Hydro-climatic particularity of the period 1996-1998 over East Africa: the case of Lake Hawassa, Ethiopia

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Abstract: The period 1996-1998 has been quoted several times in hydrology, climate, health and similar disciplines for its particularity in terms of its extreme events. Motivated by that, this paper hypothesized the possible regime shift of the key hydro-climate variables at the local level in one of the Ethiopian Rift Valley Lakes system-Hawassa. The candidate variables include: lake level, rainfall, evaporation, streamflow, run-off coefficient and Net-Basin Supply (NBS). The occurrences of regime shifts were detected using Pettit΄s Homogeneity test for the duration between 1986 and 2006. Assessment of the patterns of co-occurrences of possible drivers was also part of the article. The Pettit΄s Homogeneity test shows that all of the variables, except rainfall, undergone significant regime shift at and around the year 1996. The average annual lake level has undergone a regime shift from an average lake of 20.43m into 21.14m around 1996. Evaporation has shifted from the state of high annual magnitude of 2163mm down to 1678mm whereas stream flow of Tikur Wuha River shift from 82.1 MCM of annual flow to the magnitude of 105.1 MCM. The run-off coefficient and Net Basin Supply (NBS) also found to regime shifts at the beginning of the episode 1996-1998. The climate regime shift (CRS) in the Pacific sea surface temperature (SST) pattern which was identified in 1996/1997 was the likely prime driver to initiate this local hydro-climate instability. It is likely that the co-occurrences of CRS in 1996/97 and the record breaking El Niño in 1997-1998 has exacerbate the subsistent change. As consequence of hydro-climate regime shifts, there might be equivalent shifts in the ecosystem structure and function which eventually impact the ecosystem services as living things are intimately connected to their physical surroundings. The question of adaptation to such situation apparently becomes important development topic at this point and in the future.

Keywords: *Regime shift, Pettit's homogeneity test, El Niño, sea surface temperature*

1. Introduction

The period 1996-1998 has been quoted several times in hydrology, climate, health and similar disciplines for its particularity. For instance, the winter (December 1997- February 1998) of US was the second warmest and seventh wettest since 1895 (Ross et al. 1998); the 1997 Central European flood caused material damages estimated at $4.5 billion (Konieczny et al. 2011; Kundzewicz, 2007); the 1996 flooding of the Yangtze River in China killed more than 2700 (UNEP, 1999); Maes et al. (2014) showed the exceptionality the Kenyan rainfall in during the period 1996-1998; Lake Nasir (in Egypt) rose to its highest level ever due to heavy rain in Ethiopian source of the Nile (Lulla and Dessinov, 2000); 55% of the malaria cases were reported in the southern Rift Valley of Ethiopia during the 1998-1999 in people $\geq$10 years old (Ministry of Health, 1998) and Lake Abaya and Lake Hawassa in the Ethiopian Rift Valley Basin experienced the highest recorded peaks in the year of 1998/99 and the resulting flood induced total physical damage about € 5.4 million (WRDB, 2007). Many other particularity of the period 1996-1998 can be cited from previous literature.

The above extended particularities of the period 1996-1998 set the floor to hypothesize that the key hydro-climate variables might undergo regime shift during this period. The objective of this paper is to test for the occurrence of hydro-climatic regime shift during this period using

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the following six variables of Lake Hawassa hydrosystem in South Ethiopia: lake level, rainfall, evaporation, streamflow, run-off coefficient and Net-Basin Supply (NBS). Assessment of the patterns of co-occurrences of possible drivers was also part of the article.

2. Methodology

2.1 Description of the study area

Lake Hawassa watershed is located in the central North-East of the Ethiopian Rift Valley Basin (Figure 1) and covers an area of 143,651 ha. The geographical co-ordinates of the watershed are $6^{0}45^{1}$ to $7^{0}15^{1}$ North and $38^{0}15^{1}$ to $38^{0}45^{1}$ East latitude and longitude respectively (Belete, 2013). The watershed is characterized by three main seasons: the long rainy season extends from June-September and the wet period represents 50-70% of the mean annual total rainfall. The dry period extends between October and February (Legesse et al., 2003; Legesse et al., 2004). As computed from the long-term (1973-2010) rainfall record of Hawassa meteorological station, the annual average magnitude is computed to be 961 mm. Figure 2 shows the long-term average monthly distribution of rainfall and temperature (Belete, 2013).

