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Holistic Approach for an Integrated Management of Mouhoun River in Climate Change Context: Impacts and adaptation measures

Yacouba Sanou (1)*, Samuel Pare (1)

[1] *Laboratory of Analytical, Environmental and Bio-Organic Chemistry, UFR/SEA, Sciences and Technology Doctoral School, University Joseph KI-ZERBO, 03 BP 7021, Burkina Faso.*

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prosperyacson@gmail.com;
Phone: +22672191530;
Fax: +22625307242

Abstract
This research was focused on Integrated Water Resources Management as one of the most effective approaches for an efficient management of Mouhoun River and ecosystem goods, and Services. Our study investigated the effects of climate change on Mouhoun River in Burkina Faso as contribution to water availability and climate action. Data and water samples were collected and analyzed using standard methods. Results revealed a decrease of precipitations leading to a decrease of water level in the river and soil moisture which are important factors highlighting drought and other negative effects on water resources. In addition, it was noted the decrease of agriculture production yields due to the decrease of water quantity. An increase of temperature, electric conductivity, and pH indicating a possible pollution of water due to climate change was noted after 3 samplings. High turbidity of water from Mouhoun River is due to erosion. Using Hadcm3 and CSIRO models, it's expected an increase of populations which needed a safe water if the temperature increases of 4°C.

1. Introduction
Climate change poses serious threats to the world [1]. From future climate change perspective, both human and natural systems are at risk [2, 3]. Climate change impacts on societies, biodiversity and ecosystems through water [4]. Climate can become warmer or colder and the average of each factor of its components increases or decreases over the time, so climate change is an irreversible change in the average of weather conditions that occurs in a region [5]. This change can be in the average temperature, precipitation, humidity, weather patterns, wind, solar radiation and any other weather components. Many people make a confusion between climate change and global warming while global warming is just one aspect of climate change [6]. Climate change is a complex and long-term global atmospheric-oceanic phenomenon which can be influenced by natural factors such as volcanoes, solar, oceans and atmosphere activities which they have interactions between or may be as a result of human activities [7]. Climate change poses a serious challenge in water resources management and therefore, requires a consideration from holistic review and research. According to Chéné [8], integrated management means that different aspects of water resources are considered together, ensuring optimal social benefits of water resources uses as well as to the protection of human health and the environment. Climate change and its variability can be mitigated by appropriate integrated water resources management policies and adaptation measures, which can reduce vulnerability for natural and human systems [9].
In Burkina Faso, water resources are facing many challenges such as increasing demand, scarcity, pollution and climate conditions. Water demand is a major concern in Sub Saharan Africa with lack of appropriate drinking water, demographic dividend, and population growth. Many people in rural areas of developing countries do not have a safe water for consumption [10]. In rural Sub-Saharan Africa,

millions of people share their domestic water sources with animals or rely on unprotected wells that are breeding grounds for pathogens. In Sahel area, access to safe water is one of most challenges that authorities are facing in the context of insecurity, political conflicts and climate change. In Burkina Faso, Mouhoun region, with its surface area of 34 497 Km^2 has a population density of 43.31 inhabitant / Km^2, and 397 billion m^3 of water resources with many fertile lands and earths, available for agriculture [11]. The drastic decrease of the pluviometry caused many difficulties on the development of activities such as breeding, agriculture, and fishing. Agricultural productivity is affected by various factors including rainfall pattern, variation in temperature, and variation in dates of harvesting and sowing, availability of water, and evaporation along with suitability of land [12]. To face the risks in agriculture associated with climate change, adaptation is the key factor to address the negative impacts of climate change. Adaptation is an important policy response to climate change in agriculture sector [13, 14]. The Intergovernmental Panel on Climate Change (IPCC) emphasizes that it is very fundamental for the agricultural sector to adapt to climate change.

Our work aims to contribute to water availability and management because mismanagement of water resources is one of the reasons of the lack of water for human and animal needs. The objective of this study is to evaluate the effects of climate change on water resource of Mouhoun region using both quantitative and qualitative aspects. To contribute to drinking water supply, holistic approach for an integrated management will be used to propose some adaption strategies to climate change.

