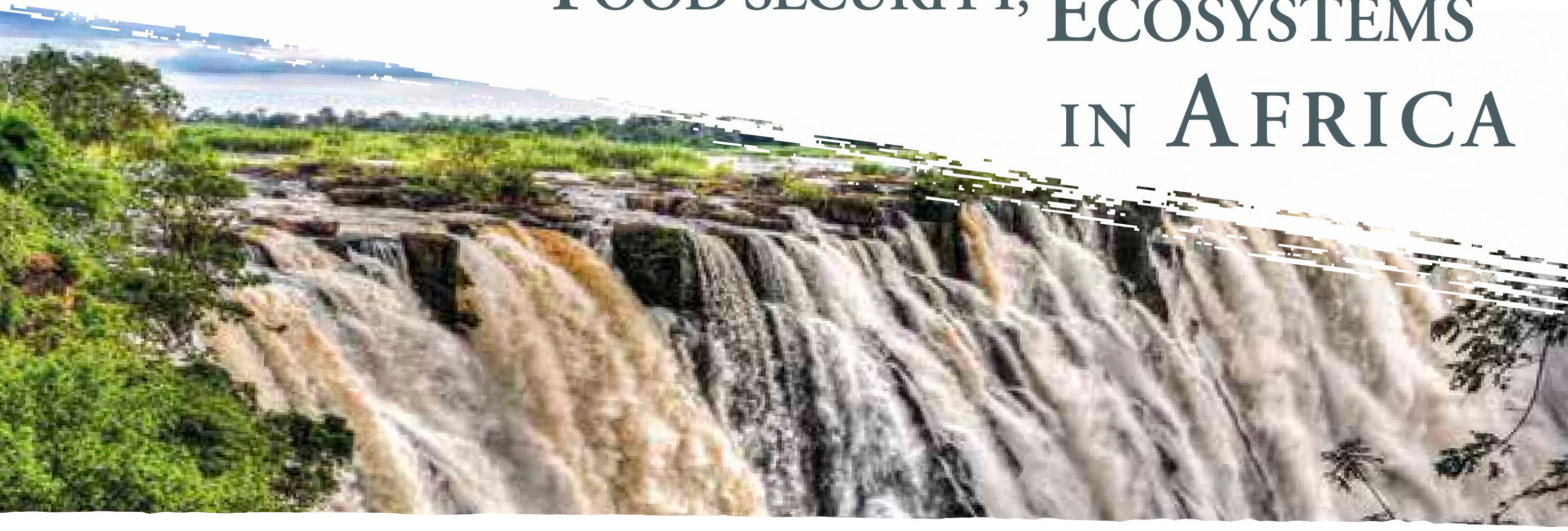
European Commission

JRC TECHNICAL REPORTS

Water, Energy, Food security, Ecosystems in Africa



Editors:
FARINOSI, F.
CRESTAZ, E
MARCOS-GARCIA, P.
PASTORI, M.
CARMONA-MORENO, C.

2021

JRC 124433

Joint Research Centre

Contact information
Name: Arnaud DE VANSSAY – DG INTPA
Email: Arnaud.DE-VANSSAY@ec.europa.eu
Tel.: +32 229 89766

Name: César CARMONA-MORENO – DG JRC
Email: cesar.carmona-moreno@ec.europa.eu
Tel.: +39 0332-789654

EU Science Hub
https://ec.europa.eu/jrc

JRC124433

Ispra: European Commission, 2021

Italy: Printed by Publications Office of the European Union, 2021

How to cite this report: Water–Energy–Food Security–Ecosystems in Africa. Editors: F. Farinosi, E. Crestaz, P. Marcos-Garcia, M. Pastori, C. Carmona-Moreno. Publications Office of the European Union, Italy, 2021 - JRC124433

JRC TECHNICAL REPORTS

Water, Energy, Food security, Ecosystems in Africa

Editors:
FARINOSI, F.
CRESTAZ, E
MARCOS-GARCIA, P.
PASTORI, M.
CARMONA-MORENO, C.

2021

JRC124433

Joint Research Centre

Contributors

in collaboration with

Coordinated by:

European Commission

United Nations
Educational, Scientific and
Cultural Organization

Intergovernmental
Hydrological
Programme

Contents

FOREWORD

Although there are water resource problems in all regions of the world, no region is more affected than sub-Saharan Africa. Inadequate infrastructures, including deficits in development and digitalisation, are among the main reasons for its susceptibility and vulnerability to water-related issues. Accessibility to water in the African continent is crucial, because current resources (human, financial and infrastructural) are generally insufficient to ensure adequate and equitable water distribution and management.

Good access to water resources is vital to many dimensions of development. It contributes not only to economic growth but also to the well-being of African populations and, consequently, to improving their political stability. There is a paradox that is particularly evident in Africa, whereby the precariousness of the poorest economies often hinders the implementation of medium- and long-term development programmes, thus preventing the creation of the robust infrastructure that is necessary for economic growth. The spread of infectious diseases in regions with limited water access[1] also hampers development and social welfare. For example, malaria costs Africa more than US$12 billion a year, slowing its economic growth by 1.3% annually[2].

Sustainable agriculture, the most important economic activity in most African countries, is another water-related issue. It is still 96% rain-fed and provides employment for about two-thirds of the continent's working population. Extreme climate variability in sub-Saharan Africa greatly affects agricultural productivity, undermining both food security and economic activity. Better-adapted and better-targeted policies on water resources management would improve the efficiency of water use and help to reduce the volatility of African economies.

Management and policies must also include both surface water and groundwater storage and their interactions, since they are essential to the resilience of African agriculture and the continent's energy development. However, the environmental impacts of water infrastructure must be appropriately assessed. While hydropower constitutes an attractive clean energy source for industrial and economic development at regional level (due to its relative insensitivity to fluctuations in global oil and gas prices), its availability is also highly volatile due to climate change[3]. Some African countries have significant resources with renewable energy potential (photovoltaic, bioenergy, wind and – along the Eastern Africa Rift Valley – geothermal energy) that could be exploited more actively, leading to benefits in terms of low greenhouse gases emissions and low sensitivity to climate change.

G. DE SANTI, Director European Commission - Joint Research Centre (JRC)

C. KANANGIRE, Executive Sec. African Ministers' Council on Water (AMCOW)

A. AMANI, Director UNESCO Intergovernmental Hydrological Programme (IHP)

All these aspects briefly synthesise how water, energy, agriculture, food security and ecosystems (WEFE) are closely interlinked sectors that are essential for sustainable development. An integrated understanding of the multi-sectoral issues of WEFE, the identification of priorities, their interactions and trade-offs and the joint development of knowledge and human capacities is the basis for informed, responsible and sustainable decision-making.

This work is the result of the past four years of collaboration, supported by the Directorate-General for International Partnership (DG INTPA) and jointly coordinated by the Joint Research Centre (JRC) of the European Commission and UNESCO-IHP working with the AUDA-NEPAD Centres of Excellence in Water Sciences, the Executive Secretariat of African Ministers' Council on Water (AMCOW), the Regional Economic Communities (ECOWAS, IGAD, SADC) and the authorities of the African basins of Niger, Nile, Senegal and Zambezi.

This report presents the findings, conclusions and recommendations arising from the various activities on the WEFE Nexus in Africa. More than 80 deliverables, including technical reports, good practice manuals, databases, human capacity development products and policy briefs have been produced. This document demonstrates how long-term collaboration between research and policy institutions contributes to sustainable development through information sharing, data and joint knowledge development.

1 WHO - World Health Organization Regional Office for Africa, 2019. Of the estimated 10 million deaths per year resulting from infectious diseases, the majority occur in Africa.

2 "Focusing on improved water and sanitation for health". Bartram J, Lewis K, Lenton R, Wright A. The Lancet. 2005;365:810–812.

3 ECOFIN Agency. June 2020. Africa's hydropower segment needs to increase its resilience to climate change. Dams currently provide 17% of the continent's electricity, and 23% by 2040. Climate variability represents 3% of an electricity loss per year.

ACKNOWLEDGEMENT

The editors would like to acknowledge the efforts of all the institutions, scientific and technical staff who have collaborated on this work over the past years. This is evidence of a pragmatic approach to Science and Water Diplomacy, based on close and long-term collaboration between institutions, which tackles concrete and real problems in order to work towards the Sustainable Development Goals.

We would like to thank the DG International Partnership (INTPA), DG JRC, UNESCO, the African Ministers' Council on Water (AMCOW) and AUDA-NEPAD for envisioning the need for this collaboration between research institutions, which has been ongoing since 2009, and for understanding that it is only by working together over the long term that challenges of an often complex nature can be tackled and resolved.

SUMMARY

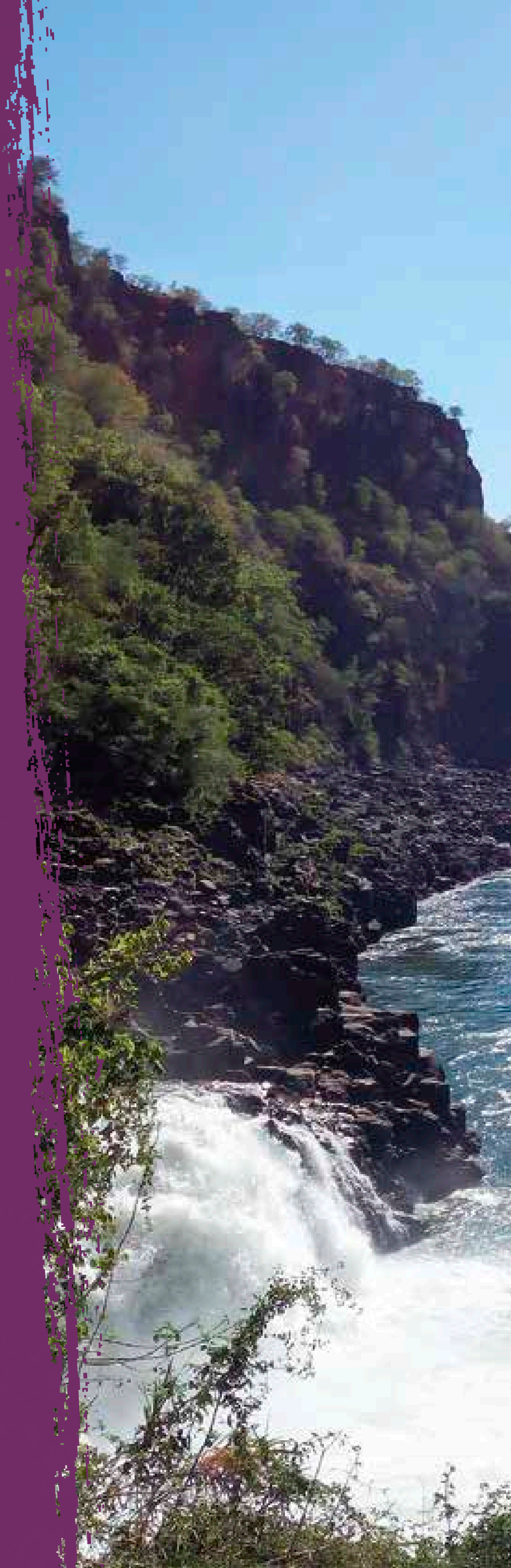
This report summarizes the main findings of the different activities that the Joint Research Centre of the European Commission and the different partner institutions are conducting within the framework of the Water Energy Food Ecosystem nexus analysis in sub-Saharan Africa.

After introducing the topic, the priorities and needs identified by the African institutions, and illustrating the response of the European Commission and its partners, the report illustrates the past and current state of the WEFE nexus dynamics in the region. It identifies the main challenges that the interconnected sectors within the nexus are likely to face in the coming decades. In particular, the region is expected to be strongly affected by global climate change affecting African regions unevenly and by rapidly changing socio-economic and demographic dynamics. These topics are analysed in a general way for the sub-Saharan macro-region, but also through specific case studies carried out jointly with the AUDA-NEPAD African Centres of Excellence on Water Science and Technology, in collaboration with AMCOW, AUDA-NEPAD, regional economic committees and river basin authorities. Concretely, WEFE nexus analyses are presented for the Senegal, Blue Nile and Lake Victoria, Zambezi, and Niger Basins, with particular focus on the main challenges related to water management and the application of the WEFE nexus approach. Challenges with regard to integrated water management are thoroughly discussed and then structured in a set of concluding messages, followed by a set of policy recommendations drafted from the interaction between the scientific community and the institutional environment involved in water management across the sub-Saharan African region.

The publication also includes a series of seven factsheets ("The Science Behind the Debate") which deal in more detail with topics of particular relevance in Africa and which complement the technical report.

1.

INTRODUCTION



INTRODUCTION

On 22nd November 2006, African Ministers and the respective Councils for Science and Technology and for Water (AMCOST and AMCOW, respectively) met in Cairo, Egypt, to recognise the need to create a coordinated network of African Centres of Excellence to support policy makers. These centres would focus on understanding the different thematic priorities and creating and managing the knowledge, information and data needed to address key African challenges. Finally, the centres would be responsible for developing and training appropriate expertise and proposing concrete solutions to policy makers under the leadership of AUDA-NEPAD and with the support of the AMCOW Executive Secretariat. By resolution, Council delegates committed to establish the AUDA-NEPAD Network of Centres of Excellence on Water Science and Technology as a first step in this objective.

Since 2009, in the framework of the ACEWATER project, the European Union has started to support the implementation of such an African network. Its main objectives are research, knowledge development, sharing of technology, knowledge transfer and human capacity development for junior and senior professionals and technicians in the water sector in Africa. The project is funded by the Directorate General for International Partnership (DG INTPA) and coordinated by the Joint Research Centre (JRC) of the European Commission with the collaboration of UNESCO - Intergovernmental Hydrological Programme (IHP). The project addresses the main continental and regional priorities in the water sector, as defined by the African Union (AU), African Ministers' Council on Water (AMCOW), Regional Economic Communities (RECs), River Basin Organisations (RBOs) and other key stakeholders.

Over the past four years, research has been carried out in close collaboration between the JRC, UNESCO-IHP and more than 30 research institutions, including the AUDA-NEPAD Centres of Excellence in Africa, to jointly address scientific and technical key challenges related to the Water, Food, Energy and Ecosystem (WEFE) nexus. The scientific and technical analyses were undertaken in the main transboundary African river basins, namely the Gambia, Senegal, Niger, Blue Nile, Lake Victoria and Zambezi river basins. This research demonstrates that an integrated analysis must necessarily address the environmental and socio-economic issues that accompany the development of these sectors. In addition, human capacity development (HCD) in the context of WEFE nexus is also a key element, closely linked to the basic concepts of sustainability.

The work carried out by such a collaborative network, with the support of the EU, UNESCO, AMCOW and AUDA-NEPAD, provides a solid basis on which to build the future strategy for scientific and political cooperation in the region. **Future objectives** for the coming years should be established around a **Think Tank under the aegis of AMCOW** to bring together policy makers, research and training institutions, while including the private sector. This will help meeting the increasingly complex challenges that will arise over the coming decades. DG INTPA, together with the JRC, UNESCO-IHP, AMCOW and AUDA-NEPAD, will also have there the opportunity to make even more ambitious progress under the umbrella of the **Joint Africa-EU Strategy**[4]. This collaboration will have to take into account the development of a sustainable green economy, improving the access to energy and contributing to digital transformation (satellite data processing, improved communications and strengthening of analysis capacities that should lead to better knowledge sharing, capacity building and the development of more efficient information networks). It should also work towards the creation of more sustainable economic growth and jobs by working together for more constructive cooperation and governance, and contribute to more sustainable migration and mobility, thereby ensuring regional stability by building it on their own capacities.

The continuity of this collaboration will enable better information availability for policy makers to adopt knowledge-based decisions, hence being able to address current and future challenges at regional, national and local levels. The results of this study will contribute to the **AMCOW African Knowledge Hub**[5] to make knowledge and products easily accessible to AU member states and their key stakeholders. The ultimate objective of these studies was to encourage and support the engagement of all partners in learning, knowledge development and sharing and information creation and exchange, to properly tackle the underlying issues at the base of sustainable development.

4 https://www.europarl.europa.eu/RegData/etudes/STUD/2017/603849/EXPO_STU(2017)603849_EN.pdf
5 https://knowledgehub.amcow-online.org/

1.1 Why this report? Need for scientific applications to the water management in Africa

As Africa's sustainable development largely depends on goods and services derived from its natural capital, the management of the continent's natural resources, especially water, constitutes a critical aspect with regard to the achievement of the Sustainable Development Goals (SDGs). Currently, there is a great potential for development in the agri-energy sector: only 15-30% of Africa's hydropower potential is developed (AMCOW, 2016), and the huge irrigation prospects in its 64 transboundary river basins are not properly leveraged to ensure food and nutritional security. However, water insecurity is an undeniably limiting factor, exacerbated by complex hydrology, climate change and growing demand.

Therefore, it is necessary to assess key emerging priorities for the African water sector, within the context of the express plans for productive use of water in the sectors of energy and agriculture. According to a recent study (Mbaziira, 2020b), the following priorities could be listed:

1. Promoting a new narrative on water that recognises the full potential of water in the economy to further Africa's future development needs. The new narrative should foster an appreciation of the vitality of water in economic growth; job creation; and industrialisation. It should also raise the business case and profile of water in national and regional development. Indeed, aggressive efforts are required to: 1) improve the position of water in the economy; 2) accelerate the pace of water infrastructure investments; 3) increase awareness of water's critical role in enhancing job creation; and, build on the foundations of integrated water resources management in order to advocate for approaches such as the Water-Energy-Food-Ecosystem (WEFE) nexus.

2. Strengthening the business case for water investments, as well as raising the profile of water in national and regional development in Africa. The economies of many countries in Africa are extremely vulnerable to climate variability and climate change, as they are largely based on natural resources (water, land, energy, forests/ecosystems). In this context, the lack of investments to enhance human and institutional capacities, build infrastructure and improve information systems to support water management exacerbates the difficulties.

3. Water infrastructure development should be advocated for, and promoted as a means to provide a service – water – to the economy, in order to enable growth and boost development. Water sector interventions, especially for such resource management functions as water storage and flood control, should not be designed and marketed from the perspective of 'water sector development'. Rather, the approach to packaging them for investment should be centred on their eventual utility – from an economic perspective – in terms of providing water for food and energy production. This should be extended to the opportunities for employment and wealth creation: not to mention peace, social security and political stability.

4. Application of the High Level Panel on Water (HLPW[6]) principles for valuing water could benefit the strategies aimed at improving the investment outlook for water and related resources development. The principles provide a guideline for determining the real value of proposed investments; the associated costs; and the benefits that can be expected. In essence, they serve the purpose of improving the appreciation of the economics of water in a country, river basin or region. The application of the principles – together with targeted interventions to catalyse change – are promising for the delivery of sustainable solutions, in order to provide water for energy, food and environmental security in Africa.

5. Investment led transboundary management and governance of water and environmental resources. The aim is to consolidate and capitalise on the achievements to-date of implementing the principles of Integrated Water Resources Management (IWRM). To this end, the African Water Resources Management Priority Action Programme 2016–2025 (WRM-PAP), the AMCOW Strategy 2018–2030, and the Africa Water Investment Programme (AIP) promote the following strategic initiatives: 1) establishing economic accounting for water to improve the financing and investment outlook for water resources management; 2) enhancing national-level capacities for collecting complete and reliable hydrometeorological and piezometric data; 3) applying nexus perspective solutions to assure water, food and energy security; 4) improving agricultural water management; 5) implementing the Programme for Infrastructure Development in Africa (PIDA) transboundary water and energy projects and; 6) enhancing the use of wastewater and sludge for nutrient recovery in agriculture and bio-gas energy production.

6 The High Level Panel on Water (HLPW) was co-convened in 2016 by the UN Secretary General and the World Bank President. It aims to identify suitable options to work towards SDG 6 (ensuring availability and sustainable management of water and sanitation for all)

1.2 Not only science, but also Human Capacity Development

African ambitions for growth and transformation, as envisioned in the African Union Agenda 2063 (AUC, 2014), depend on ensuring water security due to the influence of water access and use on the overall economic output. Besides, the Africa Water Vision 2025 (UNECA, 2003) recognises the necessity of improving water wisdom (the recognition of the unique value of water, leading to sustainable, equitable and efficient water management) to fulfill the aspiration of a prosperous Africa, based on inclusive growth and sustainable development. However, the current situation regarding Human Capacity Development (HCD) in Africa is worrisome: according to the African Development Bank (AfDB), the continent has only 35 scientists and engineers per million inhabitants, in comparison to 2,457 for Europe and 4,103 for the United States (AfDB, 2012). Hence, Africa needs to foster its progress in science, technology and innovation, but African students generally show preference for social and economics subjects and the presence of capacity constraints in the water sector threatens the achievement of Africa's development agenda. Besides, the low investment in research and development constitutes a barrier to the global competitiveness and productivity of the continent.

In order to add value, HCD programs in the water sector must reflect national circumstances, be informed by appropriate institutional schemas and integrate sectorial and national development aspirations. Therefore, they should be designed to overcome several challenges already detected through previous experiences, such as the lack of clarity about the focus of HCD programs aimed at junior water professionals and technicians, the inadequate connectivity and collaboration between key institutions, the performance of non demand-responsive HCD assessments (whose outcomes were generally neither institutionalized nor sustained), the existence of High Education (HE) and Technical and Vocational Education and Training (TVET) programs unable to properly address the sectorial needs (and which trigger a negative perception of the industry towards the new graduates) or the absence or inadequacy of specific internship or mentorship initiatives for students, trainees or participants in lifelong learning (LLL).

In this context, the education and training sector in Africa is currently undergoing strategic reforms, which could offer a suitable framework to identify and implement the main HCD priorities for the water sector. Concretely, these priorities could be divided into four broad categories (Mbaziira, 2020a):

1. Building critical missing skills: particularly, in the fields of sustainable development and the management and use of water and related resources. The main goal is to foster economic growth and social transformation, through the encouragement of technological empowerment, e-education and adaptive learning.
2. Updating and transforming the HE and the TVET sectors: to integrate flexibility and adaptability for current and continuous learning in the education and training supply. In particular, TVET is regarded as the most relevant training level where the biggest HCD gaps must be addressed.
3. Supporting Earth observation science and research, teaching and outreach: the application of space science and technology to effectively manage resources such as water, land, forests, and marine ecosystems offers multiple opportunities that are currently unleveraged. The use of space technology is also of key relevance in the generation of acutely needed information to support decision making for the sustainable utilisation of the resources.
4. Recognition of competences from non-formal and informal education and training (NFET): this significant goal is twofold: firstly, to ensure the access to existing technological preferences, cultural practices, local values and traditions of community learning to impart life skills for a wider contribution to management and running of a water sector and; secondly, contribute to integrating of mainstreaming indigenous water and pollution management knowledge and practices into LLL systems as well as into the education and training sector.

1.3 The EC response

In the **Agenda 2030**, the establishment of a sustainable development target dedicated to water (**SDG 6 - Clean Water and Sanitation**) reflects the importance of water and sanitation issues on the global political agenda, but water is also linked to other SDGs. This is the case for those related to governance, policy making and policy coherence (target 16.6, target 16.7 and target 17.14) and community involvement in water resources management (target 6.b and target 1.b), while using the principles of integrated water resources management (target 6.5) with overall benefits for poverty reduction (target 1.2) are presented in what can be considered the "software" of the water resources management system.

On the other hand, the linkages between the SDG targets on access to and supply of clean water (targets 6.1, 9.4, 9.a), and appropriate disposal and management of wastewater (target 6.2) in an urban (target 11.6) and rural environment critical to human health (targets 3.2 and 3.3) are described in what is considered the "hardware" of the water resources management system.

Target 6.3 on improving water quality by reducing pollution and untreated wastewater, eliminating discharges, minimising discharges of chemicals and hazardous materials is one of the most important leverage points in this model of interconnected systems.

The use of wastewater (target 6.3) for energy production (target 7.1) through innovation (target 9.b), contributes to the creation of new decent jobs (target 8.5) and to overall economic growth (GDS 8). Another important impact concerns sanitation and hygiene (target 6.2) and the use of wastewater for food production (target 2.4 and target 12.4) in peri-urban areas.

By recognising the important role played by water in development, through the **European Consensus on Development**[7]**,** the EU and its Member States have confirmed their intention to support increasing access to water, sanitation and hygiene (WASH) services and to promote integrated water resource management (IWRM), conservation of water resources, and enhanced water-use efficiency and recycling.

More recently, the EU Council adopted conclusions on **Water Diplomacy (2018)**[8] and **EU Human Rights Guidelines on Safe Drinking Water and Sanitation (2019)**[9]. In these Council conclusions statements, the EU and its Member States recall that water is a prerequisite for human survival and dignity and a fundamental basis for the resilience of both societies and the environment. They call for an enhanced EU diplomatic engagement on water as a tool for peace, security and global stability, and reaffirm the EU's commitment to the human right to safe drinking water and sanitation.

Water also represents an essential component of nearly all the climate adaptation and mitigation and strategies under the **Paris Agreement**. It is identified as a priority for most of the **Nationally Determined Contribution's** (NDC) adaptation actions and is directly or indirectly related to all other priority areas[10]. Overall, climate change and an increasing variability will exacerbate water scarcity, flooding and sea level rise. There is also a link to climate change mitigation, as water infrastructure is a large (and often inefficient) consumer of energy. The increasing scarcity of water resources, combined with increased demand for water, food and energy due to constant population growth, requires intersectoral, holistic and integrated water management approaches and frameworks. Priorities should focus on access to water and sanitation, efficient use of water in agriculture, industry and energy. As we have seen at the beginning of this section, integrated approaches such as the links between food, water and energy (**WEFE NEXUS**)[11] should be promoted to ensure synergies and enhance the sustainability of intervention projects. The World Committee on Food Security issued a special report on water for food security and nutrition with clear policy recommendations[12]. In this way, the EU promotes sustainable water use in the water-energy-food-ecosystems (WEFE) nexus in its Green Deal:

- ***Policy*** – promote water-friendly sustainable agriculture, energy and industrial consumption and production where relevant, using economic incentives that encourage efficient and sustainable water use. Minimise industrial, agricultural and chemical pollution as a basic approach in agriculture, industry and energy policies and programmes. Promote the reuse of wasted waters and the deployment of nature-based solutions for water provision and rainwater

7 https://ec.europa.eu/international-partnerships/european-consensus-development_en
8 https://www.consilium.europa.eu/media/37022/st13991-en18.pdf
9 https://www.consilium.europa.eu/media/39775/st10146-en19.pdf
10 UNESCO, UN-Water, 2020. United Nations World Water Development Report 2020: Water and Climate Change, Paris, UNESCO.
11 https://ec.europa.eu/jrc/en/publication/position-paper-water-energy-food-and-ecosystem-wefe-nexus-and-sustainable-development-goals-sdgs
12 CFS, 2015, Water for food security and nutrition. Available at: http://www.fao.org/3/a-av046e.pdf

discharge, wastewater treatment, and disaster-risk reduction. Promote innovative technologies.