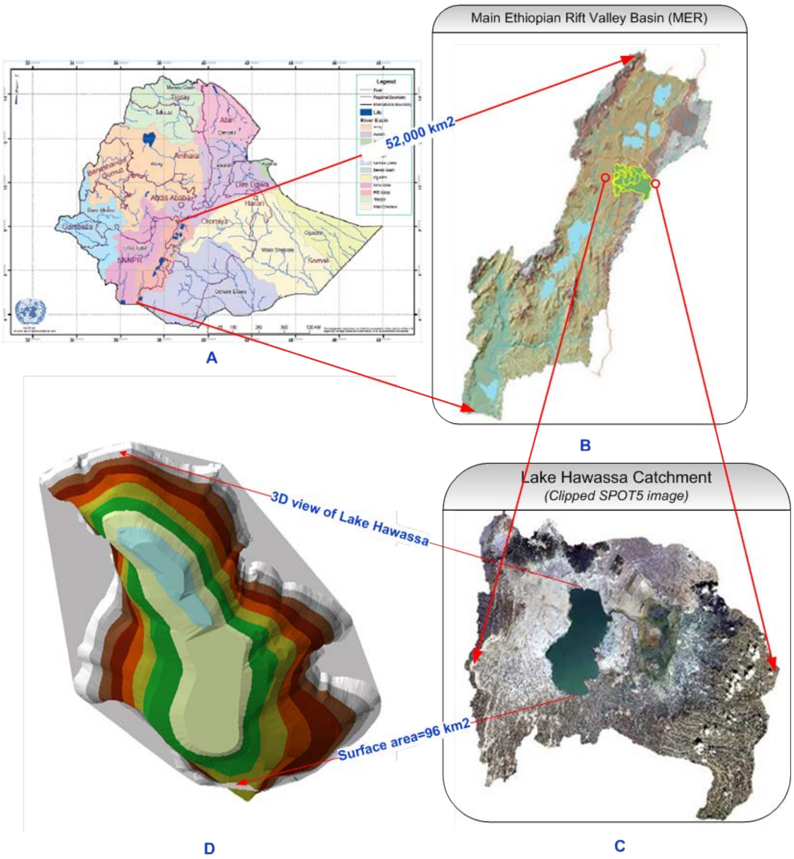


Figure 1 *Maps of the study area at different scales (A: The 12 river basins of Ethiopia; B: The Main Ethiopian Rift Valley basin (MoWR, 2010); C: Lake Hawassa watershed as clipped from SPOT5 satellite image (Belete, 2013); D: 3D view of Lake Hawassa as generated by ArcGIS10 from the 1999 bathymetry map (Belete, 2013)*

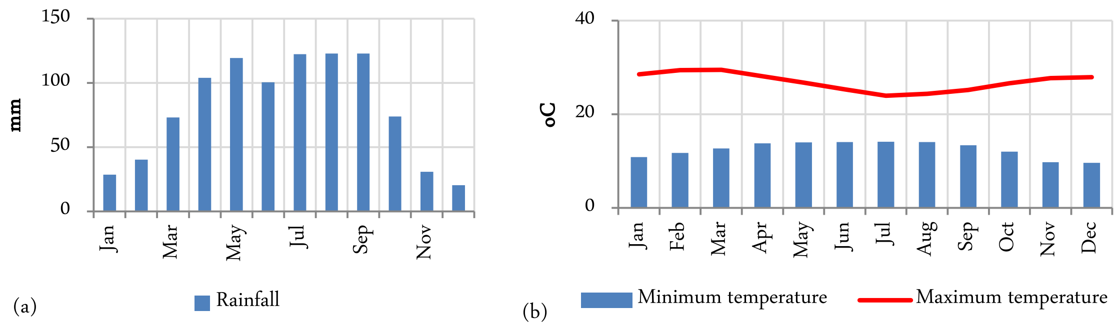


Figure 2 Distribution of monthly rainfall (a) and temperature (b) at Hawassa

2.2 Data availability

As shown in T*able 1*, available data are of different temporal scale and the analysis was governed by the common span of time which is 1986-2006.