2. Material and Methods

2.1. Description of the study area

Mouhoun River is located in Mouhoun region (12°30'N, 3°30'W) in Burkina Faso (Fig. 1). It is the bigger water resources in this region that has 1677018 inhabitants, belong to the Soudano-Sahelian part of Burkina Faso [11]. One notes six provinces in the region such as Mouhoun, Kossi, Banwa, Bales, Sourou and Nayala. On hydrographic plan, the region has a dense network from Mouhoun River long on 280 km with three watercourses constituting the basin of Mouhoun. Access to drinking water in this region is mainly from wells: 0.4% of boreholes has access to tap water, 14.8% of population uses nozzle wells water, and 18.5% uses drilling or fountain water, 66.1% for ordinary wells, rivers and watercourse and50% of people need 30 minutes for drinkable water harvest at public water points [15, 16].

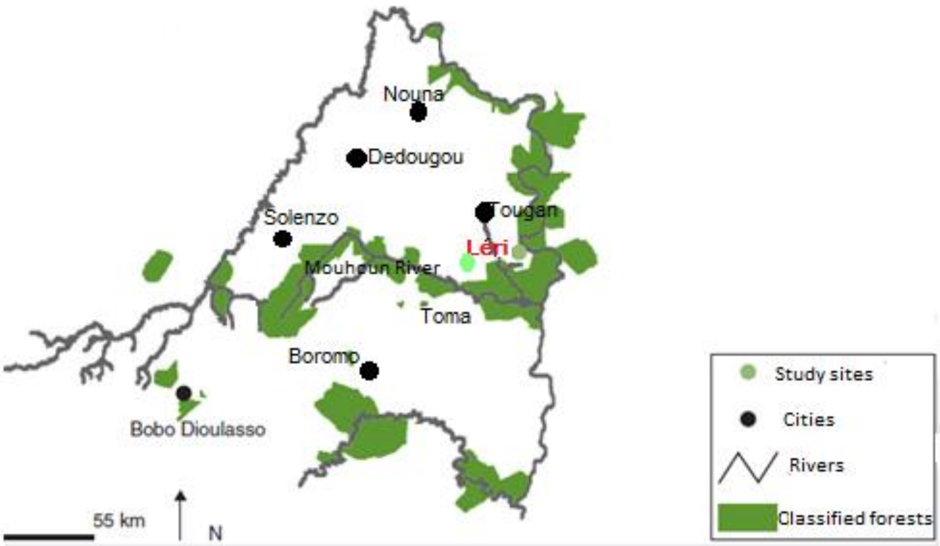

Figure 1: Hydrographic network of the study area.

2.2. Sampling and determination of water physico-chemical parameters

Water samples have been collected on September 2012, 2015 and 2018. The sampling site was Leri Village located in the Mouhoun region (Burkina Faso). Leri site has been chosen for sampling because it is closed to Sourou Valley and regarding the results of previous works on Mouhoun River [17].

Parameters measured in situ include pH and temperature using a pH meter (Martini, Mi 606 electrode), electrical conductivity (EC) with a conductimeter (Orien 3STAR, thermo scientific) and turbidity with a Wagtech turbidimeter. Water samples were sent to the laboratory in Ouagadougou where Chemical oxygen demand (COD) and dissolved oxygen (DO) were determined using standard methods as described elsewhere [18]. In addition, some anionic species such as phosphate, nitrite and nitrate have been analyzed by spectrometric method using a ultra-violet spectrometer (Hach Lange, DR 3900). Ammonium amount was determined using a colorimetric method. Total suspended solids were determined by filtration on wattman filter paper. All measurements were repeated three times.

2.3. Data collection and analysis

It was carried out in three (3) stages: documentary research, field surveys and interviews. Field surveys include physical observations in the field and interviews with local populations closed to the river. Qualitative data were collected using literature review, key exchanges and discussions with local communities closed to Mouhoun River. Quantitative survey was carried out with a focus group using Active Method of Research and Participative Planning. Some activities such as workshops, and information on the protection of river ecosystem have been carried out with the support of Mouhoun Regional Council and Mouhoun Water Agency.

