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EFFECTS OF HYDROCLIMATIC VARIABILITY ON THE SPATIAL DYNAMICS OF PONDS (*Simenti, Kountadala and Oudassi*) OF THE GAMBIA RIVER BASIN IN THE NIOKOLO KOBA NATIONAL PARK (*Senegal*)

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ABSTRACT

With climate change, West African watercourses have undergone profound changes with large runoff deficits, faster dryings and very severe low flows. These modifications have led to a sharp decrease in water resources and a drying up of some water bodies. This article evaluated the effects of hydroclimatic variability on the spatial dynamics of a few ponds (Simenti, Kountadala and Oudassi) in the Gambia Basin in the Niokolo Koba National Park, NKNP, (Senegal). Data from five sets of images are used for pond trend mapping (Landsat, Google Earth and Sentinel). The hydroclimatic data used in this study include precipitation, temperature, evaporation, and discharge data from the Gambia Basin subjected to trend (Mann-Kendall) and rupture (Pettitt) tests. The results show that the trend is positive and significant for temperatures and evaporation and negative and significant for precipitation at a 95% confidence level. The surface area of the ponds, from 40.3 ha in 1975, increased sharply to 79.3 ha in 1988, then rose slightly in 1999 with 80.2 ha and in 2010 with 83.4 ha before to shrink sharply from 67.8 ha in 2019 due to rainfall deficit and the expansion of aquatic vegetation. Recommendations were made on how to improve the problem. Faced with the scarcity and drying up of water in these ponds of Niokolo Koba Park, water transfer operations such as those noted with the Simenti pond to save animals, remain fundamental according to some conservatives.

Contribution/Originality: This study contributes to the exist literature by evaluating the effects of hydroclimatic variability on the spatial dynamics of a few ponds (Simenti, Kountadala and Oudassi) in the Gambia Basin in the Niokolo Koba National Park, NKNP, (Senegal).

1. INTRODUCTION

Lakes and ponds are major repositories of biodiversity and provide multiple ecosystem services (Politi *et al.*, 2012). These are vital resources for aquatic wildlife and human needs. Any change in their environmental quality and water renewal rate has far-reaching ecological and societal consequences (Vincent, 2009). Lakes and ponds are widely recognized as key indicators of environmental change. They exhibit remarkable variability over time in their morphometric, physical, chemical and biological characteristics (Omondi *et al.*, 2014). These variations are mainly driven by climate change and human activities in their watershed. Ponds are strongly influenced by regional and global climate change in the short and long term (Nzoiwu *et al.*, 2017). Their water level varies according to the precipitation / evaporation ratio, the groundwater inflow, the water abstraction rate and other factors. Therefore, as sensitive indicators of change, they are able to integrate the effects of human activities in their watershed and the additional disturbances caused by global warming (Magnuson *et al.*, 1997).

The global climate has changed significantly from a climate system dominated by natural influences to a system dominated by human activities (Bronnimann *et al.*, 2007). The average temperature on the surface of the planet has increased by about 0.6 ° C during the twentieth century (Intergovernmental Panel on Climate Change, 2013) and current global circulation patterns predict an increase in air temperature of several degrees by the end of the 21st century, combined with large changes in regional rainfall distribution and intensity (Vincent, 2009). This awareness has led to questions about the relative effects of changes in climatic conditions on natural ecosystems. The two main hydro-meteorological variables that affect the ecosystem of a pond are precipitation and air temperature (Magnuson *et al.*, 1997). Changes in air temperature and precipitation have direct effects on the physical, chemical and biological characteristics of ponds. Studies have shown that climate change can affect water temperature, surface water elevation and alter pond structure (Carpenter *et al.*, 1992) enhance eutrophication by altering the internal nutrient loading and external, evaporation rates and further decreasing dissolved oxygen supply, resulting in increased biological oxygen demand (Rooney and Kalff, 2002). These abiotic changes would be accompanied by a general change in the biotic characterization of ponds and cuvettes.

In addition, like lakes, ponds are important links in the Earth's hydrological cycle, and studies have shown that predicted climate change may alter the hydrological and physical characteristics of lakes (Magnuson *et al.*, 1997). Hydrological systems are potentially very sensitive to climate change (Arnell *et al.*, 1996) and can affect many aspects of lake and river ecosystems, such as the flow of water into and out of ponds, the net water supply of the basin and the water levels of the ponds. In the long term, the volume and extent of lakes have changed several times due to climate variability (Lozan *et al.*, 2001) and uncontrolled urbanization. Thus, Ayoade (1975) also pointed out that an accurate assessment of the water resources of any region requires knowledge not only of the extent of rainfall and its spatial and temporal distribution, but also of the nature and magnitude loss of water by evaporation. This change in precipitation and temperature that accompanies climate change has the potential to alter the connectivity of ponds with biological implications (eg for migratory fish species), changes in volume, area, and pond depth, as well as other related limnological properties (Nzoiwu *et al.*, 2017).

Changes in the water balance due to climate change may make the ecosystem of the pond vulnerable to climate change, while these changes are likely to affect species composition (Lehtonen, 1996). The aquatic macrophyte communities in the littoral zone of the lakes (Yem *et al.*, 2011) have shown that with decreasing lake areas, the relationship between littoral and pelagic habitat is increasing. Studies have shown that variations in lake area, due to human water abstraction or climate change, are responsible for variations in the abundance of fisheries, diversity and richness of fish fauna. lakes (Inyang, 1995) species richness and length of the food chain increased with lake size (Reche *et al.*, 2005). The effects on the climate have been exacerbated by the growing need to irrigate farmland, provide municipal water supplies, industrial uses, power generation, etc (Nzoiwu *et al.*, 2017). In all scenarios, the capacity of African countries to cope with the potential effects of changing climate variables on the freshwater ecosystem should be seriously challenged and potentially outweighed by the magnitude of these impacts.

In West Africa, and more particularly in the Sahelian regions, which are often described as arid or semi-arid, lakes and ponds fulfill important functions for the environment Sène *et al.* (2006). Senegal is a Sahelian country located in the western part of the African continent (Economic Community of West African States, 2006). It is subdivided into six eco-geographical zones Figure 1 each of which contains several coastal, continental and artificial wetlands.

The climatic variability and consequently that of the hydrological regime conditions the dynamics of the vegetation cover of the Niokolo Koba National Park (NKNP). The hydrographic system of the latter represents more than 10% of the Gambia River watershed (77 000 km^2) which runs over nearly 200 km (Renaud *et al.*, 2006). Lateral water inflows contribute to the rapid flooding of the Gambia River despite the low slope (0.27%) in the park

(Bâ, 2008). When the flood of the river reaches a certain height, the water floods the ponds which can conserve water for several months. The most important of these ponds are Wouring, Fourou, Nianaka, Kountadala, Simenti, Impanthie, Sita Ndi, Kandi Kandi, Woeni, Dala Fourounté, Kandiou, Soutou and Tochke (Boureima, 2008). These areas are thus important water points, interconnected with each other, which allow the development of a diverse herbaceous and shrubby flora (Gueye *et al.*, 2015) and which also serve as a watering place for wild beasts.

