BLUE NILE BASIN HYDROLOGY RELATIONSHIP TO CLIMATIC INDICES

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ABSTRACT

Climatic teleconnections to regional rainfall and stream flows have been correlated and respective predictions have become part of water management decision in regions such as South Florida in the United States. As changes in the climate is expected to have dramatic changes in temperature and precipitation, the ability to predict and make water resources management decisions is more critical than ever. For some parts of the world, these hydrologic changes may present major challenges to continue to provide for human water needs while balancing concerns about ecological integrity. Studies have shown that climatic indices associated with the prevailing climate have a very strong correlation to regional hydrology. Climatic teleconnections to the Blue Nile River Basin, Ethiopia, hydrology was evaluated using spatial average basin rainfall and Blue Nile flows at Bahir Dar. The El Niño Southern Oscillation index (ENSO) relationship using sea surface temperature (SST) anomalies in region Niño 3.4 and variation in air pressure between the western and eastern tropical pacific was used for analysis. The analysis indicates that the Upper Blue Nile Basin rainfall and flows are connected to the ENSO index. High rainfall and high flows are likely to occur during La Niña years and dry years are likely to occur during El Niño years at a confidence level of 90 to 95 percent. Extreme dry and wet years are very likely to correspond with ENSO event as given above. The great Ethiopian famine of 1888-1892 corresponds to one of the strongest El Niño years, 1888. The recent drought years of 1965, 1972, 1983, 1987 and 1997 in Ethiopia correspond to strong El Niño years. In this paper a new approach is proposed on how to classify the strength of ENSO events. A cumulative SST index value ≥ 5 and cumulative southern oscillation index value of ≤ -7 indicate strong El

Niño. A cumulative SST index value of $\leq$ -5 and cumulative southern oscillation index of $\geq$ 7 indicate strong La Niña.

Key Words: Blue Nile Basin, ENSO, El Niño, La Niña, Climate Teleconnection

INTRODUCTION

Variation in the weather in the short term and climate in the long term has been a mystery for man kind for a long time and many cultures attribute the phenomena to super natural forces. In the last century, significant progress has been made in understanding the ocean, the atmosphere and land processes, inter-relationships and regional teleconnections. Modeling of these complex systems and prediction of weather and climate has achieved significant progress with a lot more work left for more understanding of the various processes and reduction of uncertainties in weather forecasting and climatic predictions for practical applications. Weather is defined as the state of the atmosphere or meteorological conditions as temperature, humidity, atmospheric pressure, wind speed and precipitation. Weather forecasts are made up to 10 days into the future with forecasting error increasing for longer periods. Climate is the weather averaged over longer temporal and spatial domain for months to years to centuries (Garbrecht and Piechota, 2006). Prediction of hydrometeorology using global climate indices or other methods has become a necessity for water resources management in a future where water supply per capita declines and the impact of variability of the resource increase. Prediction of temporal and spatial variation of precipitation and runoff is necessity for water resource management and planning to mitigate impacts of droughts and floods.

Analysis of climate variation is evaluated from directly measured hydrometeorology data such as rainfall, stream flow, stream water level, groundwater level, and air and water temperature. Significant climatologic variation can be derived from historical events of droughts and floods. Ice cores and tree rings analysis have been used to derive long-term climatic data. Sea surface temperature variation and pressure gradient records have been correlated to regional weather and climatic variations. One of the earliest works done on global climatic relationships is by Walker and Bliss in the early 1930s (Walker and Bliss, 1930). They studied world weather and developed statistical correlation equations to predict a weather parameter at a part of the world using different weather parameters of other parts of the globe as variables. One case is where they related Honolulu and Port Darwin atmospheric pressure, the Nile flood and Indian monsoon to air temperature in western Canada. Sun spot number was one of the variables in their studies.

The Atlantic Multidecadal Oscillation (AMO) between warm phase and cool phase is shown to explain 10 percent of the Mississippi River outflow and 40 percent of Lake Okeechobee inflow in the United States. ENSO, AMO and Pacific Decadal Oscillation have been linked to the climate of South Florida (Enfield et al., 2001, Zhang and Trimble, 1996). Not only atmospheric, oceanic and land processes affect the climate but also solar activity has link to hydrometeorology variation (Trimble et al., 1997, Soon et al., 2000). Solar sunspot activity is measured by the number of sunspots and by the magnitude of geomagnetic activity. Solar sunspot activity has an average cycle of 11 years with reversal in the sun's magnetic field between cycles. Trimble et al. (1997) have shown that the runoff inflows into Lake Okeechobee of South Florida are associated to solar activity as estimated by the number of sunspots and geomagnetic activity. Other researchers have also shown evidence in the connection between solar activity and the earth's climate (Friis-Christensen and Lassen, 1991).

Seleshi and Zanke (2004), in their analysis of recent changes of rainfall in Ethiopia, concluded that Ethiopian Highlands June-September rainfall is positively correlated to the Southern Oscillation Index and negatively correlated to the equatorial eastern pacific sea surface temperature. The variables for linear regression equations developed to forecast Ethiopian summer rains included sea surface temperature (SST) anomalies of the western Indian Ocean, the tropical eastern Indian Ocean, and Niňo3.4 SST anomalies for the preceding March, April and May rainfall (Gissila et al., 2004).