3. Results and discussion

3.1. *Implementation of IWRM in Burkina Faso*

Water is a natural resource, needful for the life and ecological systems, enable to the economic and social development. For Burkina Government, it should have a safe water in quantity and quality for populations by preserving the hydrological, biological and chemical functions of ecosystems and limiting the harmful effects of human activities and the pollution [19]. To mitigate water resources problems, Government of Burkina Faso adopted a National Plan of Integrated Water Resources Management with objectives such as:

-Protect water resources and improve knowledge by the populations;

-Plan the use of water resources in the most important sectors such as agriculture, domestic needs, breeding, hydro-energy, aquaculture, and fishing;

-Save the ecosystems and prevent the risks of flooding, drought and erosion.

Many organizations and institutions have been established in Burkina Faso including National Action Program for Adaption (PANA), Action Plan for Integrated Water Resources Management (APIWRM) and Rural Development Strategy to contribute in actions of adaptation and resilience of climate change. In Mouhoun region, regional authorities have implemented a water agency (Mouhoun Water Agency) those the roles include the following three aspects [15]:

-regulation aspects: water use permits in water bodies under federal domain, regulation of public irrigation and water adduction, rules for reservoir operation and dam safety;

-management aspects: implementation of water policy is supporting by National Water Resources Management System;

-induced aspects: actions to promote inducing programs and projects which stimulate the rational use of water and the raise of water availability.

The target public is the local communities which are vulnerable and living in the areas with lower capacities of the economic and ecological resilience to insure the sustainable development of populations in agreement of Sustainable Development Goals, i.e. 6 and 14.

3.2. *Climate change impact on Water quantity*

The relation between water and climate change is particular reversible because water is involved in all the climate systems through the atmosphere, the surface of earth, and biosphere. The impacts of climate change on human being have occurred toward water such as drought, flooding, enhancement of river level [20]. Precipitations and flow rate of Mouhoun River increased in the South part causing flooding risks, such as the one occurred on August, 2005 (Fig. 2). This modification of river flow started to increase from central part to South involving a degradation of water quality from river. The intensity of precipitations could heighten the water pollution in the case where precipitations would bring more moving pollutants to ground aquifers. If precipitations and river flowrate are more important causing flooding, there are some risks of the saturation of the recovery and treatment systems of river water. In opposite, low precipitations and river flow causes a lack of needful water quantity to dissolve the inorganic and organic pollutants. Enhanced growth rates of algal blooms in freshwater bodies are one of the most important effects of climate change on water quality. In the north part of the river, the decrease of precipitations caused a decrease of water level in the river and the soil moisture which are the important factors of drought. This results is confirmed by Dezetter [21] who showed that climate change and human activities are the main reasons of drought in Sahel. A previous study in Mouhoun region concluded that the drought due to the runoff of rain water was an impact of climate change on water resources and depending of the type of soil [22]. That caused the degradation of soil which controls the runoff and the infiltration of rain water. . According to climate scenarios, hydrological simulation shows that flows will change more or less strongly in the future with the annual rate ranging from – 6 to +22% [23].