These basins that border the Gambia between Simenti and Bansang are generally separated from the river by a rim of bank. They are filled in the rainy season by the lateral inputs (runoff and small tributaries), then by the river in flood, since the rise of the level (several meters) is sufficient to overflow by the outlets. In the dry season, the cuvettes gradually dry out (with the exception of a single pond and / or a marshy area that remains in the shallow). On the outskirts of this still damp bottom, the basin is occupied by temporary meadows and shrubs. The basins of the Gambian reach border the upper estuary which is characterized by a constantly fresh water and a tide, of low amplitude, without significant ecological role (White, undated).

Permanent or temporary wetlands in flood plains play an important role because of their ecological functions (flood spreading, groundwater recharge, spawning grounds, habitats for aquatic and semi-aquatic fauna: waterbirds, manatees, etc.). In the Niokolo Koba National Park (NKNP), the cuvettes or ponds located in the heart of the Park, the most important ones being those of Simenti and Kountadala, attract in the dry season some species and are privileged sites for the tourism of vision. Downstream from the NKNP, the cuvettes bring numerous resources to the populations (fish, pastures, wood, water, game, tourism ...) and are cultivated where the risk of flooding is low (rainfed rice, bananas, market gardening) (White, undated).

In Senegal, several studies have been conducted on the state of wetlands across the country. However, there are few that, on the ponds and troughs of the Gambia River, in the NKNP, approach them in a specific way and at local scales. Nevertheless, the studies carried out on land-use changes indicate a gradual degradation of Senegal's wetlands, like those of the whole of West Africa (Dia, 2003). The fourth national report on the implementation of the Convention on Biological Diversity (CBD) highlights the fact that Senegal's wetlands show a regressive dynamic (Institute of Environmental Sciences (ISE) and Directorate of National Parks (DPN), 2010). The document of the new National Policy for Wetland Management (PNGZH) of Senegal, the most recent state of play, shows a significant evolution and largely linked to conversions (Ministry of Environment and Sustainable Development of Senegal, 2015). The study of wetlands in the NKNP is particularly interesting. The complexity of these wetlands is linked both to their location in the Park area, to their biodiversity which is still rich and to their participation in the watering of wild animals. They are ideal to study a dynamics of the occupation of the soil because of the natural influence (water, vegetation, etc.). The use of mapping through geomatics is a relevant approach to highlight the dynamics of land use. The latter can be defined as the evolution of land-use classes, either towards a stage of degradation or improvement, or towards a state of more or less stable equilibrium (Diop *et al.*, 2018). When this dynamic is studied through the use of aerial photographs or satellite images, it becomes an important element for describing and quantifying changes in the time and space of a land-use unit (Center for Ecological Monitoring of Senegal (CSE) *et al.*, 2012). The purpose of this article is to evaluate the effect of variations of climatic elements (temperature, precipitation, evaporation) on the NPHP ponds, the Simenti pond first, for 40 years and to recommend measures in the face of environmental risks.

2. STUDY AREA

The Niokolo Koba National Park is located in southeastern Senegal, between parallels 12 ° 30 and 13 ° 20 north latitude and between meridians 18 ° 30 and 13 ° 42 west longitude Figure 1 (Gueye and Noba, 2015). It covers an area of 9130 km^2 (Renaud *et al.*, 2006). The relief consists of several geomorphological units such as plateaus, valleys and hills. The climate is Sudano-Guinean influenced by two air masses, the trade winds and the monsoon, but also by precipitation and temperature (DPN, 2000). It corresponds to the tropical type climate domain with long dry season (Gueye, 2014). Rainfall ranges between 900 and 1200 mm with a rainy season from June to October while temperatures range from 25 ° C in December to 33 ° C in May (Ndiaye, 2012). The river system of the park consists of the Gambia River and its main tributaries, Niokolo Koba and Koulountou, as well as several ponds and ponds (Ndiaye, 2012). In the Niokolo Koba National Park (NKNP), the most important ponds, such as the Simenti and Kountadala ponds, as well as the Oudassi pond, are the subject of this study. The pond of Simenti is the only permanent park and attracts the beasts of the savannah that drink from very salty water and roll in the mud. The area of Simenti stretching from the grand viewpoint to the Patte-d'oie is the most popular part of Niokolo Koba Park.

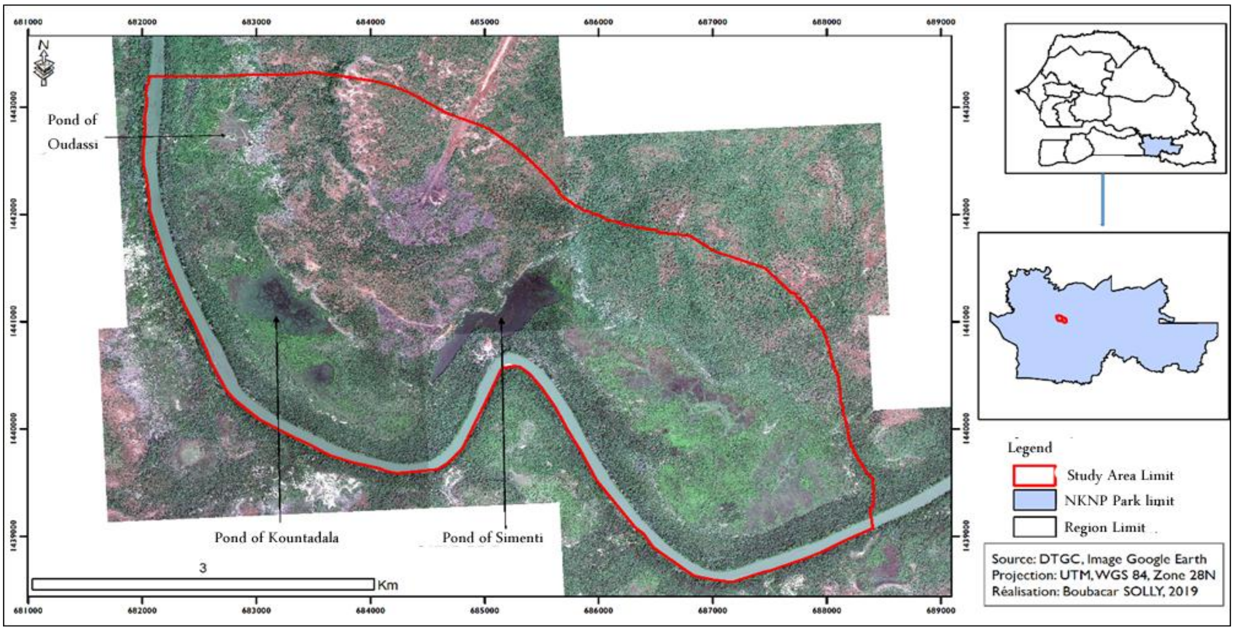

Figure-1. Location of the Gambia River ponds in the NKNP.

Source: DTGC, image Google Earth.

3. DATA AND METHODS

3.1. Data

3.1.1. Aerial and Satellite Data Used

Five series of images are used to map the evolution of the ponds. These are Landsat MSS images from 1975, TM 1988, ETM + 1999, Google Earth Pro 2010 and Sentinel 2 2019 Table 1. These images are chosen according to their availability while respecting a time difference of more or less ten years. The 1975 Landsat MSS image is the oldest available and usable in the study area. It allows to have the oldest possible situation of the ponds. The Sentinel 2 image from 2019 provides a glimpse of the current state of the ponds. The images of 1988, 1999 and 2010 give an idea of the ponds evolution during these different periods. Images taken just at the end of wintering are preferred.

