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ARTICLE

A Review of the Effects of Climate Change on Hydropower Dams in Cameroon

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ABSTRACT

One nation in sub-Saharan Africa that is vulnerable to the adverse consequences of climate change is Cameroon. The government of Cameroon has been funding the building of hydroelectric dam infrastructure for many years in an effort to expand the energy sector, which generates revenue and jobs and aims to make the nation a rising nation by 2035. Climate change, however, may make it more difficult for the hydroelectric projects the nation has committed to, which would interfere with its development strategy and possibly impede its ability to meet its own targets for emergence. Thus, the topic of this article is the influence of climate change and its detrimental impacts, which could impede Cameroon's hydropower industry's development. The methodological approach involved searching using search engines like Microsoft Academic, Scopus, ResearchGate, and Google Scholar to critically evaluate over 80 papers and do bibliographic analysis. ENEO Cameroun SA, the firm in charge of producing and selling power in Cameroon, provided certain documents. The literature review's findings show that hydropower production in Cameroon is seriously threatened by climate change, both generally and specifically with regard to the Lagdo hydroelectric facility, which is situated in the country's northern regions. The literature analysis also demonstrates how Cameroonian water resources—which continue to be a crucial element of hydropower projects—are significantly impacted by climate change. Mitigation of the adverse impacts of climate change on hydroelectric schemes in Cameroon may be achieved by adaptation strategies that entail the expansion of

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diverse hydroelectric production sources, especially in specific advantageous locations like Ngaoundere. The government of Cameroon may potentially make investments in alternative energy generation methods, like renewable energies. To better direct decision-makers toward investment, particularly in the development of hydroelectricity in Cameroon, studies must be conducted in various regions of the nation to map the potential of renewable energies (solar, wind, etc.) in each of those regions and to promote the construction of micro-hydroelectric dams that can operate both during the rainy and dry seasons.

Keywords: Cameroon; Climate change; Hydropower

1. Introduction

We live in an interconnected and complex world, in a continent and a country facing major economic, social and environmental challenges. Among the most important environmental challenges facing sub-Saharan Africa is the issue of climate change. According to the Intergovernmental Panel on Climate Change (IPCC), 2007 [1], long-term climate change refers to a change in climatic parameters over time and space (local, regional and global). According to Christoph et al. 2004 [2] the climate also varies due to astronomical factors (solar radiation, atmosphere), geographical factors (topography, ocean) for Bigot et al. 2005 [3] and meteorological factors.

According to Pan et al. 2004 [4] and Miller et al. 2006 [5], short-term global climate variability is generally associated with phases of coupled oceanic and atmospheric phenomena, including El Niño (ENSO) and the North Atlantic Oscillation (NAO). While the El Niño Southern Oscillation (ENSO) affects weather and climate variability worldwide, the North Atlantic Oscillation (NAO) represents the dominant climate mode in the North Atlantic region. These oscillations have been used in a number of research studies to develop accurate models capable of predicting climate variability.

According to the scientific journal VivAfrika, 2015 [6] in Cameroon, climate change could well jeopardise the major development gains achieved in recent decades. Climate change could also threaten the future growth and development of hydroelectric schemes (water being the main raw material). Irrespective of any climate change, and according to UNDP-GEF 1998 [7], the high sensitivity of catchment areas to small variations in climatic variables means that the volume of water that can be mobilised will be greatly affected by the reduction in runoff. Annual rainfall frequently exceeds 3,000 mm, but decreases rapidly towards the east. According to Suchel, 1987 [8] this decrease is due to the alteration of the monsoon flow on the continent, reinforced by the restrictive effect of a few massifs exceeding 1000 m on the plateau. According to Gaston Liénou et al., 2008 [9], an analysis of the spatio-temporal variability of rainfall totals, flow rates and runoff coefficients at monthly, seasonal and annual time steps in the equatorial south of Cameroon reveals that annual rainfall and flow rates have decreased. According to Gaston Liénou et al., 2008 [9], the most significant climate change is the change in rainfall patterns during the dry seasons, modifying the annual hydrological cycle. The drought observed in the equatorial and humid tropical regions of Africa, where the climate is dependent on the Atlantic seaboard, has some similarities with the Sudano-Sahelian zone, as explained by Olivry et al., 1993 [10]; Bricquet et al., 1997 [11]; Servat et al., 1999 [12]; Mahé et al., 2001 [13]; L'Hôte et al., 2003 [14]; Fontaine et al., 2007 [15]. According to Mahé, 1993 [16], this equatorial zone is a highly contrasted hydrological environment. These studies have made it possible to identify the manifestations of climatic variability, in particular the drought observed over the last thirty years in the tropical African sub-region. In Cameroon, while rainfall deficits are well established in the north, the effects of climate variability are less visible in the south, where resources are still substantial in absolute terms, according to Sigha-Nkamdjou et al., 1998 [17]. As water is an essential element in the production of hydroelectric power, it has been established that climate change could have a very negative influence on water resources in Africa. However, hope is not totally lost. Year on year, our understanding of the phenomenon of climate change is improving, we are witnessing a global governmental convergence of this climate challenge, and countries are making major efforts to mitigate the effects of climate change in order to adapt to this changing climate. It is in response to these concerns that the activities carried out by the United Nations Development Programme

(UNDP), 2018 [18] in the field of energy respond to the main targets of MDG 7: "By 2030, ensure access for all to reliable, sustainable and modern energy services at an affordable cost; cooperate with countries to increase the efficiency of energy production and consumption; and ensure that the share of renewable energy in the global energy mix is increased".

The sub-Saharan African region appeared all the more relevant for assessing the evolution of the water resources in this region are very fragile from an environmental point of view (strong anthropic pressure on the environment, deforestation, desertification, soil degradation, drought, etc.). According to Daniel SIGHOMNOU, 2004 [19], while rainfall deficits average 20 to 25%, the drop in runoff is much greater. It is generally at least double the rainfall deficit, i.e., 40 to 50% on average, but can be more than triple, particularly in arid and semi-arid regions.

We are proposing a study to review the impacts of climate change on hydroelectric schemes in Cameroon. This is an appropriate subject of study for dealing with climate-related variability and the modelling of water resources, insofar as the development of this region depends largely on their control.

2. Bibliographic analysis

The literature was evaluated on the basis of a critical reading of more than 80 articles from several search engines, including Microsoft Academic, Web of Science, Scopus, Google Scholar and ResearchGate, which were selected on the basis of the relevance of their titles and abstracts. All published articles whose title combined the keywords "climate change", "hydropower", "dam", "hydroelectric dam", "water resources", "impact of climate change", were analysed. Publications with the highest number of citations using other keywords, such as "climate change", or related keywords (**Table 1** above), were also selected. Some documents were obtained from the company in charge of producing and marketing electric power in Cameroon (ENEO Cameroun SA.) during our research internship, which took place from 1 October to 30 November 2022.

Table 1. List of keywords used in the bibliographic analysis.

Keyword 1	Keyword 2	Keyword 3
Climate change	Cameroon	
Impacts of climate change	Water resources	
Impacts of climate change	Hydroelectric development	
Impacts of climate change	Hydroelectric dam	Cameroon
Impacts of climate change	Water resources	Cameroon
Climate change	Hydropower	Cameroon
Impacts of climate change	Hydroelectric development	Cameroon

3. Study area

3.1 Geographical location of Cameroon

According to the Atlas of Cameroon, 2015 [20], Cameroon is a country in the Gulf of Guinea on the western coast of Africa. It has 590 km of indented coastline along the Atlantic Ocean. The country has a very wide latitude and is roughly shaped like a triangle, with its base at 2 degrees north latitude and its apex at the 13th parallel on the shores of Lake Chad. Cameroon is surrounded by the following countries and bodies of water:

1) Nigeria and the Atlantic Ocean to the west;
2) Equatorial Guinea, Gabon and the Republic of Congo to the south;
3) The Central African Republic to the east;
4) Lake Chad to the north.

With a surface area of 475,442 km^2 and a population estimated at 19,598,889 according to work carried out by BUCREP, 2016 [21], Cameroon is a medium-sized country in Africa.

The country lies between the southern edge of the Sahara and the northern limit of the Congo Basin equatorial forest in the south. The west of the country is dominated by high plateaux, and includes the highest massif in the whole of West Africa: Mount Cameroon, which rises to 4,070 m and is the ninth highest peak on the African continent. The vast majority of the east of the country is covered by a well-preserved equatorial forest. Along its 590 km of coastline, there are a number of seaside resorts: Kribi and Limbé near Mount Cameroon.

Cameroon shares borders with six neighbouring countries as shown in the **Figure 1**.

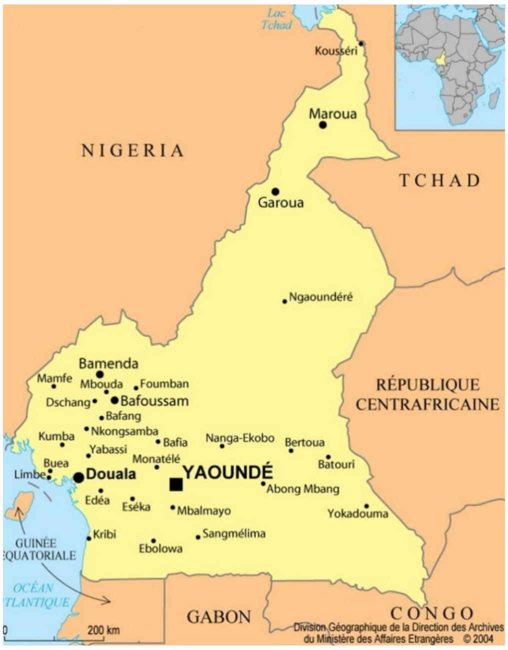

Figure 1. Map of Cameroun in the sub-region.

3.2 Relief

Cameroon's relief is made up of lowlands (the Mamfé basin in the south-west, the Benoué basin and the northern plain); the Cameroonian plateaux include southern Cameroon, with an altitude of 650 m, and Adamaoua, Cameroon's water tower, which has an average altitude of 1,000 m but rises to 2,650 m; The western highlands are a block of uplifted basement covered by basaltic outpourings, arranged in an arc known as the Cameroon ridge. The peaks range from 1,500 to 4,000 m. The best-known massifs are Mount Mandara (Far North), Mount Atlantika (North) and the still active volcanoes of Oku (North West) and Mount Cameroon (South West), which at 4095 m is the highest point in West Africa, Atlas Cameroun, 2015 [20].

3.3 Climate

1) The climate is dominated by two domains[20]:

The equatorial domain: this is characterised by abundant rainfall, high and stable temperatures and vegetation.

The equatorial domain: this is characterised by abundant rainfall, high and stable temperatures and vegetation that deteriorates as one moves away from the equator. There are four distinct seasons in the central and southern plateaux: short rainy season (March to June), short dry season (July and August), long rainy season (September to November), long dry season (December to February), and the western zone (Littoral, south-western mountains and western high plateaux) with its superabundant rainfall for nine months in a row from March to November.

2) The tropical zone: this is characterised by high temperatures and scant rainfall, either Sudanian (rainy season from May to October, dry season from November to April) or Sahelian, with very irregular rainfall, but no rain from December to March. The lowest temperatures are between 17 and 18 °C and the highest between 30 and 32 °C.

