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Research Article

Recent trend analysis of hydro-climatic data in the upper and Niger Inland Delta of the Niger River basin (West Africa)

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Abstract

The fresh water resources of the West Africa stressed due to the increasing population. The climate change has also affected the water resource availability due to the occurrence of recurrent and uneven extreme events such as drought and flood. In the context of Niger river basin, Niger Inland Delta (NID) water resource availability is a concern for water management over the basin. In this study, we evaluate the recent hydro-climatic trends in the upper basin and Niger inland delta of the Niger River basin in order to assess the potential climate change. Trend of Niger inland delta pan-evaporation were also analysed. An overall decrease of precipitation (1950-2010) and runoff (1950-2010) and an increase of temperature (1980-2010) and pan-evaporation (1970-2009) were observed (1950-2010); however, when a long study period is considered, all the trends are not statistically significant. In the same way, when IPCC standard period (1981-2010) is considered; all the climatic data show a significantly increasing trend in the NID except the evaporation whose trend is not significantly decreasing over the area. In this period, Significant decreasing trends are found for mean annual discharge at a 0.05 significance level. Therefore, it cannot be concluded that the climate has changed in the Niger basin with regards to trend analysis. But, it should be noted that the water resource availability will decrease in the NID if the current trend in the hydro-climatic data remains. Moreover, a spatial analysis shows that, the increase in precipitation is higher in the western part of the NID compared to eastern and inland part of the wetland. However, the results presented here shows a general idea about the water resource conditions in time and space, and should be taken as a basic skill for water resource management instead of models in order to reduce uncertainties.

Keywords: *Niger inland delta, hydro-climatic data, trend analysis, climate change, water resources availability*

1. Introduction

Studies of regional and global climatic changes and variabilities and their impacts on the water resources have received considerable attention in recent years. Intergovernmental Panel on Climate Change (IPCC) revealed that, the historical climate record for Africa shows warming of approximately 0.7°C over most of the continent during the 20th century, and a decrease in rainfall over large portions of the Sahel (IPCC, 2007). The surface water resources of the major river basins of West Africa in general and in particular the Sahel region show very sensitive inter-annual fluctuations due to climate changes facing this vast region for over thirty years (Le Lay *et al*., 2007; Lebel & Ali, 2009). The identification and characterization of the variability of water resources in order to better guide the mitigation approaches of potential impacts have generated much more interest among the scientific world.

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Water resource management is a major issue in Niger Inland Delta (Mariko 2003; Zwarts *et al*., 2005). The past and current trend of the Hydro-climatic data is of very high importance for a more sustainable evaluation and characterization of the past and present status of water resource (Descroix *et al*., 2009). Therefore, the hydro-climatic data can be the major source of information for the analysis of the water resource availability. In arid and semi-arid areas of West Africa rainfall is a concern for both people and the scientific world; with its important role in the successful development of the agriculture, irrigation, water supply, reservoir operation and hydro-power generation. These latter, are strongly penalized by declining resources (Mariko *et al*., 2013). Therefore, to improve understanding about the water budget for developing strategies on water resources management over the Niger River Basin (NBR); identification of the temporal and spatial patterns of rainfall that influence the hydrological processes is a must (Oguntunde and Abiodun, 2012) . To know the recent status of water resources downstream the NID in the future and to develop water balance model for satisfying hydrological functioning; understanding the spatial assessment of rainfall volume upstream is a key factor. Assessment of the overall quality of the climate information from the available data particularly precipitation trend analysis showing the degree of temporal and spatial variability which is key tools impacting on a number of concerns such as population growth, economy, society, environment and water resources (Hiernaux *et al*., 2009; Frappart *et al*., 2009; Mahe *et al*., 2013).

In this study the potential temporal and spatial trends of hydro-climatic data are considered for the upper and middle basins of the Niger river. Using the available meteorological data and the statistical methods, the major components of the water resource namely, temperature, evapotranspiration and the precipitation are analyzed.

To assess the overall quality of the climate information it is necessary to analyze trends in the hydro-climatic data. So, statistical approach is proposed to investigate consistency in the recent trends on climate with observations of hydro-climatic variables. Furthermore, the main discharge stations on the Niger basin are used to assess the runoff trend. This allows an assessment of the overall quality of the climate information from the available data in the Niger River Basin. This study focuses on the hydro-climatology of the Upper Niger River and The Niger Inland Delta (NID). The Upper Niger is defined as the Niger basin up to and not including the NID.

2. Review of the previous studies on the sahelian hydro-climatic variability

Many studies related to rainfall time series fluctuations were done across West Africa that include the NID or different parts in NRB; and show a noticeable decline trend from the 70 particularly in the Sahel region (Descroix *et al*., 2009; Druyan, 2011; Hubert P., Carbonnel, 1987; Le Barbé & Lebel, 1997; Li, Coe, & Ramankutty, 2005; Mahe *et al*., 2001; Sharon E. Nicholson & Palao, 1993; Sharon E. Nicholson, 2000; Sircoulon, 1987). The study done by Oguntunde *et al*. (2012) has included the whole NRB but the study was related to climate change. They used the climate models to assess the potential change of different climatic feature within NRB using meteorological data. The average seasonal temperature of NRB was studied using data from 6-hourly sea surface temperature data for present-day and future; and the temperature changes were plotted (Oguntunde & Abiodun, 2012). Generally, the mean baseline and future mean surface temperatures for this region show increases over a 20-year period.

New approaches to improve the estimate of one-time parameters at different time steps (decadal, yearly, etc.) were tested (Le Barbé & Lebel, 1997; T. Lebel *et al*., 1996; Taupin, Amani, & Lebel, 1998) to improve visualization of rainfall variability in the Sahel. Similarly in the past, some authors have studied the evolution of rainfall in the Sahel (L'Hôte, Mahé, Somé, & Triboulet, 2002; J. E. Paturel *et al*., 1997; J.-E. Paturel *et al*., 2003; Servat *et al*., 1997). According to their results, since the beginning of the century, four periods of droughts 1907-1916, 1940-1949, 1968-1974 and 1980-1984 affected the Sahelian zone with transboundary rigorousness (Sircoulon, 1976). Among which it has been noticed some dramatic drought's years like the 1973-1974 and 1983-1984 ones; for their considerable extension beyond the Sahel and their persistence over several years.