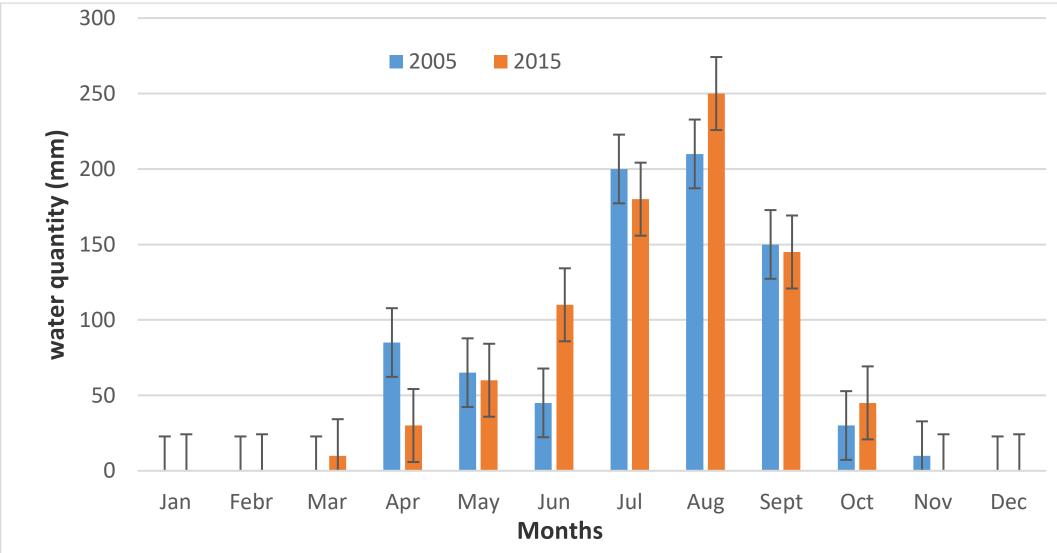

Figure 2: Distribution of the precipitations in Mouhoun Region in 2005 and 2015.

Previous study using MAGICC/SCENGEN model showed an increase of the precipitations which can achieve 780 mm and 700 mm by 2025 and 2050, respectively [19]. Results of theoretical previsions indicated an increase of populations which are facing the lack of safe water (50.000 people) if the temperature increases of 4°C [24]. Populations closed to the river will be the first victims and more affected by the increase of river level and precipitations decrease. Preliminary results of workshops and sensitizations indicated the well understanding of climate change concept and some effects on ecosystem and raining season. There is an intensity of raining in August of each year that can cause optimal seepage of runoffs with a good distribution of the raining season in 2005 (Fig. 2). The raining season started in April with the maximal pluviometry between July and September. Actually, there is a decrease of raining season and precipitations (water quantity) causing a decrease of agricultural yields in the region. Therefore, it's important to find out a technology to fit the new climatic context such as improved seeds, research of new fertilizers and planning shade trees in order to keep the productivity level of cereals even increase the agricultural yields. That will contribute to prevent the famine and the food security. Results are in agreement with those found by Mumtaz *et al.* [25] which evaluated climate change impacts on agricultural sector. The hazardous variability of rainfall in space and over time caused some pluviometry problems such as floods and droughts as described in the literature [23, 25]. Indeed, drought is considered as the most frequent climate-related disaster that often results in water deficiencies and food security. Precipitation deficit and evapotranspiration increase result in possible meteorological, hydrological and agricultural droughts. Government of Burkina Faso identified the consequences of the rainfall decrease by declining the river flows and dropping the groundwater levels [11]. In addition, our investigation showed that the problems related to human activities either significantly reduce the resource quantity or affect the water quality in relation to the different requirements of the use. We can mention:

- Upstream developments which reduce the downstream availability of water;
- Water deficits or losses are related to climate change, the temporal and spatial variability of rainfall, an increase in evaporation, and sedimentation;
- Disturbances of the flow dues to the change in infiltration regime or surface water discharges;
- All effects of water pollution (heavy metals and organic pollutants), eutrophication and erosion.

3.3. *Climate change impact on Water quality*

This section presents the potential impacts of climate change on water quality in Mouhoun River. The increasing of temperature and its associated impacts have great consequences on water quality availability for human consumption. Some physical-chemical parameters of water from Mouhoun River are listed in Table 1. All the parameters of water have been analyzed on 2012, 2015 and 2018 in order to evaluate the expected effects of climate change on water quality comparatively to World Health Organization guidelines [26].