Table-1. Satellite and aerial images used.

Type of image	Dated	Sensor	Spatial resolution
Landsat 2	05/02/1975	MSS	60 m
Landsat 5	01/12/1988	TM	30 m
Landsat 7	08/12/1999	ETM +	30 m
Google Earth Pro	18/11/2010		10 m
Sentinel 2	06/21/2019	MSI	10 m

Source: DTGC, image Google Earth.

3.1.2. Hydroclimatic Data

The data used in this study include monthly precipitation and monthly temperature data obtained from the National Agency of Meteorology and Civil Aviation (ANACIM). For rainfall, three stations monitored over a long period are selected in the Senegalese part of the Gambia Basin (Kédougou, Tambacounda and Simenti) Table 2. For temperature, data from the Tambacounda station, the only ones available in the area, were used. The meteorological stations chosen for the quality and duration of the observations were selected in order to constitute a sample as representative as possible of the variability of the hydro-climatic conditions at the scale of the watershed of The Gambia in order to guarantee a relatively homogeneous coverage. Mean values of rainfall and temperature were calculated from the arithmetic mean method. From the temperature data, potential evapotranspiration (ETP) was calculated by the Thornthwaite method (N'guessan *et al.*, 2014; Kouassi *et al.*, 2017). To characterize the impacts of climate change on surface water resources in the Gambia Basin, the Simenti water station was used and data are available from 1970-71 and 2007-08.

Table-2. Characteristics of the stations selected for the study.

Categories	Stations	Latitude (° decimals)	Longitude (° decimals)	Period
Climatology	Tambacounda	13.77	-13.68	1960-2016
	Kedougou	12.57	-12.22	1960-2016
	Simenti	13.06	-13.31	1960-2016
Hydrology	Simenti	13,03	-13.3	1970-2008

Source: ANACIM.

The meteorological data collected extends from 1960 to 2016. This period is considered to be long enough for a valid statistical study (Kahya and Kalaycı, 2004) especially since (Burn and Elnur, 2002) stipulate that a minimum length of 25 years ensures the statistical validity of the research results on trends.

3.2. Methods

3.2.1. Mapping Methodology

Three stages were followed for the mapping of the land use and the evolution of the ponds. These are geometric correction, the combination of bands for satellite images, and digitization.

Images are acquired at different spatial resolutions and at different dates (60 m, 30 m and 10 m). This is why they undoubtedly present geometrical shifts that it would be imperative to correct. To superimpose them, it is therefore necessary to bring them back to the same resolution and to give them common geographical coordinates (Ducrot, 2005). This is how we first resampled them to a resolution of 10 m using the nearest neighbor method. This uses the value of the nearest pixel, without any interpolation, to create the value of the rectified pixel. Then we brought them back to the same geometry. This step consisted in giving them common geographical coordinates. The image-by-image correction method was adopted with reference to the 1999 image using a polynomial of degree n whose number of ground control points (GCP) selected is greater than $(n + 1)^2$ and a residual error of less than 0.5.

After bringing the images back to the same geometry, we made the colorful composition of the Landsat and Sentinel images. It is an operation which consists in superimposing the bands at the level of red, green and blue (RGB) color. There are different types of color composition including the natural one used in this study. It combines the 3-2-1 bands of Landsat and 4-3-2 images of Sentinel imagery. By photo-interpretation, they allowed to identify, in addition to ponds, the other classes of land use composing the mapped surface Table 3.

Classes being identified, we first created vector shape (polygon) type files. Then we digitized the classes according to the color and shape of the objects before assigning to each polygon, the corresponding land use.

Table-3. Codes, classes and description of map units.

Codes	Classes themes	Description
1.1	Pond of Simenti	Name given to the different ponds.
1.2	Pond of Kountadala	
1.3	Pond of Oudassi	
1.4	Others ponds	Ponds deriving from Kountadala and Simenti.
2	Hydrographic Network	Watercourse.
3	Floodable surfaces	Surface temporally covered by water according to the periods and rainfall conditions.
4	Habitat	Camps around the Simenti pond.
5	Aquatic vegetation	Vegetation around lakes and often submerged with water.
6	Other vegetations	All other vegetation (forest-gallery and savannah).
7	Bare soil	Bare surfaces.
8	Track	Landing runway.

Source: DTGC, image Google Earth.

3.3. Index Calculation and Statistical Tests

To characterize temperature, precipitation, evaporation and flow variables, standardized indices (Mckee *et al.*, 1993) were developed to quantify the hydroclimatic deficit for multiple time scales. These deficits will reflect the impact of drought on the availability of different types of water resources for a given period of time (Sharma and Panu, 2010). The evolution of all temperature, precipitation, evaporation and flow variables is also evaluated using statistical tests. While the Mann-Kendall test detects possible incremental changes in the series of extreme variables (Kendall, 1975); (Pettitt, 1979) is a non-parametric test for detecting a break in the series.

4. RESULTS AND DISCUSSION

4.1. Analysis of Hydroclimatic Data

4.1.1. Annual Climatic Indices

The overall trend is the annual temperature change at the Tambacounda station. The coefficient of variation is slightly higher on the minimum (TN) and average (TM) temperatures with 0.03 than on the maximum (TX) temperatures with 0.02. These three variables, TX, TM and TN, showed a slight increase from 1960 to 2016. Disagreeing with global variation (IPCC, 2013) this warming seems to have been less important for minimum temperatures (at 0.49° C / year), only for the maximum temperatures (with 0.54° C / year), although the difference between the two is very small (0.05). The standard deviation is 0.59 ° C on the global average and indicates the low interannual variability relative to the warming over the period. The average temperature in Tambacounda has thus gone from a minimum value of 27.7° C (in 1965) to a maximum value of 30.3° C (in 2016) out of a total of 59 years. During the year 2016, the hottest year of the series, the maximum temperature reached 37.0° C and the minimum temperature 23.6° C. As for 1965, the "coldest" year of the series, the maximum temperature did not exceed 35.2° C and the minimum only 20.2° C.

The annual totals of precipitation vary between 1424 mm in 2003 and 666 mm in 2007. The gap between the maximum and the minimum of the series is 980 mm. Rainfall therefore varies with a coefficient of variation of 0.19. Unlike the temperatures, there is a significant trend in the decrease of rainfall over the period 1960-2016. Annual average temperatures and precipitation are standardized by the average of the period 1960-2016. This results in a series of annual temperature and precipitation anomalies as well Figures 2 and 3.