Many authors have studied the rainfall variability in the Sahel which has strongly affected the discharge evolutions over the past decades in West Africa (WA) (L'Hôte *et al*., 2002; J.-E. Paturel *et al*., 2003). However, after the wet periods 1950s and 1960s, and the strong rainfall deficit since 1970; some studies have highlighted that the rainy seasons are becoming wetter and wetter in some parts of WA (Thierry Lebel & Ali, 2009; Ozer, Erpicum, Demaree, & Vandiepenbeeck, 2003). Therefore, it is important to assess this affirmation from those authors in the NID's local condition. Recently, Descroix *et al*., (2015), based on the variation of rainfall, pointed out a strong fluctuations in river discharge with a generally decreased trend from 1960 to 2010. While (Mahe *et al*., 2013) emphasized on the nonlinear effect of the negative rainfall variation over WA resulting in a decrease runoff.

Therefore, this study seeks to analyze the recent spatiotemporal change of annual rainfall in the Niger river basin in general and the NID in particular during 1981 - 2010; including analysis of discharge trends by using Man-Kendall test as non-parametric approach and a simple linear regression method, known as a parametric approach. Also a nonlinear trend analysis was performed by means of polynomial regression method. In order to have good understanding of the hydro-climatic change, analyses are not only based on rainfall and runoff time series but include temperature and, evaporation.

3. Materials and Methods

3.1. Study Area

The Niger River Basin (NRB) is a transnational catchment shared by ten riparian countries: Algeria, Benin, Burkina Faso, Cameroon, Chad, Guinea, Ivory Coast, Mali, Niger and Nigeria. NRB lies between latitudes 5°N and 24°N and longitudes 17°E to 12°W and covers a huge area of land of the order of 2.27 million km^2. The source of the Niger is located close to the Fouta Djallon Mountains in the South of Guinea at an altitude about 800 m. With a length of 4,200 km, NRB is the third longest river in Africa after the Nile and the Congo River. The watershed is 8.5% in Algeria, 2.0% in Benin, 3.4% in Burkina Faso, 3.9% in Cameroun, 0.9% in Chad, 4.3% in Guinea, 1.0% in Ivory Coast, 25.5% in Mali, 24.8% in Niger, and 25.7% in Nigeria.