- ***Capacity and exchange of best practices*** – develop capacity and promote awareness and development of norms, standards and cultural behaviours that understand and value water, also in line with EU approaches. Develop capacity in sustainable water management in the energy and agricultural sectors, as well as for the integration of disaster risk management and climate change in water management. Strengthen educational thematic structures and vocational training.

- ***Investment*** - promote/mainstream water use efficiency, re-use, recycle, reduce and sustainable water management in all water related investments; enhancing investment in multi-purpose and climate proofed water management infrastructure that increases efficiency, especially in vulnerable catchments; promote do-good approaches in the planning of new infrastructures or the rehabilitation of existing ones.

In this context, the European Union is actively cooperating with the African Union in the frame of the **Joint Africa-EU Strategy** to promote an integrated approach to water development in Africa. Concretely, the Water, Energy, Food and Ecosystems in Africa (WEFE-Africa) work programme of the Joint Research Centre of the European Comission (DG JRC) implements initiatives in collaboration with the directorates of International Partnership (DG INTPA) and Environment (DG ENV) on WEFE Nexus assessment in relevant river basins in Africa. The integrated multi-sectoral approach to water management at river basin level is combined with proactive and all-inclusive cooperative dialogues. The dialogues draw participation from the policy organs and decision makers of such African institutional partners as the Executive Secretariat of the African Ministers on Water (AMCOW), River Basin Organisations (RBOs); Regional Economic Communities (RECs); and research and academic institutions – including the AU-NEPAD Water Centres of Excellence with the objective of addressing the 10th AMCOW General Assembly (Dar Es Salaam, July 2016) – Decision 14.

With regards to the human capacity development (HCD) activities, the JRC, in collaboration with the UNESCO-IHP and the AUDA-NEPAD Centres of Excellence on Water Science, aim to foster sustainable capacity development in the water sector at the scientific, technical and institutional levels with the objective of addressing the 11th AMCOW EXCO (El Cairo, June 2013) – Declaration 12. A key aspect of the project is the alignment of the identified HCD priorities with the current implementation of the strategic and operational plans of the AU-NEPAD Centres of Excellence (CoEs). Therefore, the project aims to build synergies and complementarities and to avoid the duplication of efforts, maximizing results and impacts through the optimal use of available resources. Hence, the role of monitoring and evaluation (M&E) is to be highlighted, in terms of relevance, efficiency and effectiveness.

Concretely, activities conducted within the project framework include the celebration of regional consultative workshops and national dialogues with the main stakeholders, aiming to assess HCD needs in the water sector at different scales, to identify potential links to other relevant initiatives, to validate the outputs of the process and to inform its implementation. Pilot training courses were also a key part of the project and a difficult one due to the COVID-19 pandemic: it was necessary to perform a risk mapping and e-readiness assessment, in order to realign the planned courses and implement them online. Finally, M&E was carefully tackled through a specific developed tool, along with impact studies to assess the real significance of the project. In this regard, it should be highlighted that the role and visibility of the EC in the water sector in Africa has improved strongly thanks to the relationships established with the CoE and with their African partner institutions in the water sector.

2.

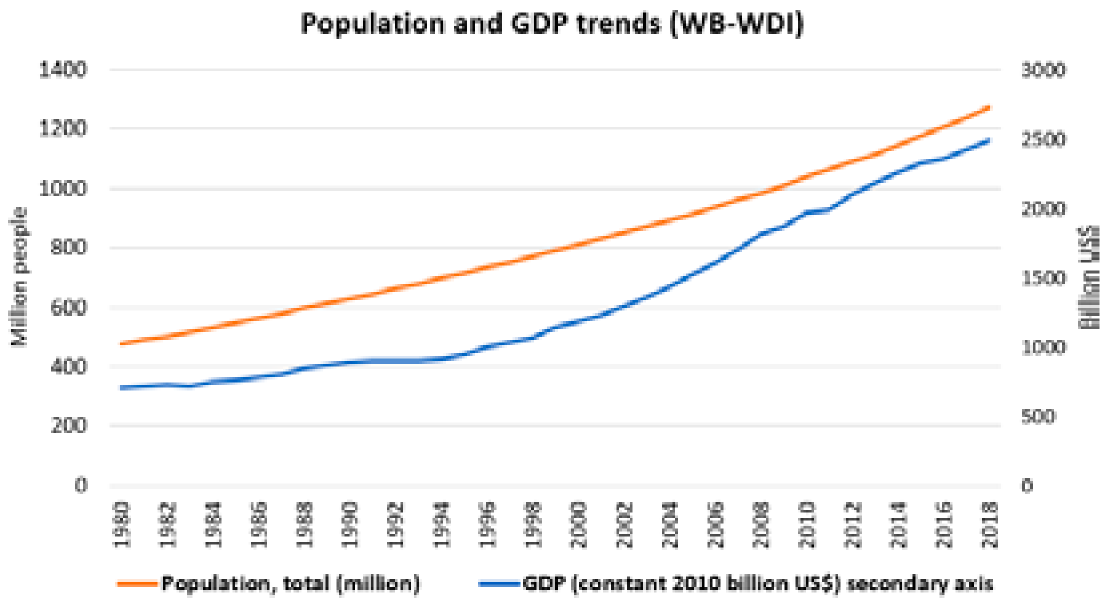
PAST AND CURRENT STATE OF THE WEFE NEXUS IN THE AFRICAN CONTINENT

2. PAST AND CURRENT STATE OF THE WEFE NEXUS IN THE AFRICAN CONTINENT

2.1 State of the art knowledge on WEFE nexus in the continent

The African continent is today the house of about 1.27 billion people, corresponding to roughly 16% of the world's population. In the past decades, demand for energy and food increased along with the population and economic growth. Crop production rose by more than 35% between 2006 and 2016, while demand for electricity increased by more than 20% in the same period. Current agricultural production is mainly rainfed. Irrigation and flood recession agriculture are highly developed in arid areas along the main rivers in Sudan, Egypt, Mali, Niger, Nigeria, Senegal, Namibia, and Zimbabwe. Only a minor fraction (about 5%) of the poorly available water resources are currently withdrawn, primarily in the Northern portion of the continent and mainly used for agriculture. Large investments in new irrigation facilities are foreseen in the coming years (FAO website, last access 2020).

Figure 1. *a) Population and GDP trends in the African continent 1980 – 2018 (World Bank, n.d.); b) crop production index (2004-2006 = 100) and electricity consumption trends1980 - 2016 (US EIA, n.d.; World Bank, n.d.)*



Majority of the continent's electricity is produced in a network organized in 5 power pools (West, Southern, North, Eastern and Central African Power Pool, respectively), which aim to coordinate power system planning and operation across their member countries (Figure 2) through growing interconnection levels and a gradual implementation of market-based integrated approaches (De Felice et al., 2019; Busch et al., 2020; Pavičević et al., 2020; IRENA, 2020). Hydropower represents the main renewable electricity production source in the continent and the second source after fossil fuel powered thermal production (Gonzalez Sanchez et al., 2020; US EIA, n.d.). However, Africa still has the highest untapped hydropower potential in the world, as it is estimated that only 11% (37 GW) is currently used (IHA, 2020).

Figure 2. *African Power Pools. Adapted from UNEP (2017)*

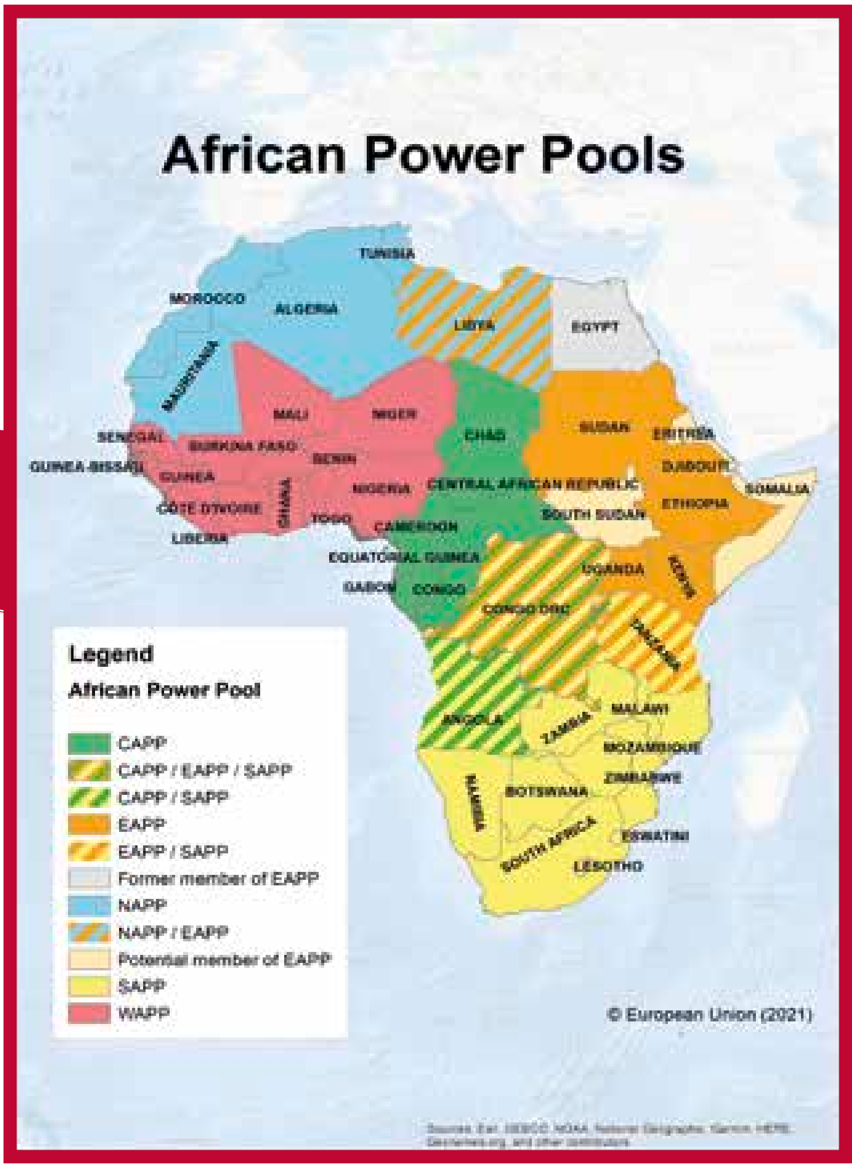
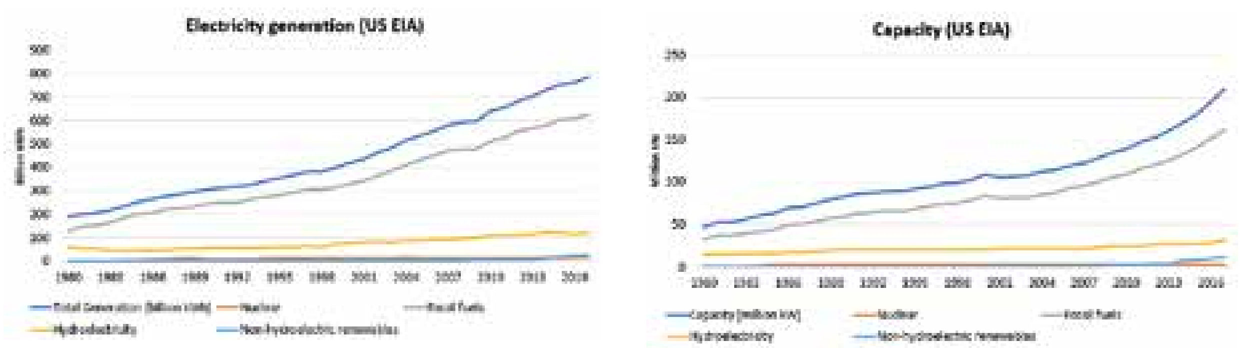
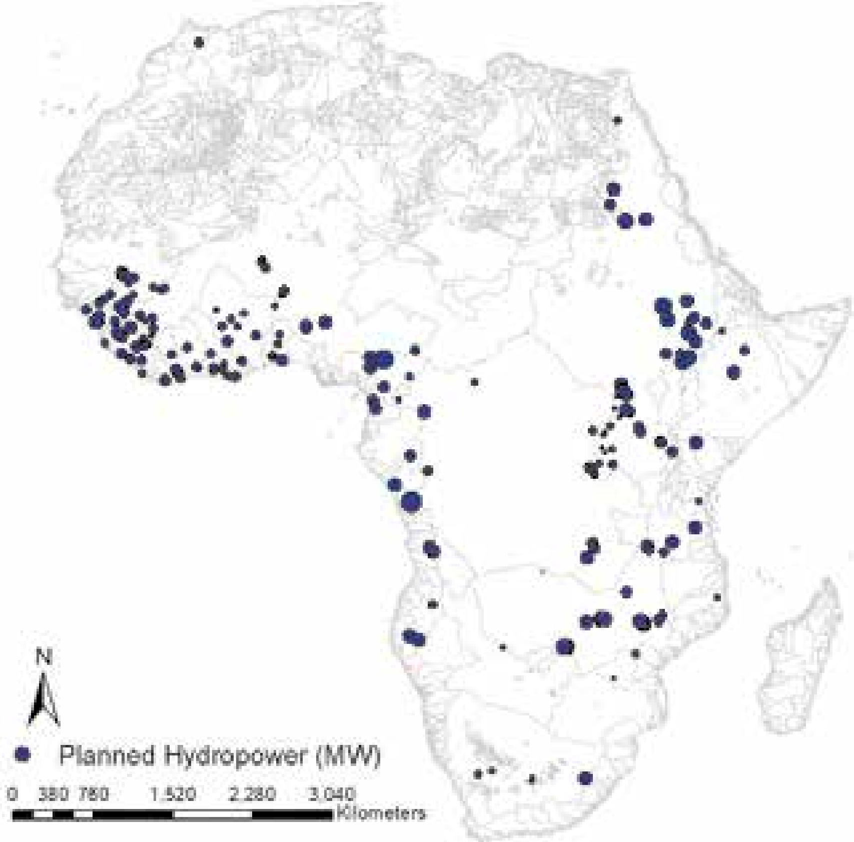


Figure 3. *Electricity generation (billion kWh) and installed capacity trends (million kW) in the African continent (US EIA, n.d.)*



Large investments directed towards the expansion of hydropower capacity are foreseen for the coming years, which will be translated into more than 200 new facilities according to Zarfl et al (2015). The majority of these new installations are planned to be implemented in the most water abundant basins and the wettest areas of the continent.

Figure 4. *Planned hydropower projects in the African continent (Zarfl et al., 2015)*



In addition to hydropower development, several ambitious water transfer projects are being considered in the main basins of the continent. Some of them are in an advanced state of development, as the "Lesotho Highlands Water Project" between Lesotho and South Africa, or the "Mzimvubu" and the "Mokolo and Crocodile River Water Augmentation" projects in South Africa. Other ones are in a less mature state of implementation, as the "New Nile" and the "Transaqua" projects, which plan to diverge water from the Congo basin to the Nile and towards Lake Chad respectively (Shumilova et al., 2018). Additional water transfer schemes were designed for the Zambezi basin, between Zambia, Namibia, Botswana, and Zimbabwe.

2.2 Water and Agricultural sector

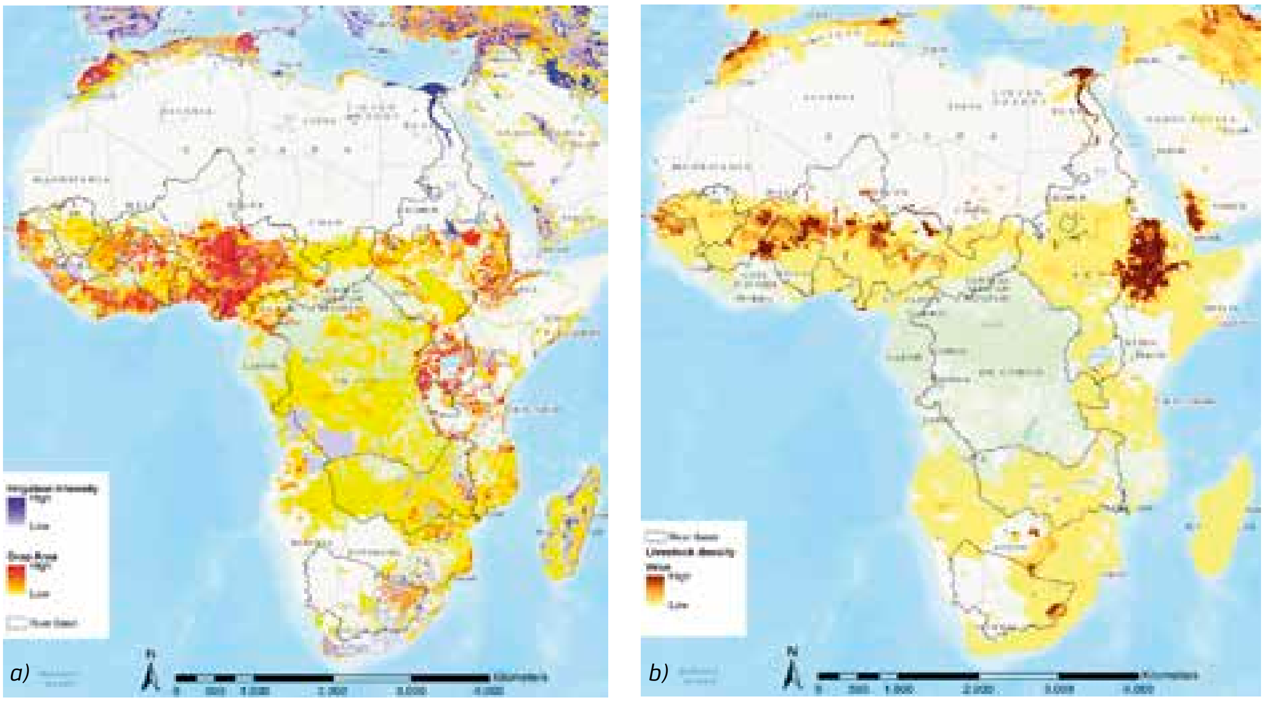
The demand for crops and other agricultural products is projected to increase following the population growth in the continent. According to a recent outlook (OECD/FAO 2020), population in the continent is expected to expand by more than 300 million people in 2030, boosting the demand for agricultural products and increasing the production by about 21% in terms of net value added (about 16% represented by crop production, 5% by livestock and fish farming). Main outputs are expected to be represented by roots and tubers, grains, and cotton. The expanded agricultural production is projected to be mainly the result of cropping intensification and increased production efficiency, but it will also soar the demand for agricultural land, with the harvested area expected to rise by about 4 Mha.

Demand for animal proteins, as bovine and ovine meat and poultry, is projected to grow steadily in the coming decade. The derived production growth will be mainly allowed by a modernization of the farming supply chain and techniques, but it will also cause an estimated 18% increase in GHG emission from the agricultural sector. Population growth remains the main factor determining the expansion of the overall agricultural sector, but also per capita consumption is expected to increase by 75 Kcal/day, reaching about 2510 Kcal/day. This value, despite being the world's lowest one, brings the African per capita consumption figures to about 80% of the world average (OECD/FAO 2020).

The continental agricultural market is expected to largely benefit from the implementation of the African Continental Free Trade Agreement signed in 2019, ensuring a reduction of the transaction costs by more than 90%. The main constraints to agricultural development are represented by the limited access to technology, lack of infrastructure, fragmentation of the suitable arable areas, limited water resources and large climate variability, and limited access to irrigation techniques in the areas where arable land is mostly available (OECD/FAO 2020).

Initiatives to increase the competitiveness of agriculture have been already envisaged in several African countries. For example, Tanzania has proposed to reduce or remove the agricultural produce cess, which is a turnover tax on marketed agricultural products charged by local government authorities (LGAs) at a maximum of 5% of the farm-gate price. Although it constitutes a significant source of revenue for many LGAs, it has been strongly criticized by farmers, agribusiness and stakeholders for hampering the competitiveness of Tanzanian agriculture, reducing farmers' incomes and their incentive to produce more commodities, and worsening food insecurity and poverty for consumers (Louhichi et al., 2020). In Kenya, the analysis of the impact of agricultural policies (with focus on fertilisers) showed a generalised decrease of food prices and a positive food access effect for all households in the country, along with an increase in food consumption under all simulated scenarios. However, this increase differed across households according to their income, dietary energy consumption, dietary diversity and children' nutritional status (e.g. for the poorest households the greatest increase in macronutrients intakes came from proteins, while for middleincome households it came from carbohydrates) (Ramos et al., 2020).. Another example is Ethiopia, where the government has introduced the Agricultural Commercialization Cluster (ACC) initiative, as a mechanism to improve agricultural productivity and production in high-potential areas for a limited number of priority commodities (wheat, teff, maize and barley) (Louhichi et al., 2020).

Figure 5. *a) Crop and irrigated areas; b) Livestock distribution. The figure reports also the boundaries of the main African Transboundary River Basins (Farinosi et al 2018b, Malago and Bouraoui, 2021; You et al., 2005 on MapSpam data)*



2.3 Water and Energy Nexus

In most African energy systems hydropower is the dominant renewable energy source and, according to the World Bank, electricity and water demands are projected to grow significantly up to 2050 in the continent, by 700% and 500% respectively, with respect to 2012 (Rodriguez et al., 2013). Other salient characteristics of these systems are their low electrification rates, small sizes, high shares of oil in the power generation mix, and the lack of significant power and gas interconnections.

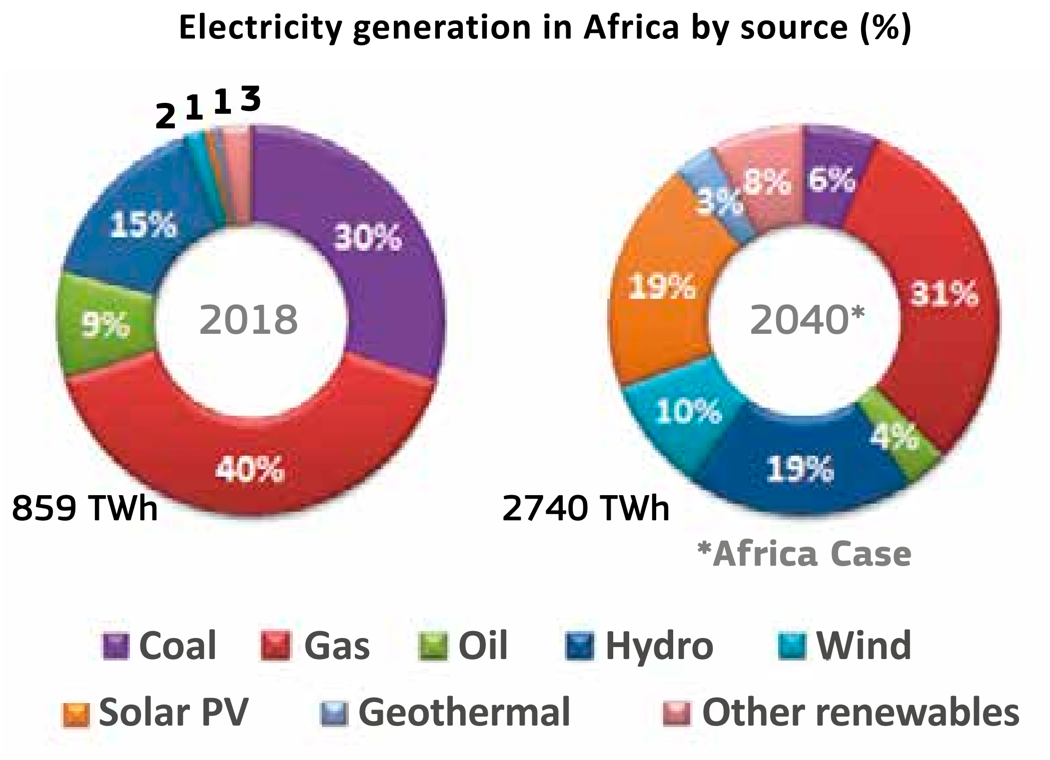
Power systems are constrained both by the availability and temperature of water resources, as thermal power plants need water for cooling and hydropower generation relies on water to operate. Therefore, climate variability has a strong impact on African energy systems (where hydropower is the dominant renewable energy source), affecting their energy mix, operational costs, CO_2 emissions and water consumption for energy generation. For example, in the North, Eastern and Central African Power Pools, differences between dry and wet years could vary the share of electricity coming from hydro units up to 5.2%, introduce changes in the operational costs around 1.4 billion € (or 3.28 €/MWh) and induce oscillations in CO_2 emissions up to 15 millions tons per year (Hidalgo Gonzalez et al., 2021). Besides, power systems may impact in the quantity and quality of the water resources. For example, water losses due to hydropower generation in Africa cannot be ignored: 42 billion cubic meters in 2016 (when the correspondent to all the other fuel types combined were estimated at 1.2 billion cubic meters). In this context, the use of non-hydro renewable energies instead of fossil fuels can contribute substantially to reduce water use while meeting the increasing energy needs of the continent (Gonzalez Sanchez et al, 2020). Moreover, grid interconnections could play a significant role, reducing water withdrawals and consumption for energy generation in comparison to the existing system configurations, as well as the average electricity price (Hidalgo Gonz alez et al., 2021).