3.4 Vegetation

Cameroon's vegetation is diverse and can be divided into two main zones[20]:

1) The tropical zone: this is largely covered by savannah, including the wooded savannah of Adamaoua, which is rich in shrubs; the grassy savannah of the north; and the steppe of the Far North, which is poor in trees and grasses. The trees found in the steppe are thorny and deciduous to better withstand the drought.
2) The equatorial zone: the vegetation in Cameroon's equatorial zone is luxuriantly green and comprises the dense humid forest of the south and east, made up of very large trees; the gallery forests of the west and north-west along watercourses and in low-lying areas;
3) Mangroves on the coast in the Littoral and South-West.

3.5 Hydrography

Cameroon has a very dense hydrographic basin[20] made up of watersheds and rivers including the Atlantic basin (the Wouri, Nkam, Noun, Sanaga, Nyong, Kellé); the Congo basin (Bok, Lobo, Sangha, Dja); the Niger basin (Mayo Kébi, Bénoué, Faro); the Chad basin (Logone, Vina, Chari).

The Sanaga is Cameroon's longest river (918 km). The main rivers are: Bénoué, Boumba, Chari, Dibamba, Dja, Kadey, Kellé, Kienké, Lobé, Logone, Lokoundjé, Lom, Makombé, Mbam, Mbéré, Mefou, Moungo, Ndé, Ngoko, Nkam, Noun, Ntem, Nyong, Sanaga, Sangha, So'o, Vina, Wouri.

Lakes: crater lakes (Lake Oku, Lake Tison, Lake Bini, Lake Barombi Mbo, Lake Nyos); subsistence lakes (Lake Ossa, Lake Dissoni, Lake Ejagal); basin lakes (Lake Chad, Lake Fianga); artificial lakes (Lake Bamendjing on the Noun, Lake Mbakaou on the Djerem).

Waterfalls: Lobé Falls, Moakeu Falls, Ekom Falls, Mètché Falls, Mamy Wata Falls, Bamensingue Falls.

3.6 The country's water balance

Rainfall in the country is fairly abundant on average, feeding often powerful rivers. According to Aquastat, the average annual rainfall is 1,604 mm, covering an area of 475,440 square kilometres, with an annual rainfall volume of 762.61 cubic kilometres. Of this volume of precipitation, evapotranspiration and infiltration consume some 494.61 km^3. This leaves 268 km^3 of surface water resources produced within the country (internally). In addition, a renewable quantity of 5 km^3 of groundwater is produced each year, also internally. This gives a total volume of 273 km^3 of internally produced water.

The country also receives additional water from neighbouring countries, namely 4 km^3 from the Republic of Chad, representing the flow of tributaries of the Benoué (Mayo Kébi), and 8.5 km^3 also from Chad, representing half the flow of the Logone (17 km^3), a border river. This makes a total of 12.5 km^3 from external sources.

3.7 Hydroelectric dams in Cameroon

According to eneo, 2020 [22], the structure in charge of producing and marketing electricity, in term of hydroelectric potential, Cameroon is ranked second largest holder of hydroelectric reserves in sub-Saharan Africa, which is estimated at 20,000 MW, and should increase its installed capacity to 3,000 MW in 2020 with the commissioning of major hydroelectric projects currently underway. Cameroon has a number of hydroelectric dams (**Figure 2**) already in operation, which account for most of the country's electricity production, and others under construction (**Table 2**).

Table 2. Hydroelectric dams in Cameroon.

Name	Region	River	Capacity	Stadium
Songloulou	Littoral	Sanaga	384 MW	In service since 1981
Edéa	Littoral	Sanaga	276 MW	In service since 1950
Lagdo	Nord	Benoue	72 MW	In service since 1986
Njock	Centre	Nyong	200 MW	Full feasibility study
Warack	Adamaoua	Bini	75 MW	In progress
Noun-Wouri	Ouest-Littoral	Noun+Wouri	20,000 MW	Project mothballed pending potential
Memve'ele	Sud	Ntem	201 MW	Investor
Lom Pangar	Est	Sanaga	6 billion m^3 of storage capacity	Commissioning in 2016
Nachtigal	Centre	Sanaga		In progress

Source: Eneo Cameroon, 2020 [22].

4. Climate and climate change

4.1 Climate system

For Mahé, 1993 [16] Climate is defined as the set of phenomena (pressure, temperature, humidity, precipitation, sunshine, wind, etc.), which characterise the average state of the atmosphere and its evolution in a given place. He quotes Gibbs, 1987, specifying that the term "climate" is used to indicate the statistical probability of occurrence of various states of the atmosphere in a given place or region over a certain period. It differs in this respect from the term "weather", which is used to indicate the state of the atmosphere.

According to Reghezza-Zitt, 2023 [24] the global climate system is an extremely complex system whose components (atmosphere, hydrosphere, cryosphere, geosphere, biosphere including human societies) interact (**Figure 3**). It evolves over time under the effect of its own internal dynamics and as a result of external forcing (constraints) such as orbital variations, solar evolution and cycles, major volcanic eruptions and anthropogenic forcing such as changes in atmospheric composition and changes in land use.

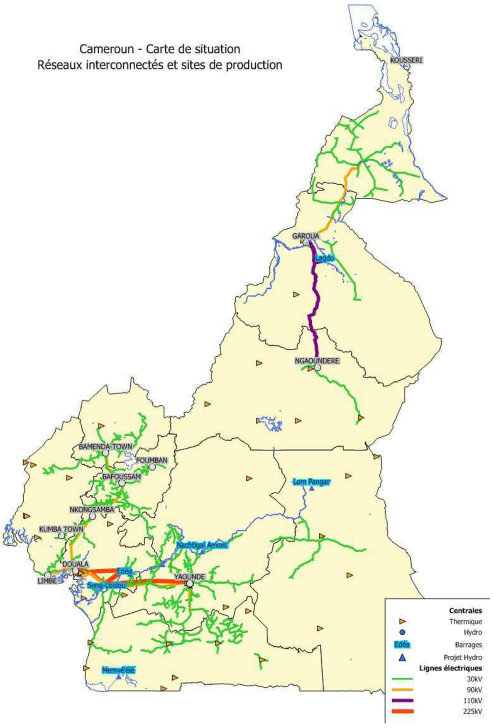

Figure 2. Map of the situation in Cameroon - Interconnected networks and power plants (ARSEL, 2014) [23].

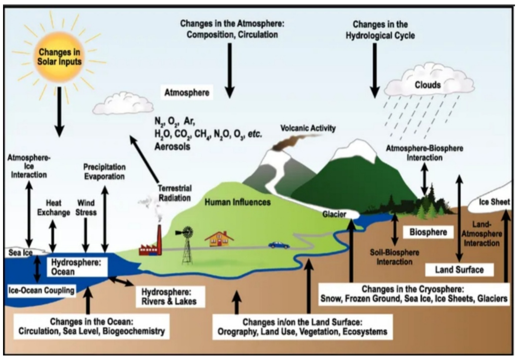

Figure 3. Schematic view of the components of the climate system, their processes and interactions (IPCC, 2007) [25].

4.2 General information on climate change

According to the United Nations Development Programme (UNDP), 2018 [18] Climate change is a global, regional and local problem that affects agricultural productivity, the state of the climate, biodiversity, water reserves and the functioning and provision of ecosystem services. According to the report by the United Nations Convention to Combat Desertification (UNCCD), 2016 [26], experts estimate that by 2030, energy needs will have increased by 50%, food needs by 45% and water needs by 30%. When water is scarce, wasted, polluted or inaccessible, it is a source of tension and even conflict, as identified by the UN. The 'environmental compartment' that makes up water interacts with air and soil, via aerosols, groundwater, ecotones such as riverbanks and shores, sediments, turbidity, hygrometry and dissolved oxygen (or anoxia) levels in particular. For sustainable development, good management necessarily involves a global approach to heritage and the environment, with three complementary components: restoration, protection and management of the resource. This makes water a common good at the heart of governance processes that are intended to be ethical and sustainable, or pragmatic in the medium term, but also a source of conflict in the event of disagreement between riparian states. In the broadest sense, water resources include all water that is accessible as a resource, i.e., that is useful and available to man, the plants he grows, the livestock he raises and the ecosystems at different points in the water cycle. This resource is limited in quantity and quality (especially in the dry season). It is essential to life and to most human activities, such as agriculture, industry and domestic use (drinking water supply). It is vital to the functioning of terrestrial ecosystems. It is locally threatened or severely degraded by pollution and eutrophication. In a growing number of regions, water resources are being over-exploited, with water being diverted or abstracted by pumping or for irrigation to such an extent that it exceeds the threshold for renewal and self-purification of surface water bodies or water tables.

Climate change is a reality that is becoming increasingly apparent. Numerous studies have clearly shown that increased economic activity has led to rising global temperatures and climate disruptions, such as an increase in extreme weather events. This climate change has a direct impact on natural resources, ecosystems and societies. The water sector is one of the most affected sectors, as demonstrated by expert projections. The impacts of climate change on water resources are complex and vary from one region to another, with major environmental and socio-economic repercussions. Africa is also a victim of the impacts of climate change, yet it is a low emitter of greenhouse gases. According to the World Water Committee (WWC), 2016 [27], arid and dry subtropical regions of Africa will be affected by climate change, which will be more significant by 2100. This is when regions already affected by severe aridity, such as the Sahel, can expect an increase in drought episodes. The proportion of the African population likely to be faced with water stress will be greater, increasing from 47% in 2000 to 65% in 2025 [27]. During COP21, water was in the spotlight for the first time during a climate conference. Several initiatives have been launched as part of the Action Program. The Paris conference also saw significant mobilization of stakeholders. According to forecasters, the cumulative effects of climate change and those of overexploitation and pollution (which do not stop at borders) will also affect water resources and the difficulties of managing them sustainably[27].

In recent decades, climate change has become a real issue for the international community. As a result of the increase in greenhouse gas concentrations in the atmosphere to levels not seen for a long time, the planet's radiation balance has become slightly positive, which means that the Earth is warming. The fourth report of the International Panel on Climate Change (IPCC, 2007) [1] confirms that the last three decades have been the warmest on record. From the end of the pre-industrial era to the present day, the average global surface temperature has risen by 0.85 °C. This increase may not seem very impressive, but it conceals major regional disparities: while some areas have experienced little warming, others have already recorded increases of more than 2 °C. According to KD Crowlely and N. Huddleston, 2007 [28] scientists began to see the importance of certain gases in regulating global temperature in the 1820s. Joseph Fourier was the first to suggest that the planet's atmosphere acted as a heat insulator. The gases in question include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapour, all of which help to maintain a moderate temperature at the planet's surface. Solar radiation intercepted at the Earth's surface is partly reflected, partly absorbed by the oceans and continents, and then re-emitted in the form of infrared radiation. Without the greenhouse effect, this radiation would escape into space. Thanks to greenhouse gases (GHGs), they are redirected in several directions, including towards the earth's surface, warming the atmosphere. The problem is that the atmospheric concentration of these gases, which has remained constant over the last few thousand years, has exploded since our industrial revolution[28]. These gases have various origins, some natural, others completely anthropogenic. Their exponential increase since the pre-industrial era (**Figure 4**) is mainly linked to the use of fossil fuels. According to Stocker et al., 2014, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have reached concentrations not recorded for at least 800,000 years on the surface of the globe. Their effects, combined with those of other anthropogenic factors, have been detected within the climate system and are, with an extremely high probability, the dominant cause of the warming observed since the middle of the 20th century.