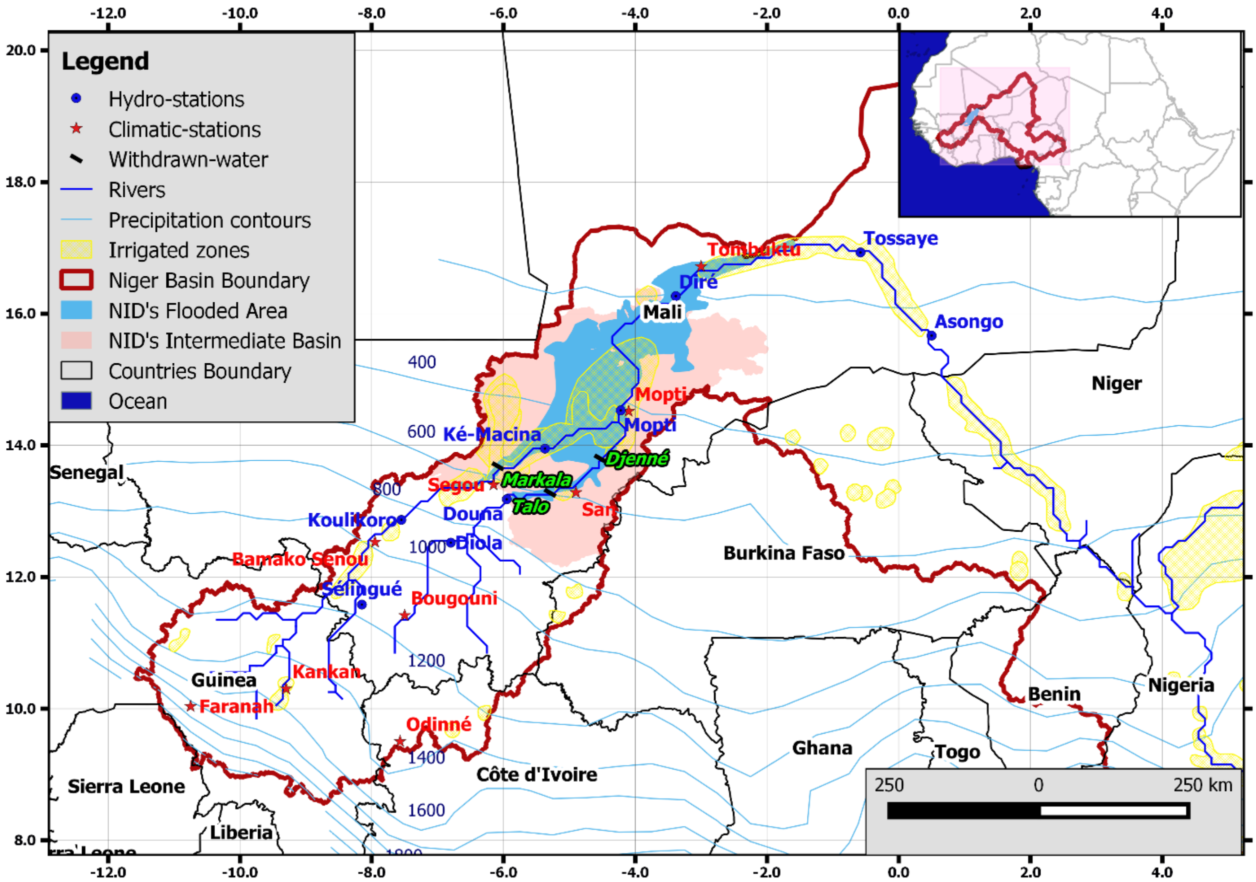


Fig.1: Location Map of the study area

The coverage of the Niger basin is shown in Figure 1. The Niger Inland Delta (NID) has a maximum submerged area of 73000 km^2 (Mahe *et al.*, 2009) and is one of the most important wetland in Mali. Major tributaries to the NID include the Niger river, and the Bani river (both rivers flow from Guinea and Ivory Coast respectively). Average annual river flows in the Niger Basin, observations since 1907, at the inlet monitoring station of delta (Koulikoro, Mali) has been as high as 2308 m^3/s (1925)and as low as 637 m^3/s (1989) (Zwarts *et al.*, 2005). A large part of the water is lost in the NID due to evaporation and seepage. Temperatures vary between approximately 10°C and 45°C depending on season, time of day, and elevation. Highest rainfall levels occur in the south west and can be as high as 2000 mm/year, where levels in the north-eastern regions can be as low as 250 mm/year. Throughout the region, main land cover types include savanna, grassland, rain forest, water bodies, shrubs and croplands (Oguntunde, *et al.*, 2012).

3.2. Data source and quality control

The data used in this study include climate, hydrological, and topographical data. To analysis the long-term hydroclimatic trends in the NRB the following available hydro-meteorological datasets were used. Daily precipitation and temperature data (1950 - 2010) from 5 National Meteorological Observatory (NMO) stations were provided by the countries National Meteorology Agency and the AGHRYMET regional Centre of Niamey. The monthly and annual precipitation & temperature used in this study were compiled from the 5 rain gauge stations, whose records started from 1950s, 1960s, and 1980s and ended in 2006 & 2010 (each station having a 30-year long record at least). The location of the stations in the basin is shown in Figure 1, and their longitudes latitudes are listed in Table 1. In addition, the daily streamflow data (Table 2) of the NRB used in this study, was sourced from the Bureau of Niger Authority Basin (NBA) of the Niger river.

Besides, to view the long-term climatic trends in the NID the historical available remote sensing precipitation: Modern-Era Retrospective Analysis for Research and Applications (MERRA), MERRA precipitation with the observation-based Global Precipitation Climatology Project (GPCP) pentad product 1-degree daily data set were used. The data cells that cover the study area were sorted out from the daily climate data of the world. The range of the spatial coverage was taken between 10°W to 10°E and 5°N to ~20°N. The annual aver-age and the average of the cells were calculated for year 1996 to 2013.

Table 1: List of the stations and available climate data

No.	Station name	Latitude (°decimal)	Longitude (°decimal)	Country	Climatic Data	Range
1	Faranah	10.03	-10.75	Guinea	Precipitation	1950-2006
					Temperature	-
2	Kankan	10.30	-9.30	Guinea	Precipitation	1950-2006
					Temperature	-
3	Sikasso	11.35	-5.68	Mali	Precipitation	1950-2010
					Temperature	-
4	Bamako-Senou	12.53	-7.95	Mali	Precipitation	1950-2010
					Temperature	1980-2010
5	Bougouni	11.42	-7.50	Mali	Precipitation	1950-2010
					Temperature	1980-2010
6	Segou	13.40	-6.15	Mali	Precipitation	1950-2010
					Temperature	1980-2010
7	Mopti	14.52	-4.10	Mali	Precipitation	1950-2009
					Temperature	1980-2010
					Pan ET	1970-2009
8	Tombuktu	16.72	-3.00	Mali	Precipitation	1950-2010
					Temperature	-
9	San	13.28	-4.90	Mali	Precipitation	1950-2010
					Temperature	-

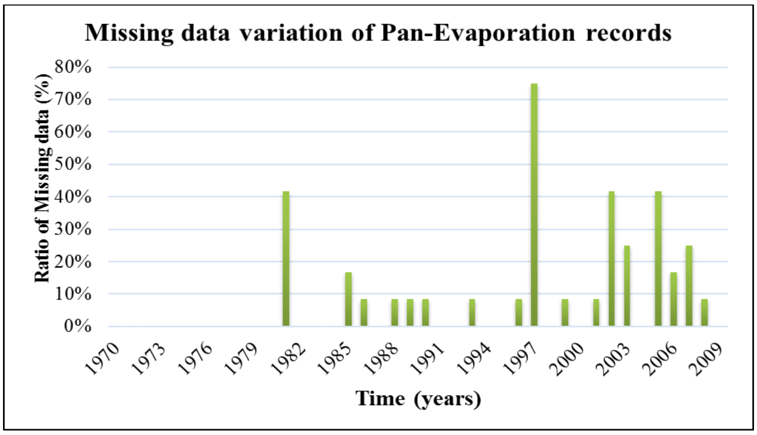


Figure 2: Gap ratios in monthly Pan evaporation records at Mopti (1970-2009)

Table 2: Hydrometric stations on the Niger Basin and available data

Serial No	Longitude	Latitude	River	Station Name	Observation period	Country
1	-7.56	12.86	Niger	Koulikoro	1921-2013	Mali
2	-5.39	13.96	Niger	Ké-Macina	1954-2013	Mali
3	-5.9	13.21	Bani	Douna	1923-2004	Mali
4	-3.38	16.28	Niger	Diré	1950-2013	Mali
5	-4.22	14.53	Niger	Mopti	1952-2013	Mali
6	-8.66	11.68	Niger	Banankoro	1968-2013	Niger

Data quality control was conducted for all variables since there is a lack of good climate data throughout African Sahel. For each station, rain gauges' time series have less than 10% missing data as this ratio varies from 0 to 6% for all 9 stations over the period. Also, only a few gaps were found in the other climate data records, and they do not alter the quality. For the Mopti pan evaporation records, figure 3 shows that the annual missing data ratios are significant (>10%) at the beginning of the series, and more pronounced in 1997 (75%). We have an average rate of missing data of 9% per year for the period 1970-2009. Interpolation process was used to approximately fill the gaps. Then, annual values were by summing up for a year all the monthly values.

For runoff, the data are characterized by missing data ratios of 0 to 46% over the period. Runoff analyses were done with the raw data and periods of non-negligible discharge flow found. Mean runoff of a given month is considered insignificant if it is less than 25% of the mean monthly discharge of the entire period. Time series with more than one month of missing data within the hydrological year of non-negligible discharge were omitted.

