PAN-AFRICAN UNIVERSITY

INSTITUTE FOR WATER AND ENERGY SCIENCES

(including CLIMATE CHANGE)

Master Dissertation

WATER ENGINEERING

Presented by

Jamiilah NGAPOUT NGOUGOURE

Hydraulic engineer

Analysis of integrated water resources management (IWRM) strategies in the urban sub-watersheds of Yaoundé (Cameroon): case of Odza and Nkie watersheds

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Defended on 16/04/2025

at Pan-African University of Water and Energy Sciences (including Climate Change),

Abu Bekr Belkaid University, Chetouane Pole

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Defended on 16/04/2025 Before the Following Committee:

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Internal Examiner	Abdelkader ELOUISSI	Dr.	University of Mascara (ALGERIA)

DEDICATION

I dedicate this work to my parents Mr. Seidou NGAPOUT and Mrs. Adama NTENTIE, and my lovely son Edison ZACHARIA for their constant love, support and encouragments.

DECLARATION

I, NGOUGOURE NGAPOUT Jamiilah, the undersigned, declare that this thesis is my original work, and has not been presented for a degree in any other university. All the information, material and results from other works presented here have been fully cited and referenced in accordance with the research ethics.

Signature: Date:

NGOUGOURE NGAPOUT Jamiilah

I undersigned, Professor Celestin DEFO, certify that Mrs. NGOUGOURE NGAPOUT Jamiilah conducted her Master Thesis research titled “Analysis of Integrated Water Resources Management (IWRM) strategies in the urban sub-watersheds of Yaoundé (Cameroon): case of Odza and Nkie watersheds.” under my supervision. This thesis has been prepared under my close supervision and is the candidate’s original work. It is therefore presented for examination under my approval.

Supervisor:

Signature:  Date : 19-03-2025

Prof Celestin DEFO

Biographical Sketch

Born on July 19, 1996, in Yaoundé, Cameroon, Jamiilah NGAPOUT NGOUGOURE is a young lady who completed her entire primary and secondary education in the city of Yaoundé. Holder in 2015 (ending her secondary cycle) of a GCE/AL (General Certificate of Education, Advanced Level), option mathematics and physical sciences, obtained at the Government Secondary Bilingual High School of Mendong in Yaoundé. Afterwards, she began her university studies in the first year of physics at the Faculty of Sciences of the University of Yaoundé 1 in 2016. Upon a very competitive entrance national examination, she was admitted in selection in 2017 at the Ebolowa Campus of the Faculty of Agronomy and Agricultural Sciences of the University of Dschang, the School of Wood, Water, and Natural Resources (SWWNR). Since 2022, this School became the Higher Institute of Agronomy, Forestry, Water and Environment of the University of Ebolowa. In 2021, she completed successfully her master's in water and Sanitation Engineering at the Department of Hydraulics and Water Engineering of the same Institute with honors and appreciation. In June 2022, she began a professional career in the WASH field with a non-profit organization called Sustainable Alternatives for Development (ADD) in the city of Mbalmayo in Cameroon, where she served as a WASH Assistant and then as Technical Advisor in charge of WASH projects. It was in this organization that she developed extensive skills in setting up and drafting WASH projects funded by international organizations such as Caritas Italiana, "La Francophonie", GIZ, etc. In May 2023, she was admitted after a competitive screening at the Pan-African University, Institute of Water, Energy Sciences (including Climate Change) (PAUWES), where she is currently finalizing her Master of Sciences program in water engineering. Since, few years, she has been admitted as member of the Non-Governmental Organization "Water for Life" (W4L) Cameroon, where she got numerous positions of responsibility since 2021. She also contributed to the development of a feasibility studies on stormwater sanitation in the commune of Mora (North Cameroon), the estimation of flood flows in ungauged watersheds in the city of Yaoundé, and the rehabilitation of water, hygiene, and sanitation infrastructure in three nursery and primary schools in the city of Yaoundé. Her experiences within organizations such as the Cameroon Pasteur Center (CPC), the Ministry of Housing and Urban Development (MINHUD), the National Participatory Development Program (NPDP-Sud), as well as the numerous workshops, seminars, and conferences in which she has had the privilege of participating, have allowed her to develop numerous skills and further shape her career. Passionate about humanitarian issues and natural resources management, she aims to become a specialist in integrated water resource management and wishes to use her skills to support the development of her country, Cameroon, to contribute to building a just and equitable society where human values, integrity, love, and mutual respect are emphasized.

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I would like to extend my sincere appreciation to the African Union through the Pan African University Institute of Water and Energy Sciences (including Climate Change) (PAUWES), for the scholarship award and the research grant that facilitated my undertaking of this master's thesis research. I also thank my supervisor Prof. Celestin DEFO for the continuous support, mentorship and guidance throughout the research period, the multiple editions of this thesis up to the production of the final version. Special thanks to the Director of PAUWES Prof. Abdellatif Zerga and the entire staff for their continued hard work to uplift PAUWES to greater heights. I would also like to express my sincere gratitude to Mr. Stephane LAKO, the Executive Secretary of Water for Life Cameroon (W4L) and my Internship Supervisor for the research Internship opportunity, and his guidance and provision of facilities for field work, data collection, and for fulfilling the internship goals and objectives necessary for my thesis writing. Special thanks to the Director of the Mobilization of Water Resources (WRMD/MINWRE) at the Central Service of the Ministry of Water and Energy, Yaounde, Mr. Achille NGOKO; to the coordinator of RECOJAC, Doctor Michele OKALA ABEGA; to the Regional Coordinator of Global Water Partnership-Central Africa (GWP-caf), Mr. Djibrilla MOHAMMADOU; to Professor FANTONG YETOH of the Ministry of scientific research and innovation (MINRESI); to Mrs. Gloria TAKEM of the Research Center on Water and Climate Change (RCWCC); to Doctor Rene MEYONG of the National Observatory on Climate Change (NOCC); to Doctor Rodrigue DJAKOU of the World Bank (Yaoundé); to Professor NGNIKAM of ERA Cameroon for provision of the necessary data and information which made this work a success. I also acknowledge the Cameroon National Meteorological Direction (NMD) for all the information and datasets provided in undertaking this research. Finally, I thank my family, friends and the 9th cohort PAUWES and Water Engineering track for the encouragement and support throughout the research period.

Abbreviations and Acronyms

AHP: Analytical Hierarchy Process

ADB: African Development Bank

AMCOW: African Minister's Councils on Water

AVHRR: Advanced Very-High-Resolution Radiometer

ARID: Agricultural Research Institute for Development

AMCAE: African Minister's Conference of Environment

AIP: Africa water Investment continental Program

BCAS: Bank of Central African States

BOD: Biological Oxygen Demand

CAFC: Central African Forest Commission

CAR: Central African Republic

CAMWATER: Cameroon Water Utilities Corporation

CAFCOMI: Central African Forests Commission

CRHPP: Center for Research in Health and Priority Pathologies

UCCC: United Councils and Cities of Cameroon

DEMNAS: Digital Elevation Model Nasional of Indonesia

DTC: Decentralized Territorial Communities

DSMW: FAO Digital Soil Map of the World

DWS: Drinking Water Supply

ECCAS: Economic Community of Central African States

EU : European Union

ET : Evapotranspiration

ETP : Potential Evapotranspiration

ETR: Real Evapotranspiration

EBF: Evidential Belief Functions

ENEO: Energy Of Cameroon

EDC: Electricity Development Corporation

EMCCA: Economic Monetary Community of Central Africa

FAO: Food and Agriculture Organization of the United Nations

FR: Frequency Ratio

FSR: Fact Sheet on RAMSAR Wetlands

GWP: Global Water Partnership

GDP: Gross Domestic Product

GCF: Green Climate Fund

GDE: General Directorate of Enterprises

GWPZ: Ground Water Potential Zones

GR: Ground water Recharge

HRC: Hydrologic Research Center

HIAWWE: Higher Institute of Agronomy of Wood, Water and the Environment

ICCOS: International Commission of the Congo-Oubangui-Sangha basin

IFAD: International Fund for Agriculture Development

IHP: Intergovernmental Hydrological Program

IGMR: Institute of Geological and Mining Research

IWRM: Integrated Water Resources Management

IPCC: Intergovernmental Panel on Climate Change

ICRE: International Commission of Rural Engineering

IMF: International Monetary Fund

IWMI: International Water Management Institute

IWRC: International Water Resources Conservation association

IUCN: International Union for Conservation of Nature

KRC: Kurose River Catchment

LCBC: Lac Chad Basin Commission

LULC: Land Use Land Cover

MARD: Ministry of Agriculture and Rural Development

MINWRE: Ministry of Water Resources and Energy

MINHE: Ministry of Higher Education

MENPSD: Ministry of the Environment, Nature Protection and Sustainable Development

MSOC: Ministerial Steering and Orientation Committee

MINHUD: Ministry of Housing and Urban Development

MINLFAI: Ministry of Livestock, Fisheries and Animal Industries

MINEPRD: Ministry of Economy, Planning and Regional Development

MINFA: Ministry of Foreign Affairs

MINTAD: Ministry of Territorial Administration and Decentralization

MINPH: Ministry of Public Health

MINFI: Ministry of Finances

MINSRI: Ministry of Scientific Research and Innovation

MINCOMMERCE: Ministry of Commerce

MINMITI: Ministry of Mines Industry and Technological Innovation

MINTRANSPORT: Ministry of Transport

MINDLD: Ministry of Decentralization and Local Development

MNDWI: Modified Normalized Difference Water Index

MODIS: Moderate resolution Imaging Spectroradiometer

NAPIWRM: National Action Plan for Integrated Water Resources Management

NASA: National Aeronautics and Space Administration

NBA: Niger Basin Authority

NANB: National Agency of the Niger Basin

NBI: Nile Basin Initiative

NMD: National Meteorological Directorate

NEPAD: New Partnership for Africa's Development

NHPS: National Higher Polytechnic School

NGO: Non-Governmental Organization

NCM: Normal Cloud Model

NDVI: Normalized Difference Vegetation Index

NDWI: Normalized Difference Water Index

NOAA: National Oceanic and Atmospheric Administration

NOCC: National Observatory on Climate Change

NDS: National Development Strategy

NWC: National Water Committee

ONAFE: National Office for Training and Development

OECD: Organization for Economic Cooperation and Development

NOWS: National Office for Water and Sanitation

PPRA: Public Procurement Regulatory Agency

POA: Partial Order Analysis

RAPIWRM: Regional Action Plan for Integrated Water Resources Management

RECOJAC: Water and Climate Network of Central African Youth Organizations

RGB: Red, Green Blue

RWC: Regional Water Council

RCWCC: Research Center on Water and Climate Change

SEWASH: Cameroon Water Security and Supply project

SWAT: Soil and Water Assessment Model Tool

SEBAL: Surface Energy Balance Algorithm for Land

SDG: Sustainable Development Goals

SQPA: Quatropontense Water System

SWOT: Strength, Weaknesses, Opportunities, Threats

SYNCOLEK: Syndicate of Councils of Lekie Division

SYCOMI: Syndicate of Councils of Mbam-Inoubou Division

SYCNYO-EK: Syndicate of Councils of Nyong-Ekelle Division

TMC: Technical Monitoring Committee

TM: Thematic Mapper

TFP: Technical and Financial Partners

UNO: United Nation Organization

UNDP: United Nations Development Programme

UNICEF: United Nations Children's Fund

UNESCO: United Nation for Education, Sciences and Culture Organization

UNEP: United Nations Environment Program

UNEP-DHI: United Nations Environment Program Centre for Water and Environment

UN : United Nations

USAID: United States Agency for International Development

UYI: University of Yaoundé 1

USGS: United States Geological Survey

WIS: Water Information System

WWAP: World Water Assessment Program

WHO: World Health Organization

WRMD: Water Resources Management and Mobilization Directorate

WRMCC: Water Resources Management Coordination Center

WASH: Water Sanitation and Hygiene

WaSiM: Water balance Simulation Model

WRSU: Water Resources Sustainable Utilization

WWETS: Wood, Water and Environment Trades Sector

YCSP: Yaoundé City Sanitation Project

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ABSTRACT

This study analyzed the integrated water resources management (IWRM) strategies in urban sub-watersheds of Yaoundé, Cameroon, focusing on the Odza and Nkie watersheds. The objective of the research was to contribute to the improvement of sustainable water resource management in urban sub-watersheds in developing countries, particularly in Cameroon. The study used a mixed approach, integrating data obtained through interviews with 21 key stakeholders involved in water management in the city of Yaoundé, hydrometeorological data and GIS data. The methodological approach included a SWOT analysis of the regulatory and institutional framework of IWRM at the local level, water resources mapping, land use classification using the Semi-automatic Classification Plugin (SCP) of QGIS 3.34 software and sentinel-2 images dating from December 2024 for the determination of spectral indices (NDWI, NDVI, SAVI) and the realization of the hydrological balance. This methodology was based on a set of considerations, such as the validity of the precipitation data from the Ekounou station for the watersheds studied, and the importance of interactions between surface water and groundwater. The SWOT analysis of IWRM implementation reveals major strengths and opportunities. Unfortunately, the political will faces numerous weaknesses and threats, such as incomplete legal frameworks, a framework law on water regime that is not yet aligned with the IWRM principles, despite being revised, and insufficient funding, which hinders its expansion. Water resource mapping revealed high urbanization, which impacts water quality, with significant pollution due to various human activities. Furthermore, hydrological analyses demonstrated considerable variability in precipitations, evapotranspiration, and infiltration over the years, highlighting the challenges posed by climate change. Overall, the results highlight the need to strengthen institutional coordination, improve the participation and engagement of local stakeholders, develop more effective management tools and mobilize sufficient financing to address existing challenges and promote sustainable water resources management in Yaoundé's urban sub-watersheds.

Key words: IWRM; pollution; ungauged watersheds; water cycle; hydrological balance.

CHAPTER 1

INTRODUCTION

1.1. Context and Justification

Water is a fundamental resource for human well-being and that of natural ecosystems. It is distributed in nature in the form of rainwater, groundwater, river water, lake water, spring water, etc. Potential sources of drinking water are classified as either groundwater or surface water. About 71% of the Earth's surface is covered by seas and oceans, hence the name "blue planet" is often given to Earth. However, most of this water (about 97%) is salty and contained in the oceans, making it unusable for human needs. Of the remaining, 2% of this water is contained in glaciers and inaccessible. Fresh groundwater represents less than 1% of accessible water, while surface fresh water represents barely 0.3% of the accessible water volume (Swati et al., 2012). In the face of this limited availability of water resources, and in view of the ever-increasing urbanization, amplified by the impacts of climate change that affect hydrological conditions in understanding the groundwater situation, the availability of water inputs in the basin for groundwater storage, the movement of water within the groundwater system for extraction purposes, and the influence of parameters such as precipitation, evapotranspiration, infiltration and runoff which are crucial in quantifying the water resource (Nwankwoala et al., 2014), every government in the world is concerned with the sustainable management of its water resources, in line with the Sustainable Development Goals (SDGs). In this spirit, the United Nations (UN), according to the Rio de Janeiro Summit and the Dublin Conference in 1992, proposed the implementation of Integrated Water Resources Management (IWRM) which therefore appears as a new concept that responds to the challenges related to the sustainable management of water resources. The IWRM Action Program (SDG 6) is coordinated by the Global Water Partnership (GWP), in close collaboration with the UNEP-DHI and UNDP Cap-Net Centers and was designed to encourage countries to improve the management of their water resources; necessary to respond to clearly identified and defined priority issues. The issue of IWRM strategy analysis has been the subject of much debate and research in recent years. For some, the IWRM approach seeks a framework that addresses political objectives, the physical state of water and land use planning. This approach aims to establish agreements between the different beneficiaries of water. For others, IWRM can be carried out to explore adaptation

measures to the impacts of climate change (Hamidreza, 2018) and to resolve a wide range of water-related conflicts that arise between governments and stakeholders around the world. SDG 6 indicator 6.5.1 for assessing the level of implementation of IWRM at the global level revealed in 2023 that most developing countries recorded a score of medium low to low (about 87 countries), apart from a few countries such as Rwanda, Morocco, Mozambique, Namibia, Angola, Algeria which recorded medium high scores. Developed countries recorded scores ranging from medium high to high, reflecting their strong involvement in the implementation of IWRM at the national level. In 2020, 171 countries invested significant efforts to complete the 6.5.1 survey, with most countries organizing multi-stakeholder consultation processes. For most, this was an update of baseline reporting completed in 2017. This demonstrates the significant commitment of countries in working towards implementing IWRM in the context of the SDGs (United Nations, 2021). Despite the establishment of various regulations and initiatives, there is still some skepticism about the effective implementation of IWRM in some countries around the world. In most developed countries, IWRM is already fully implemented, while in some developing countries, governments are still struggling to update the water policy and regulatory framework to promote IWRM as a basis for sustainable development (Collado et al., 2023). Cameroon, a Central African country, generally nicknamed "Africa in miniature", has undertaken initiatives since 2005 aimed at integrating IWRM into the national water resources management strategy. The national stakeholder consultation workshop for the monitoring process of the implementation of SDG target 6.5.1 in Cameroon for the year 2023 reveals a final score of 49/100. This score reflects the degree of implementation of IWRM, on a scale of 0 to 100, where 0 indicates a “very low” degree of implementation and 100 a “very high” degree of implementation (MINWRE, 2023). Compared to the year 2020 (40/100), there is a slight improvement in the four main sections contained in the questionnaire for assessing the implementation of SDG target 6.5.1 (enabling environment; institutions and participation; management instruments; financing). Although there is some improvement, considerable efforts remain to be made. The enabling environment component is illustrated by the absence of a National IWRM Plan (pending since 2009) and the delay observed in sub-national regulations (at regional and municipal levels).

1.2. Problem statement

According to the IPCC (2022), all components of the global water cycle have been modified due to climate change in recent decades (Douville et al., 2021). with hundreds of millions of

people now regularly experiencing hydrological conditions that were previously unfamiliar. Extensive records from weather stations, satellites and radar clearly show that precipitation patterns have shifted worldwide. Global water demand is increasing at a rate of about 1% per year driven by population growth, economics, development and changing consumption patterns, and will continue to grow significantly over the next two decades. (United Nations World Water Assessment Program (WWAP, 2018). Lack of awareness of the need to conserve water resources and unfriendly lifestyles have contributed to high pollution and exacerbation of environmental problems. In Asia, many countries are struggling to meet their water needs as water shortages have recently become a major concern, with growing gaps between water supply and demand (Xueping et al., 2017). In North African countries such as Algeria, access to drinking water, although equitably deployed, seems inaccessible for some rural areas, particularly for irrigation, the needs of which are only 40% covered. The balance between resources and needs remains inequitable (Baghili, 2018). In most developing countries, the problem of water resources arises in terms of its distribution. Although moderately irrigated in most cases, these countries have low coverage of drinking water supply, paradoxically to the availability of the resource. In addition, the lack of data on the state of groundwater in different areas constitutes a major problem limiting scientific research, particularly on how climate change is expected to affect groundwater, which makes it difficult to develop mitigation and adaptation strategies (Defo et al., 2016). Moussima et al., (2020), mentioned the fact that in Cameroon, 86.2% of large cities are equipped with drinking water supply systems, yet only 25% of households have access to these services. Similarly, 3% of the population of the city of Yaoundé defecate in the open air, due to the lack of adequate sanitation systems. Up to 15% of the population of this city dump wastewater from toilets into open sewers. The issue of financing remains the weak link in the implementation of IWRM in Cameroon. It is characterized by a lack of funding allocated to the water sector, due on the one hand to the lack of interest of donors in investing in it and on the other hand to the low level of national budgets reserved for. At the subnational level, this situation is even more exacerbated because there is no national water fund to centralize, control and monitor resources. The financing strategy for the water sector in Cameroon is non-existent (IWRM data portal of UNEP-DHI). The problem of water resource management in the country is characterized by a pronounced absence of the valorization of the resource and the rationalization of its use. In small, ungauged watersheds such as Odza and Nkie, the problem of water resource management is more acute due to the critical lack of information on the hydrological interactions that take place there, the lack of quantification of water resources for better allocation, but also the lack of hydrometeorological

stations for monitoring them. These basins are almost abandoned to themselves and not valued. Most hydrological studies carried out in Cameroon focus more on large watersheds such as Mfoundi and Nyong. It therefore appears clear that the integrated management of a country's water resources requires the quantification and evaluation of the quality of the resource for better decision-making. The transversal and multisectoral nature of water therefore requires the establishment of an adequate institutional framework for its concerted and coordinated management (Njikam, 2021).

As the management of water resources requires several key items, the study will focus on (i) understanding IWRM management scheme, (ii) understanding the resource distribution and dynamics (flows) and (iii) analyze possible appropriate strategies for sustainable water resource management in Odza and Nkie watersheds. These will help to address the complexity of water resources management in its technical, institutional and financial aspects, considering the impact of human activities on these resources.

1.3. Research questions, objectives and the working hypothesis

1.3.1. Questions :

- What are the key regulatory instruments and institutional actors involved in Integrated Water Resources Management (IWRM) in the Odza and Nkie watersheds?
- What are the main uses and spatial distribution of water resources in the Odza and Nkie sub-basins?
- What is the water budget of the sub-watersheds and are they experiencing water deficits or surpluses?

1.3.2. Objectives of the study

1.3.2.1. General objective

The overall aim of this research is to contribute to improving knowledge on sustainable management of water resources in urban sub-watersheds in developing countries, particularly in Cameroon.

1.3.2.2. Specific objectives:

To achieve this objective, these include:

- Perform a SWOT analysis of the regulatory and institutional framework of IWRM at the level of Odza and Nkie watersheds.

- Map up the water resources of the Odza and Nkie sub-basins and identify their main uses;
- Determine a hydrological balance scheme of the Odza and Nkie sub-watersheds.

1.3.3. Working Hypothesis:

This study is based on the following assumptions:

- The current water management practices in Odza and Nkie watersheds are inadequate to meet the growing water demands of the population.
- Interactions between surface water and groundwater play an important role in maintaining the water balance in the sub watersheds of Odza and Nkie;
- The effective involvement of all local stakeholders and the adoption of a participatory approach are essential for the successful implementation of IWRM in the study watersheds.
- Effective governance mechanisms and clear institutional frameworks are needed to facilitate inclusive and equitable decision-making on IWRM in the study sub watersheds.

1.4. Relevance of the study

- **Sustainable Development Goals (SDGs):** This research directly addresses SDG 6, which aims to ensure equitable access to safe drinking water and sanitation for all by 2030. This goal cannot be achieved without a deep understanding of water resource management in each country. By analyzing IWRM strategies, the study therefore contributes to achieving this goal in an urban context, which is crucial given the increasing urbanization trends worldwide.
- **Global Water Crisis:** Many urban areas around the world are facing water stress due to population growth, climate change and inadequate water resource management. The Yaoundé case study can provide valuable lessons for other cities facing similar challenges, contributing to the global effort to address the water crisis.
- **Transboundary Water Management**: Although the Odza and Nkie watersheds are in Cameroon, IWRM principles are very crucial for transboundary water management. The study can provide important insights on how to effectively manage water resources in a holistic and participatory manner to resolve transboundary conflicts over shared water resources and promote cooperation.

- **Cameroon National Development Strategy by 2030 (NDS 30):** In accordance with the NDS 30 which, in its development policy, plans to increase the drinking water supply rate and access to sanitation to 75%-60% respectively by 2030, and to improve knowledge on water resources in Cameroon. This study is in perfect correlation with the national development strategies of the water sector and provides scientific knowledge on the management of water resources in small watersheds in Cameroon where studies are very rarely conducted.
- **Decentralization and local governance:** Cameroon is implementing decentralization reforms that enable decentralized local governments to manage water resources. Research can provide guidance on how to implement IWRM at the local level, particularly in the council of Yaoundé IV where the Odza and Nkie watersheds are located, promoting community participation and ownership in water management.

1.5. Scope of the work

The study is limited to the Odza and Nkie sub-watersheds in the metropolitan area of Yaoundé IV district. This means that the research will not extend beyond the boundaries of these two sub-watersheds. It will not include other sub-watersheds in Yaoundé unless they have a direct impact on the Odza and Nkie systems. The study was conducted from December 1er, 2024 to February 28, 2025, in Yaoundé.

1.5.1. Thematic Scope :

- **Integrated Water Resources Management (IWRM):** The central theme is IWRM, which means that the research will examine water resources management holistically, their various uses and the social, economic and environmental aspects related to them.
- **Regulatory and Institutional Framework:** The research will look at the existing laws, policies, regulations and institutions responsible for water management in the Odza and Nkie catchments. This involves an analysis of their effectiveness, gaps and potential conflicts.
- **Water Resources Mapping and Uses:** The study will map the physical water resources (rivers, streams, wetlands) in the two sub-catchments. It will also document and analyze the various uses of these water resources.

- **Hydrological balance**: This involves quantifying water inputs (precipitation), water losses (evapotranspiration) and how water is stored and flows through sub-catchments, considering the influence of land use. This will provide a scientific understanding of water availability and dynamics in the region.

1.5.2. Methodological Scope:

The research uses a mixed method approach, combining:

- **SWOT analysis:** a structured analysis of the strengths, weaknesses, opportunities and threats of IWRM at the national level.
- **GIS and remote sensing:** to map water resources, land use and possibly analyze hydrological data.
- **Data collection:** this involves field coordinate surveys, collection of hydrological information from relevant authorities, stakeholder interviews and review of existing data.

1.6. Thesis structure

1.6.1. Introduction

This chapter will present an overview of the global water crisis and the notion of integrated water resources management in the world and in Cameroon in particular. It will then narrow down to the challenges of IWRM in Cameroon. It will comprise the following sections: background, problem statement, research goal and specific objectives, research questions, and structure of the thesis.

1.6.2. Literature review

The literature review will provide a broader perspective of previous research related to the topic. It will highlight key concepts on IWRM implementation at subnational level, small basin water balance, water resources mapping and uses, water resources management policies in Cameroon, SWOT analysis tool for IWRM and ecosystem-based management.

1.6.3. Materials and methods

This chapter will focus on providing information on how and what steps to take to carry out the research. It will introduce all the tools and materials needed for the procedures and models that

will lead to appropriate results. It will also explain how the data is collected and the methods used for analysis. This chapter is therefore very important because it will provide the basis for the validity and reliability of this research. The outline of this chapter is as follows: Description of the study area; Research design; Sampling method; Data collection, modelling and analysis.

1.6.4. Results and discussions

The results and discussion chapter will serve to present and discuss the results of our study. The general idea will be to interpret the results and explain their significance so as to adress the research problem that was earlier mentioned and to reveal more input on what was already known about the subject. This chapter will include:

- SWOT analysis of the regulatory and institutional framework of IWRM in Odza and Nkie sub-watersheds.
- Water resources and water uses mapping in Odza and Nkie sub-watersheds.
- Hydrological balance and flow model on Odza and Nkie watersheds.
- Discussion of the IWRM strategies for Odza and Nkie urbanized sub-watersheds strengths, limitations, and applicability.

1.6.5. Conclusion and recommendations

In this section, the main argument of the research will once again be stated, in order to prompt the reader to remember it. It will equally echo the most important affirmations that support the research argument. Furthermore, based on the results and discussion, the section will also mention the most plausible way forward as regards the topic, as well as areas to explore in the future. This part will encompass: the summary of the research findings and proposed solutions for IWRM in the council of Yaoundé 4; recommendations for stakeholders and future research on the topic.

CHAPTER 2

LITTERATURE REVIEW

A literature review is an overview of scientific sources on a specific topic. It provides an overview of current knowledge, identifying relevant theories, methods, and gaps in existing research that can be applied to a dissertation, thesis, or thesis topic. This section will cover reviews on the previous findings on integrated water resources management (IWRM) including, the analysis of institutional and regulatory framework for water management in Cameroon, water resources mapping, water balance at the watershed scale.

2.1. Definition of keys concepts

- **Integrated Water Resources management (IWRM)**

Integrated Water Resources Management (IWRM) is a concept that has evolved over time and is subject to different definitions, all highlighting the need for a holistic and participatory approach to water resource management.

According to the Global Water Partnership (GWP, 2010), "**IWRM** is a process that promotes the coordinated management and development of water, land and related resources, in order to maximize economic and social well-being in an equitable manner, without compromising the sustainability of vital ecosystems."

- **Institutional framework**

According to the United Nations (2016), "The **institutional framework** encompasses the laws, policies, organizations and practices that govern the management of water resources."

- **Regulatory framework**

The regulatory framework, in the field of water resources management, is a set of legal texts that define the rules, obligations and responsibilities of the different actors involved in the use and management of water resources.

According to the Global Water Partnership (GWP): "The **regulatory framework** is an essential element of integrated water resources management (IWRM). It provides a legal framework for decision-making and the implementation of actions."

According to the Food and Agriculture Organization of the United Nations (FAO): "The **regulatory framework** is the set of laws, regulations, decrees and other legal instruments that govern the use and management of water resources."

- **Water management**

According to the Global Water Partnership (GWP, 2017), "**Water management** is the process of planning, developing, and managing water resources in a way that meets the needs of present and future generations without compromising the ability of future generations to meet their own needs."

- **Watershed**

Flotemersch (2015), defined **watershed** as the landscape that contributes surface water to a single location, such as a point on a stream or river, or a single wetland, lake or other waterbody."

- **Water balance**

Basically, the **water balance** is an account of the inflows and outflows of water in a specific system. This system can be anything from a small plot of land to an entire watershed. It is based on the principle of conservation of mass.

According to the United States Geological Survey (USGS, 2007), "a **water budget** or **water balance** simply indicates that the rate of change of water stored in an area, such as a watershed, is balanced by the rate at which water flows into and out of the area. An understanding of water budgets and the underlying hydrologic processes provides a basis for effective planning and management of water resources and the environment."

2.2. Analysis of strengths, weaknesses, opportunities and threats of IWRM

The performances of water management services are generally improved when the SWOT analyses is duly performed accordingly. Some previous works have been conducted on integrated water resources management, and the authors depicted the SWOT analysis of their findings. Table 1 summarizes the recent trend shown by some previous authors on this subject.

Table 1 : literature review of SWOT analysis of IWRM

Country/Locality	SWOT outputs recorded	Authors
Greece (Crete Island)	- **Strengths** - Good surface and groundwater - Important number of dams - Water management governance, decision support systems and engineering expertise. - Adequate statistics to monitor the parameters involved in the threats. **Weaknesses** - Seasonality in annual rainfall volume. - High water consumption for irrigation. - Limited data exchange between authorities responsible for monitoring water quality. **Opportunities:** - Improving the status of surface water and groundwater. - Increasing the availability of water data. - Improving irrigation efficiency. - Cost recovery of water services. **Threats:** - The current economic and financial situation limits the funds available for public investments. - Significant drought periods during the summer months due to climate change.	Petousi et al., 2017
India, Nepal and China	**Strengths:** Inherent capacities of selected climate change adaptation activities based on: - Socio-economic conditions, - Environmental conditions and - Technical conditions of the selected basin. **Weakness:** Deficiencies in selected climate change adaptation activities regarding: - Failure to address the negative impacts of climate change, - Insufficient level of awareness and knowledge, and - Failure to address peak demands for water during summer. **Opportunities:** Capacities for the selected activities in terms of adaptation to climate change concerning:	Hamidreza, 2018

	- Application to the hydrological model, - Execution in the study area, - Interest in funding sources. **Threats:** Risks of selected climate change adaptation activities in terms of: - Lack of response to floods, - Lack of response to drought and - Threats to investments if not properly planned.	
China (Shandong province)	**Strengths:** - Accelerated urbanization promotes development, - Improved agricultural output benefits, improved urban water security and water use efficiency, - Increased GDP per capita and national income. **Weaknesses:** - Lack of annual runoff depth and surface water with increasing water demand. - Increasing population and lifestyle demands. - Decline in agricultural land leads to land use competition for urbanization and industrialization. **Opportunities:** - Availability of water resources through inter-basin water transfer and wastewater recycling. - Increase in available water resources through environmental protection. - Development of green economy in weak watersheds. **Threats:** - Increased water consumption for excessive development; increased sources of water pollution. - Need for effective water pollution control Technik.	Xueping et al., 2017
Egypt/Nile Basin	**Strengths:** - Multinational and multi-sectoral programs of collaborative actions, exchange of experiences, trust and capacity building for regional cooperation and sustainable management of the Nile waters. - Achievement of the SDGs; development of knowledge-based tools for IWRM through capacity building in each Nile basin country.	Belay et al., 2013

	- Development of decision support system for information sharing; building trust, and collaborative relationships among all those involved in the management of the Nile water resources; broad stakeholder participation. - Strong stakeholder engagement and ownership of projects in all member countries with the establishment of project management units in each country. - Environmental management plan; strong support from donors from giant institutions. - Project monitoring framework through consolidated annual and quarterly interim financial reports; significant regional cooperation. - Governance and institutional structures and processes for constructive dialogue among riparia. **Weaknesses:** - Lack of institutional depth; inadequate capacity to develop regional databases and analyze water resources information. - lack of coordination and linkages with some stakeholders such as the Lake Victoria Basin Commission; failure to integrate local knowledge of indigenous peoples of the Nile Basin countries into project planning. - Failure to integrate the Nile Hydropower Initiative into the World Commission on Dams which provides guidelines on dam construction on international transboundary rivers. - The NBI is the most complex and ambitious river basin project ever undertaken and this may lead to misinterpretations and flawed analysis of the entire project. **Opportunities:** - Continued World Bank support for NBI projects presenting a "hope" for achieving NBI objectives. - Finalization of a CFA will help create a permanent RBO; greater involvement of NGOs and civil society will implicate the overall effectiveness and efficiency of NBI project implementation; membership of Nile Basin countries in the African Union, with the NBI project promoting the opportunity to benefit from the New Partnership for Africa's Development (NEPAD). **Threats:** - Long-term challenges to operational integration across the basin due to different sets of policies and procedures between NBI institutions; 1929 Nile Basin Waters Treaty limiting the efficient use of Nile waters.	