Table 1: Physico-chemical parameters of water compared with WHO guidelines

Parameter	Our study in 2018	Our study in 2015	Our study in 2012	WHO limit [26]
pH	8.02	7.14	7.6	6.5-8.5
EC (µS/cm)	220	111	204	50-150
T (°C)	29.1	26.3	27.4	-
Turbidity (NTU)	25	15	8	5
DO (mg/L)	6.6	7.7	6.8	-
NO_3^- (mg/L)	2.1	0.3	5.6	11.4
NO_2^- (mg/L)	0.13	0.01	0.02	3
COD (mg/L)	6.5	16	11	-
NH_4^+ (mg/L)	0.13	0.08	0.02	1.5
TSS (mg/L)	10	10	0	-
PO_4^{3-} (mg/L)	0.18	0.19	0.09	5

(-) not found

It was noted pH value is in the range of WHO guidelines while values of turbidity and electric conductivity are high than WHO limit values. High values of temperature, electric conductivity, and pH indicating an expected pollution of water due to climate change. Increasing of water temperature affects the rates of chemical and bacteriological reactions in water resulting in consequent deterioration of water quality and status of water ecology [27]. In general, higher air temperature and water temperatures have a particular correlation with the higher rates of chemical reaction for river and shallow lakes [28]. According to Indian Wildlife Institute [29], projected changes in air temperature often result in water temperature changing by 50-70%. Alteration of water quality could be directly or indirectly caused by different biochemical processes. Furthermore, the specific effects will vary among different sites along the river and Mouhoun region. It may include an increase of pollutant concentrations, an enhancement of nitrogen mineralization, and delayed recovery from acidification. During the drought period (rain scarcity), lower flows can weaken the dilution effects of some pollutants. All the characteristics are compared to previous work on water quality in Burkina Faso [17].

Table 2: Physico-chemical parameters of water compared with previous work

Parameter	Our study in 2018	Our study in 2015	Our study in 2012	Dianou *et al.*[17]
pH	8.02	7.14	7.6	7.4
EC (µS/cm)	220	111	204	115
T (°C)	29.1	26.3	27.4	25.1
Turbidity (NTU)	25	15	8	21
DO (mg/L)	6.6	7.7	6.8	7.4
NO_3^- (mg/L)	2.1	0.3	5.6	0.5
NO_2^- (mg/L)	0.13	0.01	0.02	0.003
COD (mg/L)	6.5	16	11	4
NH_4^+ (mg/L)	0.13	0.08	0.02	0.13
TSS (mg/L)	10	10	0	30
PO_4^{3-} (mg/L)	0.18	0.19	0.09	0.27

We noticed that all the values of parameters are comparable to the results of Dianou *et al.* [17] indicating that almost of surface water from rivers and lakes in Burkina Faso have a similar physico-chemical composition. Increased water temperatures are expected to result in increased nutrient loads into rivers and lakes. For instance, higher temperatures contribute to the release of phosphorous from sediments and enhance the mineralization rates of soil organic matter resulting in increased ammonium leaching [30]. It's important to evaluate the precipitations and temperatures for next decenniums regarding the sensibility of hydrological models face climate variability. The increase of the temperature by 2025 and 2050 was previously noted in the area of Nakambe River [24]. The increase of temperature affects simultaneously the different components of hydrological systems such as the quantity of rashness or precipitations and their frequency and intensity, the increase of water vapor in the atmosphere, the evapotranspiration, water content in the soil and vegetation, the force of runoff and the flow rate of watercourse. In Burkina Faso, there is a limited research on historical water quality monitoring data and climate change impacts on water resources reducing the literature review in this work. Potential impacts of climate change on surface water include changes in air temperature, which could affect water temperature due to heat exchange with the atmosphere. It was observed a degradation of biological and chemical quality of water due to the increasing of river temperature [20, 31]. Using Hadcm3 and CSIRO models, it's expected an increase of temperature of 0.8 °C and 1.7 °C in 2025 and 2050, respectively [24].

3.3.1. Hydrogen potential (pH)

pH is one of the parameters that must be constantly measured because it is linked to the amount of hydronium ions. Indeed, pH affects the acidity and alkalinity of water in a river and their degree. This parameter characterizes the physico-chemical reactions at equilibrium in water and its value depends on the origin or source of water [32]. The values of pH decreases with high levels of organic matter and decreases during a significant evaporation (low water period). Obtained results (Fig. 3) revealed an increase in pH for 6 years of study and the values are in the range recommended by WHO [26].

