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Climate change and its impact on the fisheries in Lake Kivu, East Africa

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Abstract

The climate change, its variability and impact on fish catches in Lake Kivu, were verified from the analysis of climate variables and fisheries statistics. The results show qualitative and quantitative disturbances in the variation of rainfall, significant increase in temperature of 1.57°C, 0.63°C and 0.66°C at Kamembe, Gisenyi and Lwiro, respectively around Lake Kivu watershed. The relative humidity decreased significantly by 4.5% and 7% at Gisenyi and Kamembe, respectively; the wind speed decreased by 3 m/s. These changes resulted in a decrease of 0.58 m in water level of the lake, followed by periods of declines in catches of *Limnothrissa miodon,* the major lake's commercial fish. Predictions show a decline in Catch per Unit Effort of 2.92 kg for approximate reduction of 0.01 m water level by 2025. Strategic policies should be made and adaptation measures be taken to prevent the climate change, in order to conserve the aquatic resources and avoid advert conditions in fisheries sector of Lake Kivu.

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Introduction

The Intergovernmental Panel on Climate Change (IPCC) predicted an increase in atmospheric temperatures of 1.8 to 4 °C on a global scale by 2100 (IPCC, 2007). This warming will be accompanied by the increase of sea temperatures and water levels, stronger ocean acidification, alteration of the rainy configuration and river flows, and a higher incidence of extreme weather events. Fisheries productivity, distribution and seasonality, as well as the quality and availability of habitats that support fish, are sensitive to these effects (WorldFish Center, 2009).

At the global level, the fishery and aquaculture products provide at least 15% of proteins consumed by about 3 billion of people and support the livelihoods of 520 million of people (WorldFish Center, 2008). Several fisheries have declined drastically over the past decades or have already collapsed. The major fishing zones are concentrated in areas threatened by pollution, poor management of inland waters, habitat and coastal areas modifications (WorldFish Center, 2008).

In Africa, drought seems to extend every year, already threatening Kenya, Tanzania, northern Uganda, Zimbabwe, and in the DR Congo in the estuary area of Bas - Congo (Muhigwa, 2010).

Recent studies in Lake Tanganyika on the effects of climate change on its productivity (Langenberg *et al.*, 2006) failed with the available data to conclude on the effects of climate change on fish stocks of Lake Tanganyika; however they pointed out the intensification of fisheries could be the major factor.

In Lake Kivu, recent studies associated some advert environmental conditions and decline in fish yields to climate disruption. These include: - qualitative and quantitative disturbance in rainfall and atmospheric temperature (Muhigwa, 2010; Habiyaremye *et al.,* 2011); - the decrease in water levels, the drying up of some water springs and the decrease of rivers flow of lake tributaries (Kulimushi *et al.*, 2010; Habiyaremye *et al.,* 2011); and - the decrease of fisheries yields (Kaningini *et al.*, 1999).

Thereby, there is need for adaptation measures and adequate facilities in this environment for the preservation and sustainable management of water resources.

This study is a contribution to the assessment of impacts of climate change and their impact on the fishing yields in Lake Kivu. Specifically, the study aimed:

- to identify indicators of climate change from climate statistics to know its evolution at Lake Kivu; - to determine the evolution of changes in the water levels of Lake Kivu, as well as the flow of Ruzizi River, the lake's outlet; and, - to quantify the progress of catches from fisheries statistics of Lake Kivu in relation to climate variations.

Materials and methods

Study Area

Lake Kivu is located on the south of the equator between 1°34' and 2°30'S and 28°50' and 29°23'E. With an area of 2370 km², a maximum depth of 489 m and an average depth of 240 m, it forms a natural border between the Democratic Republic of Congo and the Republic of Rwanda (Marshall, 1993). It is a mountain lake located between the neighboring high peaks of the equator in the middle of a very rainy region. About 161 km between Lake Tanganyika, where it flows through the Ruzizi River, at the highest in the valley of the East African Rift point (1500 m). Lake Kivu is oligothrophe, poor in fish (Capart & Kufferath, 1956; Verbeke, 1957). This poverty would be due to its recent origin about 16,000 years, the volcanic formation, impurity of its waters rich in sulfur products (Beadle, 1981) and especially the reduction of available habitats suitable for most aquatic species (Capart, 1960). Currently, in Lake

Kivu, there are 29 species of fish, including five (5) introduced (Snoeks *et al.*, 2012), a number that contrasts sharply with 1500, 300, 80 and 48 fish species already identified respectively in Lakes Malawi, Tanganyika, Edward and Albert (Masilya, 2011).

