological functioning of the Itimbiri River catchment, a crucial step for analyzing water management scenarios (Pouget et al., 2021). Hydrometric data from relevant stations were utilized to calibrate the model, aiming to establish a set of parameters that characterize the hydrological behavior of the Congo Basin. A manual trial-and-error method was applied to align simulated flows with observed flows. The soil moisture method in WEAP incorporates seven parameters related to soil type and land use, including the cultivation coefficient (Kc), the capacity of the upper soil layer (CCS), and the capacity of the lower soil layer.

2.4. Statistical analysis and assessment of model performance

This study focuses on the statistical analyses related to the performance criteria of hydrological models. These analyses can be straightforward, such as the ratio of simulated to observed water volumes, or involve more complex statistical methods for standardizing comparisons between simulation results and observations. Key performance criteria, including those established by Nash and Sutcliffe (1970), Beven and Binley (1992), Franchini et al. (1996), and Siebert (1999), are detailed. There is no universal criterion for evaluating model performance; however, it is advisable to compare calculated flows with observed flows. Model quality, robustness, and reliability are interpreted based on Miossec (2004). Model sensitivity is assessed using various hydrological criteria, including the Nash criterion, correlation coefficient R, coefficient of determination R^2, mean square error (NSE), and root mean square error (RMSE), which are summarized in Table 1.

Table 1. Statistical performance criteria

Mention	NSE	PBIAS	R^2
Very good	$0.75 \leq NSE \leq 1.00$	$PBIAS \leq 10$	$0.75 \leq R^2 \leq 1.00$
Good	$0.65 \leq NSE \leq 0.75$	$10 \leq PBIAS \leq 15$	$0.65 \leq R^2 \leq 0.75$
Satisfising	$0.50 \leq NSE \leq 0.65$	$15 \leq PBIAS \leq 25$	$0.50 \leq R^2 \leq 0.65$
Unsatisfactory	$NSE \leq 0.50$	$PBIAS \geq 25$	$R^2 \leq 0.50$

Source: Semsar (1999)

3. Results and Discussion

3.1. Setting up the hydrological model

The conclusions of this chapter are based on the hydrological modelling of the entire Itimbiri basin across the 32 sub-basins. The land use parameters for calibrating the model are estimated, the hydrological simulations in time series and in percentage of passage time are presented, as well as the statistical tests to validate the hydrological model.

3.2 Calibration of the hydrological model

The results of the calibration procedure, along with the boundary values of estimated parameters for each sub-basin, are essential for accurately adjusting parameters to ensure the reliability of hydrological simulations. This manual adjustment, conducted on a monthly scale using a trial-and-error method, covered the period from 1951 to 1977 based on data from the Aketi station. Key land use criteria, including crop coefficient (Kc), deep layer capacity (CCI in mm), surface layer capacity (CCS in mm), surface conductivity (CS in mm/month), preferred flow direction (DPE), and leaf area index (IF), are detailed for the 32 sub-basins of Itimbiri.

3.3. Hydrological simulations

The results of hydrological simulations in the Itimbiri basin are presented using the Aketi station and the curves of monthly averages of time series flows classified in percentage of time of non-exceedance of seven (7) land use parameters, including plant coefficient (KC), deep layer capacity, CCI (mm), superficial soil layer capacity (CCS), superficial soil conductivity (CS), preferred direction of flow (DPE), and leaf area index (IF) calibrated and validated in the 32 hydrological sub-units.

3.3.1. Hydrological simulations with crop coefficient Kc (-)

Figure 5 below presents the results illustrating the situation of thirty-two (32) hydrological sub-units of the Itimbiri river basin.