Table 1 Available hydro-climatic data used for this research

Data type	Temporal scale	Period	Sources
Lake level records	Daily	1970-2010	Ministry of Water, Irrigation and Electricity
Stream flow	»	1980-2006	»
Rainfall	»	1972-2010	National Meteorological Agency
Pan-evaporation	»	1986-2007	»

2.3 Computation of Net Basin Supply (NBS)

Brinkmann (1983) defined the Net Basin Supply (NBS) as the amount of water contributed to or lost from a lake within the confines of its natural drainage basin and it is the primary driver of lake levels on monthly and longer time scales, as inflows and outflows are essentially controlled by lake levels (Fortin and Gronewold, 2012). Lake level normally vary over a range similar to the variations in the Net Basin Supply (NBS) which comprises the over-lake precipitation, runoff and evaporation. *Equation 1* depicts the formula for NBS.

$$NBS\ (t) = R_{ain\ over\ lake}(t) + R_{unoff\ into\ the\ lake}\ (t) - E_{vaporation\ from\ the\ lake}(t) - A_{bstraction\ from\ the\ lake}\ (t) \qquad (1)$$

2.4 Detection of regime shift (Pettit΄s Homogeneity test)

Among different methods to detect change points of time series (Buishand, 1982; Chen and Gupta, 2000; Radziejewski et al., 2000), Pettit΄s test is widely applied in hydrology (Mu et al., 2007; Gao et al., 2011) and detection of shifts in the means is the most common type (Rodionov, 2004; 2005) also employed in this study too. Pettit (1979) developed a nonparametric test that is capable of locating the period (month or year) where a break is likely. The null hypothesis is that the data is independent, identically distributed random quantities, and the alternative is that a stepwise shift in the mean is present. The attributes of Petit test over other homogeneity tests are: it is more sensitive to breaks in the middle of a time series (Wijngaard et al. 2003); capable to detect the year where break occurs (Kang and Yosuf, 2012) and does not assume normality of the data. Under null hypothesis, the annual values Y_i of the testing variables Y are independent and identically distributed and the series are considered as homogeneous. Meanwhile under alternative hypothesis, the test assumes the series consisted of break in the mean and considered as inhomogeneous.

As stated in Salarijazi et al (2011) and Kahya and Kalayci (2004), the Pettit test considers a sequence of random variables X1, X2,., XT, which have a change point at $_T$. As a result, (X_1, X_2,..., X_T) have a common distribution function F1 (.), but (X_{T+1}, X_{T+2},..., X_T) are identically distributed as F2 (.), where $F_1(.) \neq F_2(.)$. The null hypothesis H_0: no change (or $_T$=T); is tested against the alternative hypothesis H_1: change (or $1 \leq {}_T < T$); using the non-parametric statistic $K_T = \max|U_{t,T}| = \max(K_{T+}, K_{T-})$ where:

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=i+1}^{T} \operatorname{sgn}(X_t - X_j) \qquad (2)$$

$$sgn(\theta) = \begin{Bmatrix} +1 \; if\,\theta > 0 \\ 0 \;\; if\,\theta = 0 \\ -1 \; if\,\theta < 0 \end{Bmatrix} \qquad (3)$$

K_{T+}=max $U_{t,T}$ for downward shift and K_{T-}=-min $U_{t,T}$ for upward shift. The confidence level associated with K_{T+} or K_{T-} is determined approximately by:

$$\rho = exp\left(\frac{-6K_T{}^2}{T^3+T^2}\right) \qquad (4)$$

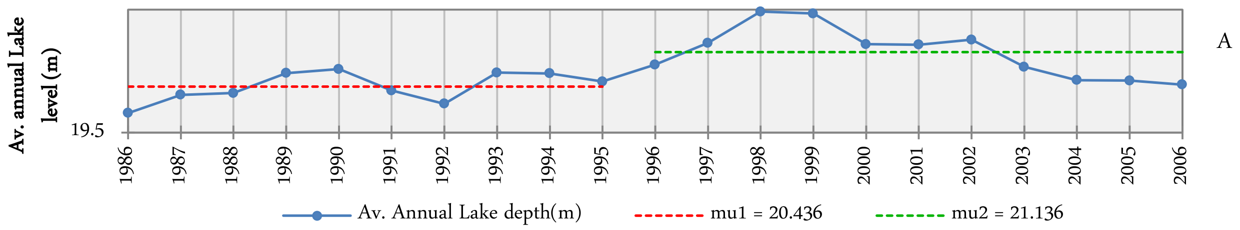
When ρ is smaller than the specific confidence level, for example, 0.95 in this study, the null hypothesis is rejected. The approximate significance probability for a change-point is defined as:

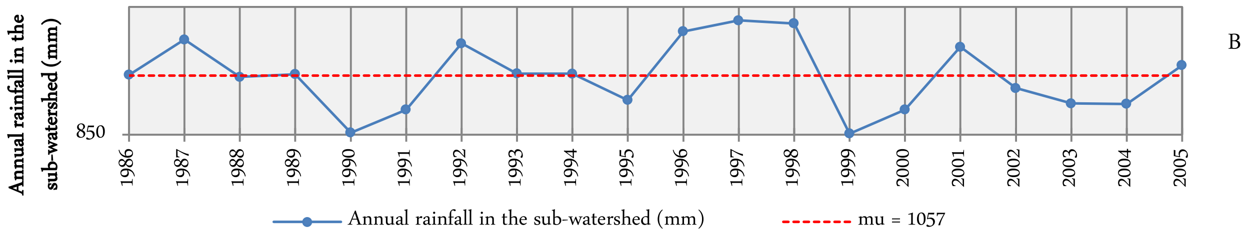
$$P=1-\rho \qquad (5)$$

3. Results

3.1 Results of homogeneity tests

As shown in Figure 3 (A to *F),* all of the variables, except rainfall, undergone significant regime shift at and around the year 1996. The average annual lake level has undergone a regime shift from an average lake of 20.43m into 21.14m around 1996. Evaporation has shifted from the state of high annual magnitude of 2163mm down to 1678mm whereas stream flow of Tikur Wuha River shift from 82.1 MCM of annual flow to the magnitude of 105.1 MCM. The run-off coefficient and Net Basin Supply (NBS) also found to regime shifts at the beginning of the episode 1996-1998. Investigating the causes of these regime shifts is not the subject of this article but the upcoming discussion section assessed possible candidate drivers.