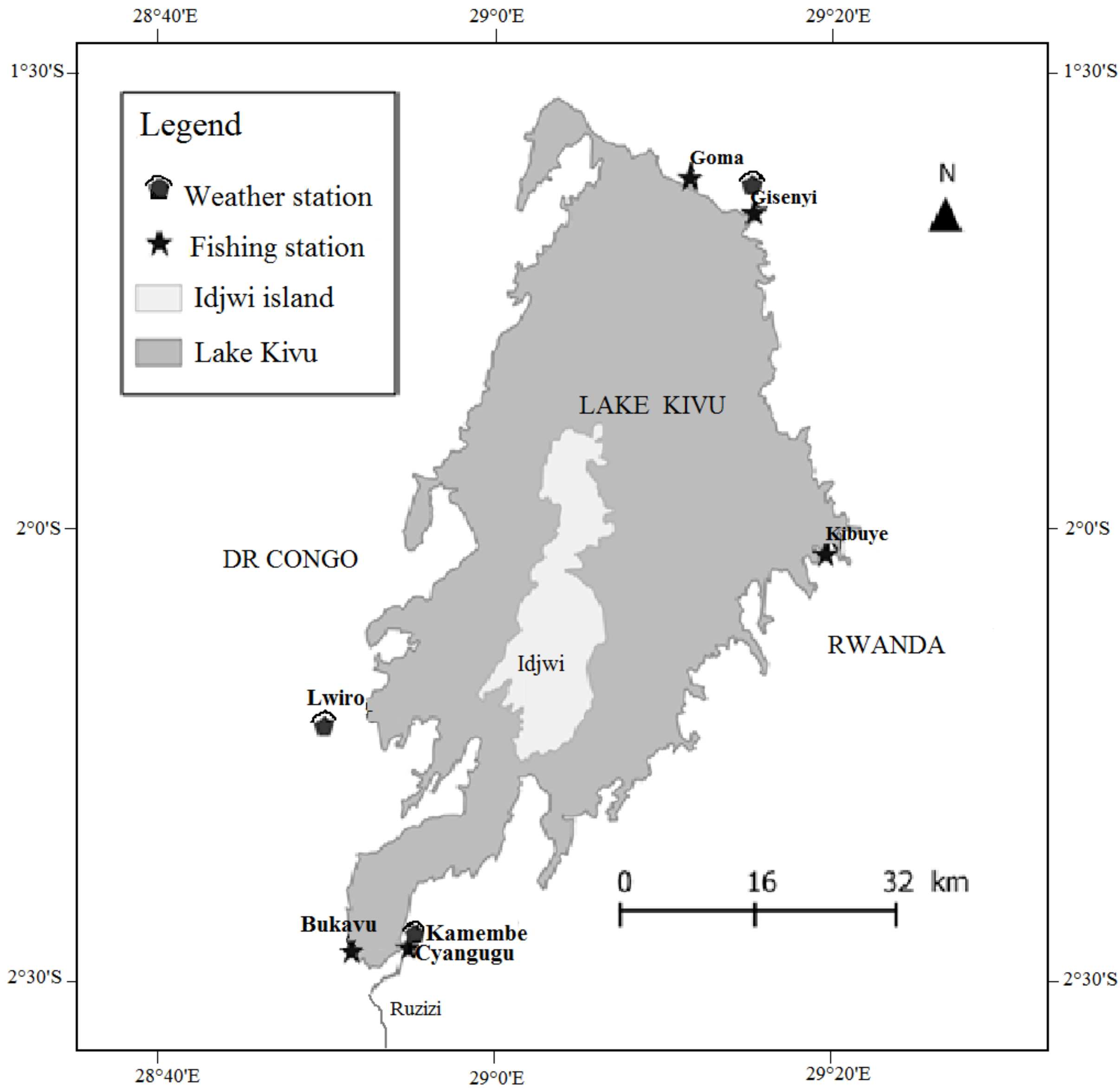


Fig. 1. Location of Lake Kivu and sampling stations.

Data collection

Daily climate data, including rainfall (mm), maximum and minimum temperature (°C), relative humidity (%) and wind speed (m/s) for 42 and 38 years (1971-2013 and 1975-2013) were collected from Kamembe and Gisenyi airports meteorological stations, located at 2°27'S, 29°54'E and 1°40'S, 29°16'E (south and northeast of Lake Kivu) respectively. Rainfall (plus number of rainy days) and temperature data for 39 years (1973-2012) were collected from the Center for Research in Natural Sciences of Lwiro (CRSN) located at 2°15'S and 28°49'E, southwest of Lake Kivu. Data on the lake water levels for 52 years (1960-2012) and the river flow of the Ruzizi River for 23 years (1989-2012), were collected from the Ruzizi I Hydroelectric Plant, located at 4 km downstream from the Ruzizi outlet.

Fisheries statistics of *L. miodon* and related equipment for 12 years (2001-2012) were collected from Gisenyi fishery station, in Rwanda. Five and three years were collected from Cyangugu and Kibuye fishery stations in Rwanda and from Bukavu and Goma (2009-2011) fishery stations, in the D.R. Congo.

Data processing and analysis

The annual and monthly averages of temperature, relative humidity, and wind speed as well as the annual and monthly totals of rainfalls were used to perform the analysis of the time series. The same analysis was used for fishing data, lake's water levels, and for Ruzizi Rver flow. The analysis of variance (ANOVA) was conducted to compare monthly averages of temperature, rainfall and relative humidity for the periods of 43, 41 and 39 years from the Kamembe, Gisenyi and Lwiro stations; and 36 years for the wind speed. ANOVA was also conducted to compare the fisheries data for 12 years from the Gisenyi station. STATISTICA V6.1 assisted to perform these analyses where possible.

The comparison of the lake water levels were conducted for the last 53 years (1960-2012).

The variation of water level relative to rainfall, temperature, relative humidity and Ruzizi River flow, has been compared according to the stations. The monthly Catch per Unit Effort (CPUE) was calculated from the ratio between the total monthly catches (kg) and the total number of nets used (Mulimbwa, 2006), for Gisenyi station. On the same station, regression analysis was performed to determine the correlation between fisheries catches and CPUE.

The annual cycles of CPUE were examined and their relationships with climate and variations of the lake water level established to estimate the potential impact on the variations of fisheries catches. These relationships were used to make predictions about the evolution of catches of *L. miodon* in comparison to the air temperature and water levels in Lake Kivu until 2025, following the regional models of Giorgi and Hewitson (2001) of climate change scenarios. Months with strong variations in precipitations were estimated from standard deviations and coefficients of variation, expressing their degrees of fluctuation between years. The regional climate was identified from the Ombrothermic diagrams using Excel software. The relation $\frac{P}{2} < T$ was estimated from the diagram to determine the dry months. Where: P and T represent the monthly average rainfall (mm) and the monthly average temperature (°C), respectively.

De Martonne annual and monthly aridity indices (I) were estimated to compare the aridity and humidity degrees between years and months, respectively, using the formulas:

$\mathbf{I} = \frac{P}{T+10}$ (Years) and $\mathbf{I} = \frac{12p}{t+10}$ (Months) (De Martonne, 1923)

Where: **I** = De Martonne index, **P** = total annual precipitation, **T** = annual average temperature, **p** = monthly total precipitation and **t** = monthly average temperature.

With: **I** < 5 (hyperarid regions), **I** ≥ 5 < 10 (arid regions), **I** ≥ 10 < 20 (semi-arid regions), **I** ≥ 20 < 30 (semi-humid regions) and **I** ≥ 30 (humid regions).