The energy mix in Africa is expected to undergo significant changes in the next decades (Figure 6). Fossil fuels (gas, carbon, oil) will continue to contribute a significant share of the energy production, still with coal and oil expected to significatively shrink. Besides, significant differences at the regional level are expected with regard to other renewable energy sources: while North, Eastern and Southern Africa could obtain renewable energy from windpower, concentrating solar power (CSP) will be important specifically in North Africa, solar photovoltaics (PV) in both the Northern and Southern regions and geothermal sources in East Africa (IRENA, 2015).

In this complex framework, the geothermal energy, that currently accounts for a marginal share (2% of electricity generation in Sub-Saharan countries, excluding South Africa), will anyway experience a large increment of generated energy and then of installed power, up to estimated 4% in 2040. Among the main advantages of this energy source are its low environmental impact and greenhouse emissions when compared to energy generated using fossil fuels; a quite constant generation output independent from weather conditions (which makes it particularly suitable for base load electric generation); a competitive levelized cost of electricity generation (LCOE) and; less proneness to the instability of the international Oil and Gas (O&G) market. In this context, the East African Rift System (EARS) creates highly favourable conditions for the existence of geothermal systems at economically and technically drillable depths (less than 4,000 m), with a global potential estimated at 15,000-20,000 MW. However, currently only Kenya has exploited a small part of its geothermal resources, because the development of this energy source in Africa is still hampered by the absence of clear and coherent legislative frameworks; the lack of local technical and managerial skills; the remoteness of many geothermal areas in relation to O&G regions (where most of the drilling contractors and service providers are based); the inadequate financing at the early stages of the projects; the competition from other energy sources and; the issue of the remunerative price for the generated electric power in still poor developed national electric markets (Battistelli et al., 2021).

Despite the apparently limited relevance ot the geothermal energy, it is worth to note that few countries retains most of the potential, and particularly a few small countries could largely cover most of their electrical energy needs (e.g. Djibouti, Comores).

Figure 6. *Electricity generation in Africa by source (%) in 2018 and 2040 in the Africa Case scenario. Adapted from IEA (2019)*



3.

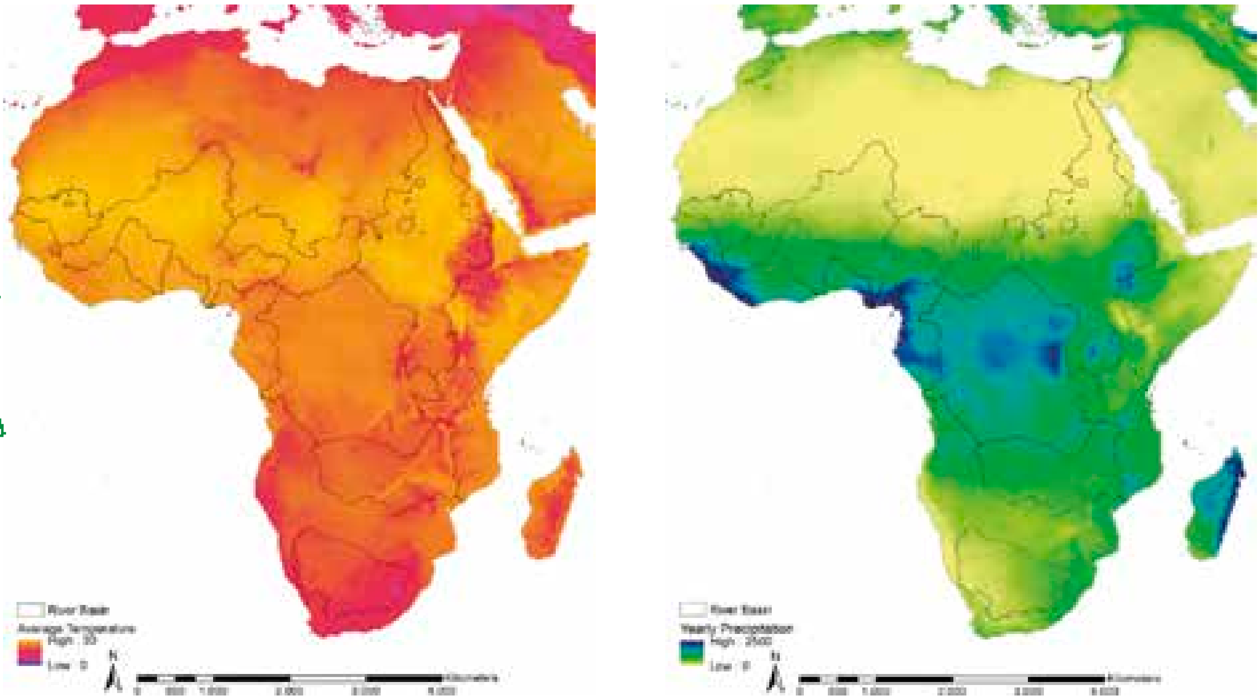
FUTURE CHALLENGES 1 – CLIMATE ANALYSIS CURRENT VS FUTURE

3 FUTURE CHALLENGES 1 – CLIMATE ANALYSIS CURRENT VS FUTURE

3.1 Climatic characterization of the continent

The continent is characterised by particularly scarce precipitations unevenly distributed over space and time (EC JRC et al., 2017). Areas characterised by a relatively more abundant precipitation are located in the Western African coastal area, in the Gulf of Guinea, Equatorial Congo, Lake Victoria area, and Ethiopia (Figure 7).

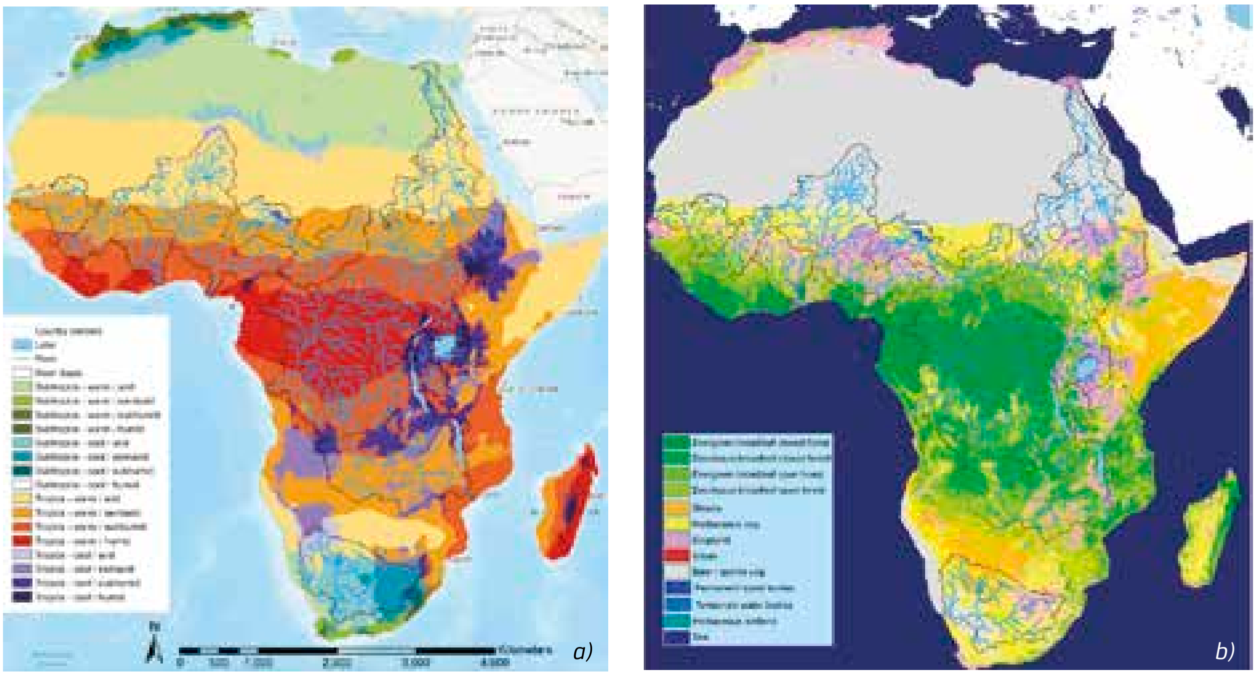
Figure 7. *Average Temperature (°C - left) and yearly total precipitation (mm - right) in the study domain in the period 1997-2012 (Farinosi et al. 2018 based on Beck et al., 2017 data).*



Excluding the most arid areas, precipitation patterns are characterised by a strong seasonality. Intra- and inter- annual climate variabilities are extremely high and cause a large uncertainty with regard to the management of natural resources in the most water intensive anthropological activities, as agriculture (Nicholson et al., 2018).

The Sahelian region has a pretty uniform precipitation pattern: after the 1960s, the precipitation heavily declined in relation to the relatively more abundant first part of the XX century, slightly going back toward an increase after the 1980s (Nicholson et al., 2018). Precipitation anomalies are heavily affected by the oceanic oscillations in sea surface temperature. Looking at the precipitation records, a decadal variability is apparent in the precipitation records after the 1930s; the Western and the Northern part of the continent experienced a significant downward precipitation trend in the past decades, with conditions radically changing after 1968 (Nicholson et al., 2018). The downward trends extended to a large part of the continent following the 1977/1978 La Nina driven shift in the Pacific equatorial area.

Figure 8. *a) Agro-ecological zones (Farinosi et al 2018b based on Sebastian, 2009 data); b) Land cover map (Farinosi et al 2018b based on Copernicus Service Information, 2017 data).*



The increasingly dry conditions heavily affected the already precarious food security position of the sub-Saharan African growing population. Looking at the projected precipitation trends for the coming decades, the situation does not seem to change towards more favourable circumstances (Dosio et al., 2019). Over the Northern portion of the continent, the precipitation regimes are not projected to change considerably. Besides, models do not agree on the possible changes in mean precipitation over Western Africa: some models projected slightly wetter, other dryer conditions. Most of them agree, however, in a reduction of the precipitation frequency and an increase of the dry spells over the region. Eastern Africa is projected to experience a slight increase in the mean annual precipitation, but in combination with an increased intra-annual variability, with more precipitation in the wet season and increasing dry spells in the dry one. Central and, in particular, Southern Africa are expected to undergo a major decline in the precipitation trends, both in terms of annual average and wet spells (Dosio et al., 2019). Dry spells, heatwaves, and drought conditions are likely to be more frequent and intense in the coming decades (Dosio, 2017; Dosio et al., 2018; Naumann et al., 2017; Spinoni et al., 2019), while more frequent floods are likely to hit the wetter portions of the continent (Alfieri et al., 2017).

The combined occurrence of the main hydro-meteorological hazards is expected to generally increase, especially in the regions where population change is projected to be more significant: therefore, the overall risk is likely to raise (Farinosi et al., 2019; Migali et al., 2018).

4.

FUTURE CHALLENGES 2 – SOCIO-ECONOMIC DRIVERS DETERMINING WATER USE IN THE CONTINENT

4 FUTURE CHALLENGES 2 - SOCIO - ECONOMIC DRIVERS DETERMINING WATER USE IN THE CONTINENT

4.1 Trends in climate extremes under different global warming scenarios, demographic change and urbanization

According to the most recent socio-economic projections, the African continent is expected to witness a considerable increase in the population figures (which are estimated to pass from 1.27 to 2 billion people in the coming decades, up to 2050; EC JRC et al., 2017; Riahi et al., 2017). Besides, Africa has the youngest population worldwide (77% is currently under the age of 35 and 2 in every 5 children in the world will be born in the continent by 2050) and urban population is expected to triple by 2050 (Hajjar, 2020). The different combinations of evolution, socio economic development and migration scenarios, are likely to change considerably the demographic variables in terms of fertility, mortality, age distribution, literacy, employment, and distribution of the economic resources. However, and although the Shared Socioeconomic Pathways (SSPs) scenarios (Riahi et al., 2017) describe these potential socioeconomic futures (considering the implementation of mitigation policies or their absence), their utility could be impaired because they do not incorporate the likelihood of growth disruptions (Buhaug and Vestby, 2019) . This could be particularly important within the context set by the current COVID-19 pandemic.

Considering the 3rd Shared Socio-Economic Pathway scenario (SSP3), the one characterised by a slow economic development, material-intensive consumption, and persistend inequalities; population growth is expected to be characterised by a lower pace in industrialised and higher in developing countries and a very sharp one in the developing world. In addition, the scenario is characterised by insufficient environmental concerns, leading to strong environmental degradation in some regions. Under this scenario, the African population is expected to increase rapidly, especially in the Western and Central-Eastern portions of the continent (**Figure 9**). Population growth is expected to be accompanied by a sharp urbanization rate (**Figure 10**).

Figure 9. *Population density change between a) 2015 and b) 2050 under the 3rd Shared Socio-Economic Pathway scenario (Baranzelli et al 2020)*

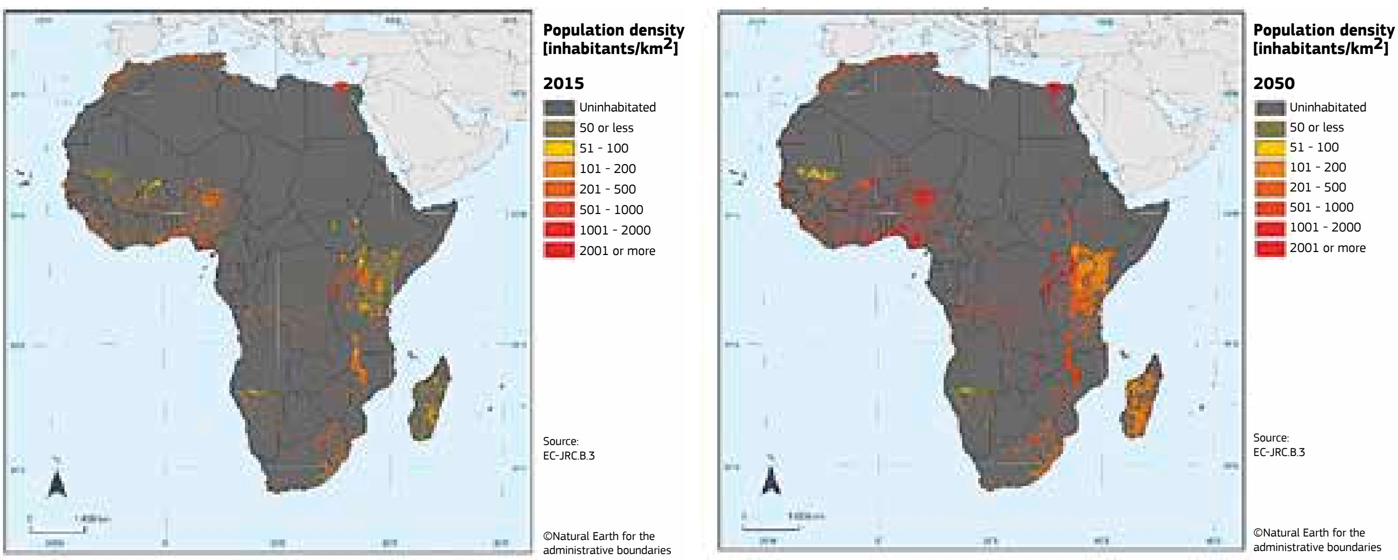
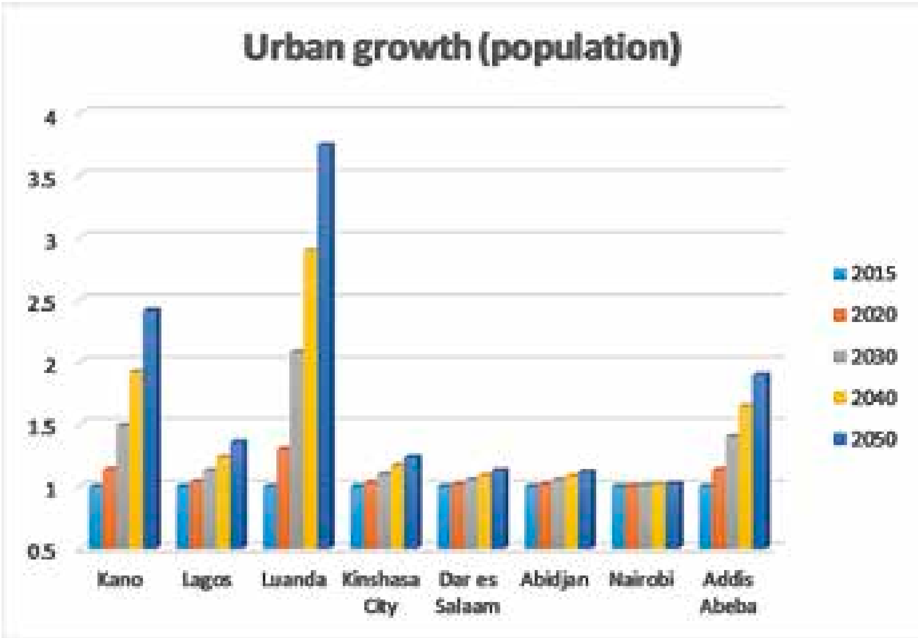


Figure 10. *Urban population growth for the period 2015-2050 in 8 cities (2015 population = 1), under the 3rd Shared Socio-Economic Pathway scenario (Baranzelli et al 2020)*



Climate change is expected to strongly impact the African continent and in particular the already stressed water resources (Farinosi et al., 2019). The evolution of the climate related dynamics is particularly impactful when combined with the socio-economic progression of the continent. The largest population change and a large part of the economic development worldwide, in fact, are expected to take place in the African continent in the next decades. Here it is presented a preliminary analysis of the potential exposure of population to future changes, with regard to the most impactful hydro-meteorological events in Africa under three Global Warming Level (GWL) scenarios.

Taking stock from the work conducted at the JRC in the specific fields (Alfieri et al., 2017; Dosio et al., 2018; Naumann et al., 2018), this analysis assessed the exposure of current and future African population to the increasing magnitude and frequency of collocated hydro-meteorological multiple hazards (drought, heatwave, and flood) under the Paris targets, respectively implying, 1.5 and 2 °C increases in Global Mean Surface Temperature (GMST) over pre-industrial levels (Frieler et al., 2017; Hoegh-Guldberg et al., 2018). In order to also assess the possible consequences of the inability to meet those targets, we considered an additional scenario which portraits a Global Warming Level (GWL) of 3°C, beyond the Paris targets (Raftery et al., 2017). The projections in climate extremes were combined with projections on population growth from the Shared Socio-Economic Pathway 3 (SSP3) (Riahi et al., 2017). The evolution of the hazards was studied both separately (Figure 11) and conjointly, in order to better understand how the synergies between multiple hazards, expected to reinforce one another, could threaten the future population in the continent. In particular, the study of the multi-hazard combination was conducted through the analysis of the distribution of the population share exposed to the overall hazard, and the analysis of the specific dynamics of the three combinations (Figure 12 a and b).

Taking West Africa as an example (and considering a normalized scale where 0 represents the lowest multi-hazard magnitude and 300 the highest one), in the baseline scenario 100% of the population (~300 million people) is expected to be on average exposed to a multi-hazard magnitude larger than 25 (interquartile range 0-40), while the most exposed 10% (~30 million people) could face up a value above 100 (75-135). In a 3°C GWL scenario, 100% of the population (projected to increase from ~300 to ~790 million) would be exposed to a multi-hazard average magnitude greater than 50 (15-70), while the most exposed 10% (~79 million people) would deal with a magnitude of about 200 (165-250). More in general, the increase of the multi-hazard exposure between 2°C and 3°C is considerably higher than between 1.5°C and 2°C scenarios.

The rise in multi-hazard exposure over the Mediterranean Region (+120% in a 1.5°C, +200% in a 2°C, +400% in a 3°C global warning scenario with respect to the reference scenario), North-East and West Africa (with similar increases of about +200%, +300%, +700% respectively) results from the combination of changes in both the hazards frequency and population exposured.

Figure 11. *Spatial distribution of drought (SPEI – Standardized Precipitation and Evaporation Index) and heat wave (HWMId – Heat Wave Magnitude Index) at global level (Farinosi et al., 2019)*

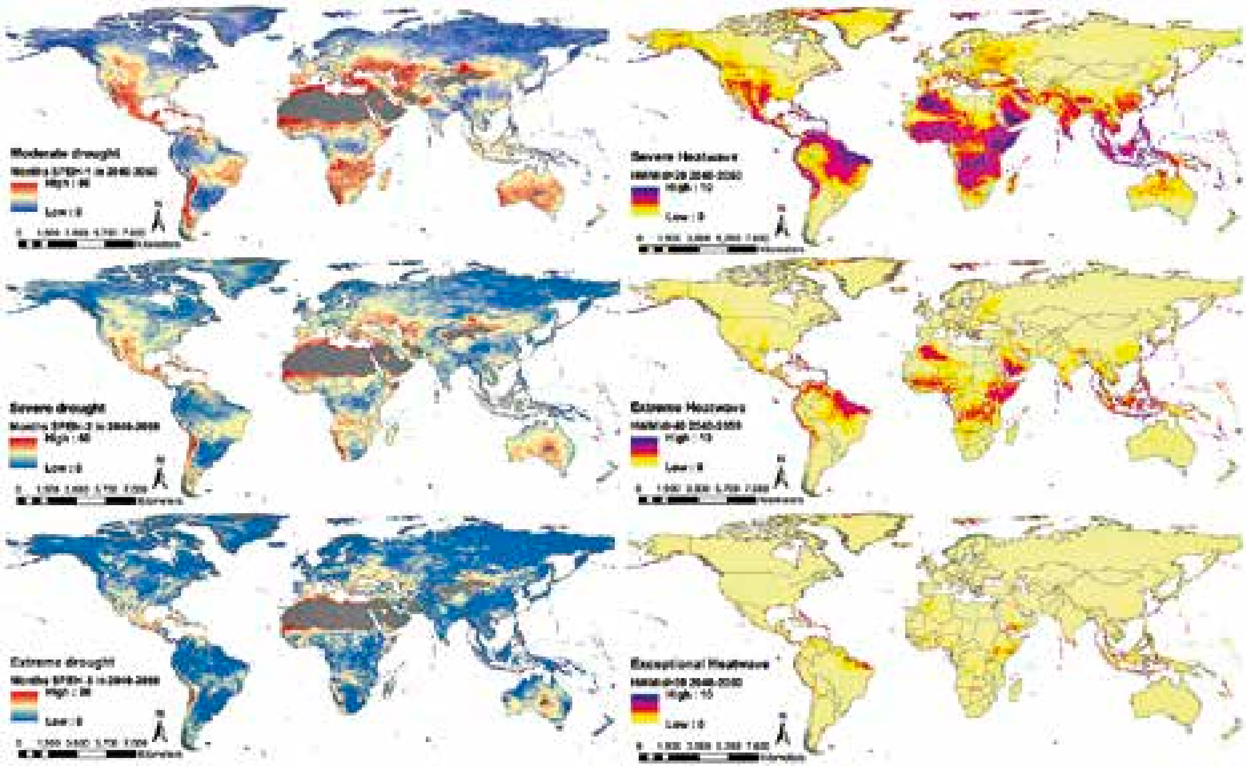
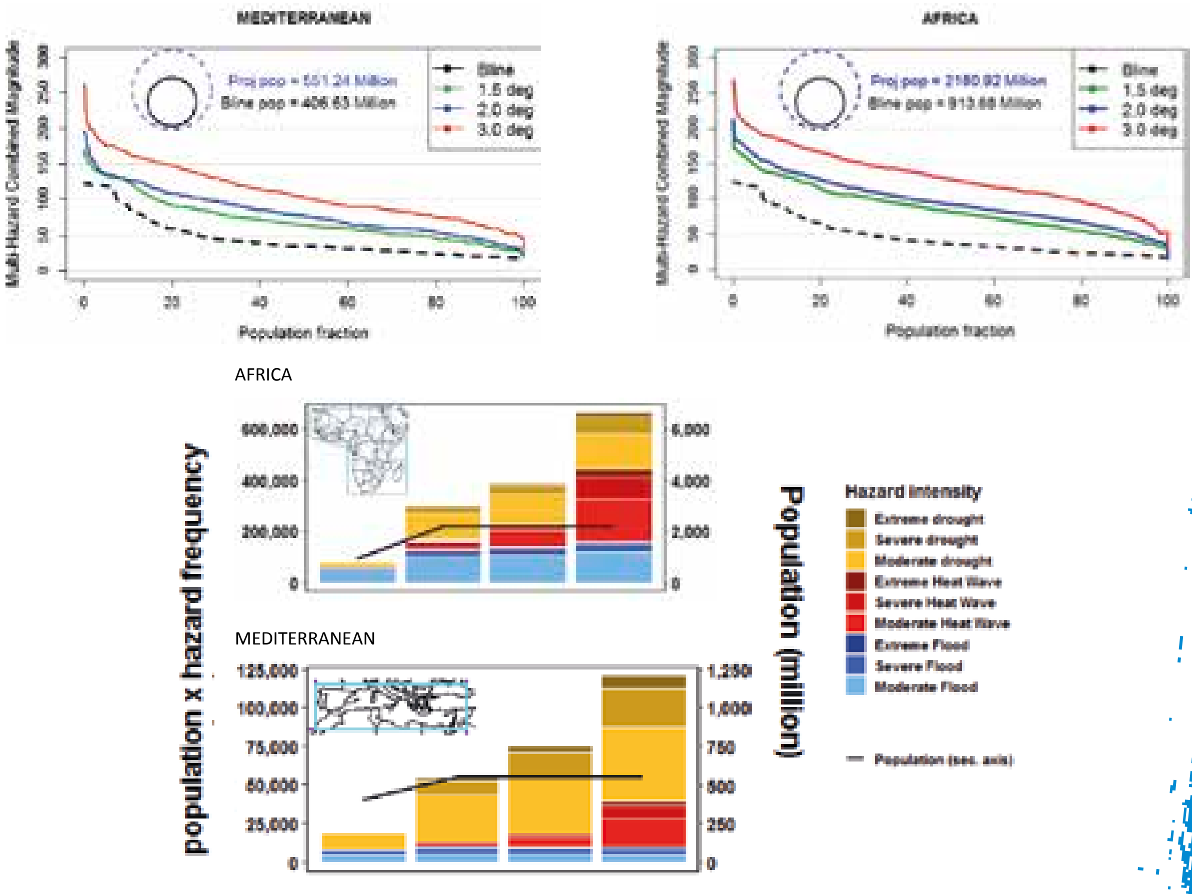
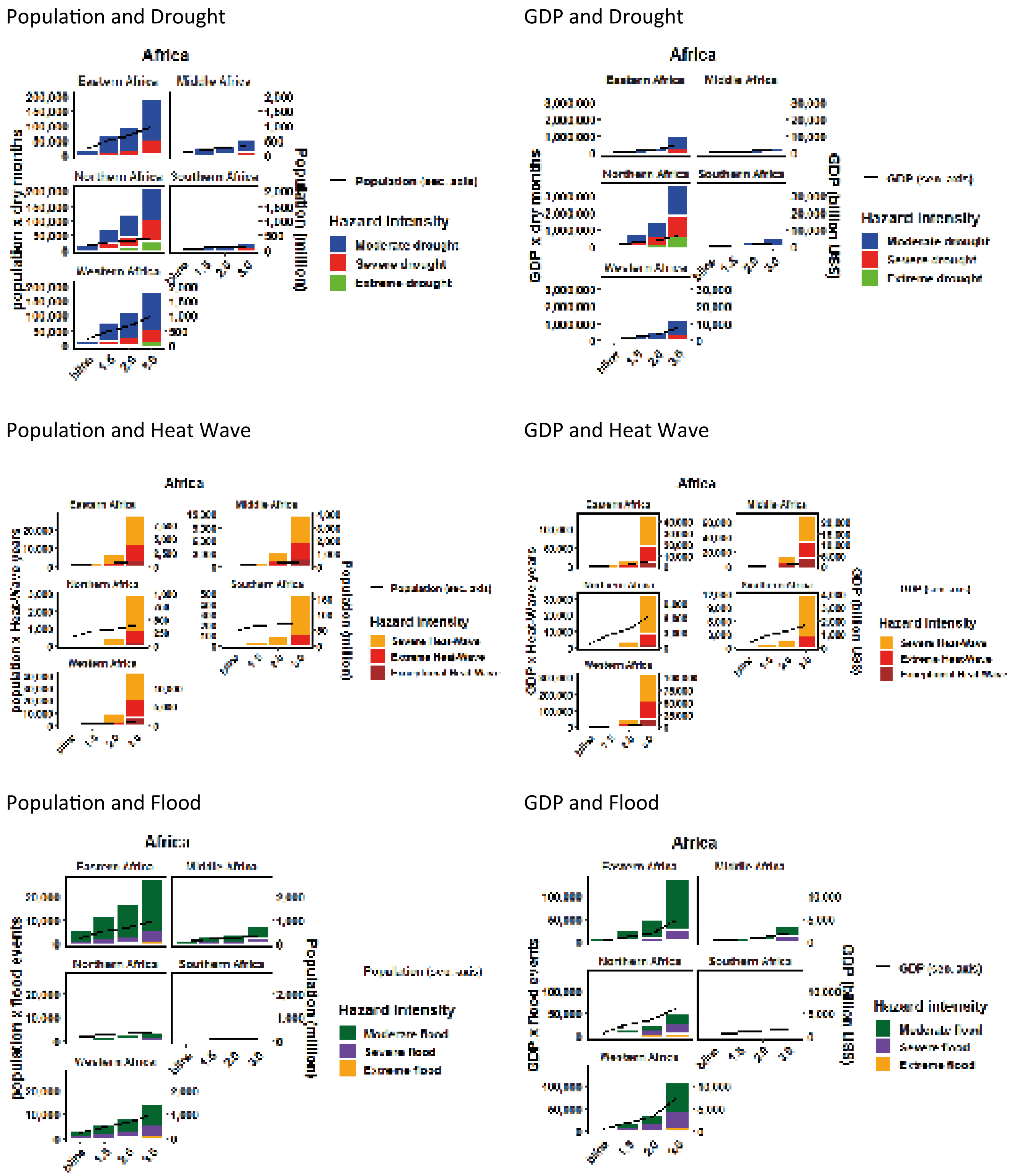