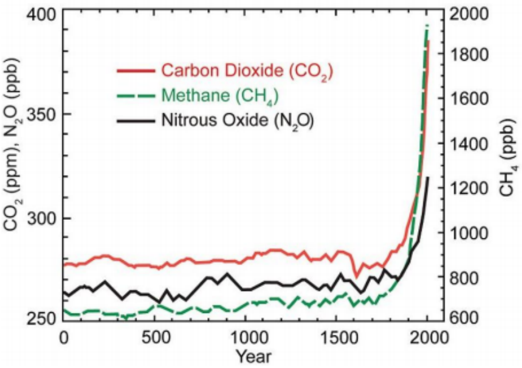

Figure 4. Changes in the atmospheric concentration of greenhouse gases over the last 2000 years (KD Crowlely and N. Huddleston, 2007) [28].

In recent decades, climate change has impacted humans worldwide and natural systems and across the oceans. The IPCC, 2014 [29] states that impacts are due to observed climate change, whatever its cause, indicating the sensitivity of natural and human systems to climate change. The evidence of observed climate change impacts is strongest and most complete for natural systems. In many regions, changes in precipitation or snow and ice melt are modifying hydrological systems, affecting water resources in terms of quantity and quality. For several key variables, the climate system is already moving away from the pattern of natural climate variability in which our society has developed and prospered. There is a significant risk that many of these trends will accelerate, leading to extreme weather events and an increased risk of sudden and irreversible climate reversals[1]. The impacts of climate change are numerous: an increase in the frequency and intensity of natural disasters, droughts, floods, rising sea levels, water acidification, diminishing reserves of drinking water, loss of biodiversity, soil erosion, etc. These impacts are very unevenly distributed and are likely to have a significant impact on the environment. These impacts are very unevenly distributed, and the countries of the South are the first victims, even though their historical responsibility for global warming is more than limited. While the African continent accounts for very little of the greenhouse gas emissions that have accumulated in the atmosphere to date, it is home to at least 22 countries that have been identified as being the most exposed to extreme risks linked to climate change. This vulnerability is heightened by the heavy dependence of the economies of developing countries on the agricultural sector.

The manifestations of climate fluctuations are many and varied. One of the main ones is drought, which particularly affects the world's two tropical regions, and intertropical Africa in particular. Numerous studies have attempted to establish relationships between rainfall fluctuations and certain climate factors in this sub-region. The main parameters studied are: soil albedo according to Charney et al. 1977 [30], solar radiation intensity measured on the ground for Courel et al., 1984 [31], Sea Surface Temperature (SST), winds aloft, cloud cover, pressure and water vapour for Lamb, 1978 [32]; Fontaine, 1991 [33]; Fontaine & Bigot, 1991 [34]; Mahé, 1993 [16] the position of the Inter-Tropical Convergence Zone - ITCZ for Citeau et al., 1988 [35] and 1989 [36]. Mahé, 1993 [16] stresses that the complexity of the phenomenon quickly became apparent and no systematic relationship was established. He goes on to point out that the correlations between the mean values of the various parameters studied are not sufficient to explain the variations in rainfall over Africa.

The climate changes observed in Cameroon over the last 50 years are characterised by a decline (−2.2%) in rainfall per decade since 1960, with the decrease in rainfall affecting in particular the Agro-Ecological Zone (AEZ) of the high plateaux (West and North-West), and above all the Sudano-Sahelian AEZ. An increase (+0.7 °C) in mean annual temperature between 1960 and 2007, with the agro-ecological zones most affected by the rise in temperature being the Guinean high savannah AEZ. The scenarios predict a drier climate in the north and a warmer climate in the south, with considerable variability across the whole of Cameroon, and a rise in sea level of between 9 and 38 centimetres in 2050, rising to 86 centimetres by 2100 [6].

By 2100, the Earth could be 15% warmer than predicted by the IPCC. The latter were therefore too optimistic. If we hope to stay below 2 °C, we will have to reduce greenhouse gas emissions even further than previously predicted. In 2014, the IPCC, the leading scientific body on global warming, published a range of scenarios predicting global warming at the end of the 21st century based on the volume of greenhouse gas emissions. Patrick Brown and Ken Caldeira, climatologists at the Carnegie Institute at Stanford University in California (USA), estimate in a study published in the journal Nature that "global warming is likely to be greater" than the IPCC's prediction models. Pointing to the degree of uncertainty in the climate scenarios, they note that the most pessimistic models, which assume an increase in greenhouse gas emissions throughout the century, predict a rise in temperatures of between 3.2 and 5.9 °C by 2100 compared with the pre-industrial period[29].

4.3 Climate change factors

Variations in land coverage of solar radiation, atmospheric concentrations of greenhouse gases and aerosols influence the energy balance of the climate system and contribute to climate change. They affect the absorption, emission and scattering of radiation in the atmosphere and at the Earth's surface. This results in positive or negative variations in the energy balance, known as radiative forcing. This is used to compare the influence of factors that warm or cool the planet's climate. Human activities generate emissions of four long-lived GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halogenated hydrocarbons. Atmospheric concentrations of greenhouse gases increase when emissions outweigh absorption processes. As a result of human activity, atmospheric concentrations of CO_2, CH_4 and N_2O have risen sharply since 1750, and are now well above the historical values determined by analysis of ice cores spanning many millennia. In 2005, atmospheric concentrations of CO_2 (379 ppm) and CH4 (1774 ppb) far exceeded the range of natural variation over the last 650,000 years. The primary cause of the rise in CO_2 concentration is the use of fossil fuels; land-use change also contributes, but to a lesser extent. It is very likely that the observed increase in CH_4 concentration is mainly due to agriculture and the use of fossil fuels. The increase in N_2O concentration is mainly due to agriculture [1]. The global atmospheric concentration of carbon dioxide has risen from around 280 ppm in pre-industrial times to 379 ppm in 2005. The annual rate of increase in CO_2 concentration has been faster in recent years (1.9 ppm per year on average between 1995 and 2005) than it has been since continuous direct atmospheric measurements began (1.4 ppm per year on average between 1960 and 2005), although it may vary from year to year [1]. The global atmospheric concentration of CH4 rose from around 715 ppb in pre-industrial times to 1732 ppb in the early 1990s, reaching 1774 ppb in 2005. The rate of increase has fallen since the early 1990s, in line with total emissions (the sum of anthropogenic and natural sources), which have remained virtually constant over this period. The global atmospheric concentration of N_2O rose from 270 ppb in pre-industrial times to 319 ppb in 2005 [1].

4.4 Climate sensitivity and feedbacks

Equilibrium climate sensitivity is an indicator of the response of the climate system to a constant radiative forcing. It is defined as the mean equilibrium warming at the Earth's surface under a doubling of CO_2 concentration. The progress made by the IPCC in their 2018 report [37] means that it is likely to be between 3 and 5 °C, and very unlikely to be less than 1.5 °C. Feedbacks can amplify or attenuate the response to a given forcing (**Figure 5**). Direct emissions of water vapour (a greenhouse gas) linked to human activities play a negligible role in radiative forcing. Thus, the increase in the concentration of water vapour in the troposphere as a result of the rise in average global surface temperature is not a forcing factor in climate change, but essential positive feedback. Variations in water vapour concentration, the main feedback influencing the sensitivity of the climate to equilibrium, are now better understood. Cloud feedbacks remain the greatest source of uncertainty. The spatial patterns of climate response depend to a large extent on climate processes and feedbacks. For example, feedbacks related to sea ice albedo tend to reinforce the response at high latitudes[1]. Warming impairs the fixation of atmospheric CO_2 in land masses and oceans, thereby increasing the portion of anthropogenic emissions that remains in the atmosphere. This positive feedback in the carbon cycle reinforces the increase in atmospheric CO_2 and leads to greater climate change for a given emissions scenario. However, the strength of this feedback effect varies considerably between models[1].

Aerosols emitted during explosive volcanic eruptions are an additional episodic cooling factor in the few years following an eruption. The range for linear contrails does not take into account other possible effects of aviation on cloud cover.

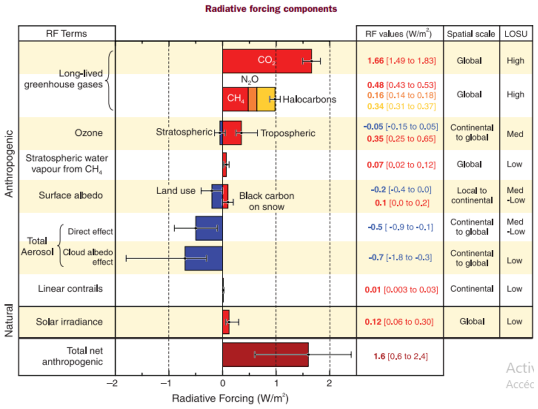

Figure 5. Global average radiative forcing (RF) in 2005 (best estimates and 5 to 95% uncertainty ranges) with respect to 1750 for CO_2, CH_4, N_2O and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). Aerosols from explosive volcanic eruptions contribute an additional episodic cooling term for a few years following an eruption. The range for linear contrails does not include other possible effects of aviation on cloudiness (IPCC, 2007) [1].

4.5 Climate change and its short- and long-term impacts under various scenarios emissions Scenarios

Given the mitigation policies and sustainable development practices already in place, global GHG emissions will continue to rise over the coming decades. The ranges of emissions anticipated in the reference scenarios published by the IPCC on emissions scenarios (SRES, 2000) are comparable to those shown in the figure below (**Figure 6**). According to the SRES scenarios, global baseline GHG emissions are expected to increase by between 9.7 and 36.7 Gt CO_2-eq (25% to 90%) between 2000 and 2030, with fossil fuels remaining the dominant energy source at least until 2030. As a result, CO_2 emissions from energy consumption are expected to rise by between 40% and 110% over this period. In the studies published after the SRES (i.e., according to the post-SRES scenarios), lower values were used for certain emissions factors, particularly for demographic projections. However, in the studies incorporating the new demographic projections, changes in other factors such as economic growth have only a slight impact on overall emissions levels. According to the projections of the post-SRES reference scenarios, economic growth in Africa, Latin America and the Middle East up to 2030 is lower than that anticipated in the SRES scenarios, but this has little impact on global economic growth and emissions as a whole. The role played by emissions of aerosols (which have a net cooling effect) and their precursors, including sulphur dioxide (SO_2), black carbon and organic carbon, is better taken into account in the post-SRES scenarios. As a general rule, these show lower emissions than those forecast in the SRES scenarios[1].

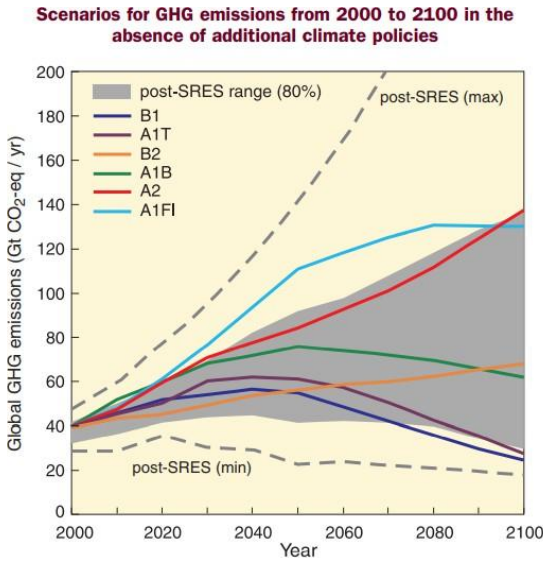

Figure 6. Global GHG emissions (in Gt CO_2-eq per year) in the absence of additional climate policies: six illustrative SRES marker scenarios (coloured lines) and 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of postSRES scenarios. The emissions include CO, CH_4, N_2O and F-gases. (IPCC, 2007) [1].

