Analysis of the Long-Term Flows of the Nile River

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Abstract
This study focuses on the Nile Basin in order to determine the climate change impacts on the basin. Discharge data of 35 years (1965 to 2000) were accumulated and used in this study.

The discharge time series of the Nile River and its main tributaries; Blue Nile, White Nile and Atbara River within Sudan were analysed. The data were filtered and missing data were computed by means of statistical regression. The discharges data were analysed for each hydrologic year (June and ends in May). In order to have accurate results of the analysis, two statistical software (Spell stat, FREQ) were used. Similar results were obtained.

All time series were tested for the absence of linear trends, the stability of the mean and the stability of the variance. The change point test (often called Pettitt test) was applied to the time series to check whether there is a step trend or not. The time series was checked for the absence of step trends for the probability higher than 0.8.

The analysis of the time series of the 1stdischarge station on the Blue Nile, Eddeim, showed insignificant linear trend. An increase in the annual yield of the Blue Nile was evident. The same was found for the discharge station of the White Nile at Malakal, but with a decrease in the annual yield of the White Nile. For both stations i.e Eddeim and Malakal, each time series was found to be stable in the mean as well as in the variance. The time series analysis of the Upper Atbara River stations showed similar results to that observed for the Blue Nile. The last station in Sudan, Dongola, showed a linear insignificant decrease and the time series was also found to be stable in both, the mean and the variance.

It was thus concluded that the changes that were observed in the Nile River and its main tributaries, within the Sudan, are partly affected by the climate change phenomena. Other changes could be attributed to the upstream demand, land use changes and to the high evaporation rates, which affected the hydrological regime of the Nile basin.

Key words: Nile River, White Nile, Blue Nile, Atbara River, discharge time series, statistical analysis, climate change impacts.

1. INTRODUCTION

The climate change has great impacts on human societies and ecosystems. On the other hand, observational records and climate scenarios projections provide abundant evidence that the fresh water resources are vulnerable and have the potential to be strongly affected by the climate change phenomena.

Observed warming over several decades affected the hydrological cycle ((i.e. atmospheric water vapour content, precipitation patterns and precipitation intensity). These warming reduce snow cover and increase ice melting. This might affect the soil moisture and runoff.

All climate model simulations for the 21st century were found to be consistent in projecting precipitation (it increases in high latitudes and some parts of the tropics, and decreases in some subtropical and lower mid-latitude regions). The increase in precipitation intensity and variability are definitely projected to increase the risks of flooding and drought in many areas.

Water stored in glaciers and snow cover could decline water availability would decrease. On the other hand, high water temperatures could affect the water quality and water pollutions from sediments, nutrients, dissolved organic carbon, pesticides etc…

Globally, the negative impacts of the climate change on fresh water systems outweigh the benefits. By the 2050s, the area of land, subjected to water stress, due to the climate change, is more than double with the area with less water stress.

Changes in water quantity and quality due to the climate change are expected to affect the food availability. This leads to food scarcity and vulnerability of poor rural farmers, especially in the arid and semi-arid regions.

The climate change certainly affects the function and operation of the existing water infrastructure; hydropower, structural flood defenses, draining and irrigation systems and water management practices. The current water management practices might not be robust enough to cope with the climate change impacts on water supply reliability, flood risk, health, agriculture, energy and aquatic ecosystems.

This study was thus initiated with the objective of highlighting the effects of the climate change on the Nile River yield within Sudan, figure (1). The research also aims at determining the long-term flows trends of the Nile River and its main tributaries; the Blue Nile, the White Nile and the Atbara River.

1.1 Study Basin

The Nile is the dominant geographical feature of the Sudan. This is attributed to the fact that 70% of the country belongs to the Nile system. There are three main tributaries of the Nile River in Sudan (Blue Nile, White Nile and Atbara River). The Blue Nile and White Nile join at the capital Khartoum. The combined river is named as the Nile River which joins Atbara River at the city of Atbara (320 kilometers north of Khartoum). This branch carries 12 milliards m3 of water.

The Blue Nile is the main source of the Nile waters during the flood time (August – September) and contributes with 68% to 82% of the whole Nile water while the White Nile is the main source during the dry season.