	- History of tensions and instability in the region, both between and within countries; population growth coupled with poverty creates pressure on Nile resources. - NBI countries are at different stages of development with six of the world's 10 poorest countries threatening the initiative's path to achieving its goals; corruption and aiding money disappearing into private pockets can ruin all planning. - Climate change and water stress can force governments to act individually trying to exploit their populations as much as possible.	
Palawan (Philippine)	In the Puerto Princesa area, the analysis shows: **Strengths:** - Updating local water management plans and policies; strengthening and well-coordinated institutional relationships for IWRM implementation. - Separating water resources management and water service provision in IWRM implementation; implementing sustainable and efficient water consumption. - Data availability and effective information sharing; sufficient financial capacity to invest in water resources allocation at the national level. **Weaknesses:** - Weak implementation of national laws and policies; slow progress in capacity building and development. - Lack of aquifer and groundwater management plans and institutions; water resources management without civil society participation. **Opportunities:** - Presence of large watersheds and many river basins; adoption and implementation of a national climate change plan. - Well-defined sector-specific policies and an overarching sector strategic plan for environmental and natural resource management, water supply and sanitation. - Proposed master plan for water supply and sanitation in the Philippines. - Growing partnership between government agencies, NGOs and development partners. **Threats:** - Increasing population pressure and industrialization; increasing negative impacts of climate change. - Lack of an integrated water policy master plan; limited availability of alternative water resources other than surface water.	Collado et al., 2023

Quatro Pontes (Brazil)	**Strengths:** - Hypochlorite treatment produced in the municipality itself; Quality product (drinking water). - Small municipality, therefore easy maintenance. - Newly built catchment system; Agility in carrying out maintenance services. - Hotline for emergencies and maintenance calls. - Support from municipal administration for system management. - Good system management planning characterized by no shortage of equipment and materials for maintenance; All employees have qualifications in the sector. - Dedicated employees. **Weaknesses:** - Few financial resources are allocated to the sector, absence of an exclusive maintenance team. - outdated pricing policy. - Lack of equipment in laboratories. - Lack of training for employees; poor communication between SQPA sectors. - Lack of laboratory space; lack of evaluation of production losses; divergence of information between managers (out-of-date files, only one employee knows the mapping of the pipes); dilapidated plumbing. - Employees not knowing where they are or their status; small work team; overlapping duties/overload; attention paid to the system only in the event of failure: lack of preventive maintenance; reservoir showing pathologies. - High maintenance costs; centralized treatment system; devaluation of the work provided to the council and the population. **Opportunities:** - Abundance of water; the possibility of harvesting rainwater in homes and public buildings. - Agreement between municipalities bordering Lake Itaipu. - City with sufficient financial resources; creation of self-sufficiency. - New sources of capture (rivers); awareness of the population; existence of new technologies/training that can be applied to the SQPA. - Use of solar panels to reduce energy costs.	Schweinberger at al., 2023

	Threats: - Waste of water by the population; contamination of water (pesticides). - Increasingly constant droughts; illegal connections; Legislation unsuitable for small towns. - Lack of wastewater collection and treatment; reduction in vegetation cover and neglect of sources. - Excessive increase in animal production which consumes a lot of drinking water and contaminates the soil. - Accelerated growth of the municipality; Dismissal of dedicated employees.	

Strengths and weaknesses are factors internal to the study area, while opportunities and threats are posed by external factors. Internal factors give certain advantages or disadvantages to water management in the study area. Whereas external analysis examines the opportunities and threats that exist independently of the study area. It is important to minimize weaknesses and threats to convert them into strengths and opportunities when implementing SWOT analysis. Similarly, strengths and opportunities should be matched to optimize IWRM in the study area. The SWOT analysis performed by Petousi et al., (2017) shows that Crete, as a hydrographic region, has surplus water resources compared to other Greek hydrographic regions. Their proper use is hampered by the uneven geographical and morphological distribution of the annual precipitation volume (Western Crete as a mountain receives 25% more annual precipitation than Eastern Crete which is a plain). Moreover, the water quality in Crete is generally good. The main problems in the region are overexploitation of water resources for irrigation and pollution by domestic wastewater and wastewater from oil mills. It is necessary to balance the needs of the people and the environment to ensure the sustainability of water resources. Reduction of water for irrigation, control of fertilizers, exploitation of saline karst springs, recycling of wastewater and construction of small dams are some of the measures proposed. Hamidreza (2018) identified six adaptation activities that take place in the physical options of the IWRM approach. These include: (i) diversification of water supply, (ii) groundwater recharge, (iii) preparedness for extreme weather events. (iv) resilience to water quality degradation, (v) rainwater control and capture, (vi) water conservation. The selected activities include various management practices/technologies and operations. After selecting the activities, a SWOT analysis was conducted to identify the strengths, weaknesses, opportunities and threats of each scenario and prioritize them using partial order analysis (POA). The beneficial aspects of the selected activities were given positive scores, and the harmful aspects were given negative scores. Each cell of the SWOT properties includes some main characteristics (It is important to clarify that there is no limitation on the number of characteristics in SWOT properties. It is assumed that there are equal number of characteristics for each property (strength, opportunity, weakness and threats) to maintain the balance between positive and negative rating scores.), which indicate the function of each activity. If an activity A1 received three check marks for the strength's property (beneficial aspects), then the beneficial score is "3". This means that the performance rating is "very good" for A1 in the strength's property. Once the performance ratings are assigned, the scores for all the selected activities are calculated and the sum of the scores shows the final performance for each scenario/activity. It emerges from his analysis that the results of studies on adaptation to climate change in various countries require a deep

prioritization analysis to gather the needs and knowledge of all stakeholders at the local level, to develop relevant responses and adaptation options reflecting the combination of development choices. In addition, the process should help in the bilateral transfer of knowledge and experiences of adaptation to climate change and its implications for stakeholders, both at the local, regional and national levels. The existing implementation of POA and SWOT analysis prioritizes adaptation activities and can result in improved water and land use planning under various climate change scenarios. Xueping et al., (2017) identified a practical assessment model to be used to analyze WRSU and recommend strategic measures that enhance sustainable water use practices. To do this, he combined three assessment methods, namely: SWOT analysis, cloud method, and WRSU assessment and strategy development procedure. An integrated framework using SWOT analysis and the Normal Cloud Model (NCM) was successfully applied to assess WRSU and identify development strategies derived from the water resources, societal, economic, and environmental dimensions of WRSU indicators, and guided by the strategy-oriented principle. His study integrates the four dimensions with SWOT analysis to develop indicators and select appropriate strategies. The strategies are defined according to the idea share of each SWOT element. If the strategy is derived from S (force) and O (opportunity) and synthesizes two forces and one opportunity, then it is named SO with the subtitle S, which stands for SO-S type. Through the comparison of internal and external factors, the SWOT coordinate diagram he developed enabled him to make the analysis of strategic options. Since each indicator (S, W, O, T) is classified according to its effect on the system, he distinguished these indicators by observing the trend of historical data. Considering that the currently used evaluation models cannot account for the random and fuzzy nature of the indicator quantification and scoring process, this study used a normal cloud model for the evaluation of WRSU. Finally, the overall evaluation scores were obtained using the variable fuzzy set method. He developed this method of evaluating and developing strategies for WRSU on Shandong Province, China, as a case study to demonstrate a more detailed modeling procedure. It should be emphasized that the precision on the results obtained is insufficient because some historical curves of indicators are not constantly increasing or decreasing. Therefore, an additional analysis to quantify the effect of the indicator on the WRSU requires a more in-depth study. In addition, the implementation of national policies and their changes undoubtedly disrupt the application of the development strategies proposed by the author. The forecast of national development trends combined with the pre-definition of different strategic scenarios could be more flexible for the application of the strategy he obtained. Collado et al., (2023) identified and prioritize the key factors affecting the implementation of the IWRM system in

04 localities (Puerto Princesa, Roxas, Taytay, El Nido) in the province of Palawan to support its implementation. This approach combines SWOT analysis and Analytic Hierarchy Process (AHP) techniques, a hybrid multi-criteria decision procedure, SWOT-AHP. They began by analyzing current IWRM assessments in areas of Palawan to determine the most important plans and management options best suited to the current situation. The assessments of IWRM in the areas were obtained from a survey. The starting point was the different stakeholders' experience and understanding of existing consumption and ecosystem issues. The expert group discussions revealed the key elements impacting on the implementation of IWRM in the study area, and these elements were classified into SWOT categories. The AHP approach was used to determine the relative relevance of each element identified in the SWOT analysis. The results show that the following ranking groups have a higher priority for Puerto Princesa: threats (group weight 48.8%), strengths (35.4%), weaknesses (10.7%) and opportunities (5.1%). The ranking group for Roxas is as follows: opportunities (36.8%), strengths (27.4%), weaknesses (21.5%) and threats (14.3%). Taytay has the following ranking: opportunities (27.9%), weaknesses (27.1%), threats (24.7%), and strengths (20.3%). El Nido ranks as follows: strengths (33.5%), weaknesses (24.3%), opportunities (24%) and threats (18.2%). The results of this research demonstrate the potential value of the SWOT-AHP approach in analyzing the strategic implementation of Integrated Water Resources Management (IWRM). It explains how to prioritize each specific factor that has an impact on the way IWRM is implemented to make the best use of the resources needed to implement a strategic plan. The elements that carry the most weight in this technique are prime targets for IWRM development or planning, as they have a greater likelihood of having an influence on the implementation of an IWRM strategy. However, when using the AHP method to examine the weightings of the SWOT groups, it is essential to note the significant variability assessed for each group. This is a point that should be highlighted. The SWOT-AHP results indicate that an effective strategic plan will be required to deploy IWRM in the study areas. This plan should be established to capitalize on the defined list of opportunities, to get rid of weaknesses, to mitigate the impact of threats and to build on the experience gained. To determine which areas to prioritize, all are considered vital but have different impacts. Low-priority elements help to consolidate change, but their influence is limited if the key issues are resolved. Schweinberger et al., (2023) presented the diagnosis of the water supply system of the municipality of Quatro Pontes through a SWOT analysis. These factors covered the areas of supply system infrastructure, management, labor and environmental aspects. They identified 10 strengths, 16 weaknesses, 10 opportunities and 11 threats to the system. The number of weaknesses stands out from the rest, suggesting that more attention

should be paid to minimizing these factors. The outstanding factors include, among the strengths, the hypochlorite treatment produced in the municipality itself, the quality of the water produced and the ease of maintenance, mainly due to the small size of the municipality. Among the weaknesses, the low financial resources applied to the sector, the absence of an exclusive team for maintenance and the obsolete pricing policy were highlighted. As for opportunities, the most important were the abundance of available water and the possibility of capturing rainwater. As for threats, the waste of water by the population and the contamination of this resource by pesticides stood out. The Nile River is one of the longest transboundary rivers and is shared and used by Burundi, the Democratic Republic of Congo, Egypt, Ethiopia, Eritrea, Kenya, Rwanda, Sudan, Tanzania and Uganda. It is a crucial resource for the economic development of the Nile Basin countries and a vital source of livelihood. The Nile Basin Initiative (NBI) is one of the international cooperative river basin management programs and a regional partnership where all Nile Basin countries, except Eritrea, join to pursue long-term sustainable development, improved land use and management practices. Belay et al., (2013), in their analysis of the challenges of the Nile Basin Initiative (NBI), showed through SWOT analysis that for decades, the people of the Nile Basin have been facing many complex environmental, social, economic and political challenges that have made it difficult to properly manage and sustain the Nile waters. The challenges of the NBI include the involvement and funding of the World Bank, lack of adequate staff, conflicts of procedures and policies, lack of coordination and linkage with other regional institutions and lack of recognition as a river basin organization. Given the complex nature of the project, Belay et al., (2013) recommend through this study, the establishment of a strong multidisciplinary monitoring and evaluation team to monitor all the projects implemented by the NBI. The NBI should conduct participatory land use planning in communities located along the river basin. Furthermore, a livelihood analysis should be carried out particularly in communities along the Nile to propose poverty eradication projects that are socially acceptable, implementable and economically viable.

2.3. Overview of institutional framework for water resource management in Cameroon

Managing water resources requires several competences which must be mobilized for smooth and sustainable water resource management. These include

- Policy design, policy decision making, and policy implementation
- Investment / Financing
- Education

- Technical support
- Cooperation
- Sciences and innovation

2.3.1. Water resource management framework in Cameroon

Table 2: IWRM Framework at national and international level

	Policy design and decision	Investment and financing	Education	Research and technology	Technical support	Cooperation
International level	UNO (UNEP, UNESCO)	World Bank	UNESCO	UNESCO	World Bank	UNESCO
	ICRE	IMF	African Union	World Bank	IMF	World Bank
	World Bank	EU	FAO	FAO	EU	ADB
	African Union	ADB	GWP	IWRC	IFAD	WHO
	ECCAS	GWP	World Bank	IWMI	GWP	GWP
	GWP	UNICEF	UNEP	UNDP	ADB	FAO
	OECD	GCF	UNICEF	ADB	FAO	EU
National level	MINWRE	CRHPP	MINHE	ARID	MINWRE	MINWRE
	MINARD	MINWRE	UY1	UY1	CDE	The National Maritime Conference
	MENPSD	FSR	HIAWWE	NHPS	FSR	The General Delegation for the Sea
	ONEA	BCAS	CENAFE	RCWCC	CRHPP	NGO
	PPRA	Basins committees	Basins Committees	NOCC	BCAS	NOWS
	National Committee of the Sea	CDE	IFRE	Basins Committees	Basins Committees	NWC
Sub national level	Regional councils	Regional council	Vocational training centers	Universities	NGOs	Public-private

						partnerships
	Town halls and local authorities	Town halls and local authorities	Schools and Universities	Approved research centers	Microfinance institutions	NGOs
	Local water agencies	Microfinance institutions	Town halls and local authorities	Approved research laboratories (ARID, HRC, RCWCC …)	Regional development agencies	Research institutions
	Basin Committees	Cooperatives and community associations	NGOs and community associations	Technical training institutions		Community associations
	Producer groups and community associations	Local development programs	Basin Committees	Regional development agencies		Regional council

The institutional framework of the water sector in Cameroon is based around three major colleges of actors which are: (i) **the State and its main branches**, in particular the Ministry of Energy and Water resource (MINWRE) but also the other ministerial departments, the organizations under supervision, and the decentralized local authorities; (ii) **other users in the private sector and civil society**; (iii) **cooperation partners** (GWP, 2009). Apart from the central role of MINWRE, several ministerial departments are concerned with water in one form or another or its uses. The other actors (the private sector, non-governmental organizations (NGOs) and the associative sector in general) are not part of the institutional framework in the strict sense of the term but play an important role in the mobilization and management of the country's water resources. (MINWRE, 2022). However, the National Water Partnership (NWP) occupies a pivotal role in the implementation of the IWRM process; its mandate is to promote IWRM alongside state structures whose mandate is the sustainable management of water resources (World Bank, 2023). Multilateral and bilateral aid agencies play a key role in financing water infrastructure and, more generally, provide financial and/or technical support to the country’s entire water sector.

At regional level, the meeting of ministers responsible for water from the member states of the Economic Community of Central African States (ECCAS) on 30 March 2009 led to the adoption of a regional institutional framework for implementing water policy, comprising the following bodies:

- The Ministerial Steering and Orientation Committee (MSOC).
- The Technical Monitoring Committee (TMC).
- The Water Resources Management Coordination Center (WRMCC).
- The Regional Water Council (RWC).
- The National Water Councils or Committees (NWC).

At continental level Cameroon is also member of the African Ministers' Council on Water (AMCOW) and works with this body on the monitoring of investments in water sector.

2.3.2. The public and parapublic sectors of water resource management

Table 3: Public and parapublic actors in water resource management in Cameroon

Organizations	Ministries /Institutions	Missions
Public actors responsible for defining water policies	Ministry of Water Resource and Energy (MINWRE)	Development, implementation and evaluation of the Government's policy on the production, transport and distribution of water
	Ministry of Environment, Nature Protection and Sustainable Development (MENPSD)	Development, implementation and evaluation of the Government's policy on the environment and nature protection
Public user actors	Ministry of Water Resource and Energy (MINWRE)	Development of government plans and strategies for water supply research and exploitation of water in cities and the countryside Planning and development of hydroelectric capacity
	Ministry of Housing and Urban Development (MINHUD)	Definition of standards for sanitation and drainage in urban areas
	Ministry of Agriculture and Rural Development (MINARD)	Promotion of agricultural hydraulics policy
	Ministry of Livestock, Fisheries and Animal Industries (MINLFAI)	Protection of maritime and river resources Studies and research with a view to renewing fishery and piscicultural resources
	Ministry of Territorial Administration and Decentralization (MINTAD) (Local authorities)	Project management and development of water supply and sanitation master plans

Public financing actors	Ministry of Water Resource and Energy (MINWRE)	Preparation of water agreements and conventions
	Ministry of Finance (MINFI)	Financing of public projects included in the Public Investment Budget (PIB)
	Ministry of Economy, Planning and Regional Development (MINEPRD)	Development of development strategies and coordination of land use planning studies Planning of strategic investments
Public facilitation and research actors	Ministry of Foreign Affairs (MINFA)	Coordination, negotiation, monitoring of the implementation of international cooperation framework agreements Preparation of instruments for ratifying treaties
	Ministry of Territorial Administration and Decentralization (MINTAD)	Administrative supervision of local authorities Development and implementation of civil protection and disaster response strategies
	Ministry of Public Health (MINPH)	Community health surveillance, promotion of hygiene and environmental health, fight against water-borne diseases
	Ministry of Scientific Research and Innovation (MINSRI) (HRC, ARID, CRWCC)	Development and implementation of scientific research programs and operations. Valorization of research results Assessment and qualification
	Ministry of Commerce (MINCOMMERCE)	Development and implementation of pricing policy, measuring instruments, quality control and standards
	Ministry of Mines, Industry and Technological Innovation (MINMITI)	Industrial standardization policy, pollution control standards and sanitation inherent in mining beneficiation industries
Organizations having received delegation of public services	Cameroon Water Utilities Coorporation (CAMWATER)	Construction, water distribution, infrastructure maintenance, water treatment, measurement, invoicing, collection of revenue, management of drinking water production, storage and transport infrastructure
Subnational water resources management structures	Council of Regions	Supports the development of Decentralized Territorial Communities (DTC), through the promotion of Small and Medium Enterprises (SMEs), the organization of fairs and exhibitions, the promotion of crafts, agricultural and pastoral activities, support for micro-projects generating income and jobs, the promotion of tourism, the management of the environment and natural resources, the management, protection and maintenance of protected areas and

		natural sites under the jurisdiction of the regions.
	Decentralized Territorial Communities (DTC)	to drive development at the local level, promote participatory democracy, local governance and development in social, educational, health, sporting, cultural, economic, craft and tourist areas.
	Council	The promotion of agricultural, pastoral, craft and fish farming activities of communal interest; the development of communal tourist sites; the construction, equipment, management and maintenance of markets, bus stations and slaughterhouses; the organization of local trade fairs; support for micro-projects generating income and jobs.

2.3.3. Technical support administrations for coordination and consultation

Due to the cross-cutting nature of water resources, consultation and coordination between the various stakeholders and operators has become a key concern for the development of this sector. Despite the existence of a wide range of mechanisms and organizations at the national, regional or local level, coordination and consultation remain almost non-existent. However, some of these organizations benefit from delegations of regulatory powers intended to increase their effectiveness. These are :

- **National Water Committee:** its mission, among other things, is to conduct, study, and make proposals and opinions to the Government to ensure rational and sustainable water management (art. 2 Implementing Decree No. 2001/161/PM of 05/05/2001). Its operation is based on the representation of ministerial departments, local authorities, the private sector and public service concessionaires. Its financing is provided by a special allocation account intended to finance sustainable development projects in water and sanitation.
- **National Environmental Committee:** it is responsible for validating impact studies of development actions on natural resources and raising awareness among populations for healthy environmental management.
- **Observatory of water resources:** it is responsible for assessing water needs, its use and relies on research for knowledge (quantitative and qualitative resources, inventory and monitoring of its management). Its organization and operation follow the model of the National Water Committee.

It should be noted that these organizations, although they have organic and regulatory frameworks, are not operational.

2.3.4. International, National and Subnational Coopération

Cameroon has adhered to several consultation and management frameworks at the sub-regional, regional and international levels to promote better management of water resources, such as the United Nations Environment Programme (UNEP), the water policy of the Economic Community of Central African States (ECCAS), the International Commission of the Congo-Oubangui-Shanga Basin, the Niger Basin Authority, the Lake Chad Basin Commission (LCBC). The Lake Chad Basin Commission (LCBC) has developed a management plan for the Logone for the Cameroonian part of its basin. At the Sanaga basin level, the development of a management plan has been initiated, but the latter is criticized for being mainly focused on the exploitation of water for hydroelectric purposes (MINWRE, 2023). It should be noted that the bulk of public funding available in the water sector is provided by these cooperation partners, released either in the form of funds, or in the form of subsidies or long-term, low-term, low-interest subsidized loans. Cameroon has also adhered to the main international initiatives, conventions and agreements relating to the management of the environment in general and water resources in particular. These include:

- RAMSAR Convention No. 28-96 of June 25, 1996, on wetlands.
- Convention No. 27-96 of June 25, 1996, on climate change and the Kyoto Protocol.
- The African Convention of April 21, 1980, on the conservation of nature and natural resources.
- The cooperation convention of July 19, 1985, on the protection and development of coastal areas of West and Central Africa.
- The constitutive act of the African Ministers' Council on Water (AMCOW) - 2001.

Institutions of transboundary water cooperation active in Cameroon are

- Niger Basin Authority (NBA)
- Lake Chad basin Authority (LCB)
- International Commission of the Congo-Oubangui-Shanga Basin

At subnational level there exist Syndicates which mandate is to advocate on behalf of councils for better access to water and sanitation. Some of those structures are

- SYNCOLEK (Syndicate of Councils of Lekié Division)
- SYCOMI (Syndicate of Councils of Mbam and Inoubou Division)
- SYCNYO-EK (Syndicate of Councils of Nyong-Ekelle Division)

At local level around water point sometimes there could be water management committee or at neighborhood level neighbors committee or local development committees.
In certain councils like Bagangte Council and Ebebda Council water committees are created and given the mandate to monitor and develop water infrastructures (mainly drinking water).

2.3.5. Facilitation and support institutions

Cameroon, like several Central African countries, is a member of sub-regional economic integration and international cooperation organizations related to water, including:

- The Council of African Ministers in charge of Water (AMCOW).
- The Central African Forests Commission (CAFCOMI).
- The Conference of African Ministers of the Environment (AMCAE).
- The Global Water Partnership (GWP).
- The World Conservation Union (IUCN).

The IWRM implementation process is mainly financed by Technical and Financial Partners (TFPs). The concept of IWRM is new in an environment like Cameroon where water is considered a natural, available and free resource. Most of the budgets used at the subnational level are transferred resources that are insufficient to cover the needs of hydraulic infrastructure (MINWRE, 2023).
No organization here includes in its missions a strong action in the direction of the coordination of actions linked to water in the sub-region. State action at sea and on waterways includes general policing and sovereignty missions.
The accomplishment of these missions at sea is done by a multitude of structures:
- **The National Committee of the Sea** which defines government policy and sets the guidelines for government action in this area.
- **The General Delegation for the Sea** which is the permanent instrument of coordination at the national level.
- **The National Maritime Conference.**
- **The Command of the Surface Forces of the National Navy** responsible for conducting State action at sea regarding the implementation of Defense resources (GWP, 2009).
Unfortunately, this system remains without any effect, because none of these structures is operational.

2.3.6. Strengths and weaknesses of the institutional framework for water management

The table below summarizes the strengths and weaknesses of the institutional framework for water resource management in Cameroon.

Table 4: Strengths and weaknesses of institutional framework

Strengths	Weaknesses
- Good governmental organization of the different areas of water resources management activities (water protection, water resource use, sanitation, research inventories, monitoring and follow-up). - Existence of an institutional framework for coordination and consultation (water resources observatory, national water committee, water information committee). - Existence of transboundary water management agreements and their applicability: Cameroon belongs to five basins, 3 of which are managed by an authority, namely: the Congo Basin (CICOS), the Lake Chad Basin (LCBC), the Niger Basin (NBA), the Sanaga Basin and the coastal rivers. The coastal river basins are being created. The objectives at the LCBC and NBA levels have been achieved, but at the CICOS level, efforts still need to be made. Cameroon joined the HELSINKI Convention on Transboundary Waters in 2021 and is implementing it (MINWRE, 2023).	- Centralized administrative organization of the State: The State has concentrated all prerogatives on matters of water in the hands of these central or provincial structures. (GWP, 2009). - Dedication of several main actors to the water sector, thus reducing the influence of MINWRE (Ministry of Energy and Water). These multiple public actors intervene with different logics and self-sufficiency. MINWRE is therefore felt as one of the direct actors in the sector and not as the main organizer of the sector. - Inefficient organization of the institutional framework for water management caused by sectoral management and the inoperability of coordination structures. - Technical and financial weakness of private actors and civil society, characterized by a lack of structuring given their numbers. - Shortcomings of the MINWRE are linked to the weak capacities of its various structures to carry out the missions and to their design. Apart from the little importance given to the sanitation function (reduced to a simple service which moreover does not have a designated manager), the other dimensions of the mission

	are identified and integrated at the different structural levels. - Lack of control of the regulatory framework for the intervention of other actors in the water sector (private sector, civil society) outside those of the public sector. - Weak decentralization of technical services (between central services and provincial and departmental delegations) leading to the centralization of decisions at the level of central services and the inhibition of local and private initiative and action capacities. - Inability of MINWRE to fully play its role in coordinating the water sector given its weak strategic positioning in the government configuration compared to other ministries involved and in the face of non-state actors. - Inoperationality of the NWC (National Water Committee) created since 2001 and the WASH (Water, Sanitation and Hygiene) sector group: the NWC, which has only met once since its creation, is no longer operational. The non-functioning of this committee poses problems of co-decision and co-production at the IWRM level. Inter-administration coordination is ensured by the Prime Minister's Office where all actions in terms of strategies and policies in the water sector are discussed and arbitrated. The Ministry of Water and Energy very often provides the secretariat for these consultation frameworks

	(Cameroon survey questionnaire on indicator 6.5.1, 2023). - Absence of a body dedicated to the management of national basins. - Insufficient budget allocated to the water sector in relation to demand (unfavorable economic situation caused by internal and external crises). In addition, the dilapidated state of hydraulic infrastructures (high cost of maintenance and low allocation of resources for the sustainability of existing infrastructures) remains a current problem.

2.3.7. Strengths and weaknesses of human resources in the context of water resources management in Cameroon

Table 5: Strengths and weaknesses of human resource in water management sector in Cameroon

Strengths	**Weaknesses**
- Average theoretical qualification of technical staff working at MINWRE. - Strong desire to set up consultation frameworks for the sector. - Growing awareness of being part of an IWRM process thanks to the actions deployed by GWP - Cameroon. - There is currently a National Gender Policy in Cameroon and gender is effectively considered in all areas, including IWRM. The law on Cameroon's water regime, currently	- Relatively weak support from the MINWRE hierarchy for the IWRM program, although a considerable number of staff benefit from long-term training. Each year, around twenty MINWRE executives undergo 2 to 3 months of training on Water Resources Management as part of cooperation with countries such as China and South Korea (MINWRE, 2023). - Vulnerable people are considered in the water law currently being revised and IWRM policy documents, but

being revised, integrates gender aspects.	implementation remains unsatisfactory. - The sector still has a long way to go, particularly in terms of training and rejuvenating the workforce. No succession policy is planned. The introduction of IWRM-related teaching remains low (GWP, 2009). The problem of insufficient staff and ageing (the national IWRM action plan document (NAPIWRM drawn up in 2009, reveals in its study that in 2011, more than 50% of staff will have reached the age limit.), added to the costs of Administration, are slowing down the deployment of IWRM. Other problems related to the definition of work situations, the motivation of agents and their careers are compromising the proper functioning of the services.

2.4. Regulatory framework for water resource management in Cameroon

2.4.1. The Laws

2.4.1.1. Law No. 98/005 of April 14, 1998

The basis of water law in Cameroon is constituted by law n° 98/005 of April 14, 1998, relating to the water regime. It is itself based on law no. 96/12 of August 5, 1996, relating to the framework law relating to environmental protection. This law establishes, in compliance with the principles of environmental management and protection of public health, the general legal framework of the water regime. Water is a national heritage asset whose protection and management the State ensures and facilitates access to this resource

for all. However, the State may transfer all or part of these prerogatives to the Decentralized Territorial Communities. Water management may also be the subject of concessions or leases according to the terms set by a decree implementing this law. The provisions of this law establish water protection measures and regulate the exploitation of surface and groundwater.

2.4.1.2. Framework Law No. 96/12 of August 5, 1996

This law establishes the general legal framework and the fundamental principles of environmental management in Cameroon. The fundamental principles are those of prevention, precaution, the polluter-pays principle and that of responsibility, the principle of participation and that of subsidiarity of customary standards in the absence of a rule of written law. Natural resources and, more generally, the environment are part of the common heritage of the Nation.

2.4.1.3. Law 2019/024 of December 24, 2019

This law establishes the General Code of Decentralized Local Authorities, hereinafter referred to as "Local Authorities". It defines the general legal framework for territorial decentralization; the status of local elected officials; the rules for the organization and operation of Local Authorities; the specific regime applicable to certain Local Authorities; the financial regime of Local Authorities.

2.4.1.4. Law No. 98/004 of April 14, 1998

Law No. 98/004 of April 14, 1998, on the orientation of education in Cameroon, which in its paragraphs 2 and 9 stipulates that “Education aims to provide training in the great universal ethical values of dignity and honor, honesty and integrity as well as a sense of discipline, the promotion of hygiene and health education.”

2.4.2. The decrees

Law No. 98/005 of April 14, 1998, is supplemented by six decrees adopted by the government:

2.4.2.1. Decree No. 2001/161/PM of May 8, 2001

This decree sets out the attributions, organization and functioning of the National Water Committee established by Law No. 98/005 of April 14, 1998, on the water regime. Indeed, the National Water Committee is responsible for studying and proposing to the Government all measures or actions aimed at ensuring the conservation, protection and sustainable use of water; to issue opinions on questions or problems relating to water referred to it by the Government; to make to the Government any proposal or recommendation contributing to the rational management of water, in particular with regard to the development and

implementation of sustainable development plans or projects in the area of water and sanitation.

However, since 2001, this Committee has not met, thereby rendering such a structure useless and compromising any reflection on the issue of water that the various identified stakeholders could have carried out.

2.4.2.2. Decree No. 2001/162/PM of May 8, 2001

This decree sets out the terms and conditions for the appointment of sworn agents for the monitoring and control of water quality. The Prime Minister, Head of Government. These agents are referred to as "Inspectors and Deputy Inspectors" of water. They are responsible for monitoring water quality, research, identification and prosecution of violations of the provisions of the law on the water regime and implementing texts.

2.4.2.3. Decree No. 2001/163/PM of May 8, 2001

This decree regulates the protection perimeters around the points of collection, treatment and storage of drinking water. The protection perimeters include, depending on the case, immediate, close and/or distant protection areas. The land included in the protection perimeters is declared to be of public utility.

2.4.2.4. Decree No. 2001/164/PM of May 8, 2001

The extraction of surface water or groundwater for industrial or commercial purposes is subject to prior authorization and is subject to the payment of a fee, the rate, basis and method of collection of which are set by the Finance Act. Any installation for the extraction of water for industrial or commercial purposes must be equipped with an effective device for measuring the volumes extracted. Said device must comply with a model approved and approved by the Minister responsible for water, after consulting the administration responsible for the control of measuring instruments.

2.4.2.5. Decree No. 2001/165/PM of May 8, 2001

This decree specifies the terms of protection of surface water and groundwater against pollution. The discharge, flow, discharge, infiltration, burial, spreading, direct or indirect deposit in water of any solid, liquid or gaseous material and, in particular, any industrial, agricultural or atomic waste likely to alter the quality of surface or groundwater or sea water within the territorial limits; to harm public health, aquatic or underwater fauna and flora and animals; to jeopardize the economic and tourist development of the regions; to harm the quality of life and comfort of local residents are prohibited. Any system for collecting, purifying or treating wastewater must be subject to the approval of the Minister responsible for water (https://www.ecolex.org/) .

2.4.2.6. **Decree No. 2001/166/PM of May 8, 2001**

establishing a special allocation account for financing sustainable development projects in water and sanitation: This account is intended to guarantee financing for the development of water resources; the supply of drinking water to urban centers and rural areas; sanitation of urban and rural areas; and agro-pastoral hydraulics. The resources of this account come from, among other things, the sanitation tax, the water abstraction fee, fines and transactions (GWP, 2009).

However, this account has practically never operated. However, the finance laws for the 2004 and 2005 financial years had provided for an allocation of 300 million FCFA for this account respectively. Since then, no other finance law has provided for an allocation for this account (GWP, 2009).

In addition to these decrees, we also distinguish:

2.4.2.7. **Decree No. 2005/493 of December 31, 2005**

Establishing the terms of delegation of public drinking water and liquid sanitation services in urban and peri-urban areas. This text, taken in application of Article 2 paragraph 3 of the law on the water regime determines the terms of delegation of public drinking water and liquid sanitation services in urban and peri-urban areas.