Six illustrative reference scenarios (SRES, coloured lines) and 80th percentile range of scenarios published after the SRES (post-SRES, shaded area). The dotted lines delimit the full range of post-SRES scenarios. GHGs are CO_2, CH_4, N_2O and fluorinated gases.

The acronym SRES refers to the scenarios described in the IPCC Special Report on Emission Scenarios. These are grouped into four families (A1, A2, B1 and B2), which study different development paths based on a wide range of demographic, economic and technological factors and the resulting GHG emissions. Only current climate policies are taken into account in these scenarios. The emissions anticipated in the projections are widely used to estimate future climate change, and the socio-economic, demographic and technological assumptions on which they are based are taken into account in many recent assessments of vulnerability to and impacts of climate change [1]. The A1 framework assumes a world characterised by very rapid economic growth, a global population peak in the middle of the century and the rapid adoption of new, more efficient technologies. This family of scenarios is divided into three groups corresponding to different directions of technological change in terms of energy sources: fossil-intensive (A1FI), non-fossil (A1T) and balanced (A1B). Canvas B1 describes a converging world with the same demographic characteristics as A1, but with a more rapid evolution of economic structures towards a service and information economy. Framework B2 describes a world characterised by intermediate levels of demographic and economic growth, with an emphasis on local action to ensure economic, social and environmental sustainability. Finally, the A2 framework describes a highly heterogeneous world characterised by high population growth, low economic development and slow technological progress[1].

4.6 The Vulnerability of water to climate change

Global warming is now a certainty, leading to climate disruption that will affect the water cycle and water resources. The Intergovernmental Panel on Climate Change clearly stated in its 5th Assessment Report that climate change impacts four specific sectors: water; ecosystems, both freshwater and marine; crop yields; and health, through the increased risk of water-borne diseases[29]. These impacts hinder the development of these sectors and do not promote their good management. Climate change has varied consequences depending on the sector of activity.

The consequences for the water cycle mainly concern changes in the average and geographical distribution of rainfall, increased evapotranspiration, and an upsurge in periods of drought and heavy rainfall. This resurgence, whose socio-economic impact is beginning to weigh on countries financially, calls on governments and the international community to implement resilience actions. Indeed, the impacts of climate change on water are already visible all over the world, in California, Brazil, the Sahel countries, etc. In the Mediterranean region, reductions in rainfall are being recorded, with an increase in extreme climatic phenomena. Similarly, global warming is having a negative impact on the regularity of river flows, which used to be fed by melting snow. On the other hand, climate change is reducing the self-cleansing capacity of rivers, exacerbating the problems of water pollution.

All these consequences mean additional pressure on water resources, which are already under pressure from over-exploitation in many parts of the world, increasing the number of challenges to be met.

According to the IPCC, 2014 [29] and in its 5th report, water cycle change trends are manifested by:

1) temperatures have been rising since the middle of the 19th century: the years from 1983 to 2012 are probably the hottest 30-year period in the northern hemisphere for 1,400 years. This increase in temperature could continue in the future. Higher temperatures will affect the nature of precipitation (rain or snow), which will have an impact on runoff patterns.
2) Changes in the average and geographical distribution of precipitation, with significant disparities at regional level: climate change tends to interfere with the spatial and temporal distribution of precipitation. As a result, some regions are likely to become wetter and others drier. The Sahel and West Africa show the strongest downward trend in precipitation. Areas such as the Mediterranean basin, southern Africa and Central America could also see fairly significant reductions in rainfall;
3) more frequent periods of drought and heavy rainfall: climate change is leading to changes in the frequency, intensity, spatial extent, duration and timing of extreme weather events. Extreme weather events represent a serious risk for people, infrastructure and ecosystems, and have an impact on water quantity and quality. In North America, precipitation is intensifying. Projections show that it is very likely that the frequency of intense rainfall will increase over time, especially in high altitudes and tropical regions, as well as in the northern hemisphere and in winter. Widespread increases in heavy precipitation events are observed even in areas where average annual precipitation is decreasing. Observations show that some regions, particularly southern Europe and West Africa, have been experiencing trends towards more intense and longer periods of drought since 1950. At the same time, droughts have become less frequent, less intense and shorter in other regions of the globe, such as North America, Central America and Western Australia.
4) Melting glaciers and reduced snow cover: Glaciers around the world have shrunk due to the effects of global warming, leading to a significant decline in water storage in glaciers and contributing to rising sea levels. In addition, snow cover has decreased in most regions, particularly in spring and summer.

Changes in runoff, river flow and groundwater flow:

1) Changes in annual rainfall volumes and extreme events will impact runoff and the rate of groundwater recharge. Runoff can also be affected by increased evapotranspiration. A downward trend in runoff has been observed around the Mediterranean basin and in West Africa. The decline in the availability of water resources in regions where runoff is falling will result in increased conflict between the various uses of water. These regions, which are already experiencing water shortages, will be the hardest hit, with an increase in the frequency and intensity of droughts in arid areas, and episodes of destructive heavy rainfall. In these regions, populations will fall back on easily accessible and over-exploited water resources, such as groundwater, to draw on non-renewable reserves, with all the known consequences for the sustainable management of this resource.
2) The impact on evapotranspiration and soil moisture: climate change affects evapotranspiration and soil moisture. In the great water cycle, evapotranspiration accounts for around two-thirds of the volume of exchanges. As a result, there is a need to invest in this subject, especially as direct measurements of this phenomenon are limited, and as a result, little reliable information about the trends observed is available. Changes in evapotranspiration and in the volume and timing of precipitation are thought to have an impact on soil moisture. However, projections of changes in soil moisture are highly uncertain. Decreases are expected in some regions (such as the subtropics, the Mediterranean and high altitudes), while increases are expected in others.
3) Rising sea levels: the continuing rise in atmospheric temperatures has resulted in the gradual melting of glaciers, the thermal expansion of water and a consequent rise in sea levels, threatening coastal towns and small islands just above or at sea level. Since the middle of the 19th century, the rate of rise in average sea levels has been greater than the average rate for the last two thousand years. The global mean sea level rose between the 19th and 20th centuries and is still rising. The spatial distribution of the change is not uniform. The other impact of climate change is the increase in water-related natural

disasters. The risk of flooding is expected to increase, particularly in South, South-East and North-East Asia, tropical Africa and South America. While the increase in the frequency and intensity of water-related natural disasters can largely be attributed to climate change, the increase in losses linked to these disasters is essentially due to socio-economic factors that contribute to increasing the vulnerability of populations: demographic growth, poverty, precariousness, absence or lack of urban planning and development, informal housing, construction in flood-prone areas, absence of monitoring, warning and crisis management systems, etc. The vulnerability of populations to water-related disasters is also increasing.

In addition, vulnerability to pollution and nuisance will only increase, especially in regions where runoff is reduced and/or more concentrated over time, due in particular to the reduced dilution and self-purification capacity of watercourses. With climate change, freshwater ecosystems are particularly at risk. Rising water temperatures, reduced run-off and the drying out of wetlands will lead to the disappearance of a large number of amphibian and other aquatic species. The coasts of deltas are also particularly sensitive to change, and reduced runoff and the construction of dams are altering sediment inputs, resulting in increased coastal erosion. Furthermore, the increase in uncertainty about the evolution of water resources is in itself the main impact of climate change, with potentially significant consequences for water management. Lastly, global warming would lead to an increase in demand for domestic, industrial, tourist and irrigation water.

4.7 Climate in Africa and water

Although Africa's resources are relatively large, there remains one of the world's most wounded continents, with with 3,931 billion m^3, or almost 9% of the world's freshwater resources. Geographically, the water situation in Africa is highly contrasted[19].

While the continent as a whole has substantial water resources, there are important disparities between the regions of Africa. Northern Africa, parts of Southern and Eastern Africa and the Sahel, which receive less rainfall, have limited water resources. Equatorial and tropical regions, on the other hand, Have many water resources. The richest water in Central Africa and West Africa are six and account for 54% of all continent resources, while the twenty driest countries account for just 7%. That said, the lack of equipment and infrastructure, combined with the rural nature of the population, means that even if Africa does not lack water, part of its population does not have access to it. A third of Africa's population, 330 million people, have no access to drinking water, and almost half of Africans suffer from health problems due to a lack of drinking water. The proportion of the population without access to drinking water is much higher in sub-Saharan Africa, at around 40% [27].

When it come in sustainable development, Africa as a whole fall well below global averages on most water and sanitation indicators: low proportion of the population with access to water and sanitation, low renewable resources, very little irrigated agriculture land, hydroelectric potential under-exploited. Some countries on the continent are already fully exploiting their renewable water resources, while others use less than 1%. Currently, more than 40% of Africa's population lives in arid, semi-arid and sub-humid zones. According to the World Bank, 2008, 47% of the African population was water-stressed in 2000. Furthermore, more than 64% of Africa's population lives in rural areas[38], a large proportion of whom depend on subsistence farming. 95% of Africa's agricultural land is rain-fed, making a large proportion of the population highly dependent on rainfall. For small-scale farms, regular and adequate rainfall is vital to living conditions and food security. In some areas, such as West Africa, where 80% of jobs are in the agricultural sector, regular rainfall is essential to the whole economy. Rainfall irregularity on interannual, decadal and longer time scales is a particular concern in arid and semi-arid zones where rain-fed agriculture is precarious. African countries with low greenhouse gas emissions and high poverty rates are suffering the impacts of climate change. This change will exacerbate the already fragile situations of both societies and ecosystems. As a result, the continent must be given special treatment. The impact of climate change is exacerbating water stress and compromising the economic development of the African continent. Climate change will be more significant by 2100 in the arid and dry subtropical parts of Africa. Regions already affected by severe aridity, such as the Sahel, are likely to experience an increase in drought. The proportion of Africa's population likely to experience water stress is likely to increase from 47% in 2000 to 65% in 2025. The global water crisis would therefore take on a particular dimension in the African context. Between 2010 and 2040, Africa's population is expected to increase by 50%, with the percentage of urban dwellers rising from 44% to 57%, according to the African Water Association (AfWA), 2010 [39].

4.8 Integrated management of water resources

Worldwide, the degradation of natural resources, particularly water resources, is a cause for concern. River basins are threatened by human activity and climate change. In Africa, from users to decision-makers, we need to raise awareness and mobilise everyone to ensure better management of water resources at basin level. This means organising stakeholders and building their capacities in terms of the measures to be taken to protect water resources, using a participatory approach that includes all the players and stakeholders involved.

Participatory approach that includes all stakeholders and users[39].

In 2014, in the Congo Basin, the NGO Eau Vive carried out a mission to bring stakeholders together, raise awareness and provide advocacy training for civil society players (livestock breeders', farmers' and fishermen's associations, etc.), planners and political decision-makers. The advocacy training workshop promoted the involvement and effective participation of all the parties concerned in the management of water resources, and trained planners and decision-makers in the management and protection of the resources of the Congo River basin, which is shared by 5 Central African countries (Cameroon, Central African Republic, Congo, Gabon and Democratic Republic of Congo) [39].

5. General information on hydroelectricity and hydroelectric schemes

People have been trying to harness the power of water since ancient times. Traces of hydraulic structures dating back to 3000 BC have been found in Mesopotamian civilisation. Throughout history, this form of energy has alternated between phases of prosperity and decline. A decisive advance came in the 19th century, when the mechanical energy supplied by rivers could be used to generate electricity. The turbine, the electric generator and the transformer made it possible to produce electricity industrially at that time. In the 20th century, particularly between 1920 and 1960, hydroelectricity underwent spectacular growth. According to the Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME), 2003 [40], in 1962, more than half of all electricity generated was hydroelectric. But this development then came to a halt, mainly because of the poor image of the large dams built in the post-war period, the environmental problems they caused and the reduction in the number of sites available. However, hydroelectricity has a number of major advantages: it is a renewable form of energy, can be stored if necessary, and does not produce greenhouse gases. As part of the Kyoto agreements signed in 1997, the European Union undertook to reduce greenhouse gas emissions to 1990 levels. To achieve this, increased use of renewable energies is essential [40].