Definitely, the Nile River and its tributaries are the main reliable water resources of the country as well as for the other Nile basin countries. Therefore, in this study the discharge time series of the main three basins (Blue Nile, White Nile and Atbara) of the Nile River as well as the Nile basin downstream Khartoum were analysed. The discharge time series of key station of each basin was analysed. These stations are as follow:

1.1.1 Eddeim on the Blue Nile

Eddeim gauge lies 102 km southeast of Roseires dam on the Ethiopian/Sudanese border. It monitors the inflows to the Roseires reservoir and it is important in controlling the operation of the reservoir. The station is considered as a very important station because the measured levels and flows at this site play a main role in determining the flood’s level at Khartoum and the stations downstream of the river. It is also considered as a flood early warning station for other gauging sites in particular when its flows reach 600-750 Mm3/day. Moreover, it is important as a valuable input to many forecasting models.

1.1.2 Malakal on the White Nile

Malakal gauge is located at the upstream end of the White Nile below the junction of the Sobat River. It monitors the total discharges of the rivers of the southern part of the Sudan. The flow at Malakal is produced by the flows in the Bahr el Jebel, el-Zeraf, el-Ghazal and by the Sobat and its tributaries. Approximately half of the White Nile water at Malakal comesw from the Sobat and half from the Bahr el Jebel.

1.1.3 Girba Dam on the Atbara River

The gauge is at Wad el Hilew on the Setit River and at Kubur on the Upper Atbara River. It monitors the inflow to Khashm el Girba reservoir. The Khashm el Girba dam is situated on Atbara River, 75 km downstream of the confluence of the Setit and Upper Atbara Rivers. It is estimated that the Upper Atbara and the Setit supply 35 and 65% of the Atbara River flow, respectively. The annual contribution of the Atbara River is estimated to be 12 milliards m3.

1.1.4 Dongola on the Main Nile

The gauge is at Dongola. It is located on the Nile River downstream of the confluence with Atbara River and thus it is the key site on the Nile River. It measures the total discharge of the Nile basin as it leaves Sudan and flows through Egypt. The flows are used to monitor the division of the Nile water between the two countries. It is operated by both countries.

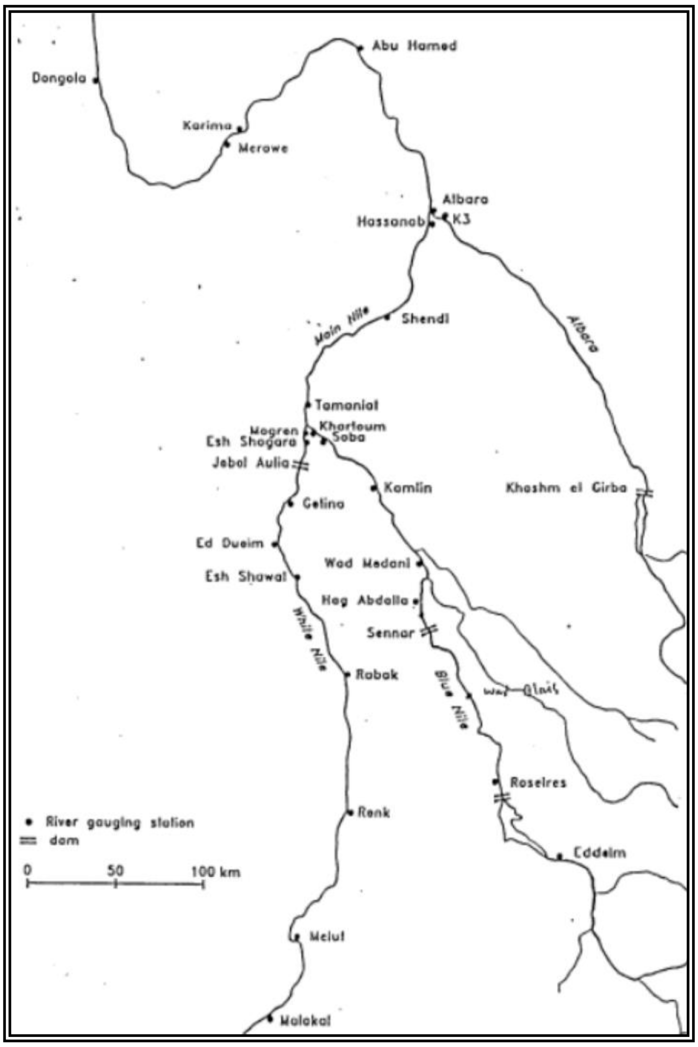

Figure 1: Sudan hydrological network and the locations of the selected gauge stations