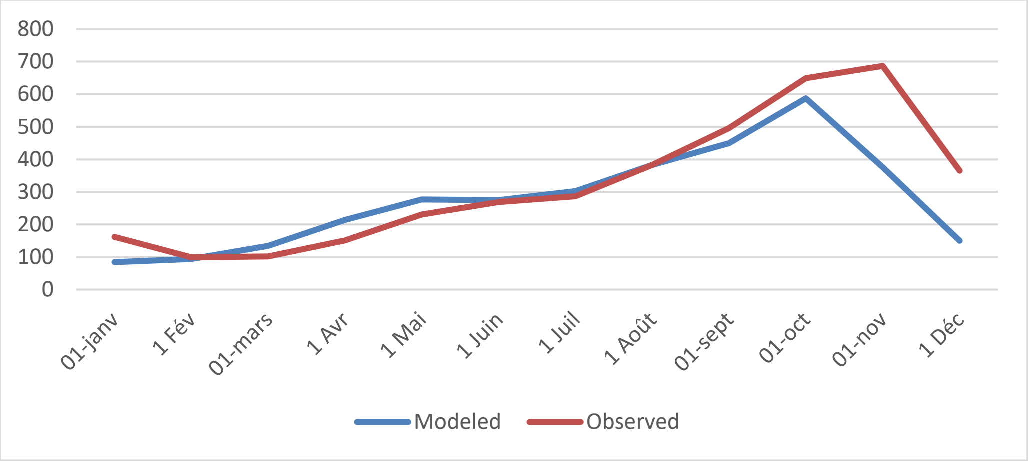


Figure 5. Hydrological simulations with crop coefficient Kc (-)

The cultural coefficient Kc (-) is present, resulting in an NSE of 0.71 and an R^2 of 0.73. Although the model's performance is justified by an underestimate (-3.3% of PBIAIS), this demonstrates a significant match and the model's ability to explain the observed variance, even though the simulated flows are underestimated compared with the observed flows due to the low-water period. The crop coefficient (KC) found estimates crop evapotranspiration (ETc) and influences the environmental characteristics of the peatland ecosystem, including species, variety, and growth cycle (Allen et al., 1998), canopy height (Doorenbos & Pruitt, 1977), planting density, and soil cover (Katerji & Hoorn, 1992), while its environmental factors include climate (temperature, humidity, wind, radiation) (Allen et al., 1998), soil characteristics (texture, moisture, salinity) (Doorenbos & Kassam, 1979), and management methods (irrigation, fertilisation, tillage) (Allen et al., 1998), which contribute to the hydrological process in the Itimbiri river catchment.

3.3.2. Hydrological simulations with deep layer capacity (DLC)

The evaluation of hydrological model performance indicates significant results for each land use parameter is shown in Figure 6.

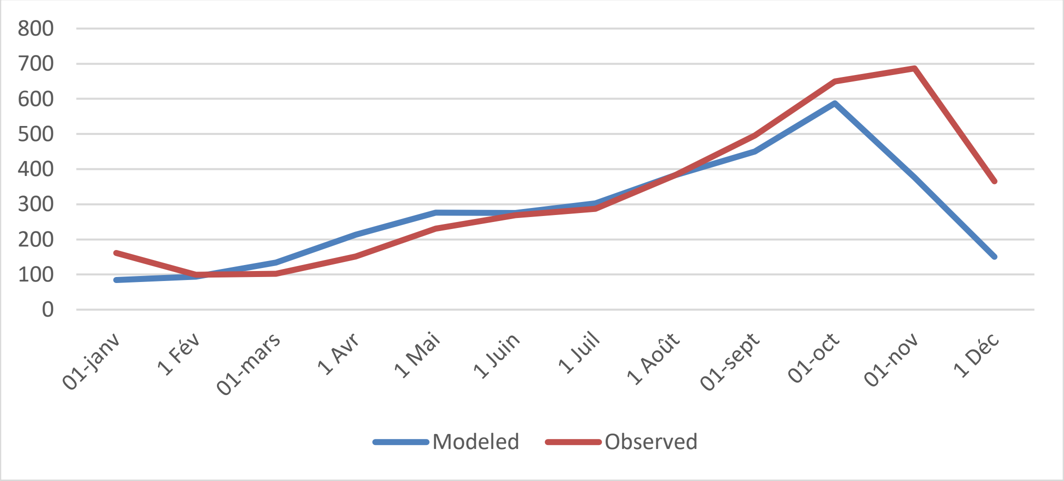


Figure 6. Hydrological simulations with deep layer capacity (CCI)