5.1 Principle of hydropower conversion

The natural cycle of evaporation and precipitation results in the appearance of water at a certain altitude; this resource may be in the form of running water in torrents, rivers or their catchment areas, groundwater in aquifers; it may also be in the form of snow on high ground or ice in glaciers. A volume of water *V existing* at a certain altitude *h* above the sea corresponds to a potential energy:

$$E=\rho gVh$$

Where ρ: the density of water,

g: acceleration due to gravity.

The purpose of hydropower schemes is to convert some of this potential energy into usable energy. From the first century BC until the middle of the 18th century, the aim was to produce mechanical energy for craft or industrial use: the potential energy of a waterfall, or the kinetic energy of a river, was used to turn a wheel or a turbine, as in all the old mills that can still be seen here and there. According to VIOLLET, 2010 [41] hydroelectricity is produced when this mechanical energy (rotation of the wheel or turbine shaft) is converted into electrical energy using a dynamo (direct current) or an alternator (alternating current). Some small hydroelectric installations use the kinetic energy of a stream of water directly to turn a turbine. However, the vast majority of hydroelectric schemes harness part of the potential energy of water at altitude by building a waterfall.

5.2 Hydropower and hydroelectric dams

According to World Hydropower, 2003 [42], hydropower, or hydroelectricity, is a renewable form of electrical energy that results from the conversion of hydraulic energy into electricity. A hydraulic turbine turns the kinetic energy of the water into a mechanical energy, and then electrical energy by a synchronous electric generator.

Hydroelectric power harnesses the energy of water moving from ahigh point to a low point, essentially to produce electricity (**Figure 7**). Hydroelectric power generation projects include reservoir dams, hydropeaking, run-of-river and in-stream powerplants at all scales. This diversity means that hydroelectric power can meet major centralised urban needs as well as decentralised rural needs. Production varies according to the vagaries of hydroelectricity (flow in a given year or month compared with a year or month considered "normal"). The use of hydropower dates back to the beginning of our era. Until the Middle Ages, numerous mills provided mechanical energy. Some of them still producerenewable electrical energy today. The sites were converted to electricity production in the 19th century. In terms of volume, the resource available on a given date is not always sufficient to meet demand. Consequently, networks of reservoirs are essential in order to store surplus water on a given date and redistribute it when the need arises [39].

The term *reservoir* covers all structures used to store water. Among the most common reservoirs are dams (also considered as control structures) but also smaller structures such as adjustable weirs and numerous agricultural reservoirs. These networks of structures are directed/optimised using a set of management rules that enable daily allocation decisions to be made. The large dams, generally located upstream, are the key structures in these hydraulic schemes because of their large storage capacity. This research focuses on this particular type of construction. According to Florence Padovani, 2004 [43], the main producers of hydroelectricity in 2022 will be China (30.7%), Brazil (9.6%), Canada (8.9%) and the United States (5.9%), whose power stations are among the most powerful. In 2019, hydroelectricity will account for 93.4% of electricity production in Norway, 63.5% in Brazil and 58.8% in Canada.

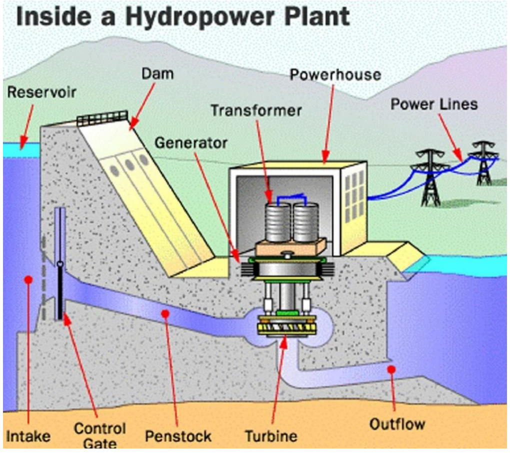

Figure 7. Operating principle of a hydropower plant.

5.3 Hydropower and the environment

According to Sarradin P., 2007 [44], hydropower is considered a renewable energy, unlike oil or natural gas. Some research casts doubt on the greenhouse gas balance of hydropower systems. Bacteriological activity in the water of dams, especially in tropical regions, is said to release large quantities of methane (a gas with a greenhouse effect 20 times greater than CO_2). In dam projects, the production of hydroelectricity often complements other objectives, such as controlling flooding and its consequences, improving the navigability of a river, supplying water to canals, building up water stocks for irrigation, tourism, etc. Since the creation of the Three Gorges Dam on the Yangtze River in China in 2014, that country has been a leader in hydroelectric production, not only in Asia, but also in Africa and South America. The economic stakes of such constructions, as well as the fight against global warming, take precedence over other ecological issues.

6. The hydrological balance: from global to catchment scale

According to Musy, 2004 [45], planet Earth is the only planet in the solar system to possess water in its three physical forms (liquid, solid and gaseous) in sufficient quantity to allow life to develop (**Figure 8**). On a global scale, the energy provided by solar radiation evaporates the water on the surface of the oceans and continents. This water vapour condenses,then precipitates in liquid or solid form. Over the continents, the excess of precipitation over the quantity evaporated creates run-off, forming rivers and streams, allowing the water to return to the oceans. The amount of water on the surface of the globe is constant. So, according to Cosandey and Robinson, 2015 [46], we cannot speak of "consumption" of the resource, but rather of its "use". But the distribution of this resource is unequal.

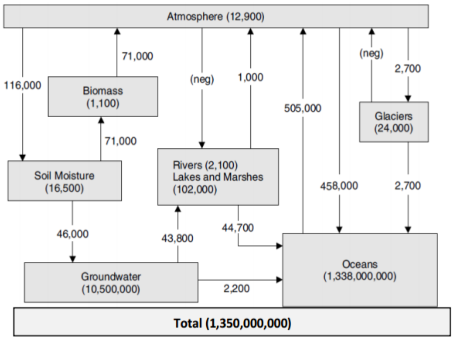

Figure 8. The water cycle (Dingman, 2008) [47].

The total volume represents nearly 1.4 billion km^3, but the part that makes up the hydrological cycle (precipitation or evapotranspiration) represents only 500,000 km^3. By definition, hydrology according to Chow, 1965 [48] is the science that studies water. But for obvious reasons, this science has not covered all areas where water is present. For example, it does not cover the study of the oceans (oceanography) or the study of water in the human body (medical hydrology). It is concerned with describing all the many processes that affect the hydrological cycle. Through its links with climatology, meteorology, agronomy, soil science, geology, land use planning and many other disciplines, hydrology is a multidisciplinary science, whose members form a family described by Klemes, 1986 [49], as a 'blended family', given the variety of fields from which hydrologists come.

According to Roche et al., 2012 [50], the spatial scale at which the hydrological cycle is studied has evolved with the issues. Initially studied on a local scale, then on an integrated basin scale, the hydrological cycle is now increasingly studied on a global scale, as part of climate change studies. Nevertheless, the catchment scale remains essential for hydrologists. According to Gril and Dorioz, 2004 [51], it provides a coherent spatial framework for addressing issues relating to water management and operational decision-making in a given area. By taking measurements at its outlet (flow rate, concentration of elements), the catchment area can be used to understand the "rain-flow" relationship, but it also provides information on pollutant flows. According to Roche, 1963 [52], the concept of a catchment area can be defined as a hydrological unit within which precipitated water is drained to a specific point on a watercourse, known as its outlet. Ideally, the ridgeline bordering the watercourse defines its recharge zone, and therefore the geographical extent of the catchment area. The hydrological balance is then established between the quantity of water precipitated over its catchment area, the run-off measured at its outlet and the quantity of water evapotranspired. But this simplification is not the reality, as exchanges of various origins are possible with outside the catchment area: either of natural origin (underground circulation, in karstic areas for example), or anthropogenic (withdrawals and/or discharges outside the catchment area). What's more, the more the "rainfall-flow" relationship is analysed at a finer time step, the more processes will affect it. An annual balance is simple because it does not take into account the delay in runoff and stock variations during the hydrological year. E. BRULEBOIS, 2016 [53] believes that a balance carried out at a shorter time step should take into account the interception of rainfall by vegetation, the retention of water in soils, which is a function of the initial soil moisture conditions, the delay in the various flows (low for surface runoff, moderate for subsurface flows, and high for deep flows), and the presence of water bodies, the filling of which can slow down the hydrological response of the catchment. On a sub-annual scale, the hydrological balance can be negative (when losses exceed effective rainfall, when reserves are depleted) or positive (when reserves are replenished).

7. Climate change, risk and Future impact

Cameroon is a sub-Saharan African country and there is a clear consensus that the African climate has undergone some changes in recent decades as stated by Christensen et al., 2007 [54], and climate change has had an impact on many river basins in the region, including Cameroon's rivers. For this reason, several studies have been carried out to determine the level of impact and its possible future projection in many river basins in Africa. For Tarhule et al., 2015 [55]; Liénou et al., 2008 [9]; Dzana et al., 2011 [56]; Amougou, 2018 [57], there is a general consensus that, around 1970, an abrupt change in rainfall and runoff patterns across Cameroon and West Africa in general occurred.

Continued greenhouse gas emissions will lead to further warming and cause long-term changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts on people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions, which, combined with adaptation measures, can limit the risks of climate change.

7.1 Key factors controlling future climate

According to IPCC, 2014 [58] cumulative CO_2 emissions largely determine global average surface warming at the end of the 21st century and beyond. Projections of greenhouse gas emissions cover a very wide range, depending on both socio-economic development and climate policies. Anthropogenic greenhouse gas emissions depend mainly on population size, economic activity, lifestyle, energy consumption, land use, technology and climate policy. The RCP scenarios used to make projections based on these factors describe four different trajectories for the 21st century in terms of greenhouse gas emissions and concentrations, air pollutant emissions and land use. The RCPs include a mitigation scenario leading to very low forcing (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and a scenario with very high greenhouse gas emissions (RCP8.5). The scenarios with no climate policy aimed at reducing emissions (“reference scenarios”) correspond to trajectories between RCP6.0 and RCP8.5. RCP2.6 is representative of a scenario that aims to keep global warming below 2 °C compared with the pre-industrial period.

7.2 Climate models

The IPCC defines climate models as “highly sophisticated computer programs that encompass our climate system and simulate, with as much fidelity as possible, the complex interactions between the atmosphere, ocean, land surface, snow and ice, global ecosystem and various chemical and biological processes”.