2. STATISTICAL ANALYSIS SOFTWARE

The discharge time series of each station was analysed using two statistical software's (Spell-Satat and FREQ). The Spell-Stat is time series statistical analysis software, developed by Jorge A. GUZMAN and Ma. Librada CHU Universidad Industrial de Santander, Bucaramanga – Colombia. The Spell-Stat provides an easy way to evaluate homogeneity, consistency and independence of hydrological data. Other functions have been incorporated to make the statistical analysis of time series easier (Agore and Librada, 2005). In this study, the Spell-Stat software version 1.7.5.46 B was used.
The FREQ is a program for analysis of time series and sampling frequency developed by Y. Zhou in1992 at the UNESCO-IHE - Institute for Water Education. It was applied to verify the results that were obtained by the Spell-Stat.
The software applies the following functions to the time series under consideration:

- Change point test
- Test for absence of trend
- Test for stability of variance
- Test for stability of mean

3. DATA ANALYSIS

In this study, the hydrological records (discharges), available at the Hydraulics Research Station (HRS) of the Ministry of Irrigation & Water Resources, Sudan, was used. The records extend from year 1965 to 2000. The existing validated database was processed and analysed for the purposes of research works (Mekawi, 2005; Dahmen and Hall, 1990).

The time series analysis was carried out using the statistical software's; Spell – Stat and FREQ similar to the analyses of Bushara, 2007. The analysis included the key gauging sites on the Blue Nile, the Atbara River, the Nile River downstream Khartoum and the White Nile downstream Malakal.

4. RESULTS AND DISCUSSION

From the discharge time series of the Blue Nile, the White Nile, the Nile River and the Atbara River, the hydrological year was found to start in June and ends in May. For each station, the discharge time series was analysed using the hydrological year concept.

The annual flow volume for the period 1965-2000 at Eddeim station indicated 2 maximum values (i.e. 1988 and 1998). The two flow volumes occurrences were 64.44 and 62.30-milliard m3, respectively. The minimum at the station was 29.73-milliard m3 that occurred in 1984. The mean annual discharge was estimated to be 46-milliard m3. The statistical properties of the data and the discharge annual trend are summarized in table [1].

Figures [2] and [3] show the annual and the monthly trend flow at Eddeim station, respectively. The trends slightly increase for the period of inspection. The annual and the monthly time series were found to be stable in the mean as well as in the variance and there was no step trend in the time series using the change point test (figure 4). This change could be attributed to the climate change at the Blue Nile watershed.

From figures [3] to [14] (except the change point test figures and figure 8) the red lines indicate the trends while the green lines indicate the mean discharges of the time series under consideration. In the change point test figures (4, 7, 11 and 14), the green line indicates the probability of 0.8, while the dashed line is the data probability. If the probability of the data is higher than 0.8, the time series is checked for the absence of step trend at that point. The x-axes in the change point test figures indicated the sequence of the data for the period of analysis. The analysed period for each station is shown in table [1]. From the change point test figures for Eddeim, Malakal, Girba dam and Dongola station, the probability was higher than 0.8 for some years. However, all the stations were found to be stable in the mean and in the variance for the tests carried out for the stability of the mean (t-test) and for the stability of the variance (F-test).

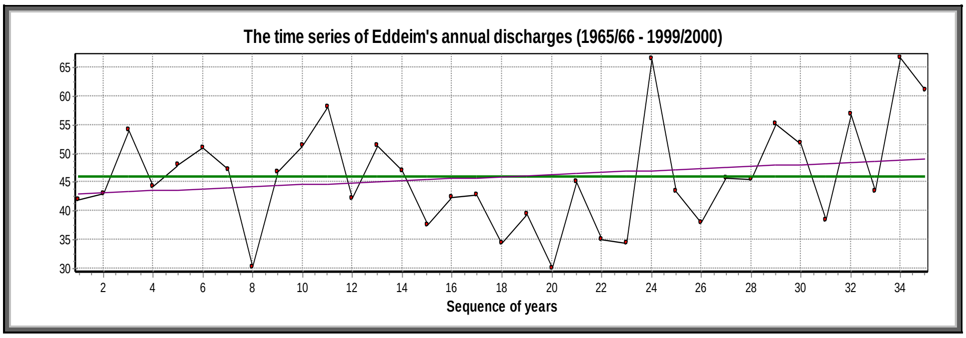

Figure2: Annual discharge time series at Eddeim gauge (1965/66 – 1999/00)