Specifically, the capacity of the deep layer (CCI) shows high efficiency, with an NSE of 0.63 and an R^2 of 0.74, reflecting a strong correlation between model simulations and observations. The PBIAS of -9.3% suggests a slight tendency to overestimate forecasts, highlighting the hydric behavior of agricultural soils and their capacity to store water at depth. This deep-water reserve is vital for crop resilience to water stress, influenced by various soil and environmental factors, including soil texture (Rawls et al., 1982), profile depth and continuity (Håkansson & Lipiec, 2000), and organic matter content (Saxton & Rawls, 2006), as well as climate conditions (Allen et al., 1998) and topography (Bohne, 2005).

3.3.3. Hydrological simulations with surface layer capacity (SLC)

Figure 7 below shows the hydrological simulations in time series of the capacity of the surface layer (CCS) and the curve of the classified flows obtained in the situation of thirty-two (32) hydrological sub-units of the Itimbiri river basin.

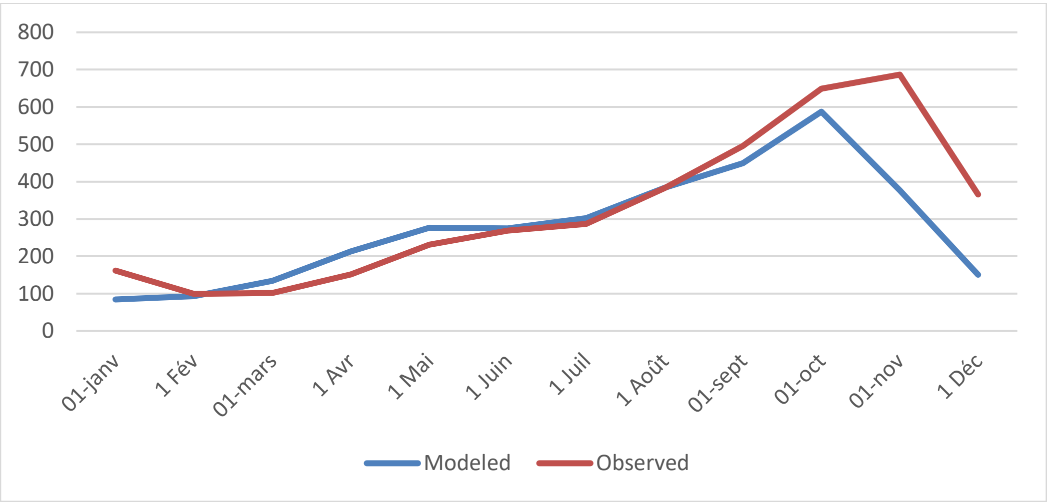


Figure 7: Hydrological simulations with deep layer capacity (CCI)

The forecasts were very effective, with an NSE of 0.71 and an R2 of 0.74. However, the presence of a slight systematic underestimation of the forecasts is highlighted by the PBIAS of -3.1%. These results indicate a reasonable match between forecasts and observations, although simulated flows may be slightly lower than the actual observed flows. Water stored in the surface root zone plays an essential role in crop water supply, particularly at the start of the cycle in the Itimbiri catchment.

3.3.4. Hydrological simulations with Superficial Conductivity (SC)

Figure 8 below shows the results for thirty-two (32) hydrological subunits in the Itimbiri river basin. Superficial conductivity (CS) is present, resulting in an NSE of 0.69 and an R2 of 0.73. And a Percentage Bias (PBIAS) of -3.3%, demonstrating a significant correspondence and a capacity of the model to explain the variance, despite a slight systematic underestimation.