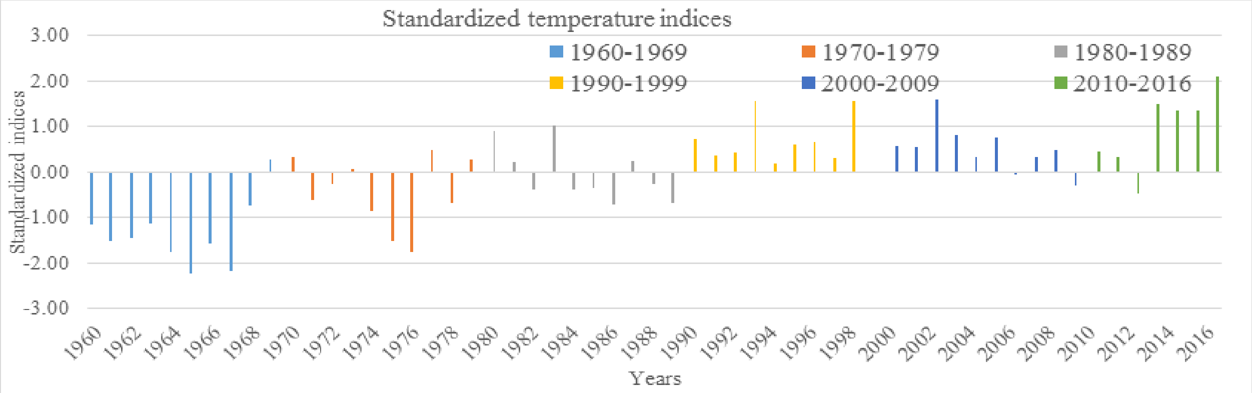

Figure-2. Standardized indices of average temperatures in the Gambia Basin over the period 1960-2016.

Source: ANACIM.

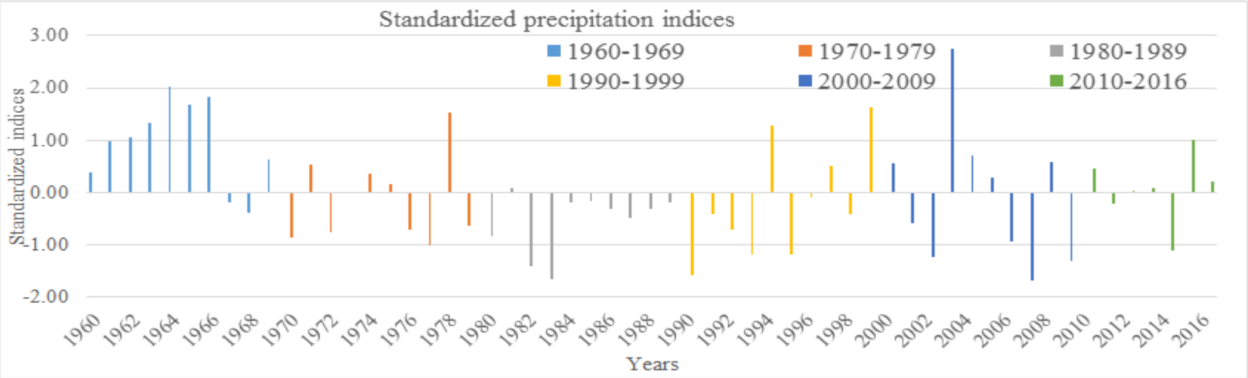

Figure-3. Standardized rainfall indices in the Gambia Basin over the period 1960-2016.

Source: ANACIM.

For the average annual temperatures, we distinguish a first part where the standardized temperature indices are mostly negative (the minimum being -2.22 ° C in 1965) and a second part where they are mostly positive (the maximum being 2, 1 ° C in 2016). In addition, the negative indices appear to be lower compared to the average than the positive indices which would be higher and higher at the end of the series, reflecting a non-homogeneity in the warming. Compared with rainfall, the standardized precipitation indices for the period 1960-2016 are not clearly divided according to time and average temperatures. They change sign from year to year and the maximum of successive years of the same sign seldom reaches a whole decade, despite a significant downward trend in rainfall patterns in Tambacounda. Nevertheless, the three decades 1970, 80 and 90 represent the most deficit period of the series. Table 4 shows the results of the Pettitt and Mann-Kendall tests on annual temperatures and precipitation recorded in the Gambia Basin from 1960 to 2016.

On the minimum, maximum and average temperatures, the two tests (Pettitt and Mann-Kendall) show the presence of a break and / or trend. Pettitt's test indicates the year 1989 as a break date for TXs. These breaks are confirmed by the Mann-Kendall test, which has positive Kendall τ with 0.54 for TX, 0.31 for TN and 0.49 for TM. So the trend is on the rise; and it is more significant on TX than TN. To quantify the temperature variation across the rupture date, we have divided the time series into two sub-periods: 1960-1989 and 1990-2016. The comparison of the two sub-periods shows the existence of a surplus of 2.7% between 1990-2016, compared to 1960-1989, for the TX, an increase of 0.9° C.

Table-4. Results Pettitt tests and Mann-Kendall on temperatures and annual precipitation in the Gambia basin 1960 to 2016.

Mann-Kendall test						Pettitt test					
Descriptors	**P (mm)**	**TX**	**TN**	**TM**	**Qm3 / s**	**Descriptors**	**P (mm)**	**TX**	**TN**	**TM**	**Qm3 / s**
Trend	0	0	0	0	0	Breaking	0	0	0	0	0
Sense of the trend	drop	rise	rise	rise	rise	p-value	0.0026	<0.0001	<0.0001	<0.0001	0.0507
τ of Kendall	-0.17	0.54	0.31	0.49	0.24	Date of rupture	1966	1989	1968	1976	2004
S	-275	863	493	785	169	Mean before break	1182	35.6	20.8	28.4	125.4
p-value	.0661	<0.0001	0.0007	<0.0001	0.0341	Average after break	922	36.5	22.2	29.3	341.7
Slope	-3.09	0.03	0.02	0.03	1.82	Variation in %	-22.0	2.7	7.0	3.1	172

0 (yes) = presence of a trend or a break; N (No) = absence of trend or break τ = Tau from Kendall ; S = S statistics; p of the test = p-value unilateral; TX = Maximum temperatures; TN = Minimum temperatures; TM = Average temperatures; P (mm) = Precipitation ; Qm3 / s = Flow past.

Source: ANACIM.

For precipitation, the Pettitt and Mann-Kendall tests indicate a break in 1966 and a significant downward trend of order -0.17 mm / yr. The evolution of standardized precipitation indices shows a decline in values, especially since the 1970s, showing the slope of Sen which is negative with -3.09. On both sides of the rupture date, the variation of precipitation is of the order of -22% between 1960-1966 and 1967-2016.

4.1.2. Annual Hydrological Indices

To better appreciate the impact of climate variability on surface flows in the Gambia Basin, the evolution of the annual Modules of the Gambia Basin at Simenti is indicated to illustrate the impacts Figure 4.

Like rainfall, the evolution of hydrological parameters that is reflected in discharged flows from the basin from 1970 to 2008 first showed a decline during the 1970s before recognizing an increase from 1994 Figure 4. Thus, the average flow rate, which was 144 m3 / s over the period 1970-2008, first decreased very sharply with only 113 m3 / s over the period 1970-1994 and then began to increase again with 204 m3 / s over the period 1995-2008. This new upward trend in the Gambia Basin, although not significant, is consistent with the improved rainfall conditions that began in the 1990s and confirms the work of Niang (2008); Ozer *et al.* (2009); Ouoba (2013) and Faye and Mendy (2018). This noted variability is almost synchronous with the presence of the two hydroclimatic periods (a dry period between 1970 and 1994 and a dry period between 1995 and 2008). Thus, beyond the hydrological drought of the 1970s, a new hydrological change occurred again at the turn of the century (1990s), with river flows increasing, with surpluses at Simenti being significant with value of 81%.