3.3. Data Analyses

3.3.1. Trend analysis for considered time series

From literature review, moving average method is not a relevant test for trend analysis. We have two types of trend: a linear and nonlinear. Classically in literature we can find the linear trend as linear regression that fits data with straight lines in selected time intervals (e.g., linear test, Mann-Kendal, etc.). Such a trend is frequently sensitive to the selected time series intervals. Therefore, based on our data, to evaluate the trend and variability of hydro-climatic elements including precipitation, temperature, Pan-evaporation and river discharge in the basin during the recent years, we employed some trend analysis methods, such as the moving-average method, non-linear regression method and Mann-Kendall method. A trend is considered to be present if it has been detected by at least 2 tests. The trend analysis tests were applied on stations for available climatic data on the upper and Niger Inland Delta regions. Using Thiessen polygon method, mean annual catchment temperature and precipitation were calculated for the upper Niger and NID for the year 1950 - 2006 and 1950 - 2010 respectively, from the stations where data was available (Table 1). Stations that do not have data of temperature during the period of collection were not considered (Table 1).

3.3.2. Breakpoints analyses of runoff

Another approach was to assess change points. The breakpoint analysis in the annual maximal discharge using Cross-Entropy method (Priyadarshana and Sofronov, 2014) embedded in the R-software. The Cross-Entropy method seems the most appropriate techniques providing multiple breaks and offering the possibility for the user to choose the number of breaks desired; as compared to other widely used statistical methods such as the non-parametric Pettitt test (Pettitt, 1979), and Hubert's Segmentation (Hubert, 1989). Also, this method is more suitable to the context of high inter-annual rainfall and runoff variability in West Africa.

3.3.3. Precipitation spatial analysis

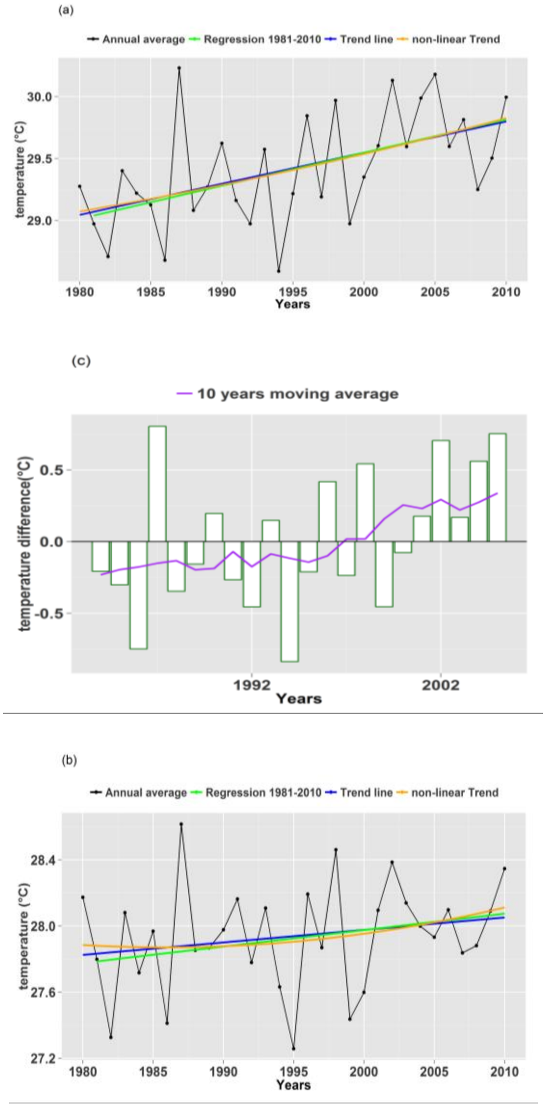
In this study, we use the interpolated technique, explicitly, Ordinary Kriging (OK) to spatial analysis of annual precipitation trends in the basin. The OK is a stochastic model that incorporate autocorrelation, referring to the statistical connections among the measured sites in order to provide estimates for accuracy in predictions (Ali, Lebel, and Amani, 2005). Furthermore, the performance technique of the OK is better; compared to other interpolation techniques such as Inverse Distance Weighted (IDW) and Spline interpolation (Fathian & Aliyari, 2016).

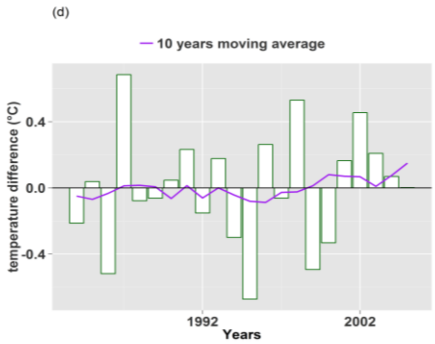
4. Results

4.1. Climatic and hydrologic data trend

4.1.1. Temperature

The meteorological station data shows a general increasing trend of the temperature in the Niger basin. The increase is not significant for the period of the IPCC standard period (1981-2010). On the other hand, the trend seen over the NID and at upstream NID for the study period of 1980 to 2010, the rise is slightly less and not statistically significant as compared to IPCC standard period (Fig. 3 (a) & (b)). The average temperature for IPCC standard period for the upper and inside the NID is respectively 27.9°C & 29.4°C. However, the 10 years moving average over the NID shows that the temperature decreased by 0.2°C by the year 1990 and increased by 0.3°C up to 2005. While, the 10 years moving average at NID's upstream shows that the temperature decreased by 0.1°C by the year 1994 and increased by 0.1°C at 2007 (Fig. 3 (c) & (d)). Then, the temperature showed an increasing trend by 0.5°C by the year 2010 with reference to the average temperature at IPCC standard period (Fig. 3 (c)).



