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Hydro-climatic trends in the Abay/Upper Blue Nile basin, Ethiopia

S. Tekleab [a,b,c,d,*], Y. Mohamed [a,d,e], S. Uhlenbrook [a,d]

[a] UNESCO-IHE Institute for Water Education, P.O. Box 3015, 2601 DA Delft, The Netherlands
[b] Addis Ababa University, Institute for Environment, Water and Development, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia
[c] Hawassa University, Department of Irrigation and Water Resources Engineering, P.O. Box 5, Hawassa, Ethiopia
[d] Delft University of Technology, Faculty of Civil Engineering and Applied Geosciences, Water Resources Section, Stevinweg 1, P.O. Box 5048, 2600 GA Delft, The Netherlands
[e] Hydraulic Research Center, P.O. Box 318, Wad Medani, Sudan

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ABSTRACT

Trends of the three hydro-meteorological variables precipitation, temperature and stream flow, represented by 13, 12, and 9 gauging stations, respectively, within the Abay/Upper Blue Nile basin have been studied to support water management in the region. The Trends were evaluated over different time periods depending on data availability at the stations. The statistical Mann–Kendall and Pettitt tests have been used to assess trends and change points respectively. The tests have been applied to mean annual, monthly, seasonal, 1- and 7-days annual minimum and maximum values for streamflow, while mean annual, monthly and seasonal timescales were applied to meteorological variables. The results are heterogeneous and depict statistically significant increasing/decreasing trends. Besides, it showed significant abrupt change of point upward/downward shift for streamflow and temperature time series. However, precipitation time series did not show any statistically significant trends in mean annual and seasonal scales across the examined stations.

Increasing trends in temperature at different weather stations for the mean annual, rainy, dry and small rainy seasons are apparent. The mean temperature at Bahir Dar – typical station in the Lake Tana sub basin, has been increasing at the rate of about 0.5 °C/decade, 0.3 °C/decade in rainy season (June–September), 0.6 °C/decade in small rainy season (March–May), and 0.6 °C/decade in dry season (October–February). Other stations in the Abay/Upper Blue Nile show comparable results. Overall it is found that trends and change point times varied considerably across the stations and catchment to catchment. Identified significant trends can help to make better planning decisions for water management. However, the cause attributes to the observed changes in hydro-meteorological variables need further research. In particular the combined effects of land use/land cover change and climate variability on streamflow of Abay/Blue Nile basin and its tributaries needs to be understood better.

1. Introduction

In recent years significant progress has been made to study trends and variability of hydro-climate variables in different parts of the world. For example Hu et al. (2011) studied streamflow trends and climate linkages in the source region of the yellow river, China over the period 1959–2008. Their study concluded that the decrease in precipitation in wet season along with an increase in temperature causes the decrease in water availability for the down stream water user. Masih et al. (2010) studied streamflow trends and climate linkages in the Zagros Mountains, Iran over the period 1961–2001 and pointed out that most of the streamflow trends could be attribute to the change in precipitation. Love et al. (2010) showed that the rainfall and discharge from the northern part of Limpopo basin Zimbabwe depict declining trend.

Abdul Aziz and Burn (2006) studied trends and variability in hydrological regime of Mackenzie River basin North Canada over different time period. Their study indicated that increasing flows for the winter season and the temperature data exhibit increasing trend in winter and spring seasons. Though, the precipitation data exhibit less well defined trend. Birsan et al. (2005) analyzed 48 catchments in Switzerland over the period 1931–2000. They reported that strong relationship between streamflow trends and catchment characteristic suggests that mountain basin is most vulnerable environment from the point of view of climate change.

Assessment of long term variability of the transboundary Abay/Upper Blue Nile flow and patterns of hydro-climatic variables is crucial for sustainable water resources management and peace in the region (Kim et al., 2008). A number of hydrological studies have

* Corresponding author at: Hawassa University, Department of Irrigation and Water Resources Engineering, P.O. Box 5, Hawassa, Ethiopia. Tel.: +251 916829063; fax: +251 46 220 51 87.
E-mail addresses: siraktekleab@yahoo.com, sofoniaslove@gmail.com (S. Tekleab).

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been conducted in the Abay/Upper Blue Nile to investigate basin water balance (e.g. Johnson and Curtis, 1994; Conway, 1997; Kebede et al., 2006; Mishra and Hata, 2006; Tekleab et al., 2011). A recent research addressed hydrological and runoff generation processes, e.g. Kim and Kaluarachchi (2008), Setegne et al. (2008), Wale et al. (2009), Rientjes et al. (2011a), Setegne et al. (2010a,b), Uhlenbrook et al. (2010). Soil erosion and sedimentation studies were reported in Setegne et al. (2010a), Easton et al. (2010), and Betrie et al. (2011). The literature showed many publications on land use/cover change studies by Zeleke and Hurni (2001), Hurni et al. (2005), Bewket and Sterk (2005), Teferi et al. (2010), and Rientjes et al. (2011a,b). Few climate change impact studies were conducted by e.g. Kim et al. (2008), Abdo et al. (2009), Elshamy et al. (2009) and Di Baldassarre et al. (2011).