Figure 12. *a) Share of the population exposed to the multi-hazard situation (combined magnitude normalized to a 0-300 scale) for the reference and global warming levels by continent; b) Continental level, population exposure to the three degrees of the intensity (moderate to extreme corresponding to lighter to darker colours) of the three hazards (flood-blues, heat waves-reds, and drought-browns) for the three warming levels (Baseline, 1.5, 2, and 3 degrees increase in GMST). The black lines show the population (in million on the right axis) between 2010 (baseline) and 2050 (projection). Left axis represents the exposure level, here defined as Exp=Pop*Haz (population times hazard frequency) (Farinosi et al., 2020, 2019)*



Breaking down the exposure of population and Gross Domestic Product (GDP) to the different classes of the three hazards, the increase with the GWL is evident in all the cases for each of the African regions.

Figure 13. *Exposure of population and GDP to the hazards considered in the African Regions (Farinosi et al., 2019, 2020)*



Limiting global warming to the Paris Agreement temperature targets (1.5ºC and 2ºC, respectively), would substantially decrease the share of the African population exposed to three widespread hydro-meteorological hazards – droughts, heatwaves, and floods – against a 3°C warming scenario. Concretely, we found that keeping temperature increase below 2°C would reduce the share of population exposed to the combined extreme hydro-meteorological events by more than 50%, in Africa. Additional efforts to limit it to 1.5°C would further reduce the exposure by about an additional 10 to 30%. The high exposure of the African population to extreme hydro-meteorological events could exacerbate the issues related to water management in the African regions (Farinosi et al., 2020, 2019, 2018a, 2018b).

4.2 Climate and socioeconomic drivers in critical water management

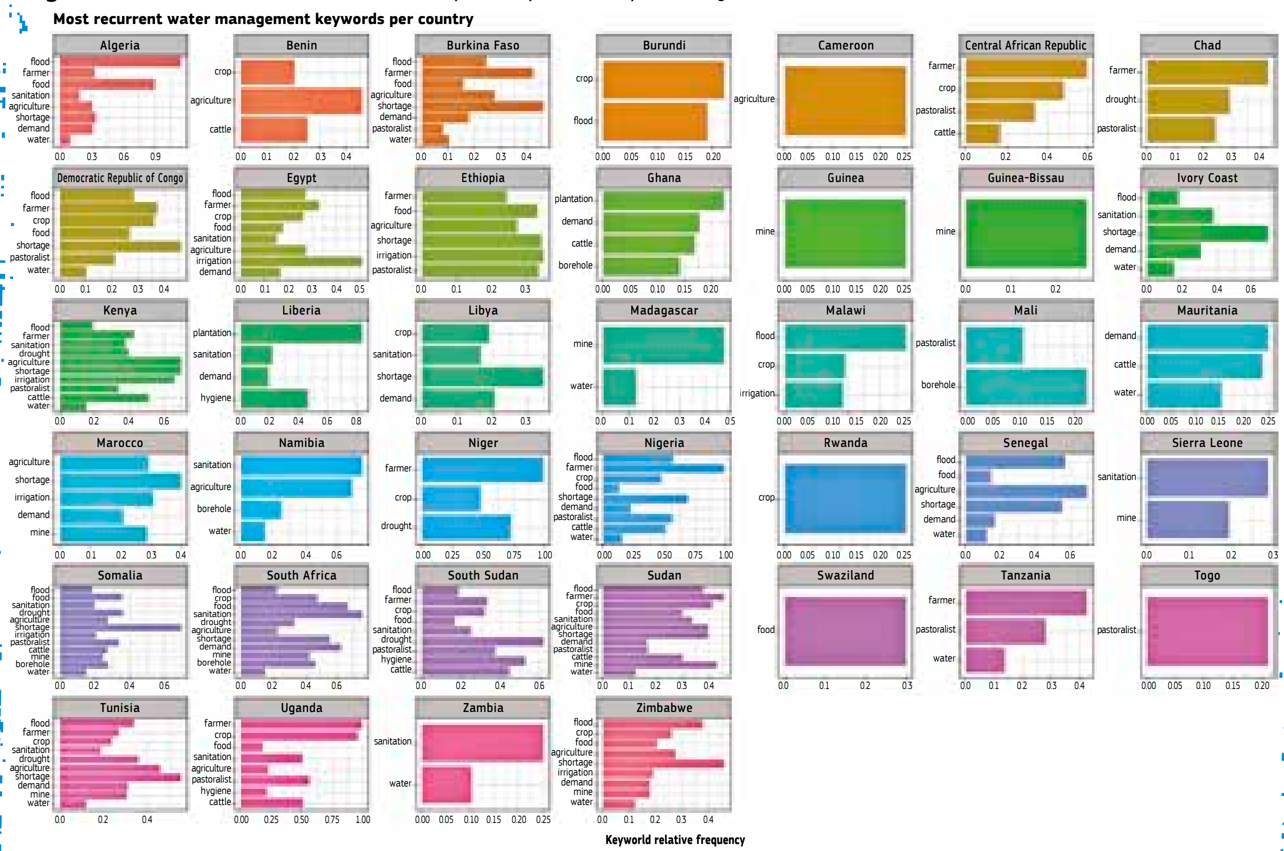
The Armed Conflict Location & Event Data Project (ACLED) (Raleigh et al., 2010) offers a collection of political violence and protest events across the developing world. The type of collected data include details about date, actors involved, type of violence, location and fatalities, accompanied by a brief description of each of these events. The ACLED database was not specifically designed to collect records of episodes of violence related to water resources use and management. The original dataset, including more than 162 thousands episodes of violence (162,705), was subset in order to identify the episodes related to water resources management by means of a selection of keywords.

The selected keywords are related to several aspects of the broader water management topic, such as: water management, water price, water availability and uses, water supply and sanitation, wastewater treatment, agriculture, irrigation, food production, natural hydro-meteorological hazards and disasters. Particular attention was paid to avoid including events in which water was used to sedate the protest, as for instance in the case of water cannons usage, or in the case of the territorial disputes over marine areas.

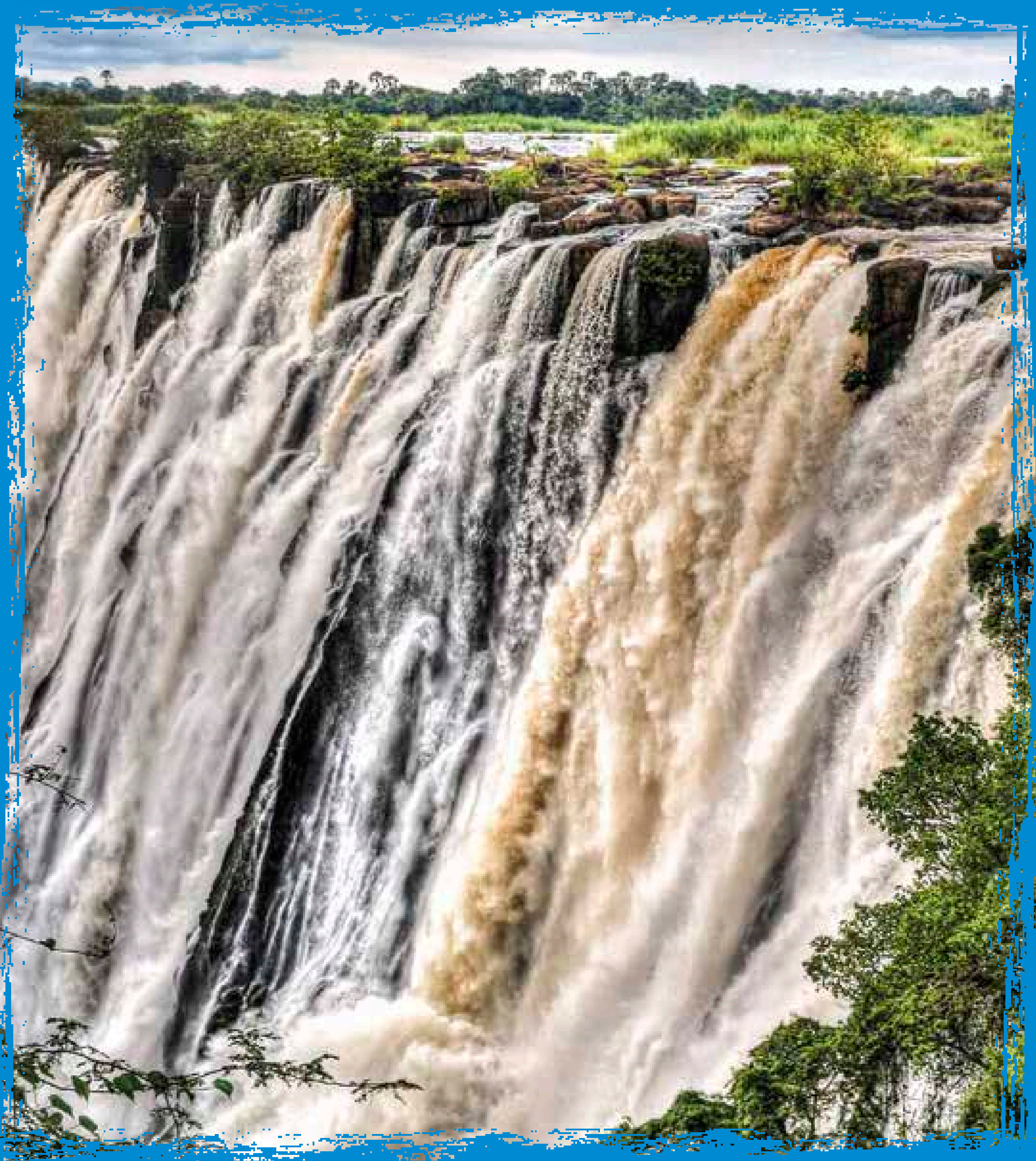
Therefore, the water related events extracted from the ACLED database are representative of water management issues in specific areas in the African continent. The spatial distribution of the events has a noticeable variation across time, but a series of spatial clusters could be identified. The most significant hotspots of water related violent episodes could be highlighted in the following areas (HD = High Density, LD = Low Density):

- North Africa
  - Coastal areas of Tunisia and Algeria (HD);
  - Nile Delta (HD);
  - West Africa
- Senegal Basin (LD);
  - Niger and Volta Basins (LD);
  - Niger Delta and Nigeria (HD);
- Central Sahel
  - Chad basin and Eastern Nigeria (LD);
- Eastern Africa
  - Central and Upper Nile (HD);
  - Lake Victoria basin (HD);
  - Horn of Africa (HD);
- Southern Africa
  - Lowed Zambezi (LD);
  - Limpopo (HD);
  - Upper Orange (HD);
  - Lower Orange (LD);
  - Coastal South Africa (HD).

Figure 14. *Most recurrent water related keywords per country in the African continent (Farinosi et al 2018b)*

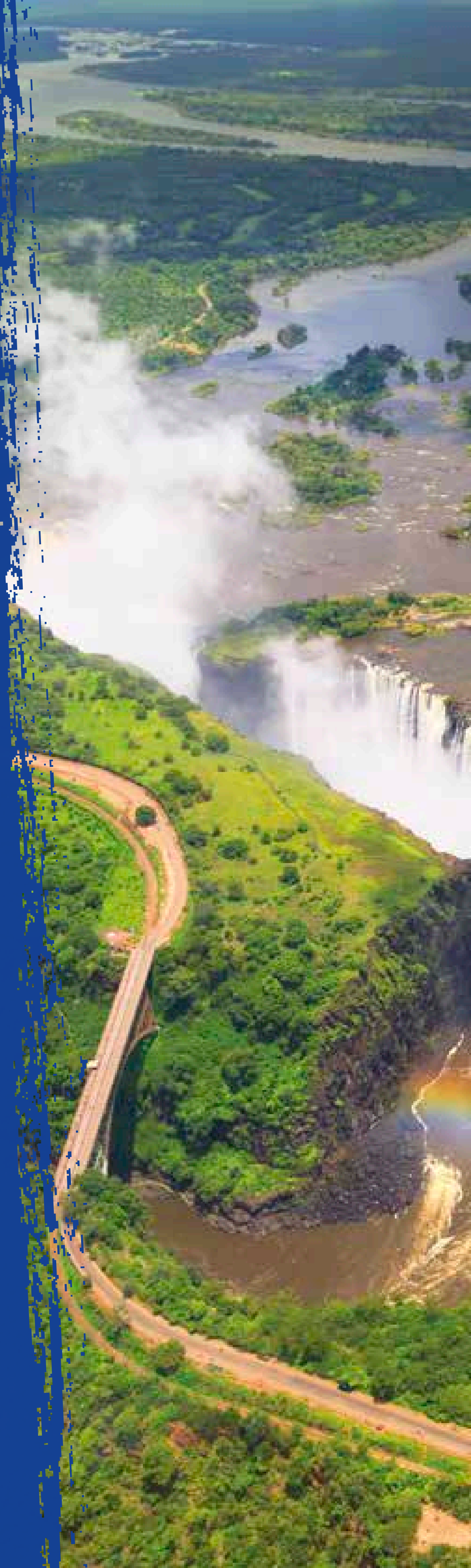


The nature of these issues is not always homogeneous among the countries. The most recurrent words in the events characterizing a specific country or portions of it might vary considerably, but in the large majority of the cases they are representative of a handful of topics (including: water supply, hygiene and sanitation; agricultural and farming use of water resources; natural hazards; mining and other water intensive economic activities). The essence of the water related violence episodes is also generally different between urban and rural areas, being the first ones mainly represented by water supply and sanitation, water price, and access to the resource, while in the rural areas issues related to agricultural use stand out.



5.

CASE STUDIES: WATER MANAGEMENT IN AFRICAN TRANSBOUNDARY RIVER BASINS



5.1 Senegal

5.1.1 Introduction

Born in the Fouta Djallon massif in Guinea, after the confluence of the Bafing, Bakoye and Falémé rivers, the Senegal River travels across Guinea and Mali and traces the border between Mauritania and Senegal until it meets the Atlantic ocean near Saint-Louis in Senegal. The journey of the second largest river in West Africa, through almost 1,800 km and four riparian countries, constitutes a lifeline for the 7.5 million of people (16% of the riparian countries' population) that inhabit within the 300,000 km^2 of the Senegal River basin (SRB). Due to the high dependency of the main livelihoods in SRB on water (agriculture, livestock, fisheries), around 85% of the population lives close to the river (UN, 2003). In this context, the development of the basin is of vital importance for the four riparian countries, which show values of the Human Development Index (HDI) among the lowest of the world and are listed among the Least Developed Countries (LDCs). Hence, Senegal, Mauritania and Mali decided to join their efforts in 1972 through the establishment of the Organisation pour la Mise en Valeur du fleuve Sénégal (OMVS), which is considered as an example of transboundary cooperation due to the effective implementation of the principle of equitable sharing among member states (regarding both the ownership of hydraulic infrastructure and the benefits associated to water resources). In 2006, Guinea joined the OMVS (Pastori et al 2021).

5.1.2 Key challenges

The SRB is highly vulnerable to climate variability and changes (Niang et al., 2021), due to the great interdependence between climate and socioeconomic activities, and it could be further challenged by the increasing pressures posed by its population dynamics on natural resources and the subsequent changes in land use (Figure 15).

If properly designed, the development of hydraulic infrastructures could act as a buffer against climate variability. Although there are only three fully operational dams in the SRB (Manantali and Felou, in Mali, and Diama, close to the river delta), the four riparian countries and the OMVS have planned to increase the number of reservoirs to further regulate the river flow, produce hydroelectricity and develop irrigated agriculture (including flood recession control). However, priorities could differ between countries: while upstream countries (mainly Mali and Guinea) are highly interested in hydropower services, downstream countries (mainly Senegal and Mauritania) prioritize food production and ecosystem services in the valley and Delta areas (Tilmant et al., 2020). Besides, a previous poor understanding of the interdependences among the components of the WEFE nexus in the SRB has lead to multiple undesirable impacts following the implementation of Manantali and Diama dams, such as threatening the future of flood-recession farming and other types of livelihoods (e.g. freshwater fish production, estuarine/marine fishery nursery grounds and dry season forage) (Sall et al., 2020), deforestation, massive population displacements, groundwater and fishing depletion, increase of the number of invader aquatic species and the rise of waterborne diseases (e.g. schistosomiasis) (DeGeorges and Reilly, 2006; Mietton et al., 2007; Diessner, 2012).

Specifically, waterborne diseases are one of the key challenges in the SRB, due to the rapid increase in their prevalence (e.g. malaria, urinary schistosomiasis, diarrhoea, intestinal parasitic diseases), and the appearance and subsequent expansion of intestinal schistosomiasis (which particularly affects agricultural and fishing populations and impairs productivity, due to its debilitating nature) (Monde, 2016). Besides, children in the SRB show the highest prevalence of another waterborne gastrointestinal parasite (Blastocystis) worldwide (El Safadi et al., 2014) due to poor hygiene, sanitation and water supply from unsafe sources, along with close contact with domestic animals and livestock. To a lesser extent, water pollution could also be a problem in certain areas (e.g. increase of nitrate concentrations due to agricultural development (Mbaye et al., 2016), eutrophication issues in the Senegal river estuary (Troussellier et al., 2004), presence of heavy metals in the Senegal river in Mauritania (e.g. Kaédi and Boghé) (El Mahmoud-Hamed et al., 2019) or marine pollution due to land-based plastic waste inputs (Jambeck et al., 2015).

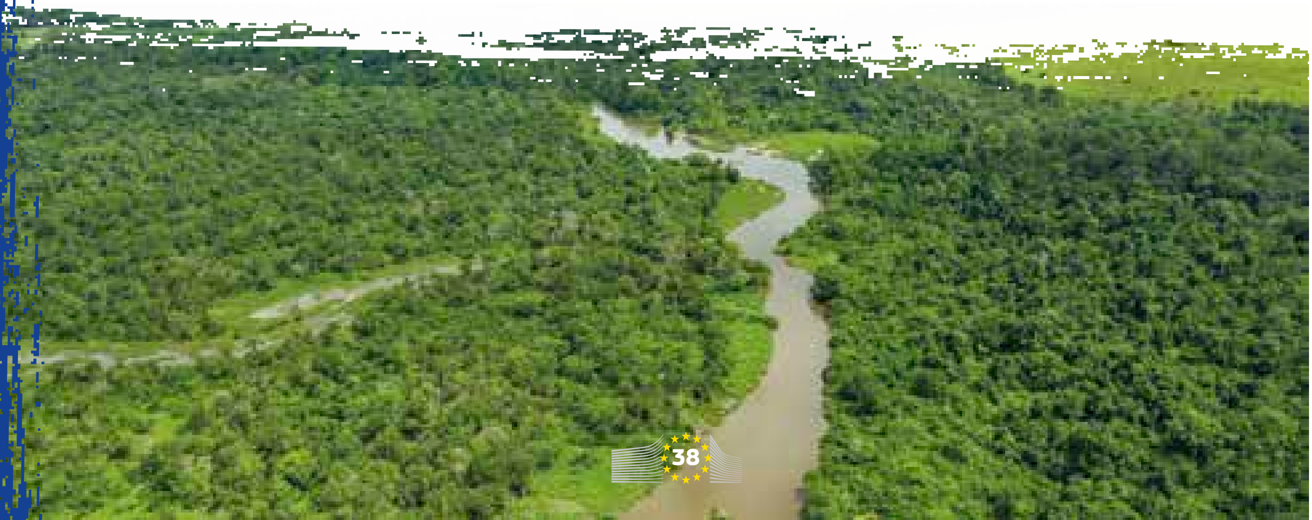


Figure 15. *Key WEFE Nexus challenges in the Senegal River Basin*

SENEGAL RIVER BASIN CHALLENGES

0.34 million of km² | **1800 km long**
2nd long- in West Africa | **Shared across 4 countries**

WATER – ENVIRONMENT

- **8** Ramsar sites and about **55 000 km²** of protected areas
- Mining impact on water quality, specifically in the *Falame;* ***heavy*** **metals** pollution
- **High rates of population growth** (3% annual) and urbanization
- land degradation and **erosion issues**
- Negative impacts of **withdrawals** in the Delta
- Natural parks are aimed towards ecotourism, biodiversity protection and veld products
- Rapid increase in the prevalence of **water-borne diseases** (Malaria, Schistosomiasis)
- Presence of fecal bacteria, parasites, nutrients and pesticides in the Delta region
- Some of wetlands and important protected areas are under threat due to development and high rates of abstraction,
- Landuse change (**from 2001 to 2019 16% decrease in tree cover –** ***Guinea - Upper Basin***)
- Maintenance of ecosystem services (fishing and bird habitat, navigation) in middle and low valley

WATER – CLIMATE

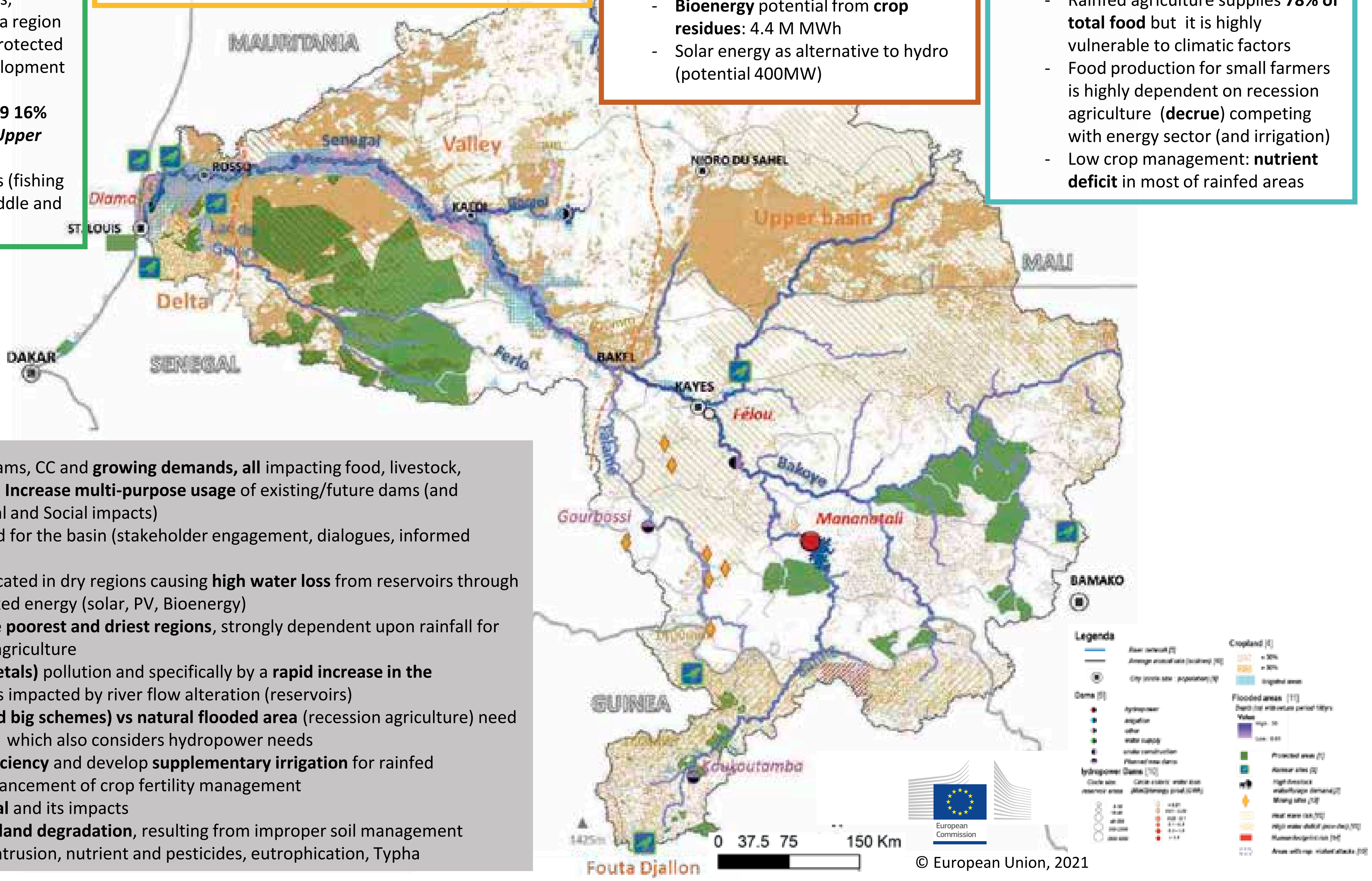
- Lower precipitation areas generally show a higher deficit variability (up to 40%), considering return periods of 5-10 years
- Natural discharge extremely variable due to uneven seasonal and spatial distribution of rainfall and low rates of conversion from precipitation to runoff
- Extended hotspots for heat waves
- Flood hazards (crop failure, casualties)
- Flow reduction. changes in flood frequency, magnitude and duration and changing land-use practices adversely affect water quality and quantity and, thereby, ecosystems' health.