Through this text, the public water service is entrusted on the one hand to a publicly owned company, a heritage company, and on the other hand to one or more companies responsible for the production and distribution of drinking water as well as the maintenance of infrastructure and water treatment, and the related commercial activity. It is by virtue of these provisions that, by decree No. 2005/494 of December 31, 2005, the President of the Republic created the CAMWATER Heritage Company. This decree sets the purpose of this company, namely, the management of assets and rights allocated to the public drinking water service in urban and peri-urban areas. As such, it sets out the missions of said company. Article 3 provides that the CAMWATER company is placed under the technical supervision of the Ministry responsible for water and under the financial supervision of the Ministry responsible for finance (NAPIWRM, 2009).

2.4.3. Orders

2.4.3.1. Order No. 067/PM of November 13, 2001

This decree establishes the Technical Committee for Coordination and Monitoring of the Inter-Basin Water Transfer Project.

A Technical Committee for Coordination and Monitoring of the Inter-Basin Water Transfer Project, hereinafter referred to as "the Committee", is hereby established under the Ministry of Public Investments and Regional Planning.

The purpose of the Inter-Basin Water Transfer Project is to recharge Lake Chad and concerns the Logone/Lake Chad basins, the Benue/Niger basin; the Boumba/Kadey/Ngoko/Sangha/Oubangui/Congo basin.

2.4.3.2. Order no. 2010/00000298/a/MINWRE of September 1, 2010

This decree sets out the specifications specifying the technical conditions and methods for exercising the powers transferred by the State to the municipalities in terms of drinking water supply in areas not covered by the public water distribution network granted by the State.

2.5. Strengths and weaknesses of the legal framework of the water sector in Cameroon

Table 6 recapitulates the analysis of strengths and weaknesses of the legal framework of the water sector.

Table 6: Strengths and weaknesses of legal framework of water sector

Strengths	**Weaknesses**
- Existence of a legislative and regulatory framework clarifying the institutional landscape: this legal framework essentially deals with problems relating to the water supply of populations and defines the legal regime applicable to the protection of water resources. - Abstractions and catchments are subject respectively to an authorization regime and a protection zone regime. Other provisions address issues of sanitation and waste disposal. - Since 1998, Cameroon has adopted the law on the water regime following the framework law on environmental management of 1996. Several implementing texts for these laws have been produced, although some still exist. - A water diagnosis was adopted in 2006, and the urban drinking water supply sector	- Complex diversity of laws and regulations relating to water resource management, and absence of laws in certain specific contexts creating uncertainty that hinders water development. - Lack of a "national water policy" as a single framework for guiding actions to be taken in the management of the country's water resources. - The National Water Policy based on IWRM, finalized in May 2023, has not yet been fully disseminated to all stakeholders (MINWRE, 2023). This process, which is highly participatory in nature, has not yet been completed for various reasons (PAGIRE, 2022). - Lack of a national plan for integrated water resource management. An inventory carried out in 2009 has not been validated. These texts do not take into account

has just been equipped with the urban water policy letter which has made it possible to establish the reform process of this sector with the creation of a heritage company "CAMWATER", and a farming company "La Camerounaise des Eaux". - The rural sector is also experiencing a resurgence of activity with the ongoing development of the rural drinking water supply and sanitation policy.	traditional oral prescriptions. - Centralized management of the water sector. - Decentralized water management is not yet fully supported by the resources necessary for its implementation, there is still a lack of a reliable regulatory framework to support local stakeholders in water management. - Absence of texts defining the regime applicable to "waters of regional interest". Thus, we see in practice that the principles of subsidiarity and participation are not yet applied in the water management system in Cameroon. - Non-existence of a regime for the protection of hydrographic basins. All legal instruments seem to ignore this aspect of the issue. - Lack of political will in the application of the standards in force, which clearly translates into a tendency to complacently repress the most serious infractions, given the absence of effective control of the application of the regulations. - Rigidity of distribution mechanisms that hinder the transfer and redistribution of rights: Cameroon has adhered to several international conventions dealing with water issues, but activities to participate effectively in the implementation of these conventions are generally non-existent. - The legal basis for water in Cameroon remains inconsistent and relatively ineffective. (GWP, 2009).

2.6. Analysis performed on water resources, their uses and pollution implications

Water Resource Mapping (WRM) refers to the process of mapping the amount of water present in each source for scientific and environmental purposes. In other words, as science advances, many maps are created using geographic water data that provide information about the amount of precipitation in an area, streams, rivers, the direction of water flow in each of them, the

amount of groundwater depending on the area, and many other water-related information. The usefulness of these maps lies in the need for better water resource management and environmental improvement. (https://uizentrum.de/water-resource-mapping-methods/?lang=en).

Table 7 recapitulates the analysis of some previous findings on the description of water resources, their uses, the pollution occurrences and implications.

Table 7: overview of water uses and pollution implications

Country/ locality	Water resources	Uses and pollution impacts	Authors
Carp river watershed (Ottawa, Canada)	The Carp River watershed characteristics: - 42 km long, drains an area of approximately 265 km², - 10 different land use types with a predominance of agricultural land, covering more than half of the total area (52%), - Urbanized area accounts for 10%. - Water quantity in the Carp River watershed: more sensitive to climate change than to urbanization when factors are considered individually. The impacts of climate change and urbanization: - That varies considerably depending on spatial scale and geographic location. - Climate change is likely to be the most dominant factor.	- It is one of the main sources of the City of Ottawa's drinking water. - In terms of water quality, the sources of N and P pollution are more linked to land uses such as urban and agricultural uses.	Zango et al., 2022
Oconee River Basin (United States)	- Surface water found streams, rivers, and lakes throughout the basin for public water supply as well as industrial and agricultural use. - Industrial water supply in the basin comes largely from groundwater. Kaolin mining and processing is a particular industry in the middle part of the basin. - Treated wastewater is returned to surface waters in the basin through discharges from municipal and industrial wastewater systems.	- Withdrawals for agricultural water use include water for crop irrigation, livestock operations, and nursery operations. - As with industrial use, most agricultural demand in the basin is met by groundwater withdrawals. - When pollutants increase beyond the absorption capacity of a river or stream, water quality declines.	Baker et al., 2022

		- This negatively impacts other uses, including water supply, recreation, and habitat for aquatic animals and plants. - Treated wastewater is not the only source of pollutants. - Runoff after rainfall carries many pollutants from the land surface, contributing to higher pollution levels than permitted wastewater discharges. - Run-of-river hydroelectric dams alter habitat and block connectivity between river segments, affecting fish populations and recreational activities. - However, their impacts are generally less severe than those of large reservoir dams.	
Shandong province	Very low GWPZs have 23.67% FR area and 23.60% EBF area (22.89% FR+EBF area). Low GWPZs have 40.60% FR area and 41.62% EBF area (with 39.94% FR+EBF area). Moderate GWPZs have 26.44% FR area and 24.44% EBF area (with 26.22% FR+EBF area). High GWPZs have 8.90% FR area and 9.57% EBF area (with 8.98% FR+EBF area). Very high GWPZs have 0.39% FR area and 0.78% EBF area (with 1.97% FR+EBF area).	The Yellow River is mainly polluted by industrial waste and sewage from expanding cities. These main sources of pollution are industrial, agricultural and domestic wastewater, as well as industrial waste gases. The increasing discharge of wastewater into the river threatens the sustainability of surface water use. Therefore, groundwater has become a suitable and clean water resource for water supplies in areas where surface water quality is threatened.	Yang et al., 2023

Cameroon	- Water resources are unevenly distributed across Cameroon. - They depend on the geographical position of the regions. Water uses are increasing with the increase in population, leading to the deterioration of its quality. - Access to drinking water in urban areas is undermined by uncontrolled urbanization, industrial production, the sanitation system and the incivility of the population. In general, the quality of water in Cameroon is satisfactory. - But by focusing on the large cities, we see that it is deteriorating due to industrial pollution of surface water. - Despite its abundance, access to drinking water is very unfavorable in rural areas compared to urban areas.	- **Water for Agriculture** (Irrigated agriculture in Cameroon is not yet developed. - It is dependent on rainfall. It is much more practiced in the northern part of the country and in the market gardening areas of the Center, in the lowlands, the large escarpments and the mountains of West Cameroon). - **Water for livestock farming** (Livestock farming is more common in areas with low rainfall (northern and western mountains of Cameroon). - Water is a source of conflict between livestock farmers, farmers and the company responsible for distributing drinking water). - **Water for energy** (Cameroon has poorly exploited hydroelectric potential. - The country has 06 hydroelectric dams (Edéa, Song Loulou, Sanaga, Mékin, Chollet and Mokolo) which mobilize approximately 20 billion m3 of water. - Other hydroelectric dams are almost complete (Memve'ele, Lom pagar, Nachtigal).	Njikam, 2021

		- However, electricity production in Cameroon is heavily dependent on hydroelectric developments (approximately 84% of energy produced)). - **Water for domestic needs** (Cameroonian populations are supplied by surface water and groundwater. In 2018, the rate of access to drinking water was estimated on average at 77% in urban areas and 45% in rural areas. - The drinking water requirement of the Cameroonian population corresponds to 4% of the available freshwater resource. Water supply in rural areas is carried out through human-powered pumps, a mini drinking water supply system served by standpipes and developed water sources.	
Cameroon	- The surface water resources of the Republic of Cameroon are well distributed throughout the length and breadth of the country. - The country has four drainage patterns. - The entire country is home to different river basins. - Cameroon's groundwater resources are estimated at 55.98 km3, this volume represents 21% of surface water.	- Hydropower is the sector that consumes the most water in Cameroon (88.74%), followed by irrigation (7.25%), then domestic water (2.96%). - Solid and liquid waste from households, industries, and municipalities are associated with groundwater pollution.	Defo et al., 2016

		- Numerous cases of waterborne diseases such as typhoid, cholera, and amoebic dysentery are recurrent in most urban cities in Cameroon. - There is virtually no sanitation system except in a few newly built neighborhoods in Yaoundé and Douala. These two cities produce wastewater with BOD loads exceeding 11,700 and 14,000 tons per year, respectively. - Many cases of waterborne diseases such as typhoid, cholera and amoebic dysentery are recurrent in most urban cities in Cameroon. – - These diseases are associated with water and sanitation systems. - Intensive use of fertilizers and pesticides in different agro-industrial complexes has been reported. - Effluents from industries are discharged untreated on the ground surface where they flow into rivers. Most of these pollutants are often found in excessive quantities in groundwater.	

Odza watershed (Yaounde IV)	- The Odza watershed is drained by the Odza River and its tributaries. Its source is at the head of the valley at Ekié, to the north of the watershed. - Households with septic tanks and cesspool latrines are the most connected to the CDE water distribution network (60%). As for the latrines with a bottom loss, they mainly use water from wells (16%). - The Odza watershed is largely devoid of adequate sanitation infrastructure. The lack of a sewer network is one of the conditions for the discharge of wastewater into the environment by populations. 53% of households surveyed state that the poor sanitation practices they adopt are explained by the lack of collective wastewater and excreta management system. - Urban wetlands (rivers and marshy areas) are receptacles for all types of pollution and are also environments with very fragile ecology. In the Odza watershed, the rivers are very polluted due to suspended matter, water discoloration and odors. - The households surveyed who live near the rivers all attest that the rivers are extremely polluted. It appears that the impact of wastewater (domestic and industrial) is noticeable on the quality of the water in the rivers.	- The level of education plays a very important role in the choice of sanitation methods and practices, the higher the level of education, the more households use improved facilities. - 2% of individuals with monthly incomes of 0 FCFA to 50,000 FCFA, from 150,000 FCFA to 300,000 FCFA and more use gutters and channels for wastewater disposal. On the other hand, - Only 6% of heads of households using this same sanitation system have a monthly income of between 100,000 FCFA and 150,000 FCFA. - Most households (16%) that use pit latrines have an income of 50,000 FCFA to 100,000 FCFA. Households (4%) that use this method of wastewater disposal less have monthly incomes of 00 FCFA to 50,000 FCFA. Cesspools are used more by households (24%) with incomes of more than 300,000 FCFA and less by households (2%) with a low income. - The use of sanitation facilities varies fundamentally depending	Nyembe et al., 2021

		on whether the area is subdivided or not. Subdivided areas use, in order of preference, cesspools (20%), followed by gutters and channels (14%) and, increasingly, latrine pits (4%) to evacuate laundry, dishwashing and shower water. - Undeveloped or poorly developed neighborhoods mainly use gutters and channels (38%) for wastewater treatment. Structured neighborhoods (developed) pollute less because households have modern wastewater and excreta evacuation systems.	

Table 7 depicts the water resources, their uses, their pollution occurrences and impacts found in recent research. Yang et al., (2023) applied GIS-based frequency ratio (FR) techniques and evidential belief function (EBF) models to reveal groundwater potential zones (GWPZs) in Shandong Province, a lower section of the Yellow River. This study found that, according to remote sensing data analyses, GWPZs are controlled by topographic, geomorphic, hydrological, and climatic conditions. Regarding the applied FR and EBF models, precipitation, NDVI, lineament density, and distance to the river were positively correlated, and there was more water well locations in high-altitude areas that consisted of plateaus enriched with vegetation and annual precipitation, as well as surface water, near the Yellow River and Zihe River (in the south). The highest well locations were on the Eastern, Northeastern, and flat slopes, as the Northern hemisphere and North- and East-facing slopes contain more water resources than South- and West-facing slopes. Recharge in vegetated areas is significantly lower than in non-vegetated areas. In addition, recharge is higher in agricultural and grassland areas than in permanent lands, such as shrublands and forests. The applied FR was better validated than the EBF. The combination of the two models (FR–EBF model) produced better results than either individual model. In addition, the combined FR–EBF model increased the very high perspectivity areas to 1.97, compared to 0.39 and 0.78 of the FR and EBF models, respectively. Njikam (2021), made a global analysis of the water management framework in Central Africa, particularly in Cameroon. He carried out an inventory of water resources in Cameroon, identified the actors in charge of water management and their respective roles, as well as the legislative framework for water resource management, and made a comparative study of the state of the IWRM implementation process in six Central African countries. His methodology is based on documentary research. His analysis shows that water management in Cameroon has been organized around an institutional and legal framework that seems weakly applied and unsuitable, although the country has potential in terms of water resources and commitment to improve the IWRM framework. The commitment of States to meet the challenges of climate change in relation to the issue of water resources is perceptible. However, he emphasizes that the development of the IWRM process depends on the specificities of each country. The implementation of IWRM in these countries faces political, institutional and financial challenges.

Defo et al., (2016) assessed the availability of groundwater resources in Cameroon. This study shows that Cameroon is rich in groundwater resources. However, these resources are exposed to pollution which are generally associated with anthropogenic activities and the weakness of the water resources monitoring and evaluation system. Despite government efforts to improve

the water supply system in Cameroon, water needs are increasing proportionally to the expansion of the population. The access to community water supply is low, whether in rural or urban areas. Their study showed that groundwater plays an important role in meeting water needs, particularly the domestic water needs of rural and urban populations. These observations are consistent with those recorded by many authors examining groundwater management in Africa. Groundwater management in Africa therefore remains a challenge in terms of protection, availability and pollution. Based on the analysis and their understanding of the system, they made specific recommendations on the establishment of a comprehensive groundwater inventory in Cameroon. Because it is necessary to research and understand the hydrodynamic, geochemical and pollution status of aquifers in the different basins of the country. To carry out effective modeling in groundwater research in Cameroon. As a powerful tool that can predict the behavior of aquifers over an extended period, researchers must introduce these tools intensively in groundwater research in Cameroon to produce the data needed by decision-makers to plan actions for effective management of groundwater resources. According to them, the government of Cameroon must launch a national mass education program, empower institutions and the local population to take care of water resources by cleaning polluted rivers and protecting unpolluted ones, maintaining water infrastructure, and enforcing the law on environmental protection to limit the production of waste and pollutants. Effectively implement the IWRM approach by basin for better coordination of stakeholders in water resource management. Promoting wastewater recycling (at low cost through artificial wetland technology) as a strategy for mitigating environmental pollution is seen by the authors as an initiative to be encouraged in industries, municipalities and agriculture.

Zango et al., (2022), using the SWAT hydrological model, assessed the influence of urbanization and climate change as well as their coupled impact in the Carp River watershed in the Ottawa region. The results of their study show that considering only climate change in the watershed, the increase in peak discharge is expected to be in the range of 0.90 to 3.76% at the main outlet. Urbanization will only increase the peak discharge by 0.76%. Similarly, urbanization is expected to increase the average discharge by 1.57%, while climate change is expected to be in the range of 5.49 to 7.42%. The analysis of monthly discharges indicated that extreme events were likely to occur in late winter (around April) and during the summer. This study showed that the contribution of snow to total precipitation is greater than that of precipitation, as April peaks are higher than during the summer, meaning that flooding is expected to be more severe in April. In terms of water quality, based on the impacts observed in the scenario of urbanization, N appears to be more sensitive to agricultural land in July-August when agricultural activities

take place. The sensitivity is also demonstrated by a decrease of 1.88% in the total annual load at the main outlet when the agricultural land ratio is reduced by 2.63%. Similarly, a more significant decrease was observed at the local scale when the agricultural land ratio decreased from 49.7 to 10.6%, resulting in a reduction in the impact from 1.88 to 29.00%. The increase in urban areas has led to an increase in the annual P load, so P pollution is dominated by urban areas.

Nyembe et al., 2021 assessed the state of wastewater and excreta sanitation in the Odza watershed. From this study, it appears that the sanitation deficit is explained by socio-demographic, economic and environmental factors. The main pollution factors in this watershed are the level of education of the head of household, the income of the head of household, the type of plot occupied by the household, the type of water supply, the occupation of non-constructible areas and the absence of a sewer network. Anthropogenic pollution has a real impact on the environment, particularly on the health of populations and on the quality of water in rivers and marshy areas. In the future, reducing wastewater and excreta sanitation deficit will require the community to adopt eco-citizen behaviors and for the public authorities to encourage and support populations to install the ecological latrines recommended by the WHO. Public authorities should set up sewerage networks and treatment plants for the treatment of wastewater before its discharge into the environment. Finally, state public authorities should also raise awareness among the population on the management of liquid waste and excreta and on the benefits of sanitation on the urban environment. Globally water resource management in literature focuses on: water use, water distribution, water quality, water infrastructure and wastewater production.

2.7. Analysis of findings for water balance in river catchment

The hydrologic cycle, or water cycle, encompasses all the processes by which water moves from land and ocean surfaces to the atmosphere and then returns to the Earth's surface as precipitation. It includes processes such as evaporation, condensation, precipitation, infiltration, and surface runoff that regulate the movement of water in nature. This is essential to understanding the availability of water resources in a given region. Understanding the hydrologic cycles in a watershed and knowing the water yield potential of a watershed are essential for proper water planning and management in the region and for assessing water productivity. The water balance of a watershed is a numerical summary of the different components of the water cycle, distinguishing between inputs, i.e. water reaching the watershed

as precipitation, and outflows, including surface runoff, evaporation from fields, irrigation and groundwater recharge. An understanding of the hydrological cycle helps in the sustainable management of water resources, particularly during periods of drought, as well as in making informed decisions regarding land use planning (Katarzyna et al., 2024).

Water balance can be applied to many different systems: it can refer to the ways in which an organism maintains water in dry or warm conditions, most commonly in reference to plants or arthropods. In hydrology, a system can be one of many hydrological domains, such as a soil column or a drainage basin, and water balance is normally used to describe the flow of water into and out of the system and determined as a "*numerical calculation that accounts for the inputs, outputs, and volume changes of water in the various components of the hydrologic cycle, within a specified hydrologic unit and during a specified unit of time, occurring both naturally and due to human-induced withdrawals and returns of water*" (USAID, 2015).

The water balance can be calculated in different ways depending on the availability of hydrometeorological data and the technological capacity to estimate the missing data. Depending on the methodology adopted, the water balance can be used for different purposes:

- In the absence of permanent monitoring systems, a prospective water balance can be established from historical data to estimate the average availability of the resource to satisfy the water demand at the time of calculation.
- When many real-time hydrometeorological data are available, the water balance can be calculated to estimate the water withdrawal over a defined period (day, week, month, year, etc.).
- Water balance calculation can be used by water utilities to operate reservoirs and water distribution systems to ensure the most efficient distribution of the resource.

In the case of a river basin, the most common methods for calculating the water balance rely mainly on extensive monitoring activities of the current and past water and ecological situation. This monitoring should allow the collection of data such as river levels and discharge, runoff, groundwater levels, precipitation, evapotranspiration, temperature, wind speed, solar radiation, air humidity, etc. It is important to be aware that there is no simple way around the lack of data and that the approaches are generally very rigorous, requiring at least one year of data collection before meaningful information can be compiled. The reliability of water balance estimates will depend on the development of the conceptual model as well as the performance of a site-specific model. When an appropriate monitoring system is in place, the water balance also allows us to understand which parts of the catchment, due to existing abstractions, may not have enough water to support the river ecology. With an accurate water balance, the responsible authority

should be able to consider, based on the evidence of the results, modifying or revoking water abstraction licenses and permits (USAID, 2015). Many authors have worked on estimating the hydrological balance at the scale of a watershed using different approaches. The table below presents a brief overview of some recent work on this topic.

Table 8: overview of the water balance and parameters implications in a subcatchment

Country/locality	Parameters (Cr, P, Etp, GR)	Authors
Majalaya watershed (Indonesia)	- Years of high precipitation tend to result in higher surface runoff and lateral flow, while baseflow and groundwater recharge respond to longer-term patterns of infiltration and soil moisture conditions. - During the observation period, annual precipitation in the study area showed significant fluctuations, with a peak of 3834 mm recorded in 2016 and a low of 1492 mm in 2019. Surface runoff, which peaked at 2261.6 mm in 2016, coincided with the year with the highest precipitation, indicating a correlation between precipitation amount and runoff intensity. Lateral flow, i.e. the horizontal movement of water through the soil layer, followed a similar trend, with the highest value recorded in 2016 (19.9 mm) and increasing in 2022 (19.8 mm), reflecting the sensitivity of these processes to variations in precipitation. - Evapotranspiration remained relatively stable, fluctuating between 938.1 mm and 991.6 mm. This stability suggests that evapotranspiration is not very sensitive to changes in annual precipitation, likely due to vegetation cover and consistent climate conditions in the region. - Baseflow, the process by which water flows below the ground surface, showed more variability, ranging from a low of 151.1 mm in 2019 to a high of 262.0 mm in 2017. - This variability suggests that higher levels of baseflow tend to occur after several years of higher precipitation. Similarly, deep groundwater recharge showed a slight increasing trend, from 17.1 mm in 2019 to 29.4 mm in 2022, reflecting changes in underground storage capacity.	Kardhana et al., 2024
Greece	- A common result observed across all basins is that evapotranspiration (ET) is the largest component of the water budget, returning most precipitation to the atmosphere. - The lower ET rates may be associated with lower precipitation rates in combination with the plain topography and alluvial deposits that favor GR. - ET in the studied regions accounts for about 54% of precipitation during the period 2013-2018. The average annual ET in the studied basins range from 39.3 to 62.5% of precipitation for the same period. - GR accounts for 24% precipitation, ranging from 19.5% to 31.5% precipitation, while SR has an average annual precipitation of 22%, ranging from 17.9% to 29.1% of precipitation.	Gemitzi, 2020

	- In this work, ET represents about 51% of the precipitation and the sum of GR and SR represents the remaining 49% of the precipitation. - The performance of the methodology is evaluated by a comparison of the acquired results with the results of the SWAT model. In general, MODIS ET is higher than SWAT ET and scaled ET. Scaled ET and SWAT ET show similar obvious trends, with SWAT ET always showing higher values in dry periods compared to scaled ET. - This is because SWAT allows soil water ET even when precipitation is limited. - However, downscaling MODIS ET with local precipitation data could lead to underestimation of soil water losses during summer months as it forces losses to be equal to precipitation during these months. - A significant discrepancy between MODIS ET, SWAT ET and scaled ET is observed during the summer months of 2016 and 2017, when precipitation was very low in the study basin. In this case, MODIS ET appears to be closer to the ETP and not to the actual ET. - The SR is higher in the dry period in the SWAT model, which corresponds to the baseflow. However, the trends of the two datasets are similar this time. A significantly lower performance was detected for the raw (unscaled) MODIS ET data, due to the higher ET values, especially during summer, compared to the local precipitation data. - This methodology can be used for the calculation of the water balance at monthly or coarser time steps at the basin scale. Although it cannot represent the fine spatial and temporal resolution of the hydrological model output, it can accurately attribute monthly precipitation to various water components at the catchment scale with reasonable accuracy. - This method requires only monthly precipitation information, either from terrestrial meteorological stations or as a remote sensing product. - It can be applied even to ungauged basins, provided that there is an established relationship between precipitation and GR in a basin of analogous hydrological and climatic framework.	
Japan	- Water yield, which is crucial for water management in the KRC, showed a decrease of 17.2% in the 2009 land use scenario compared to 1987. The evapotranspiration (ET) component accounts for the largest share of the water balance among the water balance components.	Bih Kimbi et al., 2024

	- The visual representation shows an apparent increase in the proportion of ET in the 2000s, reflecting the relative contribution of ET to the total water balance, which has decreased due to reduced precipitation. ET decreased from 699 mm in the 1980s to 664 mm in the 2000s, representing a reduction of 5.1%. - This decrease can be attributed to a 4.7% reduction in forest cover between the two periods. Surface runoff increased significantly from 92 mm in the 1980s to 213 mm in the 2000s, an increase of 131.7%. - In contrast, average annual groundwater recharge and **ba**seflow decreased by 34.9% and 41.4%, respectively. - Deforestation and urbanization therefore have a significant impact on the water balance, reducing groundwater recharge and increasing surface runoff. Surface runoff, which is highly sensitive to land use change, tends to increase with urbanization, reducing groundwater recharge. - CN2, an important parameter influencing surface runoff, was identified as a key factor associated with land use change. CN2 values increased from 47.4 in the 1980s to 65.6 in the 2000s, reflecting reduced infiltration rates and increased surface runoff due to land-use changes. - This observed increase in surface runoff raises concerns about flooding, which poses potential threat to current and future water resources in the KRC. - In addition, changes in land-use patterns and precipitation intensity make the watersheds susceptible to soil erosion. - Overall, the combined effects of reduced ET and increased surface runoff due to urbanization have decreased groundwater recharge, which is likely to lead to problems such as reduced baseflow in rivers and decreased water availability for agricultural, industrial, and other uses in the watershed. - Comparison of the components of the average annual water balance over three major land use types (rice fields, forests and residential areas) during the 1980s and 2000s shows that groundwater recharge varies considerably across land uses. In forest areas, the average annual recharge decreased from 168 mm in the 1980s to 123 mm in 200s. - Residential areas, which had higher recharge in the 1980s (202 mm) than forest areas, experienced a significant decline to 88 mm in the 2000s. Rice fields showed the highest recharge rates, decreasing from 214 mm in the 1980s to 180 mm in the 2000s.	

	- The reduction in groundwater recharge in residential areas is attributed to the expansion of residential land, which increased from 12.8% in the 1980s to 34.5% in the 2000s, with over 45% of rice fields converted to residential areas due to urbanization. - Rice fields consistently maintained the highest recharge rate. In the 2000s, surface runoff in residential areas increased significantly from 212 mm to 482 mm, contrasting with insignificant changes in rice paddies and forest areas. - Rice paddies and forests facilitate slow infiltration of water by stream flow when precipitation is not intercepted or evaporated.	
Brezina watershed (Algeria)	- The runoff coefficient is a function of slope, vegetation cover and soil type. The runoff coefficient (Cr) is very high at the limestone bar in the North and at the South interface of the basin, reducing the permeability of the land. - On the other hand, Cr is very low for sandy soils (around 0.26), causing strong infiltration on the land. In the rest of the basin, Cr is moderate (from 0.3 to 0.6). - The irregularity of precipitation, the diversity of soil types, the steep slopes, disrupt the distribution of the water blade runoff on the watershed. This disruption is remarkable on pixels with higher precipitation and a higher runoff coefficient. This water blade decreases from North to South and from West to East where precipitation is higher, and the hydrographic network is well-organized. - At the outlet, the cumulative value of the water blade received reaches 784 mm/year, which is low compared to the surface area of the basin. This shows that there is a large quantity of water that infiltrates before arriving at the southern interface of the basin. - The cross-referencing of the different maps (soil type, vegetation cover and relief) of the study area allows the infiltration map to be developed. - This shows that infiltrability is linked to soil permeability. A high infiltration characterizes most pixels in the watershed, up to 300 mm. This observation is directly linked to the type of soil, which may be cracked, and to the presence of caves at a shallow depth. - Evapotranspiration is the most important parameter of the hydrological balance. Evapotranspiration is a function of the vegetation cover and the geographical position in the site. Regarding vegetation cover, high evapotranspiration is observed in dense areas. It reaches 68 mm/year.	Yamani et al., 2012

	- This value decreases from North to South where the bare areas are located (South-West of the basin). In these areas, evapotranspiration does not exceed the value of 10 mm/year. - The value of evapotranspiration varies according to the geographical position, it is remarkable in the North-West part of the basin. It thus reaches the value of 40 mm/year. This value decreases in the South-East areas, it only reaches 20 mm/year.	
Ethiopia	- The total cropland/agricultural land cover class was about 28.92% of the total watershed area. It increased rapidly to 34.12% and 43.3% of the watershed in the 2002 and 2015 land use maps respectively. - This is mainly due to population growth which has led to an increase in the demand for new cropland and settlements, which in turn has led to a decrease in other land uses in the area. - The forest cover in 1989 was about 21.79% of the total watershed area. In 2002 and 2015, it has reduced to nearly 12.79% and 6.4% of the total area respectively. - The contribution of surface runoff simulated total discharge and intermediate flow increased from 1989 to 2015, this is related to the surface cover of the watershed since the change of forest land in the watershed to agricultural land accelerated the runoff rate and reduced the infiltration of soil moisture content. - Forest areas decreased from 1989 to 2015, which contributed to the increase in the contribution of surface runoff. - Evapotranspiration rate decreased from 1989 to 2015, indicating that losses are mainly due to evapotranspiration. Land use/cover change has significant impacts on infiltration rates, runoff generation, total simulated flow, intermediate flow, baseflow, evapotranspiration and soil water retention capacity or soil storage change. - This consequently affects the water balance of the catchment, because the land cover, under low vegetation, is subject to high surface runoff, low water retention and low evapotranspiration. - The change in simulated total discharge increased by 77.83%, and direct runoff, intermediate discharge and base flow increased by 80.23%, 75.69% and 87.79%, respectively. - Therefore, evapotranspiration decreased by 6% throughout the study period.	Mulatu et al, 2021

According to data in Table 8, Yamani et al., (2012) used remote sensing and GIS for mapping the hydrological balance at the scale of the Brezina watershed in Algeria. This site is distinguished by its geographical position (steppe ecosystem), housing a dam subject to a fluctuating hydrological regime, a fragile physical environment and an agro-pastoral socio-economic lifestyle. The methodology adopted is based on mapping parameters such as precipitation, infiltration, runoff coefficient and evapotranspiration at the pixel scale. From NOAA AVHRR imagery and the energy balance model, the extraction of the information necessary for the development of hydrological balance, in particular evapotranspiration, runoff and infiltration were done. The sensitivity analysis was based on the average values of the different values at the watershed scale. It therefore follows from this work that, regarding rainfall, a good correlation between the latter and the characteristics of the stations is observed, despite a low density of the rainfall network (correlation coefficient reached 95%). This justifies the validity of the chosen method. Concerning evapotranspiration, the value deduced from the SEBAL model (68 mm) is close to that found by the Turk model (72 mm). The use of the application of the Turk model by the author is justified by the fact that ground measurements of evapotranspiration are not available. Evaporation was calculated from the equation involving the average value of annual rainfall and the average annual air temperature estimated from satellite data, with an error of 5%. The error value is relatively low, which justifies the choice of the SEBAL model for mapping evapotranspiration at the watershed scale. They also mention the key importance of evapotranspiration and precipitation parameters as essential parameters for the assessment of hydrological balance.

The values of infiltration and runoff are deduced from rainfall and evapotranspiration. The cumulative runoff value at the pixel scale exceeds the value (600 mm). While the cumulative infiltration value at the pixel scale reaches (500 mm). The previous remarks relating to the validity aspect apply to the methodology for estimating the liquid supply. The value of the latter is 0.05 m3/s. The author also mentions the fact that the study watershed belongs to a poorly watered region, located between areas with a desert tendency. The occasional occurrence of heavy downpours causes significant runoff where most of the water is concentrated in the first twenty hours. Floods generally occur in autumn and spring. The results obtained show that the results of the exploration year correspond to those of a dry year and low rainfall. Due to high infiltration, the amount of water stored at the dam is very low. Evapotranspiration is higher, given the scarcity of plant cover, which shows that the basin is exposed to drought and a lack of water resources, which are already scarce in this region.

Bih Kimbi et al., (2024) showed through their study the impact of urbanization and climate change on water resources in a suburban watershed in western Japan. This study, based on the SWAT hydrological model at the hydrological response unit scale to analyze the hydrological impacts of land use change and climate variability in the Kurose River watershed over three decades (1980s–2000s), uses hydrological response units (HRUs) to achieve high spatial accuracy in assessing the impacts of land use change and climate variability on hydrological components. They showed that, during the 30-year study period (1980s–2000s), land use change was the main driver of hydrological variability, while climate change played a minor role. Increased surface runoff, along with decreased groundwater recharge, evapotranspiration, and baseflow, have led to an overall reduction in water yield, with a 34.9% decrease in groundwater recharge, attributed to the conversion of rice fields to residential areas. In addition, the combination of increased temperature and reduced evapotranspiration in the watershed is making urban areas warmer than rural areas. This localized warming could place a strain on water resources as higher temperatures increase both evaporation rates and water demand. Projections based on current trends highlight the potential for future challenges to groundwater resources if management strategies are not strengthened.