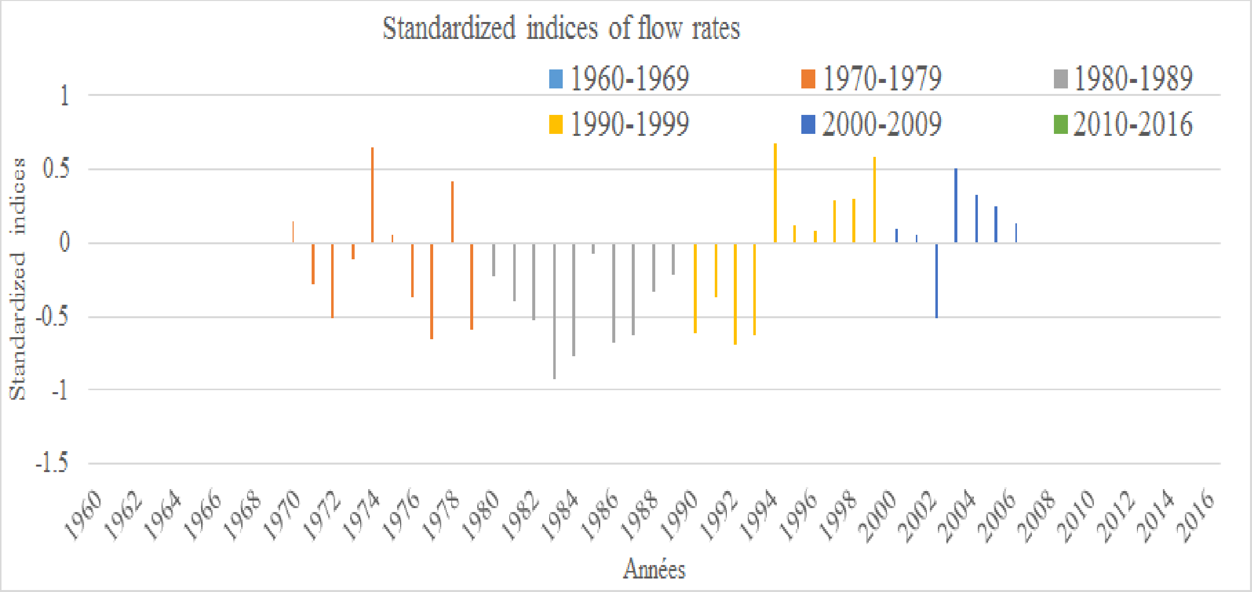

Figure-4. Standardized indices of discharges in the Gambia Basin at Simenti over the period 1970-2008.

Source: DGPRE.

4.1.3. Monthly Evolution of Some Parameters

Although the increase in temperature over the study period is statistically significant, the upward trend, particularly since the 1970s, is disturbing evidence of regional warming (Odjugo, 2010) average monthly temperature was calculated for the study period and the variation scheme presented in Figure 5. The result shows that there is a marked change in amplitude and seasonal temperature pattern with an increase that over the years (the decades of the recent period being warmer than those of the old period). The temperature model shows that the temperature has increased during the months of March to May and from October to November. The months of June, July, August and September did not show any noticeable change in temperature.

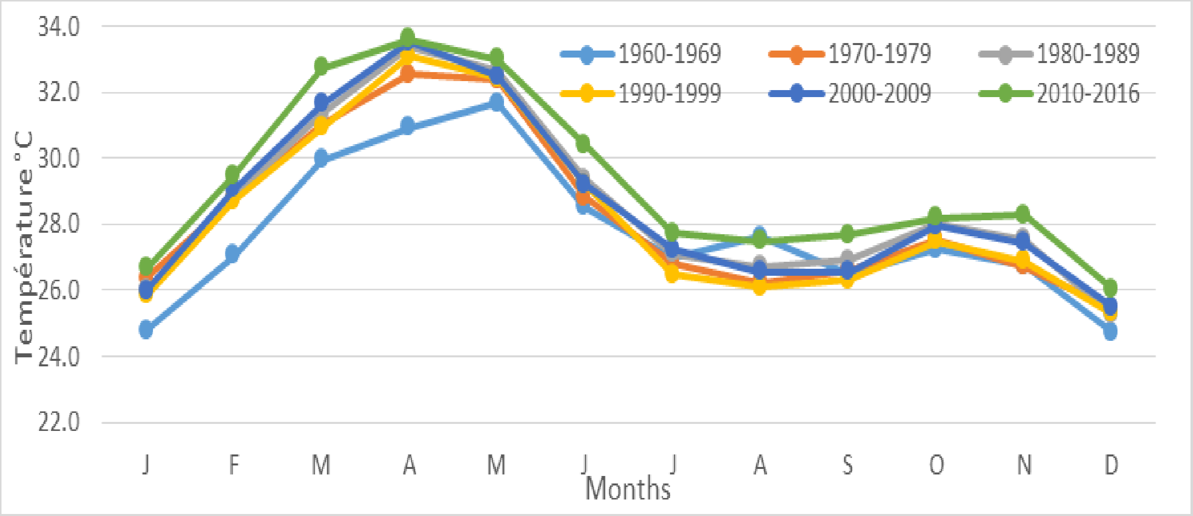

Figure-5. Monthly evolution of the average temperature per decade in Tambacounda over the period 1970-2008.
Source: ANACIM.

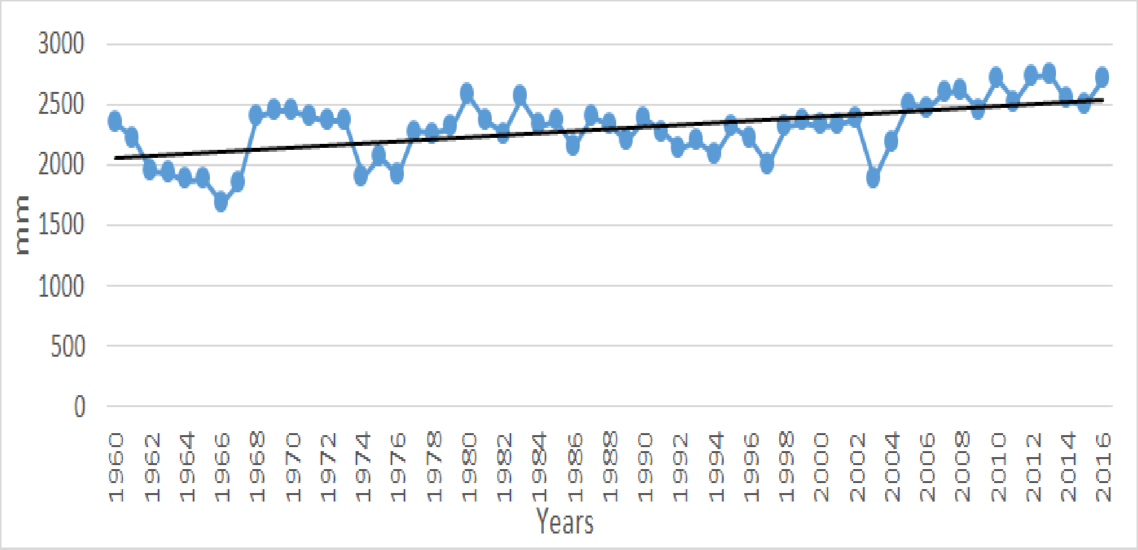

Figure-6. Annual evolution of potential evapotranspiration at Tambacounda over the period 1970-2008.
Source: ANACIM.