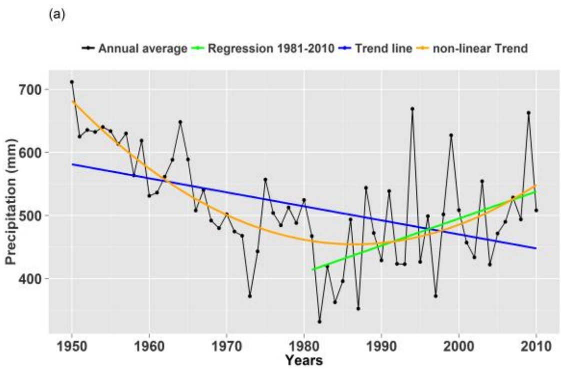


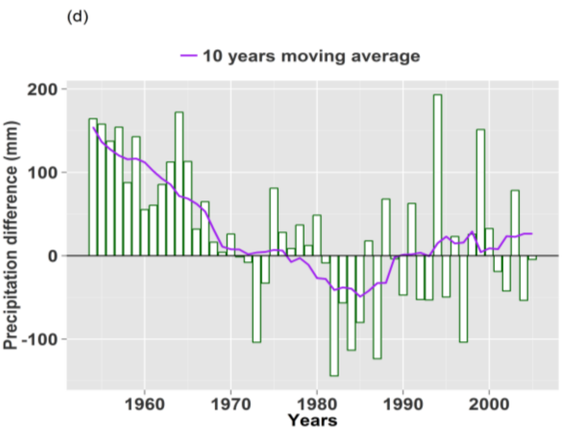
(a) annual average temperature trend of the meteorological stations (Segou & Mopti) data over the NID, b. annual average temperature trend of the meteorological stations (Bougouni & Bamako Senou) data at upper the NID, (c) Annual average temperature trend over the NID minus the mean IPCC standard period average temperature for meteorological stations data, (d) Annual average temperature trend upstream the NID minus the mean IPCC standard period average temperature for meteorological stations data

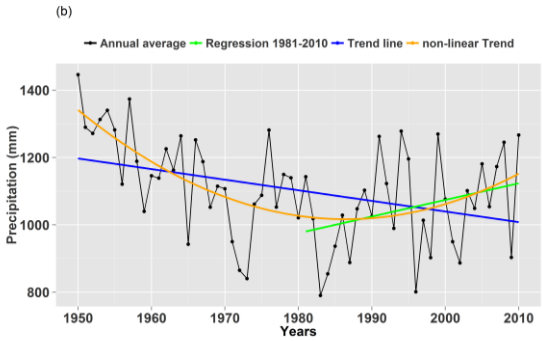
Fig. 3: The average temperature trend

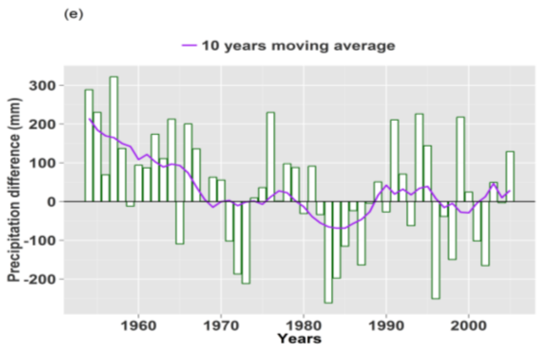
4.1.2. Precipitation

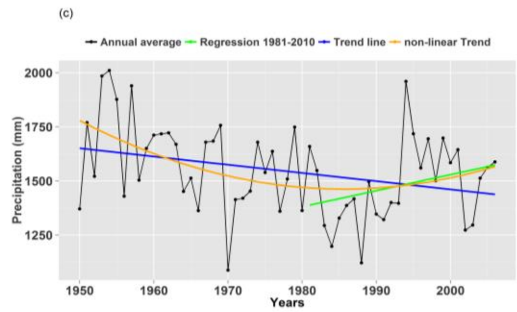
In case of precipitation, the trend is opposite to the temperature. For the period of 1950 2010, it is decreasing. In contrast, during the IPCC standard period it is increasing and is statistically significant. The average precipitation over the NID, Mali-upstream NID, and Guinea-upstream NID, for the IPCC standard period according to the meteorological stations records is 475, 1051, and 1481 mm/year respectively (Fig. 4 (a)).

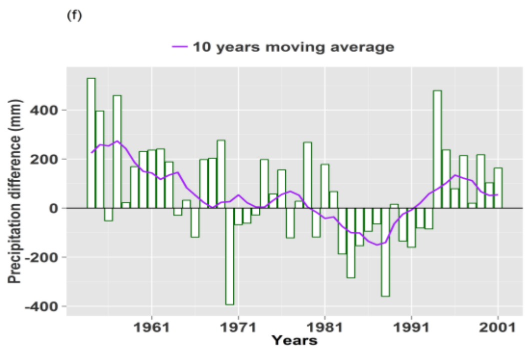












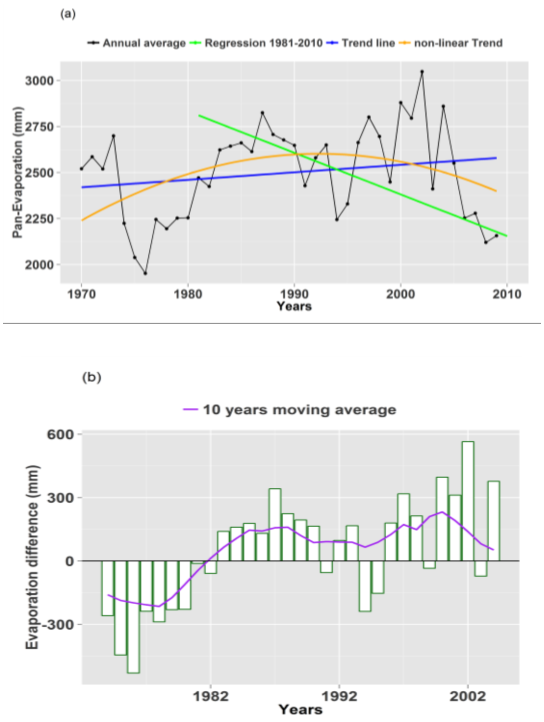
(a) annual average precipitation trend of the meteorological stations (Segou, San, Mopti & TombuKtu) data over the NID, (b) annual average precipitation trend of the meteorological stations (Sikasso, Bougouni & Bamako Senou) data at upper the NID in Mali, (c) annual average precipitation trend of the meteorological stations (Kankan & Faranah) data at upper the Niger Basin in Guinea, (d) Annual average precipitation trend over the NID minus the mean IPCC standard period average precipitation for meteorological stations data, (e) Annual average precipitation trend at Mali upstream the NID minus the mean IPCC standard period average precipitation for meteorological stations data, (f) Annual average precipitation trend at Guinea upstream the NID minus the mean IPCC standard period average precipitation for meteorological stations data