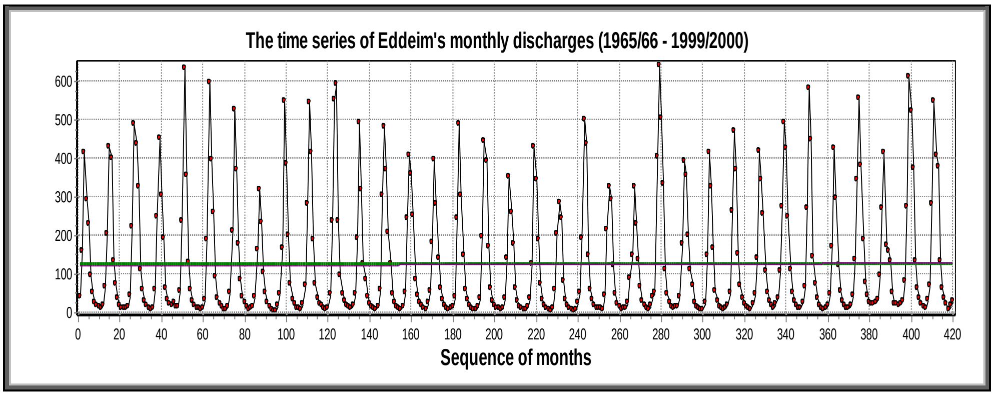

Figure 3: Monthly discharge time series at Eddeim gauge (1965/66 – 1999/00)

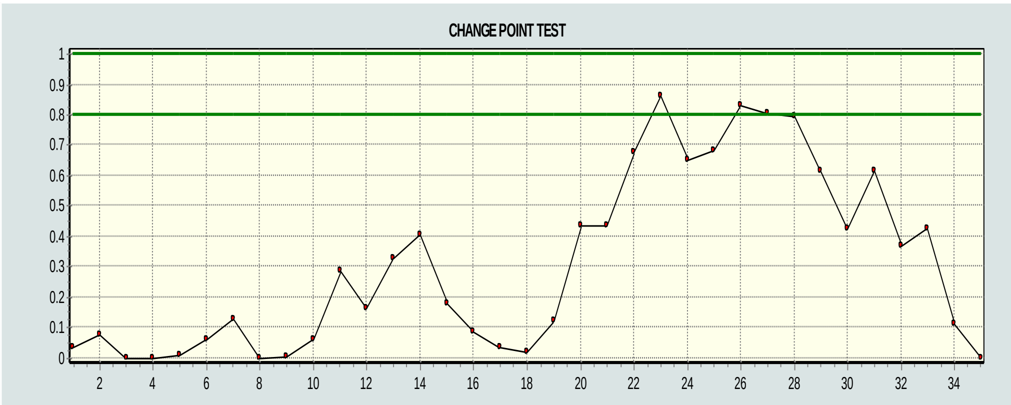

Figure 4: Change point test for the annual flow at Eddeim

Throughout the investigated period, the annual flow volume of the White Nile at Malakal station had two maximum values (i.e. 1965 and 1966) due to the high levels of the Equatorial lakes (1961-1964). The two flow volumes were 47.43 and 38.94-milliard m3, respectively. The minimum value was 25.36 milliard m3 in 1986. The mean annual flow volume at the station was estimated to be around 31.65-milliard m3. The decreasing trend is influenced by the water level of Victoria Lake. The statistical properties of the data and the discharge annual trend are summarized in table [1].

Figures [5] and [6] illustrate the annual and monthly trend flows of Malakal station. The annual and monthly time series were found to be stable in the mean and in the variance, and there was no step trend in the time series that carried out using change point test (figure7).

Figure [8] shows the cumulative distribution functions of the Blue Nile at Eddeim and the White Nile at Malakal.. The discharge cumulative distribution functions are useful when new projects have to be implemented in the considered watershed in order to cope with the climate change phenomena.