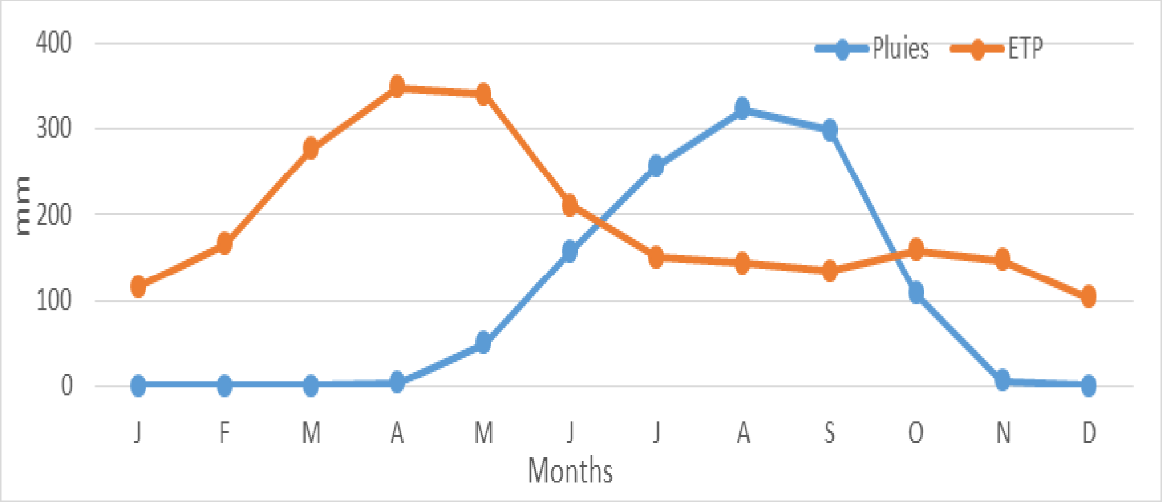

Figure-7. Monthly change in rainfall and average PET in Tambacounda over the period 1970-2008.
Source: ANACIM.

From the temperature data, potential evapotranspiration (PET) was calculated on a monthly scale by the Thornthwaite method (N'guessan *et al.*, 2014; Kouassi *et al.*, 2017) from 1960 to 2016. The Monthly values for each year were summed for a period from 1960 to 2016 to generate annual time series evaporation data for the pond area. The evolution of the PET indicates a general upward trend Figure 6 of the order of 0.36 mm per year. The significance of this trend tested with the Mann Kendall test was statistically significant at a confidence level of 0.05. The observed increase in evaporation associated with the observed change in temperature pattern, as shown in Figures 2 and 5, is later shown to affect the size of the Simenti pond.

In addition, the monthly average of evaporation was calculated for the study period and compared to the monthly rainfall recorded in the basin Figure 7. The result shows an increase in evaporation for the months of March to May and October to November and a decrease in evaporation during the months of June, July, August and September from 1960 to 2016. The similarity observed between Evaporation and temperature models reiterate the result of the correlation between the two variables and re-emphasize the extent of influence of the temperature factor on evaporation on the pond (Nzoiwu *et al.*, 2017). At the monthly scale, the analysis of the hydrological balance parameters makes it possible to distinguish two periods: a dry period and a wet period. Compared to rainfall, the area of the NKNP where the pond of Simenti is located is characterized by a wintering which lasts, in its southern part, from 5 to 6 months (generally from June to October), the The climate is of southern Sudanian continental type (Faye and Mendy, 2018) and strongly influenced by geographical and atmospheric factors (Sagna, 2005). Potential evapotranspiration records values of more than 100 mm every month, which is relatively high and indicates the extent of water deficits. Despite a rainy season that can last 5 to 6 months, the rain compared to the PET indicates a water balance that is only positive over only 3 months (257 in July, 322 in August and 297 in September). The surplus over these three months is stored in the soil until it is saturated, which can be used for infiltration and / or flow in the shallows or cuvettes (Faye *et al.*, 2017).

4.2. Mapping and Analysis of Changes in Land Use and Ponds in 1975, 1988, 1999, 2010 and 2019

The land cover change map for the five dates indicates that the ponds have had three evolutionary periods: 1975-1988, 1988-2010, 2010-2019 Tables 5 and 6, Figure 8.

4.2.1. Changes in Land Use

To analyze changes in land use in 1975, 1988, 1999, 2010 and 2019 in the study area, five main classes are selected Tables 5 and 6, Figure 8: water bodies (consisting of pond water); the Gambia hydrographic network; the flood surface; aquatic vegetation; the "other" class consisting of other types of vegetation, bare ground, tracks and the surface of the building.

Table-5. Area in hectare of land use and ponds in 1975, 1988, 1999, 2010 and 2019.

Class	1975		1988		1999		2010		2019	
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
Ponds	40.3	2.33	79.3	4.59	80.2	4.64	83.4	4.83	67.8	3.93
Hydrographic Network	107.4	6.22	107.4	6.22	107.4	6.22	107.4	6.22	107.4	6.22
Floodable surface	234.2	13.6	261.5	15.1	128.8	7.46	147.3	8.53	124.8	7.23
Aquatic vegetation	138.6	8.03	113.7	6.58	215.5	12.5	228.8	13.2	275.3	15.9
Others (others types of vegetation, bare soil, tracks and buildings)	1206.4	69.9	1165	67.4	1195	69.2	1160	67.2	1151.6	66.7
Total	1726.9	100	1726.9	100	1726.9	100	1726.9	100	1726.9	100

Source: DTGC, image Google Earth.

In 1975, the waters of the three ponds occupied an area of 40.3 ha (or 2.33% of the total area of the study area), the area flooded an area of 234.2 ha (13.6% of the total area) and aquatic vegetation an area of 138.6 ha (8.03% of the total area). The areas occupied by the other types of vegetation, the bare ground, the tracks and the buildings largely dominate the perimeter covering 1206.4 ha (that is 69.9% of the total surface). The area occupied by the Gambia water system remains constant over the entire period studied with 107.4 ha (6.22% of the total area).

In 1988, surface waters in the three ponds increased sharply to cover 79.3 ha (ie 4.59% of the total area of the study area), as was the flood zone with an area of 261.5 ha (15.1% of the total area). In contrast, aquatic vegetation shrank with an area of 113.7 ha (or 6.58% of the total area). The same is true of the areas occupied by other types of vegetation, bare soils, tracks and buildings that now cover an area of 1165 ha (67.4% of the total area).

For the year 1999, the water bodies of the ponds continue to expand weakly on the surface and amounted to 80.2 ha (or 4.64% of the total surface area) in the same way as the aquatic vegetation 215.5 ha (12.5% of the total area). The same applies to the areas occupied by other types of vegetation, bare soils, tracks and buildings which not only dominate, but increase to cover 1195 ha (69.2% of the total area). On the other hand, the areas occupied by the flood zone decreased to 128.8 ha (7.46% of the total area).

For the year 2010, the water bodies of the ponds continue to increase with 83.4 ha (or 4.83% of the total area), as well as the flood zone with an area of 147.3 ha (ie 8, 53% of the total area) and aquatic vegetation with an area of 228.8 ha (13.2% of the total area). On the other hand, areas occupied by other types of vegetation, bare soils, tracks and buildings, although dominant, decrease to cover 1160 ha (67.2% of the total area).