These results provide insights into water resource management strategies in rapidly urbanizing regions around the world and highlight the need to balance urban development with sustainable water management practices in the face of climate change and land use changes, highlighting the need for Integrated Water Resources Management that considers both land use and climate change impacts. Although this study successfully modeled groundwater recharge using land use and climate data, the lack of well data for the study period limited direct validation of modeled

recharge rates. Incorporating data in future studies would provide stronger validation of model results, providing greater confidence in groundwater recharge trends. The use of multiple weather stations or high-resolution gridded data can improve model accuracy by more accurately capturing spatial climate variability.

Gemitzi et al., (2020) developed a simple methodology for the estimation of individual components of the monthly water balance based on the predefined empirical relationship between remotely sensed evapotranspiration (ET), MODIS ET (Moderate Resolution Imaging Spectroradiometer), groundwater recharge (GR) and readily available precipitation data at monthly time steps. The developed methodology was applied in seven catchments of northeastern Greece using time series of precipitation and remotely sensed ET from 2009 to 2019. It was subsequently verified in one catchment by comparing the results obtained with those acquired from the SWAT hydrological model. The potential of this method to accurately estimate the water balance was assessed by comparing the individual components of the water balance with the modeled values. Three performance measures were examined and indicated that the methodology produces a satisfactory result. The results indicated that mean ET accounts for about 54% of precipitation, mean GR accounts for 24%, and mean surface runoff accounts for about 22% of precipitation in the study area. The proposed approach was implemented using freely available remote sensing products and the free R software for statistical computing and graphics. The remotely sensed MODIS ET data were processed and upscaled before being incorporated into the process, along with available monthly precipitation data. Although the methodology developed by Gemitzi et al., (2020) cannot represent the fine spatial and temporal resolution of hydrological models, it certainly offers a reliable and low-cost alternative to hydrological modeling for calculating monthly water balance at the catchment scale, when there are few or no gauging stations.

Kardhana et al. (2024) analyzed the water balance components in the Majalaya watershed, Indonesia, using SWAT+ over the period 2014–2022, focusing on low-flow conditions. The methodology used is a two-stage calibration approach using various datasets including ground precipitation (2014–2022), NASA POWER meteorological data, MODIS land cover, DEMNAS terrain, and DSMW soil types, as well as streamflow data for model calibration. Streamflow data from 2015 to 2022 (except 2019 for missing data) were used for calibration and validation, which detailed 57% for calibration and 43% for validation. Their study demonstrates the effectiveness of SWAT+ in watershed management and water resource optimization, especially under low flow conditions. The SWAT+ simulation provided key insights into the hydrological behavior of the watershed, especially during drought periods. The

two-step calibration process of the SWAT+ model revealed improvements under low flow conditions, highlighting the critical role of baseflow in maintaining river flow during dry periods. The second calibration step performed better for low flows, which are critical for water resource management in the watershed during dry seasons.

By examining the water balance components over the period 2014–2022, the results obtained by Kardhana et al. (2024) provided a comprehensive overview of the key hydrological processes in the Majalaya watershed. Surface runoff showed marked variability consistent with annual precipitation trends. Baseflow also showed higher values in years with increased precipitation. In contrast, evapotranspiration remained relatively stable in the Majalaya watershed, indicating its low sensitivity to annual precipitation fluctuations. Although the model effectively captured low-flow conditions, further improvements may be needed to improve its accuracy in simulating the other flow spectrum, including high-flow events. Future research should therefore focus on further modeling of smaller-scale watersheds or more specifically on sub-watersheds.

Mulatu et al. (2021), in their study assessed the impacts of land use/cover changes on the water balance of the Bilate watershed in Ethiopia between 1989, 2002 and 2015 using the Water Balance Simulation Model (WaSiM). The model was calibrated (1989-2003) and validated (2007-2015) using the discharge from the Bilate Tena gauging station. The results of land use dynamics showed that land use/cover changes have a significant impact on the water balance of the watershed. Indeed, the variation of total discharge in the simulated study basin increased by 77.83%; surface runoff, intermediate flow and baseflow increased by 80.23%, 75.69% and 87.79%, respectively; and evapotranspiration decreased by 6% throughout the study period (1989-2015). The results obtained from this study revealed that the watershed is subject to land use/cover changes that show its impact on hydrological processes and water balance. They identified six dominant land uses/covers (mixed forests, cropland/agricultural land, dryland, grassland/pasture, pasture and shrubland, settlements in the Bilate watershed) for LULC_1989, LULC_2002 and LULC_2015. The simulated water balance for Bilate watershed using WaSiM-ETH showed that the interflow component of the water balance takes a higher fraction of the simulated discharge, and the surface runoff and total simulated discharge also increased during the study period. In addition, ETR, ETP and soil storage capacity decreased throughout the study periods. Overall, the hydrological model describes the changes in the water balance from 1989 to 2015, which indicates that the variation of the simulated total discharge increased by 77.83%, and the direct runoff, interflow and baseflow increased by 80.23%, 75.69% and 87.79%, respectively.

The water balance in most studies refers to estimate of evapotranspiration, surface runoffs, ground water recharge, change in land use with implications on runoff coefficient, interannual values and trends. Few cases with monthly values

CHAPTER 3

METHODOLOGY

3.1. Presentation of the study area

3.1.1. Physical environment

Yaoundé IV is a district council of the urban community of Yaoundé, division of Mfoundi in the region of Centre of the Republic of Cameroon. Its main district is the Kondengui which borders the Ekounou, Nkolndongo, Emombo and Mimboman districts. It has 65 districts and covers in terms of command unit a surface area estimated at 57 km^2.

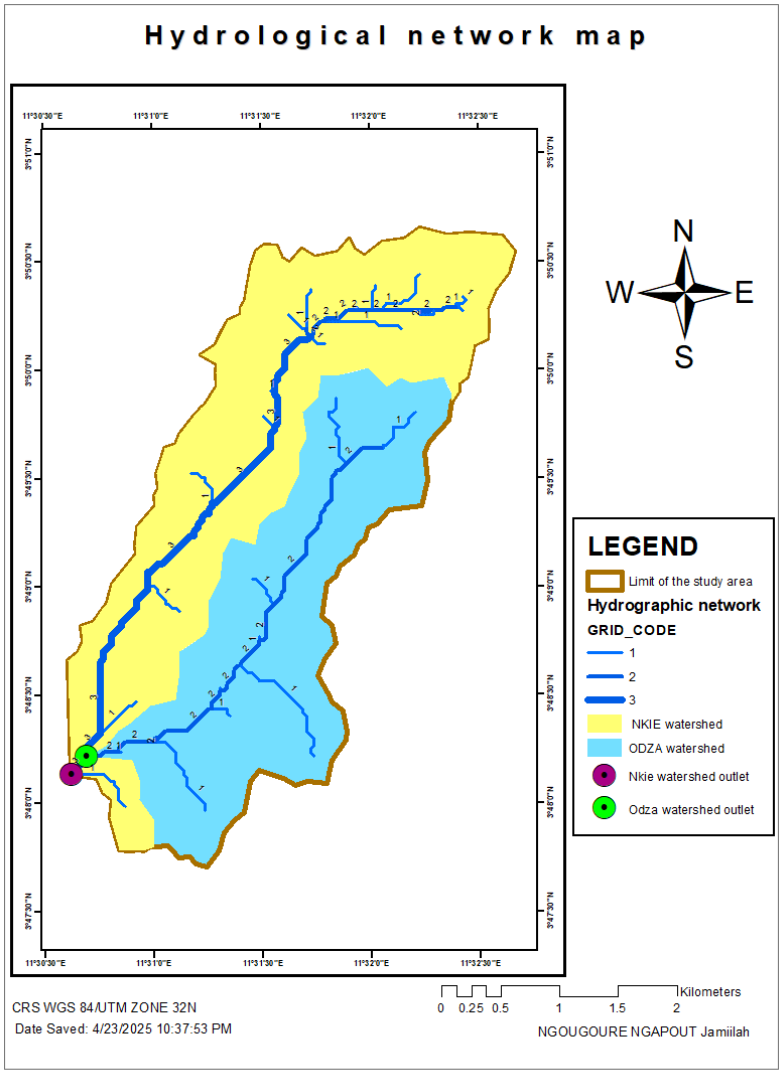


Figure 1: Presentation of the study area.

It is bordered to the north by the district of Yaoundé I, to the northeast by the river called "Nkolo II" coast 686; to the east and southeast by the Anga River to its confluence with the Mefou River; to the south by the Mefou River to its confluence with the Mfoundi River; to the west by the Mfoundi River which separates it from Yaounde III.

Climatology

The climate of the Odza and Nkie watersheds is that of the city of Yaoundé: a transitional equatorial climate with average interannual precipitation oscillating around 1562.7 mm and an average interannual temperature of 23.93°C.

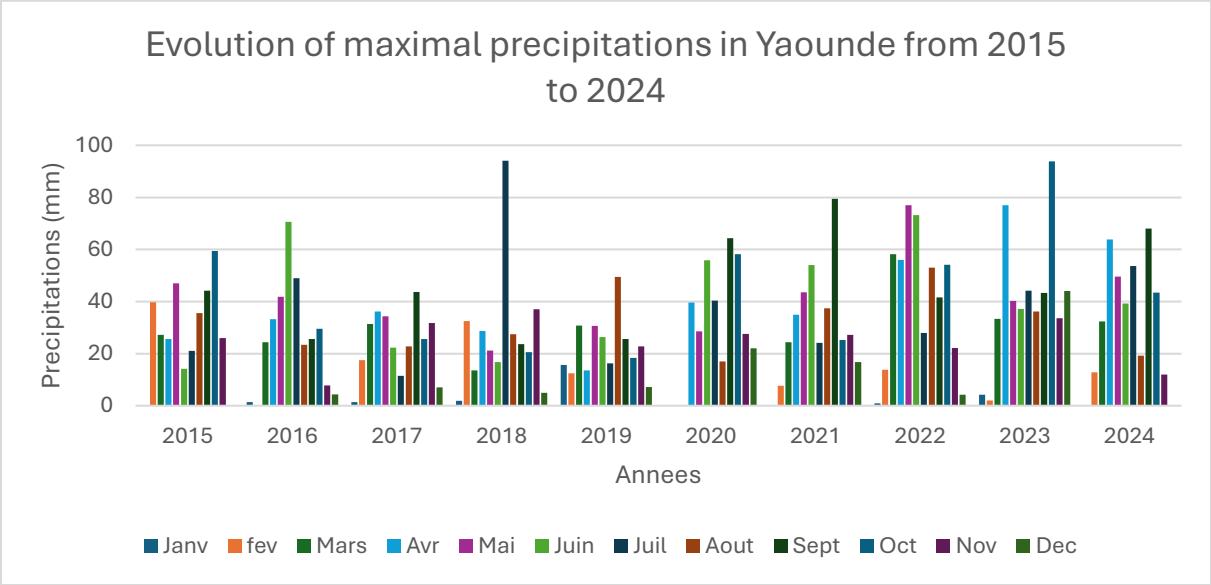


Figure 2 : Evolution of maximal precipitation in Yaoundé from 2015-2024

The evolution of precipitation in the city of Yaoundé shows a slight downward trend in annual precipitation over the last 53 years, with significant interannual variability. Despite this variability, annual precipitation in Yaoundé has remained relatively stable.

A clear pattern of seasonal variation in precipitation is observed over the years, with periods of high and low precipitation. Two periods of high precipitation are distinguished: one between March and June, and the other between September and November. January and February are the driest months. July and August also tend to experience relatively less precipitation than the potential wet seasons.

3.1.3. Hydrography

The hydrographic network of the City of Yaoundé is a set of watercourses arranged in a fan shape from two convergences towards the Mfoundi and the Mefou which are the main outlets

for rainwater. These ensure the natural drainage of runoff water and surface water which are discharged into the Mefou River, which in turn discharges its waters into the Nyong River. It is downstream of this last discharge point that the current catchment area for raw water intended to produce drinking water for the inhabitants of the city of Yaoundé and its surroundings is located. The total surface area of the watersheds covering the city of Yaoundé is approximately 450km². It is made up of 4 watersheds, namely: BV Méfou (S=417 km²), BV Mfoundi (S=95 km²), BV Anga'a (S=62 km²) and BV Foulou (S=104 km²).

The Odza and Nkie watersheds are secondary rivers feeding the Mfoundi River, which rises on the eastern slopes of Mount Fébé and follows a south-eastern direction before flowing into the Mefou, a tributary of the Nyong River. The total area of the watershed drained by the Mfoundi is 95 km², approximately 36% of the total area of the council of Yaoundé. Eleven secondary watercourses ensure the sanitation of rainwater supplying the Mfoundi, namely: the Tongolo, the Ntem, the Ebogo, the Abiergueu, the Mingoa, the Ewoué, the Olézoa, the Aké, the Nkié, the Odza, Biyeme.

3.1.4. Hydrogeology

The hydrogeological context of the city of Yaoundé has so far been little studied, however there are some interesting works (Bon et al., 2016; Djeuda Tchapnga et al., 1999; Mboudou, 2012; Takounjou et al., 2009) but which have not resulted in the development of satisfactory hydrogeological models. The geological substratum consists of metamorphic rocks (gneisses, migmatites) of Precambrian age (Nzenti et al., 1988; Nzenti and Tchoua, 1996). The facies encountered are mainly garnet and plagioclase gneisses, garnet and kyanite gneisses, pyriclasites, pyribolites and magnetite pyroxenites. On these rocks, ferralitic and hydromorphic soils develop. The vegetation is characterized by a dense semi-deciduous forest (strongly subject to anthropogenic actions).

3.1.5. Geomorphology

The city of Yaoundé, also known as the "city of seven hills", extends across many hills crossed by marshy valleys. The highest point in the region is 1060 m at Mount Fébé. The valley bottoms are often marshy. This hilly site induces significant risks of flooding, especially with the increase in anarchic urbanization, the occupation of lowlands and encroachment on the beds of watercourses. The Odza and Nkie watersheds have reliefs characterized by regular slopes leading to meandering plains. Thus, the layout of the city's relief reveals a subdivision of the site into several geomorphological units with maximum altitudes of 1,189 m and minimum of 755 m, for an average altitude of 908 m.

3.1.6. Human environment

3.1.6.1.Population growth

The city of Yaoundé covers 304 km^2, including an urbanized area of 183 km^2. In 1976, Yaoundé had 313,706 inhabitants; this figure increased to 649,258 in 1987. The growth rate recorded is quite significant and is estimated at 6.8%. Between 1987 and 2005, in 18 years, the city's population almost tripled, recording an average annual intercensal growth of 5.7% per year. Based on the projection provided in the PADY documents (2015), the population of the city of Yaoundé estimated at 2.96 million inhabitants in 2014 increased to 3.38 million inhabitants in 2017. In 2035, this population will be approximately 6 million inhabitants (SCET Tunisia, 2017). In 2020, the population was estimated at 4,100,000 inhabitants, an average density of 13,486 inhabitants per square kilometer. The population is increasing by almost 100,000 inhabitants each year.

3.1.6.2. Socioeconomics

Yaoundé IV is above all a tertiary city. However, there are a few industries: breweries, sawmills, carpentry, tobacco, paper mills, mechanics and building materials. Most of the economy of the city of Yaoundé in general is based on the informal sector, whether it is street vendors (also locally called "sauveteurs"), street vendors (paper handkerchiefs, caramelized or not peanuts, cold drinks, clothes, etc.) or small shops in the neighborhoods. The informal sector also affects the housing sector, in which many builders are non-professionals.

3.2. Data collection

3.2.1. Secondary data

Secondary data of the study area are obtained from several sources: dissertations, theses, study and consultation reports, planning documents, scientific learning platforms, etc. The themes on which the data collection focuses are the institutional and regulatory framework for water management in Cameroon; the level of implementation of IWRM in Cameroon; the establishment of IWRM at the local level; the hydrological balance on small watersheds; water resource mapping; the establishment of a SWOT analysis of the water resource management strategy.

Other digital sources are used to supplement the information collected; these are:

- Cartographic data, which were obtained from several sources according to their nature, such as the free software Google Earth for viewing aerial photographs of the study area.

- The Digital Elevation Model (DEM) of the city of Yaoundé used was downloaded from the platform https://search.earthdata.nasa.gov/
- The satellite images Sentinel-2 of the 01/12/2024 (S2A) (10m precision) of the city of Yaoundé were downloaded from the platform https://www.copernicus.eu/fr of the European Union program for water resources mapping and land use classification.

Some of this information was taken from the literature on previous works concerning the city of Yaoundé. Notably Deliege (2020), MINWRE (2023), GWP (2017), World Bank (2023), U.S. Army Corps of Engineers (2010), Li (2023), USAID (2015).

3.2.2. Primary data

Primary data comes from field interviews conducted with 21 key stakeholders identified, involved in the management of water resources in Cameroon. These include:

- Policy and policy decision makers: MINWRE (Water Resources Management Directorate (WRMD), Water Resources Mobilization Directorate (WRMD), MENPSD, MINTRANSPORT, MINDLD).
- Technical partners: GWP Caf, IHP national focal point, UNESCO, CRWCC, NOCC, RECOJAC, Water for Life Cameroon
- Finance institutions: MINEPRD, world bank
- Subnational public institutions: Yaoundé urban council, Yaoundé 4 council
- University vocational training centers: National Higher Polytechnic School, University of Yaoundé 1.

The coordinates of the main water points (wetlands, rivers, springs, etc.) found in the study area were taken using a Garmin 64s GPS.

Figure 3: Garmin 64s GPS used for collecting coordinates of points

The hydro meteorological data for the period of 1970-2024 (temperature, precipitation, evapotranspiration) come from the national meteorology department of the Ministry of

Transport, located in Yaoundé, and from the Yaoundé Meteorological Station located at Air Base 101 in the Ekounou district (the only station covering the city with continuous recordings).

3.3. Calculation assumptions considered

To carry out this study, a few assumptions were made:

- The precipitation recorded at the Ekounou station was considered valid for the Odza and Nkie watersheds.
- It was considered that the Digital Elevation Model (DEM) downloaded from the NASA data access platform corresponds to the variation in altitudes observed in the field.
- Interactions between surface water and groundwater play an important role in maintaining the water balance in the sub watersheds of Yaoundé 4.
- The effective involvement of all local stakeholders and the adoption of a participatory approach are essential for the successful implementation of IWRM in Yaoundé 4.

3.4. Data treatment

3.4.1. SWOT analysis of the regulatory and institutional framework of IWRM at the level of the Yaoundé City Hall 4

The SWOT analysis of the institutional and regulatory framework of IWRM in the Odza and Nkie watersheds was carried out using the SWOT tool (Strength, Weakness, Opportunities, Threats) which allows for an in-depth analysis of the strengths, weaknesses, opportunities and threats of the IWRM strategy implemented in these urban sub-watersheds. To carry out this analysis, we first identified the key major actors who play a central role in the development, implementation and monitoring of the IWRM strategy in Cameroon in general and in the commune of Yaoundé IV in particular (these include the technical manager of the commune of Yaoundé IV, the GWP Caf, the head of the WRMD (MINWRE), the MENPSD, the MINEPRD, the MINTRANSPORT, the IHP focal point of Cameroon, the MINDLD, National Institute of Statistics, the world bank, UNESCO, the technical manager of the urban community of Yaoundé, CRWCC, NOCC, RECOJAC, J2D Africa, National Higher Polytechnic School, University of Yaoundé 1).

After identifying the key actors, we proceeded to develop interview questionnaires specific to each actor/institution to which they are attached.

Individual interviews in person or remotely (telephone call, videoconference) were subsequently conducted with each actor to collect specific information that will be used for

SWOT analysis. Concretely, the questions addressed concern the 04 pillars of evaluation of indicator 6.5.1 of SDG 6, namely: **enabling environment** (set of conditions that aim to support the implementation of IWRM, including basic policies, legal tools and strategic planning necessary for its achievement), **institutions and participation** (set of institutional stakeholders and other groups concerned as well as their political, social, economic and administrative roles likely to support the implementation of IWRM), **management instruments** (set of tools and activities that enable decision-makers and users to make rational and informed choices regarding the options and actions to be undertaken in terms of IWRM), and **financing** (set of budgetary allocations and financing from various sources and which are made available for the development and management of water resources). Once this information was collected, we proceeded to the SWOT analysis according to the four pillars of indicator 6.5.1 of SDG 6 on IWRM. The results of this analysis are consolidated in a table.

3.4.2. Mapping of water resources in the Odza and Nkie sub-watersheds in the council of Yaoundé IV

The mapping of water resources in the Odza and Nkie sub-watersheds was carried out according to the following procedures:

3.4.2.1.Delimitation of the study area

To delimit the study watersheds, we first downloaded the Digital Elevation Model (DEM) on the NASA platform.

The DEM is then processed with the ArcGIS 10.3 software version. Once the DEM is inserted into the ArcGIS software via the "open data source manager"  , we proceeded to its reprojection according to the WGS 84/UTM zone 32N coordinates via the "warp (reproject)" tool under the "Raster" tab. Once the reprojection is complete, we use the " « arctoolbox  » " under the "spatial analysis tools" tab, with the " « Hydrology tool » "for processing and extracting the study area. The "fill " tool is used to identify, fill surface depressions and preserve a downward slope along the flow path. Then the "Channel network and drainage basin" tool was used to set a threshold for channel initiation. The "polygonize" tool contained in the "Raster" tab will then be used to convert the obtained raster image into a vector. The "clip" tool will finally allow us to extract our study area to use it properly.

3.4.2.2. Processing of Sentinel-2 images and identification of watercourses in the study area

The Sentinel-2 (S2A) (R10m) satellite image allowed us to identify the presence or absence of open water surfaces within the study area. These Sentinel-2 images were obtained on the Copernicus platform (https://www.copernicus.eu/fr.) and processed using Qgis 3.34.4 software. First, we downloaded and prepared the Sentinel-2 satellite image corresponding to the city of Yaoundé. We then calculated using QGIS software the spectral indices such as NDWI (Normalized Difference Water Index), the NDVI (Normalized Difference Vegetation Index) and the SAVI (Soil Adjusted Vegetation Index) which is a corrective index of the NDVI to identify and delimit the water body. We worked with the following Sentinel-2 bands:

T32NQK_20241201T093351_B02_10m ; T32NQK_20241201T093351_B03_10m ; T32NQK_20241201T093351_B04_10m ; T32NQK_20241201T093351_B08_10m.

The datasets were proceeded as follows:

The surface reflectance bands 2, 3,4 and 8 were used, placed in order and cropped to work only on the study area.

Step 1: We opened the QGIS software and added the downloaded S2A products (T32NQK_20241201T093351_B02_10m; T32NQK_20241201T093351_B03_10m; T32NQK_20241201T093351_B04_10m; T32NQK_20241201T093351_B08_10m) as raster files.

Step 2: Clipping the raster

The first step was to open bands 2, 3, 4 and 8. Then, with the Raster toolbar > Extraction > <<Clip raster by extent>> the same operation was performed for each band up to band 8.

Band 2 was chosen in the input layer at the right arrow of "Clip extent", choose "Draw on map canvas". Then selected the extent that appears in the box. Then press "Run".

Step 3: Composing

For this step firstly go to the toolbar Raster > Miscellaneous > Merge. In Input layer, sort the bands 2,3,4,8 in descending way from 2 until 8. Then, select "Place each input file into a separate band". Then “Run”

The step here is to add the Sentinel-2 images, once the bands are added they are merged in the Raster menu → Miscellaneous → Merge section. The generated image is thus renamed.

Step 4: Transformation

This step involve calculation of the rescaled B2R reflectance by following this step: go to the Raster toolbar→”Raster Calculator” and then use equation 1 below in the calculator field.

Perform a scaling of the shift factors to apply to the Sentinel-2 (S2A) products. The reflectance data for the (S2A) products were rescaled according to the following equation:

B2R= B2*00000275-0.2 *Equation 1*

Where B2R is the rescaled reflectance, B is the reflectance of the band in bit format. The same process was repeated to calculate the rescaled reflectance B3R, B4R and B8R

Step 5: NDWI (Normalized Difference Water Index).

This step involves calculation of the NDWI index which allows discrimination of water surfaces since NDWI present values greater than zero (0).

To do this, go to the toolbar Raster→" Raster calculator", then use equation 2 below in the calculator field.

NDWI = $\frac{B3R-B8R}{B3R+B8R}$ **(for Sentinel-2 images)** *Equation 2*

Step 5: NDVI (Normalized Difference Vegetation Index)

Follow the same process to calculate the NDVI index using the following equation

NDVI = $\frac{B8R-B4R}{B8R+B4R}$ **(for Sentinel-2 images)** *Equation 3*

Empirically derived NDVI products have been shown to be unstable and vary with soil color, soil moisture, and saturation effects of high-density vegetation. To improve NDVI, SAVI was developed to account for differential red and near-infrared extinction across the plant canopy. It can be calculated with the following equation

$$SAVI = \frac{B8 - B4}{B8 + B4 + L} \cdot (1 + L)$$

Equation 4

Where **L** is the soil brightness correction factor and could range from (0 -1).

AFTER NDVI, three more steps are needed before performing the calculation of the water body area: vectorize, polygonize raster to vector and dissolve the vector layer.

Step 6: Vectorize

The goal here is to calculate the water surface, so only the NDWI index is used, knowing that the NDWI index values for water basins are greater than 0. 5

Firstly, recorded the rooster for values greater than 0, then polygonized the raster obtained in the previous step according to the following equation:

Right-click on NDWI layer and go to the raster layer in the layers panel —> Export ---> Save as raster layer with the No Data specifications. Then, go down until we find the No Data values, and press the green cross and add the range: -2 to 0

Step 7: Polygonize Raster to Vector

Go to Raster—> Conversion —> Polygonize and save it as (renamed it)

Step 8: Dissolved the vector layer

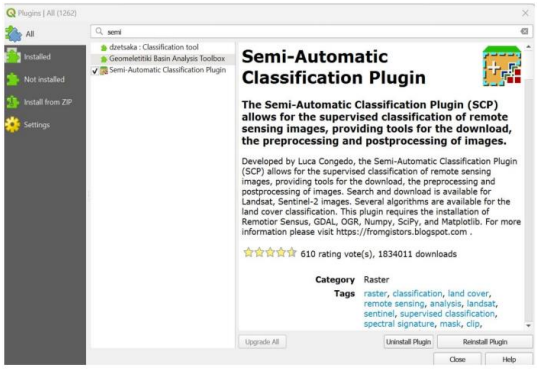
Go to Vector —-> Geoprocessing Tools —-> Dissolve

Step 10: Calculate the water body area

It is possible to calculate the area of the resulting watercourses obtained. To do this, Right-click over layer —> Open Attribute table, press the yellow pencil —> Field calculator (Abacus icon tools bar) --> put area name to the column. Choose a Decimal number and, in the expression, select "Geometry" and $area. Made double click in $area and --> Ok. The area is expressed in square meters as the vector is in UTM projection.

3.4.2.3.Land use classification under the Semi-automatic Classification Plugin (SCP)

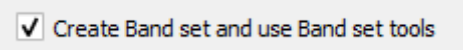
This step aims to perform a supervised classification through Sentinel-2 images. To do this, previously downloaded images with a resolution of 10m. After downloading images, open Qgis software (3.34.4 version) and install the Semi-Automatic classification plugin (SCP) tool. The Semi-Automatic Classification Plugin (SCP) in QGIS is designed for the supervised classification of remote sensing images.



After installing the SCP, the classification process begins. The first step is to clip the study zone inside the raster images. To do that, go to "Raster tool">> "extraction">> "clip by extent". The next step is to define the dataset. To do this, we go to the SCP tool SCP under the pre-processing tab and then choose sentinel-2.

In the new window that opens, indicate the path to the clipped raster images of the study area

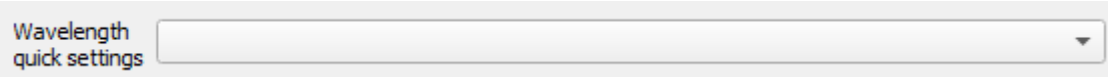
Then uncheck the tab "create a set of bands and use the toolbox"



Then, click on “Run” 

The new data bands were automatically created, and it is from these bands that the classification will be made.

then go again to the SCP>> "Band set" command and refresh the single band list and choose Sentinel-2 in the “wavelength quick settings”



Then, from the "Semi-Automatic Classification Plugin" tab  , create a new Training input by clicking on the following icon  . So, the ROIs can be used to start the digitalization of the different spaces 

So, the ROIs is used to digitalize the different spaces from a selected set of RGB color bands 

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The elements represented are classified into macro class (MC ID) and micro class (C ID). As an example, MC ID = water; C ID = river or lake. In the case of this study, a classification in macro class (MC ID) was made to reduce the margins of error and have a more reliable and less dense representation regarding the reflectance colors which can sometimes be confusing. Once the digitalization of the spaces is finished, we can use the following tool  to have an overview of the classification generated by the software. Then, to generate the final classification, go again under the command SCP>> "Band processing" >> "Classification", choose the classification model (C ID or MC ID) and choose the definition algorithm, the most used algorithm is "Spectral angle mapping", then click on “Run”.

The classification performed can be corrected from a reference shapefile generated from a Google Earth image or an Open Street map of the study area. This is to verify the level of accuracy of the classification.

3.4.3. Performing the hydrological balance of the Odza and Nkie sub-watersheds

The precipitation, temperature and evapotranspiration data series (daily and monthly) were obtained from the National Directorate of Meteorology of Cameroon over the period 1971 to

2024. The missing precipitation data (over the period 2013-2014), as well as the temperature data (over the period 2013-2015 and 2017-2022) were generated by Climate Engine (https://www.climateengine.org/).

The evapotranspiration data obtained by the National Directorate of Meteorology (NDM) (for the period 2016, 2023 and 2024) being insufficient to cover the study series, we therefore proceeded to an empirical estimation of evapotranspiration as a function of temperature over the reference periods 2016, 2023, 2024, as follows: mentioned by the Turk formula in Laborde's document (Laborde, 2009). We subsequently compared the values obtained with the reference values of the Meteorological Station. After examination, we found that 2024 was not reliable given the enormous differences with other measured years and the values found by Santiago (1992, page 5) on the hydrological balance in Cameroon. We therefore considered 2016 and 2023 as our reference data and applied a correction factor called "Alpha" for the calculation of the values of the entire missing series.

Turk's formula is derived from Penmann's formula and requires only knowledge of air temperatures and global radiation or sunshine duration. This formula is as follows:

$$\mathbf{Etp = 0.4 * \frac{t}{t+15} * (Ig + 50) * K} \qquad \textit{Equation 5}$$

With:

Etp: monthly potential evapotranspiration (in mm of water).

t: monthly average air temperature (in °C).

Ig: monthly average global radiation received on the ground (in calories/cm2/day).

K: a coefficient equal to 1 if the relative humidity **hr** is greater than 50% (generally the case in our climates); otherwise

$$\mathbf{K = 1 + \frac{50-hr}{70}} \qquad \textit{Equation 6}$$

If the global radiation Ig is not measured, it can be evaluated from the duration of insolation **h** using the formula

$$\mathbf{Ig = IgA\ (0.18 + 0{,}62 * \frac{h}{H})} \qquad \textit{Equation 7}$$

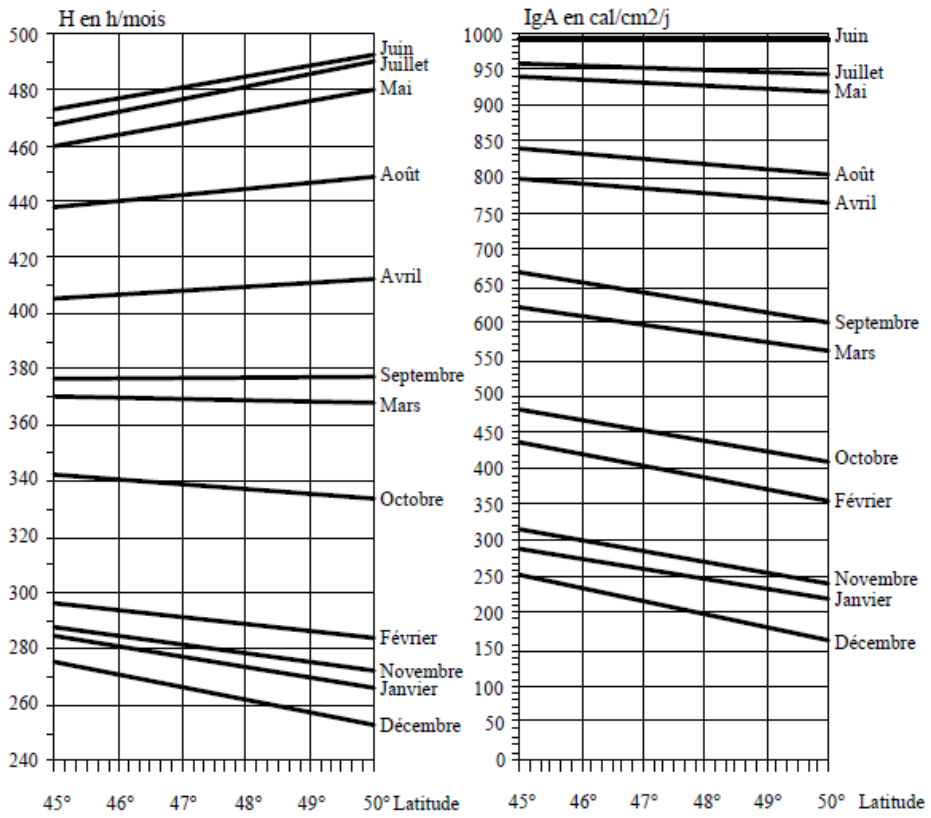
With

IgA: theoretical global radiation (in cal/cm^2/day).

H: theoretical duration of the days of the month.

The following charts and formulas allow to evaluate IgA and H according to the latitude and the month in the

same units (cosine of angles in º) and by numbering the months from 1 (January) to 12 (December).