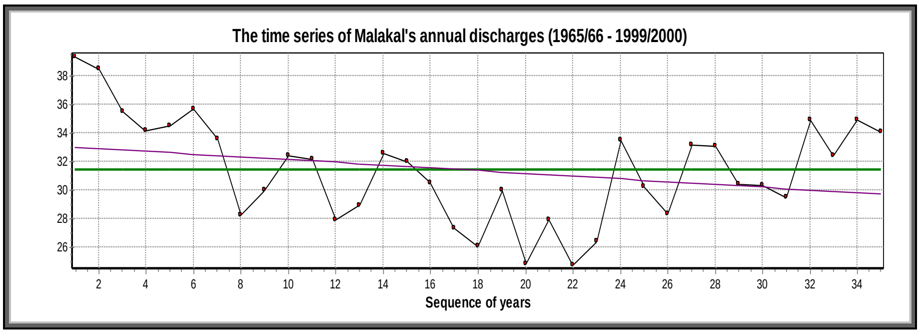

Figure 5: Annual discharge time series at Malakal gauge 19(65/66 –1999/00)

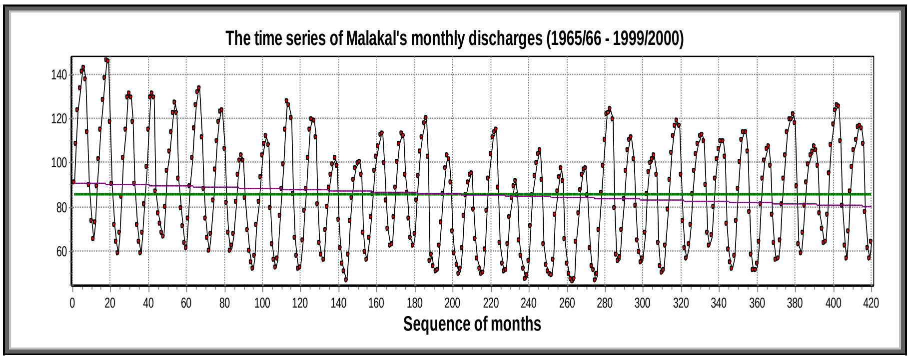

Figure 6: Monthly discharge time series at Malakal gauge 19(65/66 –1999/00)

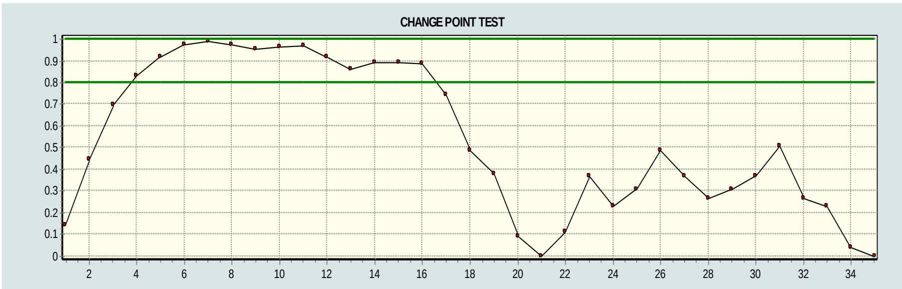

Figure 7: Change point test for annual flow at Malakal station

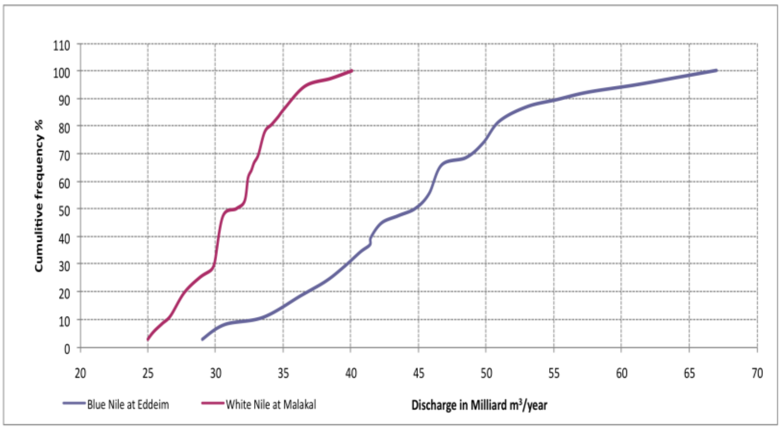

Figure 8: Cumulative distribution functions for Eddeim and Malakal stations

In this paper, the flow time series of Wadi el Hilew and Kubur stations are not presented although their analysis showed similar behavior to the Girba Dam time series.