According to Charron, I. 2016 [59] many elements influence climate, including ocean temperatures, clouds, precipitation and vegetation growth. Each of these processes can be simulated in a climate model. Climate models are so complex that running a simulation can take several weeks, even with supercomputers. In order to reduce calculation time as much as possible, climate models divide the Earth into large grid cells. IPCC, 2013 [60] states that for Global Climate Models (GCMs) that cover the entire globe, grid cells are often more than 100 kilometres (km) in size. Data from grid squares smaller than 100 km may be required for impact, vulnerability or adaptation studies. For example, extreme precipitation events often occur on scales much smaller than 100 km. In addition, local landscape features can have an impact on local temperatures. Dynamic or statistical downscaling is one way of obtaining higher resolution data (smaller grid cells). Dynamically scaled models are also known as Regional Climate Models (RCMs). RCMs simulate the climate of a smaller region based on the information provided by GCMs. RCM grid cells are generally between 10 and 50 km in size. Mc Sweeney, Robert, Hausfather, Zeke, 2018 [61] states that RCMs use the laws of physics to simulate local climate. Statistically scaled models take advantage of statistical relationships between local climate variables (such as precipitation) and large-scale variables (such as atmospheric pressure). The relationships are then applied to GCM projections to simulate the local climate. Climate models are used to predict future climate conditions based on the assumptions of the Representative Concentration Profiles (RCP). In other words, this means that a climate projection shows how certain elements of climate, such as the average temperature of a region, might vary according to a RCP[60]. Although climate models are based on the laws of physics, different methods can be used in different climate models to simulate these laws in a climate simulation. Therefore, the projections of different climate models may vary even if they are based on the same RCP[60].

7.3 Hydrological modelling

According to Singh and Woolhiser, 2002 [62], hydrological modelling is the discipline that attempts to describe quantitatively the processes of the terrestrial phase of the hydrological cycle. A hydrological model, or rainfall-runoff model, is a numerical tool for representing the rainfall-runoff relationship on the scale of a catchment. Numerous hydrological models have been developed since the late 1960s. According to Charbonneau, R., Fortin, J.-P. and Morin, G., 1977 [63] the choice of the type of model to use generally depends on the modelling objective and the input data available. Hydrological models are used to transform series describing the climate of a catchment (typically precipitation and temperature series) into a series of flows (**Figure 9**). This transformation is often divided into two parts:

1) A first part, often called "production", which consists of determining the water balances at catchment scale. This balance makes it possible to break down the gross rainfall observed (all the rain that falls on the catchment and is measured by one or more rain gauges) into net rainfall (the proportion of the gross rainfall that contributes to the flow of the catchment studied), the quantity of water evapotranspired and the quantity of water stored by the catchment.
2) A second part, often called "transfer" or "routing", which consists of distributing over time the quantity of water contributing to the flow of the catchment studied.

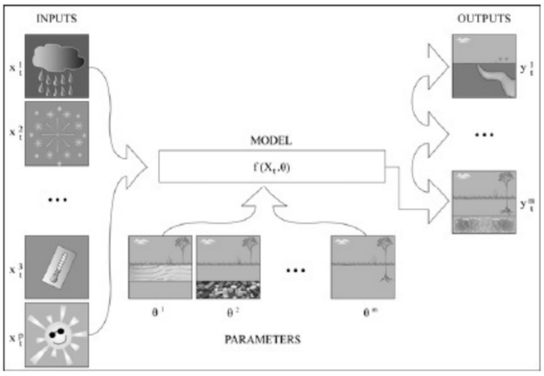

Figure 9. Schematic representation of a hydrological model (from Blasone, 2007) [64].

The simplified mathematical form of a hydrological model is described in the following equation:

$$Yt = f(Xt, \Theta)$$

This is a system of equations represented by the operator f(.), which produces at each time step t, a number m of outputs (hydrological responses) given by the vector

$$Yt: Yt = (y\ 1\ t..., ym\ t)$$

The inputs to f(.) are a vector of p meteorological inputs

$$Xt: Xt = (x\ 1\ t..., x\ p\ t)$$

And a vector of n model parameters

$$\Theta: \Theta = (\Theta\ 1,..., \Theta n)$$

Perrin, C., Michel, C. and Andréassian, V., 2003 [65] present the different types of approaches that have been developed to represent the rain-flow relationship: empirical approaches, conceptual approaches and physically based approaches.

1) Empirical model

An empirical model is built around direct mathematical relationships established between inputs and outputs observed in the catchment under consideration. This kind of model is sometimes referred to as a "black box" model since it makes no attempt to explain the mechanisms underlying the rainfall-flow relationship. For instance, the GR4J model.

2) Conceptual model

Without reference to the physical laws controlling the various processes involved, a conceptual model aims to depict the primary processes in the rainfall-runoff connection. This type of model is often made up of interconnected reservoirs, whose levels rise and fall over time and which are supposed to represent the different hydrological compartments of the catchment. The use of different reservoirs allows an initial separation of the components of the rainfall-discharge relationship. This model seeks to represent the catchment functions in the form of interconnected reservoirs[58]. Example: SWAT model.

3) Physically based model

The mechanisms of the rainfall-runoff relationship are represented by a physics-based model that makes use of the physical rules governing these processes. Another type of physically grounded model that depicts the link between rainfall and runoff is the continental surface model. It is also feasible to determine the different terms in the water balance of the catchment under study using this kind of model. Example: Modcou.

4) Global model

In a global model, the catchment is represented as a single homogenous spatial entity. The spatial variability of the processes studied is therefore not explicitly taken into account with this type of model. Example: the GR4J model requires only daily precipitation and potential evapotranspiration data to simulate the flow at the catchment outlet.

5) Semi-distributed model

In a semi-distributed model, certain processes are modelled by dividing the catchment into several spatial entities. This division of space can be achieved using hydrological criteria (division into sub-catchments) or topographical criteria (division into altitude bands). This model allows the spatial variability of the processes studied to be taken into account. Example: SWAT, HBV.

6) Distributed model

In a distributed model, the catchment area is divided into several spatial entities. This division of space can be in the form of a regular mesh, or by sub-catchments. This model allows the spatial variability of the processes studied to be taken into account. Example: Modcou.

7.4 Use of hydrological models

A hydrological model can be used in a number of contexts: flood forecasting, low-water forecasting, predetermination of extreme flows, study of anthropogenic impact on hydrology (construction of hydraulic facilities, changes in land use, etc.), study of the impact of climate change on hydrology, simulation of flows to fill data gaps and restore historical flow series.

7.5 Choice of hydrological model

According to Wagener et al., 2007 [66], although several hydrological models are now available, the relationship between precipitation and runoff is complex due to the complexity of the landscape caused by enormous heterogeneities and variability associated with the occurrence of connectivity, similarity and the uniqueness of places at all scales. In 2004 [67], this author explains that it is also for this reason that the choice of a hydrological model in river basins is made on the basis of certain specific criteria such as:

1) the structure of the model adapted to the modelling objective envisaged. The modelling objective defines aspects such as the hydrological processes that need to be taken into account and the modelling time step required.
2) the characteristics of the catchment: these are important criteria for determining which type of process description is appropriate.
3) the available data which allows a certain degree of causality in the process description and allows a particular minimum spatial and temporal resolution.

7.6 Uncertainty and ambiguity in hydrological modelling

Because of their complexity and variability, natural systems cannot be described and studied in their entirety, so modelling is used to analyse and predict their dynamics. According to Isabella Zin, 2006 [68], in the field of hydrospheres, the theories currently available cannot take into account all the processes involved and their interaction, in particular because of the great spatial and temporal heterogeneity that exists and the difficulty of instrumenting all the hydrological scales. All of this results in a large number of uncertainties: firstly, about the data that feeds the models, and secondly about their structure and the values of the parameters. All this calls into question the reliability and credibility of the simulations already carried out.

8. Climate change in Cameroon

According to Cameroon's National Action Plan for Adaptation to Climate Change (PNACC), 2015 [69]. "Climate change" has become one of the most important issues across the political world. At the beginning of the 21st century, humanity finds itself in a contradictory situation: as the example of emerging countries shows, humanity has the organisational and technological means to overcome poverty throughout the world. Without clean air, clean water, healthy soils and healthy ecosystems, long-term development is inconceivable. Over the years, it has become increasingly clear that rational and effective decision-making in the field of environmental and climate change depends on a reliable data base. One of the main tasks for statistics stems from the international conventions that aim to limit climate change and its impacts. The monitoring of conventions on biodiversity, desertification and greenhouse gas (GHG) emissions, the implementation of the United Nations Framework Convention on Climate Change (UNFCCC), and the Kyoto mechanisms and other multilateral environmental agreements are creating a range of new requirements for statistics. In this context, the question of how to determine the priority indicators to be produced by an institution in charge of environmental issues arises, all the more so as the resources to do so are particularly limited.

Cameroon, like other countries around the world, is suffering the adverse effects of climate change, which are reflected in reduced agricultural production, dwindling grazing land, the development of diseases linked to water and extreme heat, the occurrence of extreme weather conditions such as droughts and floods, and even an increase in conflicts between communities in search of vital goods, all against a backdrop of biodiversity loss. The challenge of climate change calls for the efforts of the entire international community. Cameroon is aware of the challenges posed by this phenomenon, and is resolutely committed to supporting sustainable development. As a result, it is becoming more imperative than ever to have reliable statistics on climate change, not only for the sustainable and wise management of natural resources, but also to inform the choice of public policies in the areas concerned, and to assist in development planning and the prioritisation of projects and programmes.

The national strategy is essentially based on Cameroon's National Action Plan for Adaptation to Climate Change (PNACC), which was produced in 2015 and is based on a participatory approach that allows account to be taken of the age-old information and observations accumulated by local communities on the interactions between man, his environment and climatic conditions. It is crucial to integrate this type of information into the diagnosis of vulnerabilities.

The overall objective of the PNACC is based on two pillars:

1) Ø Reducing greenhouse gas emissions to contain the rate of global warming;
2) Ø Adapting societies to the now inevitable changes in climate in order to limit the damage caused.

The PNACC also presents:

1) An inventory of climate change in Cameroon;
2) A strategy for adapting Cameroon to climate change;
3) An action plan for implementing the adaptation strategy;
4) Detailed fact sheets on projects with an indirect or close link to climate change.

The national strategy also takes into account other government programmes with links to climate change, namely: The National Action Plan to Combat Desertification, 2021 [70], the overall objective of which is to reverse desertification/land degradation trends in order to combat poverty and promote sustainable development. The NAP/LCD also aims to strengthen synergy with the major sectoral programmes and between the three United Nations Conventions (UNCCD, CBD, UNFCCC);

The National Environmental Management Programme, 1996 [71], which aims, among other things, to control pressure on natural resources, promote the regeneration of natural resources and protect biodiversity, control the impacts of climate change and promote adaptation strategies for populations, focuses on limiting the harmful effects of climate change on the environment and socio-economic activities, taking into account the protection of the ozone layer.

The PNGE aims to implement REDD+ and other GHG mitigation mechanisms, as well as existing adaptation strategies. It also focuses on the development and promotion of new mechanisms for adapting to climate change. The PNGE defines the areas of intervention and priority areas, including:

1) Combating desertification and climate change;
2) Conservation of biodiversity on land and in continental waters;
3) Management of coastal and marine ecosystems;
4) Management of natural risks and disasters;
5) Management of continental and transboundary waters;
6) Waste management and sanitation.

Lastly, the NACP takes into account the National Strategy and Action Plan for Biological Diversity, 2020 [72] and many other government programmes.

Cameroon is currently one of 7 countries to have drawn up a national plan for adaptation to climate change. The country also drew up and submitted its Nationally Determined Contribution (NDC) in September 2015. This document, submitted by the government to the UNFCCC to communicate internationally the measures taken by the country to combat climate change, includes REDD+ and the forestry sector as one of the main areas for mitigation.

For Cameroon, this commitment is contained in the appendix to the CPDN in the strategy matrix through:

1) Orientation: Ensure coherence in planning and development of rural areas to develop agriculture while limiting deforestation/degradation and;
2) Action: Ensuring consistency between agricultural development plans and strategies to limit deforestation or degradation (REDD+ process) through the National Land Use and Sustainable Development Plan in consultation with each of the sectors and territories.