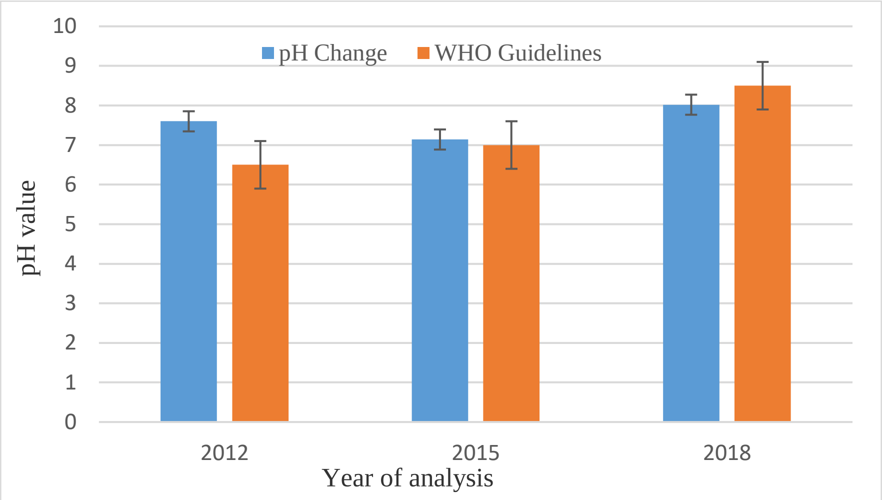

Figure 3: Temporal variation of pH value for three years

3.3.2. Temperature

The temperature of a water is an important factor in the aquatic environment as it governs almost all physical, chemical and biological reactions [33]. Indeed, it modifies the physical and chemical properties of water, mainly its density, its viscosity, the solubility of its gases (e.g. dioxygen) and the speed of chemical and biochemical reactions [34]. The temperature of water plays a significant role in the intensity of ater sensation because it is the most popular factor for the use of water in irrigation. Results indicated a slight increase for three-year analyzes (Figure 4). The temperature varied between 26.3°C and 29.1°C, an increase of 2.8 °C for 6 years studies would be due to climatic conditions.