WATER – ENERGY

- **3 existing dams**, 2 used for hydropower production 1 preventing salt intrusion
- **2 hydropower** plants with ins. capacity **of 200 and 62 MW**
- **Several new plants** under discussion (4-6) and 1 under dev. (140 MW)
- Manantali site **shows high water losses** [mcm] per energy production unit [GWh]: **0.22**
- High energy dependency of the energy sector on water availability
- Electricity access rate: 30-60% (0-30% in rural areas)
- **Woodfuel** demand increasing rapidly : **+14%** in the 2000-2018
- **Bioenergy** potential from **crop residues**: 4.4 M MWh
- Solar energy as alternative to hydro (potential 400MW)

WATER – FOOD AND SECURITY

- Agriculture contribution to GDP 15 – 38% (in the basin)
- Agriculture accounts for 70 % of freshwater withdrawals
- High crop failure risk (CC, rainy season, floods)
- Competition across pastoral (**14 M livestock UBT**), irrigated and rainfed farming (**55-75 % employment resources**)
- Water demands for irrigation and livestock 1400 and 113 M m3; 6 times more expected in 2025
- Pasture land mainly in dry regions and *Ferlo*
- Rainfed agriculture supplies **78% of total food** but it is highly vulnerable to climatic factors
- Food production for small farmers is highly dependent on recession agriculture (**decrue**) competing with energy sector (and irrigation)
- Low crop management: **nutrient deficit** in most of rainfed areas



KEY CHALLENGES

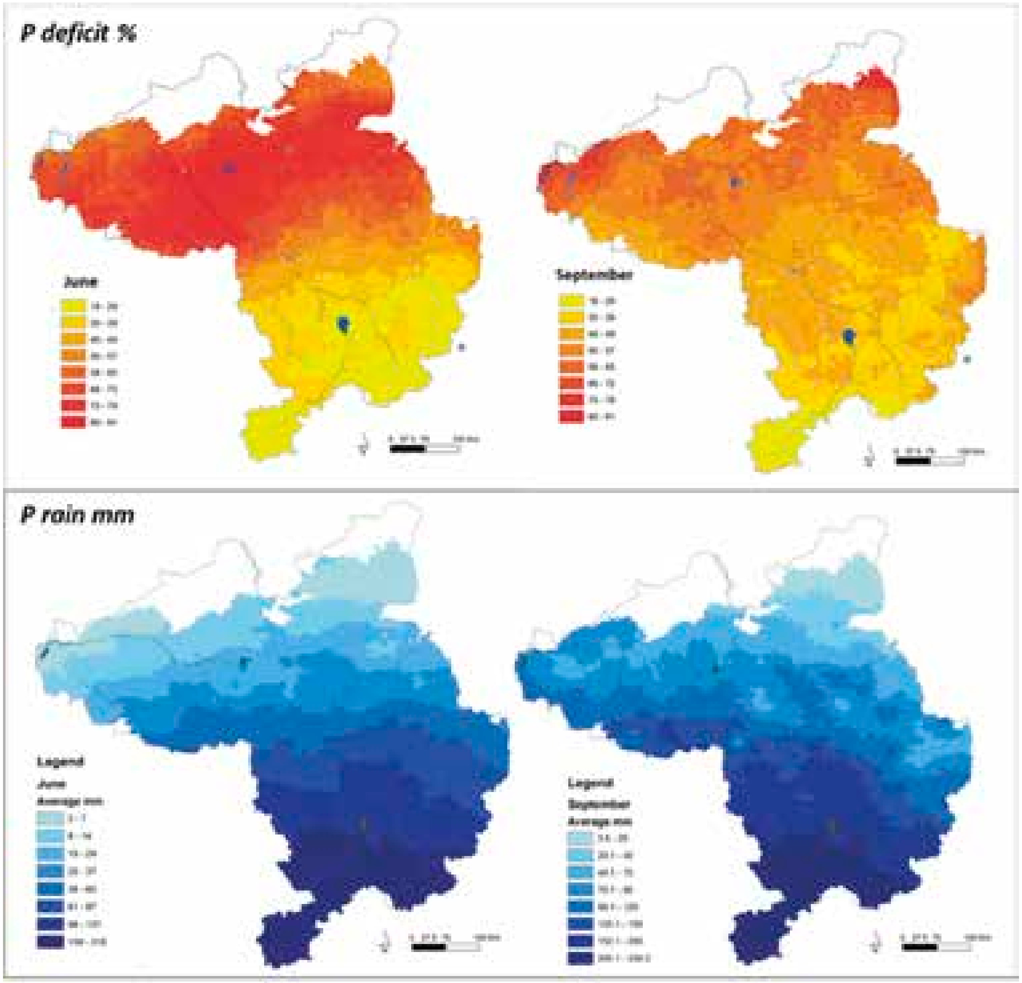
- Manage **alteration of water cycle** by dams, CC and **growing demands, all** impacting food, livestock, fishery, energy and navigation services. **Increase multi-purpose usage** of existing/future dams (and improve management of environmental and Social impacts)
- Governance and decision-making in and for the basin (stakeholder engagement, dialogues, informed decisions
- **Asses new hydropower sites,** often located in dry regions causing **high water loss** from reservoirs through evaporation, vs an improvement of mixed energy (solar, PV, Bioenergy)
- **High climate variability impacts on the poorest and driest regions**, strongly dependent upon rainfall for both human water supply and rainfed agriculture
- **Water quality** is affected by (**heavy metals)** pollution and specifically by a **rapid increase in the prevalence of water-borne diseases**, as impacted by river flow alteration (reservoirs)
- **Fully control irrigation system (rice and big schemes) vs natural flooded area** (recession agriculture) need a concerted management of river flow which also considers hydropower needs
- **Improve irrigation** (bigger scheme) **efficiency** and develop **supplementary irrigation** for rainfed agriculture farming, along with the enhancement of crop fertility management
- **Monitoring** of **groundwater withdrawal** and its impacts
- Monitoring and control of **erosion and land degradation**, resulting from improper soil management
- Protection of Delta environment: salt intrusion, nutrient and pesticides, eutrophication, Typha

5.1.3 Application of the WEFE Nexus approach

The WEFE Senegal project (Appui a la Gestion des Ressources en Eau et du Nexus Eau-Energie-Agriculture Dans le Bassin du Fleuve Senegal) aims to develop the WEFE framework in the Senegal river basin and it has been implemented with the partnership of OMVS, AICS (Italian agency for development cooperation) and the JRC of the European Commission, and in collaboration with the Directorate-General of International Partnership (DG INTPA).

Within the framework of this project, climate variability was assessed through several indicators (e.g. precipitation deficit, heat waves magnitude index, the Standardized Precipitation Index (SPI) and the characterization of dry spells), in order to help stakeholders to take appropriate measures to reduce risks and impacts (Cattaneo et al, 2019). Results showed higher precipitation deficits and variability specifically in areas with lower precipitation, that are strongly dependent on rainfall for both human and livestock water supply, as well as for sustaining rainfed agriculture and pastureland (Figure 16). The analysis highlighted that, in most cases, higher precipitation variability concentrates in areas with lower precipitation, that, by the way, are also the poorest and driest regions, strongly dependent on rainfall for both human and livestock water supply, as well as for sustaining rainfed agriculture. The analysis, performed at monthly frequency, clearly informs also about the temporal dimension of the phenomena, as related to dry and wet seasons.

Figure 16. *Precipitation deficit (% divergence with respect to mean climatology) with a return period of 20 years (top) and Average monthly precipitation (bottom) over the Senegal River basin for June and September (Pastori et al., 2021a)*



Besides, preliminary results of the application of the WEFE Nexus approach in Senegal point out that, although at country level water availability per capita is far above the critical threshold, in some regions water scarcity is already a severe problem (e.g. Dakar, Diourbel, Thies) and for others it might be (e.g. Kolda, Matam) in the near future. In addition, agriculture is and will be the driver of water withdrawals in Senegal and its share over total water demand is expected to increase over time. However, two of the largest producers of agricultural products, Matam and Kaffrine, are likely to be affected by water stress, and 63% of agricultural production is located in water stressed regions. In this context, long-term investments in water infrastructure might help to alleviate the problem, by storing and distributing water from water abundant to water scarce regions, along with careful water management strategies, policy coordination and innovative methods to increase water productivity (Niang et al, 2021). Finally, it is necessary to point out that the ongoing changes on land use have already induced environmental degradation in several hotspots located in the Senegal and Gambia river basins, such as the Fouta Djalon massif or the Senegal river delta and Gambia estuary, where water bodies and biodiversity are decreasing at the expense of bare surface expansion (Niang et al., 2021).

5.2 Niger

5.2.1 Introduction

The Niger basin, located in Western Africa, covers 7.5% of the continent (2.1 million km2) and it is shared by nine countries: Benin (2.5%), Burkina Faso (3.9%), Cameroon (4.4%), Chad (1.0%), Côte d'Ivoire (1.2%), Guinea (4.6%), Mali (30.3%), Niger (23.8%) and Nigeria (28.3%). From its headwaters in the Fouta Djallon Massif in Guinea to the terminal delta in Nigeria, the Niger river (the third longest one in Africa) travels through 4,200 km and shapes an important corridor for migration and trade, a potential conflict source and a chance for transboundary cooperation (Andersen et al., 2005). Together with its associated aquifers, it constitutes one of the most important water resources in Africa, providing drinking water, supporting livelihoods (e.g. large-scale irrigation, fisheries and livestock herding), generating hydropower and allowing navigation. In addition, one of the largest Ramsar sites in the world comprises the Inland Niger Delta, a hotspot of biodiversity and a vital part of eco-regional network (Zwarts et al., 2006). However, the basin is also extremely vulnerable due to its pronounced hydroclimatic variability, both spatially and temporally, and its complex socioeconomic context (growing population, high poverty levels, food insecurity and values of the Human Development Index (HDI) amongst the lowest in the world (Vaucelle, 2015)). In this context, the Niger Basin Authority (NBA), established in 1980 by the 9 riparian countries, aims to coordinate national water resource management efforts through an integrated development plan for the basin, in order to improve the life conditions and prosperity of the population. Currently, the basin has a great potential for development: it is estimated that only 9% of the agricultural lands are irrigated, whereas only 25% of the potential hydropower capacity is installed (NBA, 2015).

5.2.2 Key challenges

Water is a major contributing factor for increasing both agriculture outputs and sustainability in production systems like power supply. However, water resources and demands are unevenly distributed within the Niger basin, and riparian countries can be categorized into water producers, consumers, both producers and consumers, and minimum contributors and consumers (Medinilla, 2017). As a result, although the region is rich in water resources, it suffers from chronic water deficits and its overall renewable energy potential is underused. In this context, allocation of available limited water resources for sustainable water use have been issues of increasing concern, leading to higher water demand and consumption. Most of the existing reservoirs (over 450 in the Nigerian part of the basin) are devoted to domestic supply, irrigation, flood control, fishing and livestock farming, while only a few were originally designed for hydropower generation. Further water resource developments should be carefully considered: in the Hadejia-Jama'are basin, located in Northeastern Nigeria and one of the most productive ones in the region, as the full implementation of the planned infrastructure could have severe consequences for the basin's flood plain wetlands and the agricultural productivity of the areas located downstream, due to decline of the flooded area during the wet season. This reduced productivity would not be replaced by yields from the formal irrigation, since the water resources of the basin might not be able to support the envisaged extent of these schemes (Eduvie and Adanu, 2021).

In the part of the basin located in Northern Nigeria, climate variability and its impacts on the environment, food and water are already huge: the increasing temperature and decreasing rainfall have led to frequent drought and desertification, affecting large areas of arable land and reducing crop production. This has prompted massive migration and resettlement of people to areas less threatened by desertification (Eduvie and Adanu, 2021). In addition to climate change and variability, the basin faces up multiple challenges: degradation of land, water resources and associated ecosystems, vulnerability to disasters, inefficiency and poor performance of agriculture (both rainfed and irrigated), competing demands between sectors and water users and inadequate investment in water infrastructure. At a wider scale, inadequate public services, institutional and governance failure, high population growth and urbanization, poor macro-economic performance, and unemployment have also undermined the development of the basin (Namara et al., 2011). The challenges are not lesser at the river mouth: the Niger delta, where frequent oil spills are a major source of environmental pollution, has been a constant receptor of unrelenting pressure and assaults on its ecosystems, affecting negatively the health and living conditions of the people. Besides, the region suffers the effects of poor infrastructure and water management, and flooding in the area is common due to sea level rise and other factors (Ehiorobo et al., 2020).

Finally, water quality related health issues (e.g. vector borne and diarrhoeal diseases) are a main source of concern in the Niger basin, along with respiratory diseases. These "traditional environmental hazards" are amplified by malnutrition and sometimes conflict. Except for certain locations, water quality issues have little or no impact on the aquatic ecosystems and their biodiversity, which are principally threatened by the dramatic land use change linked to overall population growth (Umlauf, 2020).

5.2.3 Application of the WEFE Nexus approach

The project "Plateforme Africaine de Suivi-Evaluation du Nexus Eau-Energie-Sécurité Alimentaire-Ecosystème (WEFE): cas du bassin du Niger", a collaboration between AGRHYMET and the JRC, aimed to improve the implementation of the WEFE Nexus approach in the Niger basin. Concretely, a comprehensive methodology was applied to tackle the multidimensional nature of impacts on the Niger basin water resources, through the development of a specific SWAT model and a set of scenarios, which combine climate, land use and management projections (Ali et al., 2021). Besides, the AGRHYMET Regional Centre selected two pilot sub-basins (the multipurpose Sélingué dam basin in the Sankarani river and the Sirba river basin), considering, not only the challenges in relation to WEFE, but also the availability of biophysical and socioeconomic data (AGRHYMET, 2019).

Previously, the implementation of the WEFE Nexus approach in the Mékrou river basin (tributary of the Niger shared by Benin, Burkina Faso and Niger) showed that lack of food security due to insufficient local production could be reduced up to one third by enhancing the application and optimal distributions of fertilizers and irrigation (Udias et al., 2018).

The challenges related to climate variability and climate change face to increasing water demand and population growth were also stressed for Nigeria, one of the most densely populated countries in Africa. Hydropower remains in the region the main sustainable renewable energy (Eduvie and Adanu, 2021), a relevant substitute for fossil fuel, posing major environmental problems in the Delta region (oil spills, natural gas flaring, over exploitation of natural resources) and causing relevant impacts on fishery and farming. Socio-economic conditions in the region are even more exacerbated by oil price fluctuations, security threats and natural disasters like flooding (Ehiorobo et al., 2021).

In this complex framework, data accessibility and availability remain a major concern, due to discontinued and fragmented monitoring and limited funding. This last issue led, for example, the Nigerian Meteorological Agency (NIMET) to the decision of commercializing their data. Additionally, the lack of mandatory requirements for oil and gas companies operating in the delta region to make their data available to government and research institutions represent a serious limitation in the possibility to study the region. Overall water demand remains of marginal relevance in Southern Nigeria respect to the natural abundance, granted by favourable rainfall rates and prevalence of rain-fed agriculture. Despite this fact, the area is subject to risks related to institutional and governance failure, limited infrastructures and poor maintenance, and natural disasters. Environmental pollution and ecosystem degradation in one of the richest areas in biodiversity remain on the top of the political agenda (Ehiorobo et al., 2021).

NIGER RIVER BASIN CHALLENGES

2.1 million of km² | **3rd longest in Africa (4200 km)**
Biggest in West Africa | **Shared across 9 countries**

WATER - ENVIRONMENT

- 32 Ramsar sites and about 300 000 km² of protected areas
- Plastic waste mismanagement (**more than 0.8 kg/hab/d in Nigeria**) and oil spills in the ***Delta area***
- Population growth (**3% annual**) and urbanization
- Landuse change (**from 2001 to 2019 10% decrease in tree cover – *Upper Basin***)
- Dry season irrigation withdrawals impact on the ***Inner Delta***

WATER - CLIMATE VARIABILITY

- Higher deficit variability tends to be concentrated in areas with lower precipitation
- Higher increases of relative deficit can be reported in low rainfall areas and also during rainy season (e.g. from June to September)
- Extended Hotspots of Heat weaves
- Flood hazards (crop failure, population)

WATER - ENERGY

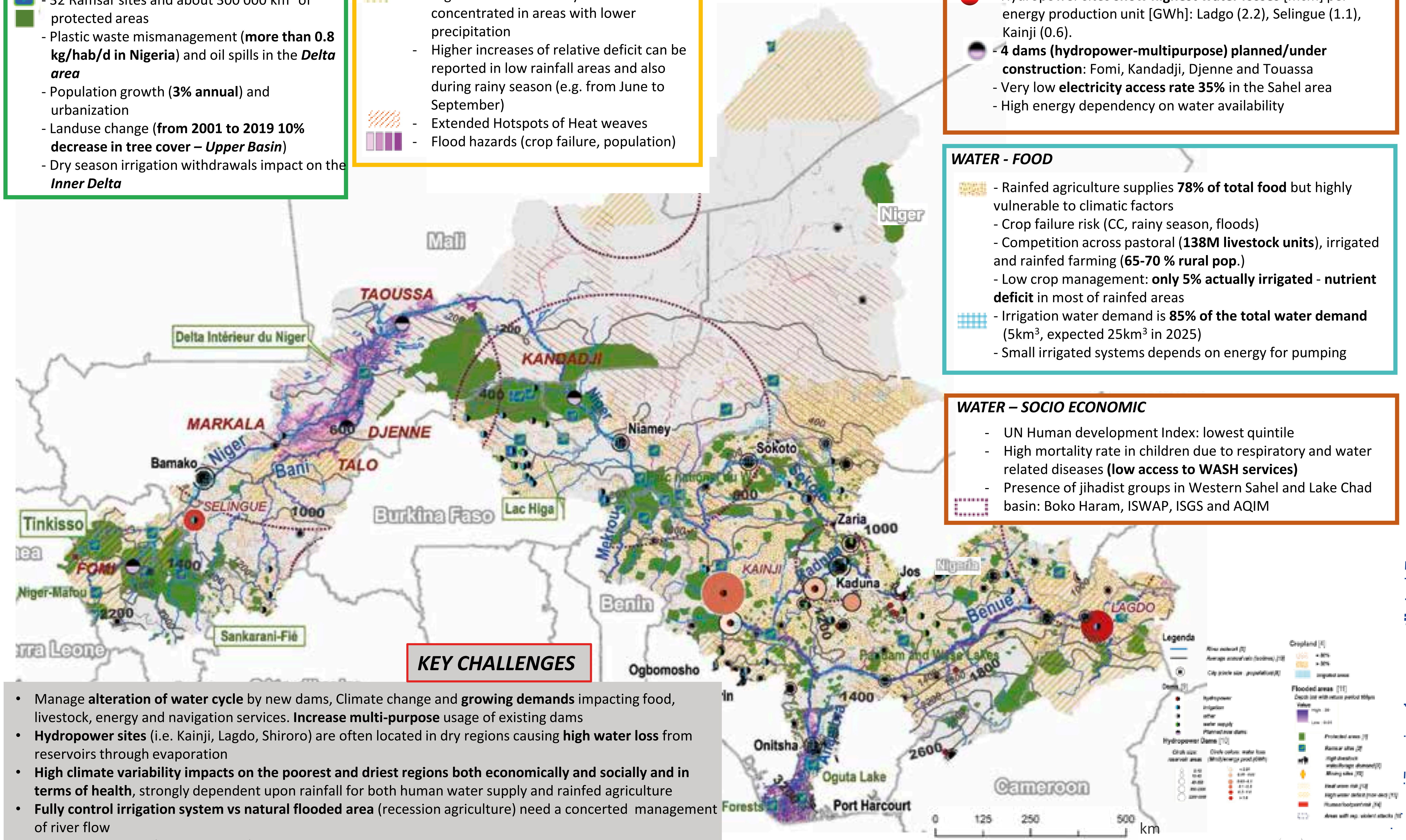
- **18 existing dams**, including 8 used for hydropower production
- **6 hydropower** plants with IC **> 5MW**: Kainji (760), Shiroro (600), Jebba (578), Lagdo (80), Selingue (48), Guarara Dam (30)
- Hydropower sites **show highest water losses** [mcm] per energy production unit [GWh]: Ladgo (2.2), Selingue (1.1), Kainji (0.6).
- **4 dams (hydropower-multipurpose) planned/under construction**: Fomi, Kandadji, Djenne and Touassa
- Very low **electricity access rate 35%** in the Sahel area
- High energy dependency on water availability

WATER - FOOD

- Rainfed agriculture supplies **78% of total food** but highly vulnerable to climatic factors
- Crop failure risk (CC, rainy season, floods)
- Competition across pastoral (**138M livestock units**), irrigated and rainfed farming (**65-70 % rural pop**.)
- Low crop management: **only 5% actually irrigated** - **nutrient deficit** in most of rainfed areas
- Irrigation water demand is **85% of the total water demand** (5km³, expected 25km³ in 2025)
- Small irrigated systems depends on energy for pumping

WATER – SOCIO ECONOMIC

- UN Human development Index: lowest quintile
- High mortality rate in children due to respiratory and water related diseases **(low access to WASH services)**
- Presence of jihadist groups in Western Sahel and Lake Chad basin: Boko Haram, ISWAP, ISGS and AQIM



KEY CHALLENGES

- Manage **alteration of water cycle** by new dams, Climate change and **growing demands** impacting food, livestock, energy and navigation services. **Increase multi-purpose** usage of existing dams
- **Hydropower sites** (i.e. Kainji, Lagdo, Shiroro) are often located in dry regions causing **high water loss** from reservoirs through evaporation
- **High climate variability impacts on the poorest and driest regions both economically and socially and in terms of health**, strongly dependent upon rainfall for both human water supply and rainfed agriculture
- **Fully control irrigation system vs natural flooded area** (recession agriculture) need a concerted management of river flow
- **Improve irrigation** (bigger scheme) **efficiency** and develop **supplementary irrigation** for rainfed agriculture farming
- **Monitoring** of **groundwater withdrawal** for irrigated agriculture and its impacts
- High amount of **land-based plastic dumped into the ocean and environmental and health issues** due to oil spills.
- **Trade-off analysis** must be undertaken in consultation with local **stakeholders** to identify optimal compromise between sectors (hydropower, irrigation, rainfed recession agriculture, fishers, navigation, ecosystems…)

European Commission

5.3 Zambezi

5.3.1 Introduction

Zambezi basin is the fourth largest in Africa after the Congo, Nile and Niger River Basins. It drains an area of about 1.4 million squared kilometres crossing the borders of 8 countries in Southern Africa. The basin area is characterized by climate characteristics varying from subtropical in the North to temperate and arid conditions in the South. Mean annual precipitation ranges between the 1200 mm/yr in the wettest areas in the Kafue and Shire subsystems, to less than 700 in the driest areas in Zimbabwe. The territory is split among the following countries (percentage of the territory and hydrological balance: [+] water producer; [-] water consumer; [º] neutral): (18.4% [+]); Botswana (1.0% [-]); Malawi (8.0% [+]); Mozambique (12.8% [+]); Namibia (1.0% [º]); Tanzania (2.0% [+]); Zambia (41.7% [+]); Zimbabwe (15.6% [+]). The Zambezi is home to about 40 million people, majority of which (~32 M) living in rural areas. Transboundary and transnational strategic management of the basin is coordinated by the Zambezi Watercourse Commission (ZAMCOM), established in 2011 by the 8 riparian countries (ZAMCOM et al., 2015; SADC/SARDC et al., 2012; World Bank, 2010).