Fig.4: The average precipitation trend

The 10 years moving average for the period of 1950-2010 show a decreasing trend of precipitation in the NID wetland. The precipitation was lowest from 1981 to 1985. The precipitation decreased by 125mm compared to the average precipitation at IPCC standard period. If the 10 years moving average is considered there is a slight increase not significant in the precipitation over the NID in the year 1990 to 2010 whereas, there is a decreasing trend in the periods 1950-1970 (Fig. 4 (d)).

4.1.3 Evaporation trend

The Mopti pan evaporation data show a slightly increasing trend in the NID. The evapotranspiration is increasing at the rate of 5 mm per year and the trend is not statistically significant. However, the decrease is at higher rate and not statistically significant at the IPCC standard period (Fig. 5 (a)). The average Mopti evaporation is approximately 2500 mm/year considering the study period 1970-2009; and The average evapotranspiration is 2485 mm/year if IPCC standard period is only considered. Similarly, the 10 years moving average of evapotranspiration has slightly increasing trend for 10 mm per year considering the period of 1981-2009 (Fig. 5 (b)).

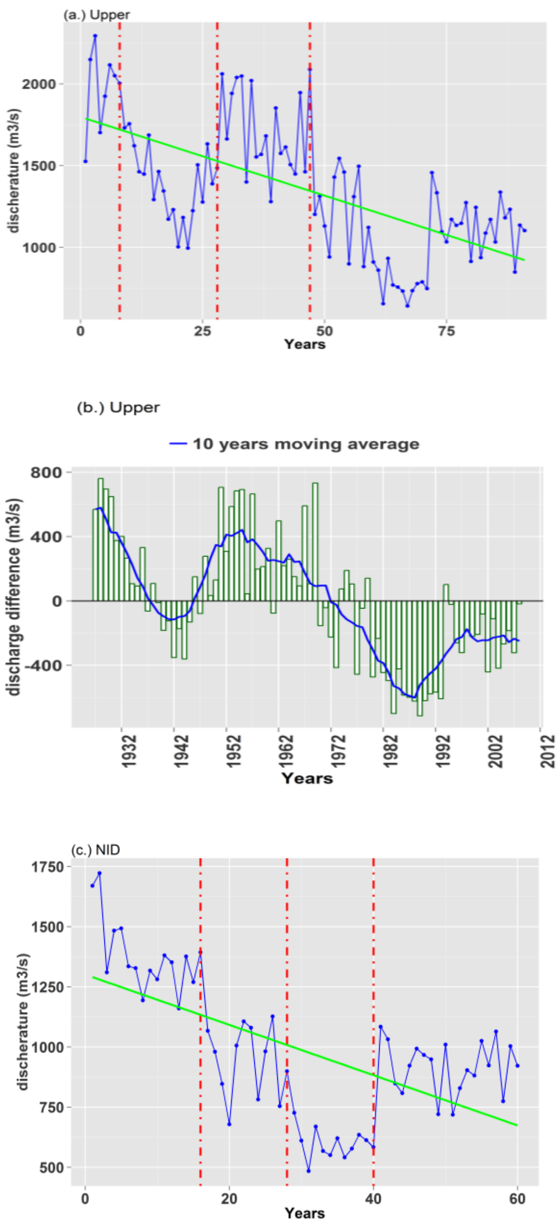


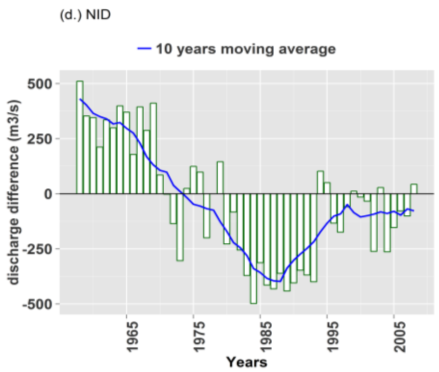
(a) annual average evaporation trend of the Mopti pan recorded data over the NID, (b) Annual average evaporation trend over the NID minus the mean IPCC standard period average evaporation for Mopti Pan Evaporation data records.

Fig. 5: The average evaporation trend

4.1.3. Streamflow trend

These results were plotted in Fig. 6. It observes that: (1) For the upper basin a wet period (1920-1930; 1945-1970) and a dry (1971-2010) period are clearly seen which have a mean annual discharge of 700 m³/s (450 m³/s) higher (lower) and (2) for the NID a mean annual discharge of 450 m³/s higher (350 m³/s) higher (lower) than the long-term mean, respectively. This variation in the discharge shows the idea of how dry or wet the part of Niger Basin are in the upstream of NID and the wetland. The discharge runoff is higher in the upper basin at the Niger basin part of Mali (for e.g. Koulikoro); whereas, the streamflow values are lower in the NID cathment at the outlet of the delta. The changepoints (breaks red dotted lines) plot for runoff timeseries (Fig. 6 (a.) & (c.) shows that there are 3 distinct changes of the specific runoff with regards test statistic for the analysis of the data. The linear fit (Fig. 6 (a.) & (c)) shows that the flow discharge decreases with the increase in area but it is not statistically significant. Furthermore, the streamflow varies according to moving average plot rather than the trend line.