Finally, for the year 2019, the land use is thus distributed: the water bodies of the ponds have shrunk with 67.8 ha (or 3.93% of the total area); the flood zone decreased with an area of 124.8 ha (7.23% of the total area); areas occupied by other types of vegetation, bare soil, roads and buildings declined to 1151.6 ha (66.7% of total area); Aquatic vegetation has reached an area of 275.3 ha (15.9% of the total area).

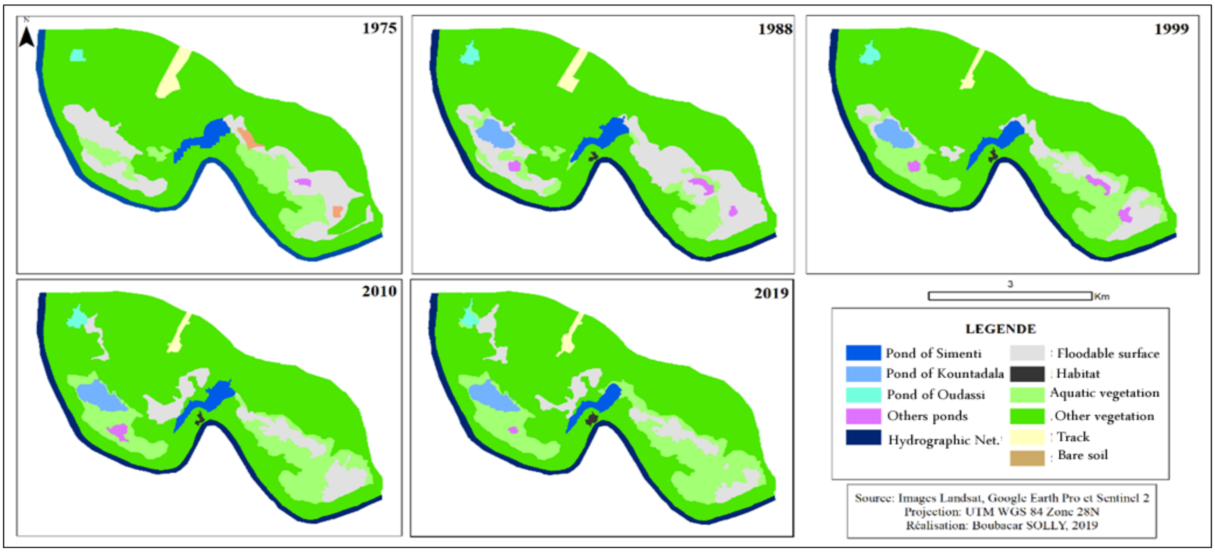

Figure-8. Evolution of land use and ponds in 1975, 1988, 1999, 2010 and 2019.

Source: DTGC, image Google Earth.

4.2.2. Changes in the Ponds Area

To analyze the changes in the surface area of the three ponds from 1975 to 2019 in the study area, the evolution of the area between two dates in hectare was determined. In 1975, the ponds occupied 40.3 ha of the mapped area; which is largely below the situation in 1988, 1999, 2010. This situation is explained by the rainfall deficit recorded in the zone. The presence of bare soil that occupied 11.5 ha (which actually corresponds to flood areas), and the drying of the pond Kountadala, during this year, are perfect illustrations. This drying up was certainly not without consequences on the watering and the survival of the wild animals of the NKNP, as noted with the crocodiles which are more and more rare in the department of Medina Yoro Foulah (located on the same gradient of rainfall) because of the lack of permanent water points (Solly *et al.*, 2018). This means that animals are forced to fall back around the other ponds along the Gambia and its perennial tributaries (Mbow, 2000). In 1988, the ponds occupied 79.3 ha. They increased by 39 ha. The same is true of the 261.5 ha flooded areas, which increased by 27.3 ha. In 1999, the ponds increased slightly compared to 1988, and occupied 80.2 ha, quite the opposite of the floodplains that fell sharply in favor of vegetation. This situation is explained by the increase in precipitation levels, which is still favorable for the evolution of vegetation. In 2010, the ponds have timidly increased in the same way as the aquatic vegetation occupying an area of 83.4 ha. Floodable areas, meanwhile, increased compared to 1999 by occupying 147.3 ha. In 2019, the ponds decreased in the same way as the floodplains and the "other vegetation" class to occupy an area of 67.8 ha.

Changes in land use indicate that the ponds have had different dynamics Figure 9. If the Simenti pond has had three periods of evolution (1975-1999, 1999-2010, and 2010-2019), the ponds of Kountadala and Oudassi have known only two, namely 1975-2010 and 2010-2019.

Between 1975-1999, the area of the Simenti pond increased from 31.3 ha to 26.8 ha. It lost during this period 4.5 ha of its surface. This decline was mainly in favor of flood plains, which also declined in favor of aquatic vegetation. However, between 1999 and 2010, the area of the pond increased by 4.6 ha, the equivalent of that lost between 1975-1999. Between 2010 and 2019, it lost 5.8 ha from 31.4 ha to 25.6 ha. This regression was in favor of aquatic vegetation.

Table-6. Evolution of the area between two dates in hectare of land use and ponds.

Class	Area in hectares					Evolution in hectares			
	1975	1988	1999	2010	2019	75-88	88-99	99-10	10-19
Pond of Simenti	31.3	29.6	26.8	31.4	25.6	-1.7	-2.8	4.6	-5.8
Pond of Kountadala	-	25.8	26.9	33.5	31.6	25.8	1.1	6.6	-1.9
Pond of Oudassi	5.6	10	10.4	10.4	8.5	4.4	0.4	0	-1.9
Others ponds	3.4	13.9	16.1	8.1	2.1	10.5	2.2	-8	-6
Hydrographic Network	107.4	107.4	107.4	107.4	107.4	0	0	0	0
Floodable surface	234.2	261.5	128.8	147.3	124.8	27.3	-132.7	18.5	-22.5
Habitat	-	1.9	2.3	2.3	3.7	1.9	0.4	0	1.4
Aquatic vegetation	138.6	113.7	215.5	228.8	275.3	-24.9	101.8	13.3	46.5
Other vegetation	1166.9	1143.5	1181.5	1146.2	1135.1	-23.4	38	-35.3	-11.1
Bare soil	11.5	-	-	-	-	-11.5	0	0	0
Track	28	19.6	11.2	11.5	12.8	-8.4	-8.4	0.3	1.3
Total	1726.9	1726.9	1726.9	1726.9	1726.9	-	-	-	-

Source: DTGC, image Google Earth.

Concerning the Kountadala and Oudassi ponds, they experienced respectively an increase of 33.5 ha and 4.8 ha between 1975 and 2010. This situation is explained by the increase of the levels of the precipitations which remain always favorable to the evolution of water bodies. However, between 2010 and 2019, they each experienced a decrease of 1.9 ha in favor of aquatic vegetation.

In 2019, the ponds have regressed to occupy an area of 67.8 ha. During the period 2010 to 2019, this decrease of 15.6 ha for the ponds of Simenti, Kountadala and Oudassi is made in favor of the aquatic vegetation. Indeed, the results of Gueye *et al.* (2015) showed that the ponds of Nianaka and Kountadala are strongly colonized by populations of Mimosa pigra with respectively an invasion rate of 93% and 99% against 50.94% at Simenti. These populations of Mimosa pigra have thus taken more than disturbing proportions in the ponds of Simenti, Kountadala and Nianaka in less than three decades. This situation is explained by the increase in rainfall levels, which is still favorable to the evolution of vegetation.