5.3.2 Key challenges

After the turbulent decolonization period, largely characterized by civil war, which in the case of Angola continued till the last decade, the Zambezi River basin countries experienced a period of fast socio-economic development. The basin is particularly rich in natural resources. Main economic activities are represented by mining, agriculture, fishery, tourism, and manufacturing. Although the economy of the area is boosted by the extraction of important resources like oil, coal, cobalt, copper, and diamonds, large part of the population still suffers from a high poverty rate, a lack of basic services, high maternal and infant mortality, and low life expectancy. Agriculture, industry and service sectors are the major contributors to the economy of the area. In particular, agriculture represents about 17% of the overall GDP of the countries sharing the basin's territory (from 2% in Botswana to 29% in Mozambique), while the industry share amounts up to 32% (from 19% in Malawi to 57% in Angola), and the service sector with 51% (32% Angola – 60% Botswana) (SAIIA, 2014). Population in the basin was estimated in about 40 million, three-quarters of it living in rural areas (50% in Zambia, 85% in Malawi), and the remaining 25% in the 21 major towns. Population living in poverty ranges between 30% in Botswana to almost 90% in Tanzania; access to clean water is pretty low (~50% in Angola, Mozambique, Tanzania, and Zambia), and the incidence of HIV/AIDS is one of the largest in the world.

Attending to an official report (ZAMCOM et al., 2015), average per capita water consumption in the basin is around 101 m3 yr-1, ranging between 27 in Angola to 203 in Zimbabwe. The most water intense sector is agriculture, to which more than 76% of the resource is destined (42% in Botswana, ~60% in Angola and Namibia, >90% in Tanzania, Mozambique, and Zimbabwe). Small-scale rainfed agriculture represents the main source of income in the majority of the basin. Corn, wheat, cassava, rice, sugarcane, sorghum, cotton, groundnuts, and tobacco are the most important crops. Agricultural land in the basin was quantified in about 5.2 million hectares, with only about 0.25 million irrigated. Irrigation infrastructural development was identified as a priority in the Zambezi area and projects to irrigate an additional amount of 0.51 million hectares were already considered. Fuelwood collection and cattle production are the main threats to the natural ecosystems of the basin, extremely important from a conservation standpoint. Fishery is the major source of income for the households living in the delta and in the wetlands along the rivers and on the lakes' shores.

The hydropower potential of the basin was estimated in about 20 GW, of which only about a quarter is currently exploited, mainly in the Cahora Bassa, Kariba, and Kafue Gorge dams in Zambia and Mozambique. About 40 additional possible installations (summing up to about 13 GW of installed capacity) have been already identified in the basin. Some of these projects are currently under construction within the Southern African Power Pool (SAPP) development program. Concretely, planned developments will increase the concentration of the SAPP's hydropower capacity in the Zambezi basin, from about 70% to 85% in 2030 (Conway et al., 2017). Several water transfer projects have been already designed for the basin, as for the Zambezi Water Transfer Scheme, or the North-South Carrier in Botswana. However, the proper maintenance and rehabilitation of the current infrastructure is a source of major concern: Kariba dam is currently in a dangerous state due to bedrock erosion (which threatens the stability of the wall foundations), and its potential collapse would entail catastrophic consequences across the basin (IRMSA, 2015).

Given the general water scarcity in the basin, climate variability and change are considered the most relevant threats in the coming future, both for the existing human activities and for the future development.

5.3.3 Application of the WEFE Nexus approach

The analysis of the WEFE Nexus dynamics in the Zambezi basin is one of the main objectives of the African Union - NEPAD African Network of Centres of Excellence on Water Sciences and Technology - ACEWATER phase 2 project. One of the project tasks included the hydrological analysis of the impacts of climate change and development on the water resources in the basin and was conducted in collaboration with Rhodes University in South Africa. The details of the model set up are described in a paper (Hughes et al., 2020), while the scenario analyses are summarised in a further assessment (Hughes and Farinosi, 2020a). Some of the uncertainties in the observational data used to establish the model and the linkages with model output uncertainties (particularly with respect to the simulation of specific runoff-generation processes) are discussed in a third work (Hughes and Farinosi, 2020b). The impacts of climate change and water use scenarios are expected to be heterogeneous across the whole Zambezi River basin. The most impacted areas are likely to be represented by the open water bodies, natural lakes and man-made reservoirs, very sensitive to the multiple effects of increased aridity. The uncertainty in the future simulation results remains hugely dependent on the selected climate models. However, results suggest a substantial decrease in future water availability under all the combined scenarios. The different water use scenarios have relatively small impacts compared to the climate change effects, with the exception of some of the semi-arid sub-basins of Zimbabwe where there are quite intensive water uses relative to the available water.

These scenarios are expected to heavily impact the hydropower system installed in the basin and thus increase the future water-related risks in the whole SAPP (primarily dependent on the Zambezi basin for hydropower production). Concretely, Zambezi hydropower output could decrease between 10-20% due to drier conditions, whereas near term system generation costs could increase by 20-30% for hydro-dependent countries (Spalding-Fecher et al., 2017). Attending Arias et al. (2021), flow changes are expected to be the largest at Cahora Bassa (-30 to -49%), followed by Kariba (-12 to -51%), Kafue Gorge (-25 to -42%) and Itezhi-Tezhi (-15 to -35%). Changes in water levels and flows could result in mild negative effects on mean average hydropower generation and significant increases in interannual variability; largest changes are expected at Kariba, where annual generation is expected to decrease from 5989 to 4152 Gwh/yr (-28.1 to -0.7%) . At Itezhi-Tezhi, average annual hydropower is expected to change from 675 to 534-536 Gwh/yr (- 21%). At Cahora Bassa, average annual generation (18017 Gwh/yr) is expected to decrease by 2%.

Hydropower is not the only water demanding sector in the basin: agriculture is the largest water consumptive activity, currently draining about 1.4 % of the basin annual renewable water resources (Senzanje & Dirwai, 2021). About 90% of the total harvested areas are located in the main floodplains and are cultivated predominantly with rainfed agriculture. However, the irrigated areas are estimated in a range between 150 and 260 thousands hectares and are expected to triple by 2025, boosting the pressure on the annual renewable water resources to about 4.5% of the total (Senzanje & Dirwai, 2021).

Figure 18. *Key WEFE Nexus challenges in the Zambezi River Basin*

ZAMBEZI RIVER BASIN CHALLENGES

1.4 million of km²
4th largest in Africa
2600 km long
Shared across 8 countries

WATER - ENVIRONMENT

- 14 Ramsar sites and about 400 000 km² of protected areas
- Human footprint increase on biodiversity and ecosystem. Woodfuel collection and cattle production are major threats to the natural ecosystems of the basin.
- Kavango-Zambezi Transfrontier Conservation Area (TFCA) : pronounced human–wildlife conflicts due to growing human population and large mammal species re-colonising formerly abandoned areas.
- Impact of mining

WATER - CLIMATE VARIABILITY

- Mean annual precipitation ranges between the 1200 mm/yr in the wettest areas in the Kafue and Shire subsystems, to less than 700 in the driest areas in Zimbabwe.
- Rainfall in the Zambezi river basin (ZRB) has already decreased during the last decades. A substantial decrease in water availability could take place under future scenarios.

Extreme events:

- heat wave risk
- High water deficit impact on rainfed crops
- Flood hazards (crop failure, population)

WATER - ENERGY

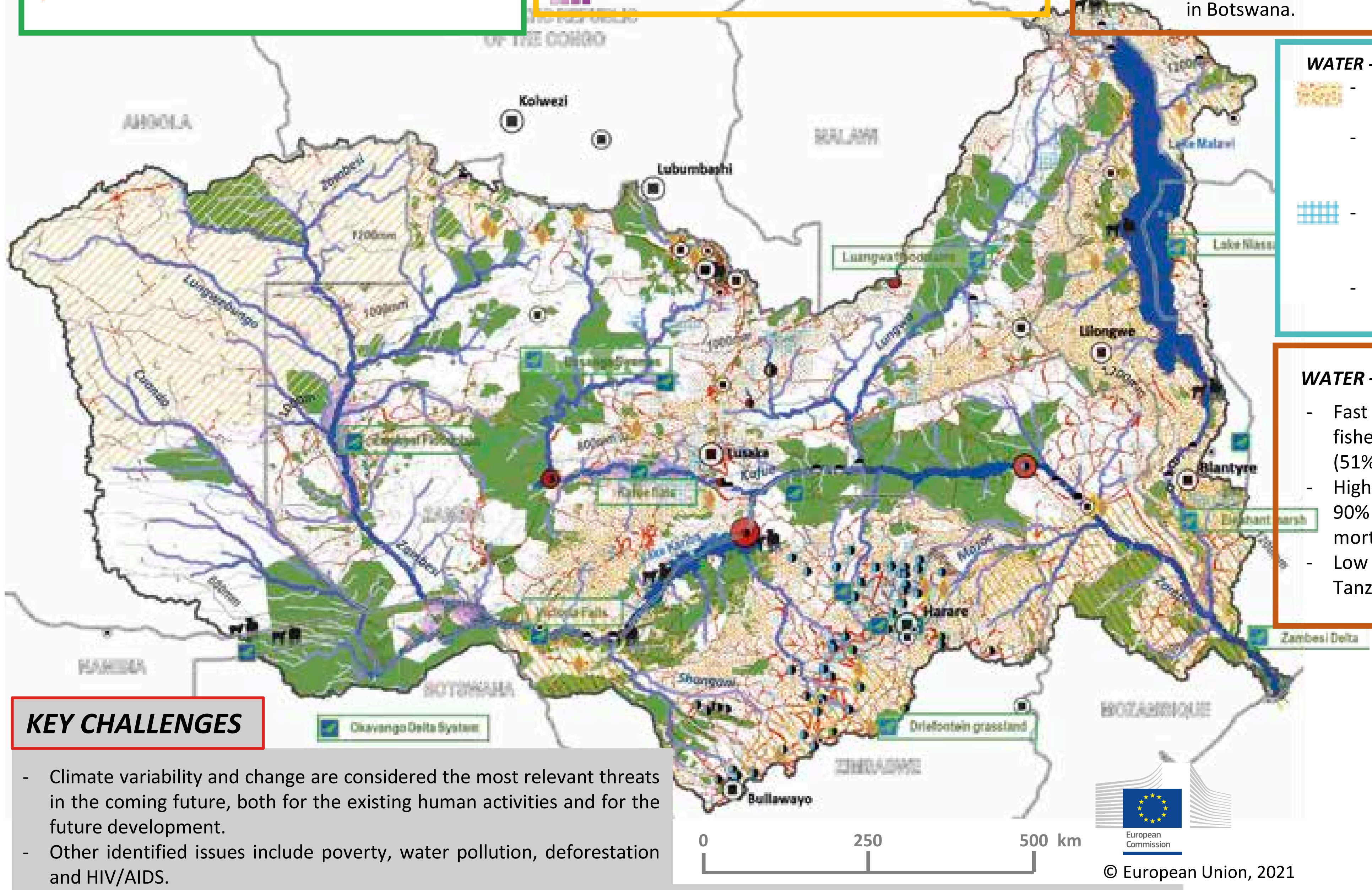
- **60 existing dams**, including 41 used mainly for irrigation and 12 for hydropower production
- **12 hydropower** plants with IC **> 5MW**: Chaora Bassa (2075), Kariba N. (1080), Kafue G. (930), Kariba S. (680), Kapichira (130), Itezhi Tezhi (120), Nkula-B (100), Tedzani Falls (92), and others
- Hydropower sites **show highest water losses** [mcm] per energy production unit [GWh]: Kariba S. (1.4), Lusiwasi (1.1), Itezhi Tezhi (1.0) and Kariba N. (1.0)
- Hydropower development: Hydropower potential in the basin is estimated in about 20 GW, but only about 25% is currently **exploited.** About 40 possible installations (up to 13 GW of additional installed capacity) have been already identified
- High energy dependency on water availability: changes in water levels and flows could result in negative effects on hydropower generation and significant increases in interannual variability
- Water transfer projects: e.g. Zambezi Water Transfer Scheme, North-South Carrier in Botswana.

WATER - FOOD

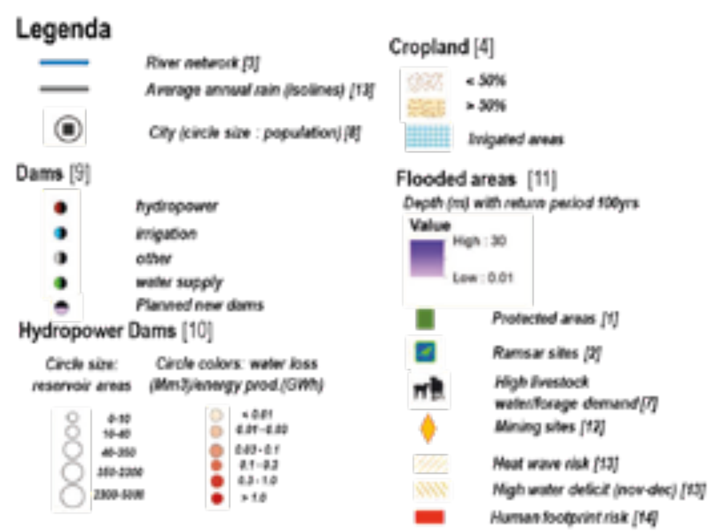
- Agriculture is the most water-intensive sector in the basin (more than 76% of the total demand).
- Small-scale rainfed agriculture is the main source of income in the majority of the basin. Crops include corn, wheat, cassava, rice, sugarcane, sorghum, cotton, groundnuts, and tobacco.
- Less than 5% (0.25 million ha) of the agricultural land of the basin is irrigated, although current projects plan to develop 0.51 million ha more.
- Fishery is the major source of income for households in the delta and in the wetlands.

WATER – SOCIOECONOMIC

- Fast socioeconomic development: mining, agriculture (17% GDP) , fishery, tourism and manufacturing, industry (32%), services (51%).
- High share of population living in poverty (30% in Botswana to 90% in Tanzania). Lack of basic services, high maternal and infant mortality, and low life expectancy, high incidence of HIV/AIDS
- Low access to clean water (~50% in Angola, Mozambique, Tanzania, and Zambia)



© European Union, 2021



KEY CHALLENGES

- Climate variability and change are considered the most relevant threats in the coming future, both for the existing human activities and for the future development.
- Other identified issues include poverty, water pollution, deforestation and HIV/AIDS.
- Critical success factors for an effective water governance in the basin include the implementation of a watercourse monitoring framework, the comprehensive characterization of water uses and the implementation of WEFE nexus approach.
- Water transfer projects sustainability: e.g. Zambezi Water Transfer Scheme, North-South Carrier in Botswana.
- Operations in hydropower reservoirs might undergo modifications in order to offset the projected changes in water levels and flows under future scenarios..

5.4 Blue Nile and Lake Victoria Basin

5.4.1 Introduction

Nile is the world's longest river draining about 10% of the landmass of the African continent. It originates from the wet tropical areas in the eastern part of the continent and from the highlands in the Horn of Africa. It flows northward through several climatic zones ranging from tropical to arid and crossing the border of 11 countries before ending in the Mediterranean sea. The broad catchment area, spanning more than 3 million squared kilometres, is distributed among the following countries (percentage of the territory and hydrological balance: [+] water producer; [-] water consumer; [º] neutral): Burundi (0.4% [+]); Rwanda (0.7% [+]); Tanzania (3.7% [+]); Kenya (1.6% [+]); Congo (DRC) (0.7% [+]); Uganda (7.5% [+]); Ethiopia (11.5% [+]); Eritrea (0.8% [+]); South Sudan (19.5% [º]); Sudan (44% [-]); Egypt (9.6% [-]). This area is home to more than 250 million people heavily dependent on the surface and subsurface water resources connected to this hydrological system for their survival. The Blue Nile basin and the Lake Victoria, from which the White Nile originates, are the main water sources for the downstream Nile: From their strategic management depends the health of the entire basin. 10 of the 11 countries sharing this basin (Eritrea participates as an observer) joined their forces in the establishment of the Nile Basin Initiative (NBI), created in 1999 to manage the transboundary resources (NBI, 2016; Wolman and Giegengack, 2007).

5.4.2 Key challenges

NNile River originates by two main tributaries: the White and the Blue Nile. The first springs from Lake Victoria in the Equatorial plateau in Eastern Africa. Its water flow is fed by the headwaters coming mainly from Tanzania, Burundi and Rwanda. Conventionally, the furthest upstream tributary of the Nile River is identified with the Kagera River, which, in turn, is originated by the Ruvyironza and Nyabarongo rivers, from Burundi and Rwanda respectively. The White Nile flows northwards from Lake Victoria, crossing the borders of Uganda, Congo (DRC), and South Sudan, forming the vast Sudd wetland and swamp area, and then flows through Sudan, joining the Blue Nile close to its capital Khartoum. The Blue Nile originates from the south-eastern bank of Lake Tana, in the Ethiopian's highlands, proceeds southeastwards through gorges, rapids, and waterfalls, towards the center of the country and turns westwards about one hundred kilometers north of the capital Addis Ababa. Blue Nile, flows then into the Sudanese territory following a north-western direction till merging with the White Nile and forming the Main Nile. From this point the Nile river proceeds through the deserts in Sudan and Egypt and flows into the Mediterranean Sea in a large delta. The Blue Nile is characterized by a high flow seasonality and represents the largest contributor in terms of discharge. The White Nile's discharge, instead, given the flow buffer effect brought by the several lakes and the large wetlands (in particular in the Sudd area) formed along its course, is more constant throughout the year. The Lower Nile in natural conditions is characterised by seasonal flooding: these events, occurring every year with different intensities, were extremely important for the civilizations living along the Nile Valley. Flood recession agriculture was the main food production activity, and in the ancient Egyptian civilization, the seasonal flood records were used as a proxy to predict the yearly agricultural productivity, and to determine the taxes imposed. Flow regulation, jointly with hydropower and irrigation potential, were the main objectives pursued during the colonial period: a large number of hydraulic infrastructure have been installed since the beginning of the 20th century, imposing radical changes to the river regimes. Currently, the seasonal flooding of the delta is completely controlled by manmade infrastructures.

The Nile River basin countries have experienced extremely turbulent political periods in the recent times. Egypt, the most developed economy and the hegemonic power in the area, is facing internal political problems started with the 2011 civil protests. Sudan was afflicted by 2 extremely harsh civil wars: the first lasted for 17 years between 1955 and 1972, and killed more than 500 thousands people forcing to massive migration several hundred thousands. War restarted in 1983, it led to the independence of South Sudan in 2011, and it is still ongoing in several parts of the Sudanese territory, as in Darfur. Burundi and Rwanda were devastated by a bloody civil war and the subsequent genocide of several tens of thousands people. Uganda, Tanzania and Congo-DRC were afflicted by numerous internal tensions, which in some cases are still ongoing. Political instability rose recently also in Kenya. Some of these countries are considered among the most "Fragile States" by the Fund for Peace organization (FFP, 2020).

Underdevelopment and lack of access to the basic services is common, especially in the southern part of the basin: people living below the poverty line are the majority of the population in the Congolese, Rwandese, and Burundian portions of the catchment. Poverty is widespread also in the other countries, with the partial exception of Egypt, main economic and military power in the basin. Rural population lives in far worse conditions respect to the urban one throughout the basin, especially in the most remote areas. Level of electrification, access to improved water supply and sanitation, remain low in all the countries except Egypt. Agriculture is still the main source of income for the rural population; the industrial sector, mainly represented by mining and extraction of fossil fuels follows. Rainfed agriculture, ~ 33 million ha, is more common in the southern part of the basin, where precipitation is more abundant: in particular in Uganda, South Sudan, Kenya, and Tanzania. Main production in these areas is represented by sesame, corn, pulses, and millet. Small scale localized irrigation schemes, however, are present in the areas surrounding Lake Victoria, in particular in the Rwandese, Tanzanian, and Kenyan territories. Large scale irrigation schemes were developed in the most arid areas, as the Blue and White Nile valleys in Sudan (1.76 million ha) and the Nile valley and Delta in Egypt (3.45 million ha). Water demand for irrigation in these two countries represent 97% of the overall demand in the basin: withdrawals were estimated in ~ 66 billion cubic meters per year in Egypt and ~ 14 in Sudan. Egypt developed about 270 thousands km of irrigation network, and, due to double cropping, its crop area is about 5 million ha. Livestock production is mainly developed around Lake Victoria, South Sudan, and Ethiopia.

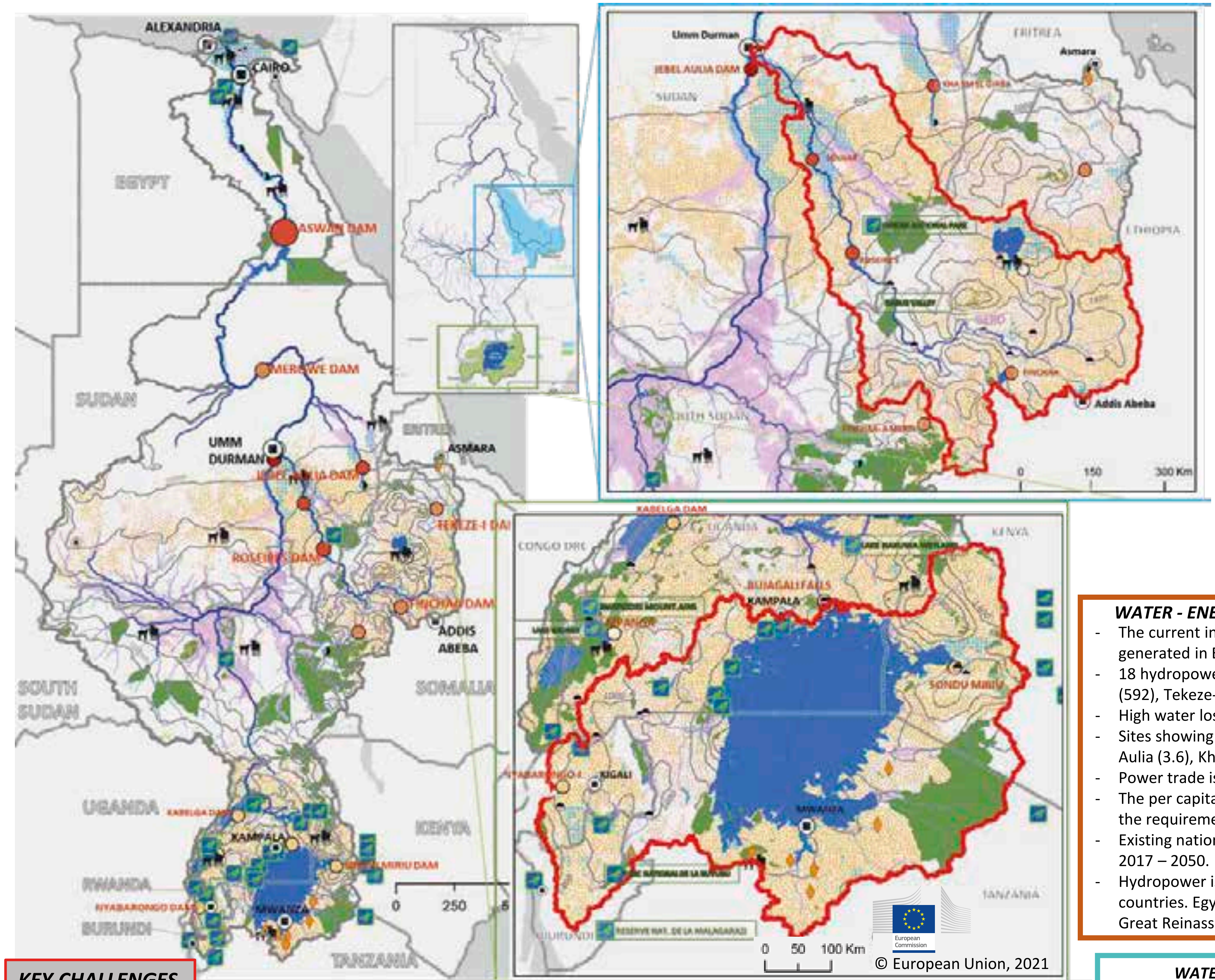
Capture fishery is highest in the Lake Victoria, while aquaculture is extremely developed in the Egyptian reservoirs. Egypt produces about 90% of the 1.23 million tons of fishery yearly production, followed by Uganda with 8%. Navigation is developed in 9 out of the 11 states sharing the Nile basin, with Eritrea and Ethiopia isolated for topographic reasons. The large wetlands in the Nile basin, extremely important under the ecological point of view, are subject to increasing antropogenic pressure. In addition, two of the riparian States (Ethiopia and Eritrea) did not take part to the RAMSAR convention.

Hydropower potential is extremely high in the basin, and it is currently the main source of tensions between upstream and downstream countries. 22 plants are already installed, for a total of 5.66 GW capacity, 2.1 GW of which are represented only by the Aswan Dam at the border between Sudan and Egypt. Additional 20 GW are planned to be installed in the next future, exploiting in particular the hydraulic potential of the Blue Nile. The Great Renaissance Dam (GERD), currently under construction in Ethiopia, is expected to contribute with about 6 GW. Egypt is particularly concerned about the hydropower development in the upstream countries. Huge diplomatic efforts are being currently made to find a new satisfactory water allocation agreement among Nile states to maximize the benefit of hydropower and agricultural development upstream, without compromising downstream water uses. In 2010, a Cooperative Framework Agreement (CFA) was signed by 6 upstream countries, with strong opposition from mainly Egypt and Sudan. A new tri-lateral agreement was signed in 2015 to ease the dispute between Sudan, Egypt, and Ethiopia over the Great Renaissance Dam.