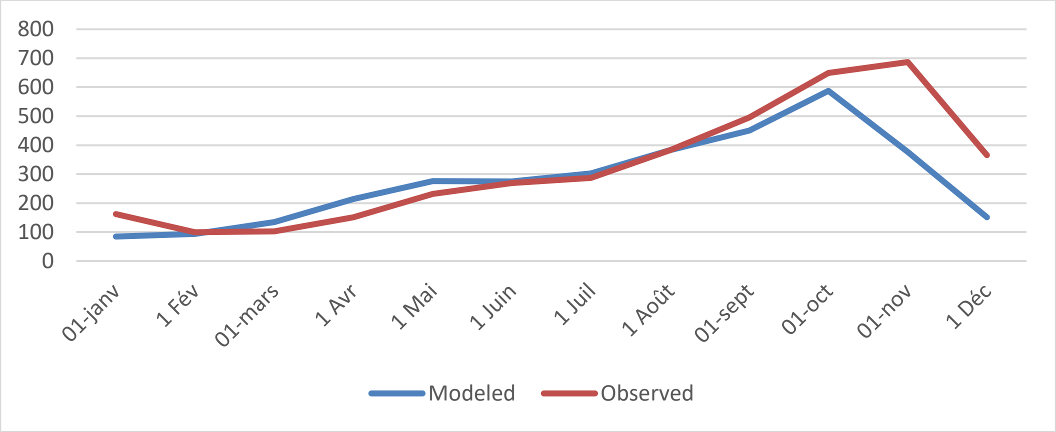


Figure 8: Hydrological simulations with Superficial Conductivity (SC)

Surface conductivity refers to the soil's capacity to evacuate water in the surface layer, usually in the first 30 to 50 centimetres. The role of this physical characteristic of the soil is crucial in water transfer mechanisms such as infiltration, runoff and evaporation, which are influenced by several characteristics of the soil and environmental conditions, as highlighted by the previous coefficients (Rawls et al., 1998).

3.3.5. Hydrological simulations with deep conductivity (CP)

Figure 9 below shows the results for thirty-two (32) hydrological subunits in the Itimbiri river basin. Deep conductivity (CP) is present, resulting in an NSE of 0.71 and an R2 of 0.75. And a Percentage Bias (PBIAS) of -3.5%, demonstrating a significant match and the model's ability to explain the variance, despite a slight systematic underestimation. The situation shows how the soil's capacity to evacuate water in the deep layers of the profile and the recharge of groundwater are characterised by this physical property (Mualem, 1976).

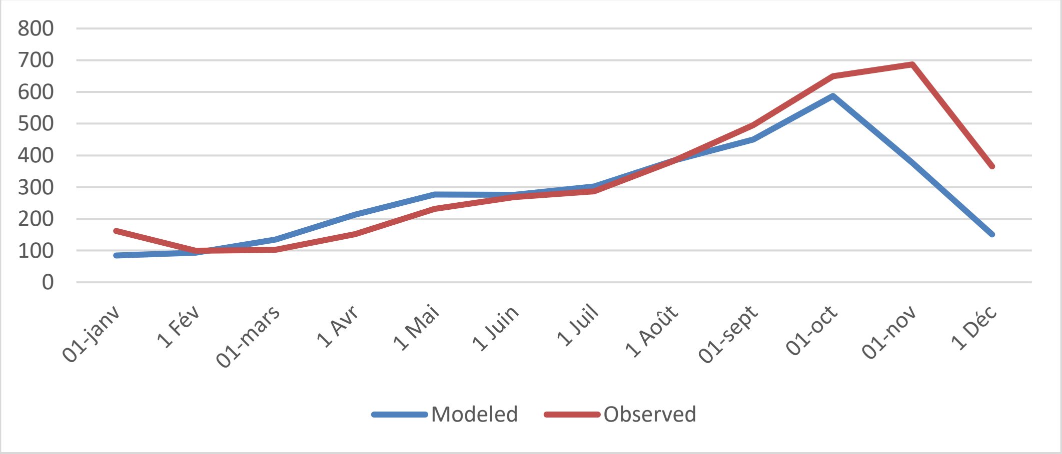


Figure 9. Hydrological simulations with deep conductivity (CP)