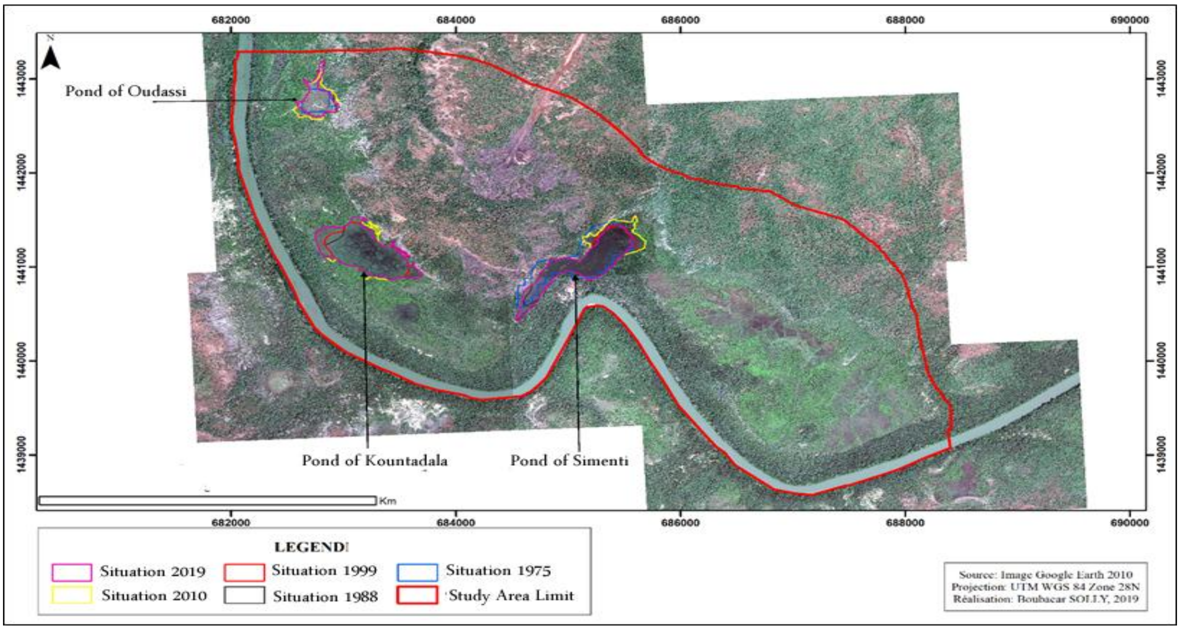

Figure-9. Evolution of ponds between 1975-1988, 1988-1999, 1999-2010, and 2010-2019
Source: DTGC, image Google Earth.

Multiple correlation and regression were performed to examine the extent of the relationship between pond surface and hydroclimatic variables, namely precipitation, evaporation, temperature and flow rates Table 7. Multiple correlation analysis gave a correlation coefficient of r = 0.54. This implies that the degree or strength of the relation between the surface of ponds and sets of independent variables of precipitation (0.60), temperature (0.40), evaporation in open water (0.70) and Elapsed flow rates (0.46) are acceptable. While the multiple correlation gave a negative correlation coefficient of -0.20 between the surface of the Simenti pond and the hydroclimatic variables, the areas of the Kountadala and Oudassi ponds recorded a positive coefficient of 0.52 and 0.52 respectively. 0.55. The surface of the Kountadala pond is strongly correlated with independent evaporation variables in open water (0.70), temperature (0.60), precipitation (0.40) and flow rates (0.36). It is the same for the surface of the pond of Oudassi whose correlations are of the order of 0.67 with the precipitations, 0.62 with the evaporation in free water, 0.55 with the flowed flows and 0, 36 with temperatures. The coefficient of multiple determination, R2, is 0.31. In addition, the value of the multiple coefficient of determination revealed that, out of 100% of the many factors affecting the surface of the pond, 31% of these variations are explained by the combined variations in temperature, precipitation, evaporation temperature, and discharges.

Table-7. Correlation matrix of Spearman between the surface of ponds and hydroclimatic variables.

Variables	T ° C	Pmm	PET	Flow rates	Pond of Simenti	Pond of Kountadala	Pond of Oudassi	Others ponds	All ponds
T ° C	1								
Pmm	0.50	1							
PET	0.90	0.60	1						
Flow rates	0.56	0.97	0.56	1					
Pond of Simenti	-0.40	-0.10	0.00	-0.31	1				
Pond of Kountadala	0.60	0.40	0.70	0.36	0.30	1			
Pond of Oudassi	0.36	0.67	0.62	0.55	0.15	0.05	1		
Others ponds	-0.30	0.30	-0.10	0.21	0.10	-0.60	0.72	1	
All ponds	0.40	0.60	0.70	0.46	0.30	0.20	0.97	0.60	1

Source: ANACIM, DGPRE, DTGC, image Google Earth.

5. CONCLUSION

This study evaluated the effects of hydroclimatic variability on the spatial dynamics of a few ponds (Simenti, Kountadala and Oudassi) of the Gambia Basin in Niokolo Koba National Park (Senegal) using data from five series of images (satellite and aerial) and hydroclimatic data. The nature of the physical relationship between this morphometric index and some hydroclimatic variables (precipitation, temperature, evaporation and flow rates) has been established. In this study, anthropogenic influences and some other climatic variables were not considered. The results show that the trend is positive and significant for temperatures and evaporation and negative and significant for precipitation at a 95% confidence level. The surface area of the ponds, from 40.3 ha in 1975, increased sharply to 79.3 ha in 1988, then rose slightly in 1999 with 80.2 ha and in 2010 with 83.4 ha before to shrink sharply from 67.8 ha in 2019 due to rainfall deficit and the expansion of aquatic vegetation. Between 2010 and 2019, the work concludes that the area of ponds has decreased by 18.7% and 31% of this reduction is attributable to changes in temperature, precipitation, evaporation and discharges. The unexplained 69% is thought to be the result of other factors not considered in this research.

Faced with the scarcity and drying up of water in these ponds of Niokolo Koba Park, water transfer operations such as those noted with the Simenti pond to save animals remain fundamental according to some conservatives. On the basis of the above, the following recommendations are made:

1) This article provided preliminary information on the current state of the NKNP ponds and its potential response to climate change. The analysis indicates the general behavior of the pond surface in the face of changes in climatic variables. Therefore, for a better characterization of this evolution of the surface of these ponds, it is recommended to improve this established relationship taking into account other factors not taken into account in this study.

2) Given that the NKNP is a very important tourism potential, it is imperative that the potential threat posed by climate change to the long-term economic viability of the park be recognized and that the government make concerted efforts to preserve this potential. Climate policies focusing on mitigation, adaptation and good conservation principles should be pursued, and water remittance operations should continue to provide water for wildlife and water supply for water, other users who use the waters of the ponds.

3) There is a need for governments to improve the network density of hydrometeorological stations located in and around inland water bodies scattered across the country to improve the collection of hydrometeorological information. This will ensure accurate prediction of the quantity and quality of these water resources. For example, the installation of measurement stations on large ponds in the Gambia Basin will provide reliable information on the water level and flow in ponds, respectively; this will ensure effective monitoring of changes in ponds throughout the year and lead to more appropriate management.

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