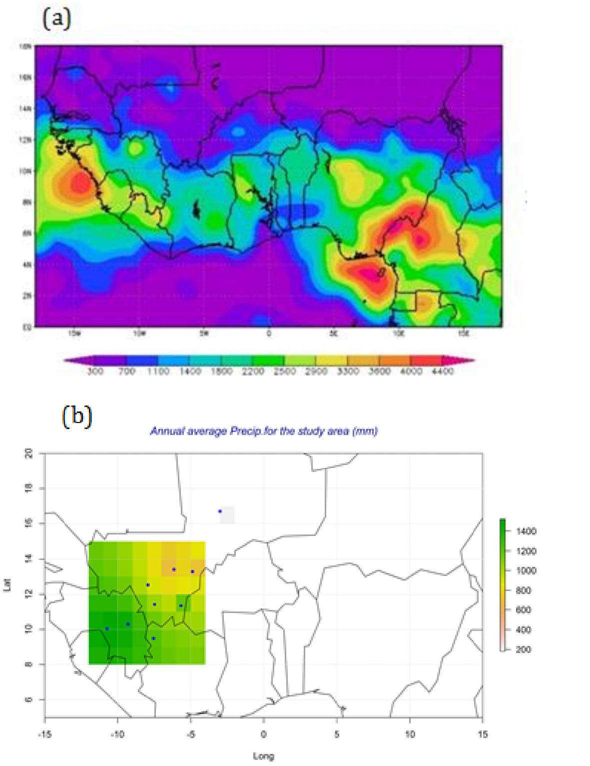


(a.) annual average streamflow of the upper gage stations of Mali with green line = trend line and red dotted lines= changepoints for the timeseries; (b.) Annual average discharge difference trend minus the long term mean period of discharge data over the upper stations of Mali; (c.) annual average streamflow of gage stations inside the NID of Mali with green line = trend line and red dotted lines= changepoints for the timeseries; (d.) Annual average discharge difference trend minus the long term mean period of discharge data over the NID stations of Mali

Fig. 6: The average discharge trend

4.2 Spatial analysis

The GCPC data which is the average calculated from 1996 - 2013 shows that the precipitation varies from 200 to 1400mm/year in the study region (Fig. 7 (a.)). The statistical analysis for the region shows that the mean precipitation is 773mm. The precipitation value is alike to the satellite climate data (Fig. 7 (b.)).



(a.) Long term annual average precipitation for GCPC dataset of study area stations of; (b.) the OK spatial variation of the of the recorded data of gage stations within the basin

Fig.7: The spatial distribution of precipitation

In this study, we use the interpolated technique, explicitly, Ordinary Kriging (OK) to spatial analysis of annual precipitation trends in the basin. In this section, the interpolated trend results are shown in Figure 8 using the method at significance levels between minimum and maximum range of Mann-Kendall statistics.

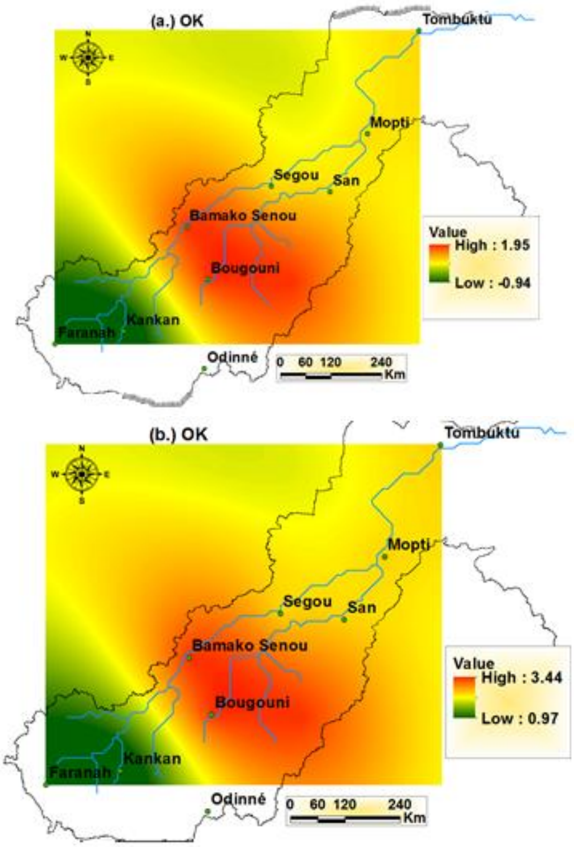


Fig. 8: Spatial distribution of the statistics Z of the Mann–Kendall test for the annual rainfall (a.) Period 1950-2010 (b.) Period 1981 - 2010

5. Discussion

5.1. Hydro-climatic data trend analysis

To study the variation of historical annual and seasonal precipitation, temperature, evaporation, and discharge, the mean annual and seasonal values for the entire study period (1950 – 2010, and 1980 -2010) and for each the IPCC period (1981 - 2010) are assessed and compared. During these periods, the climate variables in the region as regards the temperature and precipitation, show variation similar for the upper region and the NID wetland zone. The general trend of the temperature is increasing and the precipitation shows decrease in line with the previous studies in West Africa (Paturel *et al.*, 1997; Servat *et al.*, 1997; Paturel *et al.*, 2003; L'Hôte *et al.*, 2002). The period (1981-2010) is slightly warmer than the long-term average. The results demonstrate that the seasonal variations of the 10 years moving values are much larger than those of mean annual differences, especially for temperature. The climatic trend in NID's floodplain is in line with this fact (Fig. 3 & Fig. 4). The temperature and precipitation are increasing in the IPCC standard analysis (from 1981-2010). The precipitation trend is not in line with these facts for the overall study period of 1950-2010; however, the trend is not statistically significant. Henceforward, in summary the long term trend analysis demonstrate that the temperature and precipitation has increasing and decreasing trend respectively in the study area. Although it should also be noted that the current trend (after 1990s) of the precipitation is increasing but it is not statistically significant. Subsequently, the increasing trend might be linked randomly to that of the temperature for some decades.

According to many studies (Descroix *et al*., 2009; Druyan, 2011; Hubert P., Carbonnel, 1987; Le Barbé & Lebel, 1997; Li *et al*., 2005; Mahe *et al*., 2001; Sharon E. Nicholson, 2000; Sharon E. Nicholson & Palao, 1993; Sircoulon, 1987) there was a decline in rainfall from the 70 in the Sahel region. In similarity, to this study, the lowest rainfall occurred within that period (331 mm/year in 1982 for NID, 840 mm/year in 1984 for upper NID in Mali, and 1087 mm/year in 1970) and showed likely return period of some 15 to 20 years (Fig. 4 (d), Fig. 4(e), and Fig.4 (f)).