9. Impacts of climate change on hydroelectric production in Cameroon

Located in sub-Saharan Africa, Cameroon in particular and the African climate in general have undergone a number of changes in recent decades[50]. Climate change has had an impact on many river basins in the region in general and on Cameroon's rivers in particular. With this in mind, numerous studies have been carried out to determine the impact of climate change on water resources in river basins, while modelling the climate to produce future climate projections. Annual rainfall will decrease by 1–10%, while annual temperature and Potential Evapotranspiration (PET) will increase by 8–18% and 6–30% respectively. Depending on the scenarios, models and future periods, the reduction in rainfall combined with the increase in PET will lead to a significant reduction in flows in the HEBBs (up to 51%), with the direct consequence of reducing the hydroelectric potential of the Lagdo dam. According to Rodric M. Nonki, 2019[73] this region will experience extremely dry environmental conditions due to an increase in PET greater than the increase in Actual Evapotranspiration (AET). He goes on to say that the combination of reduced rainfall and water flow and increased PET will have a negative impact on the hydropower potential of the Lagdo dam under the climate change scenarios, models and future periods.

Faced with all these observations, a number of initiatives have been developed over the last few years by several players to promote renewable energies in Cameroon. Supplied by the sun, the wind, the heat of the earth, waterfalls, tides and the growth of plants, renewable energy is by definition inexhaustible. On a human timescale, their natural renewal is fast enough for them to be considered inexhaustible, and they generate little or no waste or polluting emissions. The various families of renewable energies are beginning to attract the interest of Cameroon's research and development community. Mechanical wind turbines are used to pump water in many countries. Power stations with a capacity of no more than 10 MW make up what is known as small-scale hydroelectricity. The driving force of waterfalls is used by turbines installed on rivers to generate electricity. Together with large dams and tidal power plants, small hydro is the second largest source of renewable energy in the world.

10. Conclusion

Climate change is having a strong negative impact on Cameroon in general and on hydroelectric schemes in particular. Hydroelectric production from dams is increasing because of the social conditions facing the country, such as population growth and industrial development. But it is still far from sufficient to meet the needs of the population. The purpose of this study was to provide a summary of knowledge on the phenomenon of climate change in general and its impact on hydroelectric schemes in Cameroon in particular. In this study, we talked about the climate, presented the various results of certain authors on climate change in Africa, advances in the field of climate and hydrology modelling and presented the results of researchers on the impacts of climate change on the water resources of hydroelectric schemes in Cameroon. The study shows that climate change is having a negative impact on hydroelectric production in Cameroon in general, and on the Lagdo hydroelectric dam in particular, which no longer has the necessary production capacity due to the lack of water in the dam during the dry season, which now lasts nine months, even though it used to last seven months. It is therefore imperative for the Cameroon government to set up renewable energy projects (micro-hydro power stations, wind farms, etc.) capable of sustaining the country's electricity production.

Conflicts of Interest

The authors declare no conflicts of interest.

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References

[1] GIEC, 2007. Contribution des Groupes de travail I, II et III au quatrième Rapport d'évaluation du Groupe d'experts intergouvernemental sur l'évolution du climat [Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Lead writing team] [Équipe de rédaction principale, Pachauri, R. K. et Reisinger, A. (publié sous la direction de]. GIEC: Geneva, Switzerland. 103p.

Available from: https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_fr.pdf (cited 9 May 2024).

[2] Christoph, M., Fink, A.H., Knippertz, P., 2004. Tropical-extratropical interactions causing precipitation in Northwest and West Africa: Part I: Synoptic evolution and climatological relevance. Proceedings of the 26th Conference on Hurricanes and Tropical Meteorology; May 3-7, 2004; Miami, FL, USA.

[3] Bigot, S., Brou, T.Y., Oszwald, J., et al., 2005. Facteurs de la variabilité pluviométrique en Côte d'Ivoire et relations avec certaines modifications environnementales [Factors in rainfall variability in Côte d'Ivoire and relationships with certain environmental changes]. Science et changements planétaires/Sécheresse. 16(1), 5-13.

[4] Pan, Z., Arritt, R.W., Takle, E.S., et al., 2004. Altered hydrologic feedback in a warming climate introduces a "warming hole". Geophysical Research Letters. 31(17).

[5] Miller, R.L., Schmidt, G.A., Shindell, D.T., 2006. Forced annular variations in the 20th century intergovernmental panel on climate change fourth assessment report models. Journal of Geophysical Research: Atmospheres. 111(D18).

[6] VivAfrika, 2015. Rapport annuel. 80p.

[7] Programme des Nations Unies pour le Développement - Fonds pour l'Environnement Mondial, 2003. Projet maghrébin sur les changements climatiques [Maghreb project on climate change]. Algérie - Libye- Maroc – Tunisie. Bilan et perspectives. Projet RAB/94/G31.

[8] Suchel, J.B., 1987. Les climats du Cameroun; thèse de doctorat d'Etat; Université de Bordeaux III: France. 1186p.

[9] Liénou, G., Mahé, G., Paturel, J.E., et al., 2008. Impact de la variabilité climatique en zone équatoriale: exemple de modification de cycle hydrologique des rivières du sud-Cameroun [Impact of climate variability in the equatorial zone: example of changes in the hydrological cycle of rivers in southern Cameroon]. Proceedings of the 13th IWRA World Water Congress; September 1–4, 2008; Montpellier, France. Available from: https://orcid.org/signinhttps://orcid.org/signin (cited 9 May 2024).

[10] Olivry, J.C., Bricquet, J.P., Mahé, G., 1993. Vers un appauvrissement durable des ressources en eau de l'Afrique humide [Towards a sustainable depletion of water resources in humid Africa]. In Hydrology of Warm Humid Regions (Proc. Yokohama Symp., July 1993) (ed. by J. S. Gladwell), 67–78. IAHS Publ. 216. IAHS Press: Wallingford, UK.

[11] Bricquet, J.P., Bamba, F., Mahé, G., et al., 1997. Evolution récente des ressources en eau de l'Afrique Atlantique [Recent trends in water resources in Atlantic Africa]. Revue des sciences de l'eau. 10(3), 321–337.

[12] Servat, E., Paturel, J.E., Lubès-Niel, H., et al., 1999. De différents aspects de la variabilité de la pluviométrie en Afrique de l'Ouest et Centrale [Different aspects of rainfall variability in West and Central Africa]. Revue des sciences de l'eau. 12(2), 363–387.

[13] Mahé, G., L'Hôte, Y., Olivry, J.C., et al., 2001. Trends and discontinuities in regional rainfall of West and Central Africa: 1951–1989. Hydrological Sciences Journal. 46(2), 211–226.

[14] L'Hôte, Y., Mahé, G., Somé, B., et al., 2002. Analysis of a Sahelian annual rainfall index updated from 1896 to 2000; the drought still goes on. Hydrological Sciences Journal. 47(4), 563–572.

[15] Fontaine, B., Louvet, S., Roucou, P., 2007. Fluctuations in annual cycles and inter-seasonal memory in West Africa: rainfall, soil moisture and heat fluxes. Theoretical and Applied Climatology. 88(1–2), 57–70.

[16] Mahe, G., 1993. Les écoulements fluviaux sur la façade atlantique de l'Afrique. Etude des éléments du bilan hydrique et variabilité interannuelle, analyse de situations hydroclimatiques moyennes et extrêmes [Study of water balance elements and inter-annual variability, analysis of average and extreme hydroclimatic situations]. [ORSTOM (ed.)]. Institut Français De Recherche Scientifique Pour Le Développement En Coopération, Collection Études et Thèses: Paris. 438p.

[17] Sigha Nkamdjou, L., Sighomnou, D., Lienou, G., et al., 1998. Variabilité des régimes hydrologiques des cours d'eau de la bande méridionale du plateau sud-camerounais [Variability in the hydrological regimes of rivers in the southern strip of the southern Cameroon plateau]. In: Servat, E., Hugues, D., Fritsch, J.M., et al. (Eds.). Water Resources Variability in Africa during the XXth Country. Proceedings of the Abidjan'98 Conference held at Abidjan, Côte d'Ivoire, November 1998. IAHS Pub!: Wallingford, UK. no. 252, pp. 215–222.

[18] Organisation Internationale de la Francophonie, 2018. Guide d'intégration des objectifs du Développement Durable (ODD) dans les plans locaux de développement. Projet d'appui au développement local, phase II [Guide to integrating the Sustainable Development Goals (SDGs) into local development plans. Local development support project, phase II]. 52p. Profade/OIF. Available from: WWW.francophonie.org (cited 9 May 2024).

[19] SIGHOMNOU, D., 2004. Analyse et redéfinition des regimes climatiques et hydrologiques du Cameroun: perspectives d'évolution des ressources en eau [Analysis and redefinition of climatic and hydrological regimes in Cameroon: prospects for the development of water resources] [PhD thesis]. Yaoundé: Université de Yaoundé I. pp. 18–20.

[20] Atlas du Cameroun, collection Atlas de l'Afrique, 2010. Guides touristiques, voyages [Atlas of Cameroon, Atlas Africa collection, tourist guides, travel], Jaguar, Jeune Afrique, 9782869504554, october 2010. 136p.

[21] Bureau Central des Recensements et des études de Populations, 2016. Recensement Général de la

Population et de l'Habitat [General Population and Housing Census]. Available from: https://www.instat-mali.org/laravel-filemanager/files/shares/rgph/rapport-resultats-globaux-rgph5_rgph.pdf (cited 9 May 2024).

[22] Eneo Cameroun, 2020. Revue de sécurité du barrage de Lagdo au Cameroun. Rapport de diagnostic de la sécurite et de mise aux normes du barrage de lagdo. Rapport final. [Safety review of the Lagdo dam in Cameroon. Diagnostic report on the safety and upgrading of the Lagdo dam. Final report]. Eneo Cameroun: Douala Cameroun. 161p.

[23] Agence de Régulation du Secteur de l'Electricité, 2014. Politique Nationale, Stratégie et plan d'Action pour l'Efficacité Energétique dans le secteur de l'électricité au Cameroun [National Policy, Strategy and Action Plan for Energy Efficiency in the Electricity Sector in Cameroon]. 84p. Available from: https://rise.esmap.org/data/files/library/cameroon/Energy%20Efficiency/Cameroon_Energy%20efficiency%20strategy.pdf#: :text=Politique%20Nationale,%20Strat%C3%A9gie%20et%20Plan (cited 9 May 2024).

[24] Reghezza-Zitt, M., 2003. Sociétés humaines et territoires dans un climat qui change. Du réchauffement climatique global aux politiques climatiques [Human societies and territories in a changing climate. From global warming to climate policies], Géoconfluences. Available from: https://geoconfluences.ens-lyon.fr/informations-scientifiques/dossiers-thematiques/changement-global/articles-scientifiques/rechauffement-climatique-politiques-climatiques

[25] IPCC, 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Solomon, S., Qin, D., Manning, M., et al. (eds.)]. Cambridge University Press: Cambridge, UK; New York, NY, USA. p. 43.

[26] Convention des Nations Unies sur la Lutte Contre la Désertification, 2016. Définition des cibles de neutralité en matière de dégradation des terres: un guide technique [Defining land degradation neutrality targets: a technical guide].

[27] Conseil Mondial de l'Eau et climat, 2016. Livre bleu; Avenu Hassan Benchekroune; Agdal: Rabat [Water and climate Blue Book; Avenu Hassan Benchekroune; Agdal: Rabat]. 48p.