H = 362.7 + 0.201 lat + (4.085 lat - 80.99) cos (30.01 i - 188,9) *Equation 8*

IgA = 1 035 - 9.078 lat + (7.050 lat + 49.90) cos (29.92 i - 182.5) *Equation 9*

Infiltration data were calculated from the empirical formula developed by Gemitzi et al (2017)

GR = 0.5174 * (P – Etp) + 0.2145 *Equation 10*

where

GR corresponds to monthly Groundwater Recharge (mm/month), i.e. the water quantity that infiltrates to the subsurface and can be considered as a reasonable approximation of the infiltration term in the water balance Equation.

P is the monthly precipitation (mm/month) and

Etp stands for actual Potential Evapotranspiration (mm/month).

CHAPTER 4

RESULTS AND DISCUSSION

4.1. SWOT analysis of the regulatory and institutional framework of IWRM

4.1.1. Enabling environment

The enabling environment focuses on existing regulatory, policy and strategic plans which could boost IWRM implementation in a given system or institution. This aligns with the enabling environment at national level since there seem to be no specific framework at local level. The enabling environment in Odza and Nkie watershed is marked by the existence of decentralized units in charge of planning, development and protection of water resources. According to the panel of experts consulted, the existing enabling environment includes the policies, laws and plans governing the implementation of IWRM.

Table 9: SWOT analysis of IWRM Enabling environment in Yaoundé City

Existing enabling environment	**Strengths**	**Weaknesses**
	- Political will displayed by the Cameroonian government to promote IWRM through the development of the National Water Policy (NWP) and the revision of the water law (Law No. 98/005 of April 14, 1998, was revised in 2021 to integrate IWRM). - The National Water Policy (NWP) which aligned with the IWRM approach was recently adopted at the presidency level, it defines the strategic orientations of the government. - Existence of diagnostic studies (NAPIWRM, RAPIWRM) which provide	- Unfinished legal and institutional framework (the new water law is still awaiting presidential endorsement, which is hampering the implementation of IWRM projects as well as decrees and orders at the government and subnational levels). - National development priorities (NDPs) that do not place sufficient emphasis on IWRM. - Absence of an official updated national IWRM plan (NAPIWRM not politically validated, although it has given rise to

	a knowledge base on water resources (national and transboundary) - Development of a national IWRM action plan (NAPIWRM) not validate but serving as a strategic document for the implementation of IWRM. - The existence of the law on decentralization which allows for better involvement of local authorities (local councils and regional councils) in water resource management. - Cameroon has ratified the Dublin principles and is committed to promoting IWRM. - Adoption of regional policies that promote cooperation between Central African countries through initiatives such as RAPIWRM. - Development of a sub-regional action plan with ECCAS. - Update of the status of NAPIWRM in 2022, as part of a MINWRE/IGMR partnership. - Cameroon is a member of several basin organizations (ICCOS, LCBC, NBA) and signatory of Cross-border agreements like the Helsinki Convention on Transboundary Waters convention. - Existence of subnational policy on IWRM (decentralization laws	other initiatives, its lack of validation limits its impact). - Difficulties in translating policies and plans into concrete actions. - Weak implementation of ratified international conventions - The national water policy, although adopted, still requires strengthening at the operational level. - Although laws exist, their effective implementation remains weak, limiting the impact of IWRM efforts. - Limited awareness of the NWP (not all stakeholders are yet informed).

	transferring water resource management skills to municipalities). - Institutionalization of water resource monitoring (by decree and order). - National determined contribution mention water resource as a key sector for climate resilience	
	Opportunities - The 2030 vision considers water resources as a main lever for Cameroon future development - The new water law, once adopted, will provide a clear and favorable legal overarching framework for the implementation of IWRM. - NAPIWRM raised the attention on IWRM challenges and sparked the attention on the need to consider integration, inclusivity and sustainability in water resources and water uses (this would provide an official framework and strengthen the implementation of IWRM). - Implementation of a decree regulating the volume of water authorized per use (this would allow better management of water demand). - The existence of a division in charge of IWRM in the ministry in charge of water - With the regular monitoring of SDG 6.5.1 and 6.5.2 more institutions and	**Threats** - Slow decision-making processes (delays in the adoption of the water law and other regulatory texts can compromise the implementation of IWRM). - Political instability may influence water management priorities. - Low application of instruments (policies, plans and strategies are poorly implemented). - Lack of clear financing mechanism for IWRM at national and subnational level (no specific budget indicated) - Misalignment of budget, priorities and vision may end up pushing IWRM far from key national or subnational decision makers priorities

	stakeholders are aware and sensitive to IWRM challenges and possible entry points for its implementation - The AIP score Card assessed for Cameroon in 2024 raised some case of IRWM pillars which could support more finance income for Cameroon - Opportunity to improve local policies by integrating IWRM principles into urban planning. - Integration of the Sustainable Development Goals (SDGs) into national policies, promoting a systematic approach to water management. - Growing interest in environmental issues, which may attract more support for IWRM. - Popularization of the NWP for better appropriation by all stakeholders. - Strengthened cross-border cooperation, particularly within ICCOS and LCBC.	

ECCAS: *Economic community of Central African States*
LCBC: *Lake Chad Basin Commission*
NBA: Niger *Basin Authority*
IWRM: *Integrated Water Resources Management*
SDG: *Sustainable Development Goal* ***NWP:*** *National Water Policy*
ICCOS: *International Commission for the Congo-Oubangui-Sangha Basin*
NDP: *National Development Priorities* ***IWRM:*** *Integrated Water Resources Management*
MINWRE: *Ministry of Water Resources and Energy* ***IGMR:*** *Institute of Geological and Mining Research*
RAPIWRM: *Regional Action Plan for Integrated Water Resource Management*
NAPIWRM: *National Action Plan for Integrated Water Resource Management*

The SWOT analysis of the enabling environment for the implementation of IWRM in the study area reveals that IWRM as a new concept for developing countries like Cameroon, is a field with many untapped opportunities. However, although many legal texts exist in the regulation of the water sector, the strengths highlighted by this framework are still undervalued to meet the challenges related to the weaknesses and threats to the effective implementation of IWRM in its entirety within the Odza and Nkie watersheds. The situation at national level is even more appealing at council (subnational) level where no guide exist as far as the IWRM principles are concerned. Determined to be actively involved in the emergence process initiated by Cameroon by 2030, the Yaoundé 4th district municipality, to which the Odza and Nkie watersheds belong, has, since 2019, undertaken all initiatives for the development of its Municipal Development Plan (MDP). This plan pursues clear and precise objectives aimed at identifying and analyzing the development problems of its population, involving beneficiary populations in development issues that affect their well-being, and equipping itself with strategies and a logical framework for intervention based on a three-year program and annual planning of previously selected development projects. The new planning approach is thus attached to the national policy structured on the program budget. This vision is structured around 3 technical programs, namely: the program for Improving the provision of basic social services, the program for Promoting economic development and protecting the environment and the environmental program. Belay et al., (2013), in his analysis of the challenges of the Nile Basin initiatives through SWOT analysis identified the environmental management plan, with a conducive institutional governance structure and process as strengths. These strengths of the legal framework in the transboundary management of the Nile are similar to the transboundary basin management initiatives to which Cameroon belongs with countries like Chad, CAR, Democratic Republic of Congo and Nigeria. However, his analysis reveals a lack of institutional depth, and a significant threat linked to the 1929 Nile Basin Waters Treaty limiting the efficient use of Nile waters.

These institutional weaknesses and threats also perceptible at the scale of the Odza and Nkie watersheds of the Yaoundé IV district can be justified by several factors, such as : the low awareness of the authorities of the importance of integrated water resources management, needs to raise it as a priority solutions for the efficient management of water resources, lack of water resource management tools, a wrong perception of IWRM and lack of finance resources to invest on development in the water sector. Okala et al (2021) also specified in an article in the African Journal of Rights and Political Sciences that the

difficulty of imposing the sovereignty inherent in water resources lies in its mobile nature because it ignores political borders that it crosses in several forms. Central African states, like Cameroon, have, since their accession to independence, set up a hydro diplomacy specific to each basin without restricting their sovereignty, but in a logic of preserving national interests while accepting the legal obligations that result from it.

Similarly, Collado et al (2023) identified and prioritized the key factors affecting the implementation of the IWRM system in 04 localities (Puerto Princesa, Roxas, Taytay, El Nido) in the province of Palawan through a combined SWOT-AHP analysis. The SWOT analysis of the enabling environment shows many similarities with the results obtained. In the locality of Puerto Princesa, an update of local water management plans and policies is noted as a strength (similar to the revision of the water law and the PNE in the case of Yaoundé). The weaknesses observed here are the weak implementation of national laws and policies although they exist (as in the case of Yaoundé). The adoption and implementation of a national plan to combat climate change; well-defined sectoral policies and comprehensive sectoral strategic plans for environmental management, natural resources, water supply and sanitation are the key opportunities. However, the absence of an integrated water policy master plan is noted as a threat.

In the locality of Roxas, the progressive implementation of national laws and policies; the formulation of adaptive plans for the protection and conservation of water resources are some strengths. The existence of a sustainable development plan (2016-2020) remains an opportunity to be seized in this locality.

The locality of Taytay, for its part, presents a rigorous implementation of national laws and policies.

El Nido, on the other hand, presents a much more adequate framework, with the presence of a framework for national IWRM plans; the implementation of subnational IWRM policies. On the other hand, there is a weak implementation of national policies and laws on water (weaknesses). Compared to the city of Yaoundé, we can say that the institutional and legal framework for water management is very rich, although some texts are outdated, the political framework, despite being somewhat structured, is less implemented, although there are water sectors that are not governed by texts. This is in line with Njikam (2021), who made a SWOT analysis of the implementation of IWRM in Central African countries. His analysis of Cameroon's favorable environment highlights strengths such as the existence of an institutional and legal framework, characterized by the law on

decentralization. On the other hand, he underlines the inadequacy of the legislative and regulatory framework due to the absence of a National Water Policy, what nowadays exists. Indeed, from 2021 to 2025, there has been a slight improvement in IWRM implementation status, through the revision of the framework law on the water regime, the update of studies on the knowledge of water resources used in the development of the national integrated water resource management plan (NAPIWRM) (still awaiting validation), and the official approval of the national water policy (NWP) which Cameroon recently adopted, although it is not widely disseminated. The legal and institutional context governing the water sector is gradually taking shape, many other initiatives are awaiting validation of the new water law revised to international standards in terms of IWRM, this will then lay the new foundations for the management of water resources at the national level and within the commune of CTD including the district commune of Yaoundé IV on which the Odza and Nkie watersheds depend.

4.1.2. Institutions and participation

The institutional and participatory dimension of IWRM in Odza and Nkie watershed is marked by a multitude of actors and organizations at various levels that interact on the issue of water. This dimension refers to the institutions which influence water resources and participation of stakeholders at various levels, considering social, economic and administrative institutions and other stakeholder groups that contribute to the implementation, as well as their role in this framework.

Table 10: SWOT analysis of IWRM Institution and participation in Yaoundé City

Institution and participation	**Strengths** - Involvement of partners such as the AfDB (AfDB sponsored the Mfoundi river channeling between 2013 and 2022), and the World Bank (World Bank sponsored the Yaoundé wastewater project which structured the wastewater value chain and invested in the setting up of the Yaoundé Wastewater treatment plant) in supporting water resources development. - Involvement of civil society (Water for Life Cameroon, RECOJAC, ERA Cameroon, …etc.) - Institutions such as CRWCC, which are dedicated to research on water and climate, provide crucial data for IWRM. - Existence of the GWP whose main mandate is to promote IWRM in Cameroon. - Existence of the Cameroon IHP national Committee structured with the help of UNESCO but not formally created by the government - Existence of a National Water Committee (NWC) stated by a decree since 2001. - Membership of the Municipality of Yaoundé IV to the UCCC (association within which several issues of development of decentralized territorial communities are developed and monitored) Collaboration between different ministries and agencies to strengthen water resources management and development. - Technical and financial support from partners such as the World Bank and AfDB for the implementation of IWRM.	**Weaknesses** - Weak collaboration between countries in transboundary basins. - Low overall participation (relatively low involvement of women in decision-making processes). - Poor TV and radio coverage (the municipality of Yaoundé IV communicates very little about its initiatives) Lack of coordination between Yaoundé city council and other urban council to coordinate water and water ecosystems sustainable management - Weak collaboration between the commune of Yaoundé IV and other communes (Yaoundé I and II) - Weak development of the partnership network of the commune of Yaoundé IV in decentralized cooperation. - Lack of coordination between institutions: Responsibilities for water management are often scattered across several ministries and agencies, which can lead to duplication and inefficiencies. - Weak awareness and training of local stakeholders on the IWRM approach. - Absence of joint ventures with Cameroonian companies for better implementation of IWRM. - Few opportunities of training in financial capacity, technical software and sharing of experiences. - The sharing of information between decentralized services and ministerial stakeholders in the water sector is not always up to date (deadlines not met). - Lack of clarity and consensus on IWRM implementation priorities at local level. - Low involvement of communities in the decision-making process, making initiatives less adapted to local needs.

	- Inter-institutional collaboration between MINRWE, CAMWATER and other local actors to improve water supply. - Existence of the Directorates of Water Resources Management (WRMD) and Water Resources Mobilization (WRMD) which coordinate management and monitoring efforts. - Training of MINWRE (Directorate of Water Resources Mobilization) staff in 2024 (capacity building for the implementation of IWRM). - Many IWRM workshops are organized by various actors for municipalities. - Existence of organizations such as RECOJAC, Water for Life Cameroon which promotes the participation of young people in IWRM initiatives and strengthens the capacities of local actors. - Growing awareness of climate issues and their impact on water resources, promoting political engagement. - The presence of organizations such as NOCC, NMD play a key role in monitoring climate impacts on water resources and developing hydrometeorology. - Collaboration between various ministries (MINWRE, MINARD, MINLFAI, MINTRANSPORT) to integrate climate considerations into water management. - Inter-administration coordination ensured by the Prime Minister's services. - Private sector participation (ENEO, EDC, breweries, etc.)	- Non-operationality of National Water Committee since its creation, this limits coordination. - Insufficient popularization of the IWRM strategy (many actors, such as NOCC, do not feel sufficiently involved). - Insufficient consideration of climate change (the climate aspect is not always operationally integrated into the IWRM approach).

	-	
	Opportunities	**Threats**

	- Existence of multiple expertise and commitment of diverse stakeholders to contribute to IWRM at national and subnational levels - Current discussion with world bank to develop two structural programs SEWASH (for inclusion of IWRM in drinking water development) and Rural water supply program (which will rehabilitate 350 water schemes in rural areas of Cameroon) - - Signing of collaboration agreements with all IWRM stakeholders. - Opportunity to improve coordination between actors through dialogue platforms and partnerships.	- Lack of coordination (the complexity of the actors involved in water management can lead to coordination difficulties and conflicts of interest). - Risk of fragmentation of management efforts due to poor coordination between the different actors. - Difficulty in aligning with international standards if local capacities are not strengthened. - Conflicts of competence between different ministries and organizations. - Resistance to change from established actors in water management, slowing down necessary reforms.

The SWOT analysis of IWRM institutions and participation at the scale of our study watersheds reveals that this section still has many weaknesses and very significant threats. This can be justified by the fact that not only is the water sector still mainly perceived as a social aspect (which does not give it much interest among decision-makers), but also IWRM as a new concept is not yet anchored in knowledge as a fundamental basis for the coordinated and concerted management of the resource. As a result, many actors reduce integrated water resource management to the sectors of drinking water supply, sanitation and hydroelectricity, which limits the perception of the resource in water as a whole and does not allow for full integration of all stakeholders in the sector. Okala (2023), mentioned in her article on public participation and IWRM in Central Africa that the participation of the private sector, as a major consumer of water, is not sufficiently institutionalized. The National Water Partnerships (NWP), institutions coordinated by GWP Central Africa, remain the only framework that allows and facilitates the participation of private stakeholders (NGOs, associations, etc.), although they are not yet established in all Central African countries. She also specifies that, in countries in the sub-region such as Cameroon, citizen participation is not effective at the institutional level. Belay et al., (2013) in the framework of the Nile Basin Initiative highlighted strengths such as the development of multinational and multi-sectoral programs of collaborative actions, exchange of experiences, trust and capacity building for regional cooperation and sustainable management of Nile waters; the development of knowledge-based tools for IWRM through capacity building in each Nile Basin country (similar to the GWP IWRM toolbox initiative aimed at strengthening and improving stakeholders' knowledge on IWRM); the strengthening of trust and collaborative relationships among all those involved in Nile water resources management; broad stakeholder participation, commitment and ownership of projects in all member countries with the establishment of project management units in each country; strong donor support from major institutions; and significant regional cooperation. However, he highlights a lack of coordination and linkages with some stakeholders such as the Lake Victoria Basin Commission; and the failure to integrate local knowledge of indigenous peoples of the Nile Basin countries into project planning. Furthermore, the World Bank's continued support for NBI projects, seen as a hope for achieving the objectives; the involvement of NGOs and civil society as a catalyst for the effectiveness and efficiency of NBI project implementation; the membership of the Nile Basin countries in the African Union, and the NBI project promoting the possibility of benefiting from the New Partnership for Africa's Development (NEPAD) are all opportunities to be exploited. The long-term challenges of operational integration across the basin due to different sets of policies and procedures among NBI institutions; the history of

tensions and instability in the region; and the different levels of development of member countries threaten the initiative's path towards achieving its objectives.

Collado et al (2023) noted in the locality of Puerto Princesa in the Philippines, elements such as the slow progress in capacity building and development, water resource management without the participation of civil society. The development of growing partnerships between government agencies, NGOs and development partners is an essential opportunity in financing water projects. In the locality of Roxas, there is also a strengthening of intersectoral links, with however limited participation of stakeholders and inadequate transboundary arrangements. Strengthening women's empowerment and gender development therefore appears as an important opportunity regarding the place of women in water resource management within households. The locality of Taytay, for its part, presents an effective implementation of gender objectives at the national level, despite the fact that there are very few basin/aquifers management institutions, with low public and private participation, and slow progress in capacity development. It is noted, however, that the existence of a joint provincial and municipal agreement, and a water infrastructure support office are opportunities that could help to address the limited capacity of institutional human resources. In the El Nido area, there is weak national intersectoral coordination, the absence of a drinking water supply agency is the main threat observed in terms of accessibility to the resource. The growing opportunities for international partnerships are a boon to accelerate coordination and develop an effective management framework. Many similarities are observed with the Odza and Nkie areas in terms of participation of the local population and gender; coordination between the different actors, exposing the water sector to a conflict of interest and competence, especially in a context where water resources are still little valued in all their dimensions (social, economic, environmental, cultural). It must be said that efforts are being made to take into account the opinions of the populations in the implementation of IWRM, but this remains insufficient. Vulnerable people are considered in the water law currently being validated and the policy documents on IWRM, but the application remains unsatisfactory. One of the flagship tools in terms of information sharing in the Odza and Nkie watersheds is the organization of workshops on water resources. Since the advent of IWRM, many workshops have been carried out, with the dissemination of information to many stakeholders, including the workshop for the launch of the activities of the pilot project on integrated water resources management (IWRM) and water information systems (WIS) for adaptation to climate change in the Congo basin (PROGIRE-SIEACC) organized in 2021; the media mobilization workshop in Cameroon for the popularization of texts and policies on water, climate and the environment in the Central African region organized

in 2021; the workshop to revise the law on the water regime in order to improve the implementation of IWRM organized in 2023; the workshop to evaluate the implementation of SDG 6.5.1 on IWRM organized in 2023; the workshop to evaluate the progress of transboundary cooperation in the water sector organized in 2020; the workshop to validate study reports on the resilience of WASH services to climate change organized by GWP and UNICEF in 2018; the initiative to present IWRM to students at the University of Dschang as part of the strengthening of the partnership, established since 2007, between GWP-CAf and the University of Dschang focused on technical support and the provision of courses related to IWRM at the university. The Wood, Water and Environment Trades Sector (WWETS) of the Ebolowa branch benefited from these courses provided; the organization of a hybrid session of the first regional stakeholder consultation workshop within the framework of the Integrated Water Resources Management and Early Warning System project for resilience to climate change in the Lake Chad Basin in February 2022; the opening of a national workshop to evaluate the implementation of the 2016-2024 operational plan and update that of the 2025-2033 period of the Niger Basin Authority (NBA) organized in September 2024 in Abidjan-Cocody.

4.1.3. Management instruments

The management instruments of the city of Yaoundé are marked by a set of mechanisms and actions allowing the monitoring and management of resources. This component concerns the tools and activities that allow decision-makers and users to make rational and informed choices between different actions. Management instruments include:

- **Decrees** are legal instruments that establish the framework for water resource management. They define rights, responsibilities, and regulations. In Yaoundé, decrees would be crucial for enforcing IWRM principles, such as water allocation, pollution control, and land use planning within water catchment areas. This instrument provides a legal basis for evaluation by setting the standards against which implementation is measured.
- **Sustainable Development Goal indicators** address IWRM implementation and focus on tracking progress and identifying gaps in management strategies of IWRM implementation (SDG 6.5.1) and monitoring mechanism that allows the evaluation of how well Yaoundé is cooperating with other regions in transboundary water cooperation (SDG 6.5.2). They help with providing standardized frameworks for monitoring and evaluating progress, allowing for comparisons over time and with other regions. These

mechanisms are vital for tracking the effectiveness of IWRM strategies in Yaoundé and identifying areas for improvement.

- **The emergency response standards established by MINWRE (Water Resources Mobilization Directorate) for NGOs** provide guidelines for responding to water-related emergencies, such as floods or droughts. It's a management instrument that helps in ensuring coordinated and effective responses, setting benchmarks for NGO activities, and reducing the impact of water-related disasters.
- **The GWP IWRM toolbox,** as for him, enhances the knowledge and skills of stakeholders involved in IWRM. They help in improving the ability to plan, implement, and monitor IWRM activities, promote the best practices and knowledge sharing, and increase the overall effectiveness of IWRM. The IWRM portal serves as a central platform for sharing information, data, and resources related to IWRM. It facilitates communication and coordination among stakeholders, provides access to relevant data for decision-making, and promotes transparency and accountability.

Table 11: SWOT analysis of IWRM Management instruments in Yaoundé

Management instruments	**Strengths**	**Weaknesses**
	- Existence of planning tools (NAPIWRM, RAPIWRM, NWP). - Willingness of partners such as the World Bank to use multi-phase programmatic approaches for financing projects in the water sector. - Existence of project monitoring and evaluation mechanisms, ensuring a certain degree of accountability. - Existence of transboundary basin commissions - Initiatives for monitoring water quality and quantity exist, although they are insufficient. - Cameroon's participation in monitoring water-related SDGs (6.5.1, 6.5.2, 6.5.3) (Cameroon's scores have, since 2017, evolved from 34 to 49, which shows progress). - Validation of a water resource security project (the SEWASH project which will be financed by the World Bank aims to operationalize the National Agency of the Niger Basin (NANB)). - Emergency response standards established by MINWRE (WRMD) for NGOs.	- Lack of concrete and integrated IWRM projects on the ground. - Insufficient monitoring and evaluation (data on water resources are limited). - Weak application of existing instruments (plans and strategies are often poorly implemented). - Lack of operational agencies for the management of the Odza and Nkie watersheds. - Lack of operational tools for integrated management at the local level, which hinders the application of IWRM strategies. - Non-sectorized performance indicators (the evaluation of projects is global, without distinction by district). - Project implementation process not always respected (top-down approach and lack of needs analysis). - Drinking water sector only social (lack of empowerment of the sector). - Need to improve the performance of development missions for a more assertive role. - Lack of a water resource observation system for monitoring hydrometric systems. - Performance indicators are not always sectorized, which complicates the evaluation of project impacts. - Lack of specific and systematic monitoring and evaluation mechanisms to measure the effectiveness of IWRM projects.

	- Use of experience (successful projects are duplicated). - Strategic monitoring (to direct efforts towards high-impact projects). - Cameroon is integrated into the EMCCA water program. - Management and capacity building tools such as the GWP IWRM toolbox, which are available to stakeholders. - Existence of a national surface water monitoring system at IGMR (CRWCC). - Cross-border data sharing (existing agreements and protocols).	- Reliance on unofficial documents such as NAPIWRM, which complicates the assessment of progress made. - Incomplete water information system, it focuses on drinking water and sanitation but should integrate all water uses. - Incomplete coverage of the water resource monitoring system (it does not cover the entire national territory).
	Opportunities - Establishment of a global water information system for better management of all water resources and decision-making. - Operationalization of IWRM by basin: Provided for in the new water law, it could strengthen water governance and the participation of local stakeholders. - Establishment of clear coordination mechanisms for better concerted water management. - Opportunity to use climate data to inform water management decisions. - Update of the roadmap to identify priority actions and implement them. - Extension of the water resource monitoring system - Strengthening data sharing with all stakeholders.	**Threats** - Lack of reliable data and information for decision-making. - Resistance to change and difficulties in adopting new approaches - Low autonomy of decentralized local authorities: The lack of means limits their capacity for action. - Climate change which makes water resource management more difficult - Conflicts of use between different sectors (agriculture, urban planning, etc.) which could compromise integrated management. - Water challenges are increasingly complex. - Poor valuation of resources (the abundance of certain resources is not always valued). - Disruption of water resources (water dynamics and distribution are disrupted by climate change).

IWRM: Integrated Water Resources Management
WRMD: Water Resource Mobilization Directorate
NWP: National Water Policy
IGMR: Institute of Geological and Mining Research
GWP: Global Water Partnership
MINWRE: Ministry of Energy and Water Resources
CRWCC: Center for Research on Water and Climate Change
EMCCA: Economic and Monetary Community of Central Africa
NANB: National Agency of Niger Basin
NAPIWRM: National Action Plan for Integrated Water Resources Management

Table 11 presents an instrumental framework for water resource management. The SWOT analysis here highlights many weaknesses that can however be corrected by relying on the strengths of the management system. It is nevertheless noted that many actions, although they are not coordinated and developed continuously, are implemented for resource management. These weaknesses may be due to the vertical nature of the initiatives developed without a prior assessment of technical and environmental needs but also to the non-inclusive aspect of the initiatives (which are more centralized). Xueping et al., (2017) demonstrated in his SWOT analysis that accelerated urbanization was a favorable asset for development in Shandong province in China, because it improves agricultural production, improves water security in urban areas, water use efficiency, increases Gross Domestic Product (GDP) per capita and national income. This may be due to the fact that urbanization perceived as a human resource is perhaps better trained and effectively exploited to meet the challenges of the water sector in this area. Compared to the areas of Odza and Nkie, this urbanization constitutes a threat to the accessibility of water resources in terms of quality but also quantity because in these urban peripheries where water resources are poorly maintained, we increasingly observe an accentuated eutrophication of these areas and an occupation of land for the benefit of infrastructure or agricultural construction activities. The local population, not being better equipped with water resources for well-being and development, are less concerned about the future of this resource, which they expose to all types of pollution. Many plots of land in these areas have also been subject to occupation bans by the district municipalities on which they depend (as illustrated in the figure 4).

Figure 4: Municipal sign prohibiting the filling of land in the urban periphery of Odza

Collado et al (2023) identified in their SWOT analysis conducted in 04 localities of the Philippines (Puerto Princesa, Roxas, Taytay, El Nido) the separation of water resources management and water service provision in the implementation of IWRM; the implementation of sustainable and efficient water consumption; the availability of data and effective sharing of information; the formulation of adaptive plans for the protection and conservation of water resources; stable management instruments for pollution control; recognition and preparedness for natural disasters, as well as monitoring of water availability as major assets in these localities. Furthermore, the absence of aquifer and groundwater management plans and institutions; the weakness of basin management plans and the absence of basin institutions; the lack of data and information system; the weakness of pollution control; as well as the absence of national monitoring of viable water sources are some of the weaknesses mentioned. The presence of large watersheds and numerous river basins; the adoption and implementation of a national climate change plan; the presence of water resources studies; watershed profiling and planning; the estimation of an effective land and water use plan; the inclusion of municipal watersheds in the provincial priority; and the establishment of a river and rainfall monitoring station are some of the opportunities to be exploited to address the threats related to increasing population pressure; industrialization; increasing negative impacts of climate change; salinity of water supply; increasing water resource stressors and their limited availability; gold mining and its negative impact on water resources; uncontrolled rate of land conversion and reduction in forest cover; limited availability of alternative water resources other than surface water.

4.1.4. Financing

Financing IWRM in the city of Yaoundé is a complex sector, dominated by international donors. The legal framework governing local government borrowing in Cameroon is mainly established by Law No. 2004/17 on the orientation of decentralization, and Law No. 2004/18 on rules applicable to municipalities provide the basic legal framework for local governance, including financial management and borrowing. These laws give local governments the power to collect taxes that can be used as collateral for loans. According to Law No. 2019/019, local governments can collect taxes and levies that can be used to secure loans. These taxes must be

created through the legislative process, and they must effectively manage the revenues to repay these funds.

In addition, the Mutual Aid Fund of Municipalities (MAFM) plays a key role in this framework by authorizing loans for revenue and capital expenditure, particularly for projects with social value such as schools and health facilities. MAFM is financed by local authorities, which pay 20% of their local property taxes to FEICOM to finance municipally lead regional development at the national level. Local authorities must therefore comply with specific criteria set out in these laws when applying for loans, ensuring that borrowing is consistent with national development strategies and fiscal sustainability (https://camepi.org/monetary-and-fiscal-policy/assessing-the-financing-mechanisms-for-local-governments-in-cameroon/).

To strengthen the borrowing capacity of local governments, Cameroon has established government guarantee mechanisms to mitigate the risks associated with loans. The Government Guarantee Facility was created in the 2024 Finance Law, which allows governments to guarantee loans they take from public institutions and private companies. This facility covers 30% of the loan amount for large companies and 70% for SMEs, thereby reducing their risk premium on guaranteed loans. The government is doing this to ensure local businesses have access to financing on more favorable terms and foster an environment in which infrastructure projects can be adequately and decentrally financed, without the central government itself providing loans. Not only does this mechanism support infrastructure development projects, but it also encourages economic growth by allowing local governments to invest in essential projects without exceeding their financial capacity.

Table 12: SWOT analysis of IWRM Financing in Yaoundé

Financing	**Strengths** - Commitment of the World Bank to invest massively in the water sector in Cameroon. - Support of the GWP for the implementation of IWRM. - Support of the MINWRE which finances the activities of the GWP - Existence of taxes and royalties on water constitute a source of financing of the activities of the government in the water resource sector. - Existence of non-tax revenue from collection fees, sanitation taxes and water rights. - The existence of a special allocation accounts for the implementation of WASH and DWS projects. - Granting funding by some international donors such as the IMF for flood response projects. - The possibility of grants and technical support to strengthen the capacities of the actors involved.	**Weaknesses** - Low budgeting for IWRM (it is not sufficiently integrated into public budgets). - Dependence on external financing, without guarantee of continuity - insufficient or lack of data on water investment and investment frameworks - Insufficient funding (the needs are significant and current funding is insufficient). - Lacks an integrated climate resilient national water investment plan and financing strategy - Low consumption of investment credits in the water sector. - No gender-based assessment of budgets, few incorporations of gender sensitivity in budgetary processes and promotion of gender equality - IWRM is not always considered a priority by the government, which can limit investments and concrete actions. - Need to facilitate access to climate funds to finance IWRM projects. - Funds not allocated to basin authorities (because they do not exist). - Absence of studies on the allocation of revenues collected by basin for the projects carried out. - Water rights used for the electricity sector development fund instead of IWRM.

		- Donor conditionalities (their interests are not always aligned with national priorities). -
	Opportunities - Establishment by the World Bank of an informal donor platform to mobilize additional financing to support the government in its development vision. - Use of economic and financial instruments to encourage better water management. - Exploration of innovative financing mechanisms - The World Bank plans significant investments in the water sector in Cameroon, which could boost IWRM - Possibility of attracting additional financing through pilot projects and successful initiatives. - Expanding partnerships with private actors and NGOs to diversify sources of financing. - Increased royalty base: Mining companies could contribute more to IWRM financing. - Establishment of basin agencies for better management of funds and more efficient allocation.	**Threats** - Difficulty of the government to ensure transparency and accountability in the management of funds allocated to water sector projects - Risk of misappropriation of funds and corruption - Fluctuation of external funding depending on donor priorities. - Lack of financial resources (MINWRE does not have the means to regularly monitor the projects it implements). - Economic instability (may reduce resources allocated to IWRM). - Pressure on public budgets could lead to reductions in investments in the water sector.

	- Conducting studies on revenue allocation to optimize the use of funds. - Broadening the tax base to increase revenue dedicated to IWRM. - Increased involvement of the private sector to finance water-related projects. -	- Political instability or changes in government priorities that may affect IWRM initiatives. -

MINWRE: *Ministry of Water Resources and Energy*
GWP: *Global Water Partnership*
IMF: *International Monetary Fund*
WASH: *Water Sanitation and Hygiene*
IWRM: *Integrated Water Resources Management*
DWS: *Drinking Water Supply*

The financing component of IWRM presents many weaknesses and threats. This can be explained by the fact that the prioritization of development sectors by the government is galloping, which does not facilitate the establishment of a fixed budget for a well-defined sector. The proof is that some taxes from the water sector are used for the development of the hydroelectricity sector, yet many major challenges in the water sector are still not resolved. In addition, the financing of the water sector in the commune of Yaoundé IV on which depend Odza and Nkie watersheds is confronted with the lack of financial autonomy of the Decentralized Territorial Communities (DTCs) which, despite the decentralization process which gives them a certain autonomy of management, provisions are not fully made to allow the DTCs to explore other possibilities for financing development projects.