3.3.6. Hydrological simulations with Preferred Flow Direction (PFD)

The evaluation of hydrological model performance reveals significant results for each land use parameter. Specifically, the land use parameter related to the preferred direction of flow (DPE) demonstrates very high efficiency, with an NSE of 0.69 and an R^2 of 0.75, indicating a strong correlation between model simulations and observations. The PBIAS value of -3.5% suggests a slight tendency toward systematic overestimation of forecasts. The preferred direction of flow (PDF) refers to the tendency of water to flow preferentially in certain directions rather than uniformly. Understanding this soil characteristic is crucial for comprehending the mechanisms of runoff, infiltration, and water circulation in the soil profile (Hendrickx & Flury, 2001). The preferred direction of flow in the soil is influenced by various factors such as soil texture (including clay content, silt and sand) (Hendrickx & Flury, 2001).

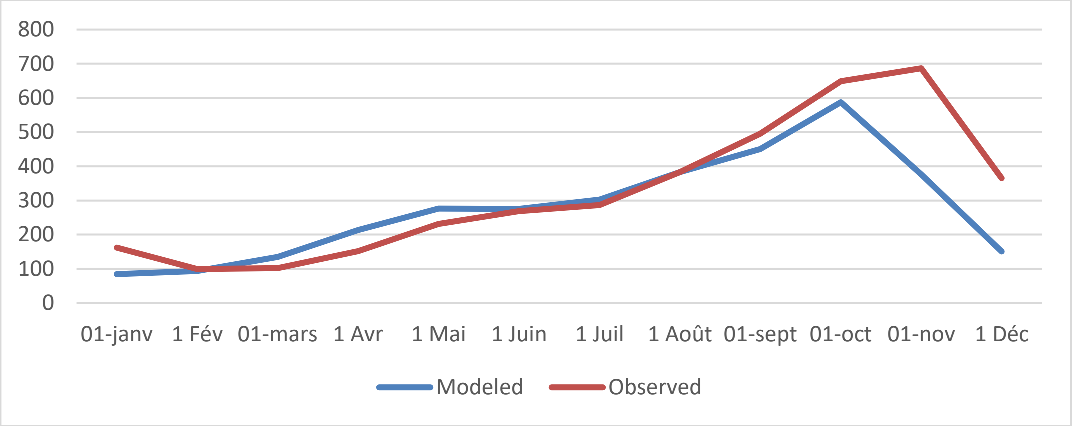


Figure10. Hydrological simulations with Preferred Direction of Flow (PDF)

3.3.7. Hydrological simulations with Leaf Area Index (LAI)

Figure 11 below shows the results for thirty-two (32) hydrological subunits in the Itimbiri river basin. The leaf area index (LAI) shows an NSE of 0.71 and an R2 of 0.76. And a Percentage Bias (PBIAS) of -3.1%, demonstrating a significant match and the model's ability to explain the variance, despite a slight systematic underestimation, which represents the leaf area per unit of soil surface in the Itimbiri basin for estimating plant productivity, solar radiation interception, evapotranspiration, etc. (Monteith, 1973).