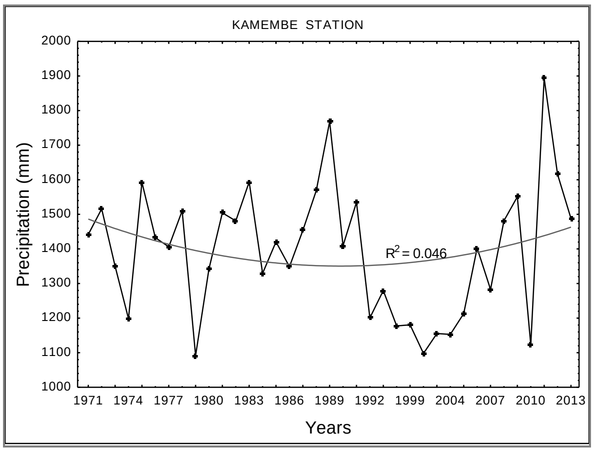
Results

Variation of rainfall around Lake Kivu

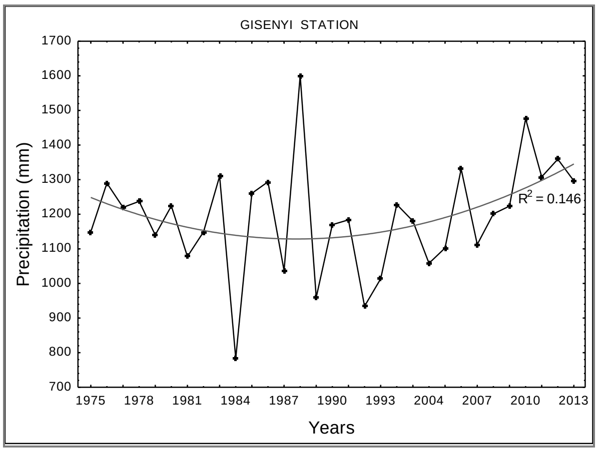
After linear and polynomial adjustments, progressive trend of rainfall shows no significant variation [p = 0.864, R^2 = 0.046 (Kamembe); p = 0.972, R^2 = 0.146 (Gisenyi) and p = 0.996, R^2 = 0.034 (Lwiro)] during the observation periods in the three areas around Lake Kivu (Fig. **2**). However, very slight decrease in rainfall is observed at Kamembe station (Fig. **2A**) and Lwiro station (Fig. **2C**), while a slight increase in rainfall is observed at Gisenyi station (Fig. **2B**).

At Kamembe station, from 1971 to 2013, the highest rainfall (1893.7 mm) was observed in 2011, while the period between 1998 and 2004, and the years 1979 and 2010 are characterized by considerable decrease in rainfall (less than 1200 mm), as observed in Fig. **2A**. At Gisenyi station, between 1975 and 2013, the decrease in rainfall was observed in 1984 (783.9 mm), whereas, the peaks in rainfall were observed in 1988 (1600.6 mm), as showed in Fig. **2B**. At Lwiro station, from 1973 to 2012, the year 1987 was found to be the wettest (2811.4 mm) and the number of rainy days decreased from 208 days to 153 days, the highest number of rainy days (214 days) was observed in 1977; and the smallest number of rainy days was observed in 2008 (143 days), corresponding to the least rainy year at Lwiro (1316.6 mm), as seen in Fig. **2C**. Therefore, the analysis of CV allows to find out that at Gisenyi, the months of April and August exhibited the strongest fluctuations in rainfall (143.34 ± 63.59 mm; CV = 86.4% and 76.07 ± 58.79 mm, CV = 81.3%); whereas at Kamembe, except a slight increase observed in April (162.37 ± 57.54 mm), there is no noticeable fluctuations in rainfall observed between months as showed in Fig. **2D.**

The present results reveal that thought the rainfall pattern did not show statistically significant variation in the watershed during the observed periods; important rainfall fluctuations were detected within each station between different years.



(A)



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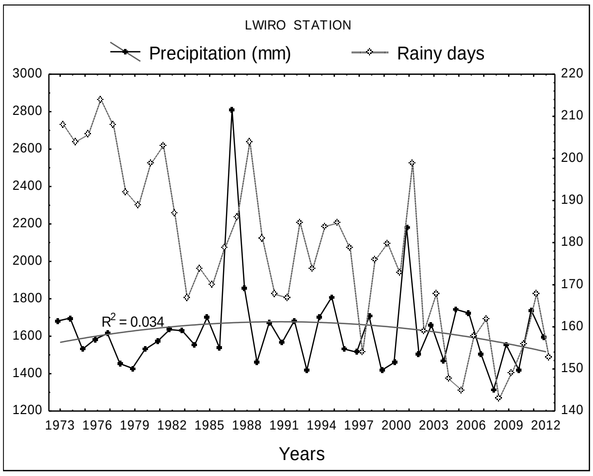

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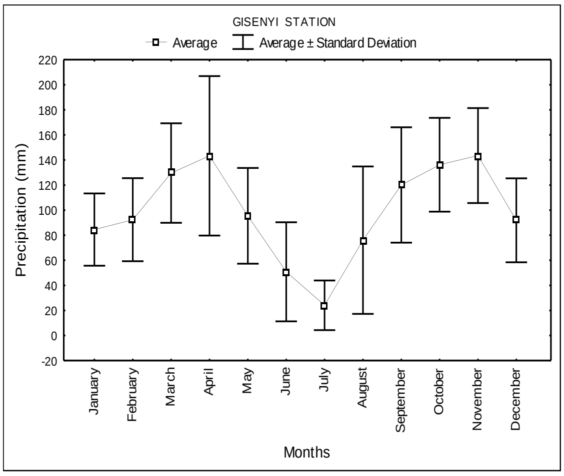


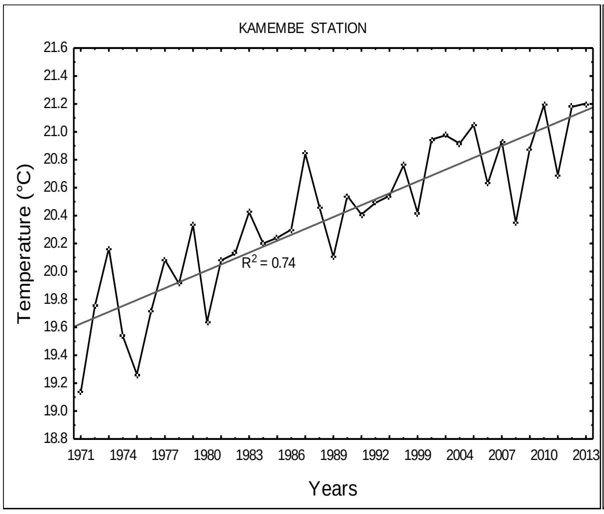
(D)

Fig. 2. Variations of annual rainfalls around Lake Kivu: **(A)** annual variations at Kamembe station (1971-2013), **(B)** annual variations at Gisenyi station (1975-2013), **(C)** annual variations at Lwiro station (1973-2012), **(D)** variability of monthly rainfall at Gisenyi station (1975-2013); the greatest differences are surrounded.