Figures [9] and [10] show a clear increase in the annual flows as well as in the monthly mean discharges of Khashm el Girba station for the period 1986-2000. The annual and the monthly time series were found to be stable in the mean as well as in the variance, and there was no step trend in the time series that carried out using Pettitt test (figure 11). The statistical properties of the data and the discharge annual trend are summarized in table [1]

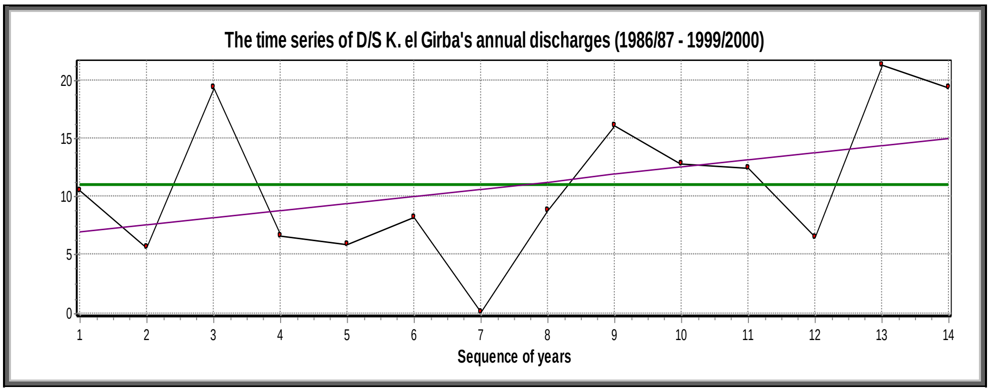

Figure 9: Annual discharge time series at D/S K. el Girba (1986/87 –1999/00)

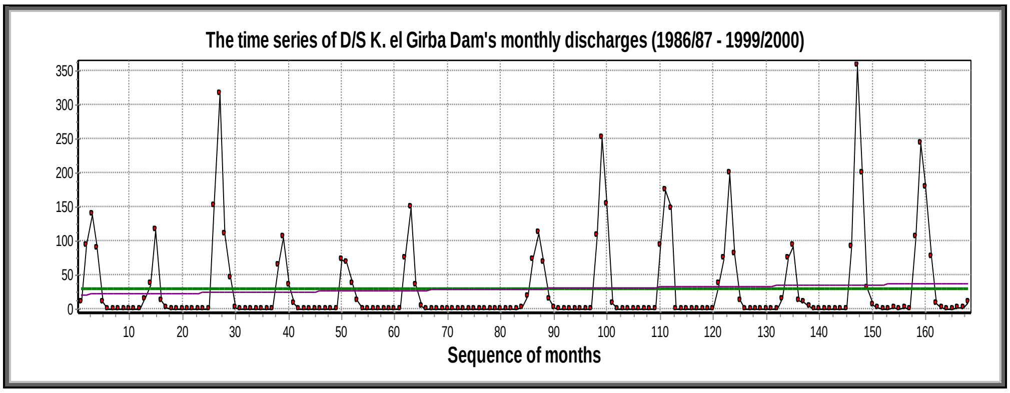

Figure 10: Monthly discharge time series at D/S K. el Girba (1986/87 –1999/00)