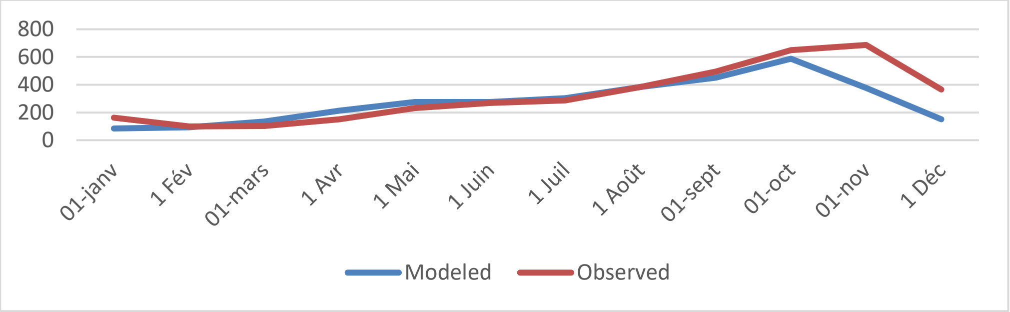


Figure 11. Hydrological simulations with Indice foliaire (IF)

3.4. Performance evaluation and model validation

Table 2 below shows the statistics for the hydrological model performance indicators for the Itimbiri basin as a whole. The aim of model validation is to assess the reliability of the calibrated land-use parameters at various periods, with varying environmental conditions (Dos Santos et al., 2022; Nicholson et al., 2019). The search for a common period to calibrate and validate the model in all the hydrological units available in the gauging station was complicated due to missing data. Thus, historical data available at the Aketi gauging site were used to confirm (Tshimanga et al., 2011). High-flow errors are better studied by the Nash-Sutcliffe criterion. Model performance for all land use parameters of 32 hydrological subunits is evaluated with mean NSE 0.69, R2 0.74, R 0.86, and (PBIAS) -4.15%.

Table 2. Validation of the hydrological model of the Itimbiri basin using Land use parameters

Parameters	NSE	BIAS (%)	R2	R
Crop Coefficient, Kc (-)	0,71	-3,3	0,73	0,86
Deep Layer Capacity, CCI (mm)	0,63	-9 ,3	0,74	0,86
Shallow Layer Capacity, CCS (mm)	0,71	-3,7	0,74	0,86
Surface Conductivity, CS (mm/month)	0,69	-3,1	0,7	0,86
Deep Conductivity, CP (mm/month)	0,71	-3,1	0,7	0,86
Preferred Flow Direction, DPE (-)	0,69	-3,5	0,75	0,86
Leaf Index, IF (-)	0,71	-3,1	0,76	0,86
Average	0,69	-4,15	0,74	0,86

Source: Authors (2024)

3.5. Discussion of Results

This study highlights the importance of land use parameters in the hydrological functioning of the Itimbiri River Basin. Previous research, such as that by Beighley et al. (2011), demonstrates that land use changes, including deforestation and agricultural expansion, significantly impact hydrological regimes. Kabuya et al. (2017) found that converting forests to agricultural land decreases water storage capacity and infiltration, affecting river base flows. The observed performance differences among parameters underscore the influence of topographical and environmental factors, with soil texture playing a critical role in infiltration capacity (Rawls et al., 1998). Allen et al. (1998) emphasize the necessity of accurately estimating the crop coefficient (Kc) for effective irrigation management, as Kc variations are influenced by environmental and crop characteristics. Breda (2003) addressed the Leaf Area Index (LAI) and its variability, noting that vegetation cover heterogeneity can introduce measurement uncertainties, which Jonckheere et al. (2004) also highlight. Furthermore, the results indicate that climate change exacerbates the effects of deforestation and urbanization, supported by Chishugi and Alemaw (2009), who found that forest conversion leads to lower groundwater levels. Recognizing the role of forests in regulating flows and recharging aquifers is vital for ecosystem preservation, as noted by Laraque et al. (2001). Finally, the recommendations by Munzimi et al. (2019) for future research emphasize improving input data quality and model calibration, advocating for process-based hydrological models to better understand the impacts of land use and climate change on the vulnerable peatland ecosystems of the Itimbiri River Basin. Overall, this study enhances the understanding of hydrological dynamics amid environmental change and underscores the need for a comprehensive approach to water resource management in this critical area.