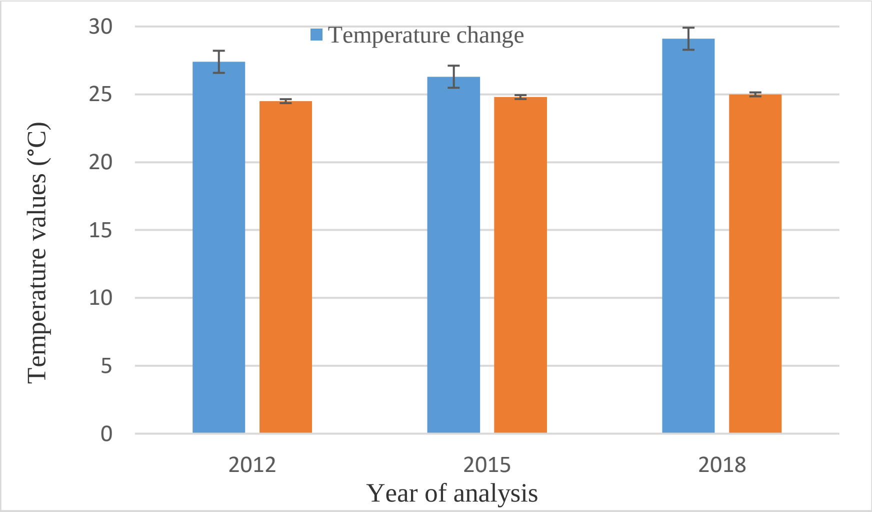

Figure 4: Temperature change for three year

3.3.3. Electrical conductivity

Electric conductivity is a measure of the abundancy of ions in water. Indeed, it is a surrogate of total dissolved solids and salts, and important property for irrigation because of salinity. It represents the capacity of water to conduct electric current. The conductivity is proportional to its mineralization, so water rich in ionized mineral salts has a high value of electrical conductivity. It is a function of the temperature, the conductivity is higher when the temperature increases [35]. The test of EC does not identify the dissolved salts or effects they may have on crops or soils, but it indicates fairly reliably the degree, with which a salinity problem is likely to occur. Obtained values (Figure 5) varied between 111 and 220 µS/cm. The values of conductivity in 2012 and 2018 are both above the WHO limit range indicating that the river is rich in monovalent and divalent ions as well as the total salinity while that obtained in 2015 is included in the recommended range [36]. These values indicate a possible pollution of Mouhoun River due to human activities.

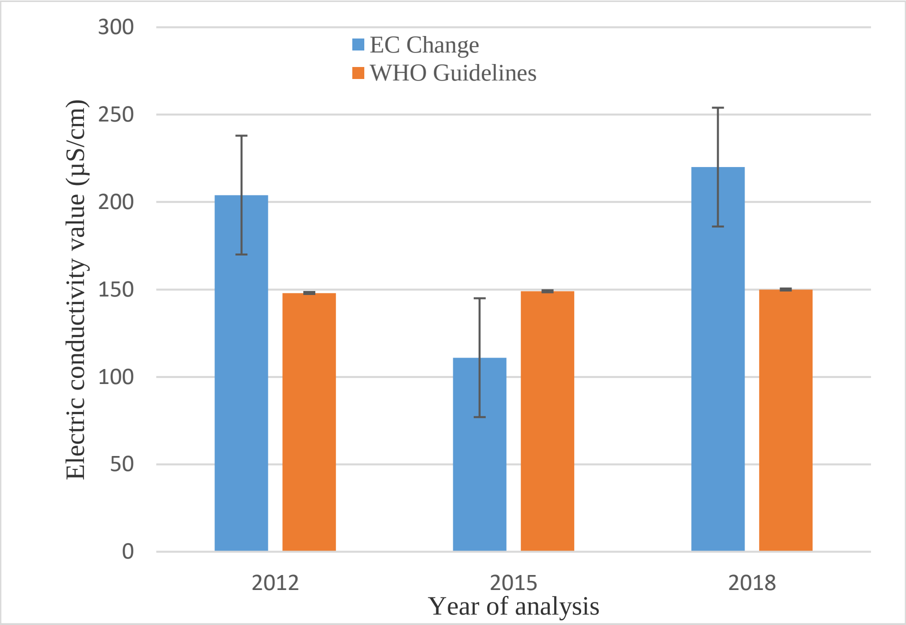

Figure 5: Variation of Electric Conductivity vs year of analysis

3.3.4.Turbidity

Turbid water is water disturbed by huge amounts of particles. This characteristic comes from the content of water in suspended matter, associated with the transport of water. These materials can be of mineral origin (clay, lion, sand, etc.), microorganisms. Turbidity and EC are characterized by high standard deviations indicating that data are widely spread due to the presence of temporal and spatial variations caused likely by natural and anthropogenic polluting sources [37]. The presence of TSS in water causes its turbidity. Obtained values of turbidity indicated an increase of this parameter each year from 2012 to 2018 while high turbidity can cause the soil erosion in agricultural fields with loose top layer (Figure 6).

3.4. *Adaption measures to climate change*

Water sector has a big role in the fighting against climate change such as mitigation and adaption conditions. Water can positively act on the stabilization of climate if the equilibrium of water cycle is conserved. Climate change can be due to the internal natural process or external forcing, anthropic change of the atmosphere composition or from the soils occupation [20, 31]. Burkina Faso is among developing countries which are facing the impacts of climate change from developed countries through industries, carbon production, greenhouse gases, etc. According to Adger *et al.* [38], adaptation actions are an important response to climate change as these actions help to reduce the vulnerabilities in the social and biological system. One of the major objectives of adaptation measures is to build the resilient in societies to face climate change [39]. Some actions such as drinking water supply, access to water for agriculture, preservation of water resources allow to increase the resilience of populations.