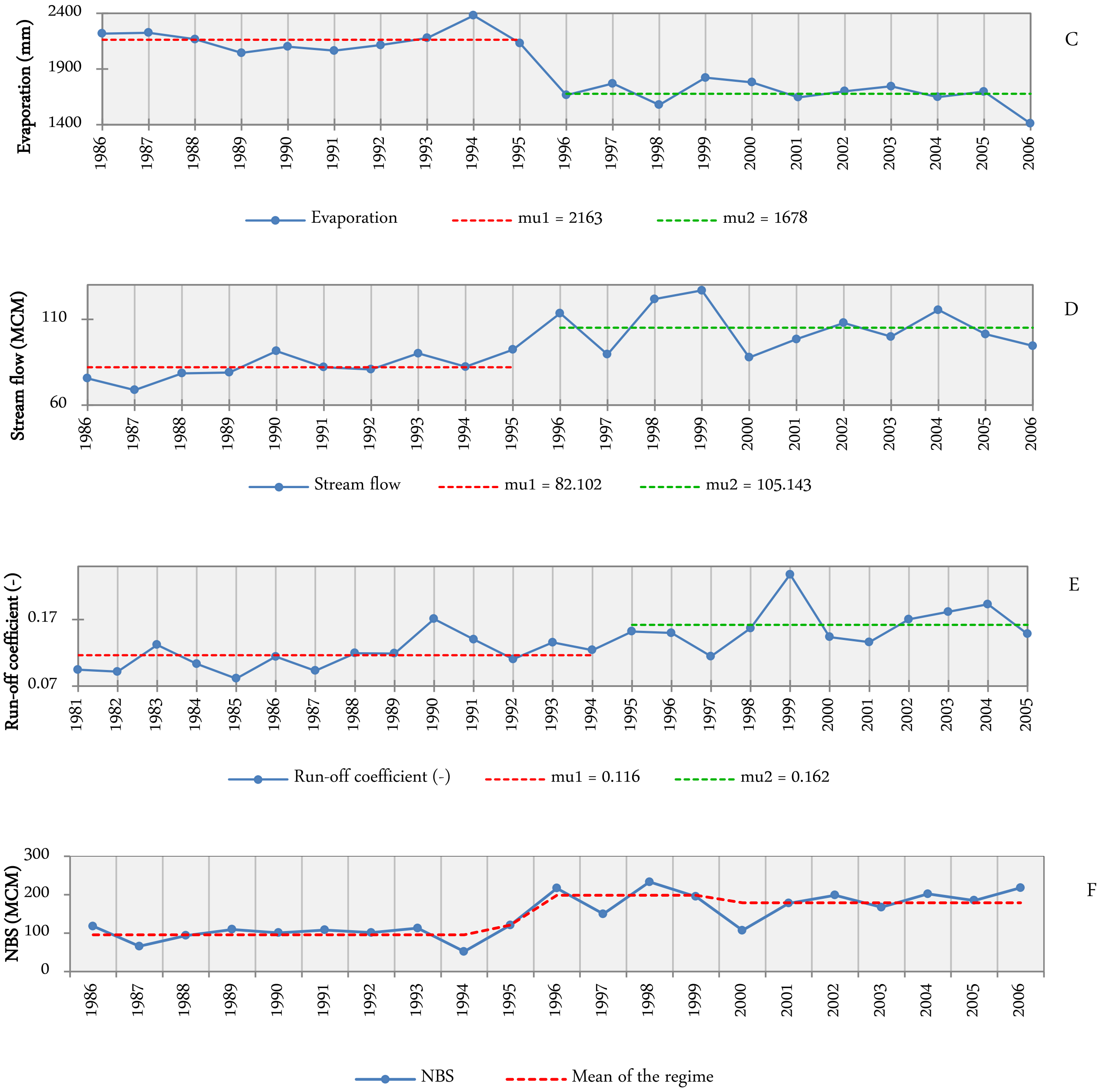


Figure 3 Dominant regime shift period of the local hydro-climate variables (NB: mu=μ=mean)

4. Discussion

Results confirmed the particularity of the period 1996-1998 by depicting the occurrences of significant regime shifts at about the beginning of 1996. The result implied that this episode distorted the hydro-climatic stability of the system. As per the basics of Pettit's homogeneity test, the statistical properties of the datasets before and after the shift are different.

The climate regime shift (CRS) in the Pacific sea surface temperature (SST) pattern which was identified in 1996/1997 (Hong et al. 2014) was the likely prime driver to initiate this local hydro-climate instability. The authors claimed that there is little evidence to claim that the CRS is caused by the global warming trend. It is likely that the co-occurrences of CRS in 1996/97 and the record breaking El Niño in1997-1998 (Ross et al. 1998) has exacerbate the subsistent change. Another coincidence of hydrological regime shift in Lake Hawassa and climate regime shift in Pacific Ocean in 1976/77 was reported by Belete (2013) that strengthen the candidacy of CRS at pacific as the main driver for the local shifts.

5. Conclusion

The hydro-climate particularities of the period 1996-98 are evidenced in this article. The climate regime shift in 1996/97 and the worst El Niño of the century are the likely drivers of the local hydro-climate regime shifts. The lesson derived from this analysis is beneficial at recent time in that we are expecting another strong El Niño in the year 2015/16 (NOAA, 2015) and will serve as early warning tool against flood and drought hazards. In addition, these findings hinted the importance of holistic assessment of climate change or variability instead of over populated concern on precipitation and temperature variables.

As consequence of hydro-climate regime shifts, there might be equivalent shifts in the ecosystem structure and function which eventually impact the ecosystem services as living things are intimately connected to their physical surroundings. The question of adaptation to such situation apparently becomes important development topic at this point and future challenge.

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