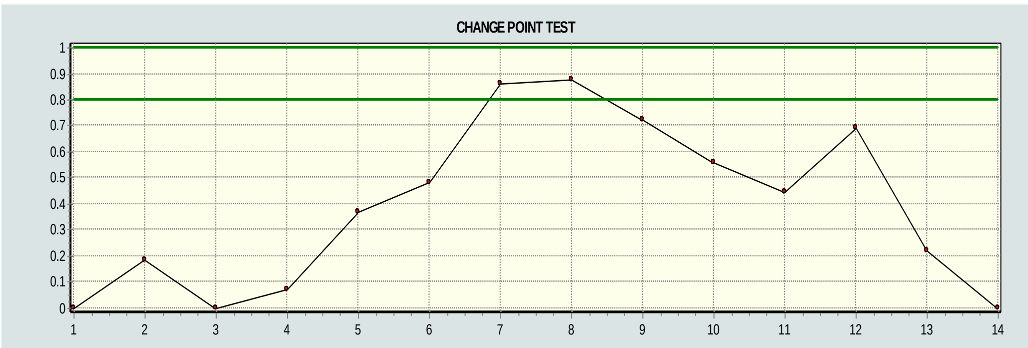

Figure 11: Change point test for the annual flow at Girba Dam station

Figures [12] and [13] represent the trend of the annual and the monthly flow of Dongola station, respectively. They are almost stable throughout the period of the investigation and no linear or step trends were observed. The annual monthly time series was found to be stable in the mean and in the variance, and there was no step trend in the time series that was carried out using Pettitt test (figure14). The statistical properties of the data and the discharge annual trend are summarized in table [1].

The decrease in the discharge that was observed in the long-term time series of the White Nile measured at Malakal is most probably due to the water levels decrease of the Victoria Lake.

As the temperature rises as a consequence of the climate change, more water evaporates from the evaporating surfaces, and more evaporation is expected to occur from Victoria Lake causing a decrease in the water levels in it. The evaporated water from Victoria Lake is then driven to the high land plateau of Ethiopia, where the incoming warm water vapour front cools down and falls as precipitation on the Blue Nile basin increasing the Blue Nile discharge. In order to investigate the decreasing trend of the White Nile discharge, this study could be linked directly to the water levels of Victoria Lake.

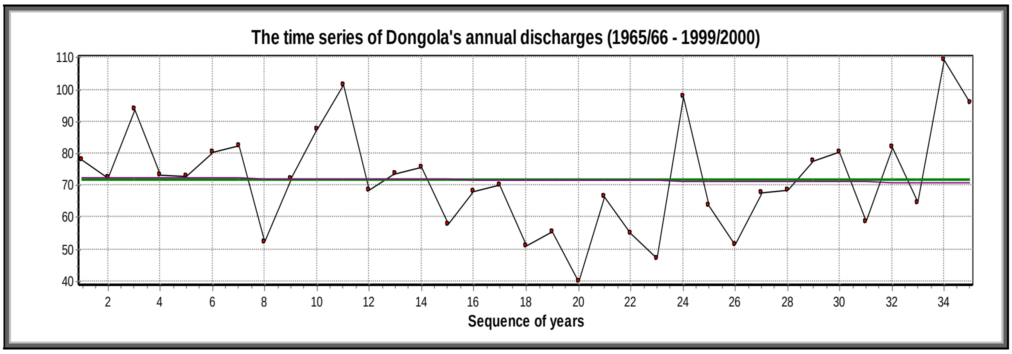

Figure 12: Annual discharge time series at Dongola gauge (1965/66 –1999/00)

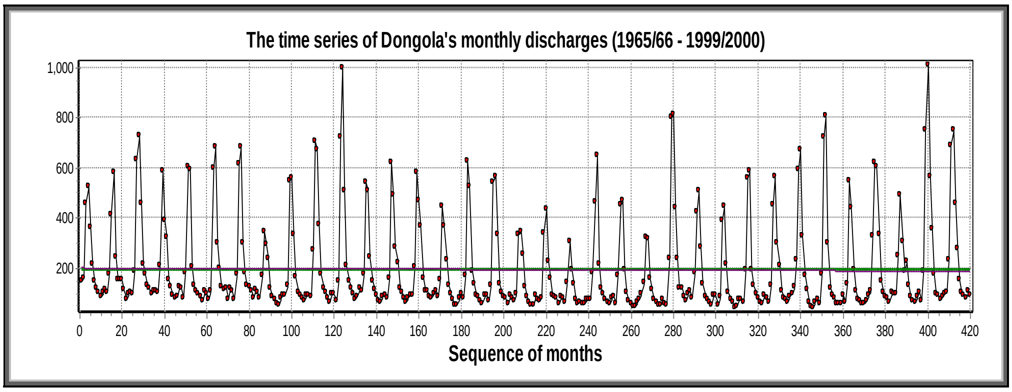

Figure 13: Monthly discharge time series at Dongola gauge (1965/66 –1999/00)