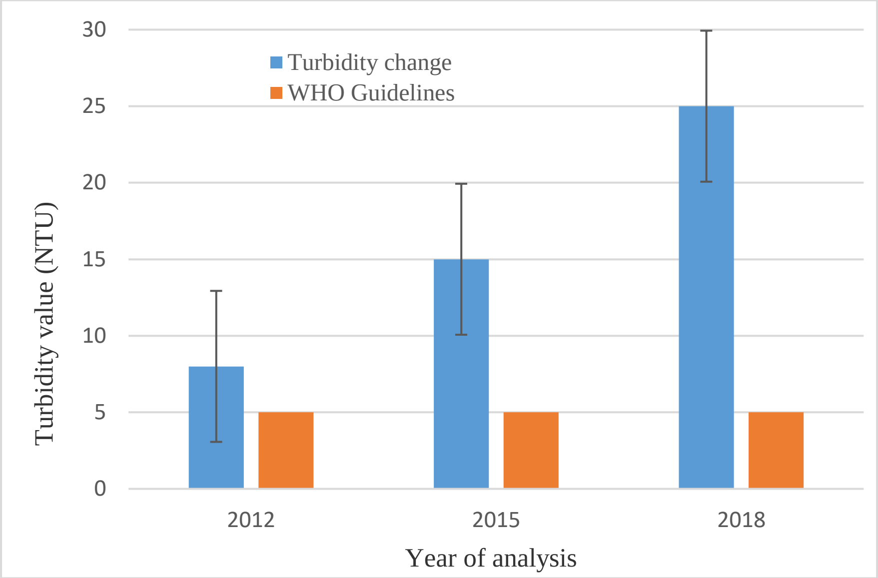

Figure 6: Variation of turdibity vs year of analysis

As adaptation measures, the development and implementation of national plans for IWRM constitute the main adaptation conditions of climate change and that involves the optimal and sustainable management of water resources. In addition, many measures can be mentioned as follows:

-increase the social capacity of populations towards the education, trainings and workshops;

-inform or sensitize the populations on climate change, water resources, and linking climate change to water security in the context of limited water resources;

-plan some research and development activities to improve the efficiency of adaptation conditions and hydrological variability;

-improve water governance and institutional dispositions for groundwater resources management.

3.4. *Economic and political consequences of climate change*

Among the economic consequences of climate change, agriculture would be the most impacted due to the decrease of water availability causing the food security. Industries will have some difficulties (lack of hydro-electricity, resources, etc.) due to lack of necessary water in dams and rivers. As political consequences, the complexity of this phenomenon commands to include the scientists and environmental workers in water management, particularly the management of water demand, its pollution and water treatment. In opposite, the accent is nowadays make on the technical solutions such as the desalination and the construction of big infrastructures such as dam, massive water transfers, etc. To deal with the complex issue of climate change, equally complex solutions are required which involve several fields of human activity and different stakeholders. Multiple stakeholders, such as civil society, research institutions, universities, private sectors, etc., play an important role in the production of responses to climate crisis together with governmental representatives [40]. The linkage of subnational/local governments with international networks provides a great potential for the development of effective policies and actions as responses to climate change [41].

Conclusion

Mouhoun River is a very important ecosystem where most of cereals in Burkina Faso are produced. This river provides some critical goods and services for livelihoods of its riparian communities. If the authorities don't take some decisions to protect this ecosystem, this river will face climate regime in next decenniums and we will have drought causing the rarefaction of water resources and decrease of agricultural yields. The sustainability of its ecological functioning faces various challenges including those related to climate change and its variability, and water resources management. IWRM approaches have been identified as key solutions to mitigate the effects of climate change. Water resources management and climate change related challenges have an overall influence on the ecological functioning of the river, largely threatening its ability to provide for current and future generations. Therefore, water resources managers need to address these impacts by reducing the diffuse pollution particularly and saving the agricultural activities. Holistic approach allowed to conclude on integrated management as better method for water resources management in Sub Saharan Africa.

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