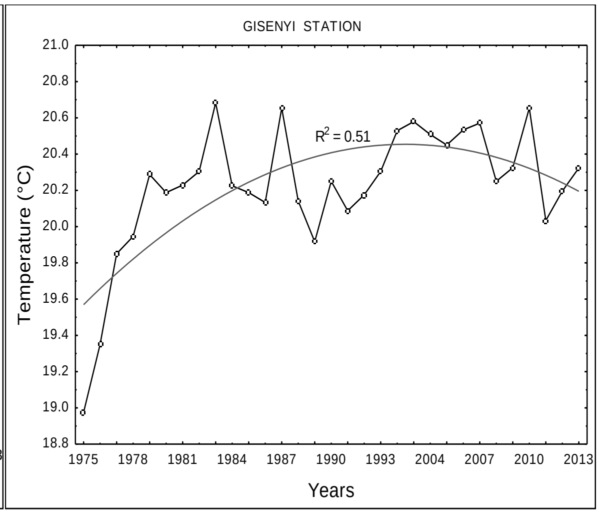
Variations of temperature, relative humidity and wind speed around Lake Kivu

The annual average temperature increased significantly ($p < 0.05$); while relative humidity and wind speed decreased significantly ($p < 0.05$) in the 3 areas during different periods, as shown in Fig. **3** and **4**. Therefore, after a linear adjustment (Fig. **3A**), the annual average temperature increased by 1.57 °C, $R^2 = 0.74$ during the period 1971-2013, unlike the relative humidity decreased by 7%, $R^2 = 0.69$ at the Kamembe station, as seen in Fig. **4A**). Similarly, at Gisenyi, after a polynomial adjustment (Fig. **3B**), the annual average temperature increased (+ 0.63 °C) for the period 1975 – 2013, $R^2 = 0.51$, while during the same period, the relative humidity decreased by 4.5%, $R^2 = 0.65$ (Fig. **4C**). At Lwiro, from 1989 to 2010, after a polynomial adjustment, there is increase in temperature of 0.66 °C, $R^2 = 0.58$. The average wind speed, from 1974 to 2009 decreased by about 4.5 m/s, $R^2 = 0.514$, at Kamembe as observed in Fig. **4B**.

The above results show a significantly increase in air temperature against a significantly decrease of the relative humidity and wind speed around the lake.



(A)



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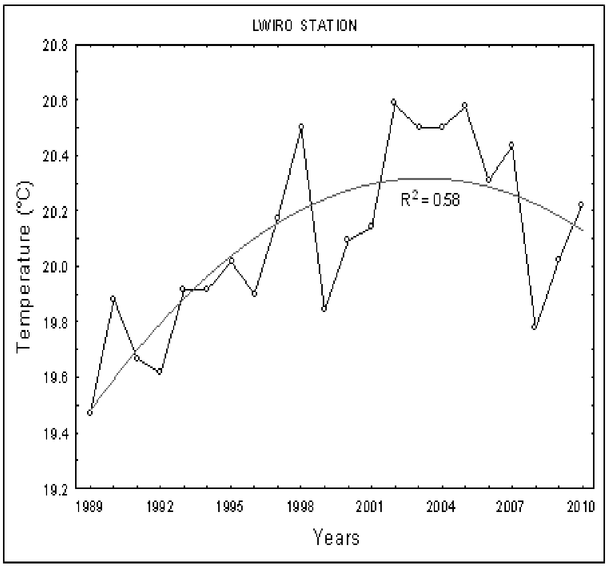
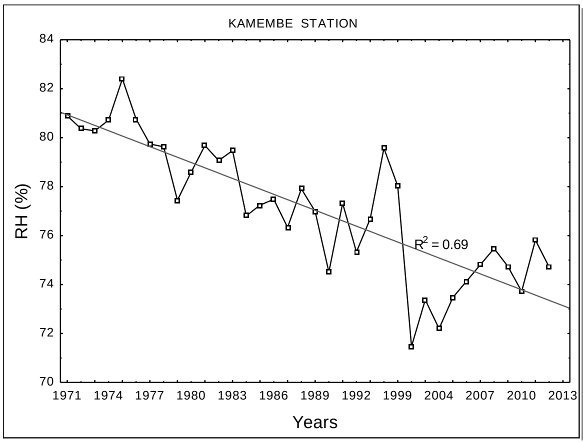
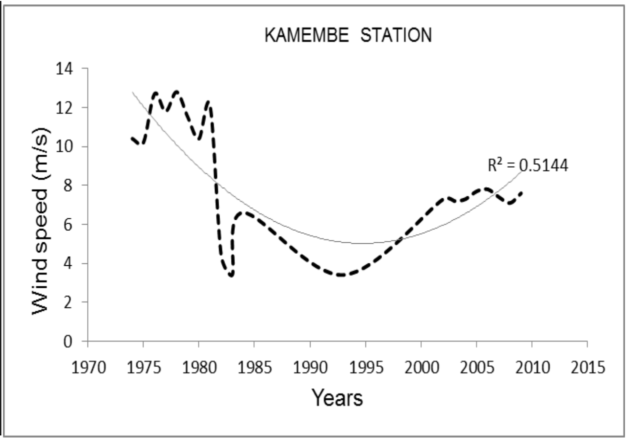


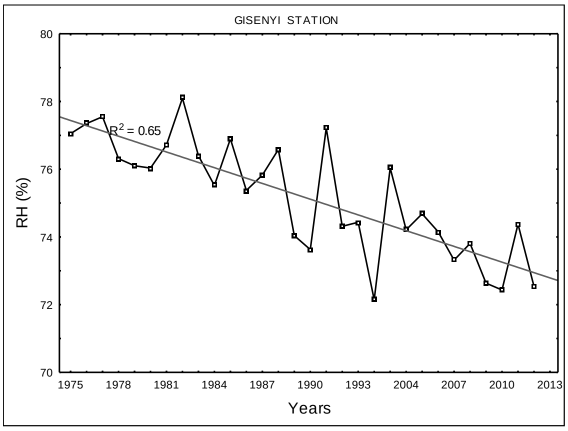
(C)

Fig. 3. Variations of average annual air temperatures around Lake Kivu: **(A)** at Kamembe (1971-2013), **(B)** at Gisenyi (1975-2013) and **(C)** at Lwiro (1989-2010).





(A) **(B)**



(C)

Fig. 4. Variations of relative humidity and wind speed around Lake Kivu: **(A)** at Kamembe (1971-2012) for the relative humidity, **(B)** at Kamembe (1974-2009) for the average wind speed, and **(C)** at Gisenyi (1975-2012) for the relative humidity.