Njikam (2021), in his SWOT analysis of the implementation of IWRM in Central African countries, highlighted the insufficient financing of the water sector and the top-down policy of the water sector as the main weaknesses. Belay et al (2013), highlighted that corruption and the

disappearance of aid money into the pockets of individuals are threats that can ruin all the planning of the Nile Basin Initiative. Furthermore, Schweinberger et al (2023) as part of the diagnosis of the drinking water supply system of the municipality of Quatro Pontes in Brazil, noted in his SWOT analysis weaknesses of the system such as the few financial resources allocated to the sector and the outdated pricing policy, yet the city has sufficient financial resources that could be exploited to create self-sufficiency.

Collado et al (2023) highlighted in her analysis many strengths available to the study localities, namely sufficient financial capacity to invest in the allocation of water resources at the national level, the adequacy of the national investment budget. These strengths face weaknesses such as insufficient budget allocations at the national and subnational levels. The financing problem is therefore one of the main obstacles that hinders the progress of IWRM in many countries such as Cameroon. The last workshop to assess the degree of implementation of IWRM shows that this component remains the weak link in the implementation of IWRM in Cameroon in general, due to the lack of interest of donors to invest in it and the low level of national budgets reserved for the cause. At the subnational level, this situation seems even more exacerbated, yet the State of Cameroon is up to date with its contributions and commitments in all the Basin Organizations of which it is a member. If this rate of progress continues, the financing section should reach a score of 50/100 in 2030. In conclusion, IWRM in the Odza and Nkie watersheds of the Yaoundé 4 district commune is at a turning point. The new water law, if adopted, could create a more favorable environment for its implementation. However, it is essential to strengthen coordination between institutions, improve the participation of local stakeholders, develop more efficient management tools and mobilize sufficient financing to address existing challenges.

4.2. Water resources mapping

4.2.1. Delimitation of the study area

The Nkie and Odza watersheds are sub-basins of the Mfoundi and are bounded on the left by the main Mfoundi and on the right by the Anga'a. These are sub-watersheds of order (3) and order (2) respectively, according to the Strahler classification.

4.2.2. Watersheds characterization

The physical characteristics of the Odza and Nkie watersheds are recorded in the table below.

Table 13: Characteristics of the watersheds

Caractéristics	Odza watershed	Nkie watershed
Morphometric characteristics		
Area (km²)	4,80	5,69
Perimeter (km)	12,97	17,39
Length of the equivalent rectangle (km)	5,63	7,98
Width of the equivalent rectangle (km)	0,85	0,71

Gravelius compactness index (Kg)	1,66	2,04
Horton compactness index (Kh)	0,29	0,27
Topographical features		
Overall slope index (m/km)	0,0063	5,57
Average slope (m/km)	19,73	20,70
Specific elevation (m)	30,41	31,72
Relief class (ORSTOM)	Low relief (R2)	Moderate relief (R4)
Hydrographic characteristics		
Order of the hydrographic network (strahler)	2	3
Drainage density (km/km^2)	2,14	2,28
Length of the longest thalweg (km)	4,54	5,98
Length of the main course (km)	4,055	4,59
Concentration time (Kirpich)	57,14 minutes	73,41 minutes

The results from the above table show that, the Nkie catchment, in terms of area is slightly larger than that of Odza. This suggests that the Nkie catchment may collect a slightly larger volume of water during rainfall. Similarly, the lengths and widths of the equivalent rectangles show that both catchments are relatively elongated, but Nkie is more elongated than Odza. The Gravelius compactness index (Kg) is higher for Nkie than Odza. A higher Kg indicates a more elongated and irregular shape, which may influence the concentration time and response of the catchment to rainfall. The elongated shape of Nkie could therefore result in slower flow and a more spread out hydrological response (this results in lower peak flood discharges due to longer delivery times to the outlet, and therefore a longer concentration time, meaning that runoff will take longer to reach the outlet) than the Odza catchment which, on the other hand, is likely to provide faster and more concentrated hydrological responses to rainfall. The Horton compactness index (Kh) is very close for both catchments, indicating a similar elongated shape. Furthermore, Odza is classified as low relief (R2), while Nkie is classified as moderate relief (R4). This means that Nkie has larger elevation variations and steeper slopes. The steeper slopes in the Nkie basin can accelerate runoff and increase the risk of flash floods. Whereas the specific elevation difference near the two basins indicates that they have close elevation variations with different distribution of elevation differences. Nkie has a higher hydrographic network order than Odza, indicating a more developed drainage network and a denser stream network in the Nkie basin. Since Nkie has a slightly higher drainage density, this basin could result in slightly faster runoff due to a denser stream network. The longer concentration time of Nkie, combined with a steeper relief, can result in more intense but more spread-out floods. However, the Odza watershed, with its lower drainage density, could have a slightly slower runoff compared to

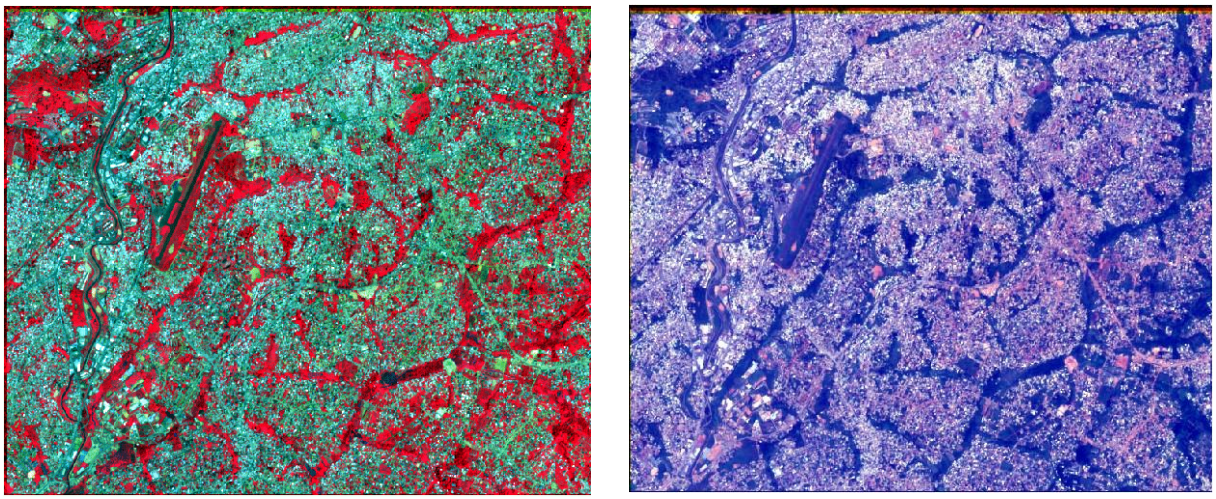
Nkie, despite its shorter concentration time. It should be noted that there are nuances in the assessment of the surface area of the Odza and Nkie watersheds respectively. Concerning the Odza watershed, Ngoumdoum (2013) obtained in his study an area of 6 km², according to SCET (2017) the Odza watershed would have an area of 4.9 km², Nyembe et al (2021) obtained rather an area of 6 km² with a perimeter of 12.5 km for the Odza watershed. Ngouh et al, (2020) in their study on the Nkie watershed obtained an area and perimeter of 5.17 km² and 14.66 km. The differences obtained can be explained by the scale or spatial resolution of the topographic maps used and the correct location of the outlet. Indeed, according to Moussa (1993), the value of the perimeter increases when the spatial resolution is finer.

Furthermore, our study area is marked by twenty altitude classes ranging from 675 to 770 m with an equidistance of 5 m. The hydrographic network presents lower altitudes ranging from 675m to 715 m. Classes between 680 and 695 are the most represented, which indicates the existence of vast plains extending over a large part of the basin (water flow line of the network). Tight curves can suggest convex slopes, while more spaced and straight curves can indicate concave slopes. This reduced spacing of contour lines along the network hydrographic indicates steep slopes. These areas are likely to be subject to erosion or flooding. The highest curves indicate the top of the watershed (north direction), while the lowest correspond to the lowest points which are generally located near the outlet (south direction). Low altitudes are more represented in the southern part of the study area, characterizing the outlet of the hydrographic network, while high altitudes are more present in the northern part of the study area, highlighting the level of extension of the hydrographic network. Ngouh et al (2020) mentioned in their work on the hydrodynamic characterization of the Nkie watershed that this basin has a relief characterized by the alternation of small hills with irregular slopes and valleys drained by the main Nkye River and its tributaries. The arrangement of the relief in this area reveals a subdivision of the site into several geomorphological units with maximum altitudes of 785 m in the northern part and minimum of 660 m in the southern part. In addition, the study of the topography of the Odza watershed by Nyembe et al (2021) shows that the Odza watershed is in the southeastern part of the city of Yaoundé and is marked by a low-altitude relief with shallow valleys. The altitudes vary between 560 and 947 m. Next to the large Odza valley which goes from Ekié to the outlet on the Mfoundi. The results of our work show us that the altitudes in the Odza watershed vary between 680 and 760 m, which is slightly different from the results obtained by Nyembe et al (2021). This difference may be due to the digital terrain model used to bring out the contour lines.

Ngouh et al (2020), in his study on the Nkie watershed highlighted the fact that the Nkié watershed has a relief characterized by the alternation of small hills with irregular slopes and valleys drained by the main Nkié river and its tributaries. The arrangement of the relief reveals a subdivision of the site into several geomorphological units with maximum altitudes of 785 m in the northern part and minimum of 660 m in the southern part. The results obtained in this work show a variation in altitudes of the Nkie watershed between 675 and 770 m. A slight difference is noted in these results. The work of Tsapy (2019) on the detailed technical study relating to the construction and asphalting of the "tsinga village – carrefour petit marche fougerole" road estimates the drainage density of the Mfoulou River at 1.9 km/km² for an area of 4.97 km², compared to the Odza watershed whose value is 2.14 km/km² for 4.80 km^2, and to the Nkie basin whose value is 2.28 km/km² for an area of 5.69 km². These observed differences can be justified by the different degree of branching of the three watersheds (the Odza watershed has a less branched network compared to the other two basins).

4.2.3. Identification of watercourses in the study area

The processing of sentinel-2 images for the identification of water surfaces reveals green areas with a humid character (wetlands) for which open water surfaces are not clearly perceptible due to a proliferation of plant species.



(a) **(b)**

Figure 5: (a) False color image (RGB 432) from Sentinel-2 (R10m); **(b)** True color image (RGB 321) from Sentinel-2 (R10m)

The colored composition of infrared color or false colors consists of making the vegetation appear in red. While the composition of colors into natural colors or true colors results from the display of the bands of the visible spectrum: the blue band as blue, the green band as green and the red band as red, as perceptible to the normal eye.

The analysis of the spectral image (RGB432) of sentinel-2 of 01/12/2024 highlights the following elements:

- A strong urbanization inside the study zone: The presence of numerous clear and regular areas on the image suggests a high density of buildings and infrastructures.
- A fragmented vegetation: The green areas appear fragmented, which could indicate significant urbanization and pressure on natural spaces.
- A strong pressure is exerted on bare land which seems practically non-existent.

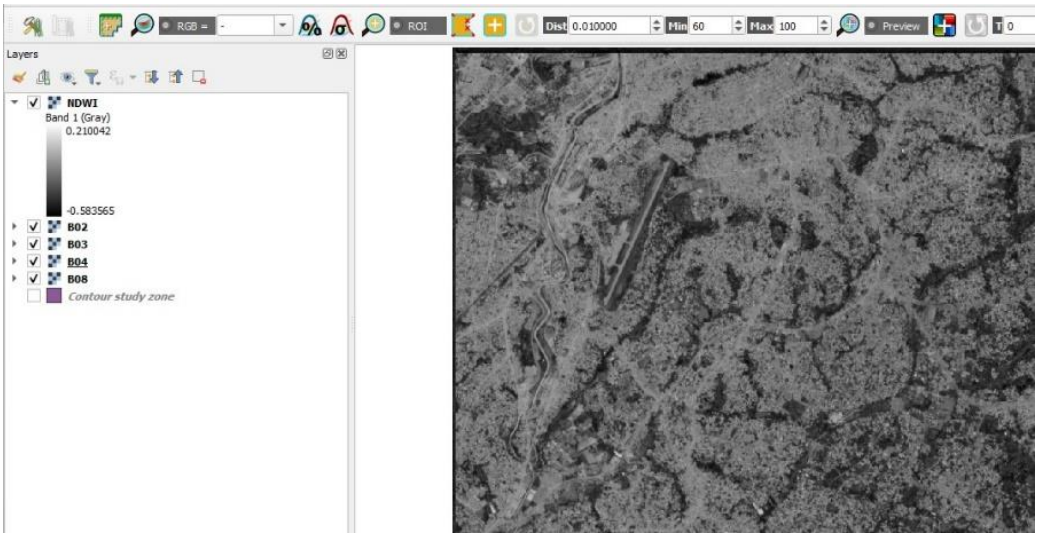


Figure 6: NDWI (Normalized Difference Water Index)

The NDWI is an index that identifies and quantifies the presence of water in an area using satellite image bands. It is particularly useful for mapping wetlands, water bodies and aquatic vegetation. The calculation of the NDWI for the study area gave us a maximum value of 0.21, likely to indicate the presence of high humidity areas. And a minimum value of -0.58 reflecting states of drought (non-aqueous surfaces). This result allows us to subdivide the result obtained into 03 classes:

- High values of light gray (high NDWI): Corresponding to areas with a high presence of water (wetlands or aquatic vegetation).
- Low values of dark gray (low NDWI): Indicate areas with little or no water (urbanized areas, bare soils, dense vegetation).
- Intermediate values of gray: Corresponding to transition areas (areas with mixed vegetation).

In view of the previous spectral analysis, we can therefore conclude that these 03 classes correspond respectively to wetlands (dominated by aquatic or hydrophilic vegetation), a highly urbanized area (with some bare spaces) and areas of mixed vegetation.

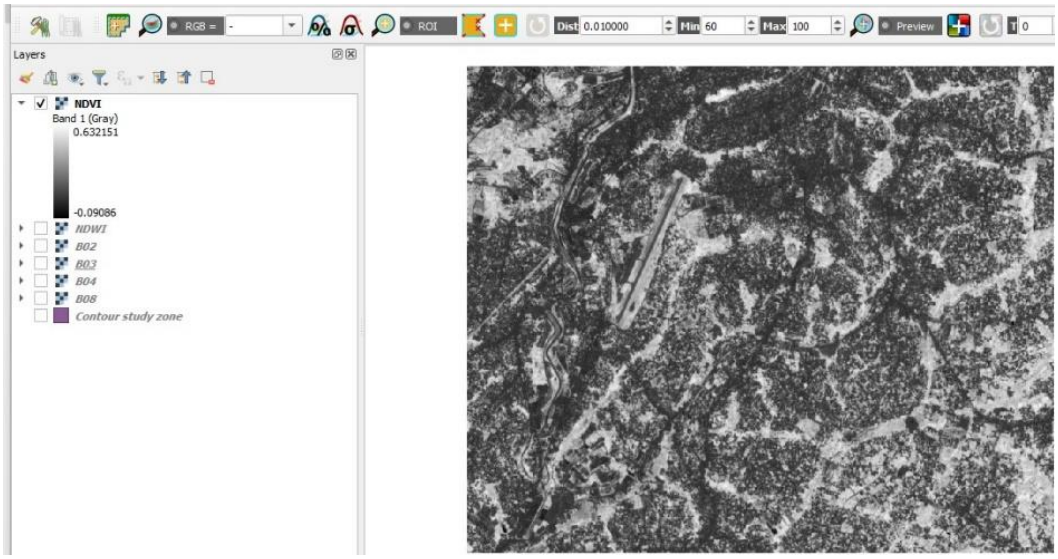


Figure 7: NDVI (Normalized Difference Vegetation Index)

To confirm the results obtained during the calculation of the NDWI, we proceeded with the calculation of the NDVI. The results obtained are in the range (-0.09 to 0.63) and allow a subdivision into 03 classes, ranging from the light zone to the dark zone:

- Light zones (high NDVI) characterize dense and healthy vegetation (forests, parks, well-irrigated agricultural areas).
- Gray zones (intermediate NDVI): represent areas of sparser vegetation (crops at different stages of growth).
- Dark zones (low NDVI): There is low or no plant activity in these areas (built-up areas, roads, bare soils).

Bahadur (2018) mentioned the fact that The Normalized Difference Water Index (NDWI) is sensitive to buildups and results in overestimation of water masses. Clear water has higher reflectivity in the blue part of the visible spectrum, so the water appears blue. Turbid water has higher reflectivity in the visible spectrum. There is no reflection in the near infrared (NIR) and beyond NDWI.

Zhai et al (2015) showed that the water data range of different sensors has significant overlap compared with other features. For OLI, the water data range overlaps with shadow, especially the water data range in MNDWI; it is slightly confused with shadow compared with other indices. Except for MNDWI, the overlap between water, built-up land, and shadow in Thematic Mapper (TM) imagery data makes it difficult to distinguish water from other features.

4.2.4. Land use classification

The supervised classification of an area makes it possible to associate each pixel of the image with a specific thematic class. The supervised classification of the study zone in macro class (MC ID) makes it possible to distinguish 05 major classes of occupations:

- **Wetlands**: Characterized by a strong reflection in the near infrared bands.
- **Ground:** Corresponding largely to bare spaces, devoid of any occupation. In certain cases, it may be land that has undergone a backfilling phenomenon, but which is not yet in use.
- **Roads**: The materials used to build roads have distinct spectral properties, making it possible to differentiate them from other classes.
- **Built-up areas:** These are urbanized areas, including buildings, infrastructure and paved areas (slabs).
- **Unclassified areas:** these are pixels for which the classification algorithm could not assign a class with certainty. This may be due to the complexity of the scene.

However, due to the non-hierarchy of buildings (according to the color code standards), especially in developing countries, it happens that two different classes have the same reflectance color (such is the case of some houses painted blue which emit the same reflectance color as water). This can lead to errors in the classification. To do this, a reclassification is carried out in order to assess the accuracy of the classification carried out.

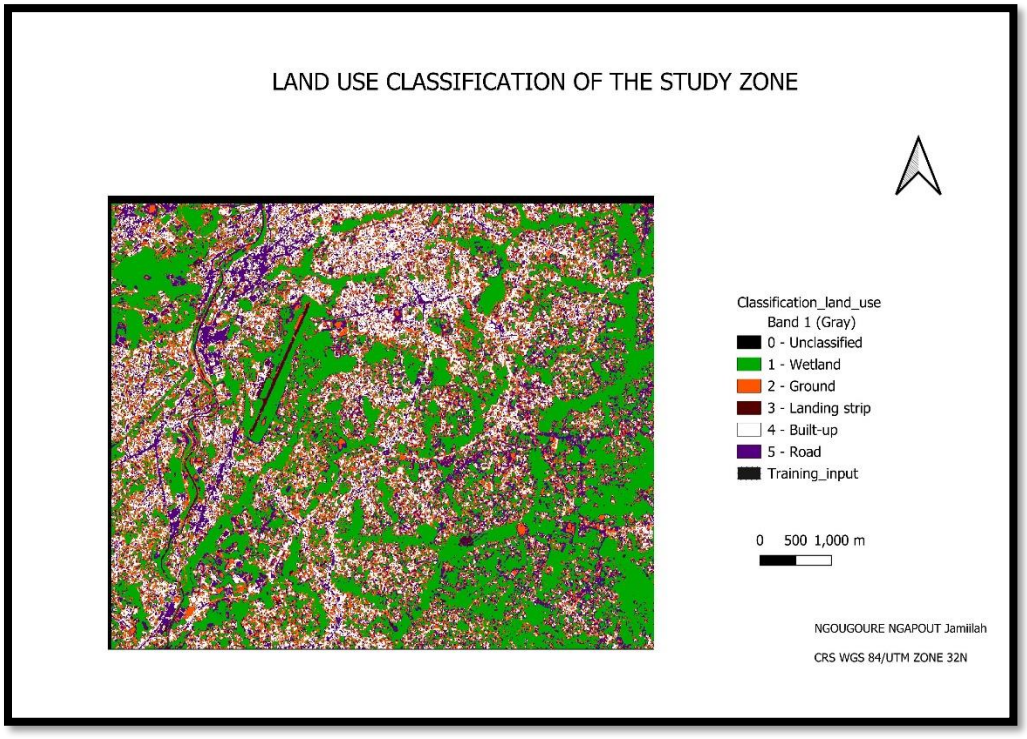


Figure 8: Land use classification of Yaoundé IV council

One of the most important final steps at the classification process is accuracy assessment. The aim of accuracy assessment is to quantitatively assess how effectively the pixels were sampled into the correct land cover classes. The accuracy assessment of the land use classification is performed by comparing the ROI's and the classification. It generally compares the producer's accuracy with the user accuracy.

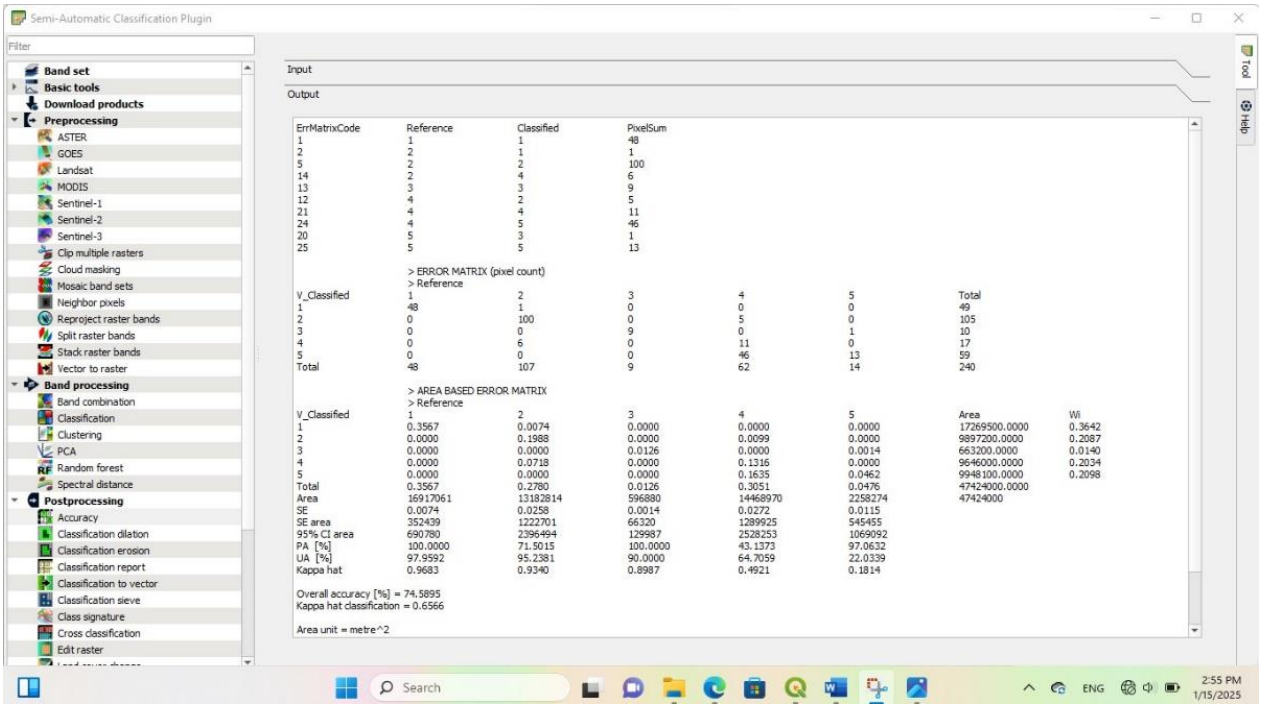


Figure 9: Land use assessment accuracy

The results show that the overall accuracy is 74.59%. This shows how accurate the classification analysis is compared to the real data. This means that the post-processed data should be correct or close to the real values in 74.59% of the cases, with a potential error margin of 25.05%. Although spatial data analysis cannot reveal 100% of the reality of the study area, it is important to correct the observed errors as much as possible to get as close to reality as possible.

In terms of land use percentage, the study area can be said to be highly urbanized, with increasing pressure on green spaces. The table below shows the distribution of land use in the study area.

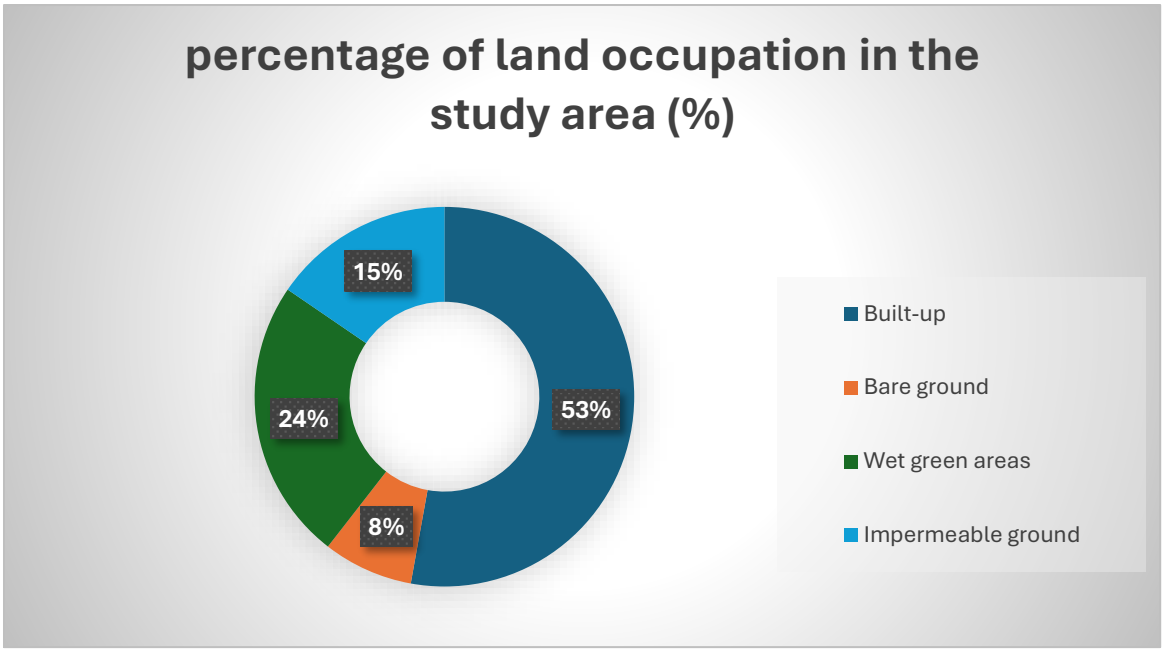


Figure 10 : percentage of land occupation in the study area

Total area of the study area: 10.41 km²

Total perimeter of the study area: 16.66 km

This urbanization contributes to significantly altering the natural water cycle. Furthermore, it contributes to increased runoff in urban areas characterized by a high proportion of impervious surfaces. These surfaces prevent rainwater from infiltrating into the soil, leading to increased surface runoff, resulting in higher peak flows in rivers and streams, thus contributing to an increased risk of flooding. Soil sealing due to urbanization reduces the amount of water that can infiltrate into the soil, thus decreasing groundwater recharge and affecting its availability for various uses. This urbanization is a major cause of deforestation, resulting in the loss of vegetation, which plays a crucial role in quantifying evapotranspiration. Indeed, the loss of vegetation cover reduces evapotranspiration rates, thus affecting the transfer of moisture to the atmosphere. Which is likely to alter local climate patterns and contribute to the urban heat island effect.

4.2.5. Wetland mapping

The wetland mapping allowed us to identify the different water points that cover the Ekie and Odza districts of the Yaoundé IV commune. This highlights the following remarks:

- Administrative delimitation is not a function of the boundary of the basins. Indeed, some watersheds are shared between two local authorities (case of certain wetlands of the Odza district which depend also on the Anga'a watershed). This suggests intercommunal management of the basins.

- We also observe an anarchic urban occupation of green areas which causes significant pollution of water resources.

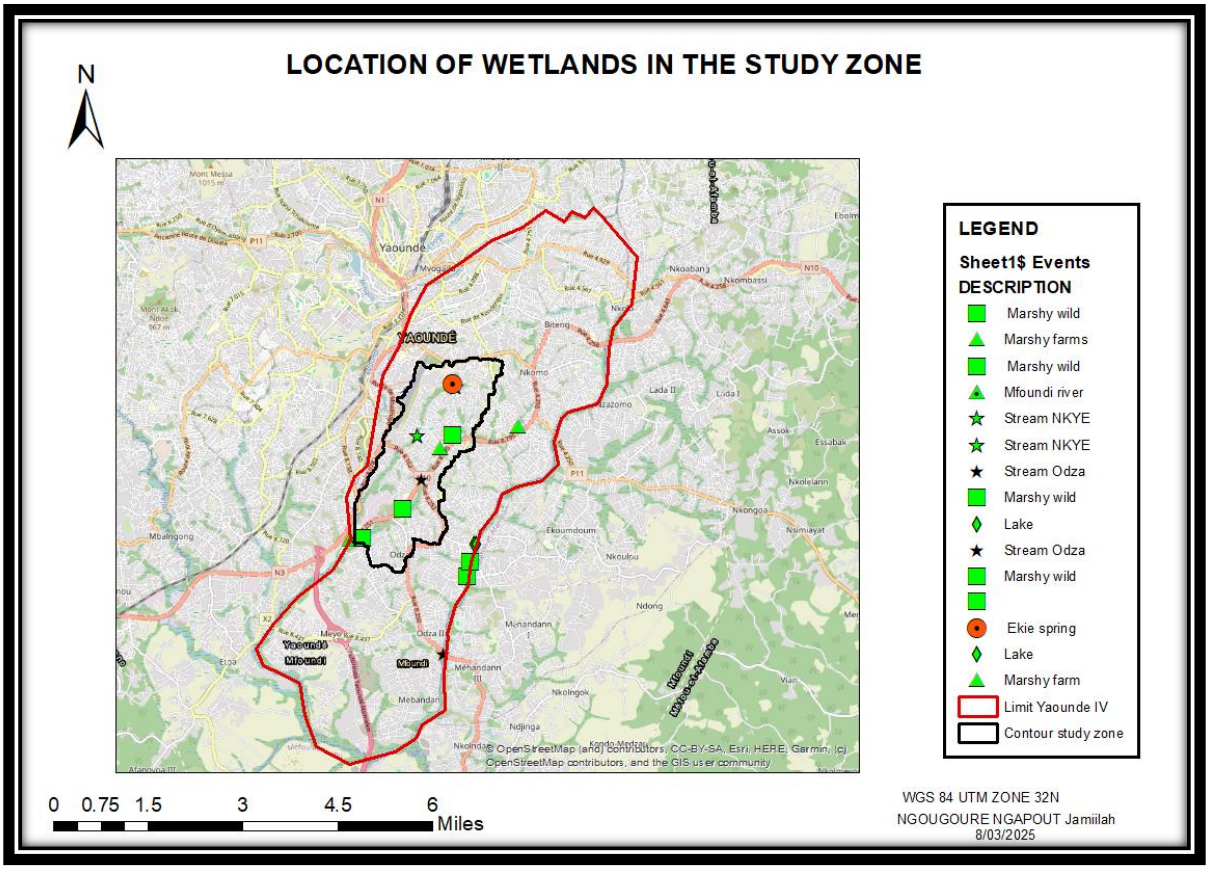


Figure 11: Spatial distribution of wetlands in the watersheds

Globally, we identify six class or categories of wetlands: **marshy wild, marshy farms, river, stream, lake, spring.** We also note the presence of numerous low-lying areas (outlet) which, in some areas, have been filled in by the local population for occupation purposes, and in others have completely dried up due to eutrophication.

4.2.6. Water uses and pollution implications

The table below presents the different uses of water in the study area as well as the pollution associated with them.

Table 14: Water resources, water uses, pollution and implications

Study zone	Uses and pollution implications	Observations
Odza watershed	- Car washes, household waste disposal sites and catering activities are present on the edges of the watershed. - These activities lead to water pollution by plastic materials (plastic bottles, plastic packaging), organic waste (food residues, etc.) and chemical materials (phosphates, surfactants, etc.) - Consequences: Advanced eutrophication of the watercourse and disruption of the aquatic ecosystem (death of species by asphyxiation due to lack of oxygen in the water).	Unlike the Nkie watershed, urbanization and wetland pollution are more prevalent. In these areas, waterways are, in most cases, converted into household waste dumps. Due to the inactivity of hygiene and sanitation services, this waste is incinerated by the local population to prevent it from obstructing the road. Income-generating activities such as laundromats, restaurants, metal welding, and vehicle repair shops are also found in this area.
Nkie watershed	- Car washes, water for household consumption, household waste dumps, catering and drinking activities are present on the edges of the watershed. - These activities cause water pollution by plastic materials (plastic bottles, plastic packaging), organic waste (food residues, etc.) and chemical materials (phosphates, nitrates, etc.) leading to advanced eutrophication of the watercourse and disruption of the aquatic ecosystem (death of species by asphyxiation due to lack of oxygen in the water).	Most waterways are covered with vegetation, with a growth in income-generating activities in the surrounding areas (mainly laundromats and small businesses specializing in laundry). Most of the wetlands identified in this area are located near households. Drinking water supply points are somewhat poorly maintained and developed, with a proliferation of plastic materials in the surrounding area.

Ngouh et al, (2020) during the analyses of the water quality of the Nkie watershed obtained a very pronounced presence of nitrates in the spring waters of the Nkié watershed, this would result from their study of anthropogenic activities, agricultural activities and septic tank effluents. They can also come from microbial degradation (mineralization then nitrification) of organic matter and the oxidation of atmospheric nitrogen. In the absence of evaporite rocks in the basin, chloride ions could have several origins: domestic (use of sodium hypochlorite), atmospheric linked to precipitation and by the presence of clay cover. The results of their physicochemical analysis are consistent with the different economic activities that have been identified around the watercourses during the present study.