Evaluates the model's performance for each land use parameter across the 32 hydrological sub-units, revealing that these parameters evolved in line with indicators such as NSE, R, and PBIAS. These indicators measure the concordance between simulated and observed flows, with NSE ranging from 0.63 to 0.71, R^2 from 0.7 to

0.76, and PBIAS from -3.1% to 9.3%. Variations in model performance across parameters can be attributed to topographical, environmental, and hydrological factors. Moreover, the conversion of forests to agricultural areas and urban development has resulted in decreased groundwater levels and reduced base flows, while climate change adversely affects peatland wetlands, which are crucial for regulating the water cycle and carbon storage in the Congo Basin.

The significance of these peatlands for maintaining the biosphere highlights the necessity of a detailed management policy to prevent ecosystem degradation, which provides essential services to local communities and humanity. This research establishes quantitative links between various land use forms and key hydrological parameters in the Itimbiri River Basin's peatland area. The findings indicate that land use changes, particularly deforestation and agricultural expansion, significantly influence the region's hydrology, emphasizing the vital role of forest areas in regulating flows and recharging aquifers that sustain peatlands.

Conclusion and Recommendations

A hydrological model was developed to quantify the relationships between land uses and hydrological parameters, enhancing understanding of land use impacts on peatland wetlands in the Itimbiri River Basin. The WEAP model performed satisfactorily but required adjustments for each sub-basin due to soil and environmental variations. The study highlights the need to protect forest areas, particularly peatlands, and proposes sustainable agricultural practices, wetland restoration initiatives, and integration of findings into water resource management strategies at the Congo Basin level. Future research should explore land use and hydrology links in other peatland regions and assess climate change scenarios against the model's results.

Acknowledgements

This research was carried out as part of the training for the International Master's Program in Water Resources organized at the Regional School of Water (ERE) of the University of Kinshasa. The authors would like to thank the management of the ERE school, Waternet and the University of Lisala for their kind support.

Compliance with ethical rules

The authors declare no conflict of interest. Field research did not involve any threat to any community or protected species. No informal or legal organization played a key role in the design of the study, the collection and analysis of data so as to decide on the final outcome of the study. The decision to prepare the manuscript and publish it was solely taken by the authors.

List of References

[1] Aloysius, N., & Saiers, J. (2017). Simulated hydrologic response to projected changes in precipitation and temperature in the Congo River basin. Hydrology and Earth Systems Research, 21(8). https://doi.org/10.5194/hess-21-4115-2017

[2] Angessa, A. T., Lemma, B., & Yeshitela, K. (2021). Land-use dynamics and drivers in the central Ethiopian highlands: Lake Wanchi watershed. GeoJournal, 86(3). https://doi.org/10.1007/s10708-019-10130-1

[3] Beighley, R. E., et al. (2011). Comparing satellite-derived precipitation datasets in the Congo River Basin using the HRR model. Hydrological Processes, 25(20). https://doi.org/10.1002/hyp.8045

[4] Chishugi, J. B., & Alemaw, B. F. (2009). Hydrology of the Congo River Basin: A GIS-based water balance model. World Environmental and Water Resources Congress 2009, 342. https://doi.org/10.1061/41036(342)593

[5] UNFCCC (2010). Handbook on Vulnerability and Adaptation Assessment. Bonn: UNFCCC Secretariat.

[6] Dargie, G. C., et al. (2017). Age, extent, and carbon storage of the Central Congo Basin peatland. Nature, 542(7639), 86-90. doi:10.1038/nature21048.

[7] Jenkins, M. W., et al. (2005). WEAP as a participatory tool for shared vision planning in Kenya's River Njoro watershed. World Water Congress 2005 Proceedings.