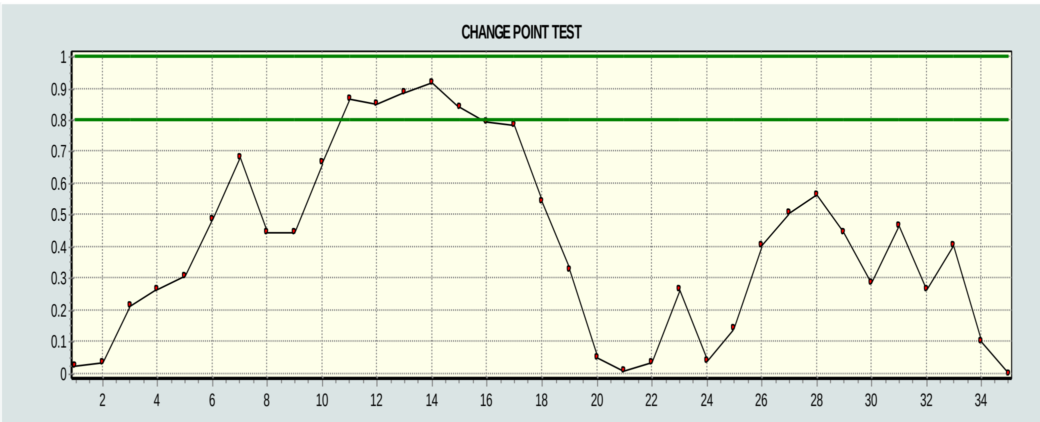

Figure 14: Change point test for the annual flow at Dongola station

Table 1: Summary of statistical tests for discharge time series

Station	Period of analysis	Mean - milliard m3/year	Variance	Coefficient of variation	Skewness	Kurtosis	Annual discharge linear trend equation
EDDEIM	1965-2000	45.9763	84.2445	0.1996	0.46	0.0453	$y = 42.955 + 0.1777x$
MALAKAL	1965-2000	31.3734	12.9891	0.1149	0.0816	-0.3313	$y = 33.03 - 0.09743x$
GIRBA DAM	1986-2000	10.9843	38.6052	0.5657	0.2346	-0.7012	$y = 6.983 + 0.61565x$
DONGOLA	1965-2000	71.7557	256.5752	0.2232	0.3121	-0.0742	$y = 72.622 - 0.05094x$

5. CONCLUSION AND RECOMMENDATIONS

For the period of the investigation (1965-2000), the analysed time series of both annual and monthly discharges indicated a linear increase of the measured discharge at Eddeim gauge. The increase could be attributed to an increase of precipitation at the upper Blue Nile and to the land use change.

It is worth to mention that the carried out analysis for the stations on the Upper Atbara River as well as for the Girba dam site revealed an increase linear trend of the discharge for the period of investigation. The obtained results are in agreement with those observed for the Blue Nile flow regime.

On the other hand, the analysed time series of both annual and monthly discharges showed a linear decrease of the measured discharge at Malakal station on the White Nile. This could be attributed to the climate change.

The decrease in the observed discharge in the long-term time series of the White Nile at Malakal is most probably due to the water levels decrease of Victoria Lake. As the temperature rises more water evaporates and more evaporation are expected to occur from Victoria Lake. This resulted in a decrease in water levels of the lake thus causing a reduction in the White Nile flows. The evaporated water from Victoria Lake is driven to the high land plateau of Ethiopia. The incoming warm water vapour cools and falls as precipitation on the Blue Nile basin thus, increasing its discharge. Furthering order to investigate the decreasing trend of the discharge of the White Nile, this study could be directly linked to the water levels of Victoria Lake. Similarly, the increase in the discharge of the Blue Nile as well as Atbara River could be linked to the precipitations in the Ethiopian plateau and to the land use changes in Ethiopia.

In this study the long-term discharge cumulative distribution functions (cdfs) for the White Nile as well as for the Blue Nile were determined. The cdfs are very useful when new projects are planned to be implemented as the discharges change to cope with the climate change.

The annual and the monthly mean discharge time series of the Nile River measured at Dongola indicated a slight decrease in the discharge during the analysed period. For all the time series, the analysed stations were found to be stable in the mean and in the variance. It was also noticed that there were no step trends in the time series. The time series are therefore suitable for any future analyses. It should be noted that for all the considered stations, the obtained results of the annual flows as well the monthly mean discharges are similar with systematic sequences.

The analyses showed that as the discharge was accurately measured, it is thus recommended to update the discharge rating curves frequently.

6. REFERENCES

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