Figure 12: State of degradation of a drinking water supply source in the Nkie watershed (left); state of degradation of a watercourse in the Odza watershed at the place called “Tropicana crossroads” (right).

The water source in the Ekié district of the city of Yaoundé above, constitutes one of the main points of supply of drinking water to the population of this area. This source is in an advanced state of degradation and raises serious health and environmental concerns. The source is submerged by plastic waste degrading the aesthetics of the place and contaminating the water significantly. The absence of protective works or pipelines around the source indicates a lack of maintenance and investment for its preservation. The same is true of the Carrefour Tropicana watercourse in Yaoundé which is littered with plastic and food waste, due to the presence of catering and laundry activities in the surrounding area. This pollution is not only unsightly but also a major source of bacteriological contamination. The color of the water, cloudy and tinted by organic waste, indicates significant pollution and a lack of oxygenation. Organic pollution causes a deterioration in water quality, making it unfit for any domestic use.

The work of Nyembe et al (2021) in the Odza watershed shows that nearly 45% of the households they surveyed are located in the lowlands and use toilets that evacuate wastewater and excreta directly into the waterways. This would justify the rapid urbanization observed in the study area and the gradual disappearance of wetlands in favor of unstructured habitats. They subsequently mentioned in their work that, in the Odza watershed, the waterways are very polluted because of suspended matter, water coloring and odors. The households surveyed who live near the waterways all attest that the waterways are extremely polluted.

(a) (b)

Figure 13: Lowlands of the Ekie area completely dried up (a); Poor disposal of solid wastes at the place called Odza broken bridge (b)

Most of the lowlands areas that we have identified have been transformed either into residential areas or sometimes used as agricultural areas, as they are considered very fertile by the inhabitants. The outlet located at the place called "broken bridge" in Odza was previously a watercourse in the Odza watershed which, due to backfilling activities, dried up. The area has been transformed by the local population into a dumping ground for all kinds of waste due to the lack of solid sanitation facilities in the area. Due to the virtual inactivity of the hygiene and sanitation officers of the municipality, the population has no choice but to resort to open-air incineration of this waste to prevent it from obstructing the public highway. This constitutes significant pollution from an environmental and health perspective. These dumps contribute to the pollution of the air, soil and groundwater. Open burning of waste releases toxic substances

into the atmosphere, while leachate (liquids from the decomposition of waste) contaminates soil and groundwater.

4.3. Hydrological balance in suburban watersheds of Odza and Nkie

Carrying out the hydrological balance of a study watershed consists of analyzing all the parameters involved in the hydrological balance equation as mentioned in the literature review. In our case, it involves analyzing the parameters of precipitation, evapotranspiration, infiltration and runoff over the entire study period (1971-2024) and observing the variation trends over the years.

4.3.1. Analysis of precipitation parameter

The analysis of precipitation over the period 1971-2024 shows a large variability from one year to another. There is no clear linear trend upward or downward over the entire period.

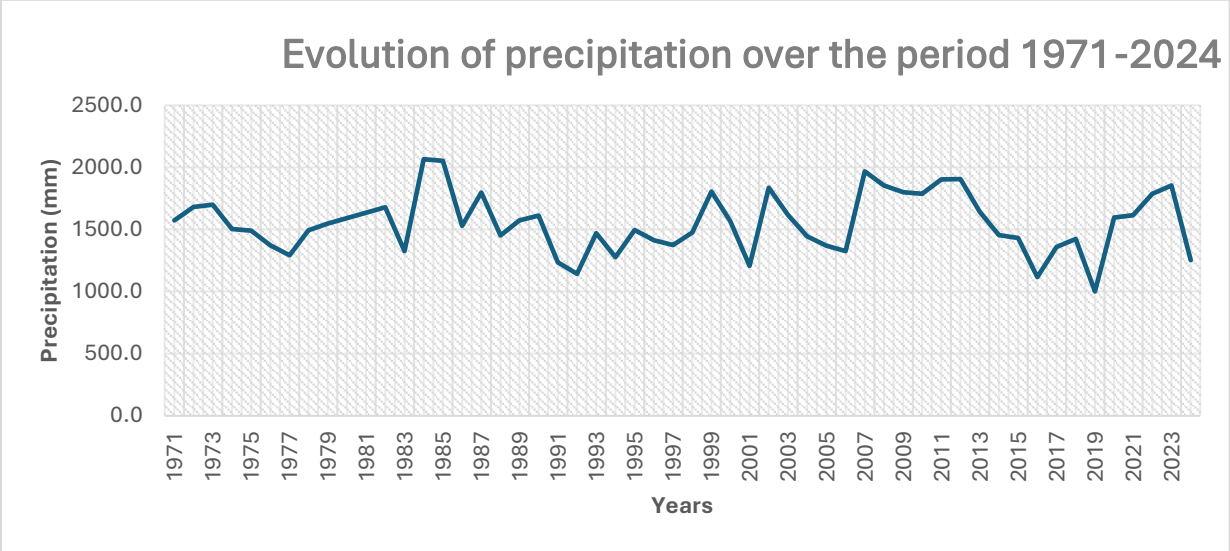


Figure 14: Annual rainfall from 1971 to 2024 in Yaoundé city

Annual precipitation appears to vary mainly between about 1200 mm and 2100 mm. Peaks in precipitation are observed in the 1980s, mid-2000s and early 2010s. Periods of lower precipitation are seen in the 1970s, early 1990s and late 2010s. January, February, November and December appear to be the driest months over the entire period. The 1980s are marked by a period of relatively high precipitation, with several peaks exceeding 2000 mm. The 1990s are a drier period, with annual precipitation often below 1500 mm. The 2000s and 2010s are marked by a further period of variability, with marked peaks and troughs. A downward trend is visible in the 2020s. The absence of a clear linear trend suggests that precipitation in this area has not experienced significant long-term change over the study period. However, this does not mean

that there have been no changes in precipitation distribution (changes in the frequency or intensity of extreme events). These observed variabilities could be related to climate change, which can lead to changes in precipitation patterns, which could have significant impacts on agriculture, water resources, flood risks and public health in Yaoundé. Yamani et al (2012), in their study on the methodology of water balance mapping from satellite data in the Brezina watershed in Algeria, observed that the annual liquid input in this watershed is low. This low input, a function of runoff water, is due to the low rainfall in the year considered.

4.3.2. Analysis of Evapotranspiration

The evolution of evapotranspiration over the period 1971-2024 shows relative stability over most of the period studied, with values oscillating around 1140 to 1500 mm.

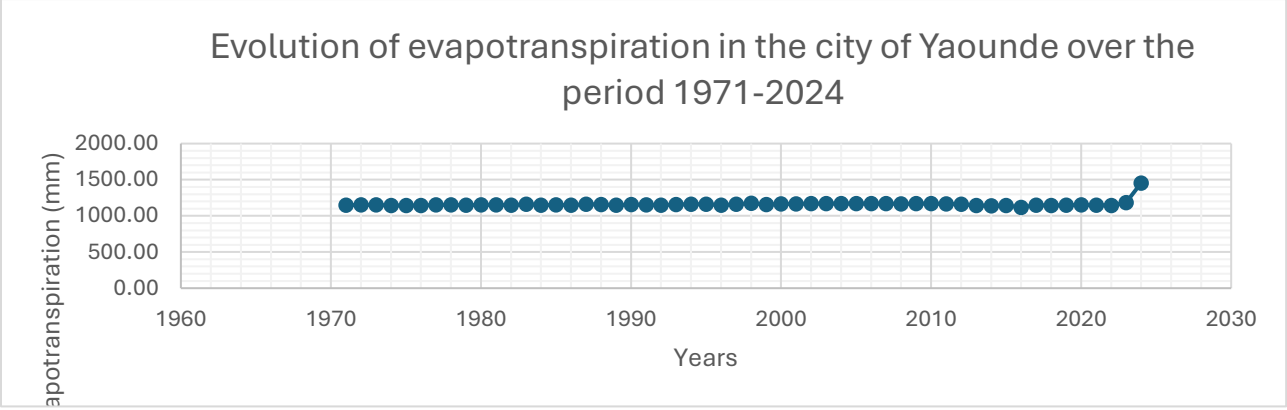


Figure 15: Annual evapotranspiration from 1971 to 2024 in Yaoundé city

Figure 16 above shows a relatively stable trend in evapotranspiration from 1971 to the early 2020s. The months of June, September, October and November appear to be the months with the lowest evapotranspiration (80 mm on average) over the entire period. From 2023 onwards, a clear increase in evapotranspiration is observed.

Most of the curve is a nearly horizontal line indicating stable evapotranspiration, the end of the curve shows a positive slope, indicating an increase in evapotranspiration. The stability of evapotranspiration for much of the period suggests that climatic and environmental conditions in Yaoundé have remained relatively constant during these years. The increase in evapotranspiration from 2023 onwards could be related to an increase in temperatures, a decrease in relative humidity, or an increase in solar radiation. These factors may be influenced by climate change. Urban expansion is also a significant factor in this area, which can alter local microclimates, leading to increased evapotranspiration, as can loss of forest cover, which can affect moisture regimes and increase evapotranspiration. Changes in agricultural practices,

irrigation, or other environmental factors could also contribute to this increase. Therefore, Yamani et al (2012), clearly indicated that evapotranspiration is the most important parameter of the water balance, certainly because it strongly influences the runoff and infiltration of water in a watershed. In the same vein, Gemitzi et al (2020) showed that, according to the annual estimates of the water balance that they carried out in their study, the average evapotranspiration in the regions studied represents approximately 54% of the precipitation during the period 2013-2018. This average annual evapotranspiration in the basins studied varied between 39.3 and 62.5% of the precipitation for the same period. In the context of this study, potential evapotranspiration represents on average 77% of the precipitation over the entire series, with a variation between 56% and 90%. For the Brezina watershed, Yamani et al (2020), in their study, observed that evapotranspiration is a function of vegetation cover on the one hand and of the geographical position in the site on the other hand. High evapotranspiration is observed in dense areas (high vegetation cover), it reaches 68 mm/year. This value decreases from the North to the South of the basin where the bare areas are located (South-West of the basin). In these areas, evapotranspiration does not exceed the value of 10 mm/year, due to the loss of vegetation cover. The value of evapotranspiration also varies according to the geographical position, it is remarkable in the North-West part of the Brezina basin and thus reaches the value of 40 mm/year. This value decreases in the South-Eastern areas, it only reaches 20 mm/year. An increase in evapotranspiration can lead to a decrease in available water resources, especially in times of drought. Agriculture can be affected by increased evapotranspiration, especially if it is not compensated by increased precipitation.

4.3.3. Evolution of infiltration

The evolution of infiltration over the period 1971-2024 shows a large variability of infiltration from one year to another. There is no clear linear trend upward or downward over the entire period.

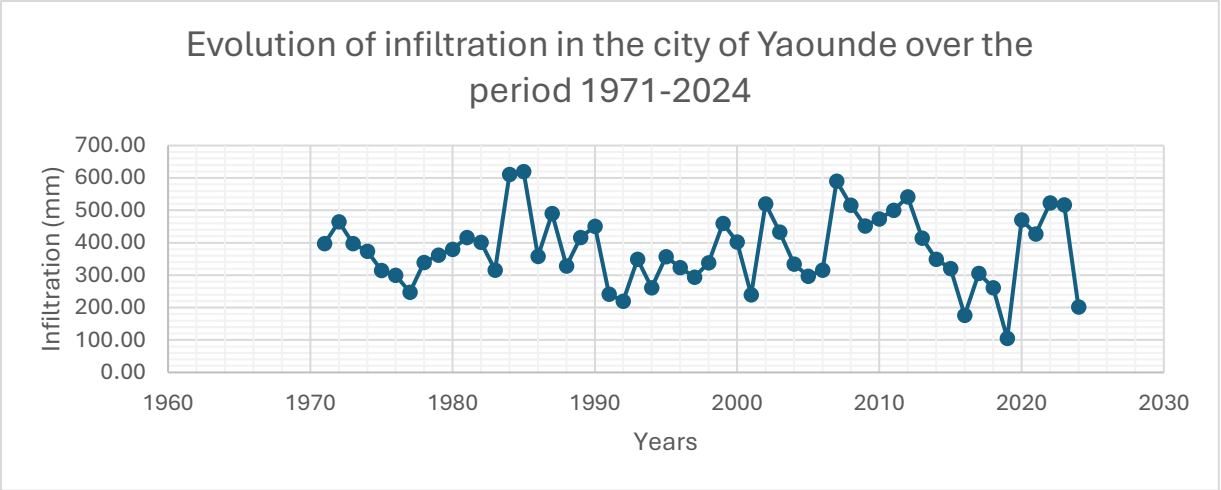


Figure 16: Annual infiltration in Yaoundé city from 1971 to 2024

Infiltration values appear to fluctuate mainly between about 200 mm and 625 mm. Peaks of infiltration are observed around 1971, early 1980s, late 1990s, early 2000s, late 2000s, 2010s and 2020s. Weaker periods of infiltration are visible in the early 1980s, around 1975, 1985, mid-1990s, mid-2000s, early 2020s and around 2022. The months of January, February and December record zero infiltration over the entire series, while the months of March, July and August record highly variable infiltration over the entire series. The years 1971 are marked by a period of variability, with peaks and troughs. In the 1980s, there is a high variability in infiltration with peaks of up to 600 mm. A period of recovery is observed in the 1990s, with a peak at the end of the decade. The 2000s and 2010s are periods of variability, with marked peaks and troughs. From 2020 onwards, a downward trend is visible. This variability may be due to various factors, such as variations in precipitation, land use changes and the effects of climate change. There appear to be cycles of periods of high infiltration followed by periods of low infiltration. These cycles may be related to natural climatic variations.

Although there are fluctuations, there is no clear upward or downward trend in infiltration over the entire period. This suggests that the variations are mainly cyclical or related to one-off events. Periods of high infiltration can lead to flooding risks, especially in poorly drained urban areas, while periods of low infiltration can lead to water supply problems, especially during dry seasons. Infiltration variability can have impacts on agriculture, vegetation and local ecosystems. Yamani et al (2012) reports that infiltrability is related to soil permeability. High infiltration characterizes most pixels in the Brezina watershed, up to 300 mm. This amount of water is considerable compared to the amount of water stored each year. This may be related to the soil type, which is likely to be fissured, and the presence of shallow caves. They also draw

attention to the fact that this infiltration phenomenon presents a major concern for the managers of the Brezina dam. Gemitzi et al (2020) estimated through their study that infiltration represented 24% of precipitation, ranging from 19.5% to 31.5% of precipitation, while runoff has an average annual precipitation of 22%, ranging from 17.9% to 29.1% of precipitation. In the context of this study, average infiltration represents approximately 23.97% of precipitation, with variations between 10% and 30% of precipitation. While, the runoff represents on average 0.03% of precipitation over the entire series, with variations between 0.01 and 0.15% of precipitation. Infiltration in Yaoundé is highly variable over time, with significant fluctuations. This variability can have significant implications for water management and urban planning. It is important to take these variations into account to mitigate flood risks and ensure a sustainable water supply.

4.3.4. Analysis of surface runoff

The analysis of the runoff curve in the study series presents runoff values oscillating between -400 mm and 300 mm. A strong variability is observed from one year to another, which suggests a sensitivity of runoff to changing climatic and environmental factors. The presence of negative values indicates a discharge of water reserves in the watersheds (reduction of stocks) due to insufficient inputs. The months of January, February and December record a total deficit over the entire series (virtually no water input into the basin to feed the watercourses), while July, August and November record a very variable deficit (alternating flood and low water periods). The graph shows periods of increased runoff (positive peaks) alternating with periods of reduced runoff (negative peaks). The most recent data (from 2020) seem to indicate an increase in runoff with a very significant decline in 2024.

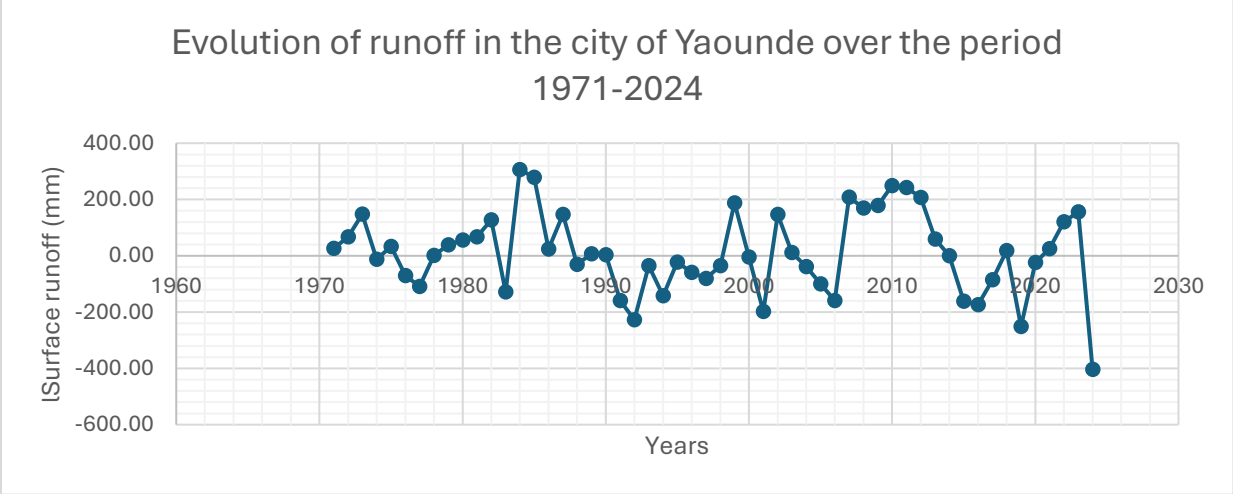


Figure 17: Annual runoff over Yaoundé City from 1971 to 2024

Peaks of positive runoff are observed in the 1971s, early and late 1980s, late 1990s, early and late 2000s, early 2010s, and early 2020s.

Periods of negative runoff are seen in the 1980s, early and mid-1990s, early and mid-2000s, mid and late 2010s, and early 2020s. The 1990s are marked by a period of predominantly negative runoff, which may suggest high evapotranspiration or infiltration. While the 2000s and 2010s represent a period of variability, with marked peaks and troughs. A trend towards strong negative runoff is observed in 2020. However, the dramatic drop in runoff in 2024 must be analyzed carefully. Runoff is influenced by water input (precipitation), infiltration which is a function of the geological structure of the soil, and evapotranspiration. Variations in runoff are likely related to changes in precipitation (intensity, frequency) and evapotranspiration. Years with positive peaks could correspond to periods of heavy rainfall, while negative peaks could indicate droughts. Indeed, the more abundant the precipitation, the greater the runoff is likely to be. Yamani et al (2012), also mentioned in the context of a study on the methodology of mapping the water balance from satellite data that runoff, including its coefficient, is a function of the slope, vegetation cover and soil type. In addition, they mention the fact that the irregularity of precipitation, the diversity of soil types, and steep slopes disrupt the distribution of the runoff water blade on the Brezina watershed in Algeria. This disruption is notable on pixels with higher precipitation and a higher runoff coefficient. This coefficient is very low for sandy soils (around 0.26), leading to high infiltration on the land. Negative runoff values may also be due to increasing urbanization in the study area, which tends to waterproof the soil and reduce its vegetation cover. It is important to note that high runoff can increase flood risks, especially in urban areas such as Odza and Nkie. In addition, runoff contributes to the recharge of rivers and groundwater (positive runoff contributes to the recharge of stocks). However, it is important to control this parameter because if it is very high it could lead to severe erosion resulting in the loss of nutrients. Stormwater management practices (drainage, infrastructure) can also play a role in the evolution of runoff. Deforestation around Yaoundé could reduce the infiltration capacity of soils and increase runoff.

4.3.5. Analysis of the water balance curve

The analysis of the water balance graph presented is quite complex with interactions between the different components. ETP remains relatively constant at around 1150 mm per year, with a slight increase towards the end of the period. This suggests a strong atmospheric demand for water. This relative stability suggests that temperature and sunshine have not undergone major

changes over the period studied. However, the slight upward trend could indicate gradual global warming. Annual precipitation is generally high, with values above 1500 mm in most years, indicating a relatively humid climate. However, significant interannual variability is observed, with drier years (around 1100-1200 mm) (2016, 2019), and very wet years (exceeding 2000 mm) (1984, 1985). Precipitation peaks can lead to flood risks, while periods of deficit can cause drought problems. Overall, infiltration and runoff follow the precipitation trend. Groundwater recharge shows great annual variability with very high values (over 600 mm). Recharge appears to be an important component of the water balance, a significant portion of the precipitation reaches the groundwater table. The average annual recharge of groundwater is in the order of 177 to 500 mm per year. A few exceptional years show surpluses greater than 500 mm (1984, 1985, 2002, 2007, 2008, 2012, 2022 and 2023) and minimums less than 177 mm (2016 and 2019). Annual runoff generally varies between 0 and 204 mm/year, however peaks of 306, 278 and 249 mm were recorded in 1984, 1985 and 2010. Several years of low runoff are recorded (1974, 1976, 1977, 1983, 1988, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 2000, 2001, 2004, 2005, 2006, 2015, 2016, 2017, 2019, 2020, 2024) with an estimated minimum in 2024 at -403 mm corresponding to an equally significant rainfall deficit. (1,454.8 mm annually). These negative values indicate a discharge of water reserves in the basins (reduction of stocks due to insufficient inputs by precipitation). Precipitation is the main factor influencing runoff and infiltration. The observed variations could be related to climate change, which can modify precipitation and evapotranspiration patterns.

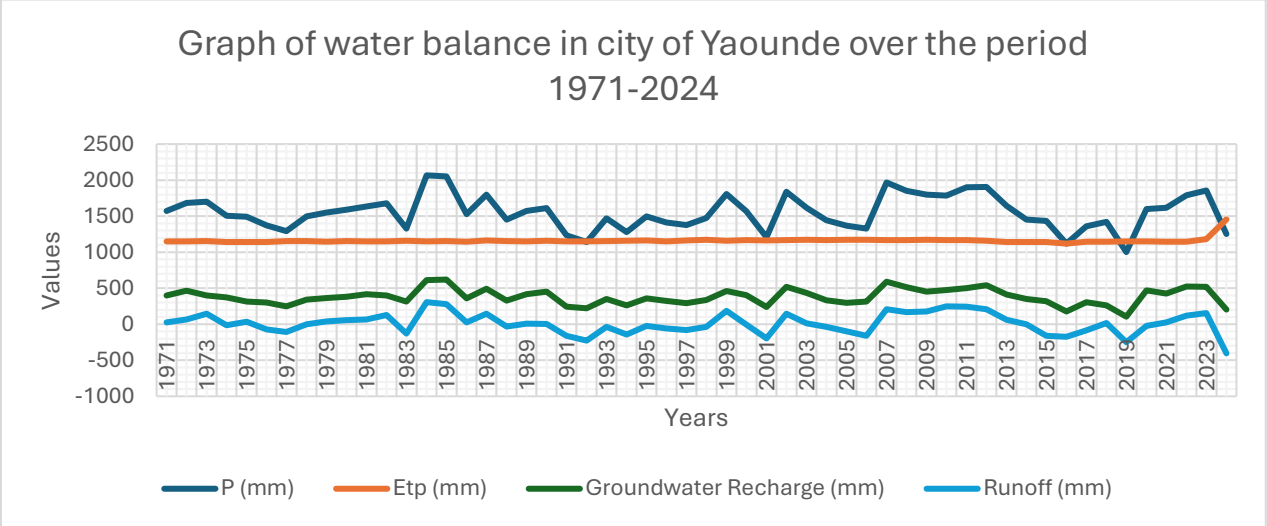


Figure 18: water balance parameters variation over 1971 and 2024

In conclusion, all components of the water balance exhibit significant annual variability, highlighting the system's sensitivity to climate fluctuations. Years with higher precipitation tend to have greater recharge, but the relationship is not always direct due to the influence of other factors (ETP, soil permeability, etc.). The overall water balance resulting from the combination of these four variables makes it possible to assess water availability in watersheds. Periods when the balance is positive indicate a water surplus, while periods when it is negative indicate a deficit. In their approach to mapping the water balance in the Brezina watershed in Algeria, Yamani et al (2012) were able to conclude that the results of the exploration year of their study correspond to those of a more or less dry year and low precipitation. Due to high infiltration, the amount of water stored at the Brezina dam is very low. Evapotranspiration is more important, given the scarcity of vegetation cover which shows that the basin is exposed to drought and a lack of water resources that are already scarce in this region. Gemitzi et al (2020), in their empirical method of estimating the water balance from Geographic Information Systems (GIS), obtained a parallel trend with different magnitudes for infiltration and runoff parameters. They specify that the empirical estimation of global infiltration from precipitation and evapotranspiration distributes about 52% of the actual precipitation into global infiltration, with the remaining part contributing to runoff. An important point that he highlights is that evapotranspiration is the most important component of the water balance, as it is the one that returns most of the precipitation to the atmosphere, thus influencing the infiltration and runoff parameters (as mentioned by Yamani et al (2012)). This hydrological balance, while significant, presents numerous challenges for water resource management in the city of Yaoundé, notably the high variability of rainfall, which is likely to make it difficult to forecast water availability and plan for droughts and floods. The upward trend in evapotranspiration, likely due to rising temperatures, and increasing loss of vegetation cover due to accelerated urbanization, could lead to increased water demand and reduced water availability.

Groundwater depletion, as indicated by negative values in some years, poses a challenge to long-term water security. High runoff during periods of heavy rainfall can lead to flooding and erosion, while low runoff during periods of drought can lead to water scarcity. Urbanization, as one of the explicit factors of human impact on the water balance, could significantly alter the water balance in the Odza and Nkie areas, therefore this factor must be taken into account in water management strategies in these areas. To address the challenges posed by this water balance and ensure continuous and efficient long-term water resource management in the city of Yaoundé and the Odza and Nkie sub-watersheds, it is necessary to implement water conservation measures to reduce consumption, particularly during periods of low rainfall. This

may include promoting efficient irrigation practices, reducing water losses in distribution networks, and encouraging water-saving behaviors among households and industries. Promoting rainwater harvesting to supplement water reserves during periods of drought is also an option to be encouraged; this may include the construction of rainwater harvesting systems for domestic, agricultural, and even industrial uses. Regulating groundwater pumping and promoting artificial recharge and the protection of recharge areas is also important. It would also be important to implement land-use policies that reduce impervious surfaces and promote infiltration. This may include preserving natural vegetation through the development of nature-based solutions, promoting green infrastructure, and controlling urban development. Improve monitoring and forecasting of precipitation, evapotranspiration, groundwater levels, and runoff is essential, this may include installing additional monitoring stations, improving data collection and analysis, and developing hydrological models.

Develop and implement climate change adaptation strategies to address water resource availability and its impacts on the water balance may include diversifying water sources, improving storage capacity, and developing drought-resistant crops.

Globally, the analysis of the Odza and Nkie watersheds reveals a complex interplay of strengths, weaknesses, opportunities, and threats regarding integrated water resources management (IWRM). To promote sustainable practices, it would therefore be wise to strengthen the legal and institutional framework of the water sector, ensuring the rapid adoption and implementation of the revised IWRM-focused water law and ensuring its enforcement, because if this law is politically valid but not properly implemented, it would lead to a double ineffectiveness. It is also extremely important, after the validation of the framework water law, to formally implement an updated national IWRM plan, with clear objectives and a roadmap, and mechanisms to translate policies into concrete actions at the national and subnational levels. Improve coordination between the various ministries, agencies and local authorities to avoid duplication and ensure effective management of water resources, but also, popularize the National Water Policy updated and politically validated by the State. Popularization is a very essential tool that allows the actors to equip the actors in terms of knowledge on the water sector, it also frames the initiatives that are carried out there and allows for coordinated actions, aligned with the standards in force. It must be said that the State makes many efforts in this direction, although decisions are often quite slow in their implementation. In terms of popularization, it is important to note here that, on the occasion of the 33rd edition of the World Water Day, placed under the theme "**The National Water Policy: a commitment to sustainable management of water resources in Cameroon.**" The government, through the

Ministry of Water Resources and Energy, plans to organize a public awareness meeting of the national water policy document on April 10, 2025, which represents a significant step forward in the implementation of IWRM at the national level. Regarding the financial sector, which is one of the main weak links in the water sector in general, it would be more advantageous to increase budget allocations for IWRM at the national and subnational levels, diversify funding sources by exploring innovative financing mechanisms, involve the private sector, and establish partnerships with NGOs and international donors, and ensure transparency and accountability in the management of funds allocated to water sector projects to minimize the risks of misappropriation and corruption. IWRM cannot be discussed without education; no discipline can be practiced without fundamental knowledge. It is therefore important to improve awareness and understanding of IWRM principles among local stakeholders, including communities, decision-makers, and technical staff, and to provide training and capacity-building opportunities to consolidate local expertise in water resources management, technical software, and financial management. Develop and implement water resource management tools, such as monitoring systems, quality assessment protocols, and decision support systems; provide technical assistance to local authorities in areas such as urban planning, infrastructure development, and pollution control. In terms of cooperation, it would be desirable to foster collaboration and information sharing between government agencies, research institutes, civil society organizations, and the private sector; strengthen regional cooperation with neighboring countries on transboundary water management, including initiatives within ECCAS, the LCBC, and the NBA; and promote community participation in decision-making processes related to water resource management to ensure that initiatives are adapted to local needs and contexts. The State would benefit from investing in research and development to improve understanding of water resource dynamics, pollution sources, and the impacts of climate change on their availability, and to promote the use of innovative technologies and approaches for the conservation, treatment, and monitoring of water resources. The implementation of these measures could help address the weaknesses and threats identified during the SWOT analysis, capitalize on opportunities, and promote sustainable and integrated water resource management in the urban watersheds of Yaoundé, and in the Nkié and Odza watersheds.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Integrated water resources management (IWRM) in the urban sub-watersheds of Yaoundé (Cameroon), particularly in the Odza and Nkie watersheds, is at a critical crossroads. This study, which focused primarily on a SWOT analysis of IWRM implementation at the local level, water resource mapping, and the hydrological balance in the urban sub-watersheds of Nkie and Odza, highlighted significant challenges and opportunities for sustainable water management. Although regulatory and institutional frameworks exist, their implementation is hampered by several weaknesses: absence of official national IWRM plan; weak awareness and training of local stakeholders on the IWRM approach; lack of operational tools for integrated management at the local level, which hinders the application of IWRM strategies; funds not allocated to basin authorities (because they do not exist). Although there are no specific legal, institutional or infrastructural measures in place for the Odza and Nkié sub-basins, the Cameroonian government has demonstrated a political will to promote integrated water resources management (IWRM) through the development of the National Water Policy (PNE) and the revision of the water law aligned with the IWRM approach. Furthermore, the existence of subnational IWRM policies such as the decentralization law that transfers water resources management responsibilities to municipalities (such as the Yaoundé IV district municipality) is evidence of the desire to operationalize and empower the water sector. The adoption of regional policies such as RAPIWRM is evidence of the desire for concerted water resources management, thus promoting cooperation between Central African countries. The involvement of civil society (Water for Life Cameroon, RECOJAC, ERA Cameroon), and institutions such as CRWCC, which are dedicated to research on water and climate, are assets favorable to the take-off of IWRM and should be exploited for this purpose. The existence of GWP, whose main mandate is to promote IWRM in Cameroon, the presence of the Water Resources Management Directorates (WRMD) and Water Resources Mobilization Directorates (WRMD) within MINWRE, make it possible to coordinate resource management and monitoring efforts. The Mfoundi River canalization and Yaoundé wastewater treatment projects (Yaoundé City Sanitation Project (YCSP)), SEWASH, and the Sanaga Basin Operationalization Project are all initiatives, albeit poorly coordinated, that adequately demonstrate the government's desire to boost Cameroon's water sector in general.

Water resource mapping identified wetlands and streams, revealing high urbanization and increasing pressure on green spaces. This uncontrolled urbanization leads to significant depletion and pollution of water resources, with potentially harmful consequences for ecosystems and public health. Indeed, it contributes to significantly altering the natural water cycle, leading to imbalances in the various components of the water balance in the Odza and Nkie watersheds. This urbanization is a major cause of deforestation, resulting in the loss of vegetation, which plays a crucial role in evapotranspiration. The loss of vegetation cover reduces evapotranspiration rates, thus affecting the transfer of moisture to the atmosphere. This can alter local climate patterns and impact water balance.

The water balance showed significant fluctuations in precipitation (P) over the years. There are periods of high precipitation (1984, 1985, 2007, 2008, 2011, 2012, 2023) and periods of low precipitation (1977, 1991, 1992, 2019, 2024). This indicates high variability in rainfall patterns, which could have implications for water resource management. Evapotranspiration, on the other hand, remains relatively stable over much of the period, but shows a notable increase in recent years, particularly in 2023 and 2024. This increase could be due to rising temperatures or changes in land cover. Groundwater levels show significant fluctuations, with both positive and negative values. Positive values suggest groundwater recharge, while negative values indicate groundwater depletion. This variability in groundwater levels is likely influenced by precipitation patterns and other factors such as human water use. Runoff also fluctuates considerably, with periods of high runoff (1984, 1985, 2010, 2011, 2012) corresponding to years of high precipitation. Negative values reflect low precipitation input (the amount of falling water is insufficient to induce runoff). To address these challenges and ensure sound water balance over the years, it is essential to improve monitoring and forecasting of precipitation, evapotranspiration, groundwater levels and runoff, develop and implement climate change adaptation strategies in terms of water resource availability, implement sustainable groundwater management practices to prevent over-extraction and ensure groundwater recharge, promote land use planning policies that reduce impervious surfaces and promote infiltration.