Determination of weather and seasons around Lake Kivu: Ombrothermic diagram and De Martonne aridity index

The Ombrothermic diagram allows finding out that the months of June and July defined the dry season at Kamembe, while at Gisenyi only July defined the real dry season. Therefore, the months of June and August were found to be semi-humid at Gisenyi and Kamembe, respectively. Other months, including January, February, March, April, May, September, October, November and December represented the rainy season; with the highest rainfall records observed in March and November at Kamembe, and in April and November at Gisenyi. Whereas, July was identified as the driest month in both areas, with P = 12 mm for T = 20 °C at Kamembe and P = 24.1 mm for T = 19.6 °C at Gisenyi, as shown in Fig. **5: A,B**.

The De Martonne aridity index is presented in Table **1**, and it is indicated that from 1971 to 2013, all the years were in average very wet; with the highest index (I = 61.7) obtained in 2011, which corresponds to the period of the peak of rainfall. The lowest (I = 35.5) was obtained in 2002, which corresponds to the period of low rainfall and lowest relative humidity (71,5%) at Kamembe station, as shown in Fig. **2A** and **4A**, respectively. Therefore, apart from the months of June and July which were dry and August which was semi-humid, other months were very wet with the highest index value obtained in November (I = 69 and in March (I = 65.3), showing them as the wettest months at Kamembe, as shown in Fig. **5A**).

Table 1. Annual and monthly De Martonne aridity indices, Kamembe station.

Year	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Index	49.5	51.0	44.7	40.6	54.4	48.2	46.7	50.5	36.0	44.6	50.0	49.2	52.4	44.0	47.0	44.5	47.1	51.5	58.7

Year	1990	1991	1992	1993	1998	1999	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Index	46.1	50.5	39.4	41.9	38.0	38.8	35.5	37.3	37.3	39.1	45.8	41.5	48.8	50.2	36.0	61.7	51.8	47.7

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Index	36.4	39.6	51.1	56.4	40.3	20.5	9.8	30.2	50.3	53.8	57.4	36.7

Table 2. Annual and monthly De Martonne aridity indices, Gisenyi station.

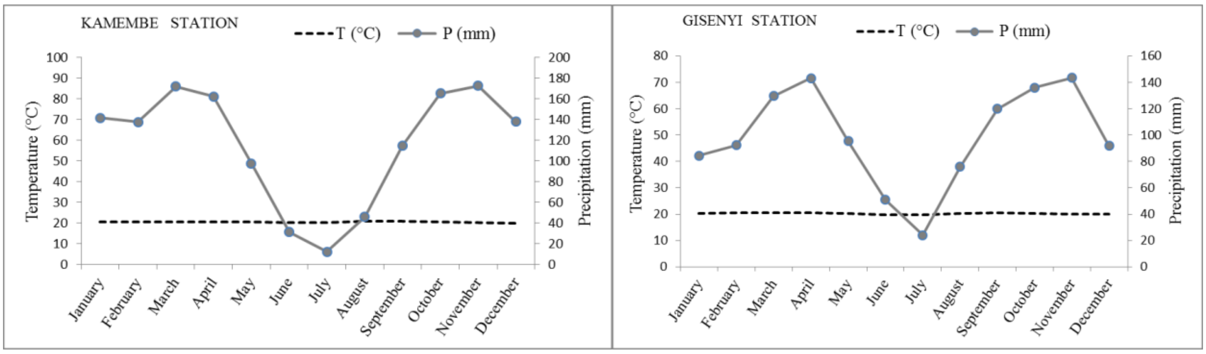
Year	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Index	39.7	44.0	40.9	41.3	37.6	40.5	35.7	37.9	42.7	25.9	41.8	42.9	33.8	53.1	32.1

Year	1990	1991	1992	1993	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Index	38.7	39.3	31.0	33.4	40.1	38.6	34.7	36.2	43.6	36.4	39.7	40.3	48.2	43.6	45.0

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Index	36.4	39.6	51.1	56.4	40.3	20.5	9.8	30.2	50.3	53.8	57.4	36.7

From 1975 to 2013, all years were in average very wet at Gisenyi, Tab. **2**, with a high index (I = 53.1) obtained in 2011, while the lowest index value (I = 25.9) was obtained in 1984 which corresponded at the same time to the period of lowest rainfall, as shown in Fig. **2B**. Considering the same period, it is observed that July was in average dry, while June was semi-humid, the rest of the months were found to be very humid, with the highest index values obtained in November (I = 57.4) and in April (I = 56.4), both corresponding to the periods of highest rainfall at Gisenyi, as shown in Fig. **5B**.

These results indicate that around Lake Kivu, the months of June and July determine, in average, the dry season, while the other ten months constitute the rainy season.



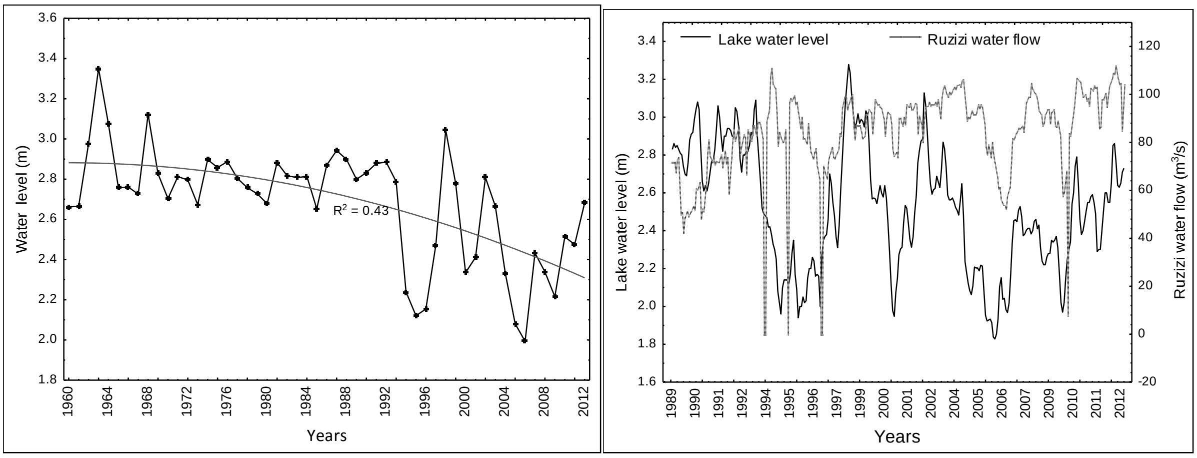
(A) **(B)**

Fig. 5. Ombrothermic diagrams representing the weather of Kamembe **(A)** and Gisenyi **(B)** around Lake Kivu.