[28] Crowlely, K.D., Huddleston, N., 2007. Overview of US national research council evaluation of spent nuclear fuel and high-level radioactive waste transportation in the United States. Packaging, Transport, Storage and Security of Radioactive Material. 18(1), 21–24. DOI: http://doi.org/10.1179/174651007X191189

[29] GIEC, 2014. Cinquième rapport d'évaluation; Bilan 2014 des changements climatiques: Rapport de synthèse [Fifth Assessment Report; Climate Change 2014: Summary Report]. GIEC: Geneva, Switzerland. 130p.

[30] Charney, J.G., Quirk, J.J., Chow, S., et al., 1997. A comparative study of the effects of Albedo change on drought in semi-arid regions. Journal of the Atmospheric Sciences. 34, 1366–1385.

[31] Courel, M.-F., Kandel, R.S., Rasool, S.I., 1984. Surface albedo and the Sahel drought. Nature. 307, 528–531.

[32] Lamb, P., 1978. Large-scale tropical Atlantic surface circulation patterns associated with subsaharan weather anomalies. Tellus. 30(3), 240–251.

[33] Fontaine, B., 1991. Variations pluviométriques et connexions climatiques: l'exemple des aires de mousson indienne et ouest-africaine [Rainfall variations and climatic connections: the example of the Indian and West African monsoon areas]. Sécheresse. 2: 259–264.

[34] Fontaine, B., Bigot, S., 1991. Modes de sécheresse ouest-africain et température de Surface océanique [West African drought patterns and ocean surface temperature]. Veille Climatique Satellitaire. 38, 37–49.

[35] Citeau, J., Berges, J.C., Demarcq, H., et al., 1998. The watch of ITCZ migration over the tropical Atlantic Ocean as an indicator in drought forecast over Sahelian areas. Tropical Ocean-Atmosphere Newsletter. 45, 1–3.

[36] Citeau, J., Demarcq, H., 1989. Questions relatives to ITCZ, migration over the tropical Atlantic Ocean, sea surface temperature and Senegal river runoff. Meteorology and Atmospheric Physics. 41, 181–190.

[37] GIEC, 2018. Rapport spécial du GIEC sur les conséquences d'un réchauffement planétaire de 1,5 °C [IPCC special report on the consequences of global warming of 1.5 °C]. Available from: http://www.ipcc.ch/report/sr15/ (cited 9 May 2024).

[38] IBRD, The World Bank, 2008. World Development Report, 2008: agriculture for development. IBRD/The World Bank: Washington, DC, USA.

[39] Association Africaine de l'Eau, 2010. Rapport d'activités [Activity report; Abidjan, Ivory Coast]. Association Africaine de l'Eau: Abidjan, Côte d'Ivoire. 80p.

[40] Agence de l'Environnement et de la Maîtrise de l'Energie, 2003. Guide pour le montage de projet de petite hydroélectricité [Guide to setting up a small hydroelectricity project]. Agence de l'Environnement et de la Maîtrise de l'Energie: Valbonne, France. 120p.

[41] Viollet, P.-L., 2010. Aménagement hydroélectrique; Article; Nouvelles technologies énergies renouvelables et stockage [Hydroelectric development; Article; New renewable energy technologies and storage]. Université peau et pays Adour: Pau.

[42] World Hydropower Outlook. 2023. Association internationale de l'hydroélectricité (IHA): London.

[43] Padovani, F., 2004. Migrations forcées et grands travaux hydrauliques en Chine: le cas du barrage des

Trois Gorges [Forced migration and major hydraulic engineering works in China: the case of the Three Gorges Dam]. Géocarrefour. 79(2), 27–34. ISSN 1627-4873 et 1960-601X. DOI: http://doi.org/10.4000/geocarrefour.504

[44] Sarradin, P.-M., Sarrazin, J., Allais, A.-G., et al., 2007. EXtreme ecosystem studies in the deep Ocean: Technological developments. Proceedings of the Oceans 2007 - Europe; June 18–21, 2007; Aberdeen, UK. Vols. 1–3, pp. 1001–1005. DOI: https://doi.org/10.1109/OCEANSE.2007.4302376

[45] Musy, A., 2004. Hydrologie [hydrology]. Presses polytechniques et universitaires romandes: Lausanne.

[46] Cosandey, C., Robinson, M., 2015. Hydrologie continentale [Continental hydrology]. ISBN 9782200246174. ISBN en ligne 9782200281564. Armand Colin: Paris. 448p. DOI: http://doi.org/10.3917/arco.cosan.2012.01

[47] Dingman, S.L., 2008. Physical Hydrology, 2nd ed.; Waveland Press Inc.: Long Grove.

[48] Chow, V.T., 1965. Handbook of applied hydrology. International Association of Scientific Hydrology. Bulletin. 10, 82–83.

[49] Klemes, V., 1986. Dilettantism in hydrology: Transition or destiny? Water Resources. 22, 177S–188S.

[50] Roche, P.A., Miquel, J., Gaume, E., 2012. Hydrologie quantitative Processus, modèles et aide à la décision [Quantitative hydrology Processes, models and decision support]. Springer: Paris; New York. Notice PPN163246416.

[51] Gril, J.-J., Dorioz, J.M., 2004. Des bassins versants de recherche aux bassins opérationnels: quels bassins versants pour connaître et maîtriser les pollutions diffuses agricoles ? [From research catchment areas to operational catchment areas: which catchment areas should be used to identify and control diffuse agricultural pollution?]. Sciences Eaux & Territoires. 39, 3–16.

[52] Roche, M., 1963. Hydrologie de surface. Office de la Recherche Scientifique et Technique Outre-Mer: Paris.

[53] Brulebois, E., 2016. Impacts du changement climatique sur la disponibilité de la ressource en eau en Bourgogne: aspects quantitatifs et qualitatifs [Impacts of climate change on the availability of water resources in Burgundy: quantitative and quantitative aspects]. Sciences de la Terre. [PhD thesis]. France: Université de Bourgogne. 323p.

[54] Christensen, J.H., Hewitson, B., Busuioc, A., et al., 2007. Regional climate projections. Climate Change, 2007: The Physical Science Basis. Contribution of Working group I to the AR4 of the IPCC, University Press, Cambridge. Chapter 11. pp. 847–940. ISBN: 978-0-521-88009-1.

[55] Tarhule, A., Zume, J.T., Grijsen, J., et al., 2015. Exploring temporal hydroclimatic variability in the Niger Basin (1901–2006) using observed and gridded data. International Journal of Climatology. 35, 520–539.

[56] Dzana, J.G., Ngoupayou, J.R.N., Tchawa, P., 2011. The Sanaga discharge at the Edea Catchment outlet (Cameroon): An example of hydrologic responses of a tropical rain-fed river system to changes in precipitation and groundwater inputs and to flow regulation. River Research and Applications. 27, 754–771. DOI: https://doi.org/10.1002/rra.1392

[57] Amougou, J.A., 2018. Chapitre 2: Changements climatiques au Cameroun–Manifestations, Vulnérabilités, Impacts et Réponses [Climate Change in Cameroon-Events, Vulnerabilities, Impacts and Responses]. Science, Economics and Politics of Climate Change: A guide for policymakers in Cameroon. p. 5.

[58] IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Group I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climat Change. [Core Writing Team, Pachauri, R.K., Meyer, L.A. (eds.)]. IPPC: Geneva, Switzerland, 151p.

[59] Charron, I., 2016. Guide sur les scénarios climatiques: Utilisation de l'information climatique pour guider la recherche et la prise de décision en matière d'adaptation [Guide to climate scenarios: Using climate information to guide adaptation research and decision-making]. Available from: https://www.ouranos.ca/sites/default/files/2022-12/hors_proj-2016-charron-guide_scenario_0.pdf#: :text=Ce%20guide%20a%20%C3%A9t%C3%A9%20d%C3%A9velopp%C3%A9%20pour%20aborder (cited 9 May 2024).

[60] IPCC, 2013. Climate Change 2013: The Physical Scientific Basis, IPCC Contribution of Working Group I to the AR5 of the IPCC. [Stocker, T.F., Qin, D., Plattner, G.-K., et al. (eds.)]. Cambridge University Press: Cambridge, UK; New York, NY, USA. p. 222.

[61] Mc Sweeney, R., Hausfather, Z., 2018. Q&A: How do climate models work?

[62] Singh, V.P., Woolhiser, D.A., 2002. Mathematical Modeling of Watershed Hydrology. Journal of Hydrologic Engineering. 7, 270–292. DOI: https://doi.org/10.1061/(ASCE)1084-0699(2002)7:4(270).

[63] Charbonneau, R., Fortin, J.-P., Morin, G., 1977. The CEQUEAU model: description and examples of its use in problem related to water resource management. Hydrological Sciences Bulletin. 22(1), 193–202.

[64] Blasone, R.S., 2007. Parameter estimation and uncertainty assessment in hydrological modelling. [PhD thesis]. Kongens Lyngby: Technical University of Denmark. p. 71.

[65] Perrin, C., Michel, C., Andréassian, V., 2003. Improvement of a parsimonious model for streamflow simulation. Journal of Hydrology. 279(1–4), 275–289.

[66] Wagener, T., Sivapalan, M., Troch, P., et al., 2007. Catchment Classification and Hydrologic Similarity. Geography Compass. 1, 901–931. DOI:

https://doi.org/10.1111/j.1749–8198.2007.00039.x

[67] Wagener, T., Wheater, H.S., Gupta, H.V., 2004. Rainfall-runoff modelling in gauged and ungauged catchments. Imperial College Press: London, UK. 332p. DOI: https://doi.org/10.1142/p335

[68] Zin, I., 2006. Thèse de Doctorat: Incertitude et ambiguïté dans la modélisation hydrologique: discussion, développements méthodologiques et application à l'hydrologie de crue en Ardèche [Uncertainty and ambiguity in hydrological modelling: discussion, methodological developments and application to flood hydrology in the Ardèche]. [PhD thesis].

[69] Plan d'Action National d'Adaptation aux Changements Climatiques du Cameroun, 2015. Document de stratégie nationale qui vise à accompagner le gouvernement et les acteurs dans leur démarche d'adaptation aux changements climatiques [National strategy document designed to support the government and stakeholders in their efforts to adapt to climate change]. 187p.

[70] Ministère de l'Environnement, de la Protection de la Nature et du Développement Durable, 2021. Plan d'Action National de lutte contre la Désertification [National Action Plan to Combat Desertification] (PAN/LCD), 221p. Available from: https://minepded.gov.cm/wp-content/uploads/2021/09/PAN-LCD.pdf#: :text=Plan%20d%E2%80%99Action%20National%20de%20Lutte%20Contre (cited 9 May 2024).

[71] Ministère de l'Environnement et des Forêts, 1996. The National Environmental Management Programme. Ministère de l'Environnement et des Forêts: Yaoundé, Cameroon.

[72] Ministère de l'Environnement, de la Protection de la Nature et du Développement Durable, 2020. Stratégie et Plan d'Action National de la Diversité Biologique. 180p. Available from: https://www.cbd.int/doc/world/ga/ga-nbsap-01-fr.pdf#: :text=ET%20PLAN%20D%E2%80%99ACTION%20SUR%20LA%20DIVERSIT%C3%89 (cited 9 May 2024).

[73] Nonki, R.M., Lenouo, A., Lennard, C.J., et al., 2019. Assessing climate change impacts on water resources in the Benue River Basin, Northern Cameroon. Environmental Earth Sciences. 78, 606. DOI: https://doi.org/10.1007/s12665-019-8614-4.