Figure 19. Key WEFE Nexus challenges in the Nile River Basin

NILE RIVER BASIN CHALLENGES

3.2 million of km^2	6695 km long	75.2 BCM/yr
1st largest in the World	Shared across 11 countries	257 M people



KEY CHALLENGES

- High dependency on the Blue Nile water contribution and by its high flow seasonality
- Large number of hydraulic infrastructure installed, imposing radical changes to the river regimes.
- Currently, the seasonal flooding of the delta is completely controlled by the manmade infrastructures.
- Extremely turbulent political periods in the recent times: some of these countries are considered among the most "Fragile States" by the Fund for Peace organization
- Underdevelopment and lack of access to the basic services is common especially in the southern portion of the basin: in the Congolese, Rwandese, and Burundian portions of the catchment. Poverty is widespread also in the other countries, with the partial exception of Egypt
- Water demand for irrigation in Egypt and Sudan represent 97% of the overall demand in the basin
- Need for a new satisfactory water allocation agreement among Nile states, to maximize the benefit of hydropower and agricultural development upstream, without compromising downstream water uses.
- Efforts need to be exerted to improve on hydrologic modelling, climate change scenarios and forecasting
- Groundwater is widely used across the basin for domestic water supply, however information in this area is still scanty.

WATER - ENVIRONMENT

- Wetlands cover ~5% of the basin. 17 Ramsar sites (8.1 million ha). Not signatories: Ethiopia and Eritrea.
- Main protected areas: e.g. Serengeti, Masai Mara, Boma, Virunga, Karisimbi and Bwindi national parks.
- Mining: impacts of artisanal gold mining and petroleum.
- Water and related environmental resources amount to 40-60% of the riparian countries' GDP.
- Main causes of environmental degradation: population growth, poverty, civil insecurity and weak policy, legal and institutional frameworks.
- Key recommendations: restoration of degraded water catchments and badly degraded lands, implementation of a regional monitoring network.

WATER - CLIMATE VARIABILITY

- High seasonality of river flows, especially in the Eastern Nile
- Extreme seasonality (intra-annual) and variability (inter-annual)
- Flood and drought risks
- In the Blue Nile, rainfall is markedly seasonal (torrential rain season followed by a long dry season which requires the storage of water.

WATER – SOCIO ECONOMIC

- Population growth: by over four fold between 1960 and 2010 and is estimated to nearly double by 2030
- Urban population with access to sanitation is less than 50%; for rural areas, the figure is less than 30%
- Low Human Development category (with the exception of Egypt)
- High political instability (some of the countries among the most "Fragile States" according to the Fund for Peace organization.

WATER - ENERGY

- The current installed capacity of hydropower is estimated at 5660MW of which 40% generated in Egypt, 28% by Sudan and 18% Ethiopia
- 18 hydropower plants with IC > 5MW: Aswan high (2100), Merowe (1250), Aswan (592), Tekeze-I (300), Roseires (280), Bujagali falls (255)
- High water loss via seepage and evaporation from the reservoirs (17.6 BCM)
- Sites showing highest water losses [mcm] per energy production unit [GWh]: Jebel Aulia (3.6), Khasm el Girba (1.3), Sennar (1.2) and Aswan high (0.6)
- Power trade is low, and only restricted to limited exchange
- The per capita energy consumption in the Nile riparian states, except Egypt, is below the requirements for rural supply in sub Saharan Africa (250kWh/ capita/year)
- Existing national plans indicate a substantial increase in installed capacity in the period 2017 – 2050. Most of the increase is expected to be in the Blue Nile sub-basin.
- Hydropower is a main source of tension between upstream and downstream countries. Egypt and Sudan are particularly concerned by the construction of the Great Reinassance Dam (GERD) in Ethiopia.

WATER - FOOD

- Agriculture is a major livelihood strategy, sustaining tens of millions of people. It provides occupations for more than 75% of the total labour force and contributes to one third of the GDP in the basin
- The total estimated annual irrigation water demand for irrigation is approximately 85BCM; 5.6 million hectares of land under Irrigation, 97% of this area is in Egypt and Sudan, accounting for more than 80% of water withdrawal
- Rainfed farming (33 Mha), is dominant. Over 70% of population depends on it
- Water scarcity remains the major limiting factor for agricultural development
- Fisheries and aquaculture are important components of agricultural production, but signs of overfishing are arising
- Daily calorie availability per person in the Nile countries (except Egypt) is below 3,000 kcal per person

5.4.3 Application of the WEFE Nexus approach

Climate variability and change, along with increasing demographic pressure and water demands for agriculture and infrastructural development are the main sources of concern for the broad Nile basin and in particular for the Blue Nile and the Lake Victoria sub-systems. Both these sections of the Nile Basin were carefully investigated within the ACEWATER2 Project activities.

In the Blue Nile, the analysis focused on the assessment of water availability over the basin, and of the impacts of the GERD (Great Ethiopian Renaissance Dam), both in terms of hydropower production and water demand for irrigation and environmental flow, downstream in Sudan. In collaboration with the Karthoum and Addis Ababa Universities, a WEFE Nexus model was set up to estimate the hydrological scenarios likely to result from the installation of the new dam and the expected impacts for the downstream agriculture and energy systems. The analysis at the moment did not take into consideration the climate change scenarios: The installation of the GERD is likely to increase the evaporative losses and to reduce the water-energy productivity of the downstream reservoirs. On the other hand, it woud regulate the flow throughout the year, and therefore partially offsetting the productivity reduction (Basheer & Abdo, 2021; Robele et al. 2020).

The main objective in the lake Victoria focused on competing water use demand, sectors interdependencies and tradeoffs under increasing pressure due to population growth, irrigation expansion, water quality deterioration, groundwater quality and environmental concerns related to lake levels, eutrophication and water quality, also assessing potential socio-economic impacts. In particular, the combination of precipitation reduction associated with future expected climate conditions in the area, and increasing demand associated to the large population growth and irrigated areas were found to be particular worrisome in a dedicated study conducted in collaboration with the IGAD Climate Prediction and Application Center (Hassan, 2021) and Makerere University (Bamutaze et al, 2021).

A strong seasonal rather than annual alteration in the precipitation pattern is likely to be experienced as a result of climate change, with the autumn season (October to December) likely to become more pronounced than spring one (March to May). Yields of the local maize variety are expected to be negatively affected by the shift in precipitation, this would be particularly important if the current agricultural practices with low inorganic and organic input were maintained. Other varieties, instead, are likely to get benefits from the changes in climate as projected by the current scenarios.

6.

CONCLUSIONS AND POLICY RECOMMENDATIONS

6 CONCLUSIONS AND POLICY RECOMMENDATIONS

6.1 Conclusions ...

6.1.1 Sustainable Development Goals (SDGs), transboundary water resources and governance

Sustainable access to clean water and sanitation, as well as water resources management, play an important role not only in SDG 6 (the only one completely devoted to provide water and sanitation for all), but also in the rest of SDGs, especially 1 (no poverty), 2 (zero hunger), 3 (good health and well-being), 4 (quality education), 5 (gender equality), 7 (affordable and clean energy), 11 (sustainable cities and communities), 12 (responsible consumption and production), 13 (climate action), 15 (life on land) and 16 (peace, justice and strong institutions). Therefore, the interdependences between the SDGs need a joint effort and collaboration among all relevant actors at all levels to ensure that by 2030 no one is left behind. However, in some countries minimum progress has been made towards their achievement, often hampered by: i) the misalignement between policies and current aspirations and goals; ii) the existence of weak institutional arrangements, fragmentation and the lack of a clear institutional responsiblility, and; iii) inadequate financing of the activities needed to pursue the SDGs.

In this regard, the African continent is particularly challenging, as 90% of water resources are found in 63 transboundary river basins and their per capita distribution is highly unequal and variable. Therefore, transboundary issues would require an increased focus from both the political and scientific perspectives, integrating cultural and historic aspects at regional level to ensure effective collaboration among countries. This is particularly relevant when it comes to transboundary water transfers and large storage projects, a source of social concern where delays may result in unilateral planning and affect the spirit of cooperation. Besides, the management of transboundary aquifers in Africa faces up specific challenges, such as hydrogeological data acquisition and management; lack of updated information to reflect the changes in climate during the past decades or; salt water intrusion along coastal areas and in the islands (e.g. Mauritius). Hence, groundwater should be regarded as a key resource for the climate resilience of the continent, requiring the full involvement of national geological services and the implementation of adequate drilling and water harvesting practices (e.g. managed recharge), in order to reduce inter-tribal conflicts for water access and cross-border resource sharing.

In this context, Water Diplomacy emerges as a suitable tool for strengthening peace and sustainability, addressing issues and challenges in water resources management in Africa, involving negotiations, international and cooperative dialogues that must be based on sound knowledge and informed decisions. Besides, the Science-Policy interface plays also an essential role in fostering water management dialogues on various institutional levels. These dialogues are particularly important in international watercourses, where competition for the allocation of water resources among countries and uses, exacerbated by climate change and population growth, could become a potential source of conflict or an opportunity for cooperation. However, this interface is always subject to tensions for several reasons, including: 1) complexity of evidence (while researchers consider scientific literature an important form of evidence, policymakers rely on practical knowledge from the field and political understanding); 2) structural underfunding of research; 3) limited incentives (for applicable and policy–oriented research publications); 4) existence of different time frames between researching and policy making; 5) gaps in the education system; 6) mistrust between researchers and policymakers; 7) inadequate expectations with regard to the research-policy interface and; 8) irregular and ambiguous communication between the two communities (Kanangire et al., 2021).

Finally, it is necessary to highlight the relevance of SDG 6 in the current pandemic context, as the lack of proper access to water, sanitation and hygiene (WASH) is a prevalent risk factor in the development of multiple infectious diseases, such as diarrhoea, schistosomiasis or lower respiratory infections (e.g. Prüss-Ustün et al., 2019). The analysis of the potential vulnerability of African countries to COVID-19, in relation to several socioeconomic factors, showed that mortality due to respiratory infections was negatively correlated to the improvement of WASH access during the period 2000-2016. However, most of African countries are still characterized by low life expectancy, weak healthcare systems and WASH services, high mortality rates and low rates of urbanization and migration remittance inflow. Therefore, they have a very limited capacity to tackle public emergencies and the flow of Official Development Aid currently directed to the WASH sector may not be sufficient to improve sanitary conditions (Carmona-Moreno and Marcos-Garcia, 2020).

6.1.2 Data, knowledge development and digitalisation

Data quality, accessibility, collection and management remain the largest obstacles to the validation of effective scientific studies in Africa. In particular, models often require a number of parameters and indicators that are poorly monitored in most African basins, and the quality of the currently available data could be questionable in certain cases. In this regard, Information and Communication Technologies (ICTs) constitute a key aspect towards a more effective data management in Africa, which is nowadays facilitated by the availability of both computing resources at low cost and open source (OS) and free software. However, the continent's digitalisation should still face up many barriers in addition to data scarcity, such as the lack of expertise, the absence of adequate financial resources to develop and maintain models or the lack of a proper Internet connection. In this regard, the COVID-19 pandemic has been a turning point to bring to light these pressing issues in the Fourth Industrial Revolution era, where emerging technologies are already impacting on all aspects of human life.

Concretely, the use of digital tools is of outmost importance when it comes to sustainable groundwater resource management in Africa, as they could be used for data gathering, archiving and analysis, spanning from digital sensors, to Geographic Information Systems, numerical modelling up to advanced artificial intelligence for data-based groundwater resource planning and management. In this regard, results from a comprehensive literature review on the use of groundwater numerical models in the last twenty years in Africa, coupled with and a survey targeting African groundwater experts, depict the following state-of-the-art: in the field (Rossetto and Veroli, 2021)

- Digital tools are recognised as needed tools for groundwater resource management at national and regional levels in the African countries, as they may provide a dynamic and easily updatable view on the resource available, used, and potentially exploitable without the need of relying on analogical or paper-based static analyses..

- At present, most used digital tools are calculation spreadsheets, then GIS applications, followed by numerical modelling tools. The latter are still seen as research oriented tools Their use in professional work is relevant, while emerging in public authorities.

- Commercial software solutions still dominate the market, while open source ones have just appeared. Open source and free software (largely preferred to commercial solutions) would be used if adequate training was provided. Capacity building on the use of digital tools for groundwater management is (extremely) necessary.

- Dedicated training on hydroinformatics (including programming) in university courses and cooperation in joint international projects would help to create a generation of experts promoting digital groundwater governance in Africa.

6.1.3 Human Capacity Development

The development of the requisite human capital to sustain the vision of an integrated, prosperous and peaceful Africa requires the implementation of strategic decisions in the education and training sectors. Concretely, four broad categories of priorities were identified regarding HCD in the water sector (Mbaziira, 2020a): 1) building critical missing skills (particularly linked to sustainable development, utilisation and management of water and related resources) to enhance economic growth and social transformation; 2) updating and transforming the High Education (HE) and the Technical and Vocational Education and Training (TVET) sectors to integrate flexibility and adaptability for current and continuous learning in the education and training supply of human resources; 3) supporting Earth observation science and research, teaching and outreach; and, 4) recognition of competences from non-formal and informal education and training.

Dedicated human and financial resources should be clearly directed to the analysis of the water sector stakeholders and capacity gaps, because they are time consuming, complicated and expensive to carry out. Besides, institutions as part of a network are able to attract more funding than as single institutions leveraging funds coming from the EC. African institutions working in Science and Technology have limited capacity and resources, but they are among the very few source of local capacity and, as such, should be stimulated and further developed. This collective approach is the proposed solution to work towards a real sustainable capacity development. Among these institutions, the CoEs are particularly relevant and should be highlighted, given their profound knowledge of the local contexts, the long-term role they play in local knowledge management and the fact that they are institutionally and politically members of the African Union framework. The involvement of continental institutions, such as RECs and AMCOW, in the framework of the project, highly increased the impact of the CoEs, their role as sustainable players for capacity development and the institutional sustainability of this initiative.

6.1.4 Water-Energy-Food security-Environment

The African Union Agenda 2063 "The Africa We Want" (AUC, 2014), envisions a prosperous Africa, based on inclusive growth and sustainable development. To work towards these objectives, water, energy and food security must be ensured through the development and operationalisation of delivery mechanisms at the required scale. However, challenges arise due to Africa's high vulnerability to

climate variability, water availability and commodity prices, which could be exacerbated in the future by climate change and a rapidly growing population. The complexity of these challenges across sectors and scales prevents the use of single sector policy perspectives and promotes the adoption of comprehensive frameworks which consider their multiple interlinkages. In this regard, the Water, Energy, Food and Ecosystems (WEFE) Nexus approach is able to integrate management and governance across the multiple sectors involved, recognizing their interdependencies and the value of natural capital, ensuring coordination among stakeholders and identifying suitable policy solutions in order to optimize trade-offs and maximize synergies across sectors (Carmona-Moreno et al., 2019).

- **Water:** water scarcity issues could arise in multiple African basins, as a combination of the decrease of the available resources due to climate variability and change and the increase of future water demands, boosted by population growth, energy requirements, livestock farming development, and the expansion of both smallholder and commercial irrigation. In addition, sea level rise and its related impacts on coastal and flat areas are likely to undermine water security in highly populated islands and coastal settlements. Therefore, the existence of growing competing demands over an increasingly scarce resource could eventually have a high potential for conflict, involving multiple stakeholders at different scales.

- Energy: the water-energy nexus is particularly challenging in Africa, as energy and water demands cannot be fully decoupled and the continent's energy needs are expected to soar due to the combined effect of economic and demographic growth. Although its full potential remains largely untapped, hydropower is the dominant renewable energy source in most African energy systems. In this context, and energy supply disruptions due to droughts frequently lead to negative economic and health aftermaths in African countries, affecting the energy mix, operational costs, CO2 emissions and water consumption for energy generation. Besides, hydropower is very water-intensive due to the evaporation losses in reservoirs. The substitution of fossil fuels by non-hydro renewable energies (such as wind or solar) could reduce significantly water use while helping to meet the increasing energy needs of the continent.

- Food security: the poorest and driest areas are highly dependent on rainfall for both human and livestock water supply and for sustaining rainfed agriculture and pastureland. Therefore, they are expected to suffer disproportionate impacts due to climate variablility, change and extreme events such as floods, droughts or heat waves, coupled with the increasing exposure of a rapidly growing population. Besides, urbanisation is progressing at a faster pace than agricultural expansion. In this context, there is a pressing need for the adoption of more effective climate change adaptation strategies, in order to tackle desertification and soil degradation issues (e.g. reforestation, soil and water conservation), including the promotion of local traditional practices and supporting smallholders to enhance rural livelihoods and food security.

- Ecosystems: African ecosystems are already facing up multiple challenges such as increasing human-wildlife conflicts due to population growth; degradation due to land use changes, woodfuel collection and cattle production; and, impacts on wetlands and other water-related ecosystems due to increasing water withdrawals, the development of water infrastructure and pollution issues due to mining (e.g. heavy metals), oil and gas extraction industry, urban settlements (e.g. plastic mismanagement, fecal bacteria and parasites) or agriculture (nutrients and pesticides).

6.2 ... and policy recommendations

Achieving the SDG goals represents a target of paramount importance in the political agenda of the continent, demanding for a joint effort and collaboration among all relevant actors. Development agenda and policy making should be closely aligned with the set of targets and goals. The institutional framework should be restructured in order to be more effective in the implementation of the plans, and adequate levels of funding should be pursued in the international market, both from donors and from the involvement of public-private partnerships.

In the case of the international watercourses, the management of transboundary issues remains one of the most challenging topics in the political and institutional agendas of the different African regions. Significant steps forward have been made, in the past few years, with the creation of the main River Basin Organizations, while promoting the interactions between these, the National Governments and the Regional Economic Communities. Water Diplomacy remains the most important tool in the hands of the institutional actors involved in transboundary water management. Water diplomacy, jointly with a robust Science-Policy dialogue, represents the most suitable path towards the achievement of the sustainable development needed more and more as a response to environmental changes, population growth, and socio-economic dynamics. Cooperation and collaboration between states, national and supra-national institutions, representatives of the competing sectors, and local populations, should be central in the discussions related to the infrastructural development and, in general, in the water management decisions. A participatory approach would make the decisions more robust and the implementation of the plans more widely accepted. In the context of the transboundary water management, this process would be greatly facilitated if norms and data were harmonized between River Basin's Riparian States and clear protocols for data sharing put in place. This could provide a common basis on which the associated dialogues and compromises could be developed.

The WEFE nexus approach represents a unique paradigm to enhance water, food, and energy security while protecting the natural ecosystem through the strategic water resources planning. Integrate the WEFE nexus framework in the development of infrastructural projects, particularly while considering the cost-benefit analysis and the environmental impact assessment phases, would ensure a more effective informed decision making process. However, the effective operationalisation of the nexus WEFE framework requires a careful examination of the specific context with the identification of concrete sets of priorities to be addressed through the appropriate involvement of stakeholders and the selection of the most effective dialogue model approach, guided by the identification of intervention projects. The integration of sustainability, climate change adaptation and mitigation strategies, transboundary dynamics and natural resource management into the development programme would facilitate a collaborative and cooperative approach to achieve sustainable resource management and development.

In this context, scientific and technical research appears to be a fundamental element for a better understanding of socio-economic and natural systems which are becoming increasingly complex. A more effective research activity, especially if it is carried out in the framework of international and regional agreements should be conducted by of ad-hoc **think tanks** involving **research-policy makers-private sector**. This would ensure better informed decision-making, contributing significantly to building trust between actors sharing and competing for common resources.

In this context, promoting the adoption of state-of-the-art digital tools and best practices, pursuing standardisation objectives and developing the expertise needed for the effective integration of water resources management throughout the continent are identified as top priorities. The diffusion of the application of digital tools and more up to date technological practices, should be accompanied by the development of the human capacity able to effectively make use of the most advanced technical tools. There is an increasing need to promote the formation of engineers and scientists able to operate in the water and related sectors among the large young population in the continent. This goal should be pursued by promoting high education and training programs among the African universities and the institutions working in Science and Technology. The water sector should also be made more attractive, in order to limit the transition of part of the more skilled labour force towards other more remunerative sectors.

Human Capacity Development programs should involve regional actors (RBOs, RECs). Local and Regional programs should be coordinated and scaled up for the wider water, energy, food and ecosystems sectors in Africa. Capacity building in the water sector should include all the scientific and economic disciplines, jointly with political science and water diplomacy. Particular attention should be devoted to both surface water and groundwater resources, their interchanges and, the monitoring of eventual quality issues detrimental for human health.

APPENDICES

APPENDIX 1 – REFERENCES

AfDB, 2012. Briefing Notes for AfDB's Long-Term Strategy. Briefing Note 1: Higher Education, Science and Technology

AGRHYMET, 2019. Sites pour le développement des scénarios de gestion de la ressource en eau dans le bassin du Niger. European Commission, Ispra, JRC123101 ACEWATER2 report

Alfieri, L., Bisselink, B., Dottori, F., Naumann, G., de Roo, A., Salamon, P., Wyser, K., Feyen, L., 2017. Global projections of river flood risk in a warmer world. Earth's Futur. 5, 171–182. doi:10.1002/2016EF000485

Ali, A, Hamatan, M, Minoungou, B, Pastori, M., Marcos-Garcia, P., Carmona-Moreno C., 2021, Hydrological modelling and water management in the Niger river basin. SWAT model setup and identification of scenarios in a WEFE context. In Crestaz et. al., 2021

AMCOW (2016). Africa Water Sector and Sanitation Monitoring and Reporting. Abuja, Nigeria: African Ministers' Council on Water

Arias, M.E., Hughes, D., Farinosi, F, (under review). Future hydropower operations in the Zambezi River Basin: Climate impacts and adaptation capacity. River Research and Applications.

AUC (2014). Agenda 2063: The Africa We Want.Addis Ababa: African Union Commission

Baranzelli, C., Jacobs-Crisioni, C., Maistrali, A., Kucas, A., Kavalov, B., Perpiña Castillo, C., Kompil, M., Lavalle, C. 2021. Urban development and regional connectivity in Africa. In "The African Networks of Centres of Excellence on Water Sciences Phase II (ACE WATER 2) WEFE Nexus assessment in Africa). JRC124127Basheer, M., Abdo, G. M., 2021. Water-energy-food-ecosystem nexus assessment in the Blue Nile Basin in Sudan. In Crestaz et. al., 2021

Battistelli, A., Crestaz, E., Carmona-Moreno C., 2021.The African Networks of Excellence on Water Sciences Phase II (ACE WATER 2). Status of Geothermal Industry in East African countries. European Commission, Ispra, JRC121913

Beck, H.E., van Dijk, A.I.J.M., Levizzani, V., Schellekens, J., Miralles, D.G., Martens, B., de Roo, A., 2017. MSWEP: 3-hourly 0.25° global gridded precipitation (1979-2015) by merging gauge, satellite, and reanalysis data. Hydrol. Earth Syst. Sci. 21, 589–615. doi:10.5194/hess-21-589-2017

Buhaug, H., Vestby, J. 2019. On growth projections in the Shared Socioeconomic Pathways. Global Environmental Politics, 19:4, 118-132.

Busch, S., De Felice, M. and Hidalgo Gonzalez, I., 2020. Analysis of the water-power nexus in the Southern African Power Pool, EUR 30322 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-21015-3, doi:10.2760/920794, JRC121329.

Carmona-Moreno et al., 2019. Position Paper on Water, Energy, Food, and Ecosystem (WEFE) Nexus and Sustainable development Goals (SDGs). 2019. Editors: C. Carmona-Moreno, C. Dondeynaz, M. Biedler, EUR 29509 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-79-98276-7, doi:10.2760/5295, JRC114177

Carmona-Moreno, C., Marcos-Garcia, P., 2020. Healthcare and WASH versus COVID-19 in Africa. Science behind the debate, European Commission, Ispra, JRC120667. d.o.i. 10.2760/31235, ISBN 978-92-76-18580-2.

Cattaneo L., Pastori M., Cordano E., Crestaz E., Seliger R., Koundouno J., Bausa Lopez, L., Carmona, C. 2019. Applications and results for the E-Nexus decision support system for the WEFE Senegal project, European Commission, Ispra, JRC119391.

Conway, D., Dalin, C., Landman, W.A. et al. 2017. Hydropower plans in eastern and southern Africa increase risk of concurrent climate-related electricity supply disruption. Nat Energy 2, 946–953. https://doi.org/10.1038/s41560-017-0037-4

Copernicus Service Information, 2017. Copernicus Global Land Service [WWW Document]. African Yrly. L. Cover map 100m Resolut. URL http://land.copernicus.eu/global/content/first-release-land-cover-map-100m

Crestaz E., Farinosi F., Marcos Garcia P., Carmona C., Biedler M. (Eds.), 2021. The African Networks of Centres of Excellence on Water Sciences Phase II (ACEWATER2): WEFE Nexus assessment in Africa. European Commission, Ispra, JRC124127

De Felice, M., González Aparicio, I., Huld, T., Busch, S., Hidalgo González, I. 2019. Analysis of the waterpower nexus in the West African Power Pool - Water-Energy-Food-Ecosystems project, EUR 29617 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-98138-8, doi:10.2760/362802, JRC115157

DeGeorges, A., Reilly, B.K. 2006. Dams and large scale irrigation on the Senegal River: impacts on man and the environment, International Journal of Environmental Studies, 63:5, 633-644, DOI: 10.1080/00207230600963296

Diessner, C. 2012. Dam Complications in Senegal: How River Dams May Hurt More than Help Vulnerable Populations in Water-Stressed Regions, 19 J. Envtl. & Sustainability L. 247. Available at: https://scholarship.law.missouri.edu/jesl/vol19/iss1/10

Dosio, A., 2017. Projection of temperature and heat waves for Africa with an ensemble of CORDEX Regional Climate Models. Clim. Dyn. 49, 493–519. doi:10.1007/s00382-016-3355-5

Dosio, A., Jones, R.G., Jack, C., Lennard, C., Nikulin, G., Hewitson, B., 2019. What can we know about future precipitation in Africa? Robustness, significance and added value of projections from a large ensemble of regional climate models. Clim. Dyn. 53, 5833–5858. doi:10.1007/s00382-019-04900-3

Dosio, A., Mentaschi, L., Fischer, E.M., Wyser, K., 2018. Extreme heat waves under 1.5°C and 2°C global warming. Environ. Res. Lett. doi:10.1088/1748-9326/aab827

EC JRC, Neuville, A., Belward, A., Alguadis, M., Bertzky, B., Brink, A., Buscaglia, D., De Groeve, T., Kayitakire, F., Mulhern, G. et al. ., 2017. Science for the AU-EU Partnership: building knowledge for sustainable development. Publications Office of the European Union, Luxembourg. doi:10.2760/429935

Eduvie, M.O, Adanu, E.A. 2021. Climate variability and extreme event, hydrology and reservoir management, agriculture and water in Northern Nigeria. In Crestaz et. al., 2021

Ehiorobo, J.O., Izinyon, O.C. Rawlings, A. 2020. WEFE Nexus assessment in the Niger Delta basin, Southern Nigeria.