[8] Kabuya, P. M., et al. (2020). Uncertainty ranges of hydrologic indices in the Congo River Basin. Journal of Hydrology: Regional Studies, 30. https://doi.org/10.1016/j.ejrh.2020.100710

[9] Kabuya, P. M., et al. (2022). Regionalized input constraint indices for hydrological model simulations in the Congo River Basin. Advances in Water Resources, 159. https://doi.org/10.1016/j.advwatres.2021.104093

[10] Karam, S., et al. (2023). Impacts of climate change on hydrological regimes in the Congo River Basin. Sustainability (Switzerland), 15(7). https://doi.org/10.3390/su15076066

[11] Laine, A. M., et al. (2016). Vegetation change linked to water table drawdown in a restored peatland. Restoration Ecology, 24(2), 214-223.

[12] Lebel, T., & Ali, A. (2009). Trends in Central and Western Sahel rainfall (1990-2007). Journal of Hydrology, 375(1-2), 52-64.

[13] Laraque, A., et al. (2020). Recent hydroclimatology of the Congo River in Central Africa. Water (Switzerland), 12(9). https://doi.org/10.3390/w12092613

[14] Munzimi, Y. A. (2019). Characterizing hydrological processes in the Congo Basin. ProQuest Dissertations.

[15] Molua, L. E. (2015). Climate Change in the Congo Basin and adaptation costs. Environment and Natural Resources Research, 5(3). ISSN 1927-0488.

[16] Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models. Journal of Hydrology, 10(3). https://doi.org/10.1016/0022-1694(70)90255-6

[17] Omasombo, T. J. (2014). Bas-Uélé: Local powers and agricultural economy. Tervuren, MRAC.

[18] Omasombo, T. J. (2011). Haut-Uélé: Tourist treasure. "Monographies des provinces de la RD Congo," Vol. 2. Brussels-Tervuren: Le Cri.

[19] OSFAC (2023). Study on Peatlands for the PIREDD MONGALA Project / DRC. OSFAC, Kinshasa.

[20] OSFAC (2020). Analysis of Wetlands in the Cuvette Centrale of the Congo Basin. OSFAC, Kinshasa.

[21] Sridhar, V., et al. (2022). Water balance and droughts in the Congo Basin. https://doi.org/10.1002/9781119842125.ch10

[22] Tshimanga, R. M., & Hughes, D. A. (2012). Climate change and impacts on the hydrology of the Congo Basin: The case of the northern sub-basins of the Oubangui and Sangha Rivers. Physics and Chemistry of the Earth, 50–52. DOI: 10.1016/j.pce.2012.08.002

REPUBLIQUE TUNISIENNE

Colloque–Formation International (EBC'2025)

06 au 11 Novembre 2025, Hammamet (Tunisie)

Indexation

ISSN Online: 1737-9350 ISSN Print: 1737-6688

Eau - Biodiversité - Climat'2025

Ressources en Eau, Biodiversité et Changement Climatique

www.jistee.org

Pour plus d'informations veuillez contacter

Pr. Noureddine GAALOUL

eauclimat@iresa.agrinet.tn

eauclimat@yahoo.com

International Journal Water Sciences and Environment Technologies (IJWSET)
Journal International Sciences et Techniques de l'Eau et de l'Environnement (JISTEE)
ISSN Online: 1737-9350 ISSN Print: 1737-6688
Open **Access**
10 Volumes, 31 Issues, (433 Papers) and 1 Book

International Journal Water Sciences and Environment Technologies: Volume (x), Issue 1 – March 2025

INTERNATIONAL JOURNAL

Water Sciences and Environment Technologies

ISSN Online: 1737-9350 ISSN Print: 1737-6688
Open Access Journal

Volume (x) - Issue 1– March 2025

Water-**B**iodiversity-**C**limate'2025

Water, Biodiversity and Climate Change

Editor-in-Chief: Pr Noureddine Gaaloul

Published by:

Scientific and Technical Association for Water and the Environment in Tunisia (*ASTEE Tunisie*)