Variation of water level of Lake Kivu in relation with rainfall, temperature and relative humidity

The polynomial adjustment reveals that the water level of Lake Kivu has significantly decreased ($p < 0.05$) at about 0.58 m ($R^2 = 0.43$) during the period from 1960 to 2012, as shown in Fig. **6A**. The highest water levels were observed during 1963, with an average value of 3.35 m; while the years 1995 and

2006 were characterized by the lowest levels, showing a decrease of 2.1 m and 2 m, respectively. It is further observed that from 1989 to 2012, the pattern of increases and decreases in water level of Lake Kivu, corresponded to the pattern of increases and decreases of the water flow along Ruzizi River, the outlet of the lake pouring in Lake Tanganyika, as shown in Fig. **6B**.



(A) **(B)**

Fig. 6. Lake Kivu water levels variation since 1960 to 2012 **(A)** and Ruzizi River water flow variations in relation with variations of Lake Kivu water levels during the period 1989-2012 **(B).**

In addition, it is observed that the pattern of fluctuations in rainfall and relative humidity around Lake Kivu (Kamembe, Gisenyi and Lwiro) are similar to those of fluctuations in the water level of the Lake Kivu, as shown in Fig. **7: A,B,C,E,F**). The average temperatures increased at about 0.02 °C and 0.04 °C per year, at Gisenyi and Kamembe stations, respectively, there was a decrease of about 0.01 m of the mean water level of Lake Kivu , which ratio are put in evidence by the predictions of 2025, in Fig. **7: C,D**.

These results show a significant decrease in Lake Kivu water levels from 1960 to 2012, its negative relation with increasing of air temperature, while the relation was positive with fluctuations in rainfall, relative humidity and Ruzizi River water flow.

The trend in catches of L. miodon in relation with the air temperature and water level in Lake Kivu

A look on Fig. **8: A,C** allows to observe that, the monthly CPUE of *L. miodon* decreased in average at about 35 kg in the interval of 12 years (2001-2012) and low catches were obtained during the period 2003-2005. Predictions of 2025 further show a decline in CPUE of 2.92 kg for a decrease of about 0.01 m in water level of the lake, in contrast to an increase of about 0.02 °C of the average air temperature for each year at Gisenyi station, Fig. **8: A,C**. Therefore, analysis shows strong and statistically correlation ($r^2 = 0.9645$, $p < 0.001$) between CPUE and catches of *L. miodon*, Fig. **8B**.

Moreover, high CPUE of *L. miodon* were obtained during the rainy season compared to the dry season in Lake Kivu (Fig. **8D**), with the peak of fisheries yield obtained in November and December; the first representing the rainiest month around the lake. Whereas, the lowest fisheries yield was obtained in June and July, which are generally dry season months around the lake.

The above results indicate a decrease in *L. miodon* catches during 2001-2012 at Gisenyi station, positively in relation with water level decrease in Lake Kivu during the same period.