Overall, it can be said that strong political commitment, increased community awareness, and inter-institutional cooperation are essential to overcome the above-identified obstacles to effective water resource management. Furthermore, the integration of the Sustainable Development Goals (SDGs) and scientific innovation must be at the heart of management strategies to ensure resilience to environmental challenges, including climate change. This study highlights the urgent need for action to ensure integrated and sustainable water resource

management in Yaoundé's urban sub-watersheds. A collaborative and multidimensional approach, involving all relevant stakeholders, is essential to promote effective IWRM adapted to the specificities of the Odza and Nkie watersheds. The challenges are numerous, but opportunities exist to implement effective solutions and ensure a secure water future for Yaoundé residents, thus ensuring the sustainability of water resources for future generations.

5.2. Recommendations

To improve Integrated Water Resource Management at the national and local levels, it would be necessary to:

For key stakeholders involved in decision-making

- ✓ Strengthen and encourage the participation of local stakeholders and civil society in water resource development initiatives across all sectors.
- ✓ Strengthening collaboration with regional development agencies (DTCs) for more effective project monitoring.
- ✓ Operationalize the National Water Committee (this would strengthen coordination and consultation).
- ✓ Strengthen the participation of youth as key stakeholders in IWRM.
- ✓ Take greater account of climate change in the water sector (the increased involvement of the National Water Agency (NOCC) is crucial for climate integration).
- ✓ Strengthening the legal and institutional framework for water
- ✓ Update and validate the NAPIWRM
- ✓ Translating policies into concrete actions
- ✓ Integrate IWRM as an explicit priority in national and sectoral budgets
- ✓ Establish innovative financing mechanisms

For Decentralized Territorial Communities (DTC)

- ✓ Integrate IWRM into local development plans
- ✓ Raise awareness among local stakeholders and youth about water issues and the need for integrated management.
- ✓ Involve more women in resource management processes (international days such as March 8 and March 22 are opportunities to strengthen their role in IWRM).
- ✓ Strengthen the technical capacities of staff in various departments.
- ✓ Develop formal partnerships with NGOs, the private sector, and civil society.
- ✓ Address the degradation of drinking water supply sources.

- ✓ Control water pollution from various sources like car washes, household waste, and catering activities.
- ✓ Implement measures to manage stormwater and reduce runoff to decrease flood risks.

For Water Sector Practitioners

- ✓ Develop robust and bankable IWRM project proposals to attract donor and private sector investment.
- ✓ Organize training for water sector technicians on water resource management techniques, hydrological modeling and financial planning.
- ✓ Conduct gender-sensitive analyses of water-related budgets and projects.
- ✓ Share knowledge and best practices in IWRM.

5.3. Limitations

- ❖ **Focus on Technical Aspects:** The focus on technical analyses (mapping, NDWI and NDVI indices) may overlook other important dimensions of water resources management, such as social and cultural dimensions.
- ❖ **Limited Stakeholder Participation:** Although interviews were conducted with key stakeholders, their representativeness may be limited, which could bias the results regarding local perceptions and challenges.
- ❖ **Environmental Change:** The impacts of climate change on water resources were not sufficiently integrated into the analysis, which could influence long-term results.
- ❖ **Level of Detail of Analyses:** Some analyses, such as watershed characterization, do not consider spatial variations within sub-basins, which may limit the accuracy of the conclusions.

These limitations highlight the need to deepen certain analyses and expand the available data to improve the understanding and management of water resources in the Odza and Nkie basins.

5.4. Perspectives

- ❖ Integrate social and economic analyses into water resource management assessments to better understand the impacts of policies on local communities.
- ❖ Expand the study to include environmental impacts and natural resource management practices for a more holistic approach.
- ❖ Use hydrological modeling tools to simulate different management scenarios and assess potential impacts on water resources.

CHAPTER 6

REFERENCES

1. Abdou Nasser Ngouh, Amidou Kpoumie, Ghislain Nyembe Etame, Aloysious Kohtem Lebga, Esse Ndjeng, Jules Remy Ndam Ngoupayou. (2020). Caractérisation Hydrodynamique et Qualité des eaux de l'aquifère à nappe libre du bassin versant du Nkié (Yaoundé–Cameroun). URL:http://dx.doi.org/10.19044/esj.2020.v16n15p281.
2. Alebel Abebe Belay, Henry Musoke Semakula, George James Wambura, Labohy Jan. (2013). SWOT Analysis and Challenges of Nile Basin Initiative: An Integrated Water Resource Management Perspective. Article in Chinese Journal of Population Resources and Environment DOI: 10.1080/10042857.2010.10684960.
3. André Firmin Bon, Jules Rémy Ndam Ngoupayou, Guillaume Ewodo Mboudou et Georges Emmanuel Ekodeck. (2016). Caractérisation hydrogéologique des aquifères de socle altéré et fissuré du bassin versant de l'Olézoa à Yaoundé, Cameroun. URI: http://id.erudit.org/iderudit/1036545ar DOI: 10.7202/1036545ar.
4. Santiago. A. (1992). An estimation of the water balance in the Cameroons and a mapping attempt. Veille Climatique Satellitaire, (42), p. 68-92.
5. Baba-Serges Zango, Ousmane Seidou, Majid Sartaj, Nader Nakhaei and Kelly Stiles. (2022). Impacts of urbanization and climate change on water quantity and quality in the Carp River watershed. doi:10.2166/wcc.2021.158. Journal of Water and Climate Change Vol 13 No 2, 786.
6. Baghli Naoual née merabet. (2018). Elaboration d'une méthodologie d'organisation de l'information pour une meilleure gestion des ressources en eau. Thèse présentée en vue de l'obtention du grade de Docteur en Sciences. Université Aboubakr Belkaïd – Tlemcen. 129P.
7. Brandon Baker, Alexander Bond, Tim Bonvechio, Bryant Bowen, Melissa Crabbe, Ben Emanuel, Robert Farris, Bruno Giri, Chris Harper, Adam Heagy, Karin Heiman, Scott Thackston Cassidy Lord, Richard Ludwig, Paula Marcinek, Angie Martin, Jeff Matthews, Justin Merrifield, Todd Miller, Laura Munn, Chris Nelson, Courtenay O'Mara, Andrew Paracca, Todd Rasmussen, Jack Rice, Hunter Roop, Charles Ross Hinkle, Steve Schleiger, Daniel Sizemore, Katie Sponberger, Dennis Stroud, Scott Taylor, Steffney Thompson, Mike Wharton, Diane Windham. (2022). Waters of the Oconee River Basin: Uses, Benefits, and Flow-Related Metrics for Water Planning.

8. C. Defo, A.K. Mishra, B.P.K. Yerima, P.B. Mabou, A.A. Ako and T. Fonkou. (2016). Current conditions of groundwater resources development and related problems in the Republic of Cameroon, West Africa. *European Water* 54: 43-68, 2016.
9. Daniel Ebang Menye, Serge Hubert Zébazé Togouet, Samuel Foto Menbohan, Norbert Kemka, Moise Nola, Claude Boutin, Victor Francois Nguetsop, Moussa Djaouda, Thomas Njiné, (2012). Bio-écologie des diatomés épilithiques de la rivière Mfoundi (Yaoundé, Cameroun) : diversité, distribution spatiale et influence des pollutions organiques. Revue des sciences de l'eau / journal of water science, volume 25, P. 203-218.
10. Diane Armelle Moussima Yaka, Ange Alex Tiemeni, Bertrand Zing Zing, Thérèse Line Laure Jokam Nenkam, Amina Aboubakar, Aline Beatrice Nzeket, Brice Hermann Fokouong Tcholong et Yvette Clarisse Mfopou Mewouo (2020). Qualité physico-chimique et bactériologique des eaux souterraines et risques sanitaires dans quelques quartiers de Yaoundé VII, Cameroun. ISSN 1997-342X (Online), ISSN 1991-8631 (Print). http://ajol.info/index.php/ijbcs
11. Djeuda Tchapnga, H., Tanawa, E., Temgoua, E., Siakeu, J., Ngo Massana, B., 1999. Mode de circulation, mécanismes de recharge et temps relatifs de séjour des eaux des nappes souterraines des altérites du milieu cristallin: cas du bassin versant de l'Anga'a, Yaounde. Cameroun, Press Univ Yaounde 117–126.
12. Douville, H., Raghavan, K., Renwick, J., Allan, R. P., Arias, P. A., Barlow, M., Zolina, O., 2021: Water Cycle Changes. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press, Cambridge.
13. EPA. (2023). European Approaches Support an Essential Definition of Ecosystem-Based Management and Demonstrate Its Implementation for the Oceans. https://doi.org/10.1080/00908320.2023.2301105
14. Ewodo Mboudou G., A. Ombolo, A. Fouepe Takounjou, A.F. bon et G.E. Ekodeck (2012). Etude des Paramètres hydrauliques des aquifères de sub-surface du bassin versant de la Mingosso, région de Yaoundé. Rev. CAMES - Série A, 13, 123-

15. George Falalakis and Alexandra Gemitzi. (2020). A simple method for water balance estimation based on the empirical method and remotely sensed evapotranspiration estimates. *Journal of Hydroinformatics.*

16. GWP. (2010). Water Security is Essential to Development: Reflections on African Partnerships in Action. Political note. www.globalwaterpartnership.org
17. GWP. (2017). Comments submitted by Member States in 2017 consultations for the preparation of a declaration of ethical principles in relation to climate change. SHS/BIO/IGM-CC/PI/2017/1
18. GWP. (2009). Etat des lieux du secteur de l'eau, connaissances et usages : Plan d'Action National de Gestion Intégrée des Ressources en Eau au Cameroun (PANGIRE).
19. Hadi Kardhana, Abdul Wahab Insan Lihawa, Faizal Immaddudin Wira Rohmat, Siska Wulandari, Wendi Harjupa,Widyawardana Adiprawita, Edwan Kardena, Muhammad Syahril Badri Kusuma. (2024). Water Balance Analysis in the MajalayaWatershed: Two-Step calibration and Application of the SWAT+ Model for low-flow Conditions. https://doi.org/10.3390/w16233498

20. H.O. Nwankwoala and S.A. Ngah. (2014). Groundwater resource of the Niger Delta: quality implications and management considerations. *International journal of water resources and environmental engineering.*

21. Intergovernmental Panel on Climate Change (IPCC). (2022). Climate change 2022: synthesis report, summary for policymakers, fifth assessment report. World Meteorological Organization, Geneva
22. Jennifer Collado Cacal, Evelyn Buque Taboada and Muhammad Shafqat Mehboob. (2023). Strategic Implementation of Integrated Water Resource Management in Selected Areas of Palawan: SWOT-AHP Method. https://doi.org/10.3390/su15042922
23. J. E. Flotemersch, S. G. Leibowitz, R. A. Hill, J. L. Stoddard, M. C. Thoms and R. E. Tharme. (2015). A watershed integrity definition and assessment approach to support strategic management of watersheds. DOI : 10.1002/rra.2978
24. J.P. Laborde. (2009). Eléments d'hydrologie de surface. Ecole polytechnique de l'université de Nice - Sophia Antipolis. Département Hydro informatique et Ingénierie de l'Eau. 202P.

25. Katarzyna Baran-Gurgul, Agnieszka Rutkowska. (2024). Water Resource Management: Hydrological Modelling, Hydrological Cycles, and Hydrological Prediction. https://doi.org/10.3390/ w16243689
26. Ke zhai, Xiaoqing WUa,b, Yuanwei QIN, and Peipei DU. (2015). Comparison of surface water extraction performances of different classic water indices using OLI and TM imageries in different situations. Vol. 18, No. 1, 32–42, http://dx.doi.org/10.1080/10095020.2015.1017911
27. MINWRE. (2022). Processus d'Elaboration du Plan d'Action de Gestion Intégrée de la Ressource en Eau (PAGIRE) du Cameroun : Document d'Orientation.
28. MINWRE. (2023), Stakeholder consultation report for SDG indicator 6.5.1.
29. Moussa R., 1993. Modélisation hydrologique spatialisée et système d'information géographique. La Houille Blanche, n° 5, pp. 293-301.
30. Mulatu Abayicho Sulamo, Asfaw Kebede Kassab, Negash Tessema Robac. (2021). Evaluation of the impacts of land use/cover changes on water balance of Bilate watershed, Rift valley basin, Ethiopia. Water Practice & Technology Vol 16 No 4, 1108 doi: 10.2166/wpt.2021.063
31. Nicole Schweinberger Bona, Silvana da Silva, Elza Hofer, José Gustavo Venâncio da Silva Ramos. (2023). SWOT Matrix as a tool for diagnosing the municipal water supply system of a small city: a case study. https://doi.org/10.5902/2236117071425
32. Njikam Linjouom, Abdou Rahamani. (2021). Analyse comparative du cadre institutionnel et législatif de la gestion de la ressource en eau au Cameroun, dans le contexte des pays de la Communauté Economique des Etats de l'Afrique centrale. Université de Liege.
33. Nyembe etame Ghislain, yogback Gertrude Estelle, kana Collins, ojuku Tiafack, ngoufo tchinda Gaelle Merveille & esse ndjeng Maximilien. (2021). State of wastewater and excreta sanitation in the Odza catchment area in the peri-urban area of Yaoundé and impact on the urban environment. Canadian Journal of Tropical Geography. http://laurentian.ca/cjtg
34. Nzenti J. P., Barbey P., Macaudiere J. et Soba D., (1988). Origin and evolution of late Precambrian high-grade Yaoundé gneisses. Precambrian Research 38: 91-109.
35. Petousi I., Fountoulakis M., Papadaki A., Sabathianakis I., Daskalakis G., Nikolaidis, N. Manios T. (2017). Assessment of Water Management measures through SWOT

Analysis: The case of Crete Island, Greece. ISSN: 2367-8941. http://www.iaras.org/iaras/journals/ijes

36. Richard W. Healy, Thomas C. Winter, James W. LaBaugh, O. Lehn Franke (USGS). (2007). Water Budgets: Foundations for Effective Water-Resources and Environmental Management.

DOI 10.3133/cir1308

37. SCET Tunisie, 2017. Études de prévention d'inondations et d'aménagements paysagers (PADY 2), 64P.
38. Sharon Bih Kimbi, Shin-ichi Onodera, Kunyang Wang, Ichirow Kaihotsu, Yuta Shimizu. (2024). Assessing the Impact of Urbanization and Climate Change on hydrological Processes in a Suburban Catchment. https://doi.org/10.3390/environments11100225
39. Solaymani Hamidreza. (2018). Applying partial order and swot analysis in water and land use planning to prioritize the adaptation strategies under changing climate. *Journal of Urban and Landscape Planning*
40. Swati Paul, Dibyajyoti Saha, S.M. Zahid Hosen, Talha Bin Emran. (2012). Overview on Water Resources and Pollution. ISSN 0975-4393
41. Takounjou, A.F., Rao, V., Ngoupayou, J.N., Nkamdjou, L.S., Ekodeck, G.E., 2009. Groundwater flow modelling in the upper Anga'a river watershed, Yaounde, Cameroon. Afr. J. Environ. Sci. Technol. 3.
42. Tek Bahadur Kshetri. (2018). NDVI, NDBI & NDWI Calculation Using Landsat 7, 8.
43. UN water, United Nations, UN Environment program. (2021). Progress on Integrated Water Resources Management: Global indicator 6.5.1 updates and acceleration needs
44. USAID. (2015). Methodology for the calculation and forecast of water balance at river basin level for the context of Georgia.
45. UNESCO World Water Assessment Program. (2016). The United Nations world water development report 2016: water and jobs. ISBN : 978-92-3-100146-8, 978-92-3-100155-0
46. World Bank. (2023). Cameroon water security and supply project (P180321): Project Information Document (PID)
47. WWAP (United Nations World Water Assessment Programme)/ UN-Water (2018) The United Nations World Water Development Report 2018: nature-based solutions for water. UNESCO, Paris

48. Xueping Gao, Lingling Chen, Bowen Sun and Yinzhu Liu. (2017). Employing SWOT Analysis and Normal Cloud Model for Water Resource Sustainable Utilization Assessment and Strategy Development. www.mdpi.com/journal/sustainability
49. Yamani Kheira, Sekkoum Mohamed, Hazzab Abdelkrim, Hamimed Abdelrahmane. (2012). Méthodologie de cartographie du bilan hydrologique à partir des données satellitaires a l'échelle d'un bassin versant.
50. Yang Li, Mohamed Abdelkareem, Nasir Al-Arifi. (2023). Mapping Potential Water Resource Areas Using GIS-Based Frequency Ratio and Evidential Belief Function. **https://doi.org/10.3390/w15030480**

WEBSITES

51. https://iwrmdataportal.unepdhi.org/country-reports (consult from 12/12/2024 to 20/12/2024)
52. https://www.ecolex.org/ (consult the 15/01/2024)
53. https://uizentrum.de/water-resource-mapping-methods/?lang=en (consult the 20/01/2024)

CHAPTER 7

APPENDIX

7.1. APPENDIX 1 : QUESTIONNAIRE ADDRESSED TO TECHNICAL SUPPORT STRUCTURES

Purpose of the survey: Assess the implementation of the IWRM strategy in Cameroon, identify strengths, weaknesses, opportunities and threats (SWOT) as well as capacity building needs.

Your expertise is valuable in helping us better understand the issues and challenges related to this problem. We thank you for taking the time to answer this questionnaire which contains 16 questions and requires approximately 20 minutes to complete.

Please note that the information collected here is primarily for academic purposes. Please indicate during the interview any information that must remain strictly confidential.

General Information

a. Name of the organization:……..

b. Name and position of the person interviewed:……..

c. Email and phone number:……..

1. What are the missions and objectives of your organization/person in the context of water resources management in Central Africa?
   ……
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   ……..
2. What is the level of involvement of your organization/person in the implementation of the IWRM strategy in Cameroon? What are the specific projects that you support?
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   ……
   …….
3. How would you describe the current IWRM strategy in Cameroon?
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   ……
   …….
4. What are the specific programs and initiatives that are being implemented to improve IWRM in Cameroon?

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What indicators are used to monitor progress?

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……..

5. What are the most significant results obtained so far thanks to the implementation of this strategy in Cameroon?
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   ……
   …….
6. Who are the main actors (government, NGOs, private) involved in IWRM in Cameroon and how do they collaborate to improve water resources management?
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   ……
   ……
   ……
   ……
7. How are local communities involved in water resource management?
   ……
   ……
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   ……
   …….
8. What monitoring and evaluation mechanisms are in place to measure the effectiveness of this management?
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   ……
   ……
   ……
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   ……
   …
9. Are there any previous initiatives at the level of the Municipality of Yaoundé 4 which have been implemented within the framework of IWRM in Cameroon (if yes, what results have you observed following these initiatives)?

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……..

10. What are the main challenges that the Municipality of Yaoundé 4 could face in the context of the implementation of IWRM in Cameroon (population growth, climate change, pollution, etc.)?
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11. How do you think Cameroon's IWRM strategy addresses the challenges of water resource management in municipalities?
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12. What are the existing IWRM financing mechanisms in Cameroon?
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13. What are the main partnerships established to implement the IWRM strategy in Cameroon?
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14. How do these partnerships contribute to strengthening the effectiveness of IWRM?
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15. What are the next steps envisaged to improve integrated water resources management in Cameroon?

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16. What are the needs in terms of financing, capacity building and technology transfer?

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7.2. APPENDIX 2: QUESTIONNAIRE ADDRESSED TO DECENTRALIZED LOCAL AUTHORITIES (CUY AND CYDE 4)

Introduction

Good morning, Sir/Madam,

We are conducting a study on the analysis of the integrated water resources management strategy in the Odza and Nkie sub-watersheds of the Yaoundé 4 commune. Your expertise is valuable in helping us better understand the issues and challenges related to this problem. We thank you for taking the time to answer this questionnaire which contains 15 questions and requires approximately 20 minutes to complete.

Please note that the information collected here is primarily for academic purposes. Please indicate during the interview any information that must remain strictly confidential.

General Information

a. Name of organization:……..

b. Name and position of the person interviewed:……..

c. Email and phone number:……..

1. What are the missions of the municipality within the framework of integrated water resources management (IWRM)?
   ……
   ……
   ……
   ……
   ……..
2. Is there currently an integrated water resources management mechanism within the municipality?
   ……
   ……
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   ……
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3. If so, how is this implemented at the watershed scale?
   ……..
   ……..
   ……
   ……
4. Are the results obtained appreciable compared to previous years?

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5. Are there any current predispositions favoring the proper implementation of IWRM within the municipality?
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   ……..
   ……
6. Are there existing institutions involved in the IWRM process (with which institutions do you collaborate in the implementation of IWRM at the municipal level)?
   ……..
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7. If so, how are they connected to decision-making institutions?
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8. What mechanisms have been put in place within the municipality to involve the local population in IWRM initiatives?
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9. What mechanisms have been put in place at the municipal level to ensure the sustainable management of water resources?
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10. What are the instruments for managing water resources at the watershed level?
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11. Are there any concrete IWRM development plans within the municipality?

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12. What are the financing mechanisms for IWRM within the municipality?

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13. Are there any previous initiatives aimed at promoting IWRM within the municipality (if so, what are the results and how have they been capitalized on)?

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14. What are the constraints/difficulties encountered in the implementation of IWRM within the municipality?

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15. What are the concrete prospects for IWRM within the municipality?

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7.3. APPENDIX 3: QUESTIONNAIRE ADDRESSED TO TECHNICAL MINISTRIES

Purpose of the survey: Assess the implementation of the IWRM strategy in Cameroon, identify strengths, weaknesses, opportunities and threats (SWOT) as well as capacity building needs.

Your expertise is valuable in helping us better understand the issues and challenges related to this problem. We thank you for taking the time to answer this questionnaire which contains 16 questions and requires approximately 20 minutes to complete.

Please note that the information collected here is primarily for academic purposes. Please indicate during the interview any information that must remain strictly confidential.

General Information

a. Name of the organization:……..
b. Name and position of the person interviewed:……..
c. Email and phone number:……..

1. What are the missions and objectives of the Ministry in terms of integrated water resources management in Cameroon?
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2. How would you describe the implementation of IWRM at the national level and in the city of Yaoundé?
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3. What mechanisms have been put in place at the Ministry level to promote IWRM in Cameroon and in the city of Yaoundé in particular?
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4. What performance indicators do you use to assess the effectiveness of the mechanisms put in place?

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5. Is there a national or local plan for integrated water resources management? If so, what are its main axes and monitoring indicators?
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6. What are the main issues related to the implementation of IWRM in Yaoundé and Cameroon?
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7. What specific strategies are being implemented to address these challenges? How do these strategies fit in with the national plan?
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8. How does the ministry collaborate with other actors (NGOs, private sector, communities) in the implementation of IWRM in Cameroon?
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9. What coordination mechanisms have been put in place to ensure concerted management of water resources?
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10. What are the financing mechanisms for IWRM in Cameroon?

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11. What major challenges do you identify in the implementation of the IWRM strategy in Cameroon and Yaoundé?

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12. What are the specific initiatives/programs implemented by the ministry to improve integrated water resources management in Cameroon and Yaoundé?

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13. What improvements have been observed following these initiatives?

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14. How does the Ministry plan to improve monitoring and evaluation of ongoing initiatives?

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15. What are the prospects for IWRM in Cameroon?

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7.4. APPENDIX 4: QUESTIONNAIRE ADDRESSED TO FINANCING STRUCTURES

Purpose of the survey: Assess the implementation of the IWRM strategy in Cameroon, identify strengths, weaknesses, opportunities and threats (SWOT) as well as capacity building needs.

Your expertise is valuable in helping us better understand the issues and challenges related to this problem. We thank you for taking the time to answer this questionnaire which contains 16 questions and requires approximately 20 minutes to complete.

Please note that the information collected here is primarily for academic purposes. Please indicate during the interview any information that must remain strictly confidential.

General Information

a. Name of the organization:……..
b. Name and position of the person interviewed:……..
c. Email and phone number:……..

1. What are the missions and objectives within your institution in the implementation of integrated water resources management in Cameroon?
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2. What is the level of integration of IWRM in Cameroon's budgetary policies?
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3. Is there an annual budget allocated to IWRM for Cameroon?
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4. Is this budget increasing, decreasing or stable compared to previous years?
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5. How does your institution assess the financing of integrated water resources management initiatives in Cameroon?
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6. What are the main sources of financing for IWRM in Cameroon?
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7. How is this funding distributed between the different IWRM projects and programs?
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8. What are the selection criteria for IWRM projects that receive funding?
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9. How does your institution prioritize investments in the water sector compared to other sectors?
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10. How does your institution collaborate with other ministries (such as Energy and Water) in planning and financing IWRM-related projects?
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11. What partnerships (international or local) are in place to support financing related to IWRM?
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12. How are these funds used in the context of IWRM?
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13. What mechanisms has your institution put in place to ensure transparency and accountability in the management of funds allocated to IWRM?
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14. How does your institution collect data to assess future financial needs for IWRM?
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15. What are the main challenges your institution faces in financing IWRM projects in Cameroon?
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16. How does your institution plan to address these challenges?
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17. How does your institution envisage the evolution of financing in the IWRM sector in Cameroon in the coming years?
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7.5. APPENDIX 5: QUESTIONNAIRE ADDRESSED TO THE CAMEROON INTERNATIONAL HYDROLOGICAL PROGRAM (PHI) FOCAL POINT

General Information

a. Name of the organization:……..

b. Name and position of the person interviewed:……..

c. Email and phone number:……..

1. What are the missions and objectives of the PHI Focal Point in the implementation of IWRM in Cameroon?
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2. What are the main strategies of the PHI to promote integrated water resources management in Cameroon and Yaoundé?
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3. What monitoring and evaluation mechanisms are in place to measure the effectiveness of the strategies implemented?
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4. Are there any specific projects implemented by the PHI within the framework of IWRM in Cameroon and Yaoundé?
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5. What are the results observed so far in terms of improving IWRM?

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6. What are the financing mechanisms for IWRM-related projects carried out by the PHI in Cameroon?

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7. How does the intergovernmental program collaborate with the different stakeholders (government, NGOs, communities) for integrated and concerted management of water resources?

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8. How does the PHI involve communities in decision-making processes related to IWRM?

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9. What are the difficulties encountered in implementing IWRM in Cameroon?

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10. What measures has the PHI put in place to improve IWRM in the city of Yaoundé and in Cameroon?

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7.6. APPENDIX 6: FIELD DATA USED FOR MAPP DEVELOPMENT (GIS RAW DATA)

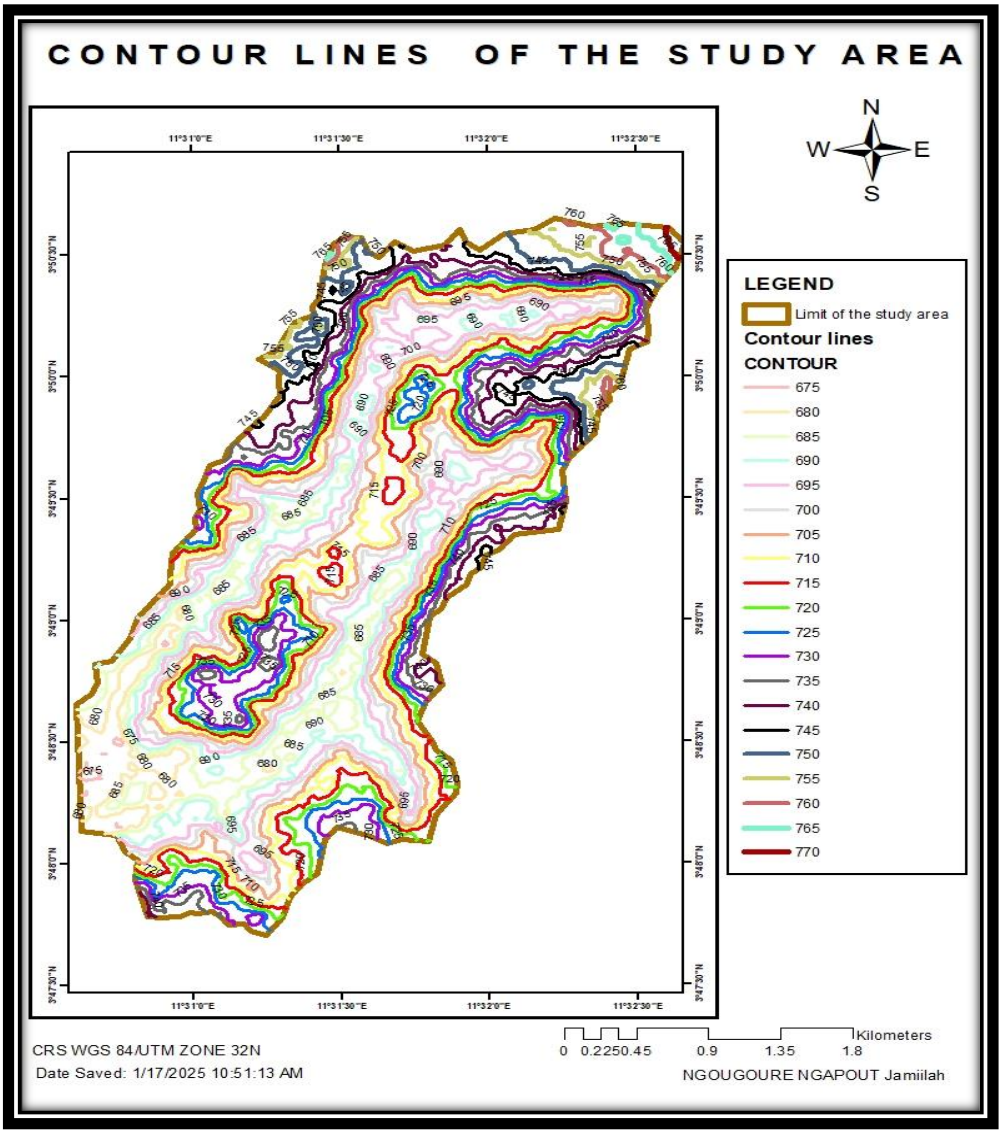

Figure 19: Altitudes classification of the odza and Nkié watersheds in Yaoundé

7.7. APPENDIX 7: WATER BALANCE PARAMETERS

Years	Groundwater Recharge (mm)	Runoff (mm)	P (mm)	Etp (mm)	temperature (°C)
1971	397.6343	26.8512	1573	1148.515	285.5
1972	464.4686	67.39817	1682.8	1150.933	287.0
1973	397.6398	147.4689	1699.2	1154.091	289.1
1974	374.3167	-12.6713	1503.9	1142.255	281.5
1975	315.0809	33.24951	1491.5	1143.17	282.2
1976	299.4248	-70.0968	1371.7	1142.372	282.0
1977	247.1413	-108.609	1291.6	1153.067	288.5
1978	339.7146	1.085894	1494.7	1153.9	288.9
1979	361.7782	38.85987	1547.9	1147.262	284.7
1980	380.2624	56.35325	1591	1154.384	289.2
1981	416.5617	67.69049	1635.5	1151.248	287.1
1982	401.1546	127.9584	1679	1149.887	286.4
1983	315.9769	-128.477	1327.2	1159.5	292.6
1984	611.2425	306.1998	2066.1	1148.658	285.6
1985	620.2819	278.5048	2051.5	1152.713	288.3
1986	358.0513	24.22286	1529.6	1147.326	285.0
1987	490.4087	147.0005	1798.7	1161.291	293.8
1988	328.4909	-30.7559	1452.9	1155.165	289.7
1989	416.695	6.779683	1572.5	1149.025	286.0
1990	451.3433	3.477652	1612.7	1157.879	291.6
1991	241.4829	-159.129	1234.5	1152.146	287.8
1992	220.3307	-227.237	1143.1	1150.007	286.4
1993	349.7806	-34.595	1471.3	1156.114	290.6
1994	260.9267	-142.54	1277.5	1159.113	292.6
1995	357.1528	-23.035	1495.5	1161.382	294.0
1996	323.6266	-59.0604	1413.9	1149.334	286.6
1997	294.2796	-80.2396	1375.9	1161.86	294.2
1998	338.6694	-35.3767	1475.7	1172.407	301.6
1999	459.9013	187.7173	1806.3	1158.681	292.2
2000	402.9081	-3.97228	1565.7	1166.764	297.5
2001	239.5624	-198.183	1206.3	1164.921	296.2
2002	520.5451	146.5972	1836.7	1169.558	299.8
2003	433.7058	11.92342	1616	1170.371	299.8
2004	334.5092	-38.2622	1444	1169.753	299.4
2005	296.6313	-99.8091	1369	1172.178	301.1
2006	315.803	-158.949	1327	1170.146	299.7
2007	589.9778	208.2952	1966.8	1168.527	298.5
2008	516.5376	169.3912	1853.1	1167.171	297.7
2009	451.8254	178.5286	1800.5	1170.146	287.7
2010	474.1725	249.5005	1786.5	1168.527	286.7
2011	500.4395	242.6893	1902.7	1167.171	288.8
2012	542.3115	206.8163	1905.6	1159.072	292.3

2013	414.0557	59.69174	1642	1143.253	281.7
2014	349.5051	0.564821	1454	1141.13	280.4
2015	320.8825	-160.844	1432.4	1142.961	281.7
2016	176.9288	-173.839	1117.2	1118.81	274.6
2017	305.9507	-85.2805	1358.6	1147.13	284.1
2018	261.1695	17.85254	1423.1	1144.078	282.4
2019	105.075	-251.376	1001.5	1147.801	284.6
2020	470.7934	-23.5316	1597.6	1150.338	286.2
2021	427.4335	25.48142	1614.9	1147.485	284.5
2022	523.3354	120.9323	1788.4	1144.132	282.4
2023	517.0464	156.0536	1854.7	1181.6	288.2
2024	201.7644	-403.764	1252.8	1454.8	293.1

7.8. APPENDIX 8: ILLUSTRATIONS OF WATERCOURSES POLLUTION

(a) **(b)**

(a) Watercourse located at the Odza interchange. (b) Marshy wild located at the Ndi Samba higher institute

(a) **(b)**

A view of Nkye stream (a); Ekie outlet (b)