The effect of increasing temperature and decreasing precipitation can be seen over the evaporation trend of the NID. In general, an increasing trend of the evaporation is seen in the NID (Fig. 5 (a) & Fig. 5 (b)). However, the trend is decreasing and not statistically significant considering the period 1981-2009 (Fig. 5 (a)). This result can be justified with the overall decreasing trend of precipitation. Nevertheless, the evaporation is increasing with temperature for the study period, the decrease in the precipitation decreases the discharge runoff. The observed streamflow based analyses shows decrease of river runoff in their long-term average for the study region. Therefore, the decreasing trend in the discharge runoff may be a major problem in the water resource management.

For each considered region (either upper or the NID), the years of break marked in dotted red lines as the significant breakpoints. For the whole area, the application of the changepoint method resulted in approximately 1972 and 1992 as the most significant breakpoints (1st break and 2nd break respectively). The year of 1st break reveals the period of significant low flow mainly observed in the West African rivers (Descroix *et al*., 2009) during the drought of the 1980s. As regards to the 2nd break (1992), it almost in line with the rising of the nonlinear trend line in rainfall data (1990).

The above discussion shows that when entering the 1970s there is a very dry period in the Niger basin. More essentially, this decrease in streamflow will have a direct impact on the very sustainability of the ecosystem's services in the NID. Though, some authors (Ozer *et al*., 2003; Pedinotti *et al*., 2012; Descroix *et al*., 2015) suggested a return of a wetted period meanwhile the 1990s. If this situation does not change in this 21st century it will have positive impact for water availability in the Niger basin region.

The trend analysis illustrates that the long term trend is not statistically significant as compared to IPCC standard period trend. This result suggests that hydro-climatic data trend is decreasing except temperature and evaporation trend. Yet, it might not be concluded that the climate has changed in the study region, because all variables are not statistically significant for the same study period. In addition, the trend analysis also shows the importance of considering the region in three features (upper Guinea, Upper Mali, and NID) of the catchment and two parts of the study period. The schematic representation of the hydro-climatic data shows that, with regards to the length of the study period, the trends look to be significant or else not significant. The decrease or increase seems to be regular for a certain period whereas, it appears to be affected by some random variation of the extreme values within the study period when range of the analysis period is changed. This fact is in accordance with Druyan, (2011) who stated that, no clear trend for either decreasing or increasing precipitation from global climate model (GCM) products. With such context, while, it could not be assumed that the climate has not changed in the Niger Basin whereas looking at the trends of the climatic data, it must be noted that there will be decrease in the water resource availability in the future if the trends in the hydro-climatic data remains. With this regards, the water resource management should be done considering the plausible decrease of the water resource availability in the Niger basin.

5.2. Spatial interpolation of precipitation

The spatial analysis of precipitation data shows different variation of change in annual rainfall. Decreasing change in mean annual rainfall is not significant for the period 1950 - 2010. For the IPCC standard (recent years 1981-2010), the increasing change in mean annual rainfall is seen to positively significant. This fact is in line with the study by Oyebande and Odunuga, (2010) that for the past 4 decades, 10 to 30% drop in mean annual rainfall was observed in the region. This decrease can be related to changes in the sea surface temperature afterward 1960s (Lebel and Ali, 2009). For the period 1981-2010, the maximum positive significant change is observed in the regions showing lower yearly rainfall (Fig. 8 (b.)). Therefore, the precipitation excess for the period 1981-2010 is increased compared to overall trend values in the basin. The potential evapotranspiration is high in the Niger Inland Delta area; this variation can be justified by the variation of the temperature and precipitation. In this context, a special focus is required to the NID zones because they are the zones with high water use. This has pointed out that evapotranspiration is most important factor compared to the precipitation.

The dominant trend in precipitation is clearly positive in southern and northern NID, while there is an apparent negative trend in western part of NID. The interpolated maps exhibit that negative trends are few and located in the west region of NID's wetland and upper region of the basin in Guinea (Fig. 8 (a.)).

Conclusion

Hydroclimatic data trend analysis is found to be with high importance for the study region. The assessment of the water resource availability from past and the probable future condition is a paramount tool for management of the water resource. For the evaluation of the water resource condition, the hydroclimatic data trend can be a reliable skill. This fact made the statistical approach of the hydroclimatic data trend to be widely used to show whether the climate change has happened in the area or if the tendency seen is just climate variation. In this research, the hydroclimatic data trend does not exhibited a consistent trend when considered overall period of the data for the study. The trend and its statistical significance differ according to the range of the study period considered. Regarding this trend analysis, it cannot be concluded that, the climate change has occurred in the upstream and NID's wetland areas. However, considering the period 1981-2010, it would be noted that all the climatic data show an increasing trend in the NID except the evaporation whose trend is not significantly decreasing over the area. The temporal trends of stream flow discharge are the result of the combined effect of precipitation and temperature. Significant decreasing trends are found for mean annual discharge at a 0.05 significance level.
The spatial variation of the hydroclimatic data shows that the precipitation is higher at the inland part of the study region. Historical data show no trend for precipitation in considering the study period while, the trend for the 1981-2010 has positive significant trend especially for the NID areas of the Niger basin at the 0.05 significance level. Hence, results in this study from the trend analysis can provide a general idea about the water resource availability in the basin.

The key findings of the study can be summarized in following points:

- The general trend of the hydroclimatic data analysis shows a decreasing trend in the basin except for the evaporation; however, all trends are not statistically significant when considering the full study period. Hence, it cannot be concluded that climate has changed in the basin.
- The long term trend shows decreasing water resource availability in the NID.
- Spatially, the increase in precipitation is higher in the western part of the NID compared to eastern and inland part of the wetland.
- The results presented here shows a general idea about the water resource conditions in time and space, this should be taken as a basic skill for water resource management instead of models in order to reduce uncertainties.

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Conflicts of Interest

The authors declare no conflict of interest.

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