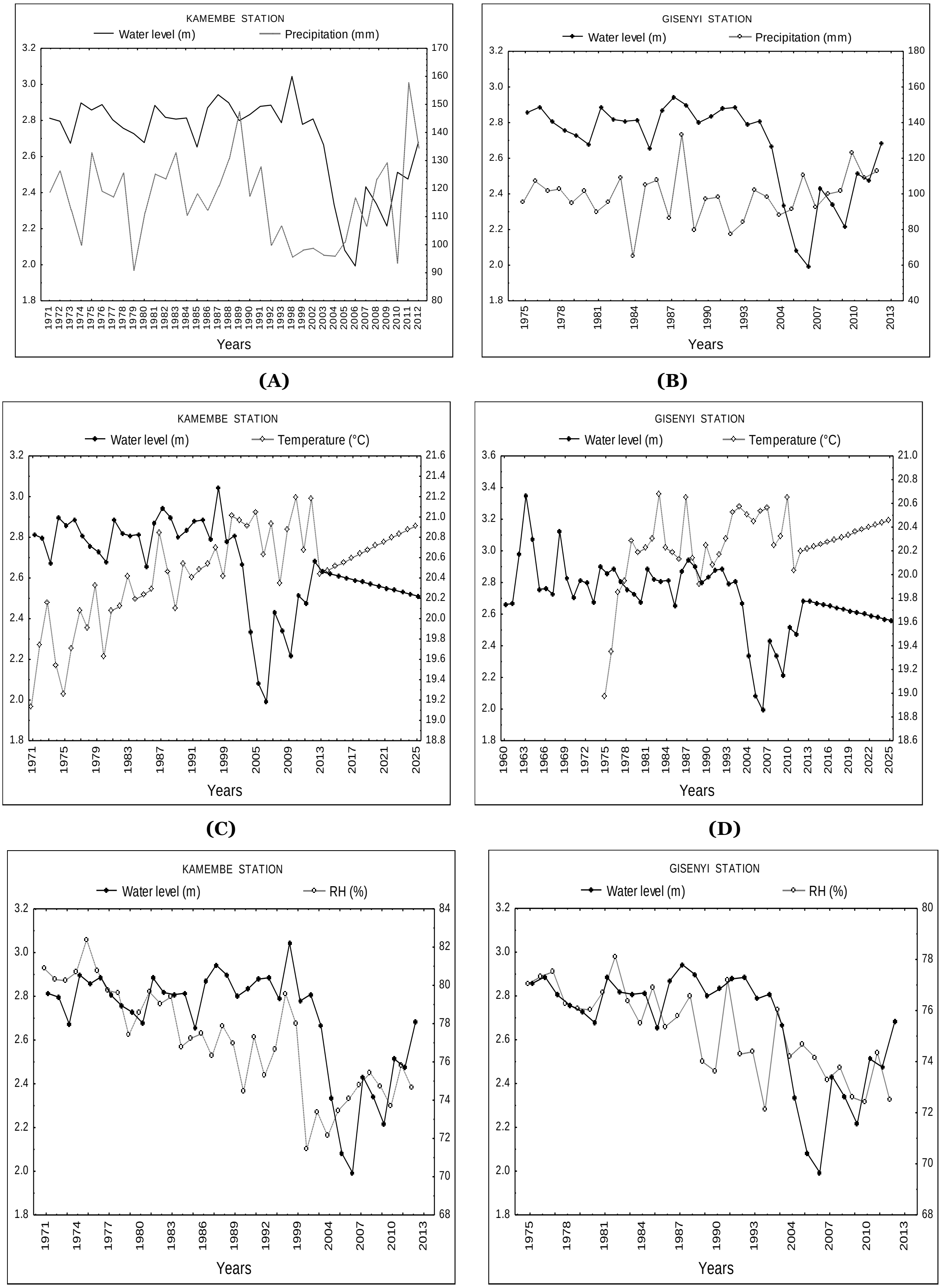


Fig. 7. Lake Kivu water levels variations in relation with the variations of the average monthly rainfall **(A,B)**, variations of the average temperature **(C,D)** and the variations of relative humidity **(E,F)** during the periods 1971-2012 and 1960-2025 at Gisenyi and Kamembe stations.

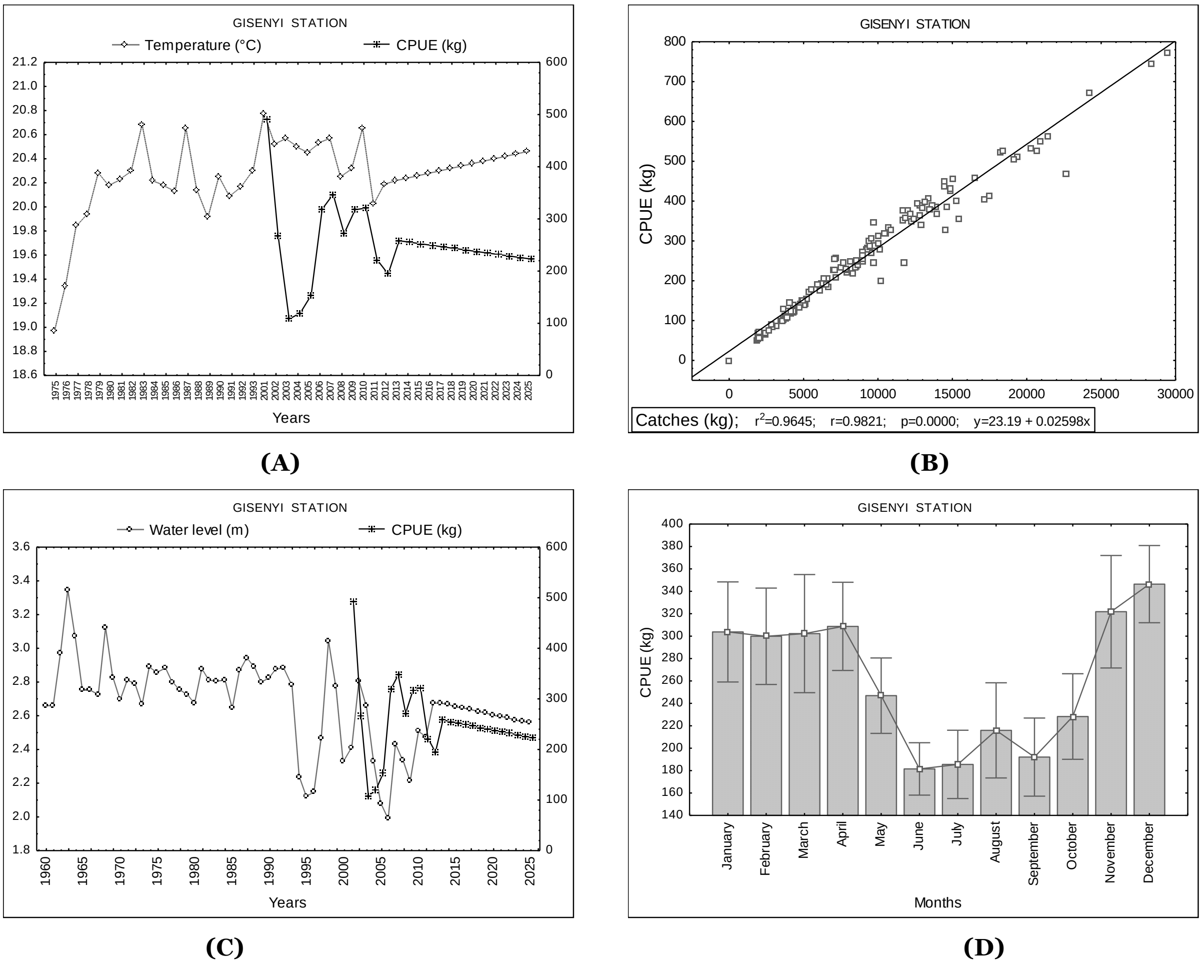


Fig. 8. Variations of the CPUE according to the average temperature **(A)** and the lake water levels **(C)**, also according to the catches **(B)** and the months **(D)** for the species *L. miodon* in Lake Kivu, Gisenyi station (2001-2012).

Discussion

Variation of rainfall, air temperature, relative humidity and wind speed around Lake Kivu

The results detected important rainfall fluctuations within each station between different years. These patterns corroborate with those of Muhigwa (2010) who reported qualitative and quantitative rainfalls disturbances in North and South Kivu provinces (the same areas). However, low rainfall recorded during 1998-2004 at Kamembe could be considered as a result of the large deforestation from which suffered Lake Kivu watershed following the 1994 influx of Rwandan refugees in eastern of the Democratic Republic of Congo (Biswas & Tortajada-Quiroz, 1996).

From 1975 to 2013 at Gisenyi station, the strong fluctuations of the rhythm of rainfall were attributed to April and August months. Accordingly, Muhigwa (2010) found out the trend of increment in rainfall in August, whereas rainfall tended to decrease in April, May and September, over the last decade around Lake Kivu watershed.

The results revealed significant increase of annual and monthly average temperatures around Lake Kivu watershed. The increased temperature in this region have been acknowledged in previous other studies; for example, the comparison of data recorded since 1960s by Plisnier (1997) revealed an increment of 0.7°C in the average temperature in Bujumbura between1964 and 1994, and 0.9 °C in Mbala (Zambia) between 1956 and 1994, around Lake Tanganyika watershed. Therefore, significant decrease of relative humidity of 7% and 4.5% was observed at Kamembe and Gisenyi stations, respectively. The above pattern shows clearly that, the decrease of relative humidity could result from the increase in air temperature observed in the same region (Sheeba & Alka, 2011).