El Mahmoud-Hamed, M.S., Montesdeoca-Esponda, S., Santana-Del Pino, A. et al., 2019. Distribution and health risk assessment of cadmium, lead, and mercury in freshwater fish from the right bank of Senegal River in Mauritania. 2019. Environ Monit Assess 191, 493. https://doi.org/10.1007/s10661-019-7627-5

El Safadi, D., Gaayeb, L., Meloni, D. et al. 2014. Children of Senegal River Basin show the highest prevalence of Blastocystissp. ever observed worldwide. BMC Infect Dis 14, 164. https://doi.org/10.1186/1471-2334-14-164

Farinosi, F., Dosio, A., Calliari, E., Seliger, R., Alfieri, L., Naumann, G., 2020. Will the Paris Agreement protect us from hydro-meteorological extremes? Environ. Res. Lett. doi:10.1088/1748-9326/aba869

Farinosi, F., Giupponi, C., Reynaud, A., Ceccherini, G., Carmona-Moreno, C., De Roo, A., Gonzalez-Sanchez, D., Bidoglio, G., 2018a. An innovative approach to the assessment of hydro-political risk: A spatially explicit, data driven indicator of hydro-political issues. Glob. Environ. Chang. 52, 286–313. doi:10.1016/j.gloenvcha.2018.07.001

Farinosi, F., Gonzalez Sanchez, Carmona-Moreno, C., Bidoglio, G., 2018b. Technical documents supporting the development of the African Water Cooperation Atlas.

Farinosi, F., Seliger, R., Udias, A., Crestaz, E., Carmona-Moreno, C., Bidoglio, G., 2019. Technical documentation about the specific applications of the African Water Cooperation Atlas.

FFP, 2020. Fragile States Index 2020. Fund for Peace organization publication: https://fundforpeace.org/2020/05/11/fragile-states-index-2020/ Last access: 19 February 2021

Frieler, K., Lange, S., Piontek, F., Reyer, C.P.O., Schewe, J., Warszawski, L., Zhao, F., Chini, L., Denvil, S., Emanuel, K., Geiger, T., Halladay, K., Hurtt, G., Mengel, M., Murakami, D., Ostberg, S., Popp, A., Riva, R., Stevanovic, M., Suzuki, T., Volkholz, J., Burke, E., Ciais, P., Ebi, K., Eddy, T.D., Elliott, J., Galbraith, E., Gosling, S.N., Hattermann, F., Hickler, T., Hinkel, J., Hof, C., Huber, V., Jägermeyr, J., Krysanova, V., Marcé, R., Müller Schmied, H., Mouratiadou, I., Pierson, D., Tittensor, D.P., Vautard, R., van Vliet, M., Biber, M.F., Betts, R.A., Bodirsky, B.L., Deryng, D., Frolking, S., Jones, C.D., Lotze, H.K., Lotze-Campen, H., Sahajpal, R., Thonicke, K., Tian, H., Yamagata, Y., 2017. Assessing the impacts of 1.5 °C global warming – simulation protocol of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP2b). Geosci. Model Dev. 10, 4321–4345. doi:10.5194/gmd-10-4321-2017

Gonzalez Sanchez, R., Seliger, R., Fahl, F., De Felice, L., Ouarda, T.B.M.J., Farinosi, F., 2020. Freshwater use of the energy sector in Africa. Appl. Energy 270, 115171. doi:https://doi.org/10.1016/j.apenergy.2020.115171

Hajjar, B. 2020. The children's continent: keeping up with Africa's growth. World Economic Forum Annual Meeting. Retrieved from: https://www.weforum.org/agenda/2020/01/the-children-s-continent/. Last access: 12 February 2021.

Hassan, M.A., 2021. Hydrology and Water Balance of Lake Victoria sub basin. In Crestaz et. al., 2021

Hidalgo Gonzalez I., De Felice M., Busch S., 2021. Analysis of the water-power nexus in the African power pools. In Crestaz et. al., 2021

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., Djalante, R., Ebi, K.L., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Payne, A., Seneviratne, S.I., Thomas, A., Warren, R., Zhou, G., 2018. Impacts of 1.5oC Global Warming on Natural and Human Systems, in: Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T. (Eds.), Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change,. Cambridge University Press, Cambridge, UK, and New York NY, USA.

IRMSA, 2015. Impact of the failure of the Kariba dam. The Institute of Risk Management South Africa Risk Research Report. IRMSA - Aon Risk Research Report, June 2015.

Hidalgo Gonzalez I., De Felice M., Busch S., 2021. Analysis of the water-power nexus in the African power pools. In "The African Networks of Centres of Excellence on Water Sciences Phase II (ACE WATER 2) WEFE Nexus assessment in Africa)

Hughes, D. A., Farinosi, F., 2020a. Assessing development and climate variability impacts on water resources in the Zambezi River basin. Simulating future scenarios of climate and development. Journal of Hydrology: Regional Studies, 32, 100763. https://doi.org/10.1016/j.ejrh.2020.100763

Hughes, D., Farinosi, F., 2020b. Unpacking some of the linkages between uncertainties in observational data and the simulation of different hydrological processes using the Pitman model in the data scarce Zambezi River basin (Authorea). https://doi.org/10.22541/au.160071214.41878822

Hughes, D., Mantel, S., Farinosi, F., 2020. Assessing development and climate variability impacts on water resources in the Zambezi River basin: Initial model calibration, uncertainty issues and performance. Journal of Hydrology: Regional Studies, 32, 100765. https://doi.org/10.1016/j.ejrh.2020.100765

IHA. 2020. Hydropower Status Report. Sector trends and insights. Retrieved from: https://archive.hydropower.org/publications/2020-hydropower-status-report Last access: 19 February 2021.

Ikporukpo, C., 2020. The Challenge of Oil Spill Monitoring and Control in Nigeria. Int. J. Environ. Monit. Anal. 8, 202–207. doi:10.11648/j.ijema.20200806.14

IRENA. 2015. Africa 2030: Roadmap for a Renewable Energy Future. IRENA, Abu Dhabi. Retrieved from: https://www.irena.org/publications/2015/Oct/Africa-2030-Roadmap-for-a-Renewable-Energy-Future Last access: 19 February 2021.

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R. et al. 2015. Plastic waste inputs from land into the ocean. Science, Vol. 347, Issue 6223, pp. 768-771. DOI: 10.1126/science.1260352

Kanangire, C. et al. 2021. Water Science to support Policy Making in Africa. Policy brief, JRC124470

Louhichi, K., Tillie, P., Ricome, A., Gomez y Paloma, S. 2020. Modelling farm-households livelihoods in developing economies. JRC Science for Policy Report Summary. Insights from three country case studies using LSMS-ISA data. JRC Science for Policy Report Summary, European Commission, Ispra, JRC118822

Malagò, A., Bouraoui, F., 2021. Global anthropogenic and natural nutrient fluxes: from local to planetary assessments. Environ. Res. Lett. doi:10.1088/1748-9326/abe95f

Mbaye, M.L., Gaye, A.T., Spitzy, A., Dähnke, K. et al., 2016. Seasonal and spatial variation in suspended matter, organic carbon, nitrogen, and nutrient concentrations of the Senegal River in West Africa, Limnologica, Volume 57, Pages 1-13, ISSN 0075-9511, https://doi.org/10.1016/j.limno.2015.12.003.

Mbaziira, R. 2020a. The African Networks of Centres of Excellence on Water Sciences PHASE II (ACE WATER 2). Volume I: Draft Report on Human Capacity Development priorities of the Water Sector in Africa. European Commission, Ispra, JRC123100 ACEWATER2 report

Mbaziira, R. 2020b. The African Networks of Centres of Excellence on Water Sciences PHASE II (ACE WATER 2). Volume II: Final Report on Development Priorities of the Water Sector in Africa placed in the context of Agri-Energy sectors. European Commission, Ispra, JRC123098 ACEWATER2 report

Medinilla, A. (2017). The Niger Basin Authority: Reconciling upstream and downstream interests on the Niger River. ECDPM policy brief. Retrieved from: https://ecdpm.org/publications/niger-basin-authority-reconciling-upstream-downstream-interests-niger-river/ Last access: 19 February 2021

Mietton, M., Dumas, D., Hamerlynck, O., Kane, A. et al. 2007. Water management in the Senegal River Delta: a continuing uncertainty. Hydrol. Earth Syst. Sci. Discuss., 4, 4297–4323

Migali, S., Natale, F., Tintori, G., Kalantaryan, S., Grubanov-Boskovic, S., Scipioni, M., Farinosi, F., Cattaneo, C., Bendandi, B., Follador, M., Bidoglio, G., 2018. International Migration Drivers, EUR-Scie. ed. Publications Office of the European Union. doi:dx.doi.org/10.2760/63833

Monde, C., 2016. Impact of natural and anthropogenic factors on the trophic interactions of molluscivores and Schistosoma host snails. Wageningen University.

Namara, R.E.; Barry, B.; Owusu, E.S.; Ogilvie, A. (2011). An overview of the development challenges and constraints of the Niger Basin and possible intervention strategies. Colombo, Sri Lanka: International Water Management Institute. 34p. (IWMI Working Paper 144). doi: 10.5337/2011.206

Naumann, G., Alfieri, L., Wyser, K., 2017. High resolution SPEI monthly projection for the globe (1975-2100) [Dataset]. Retrieved from: https://data.jrc.ec.europa.eu/dataset/jrc-climate-spei-drought-helix-ec-earth-1975-2100 Last access: 19 February 2021

Naumann, G., Alfieri, L., Wyser, K., Mentaschi, L., Betts, R.A., Carrao, H., Spinoni, J., Vogt, J., Feyen, L., 2018. Global Changes in Drought Conditions Under Different Levels of Warming. Geophys. Res. Lett. 45, 3285–3296. doi:10.1002/2017GL076521

NBA (2015). Plan d'investissement pour le renforcement de la résilience au changement climatique du bassin du fleuve Niger (PIC). Version finale. Niamey, 153 p.

NBI. (2016). The Nile Basin Water Resources Atlas. Retrieved from http://nileis.nilebasin.org/content/nile-basin-water-resources-atlas

Niang, A., Faty, A., Thiam, M., Kane, A., Kebe, E.A. 2021. Climate vulnerability and water resources variability in West Africa. Senegal and Gambia river basin case studies. In Crestaz et. al., 2021

Nicholson, S.E., Funk, C., Fink, A.H., 2018. Rainfall over the African continent from the 19th through the 21st century. Glob. Planet. Change 165, 114–127. doi:10.1016/j.gloplacha.2017.12.014

OECD/FAO. (2020). OECD-FAO Agricultural Outlook 2020-202. Retrieved from https://doi.org/10.1787/1112c23b-en Last access: 19 February 2021

Pastori M., Marcos-Garcia, P., Umlauf, G., Koundouno, J., Cattaneo, L., Cordano, E., Carmona, C., .2021. Water Energy and Food Ecosystem vulnerability in the Senegal River. In Crestaz et. al., 2021

Pavičević, M., Quoilin, S., 2020. Analysis of the water-power nexus in the North, Eastern and Central African Power Pools, De Felice, M., Busch, S. and Hidalgo Gonzalez, I., editor(s), EUR 30310 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-20874-7, doi:10.2760/12651, JRC121098.

Prüss-Ustün, A., Wolf, J., Bartram, J. Clasen, T. et al., 2019. Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: An updated analysis with a focus on low and middle-income countries. International Journal of Hygiene and Environmental Health 222, 765–777.

Raftery, A.E., Zimmer, A., Frierson, D.M.W., Startz, R., Liu, P., 2017. Less than 2 °C warming by 2100 unlikely. Nat. Clim. Chang. 7, 637–641. doi:10.1038/nclimate3352

Ramos, M.P., Custodio, E., Jiménez, S., Mainar-Causapé, A., Boulanger, P., Ferrari, E. 2020. Assessing market incentive policies in Kenya with a food security and nutrition perspective. JRC Technical Report, European Commission, Ispra, JRC 119390

Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., Da Silva, L.A., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V., Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman, J.C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A., Tavoni, M., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Glob. Environ. Chang. 42, 153–168. doi:10.1016/j.gloenvcha.2016.05.009

Robele, S., Ayele, T., Girma, Y., Gebreyohannes, A., Addis, T. 2020. Water-Energy-Food-Ecosystem (WEFE) assessment in the Upper Blue Nile upstream of GERD

Rodriguez, D. J.; Delgado, A.; DeLaquil, P.; Sohns, A., 2013. Thirsty Energy. Water Papers;. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/16536 License: CC BY 3.0 IGO

Rossetto, R., Veroli, S., 2021. Framing the state-of-the-art on the use of software and digital tools for subsurface hydrology and hydrochemistry in the African continent. report. Report prepared for the Joint Research Centre European Union (JRC123939)

SADC/SARDC, ZAMCOM, GRID-Arendal, & UNEP. (2012). Zambezi River Basin Atlas of the Changing Environment. Retrieved from https://gridarendal-website.s3.amazonaws.com/production/documents/:s_document/145/original/ZambeziAtlas_screen.pdf?1483646695 Last access: 19 February 2021

Sall, M., Poussin, J-C., Bossa, A.Y., Ndiaye, R. et al. 2020. Water Constraints and Flood-Recession Agriculture in the Senegal River Valley. Atmosphere, 11, 1192; doi:10.3390/atmos11111192

Sebastian, K., 2009. Agro-ecological Zones of Africa. . https://doi.org/10.7910/DVN/HJYYTI, Harvard Dataverse, V2 Last access: 19 February 2021

Senzanje A., Dirwai T.L., 2021. Characterization of Current Agriculture Activities, Future Potential Irrigation Developments and Food Security to Face Climate Variability in the Zambezi River Basin. In Crestaz et. al., 2021

Shumilova, O., Tockner, K., Thieme, M., Koska, A., Zarfl, C., 2018. Global Water Transfer Megaprojects: A Potential Solution for the Water-Food-Energy Nexus? Front. Environ. Sci. 6. doi:10.3389/fenvs.2018.00150

Spalding-Fecher, R., Joyce, B., Winkler, H., 2017. Climate change and hydropower in the Southern African Power Pool and Zambezi River Basin: System-wide impacts and policy implications. Energy Policy, Volume 103, Pages 84-97.

Spinoni, J., Barbosa, P., Bucchignani, E., Cassano, J., Cavazos, T., Christensen, J.H., Christensen, O.B., Coppola, E., Evans, J., Geyer, B., Giorgi, F., Hadjinicolaou, P., Jacob, D., Katzfey, J., Koenigk, T., Laprise, R., Lennard, C.J., Kurnaz, M.L., Li, D., Llopart, M., McCormick, N., Naumann, G., Nikulin, G., Ozturk, T., Panitz, H.-J., Porfirio da Rocha, R., Rockel, B., Solman, S.A., Syktus, J., Tangang, F., Teichmann, C., Vautard, R., Vogt, J. V., Winger, K., Zittis, G., Dosio, A., 2019. Future global meteorological drought hotspots: a study based on CORDEX data. J. Clim. doi:10.1175/jcli-d-19-0084.1

Tilmant, A., Pina, J., Salman, M., Casarotto, C., Ledbi, F., Pek, E., 2020. Probabilistic trade-off assessment between competing and vulnerable water users – The case of the Senegal River basin. J. Hydrol. 587, 124915. doi:10.1016/J.JHYDROL.2020.124915

Troussellier, M., Got, P., Bouvy, M., MBoup, M. et al. 2004. Water quality and health status of the Senegal River estuary, Marine Pollution Bulletin, Volume 48, Issues 9–10, Pages 852-862, ISSN 0025-326X, https://doi.org/10.1016/j.marpolbul.2003.10.028.

Udias, A., Pastori, M., Dondeynaz, C., Carmona-Moreno, C., Ali, A., Cattaneo, L., Cano, J. 2018. A decision support tool to enhance agricultural growth in the Mékrou river basin (West Africa). Computers and Electronics in Agriculture, Volume 154, Pages 467-481, ISSN 0168-1699, https://doi.org/10.1016/j.compag.2018.09.037.

Umlauf, G. 2020. An approximation to water quality related health and environmental issues.

UN, 2003. Water for people, water for life: the United Nations world water development report; a joint report by the twenty-three UN agencies concerned with freshwater. UNESCO World Water Assessment Programme. ISBN: 978-92-3-103881-5, 92-3-103881-8, 1-57181-628-3, 978-89-8225-787-2 (kor)

UNECA (United Nations. Economic Commission for Africa); AUC (African Union Commission); AfDB (African Development Bank), 2003. Africa water vision for 2025 : equitable and sustainable use of water for socioeconomic development. Addis Ababa :. © UNECA,.http://hdl.handle.net/10855/5488

UNEP. 2017. Atlas of Africa Energy Resources. United Nations Environment Programme

US EIA, n.d. International Energy Statistics [WWW Document]. US Energy Inf. Adm. - Database. URL http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm# (accessed 10.1.15).

Vaucelle, S. (2015). Le fleuve Niger et son bassin : aménagements, gouvernance et stratégies d'adaptation au changement climatique », Les Cahiers d'Outre-Mer, 270. DOI : 10.4000/com.7458

Wolman, M. G., & Giegengack, R. F. (2007). The Nile River: Geology, Hydrology, Hydraulic Society. In A. Gupta (Ed.), Large Rivers (pp. 471–490). Southern Gate, Chichester, West Sussex PO19 8SQ, England: John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470723722.ch22

World Bank, n.d. WDI - World Development Indicators Databank. Accessible from: https://databank.worldbank.org/source/world-development-indicators Last access: 19 February 2021

World Bank., 2010. The Zambezi River Basin: A Multi-Sector Investment Opportunities Analysis - Volume 3 - State of the Basin. Washington DC, USA. Retrieved from http://documents.worldbank.org/curated/en/938311468202138918/State-of-the-Basin Last access: 19 February 2021

You, L., Wood-Sichra, U., Fritz, S., Guo, Z., See, L., Koo, J., 2005. Spatial Production Allocation Model (SPAM) 2005 v2.0 Last access: 19 February 2021

Watts, M., Zalik, A., 2020. Consistently unreliable: Oil spill data and transparency discourse. Extr. Ind. Soc. 7, 790–795. doi:10.1016/j.exis.2020.04.009

ZAMCOM, SADC, & SARDC. (2015). Zambezi Environmental Outlook. Harare, Gaborone. Retrieved from http://zambezicommission.org/newsite/wp-content/uploads/ZEO_Zambezi_Environment_Outlook.pdf

Zarfl, C., Lumsdon, A.E., Tockner, K., 2015. A global boom in hydropower dam construction. doi:10.1007/s00027-014-0377-0

Zwarts, L., Van Beukering, P., Koné, B., Wymenga, E., Taylor, D. 2006. The Economic and Ecological Effects of Water Management Choices in the Upper Niger River: Development of Decision Support Methods, International Journal of Water Resources Development, 22:1, 135-156, DOI: 10.1080/07900620500405874

APPENDIX 2 - CONTRIBUTORS LIST

The Editors want to thank all the experts and colleagues, who contributed to this document. Following a detailed list of all the researchers and professionals that to different extents contributed to the report.

Contributor	***Affiliation***
ADANU E.	*NWRI, Nigeria*
ADDIS T.	*EIWR, Addis Ababa University, Ethiopia*
AYELE T.	*EIWR, Addis Ababa University, Ethiopia*
ALI A.	*AGRHYMET, Niger*
AMANI A.	*UNESCO, France*
AMDIHUN A.	*ICPAC, Kenia*
ARIAS M.E.	*Un. of South Florida, USA*
ARTAN G.	*ICPAC, Kenia*
ATHERU Z.K.	*ICPAC, Kenia*
BAMUTAZE B.	*Makerere University, Uganda*
BANDA K.E.	*University of Zambia, Zambia*
BARANZELLI C.	*European Commission, JRC*
BASHEER M.	*University of Khartoum, Sudan*
BATTISTELLI A.	*Independent expert, Italy*
BAZOUN J.	*CEDEAO-ECOWAS, Nigeria*
BUSCH S.	*European Commission, JRC*
CARMONA-MORENO C.	*European Commission, JRC*
CATTANEO L.	*Consultant at European Commission, JRC*
CHEKIRBANE A.	*University of Carthage, Tunisia*
CHINYAMA A.	*Gwanda State University, Zimbabwe*
CHIRIMA A.	*NUST, Zimbabwe*
CHUMA C.	*NUST, Zimbabwe*
CORDANO E.	*Consultant at European Commission, JRC*
COULIBALY B.	*Niger River Authority, Niger*
CRESTAZ E.	*European Commission, JRC*
DE CLERCQ W.P.	*Stellenbosch University, South Africa*
DE FELICE M.	*European Commission, JRC*
DE VANSSAY A.	*European Commission, DG INTPA*
DIRWAI T.L.	*University of KwaZulu-Natal, South Africa*
EDUVIE M.O.	*NWRI, Nigeria*
EHIOROBO J.O.	*University of Benin, Nigeria*
ELEMA N.	*Stellenbosch University, South Africa*
FARINOSI F.	*European Commission, JRC*
FATCH J.	*Stellenbosch University, South Africa*
FATY A.	*UCAD, Senegal*
GABIRI G.	*Kyambogo University, Uganda*
GAMAL ELDIN MORTADA A.	*University of Khartoum, Sudan*
GEBREYOHANNES A.	*EIWR, Addis Ababa University, Ethiopia*
GIRMA Y.	*EIWR, Addis Ababa University, Ethiopia*
GIRARDI V.	*European Commission, DG INTPA*
GONZALEZ-SANCHEZ D.	*Consultant at European Commission, JRC*
GONZALEZ-SANCHEZ R.	*European Commission, JRC*
GUDOSHAVA M.	*ICPAC, Kenia*
HAMATAN M.	*AGRHYMET, Niger*
HASSAN M.A.	*ICPAC, Kenia*
HIDALGO GONZALEZ I.	*European Commission, JRC*
HUGHES D.	*Rhodes University, South Africa*
KABEYA P.K.	*SADC, South Africa*

KAMBOMBE O.	*University of Malawi, Malawi*
KANANGIRE C.	*AMCOW, Nigeria*
KANE A.	*UCAD, Senegal*
KANYERERE T.	*University of Western Cape, South Africa*
KATIVHU T.	*NUST, Zimbabwe*
KAVALOV B.	*European Commission, JRC*
KEBE E.A.K.	*UCAD, Senegal*
KENABATHO P.	*University of Botswana, Botswana*
KOMPIL M.	*European Commission, JRC*
KOUNDOUNO J.	*European Commission, JRC*
KUKAS A.	*European Commission, JRC*
IERVOLINO A.	*Consultant at European Commission, JRC*
IZINYON O.C.	*University of Benin, Nigeria*
JACOBS-CRISIONI C.	*European Commission, JRC*
LAVALLE C.	*European Commission, JRC*
MAKAYA E.	*NUST, Zimbabwe*
MAISTRALI A.	*European Commission, JRC*
MAJALIWA M.J.	*Makerere University, Uganda*
MANTEL S.	*Rhodes University, South Africa*
MARCOS GARCIA P.	*European Commission, JRC*
MBAZIIRA R.	*Independent expert, Uganda*
MENGISTU H.	*University of Western Cape, South Africa*
MKANDAWIRE C.	*University of Malawi, Malawi*
MINOUNGOU B.	*AGRHYMET, Niger*
MISHRA A.	*UNESCO, France*
MONJEREZI M.	*University of Malawi, Malawi*
MURRAY B.	*UNESCO, Belgium*
MUTALE M.	*ZAMCOM, Zimbabwe*
MWANGO F.	*IGAD, Kenia*
MWANJALOLO M.	*Makerere University, Uganda*
NAMANGALE J.	*University of Malawi, Malawi*
NANTEZA J.	*Makerere University, Uganda*
NCUBE N.	*NUST, Zimbabwe*
NDIAYE A.L.	*OMVS, Senegal*
NDLOVU S.A.	*NUST, Zimbabwe*
NIANG (FALL) A.	*UCAD, Senegal*
NGONGONDO C.	*University of Malawi, Malawi*
OUMA J.O.	*ICPAC, Kenia*
PASTORI M.	*Consultant at European Commission, JRC*
PARIDA B.P.	*University of Botswana, Botswana*
PERPIÑA-CASTILLO C.	*European Commission, JRC*
RAWLINGS A.	*University of Benin, Nigeria*
ROBELE S.	*EIWR, Addis Ababa University, Ethiopia*
RONCO P.	*European Commission, JRC*
ROSSETTO R.	*Scuola Superiore Sant'Anna di Pisa, Italy*
SAJIDU S.	*University of Malawi, Malawi*
SAURAMBA J.	*SADC-GMI, South Africa*
SEETAL A.	*CSIR, South Africa*
SEIFELDIN H.A.	*NBI, Uganda*
SELIGER R.	*Consultant at European Commission, JRC*
SENZANJE A.	*University of KwaZulu-Natal, South Africa*
THIAM M.	*Kwame Nkrumah' University of Science and Technology, Ghana*
UMLAUF G.	*European Commission, JRC*
VEROLI Sara	*Scuola Superiore Sant'Anna di Pisa, Italy*

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

Joint Research Centre

EU Science Hub

Publications Office

JRC124433