Even with this good number of researches on various hydrological and environmental issues in the Abay/Upper Blue Nile basin, very little work has been done to investigate long term trends of hydro-meteorological variables at catchment level. Conway and Hulme (1993) studied fluctuation in precipitation and runoff in Nile sub-basins and their impacts on Nile main discharges using historical data (1945–1984). They pointed out that higher inter-annual variability of runoff compared to precipitation, attributed to the fact that rainfall-runoff relationship is very sensitive to the fluctuation in precipitation. Furthermore, due to strong seasonality in rainfall; most of the tributaries in the basin drying out during the prolonged dry season (Conway, 2000). The rainy season covers only 3–5 month of the year. This is reflected in a very high seasonality of the river hydrograph. About 80% of the Blue Nile flow occurs in 4 month only. There are also increasing demands both nationally and at transboundary level for the same water resource.

Recently, Tesemma et al. (2010) studied trends of rainfall over the Abay/Upper Blue Nile basin, and streamflow at three gauging stations along the main stem of the river, which are at Bahir Dar (outlet of Lake Tana), Kessie and at the Ethiopian–Sudanese border (El-Diem), for the period 1964–2003. They reported that no statistically significant trends were observed in precipitation over the studied period. However, annual stream flow at Bahir Dar outflow from Lake Tana and Kessie showed significant increasing trends at 5% significance level, while no change was observed at El Diem station at Ethiopian–Sudanese border. During the main rainy season (June–September), significant increasing trends were observed at all three stations.

The study by Eltahir (1996) indicates that the natural variability of annual flow of the Nile is associated with the El-NiñoSouthern oscillation (ENSO) phenomena. Similar studies also reported that the rainfall in the Ethiopian highlands during rainy season has teleconnected to the ENSO phenomena (Camberlin, 1995; Seleshi and Demaŕee, 1995; Conway, 2000; Seleshi and Zanke, 2004).

In general, the investigations of trends of hydro-meteorological variables at sub-catchment level in previous studies were largely unexplored, though it is a very relevant issue for sustainable use of water resources at sub-catchment scale. The objective of this paper is to identify the presence of hydro-climatic trends in the Abay/Upper Blue Nile basin at sub-catchment level. This is a prerequisite step to understand the cause and effect of trends and the links to water supply and use in the basin.

2. Study area and data sources

2.1. Study area

The Abay/Upper Blue Nile River originate from Lake Tana in Ethiopia at an elevation of 1780 m, see Fig. 1. The elevation ranges between 489 at the outlet to 4261 m a.s.l at Mount Ras Dashen in the north-eastern part. The catchment boundary and the drainage pattern have been delineated based on a 90 m $*$ 90 m digital elevation model of the NASA Shuttle Radar Topographic Mission (SRTM), obtained from the Consortium for Spatial Information (CGIR_CSI) website (http://srtm.csi.cgiar.org).

The climate in the Abay/Upper Blue Nile basin is governed by the migration of the Inter Tropical Convergent Zone (ITCZ), which moves seasonally from the South to the North and back (Conway, 2000; Mohamed et al., 2005). The rainfall in the basin has a mono-modal pattern. The annual rainfall during the period 1900–1998 ranges between 1150–1750 mm/y, with a mean value of 1420 mm/y. About 70% of the rainfall occurs between June and September (Conway, 2000). The mean annual temperature during the period 1961–1990 is 18.3 °C with a seasonal variation of less than 2 °C (Kim et al., 2008).

The dominant soil types in the basin are the vertisols and nitisol soil. The vegetation cover is characterized by rainfed crops accounting 25.8%, grasslands for 25%, woodland for 16.8%, shrubland for 11.8%, and cultivated land semi-mechanized farms for 10% (ENTRO, 2007). The remaining land cover accounts for less than 5%.The basin geology is characterized by basalt rocks, which are found in the Ethiopian highlands, while the lowlands are mainly composed of basement rocks and metamorphic rocks such as gneisses and marbles (ENTRO, 2007).

2.2. Data sources

Stream flow data sets based on manual water level measurements (daily at 06:00a.m. and 06:00p.m.) for nine gauging stations in the Abay/Upper Blue Nile basin for different period (see Appendix A Table A1) were collected from the Ethiopia Ministry of Water Resources and Energy. Similarly, monthly precipitation data for 13 stations and temperature data for 12 stations were obtained from the Ethiopian National Meteorological Agency. In general, the hydro-climatic data is scanty in the basin and have many data gaps. Therefore, it is essential to devote careful screening and quality checks for all data before use in any hydrological analysis. We used visual inspection and regression relations between neighboring stations to detect outliers and fill in missing gaps in the data series. For rainfall and temperature data the regression coefficient (r^2) ranges between 0.76 and 0.9. Large data gaps e.g. for the duration of one year and above, were excluded from the analysis. The selection of study catchments and gauging stations has been based on availability of data. Missing values less than 5% for daily streamflow and 11% for monthly weather data have been used over the considered period (see Appendix A, Tables A1 and A2).

3. Methodology

Investigating the presence of trends in hydro-meteorological variables is important for existing and future water resources developments in the Nile basin. To evaluate the existence of trends in precipitation, temperature, and stream flow time series of the Abay/Upper Blue Nile tributaries, the Mann–Kendall test hereinafter referred as MK test has been used (Mann, 1945; Kendall, 1975). Pettit tests have been employed to detect the change points in the time series. The periods of available data used in the analysis is given in Appendix A Tables A1 and A2. Trends and change of points have been evaluated in different time period having varying length of available data series.

3.1. Mann–Kendall test

Mann–Kendall test is a rank based, non-parametric test, which has been widely used for detection of trends in time series (e.g. Zhang et al., 2001; Burn and Hag Elnur, 2002; Yue and Hashino,