The present results showed that, the average wind speed decreased about 4.5m/s within 36 years at Kamembe. In Lake Kivu, the availability of nutrients and dissolved oxygen necessary for fish and other aquatic organisms to colonize aerobic waters to depths of 60-70 m, comes from the movement of mixing between deep waters and those of surface, which movements are induced by the action of wind, more active during the dry season (Natacha *et al.,* 2010). Thus, the decrease of wind speed would affect the movement of waters mixing of Lake Kivu.

The decrease of the average wind speed of 1.1 m/s during the period 1964-1979 and that of 1 m/s during the period 1986-1990 was observed by Ntakimazi (2006) in Burundi around Lake Tanganyika watershed. According to Plisnier (2004), the decrease in average wind speed could result from the combined effect of high air temperature and the presence of heavy cloud cover. The author stated that when the temperature increases, there is an increment of evaporation rate that results in the increment of the cloud cover, which in turn impedes the wind speed. Cloud cover could reduce the temperature differences between day and night by reducing the daytime warming and nocturnal cooling with effect of reducing temperature differences in the air masses above the lake and those above the land; it is indeed this temperature difference that determines the speed of the local winds (Ntakimazi, 2006).

Around Lake Kivu, the weather is such that the months of March, April, October and November are the wettest, while those of June, July and August are less humid. It's confirm Thomas (1949) and Vandenplas (1943) results which defined May as a wet month and January, March, April, September, October, November and December as the very wets. In addition, they identified June, July and August as the dry months in Bukavu during the period 1937-1949. This is not verified with our results to the month of August which currently tends to be rather wet around the lake. Strong fluctuations in rainfall in August at Gisenyi station during the period 1975-2013, confirm that situation.

Variations of water level of Lake Kivu in relation with rainfall, air temperature, relative humidity and Ruzizi River flow

The linear adjustment showed a significant decrease ($p < 0.05$) of about 0.6 m in the water level of Lake Kivu during 53 years (1960-2012). The lowest levels were of 2.1 m and 2 m, in 1995 and 2006, respectively, while the maximum level of an average value of 3.35 m was attributed to 1963. Disturbances in climatic factors, especially rainfall and relative humidity could better explain those water levels fluctuations; given coincidences observed between periods of changes in the water level and these two climate parameters in the last decades. Ntabagira & Bizimungu (2006), Kulimushi (2010) and Habiyaremye *et al.* (2011) agree with decreasing as a general trend in water levels of Lake Kivu and suppose that disturbance of the seasons in the region could be the main cause. The significant air temperature increase around Lake Kivu could in addition contribute to the water levels decreases through the evapotranspiration.

In the Lake Tanganyika, from 1993 to 1997, annual increases and decreases in water levels were 87 cm and 80 cm, respectively. Increases are positively correlated with precipitation in the watershed, while decreases are essentially in relation with the evaporation and didn't vary much from one year to another (Verburg *et al.*, 1997).

Positive correlations were observed between fluctuations of water level of Lake Kivu and the Ruzizi River water flow, justified by the fact of this river remain the only outlet of Lake Kivu.

Trend of catches of L. miodon in relation with rainfall, air temperature, relative humidity and water levels in Lake Kivu

On the Lake Kivu, Gisenyi station, CPUE decreased significantly during the period 2005-2006, the period following high values of air temperature, low rainfall, low water levels and low values of relative humidity. The previous decrease of catches occurred in 1995-1996, period before of fluctuations of parameters listed above, could better find its explanation in the fishing pressure at different fisheries sites. Additional confirmation of the effect of climatic disturbances on decreasing catches of *L. miodon* arises from results of the monthly variations of CPUE during the 12 years of study. It's shown higher CPUE during the rainy months compared to the dry ones. The decrease of CPUE of September compared to August could be explained by the recent trend, already mentioned; September which gradually reduces its rainfall in contrast with August which knows an opposite trend.

In 1994, Kaningini designated the great rainy season (December) as the reproduction period of *L. miodon* in the Lake Kivu; early in December, the somatic-gonad ratio index and the condition factor *K* were at their maximum values. The same author pointed out a maximum CPUE in November.

The fish *L. miodon* reproducing in coastal areas, rain remains an important trigger of its reproduction because of its influence on availing nutrients and large areas of spawning.

Periodicals and inter-annual fluctuations in the horizontal extension of Lake Tanganyika, enlarge (or reduce) littoral zone, with impacts on aquatic organisms including fish which many species prefer shallow areas to feed and reproduce (Ntakimazi, 2006). Plisnier (1997) reported a decrease of CPUE in Lake Tanganyika since 1970, as in the south of the lake (Zambia) for sardines, to the north (Burundi) for *Lates,* and supposed that the decrease of the lake productivity could be the main factor.

At the Lake Chad, frequent fluctuations observed in fisheries catches in 2011 were attributed to the disruptions of rainfall and the fishing pressure on the resources (De Young *et al.*, 2012).

The total biomass of *L. miodon* was estimated about 4398 tons in 1989-1991 in the Lake Kivu (Lamboeuf, 1991). Eighteen years later (2008), Guillard *et al.* (2012) estimated 5520 tons and supposed stable the stock of *L. miodon* for these two decades in Lake Kivu. This consideration didn't agree with our results, which, despite of fluctuations, show decrease of CPUE for the 12 years of study. With the fluctuations observed in the evolution of *L. miodon* catches in Lake Kivu, continuous observations could be appropriate to estimate the evolution of the stock over a relatively long period (FAO, 2012).

Conclusions and recommendations

The qualitative and quantitative disturbances of rainfall, increase of air temperature, decreases of relative humidity, wind speed and Lake Kivu water level, show the effectiveness of climate change around Lake Kivu.

The decrease of Catch per Unit of Effort in the fisheries of *L. miodon*, fish of commercial interest on the lake, as well as its positive relation with the water levels decrease, and negative relation with air temperature increase; point out a high probability that the fish stock is affected in Lake Kivu.

Thus, regular reforestation campaigns in the region, supported by the extraction and use of methane gas for energetic needs, can help to reduce the effects of climate change on this lake, especially on its fisheries resources.

In addition, the governments of the countries bordering the lake should place among the priority questions, the actions for fighting and adaptation to climate change effects by adopting common policies through sub-regional structures provided for this purpose for sustainable management of shared resources of Lake Kivu.

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