EL NIŇO-SOUTHERN OSCILLATION (ENSO) INDICES

El Niño is an ocean-atmosphere phenomenon where the cooler eastern pacific worms up once every two to seven years. The increase in eastern pacific sea surface temperature (SST) is attributed to the weakening of the easterly trade winds which results in warm water from the western pacific moving to the east. An average of $+0.4^{o}$ C deviation from average SST for three or more consecutive months indicates ENSO event. Based on SST anomalies in Niño 3.4 region (5^oN-5^oS, 120^o - 170^oW,) periods 1951, 1953, 1957, 1958, 1963, 1965, 1966, 1969,1972, 1977, 1979, 1980, 1982, 1983, 1986, 1987, 1990-94, 1997 and 2002-2006 were El Niño years and most correspond to periods presented in Trenberth (1997). The weather impact of El Niño varies with the strength of ENSO. In South Florida there is strong correlation between dry season rainfall (November-May) and ENSO events. Rainfall is significantly higher during El Niño and drier during La Niña events. Climatic prediction based on this correlation has become part of water management decision (Obeysekera et al., 2007). Thomas (2007) developed regression equations forecasting Colorado River stream flow using climatic index as variables for application in water resource management.

Monthly climatic index as ENSO do not amplify the strength of the event. Cumulative index clearly indicate the comparative strength of a climatic phenomenon such as SST. In this study, a new approach, the use of cumulative climatic index, is presented for analysis of relationship of annual rainfall and stream flow and climatic indices. Based on historical records of ENSO events, a cumulative SST index of ≥ 5 indicates strong El Niño and a cumulative SST index of ≤ -5 indicates strong La Niña. SST cumulative annual index is shown in Figure 1 for Niño 3.4.

Southern Oscillation (SO) is the variation in air pressure between the western and eastern tropical pacific. The SO index (SOI) is a measure of air pressure difference between Tahiti in the east and Darwin, Australia to the west as compared to historical average of the differences. Negative differences indicate El Niño conditions as lower pressure in the eastern Pacific is associated to warmer water and weakened easterly trade winds. Positive SOI correspond to negative SST index and La Niña. The proposed ENSO event strength indicators are cumulative values of 7 and -7 for La Niña and El Niño, respectively. Figure 2 depicts cumulative annual SOI.

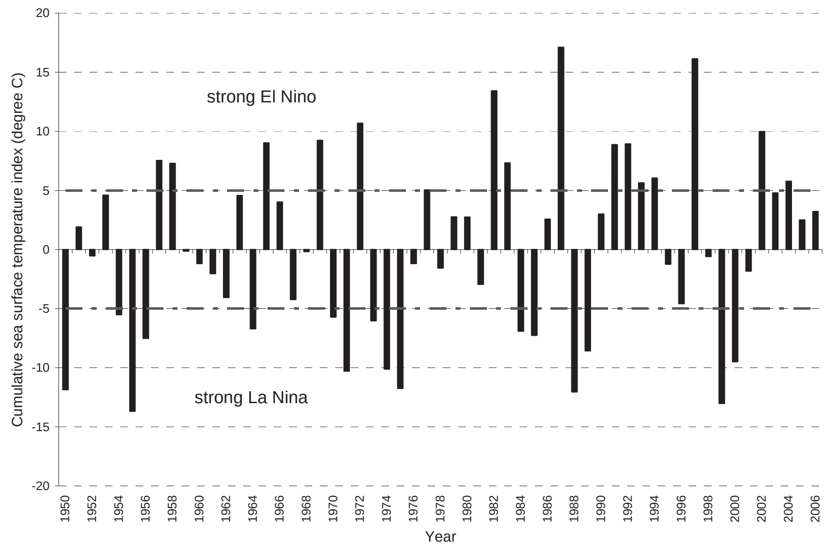

Figure 1. Cumulative annual sea surface temperature Index (Niño 3.4).

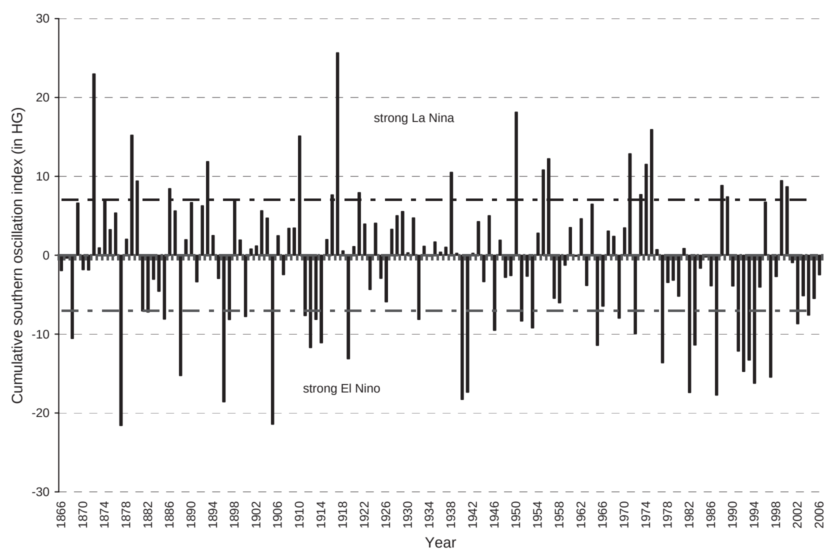

Figure 2. Cumulative annual southern oscillation index.

UPPER BLUE NILE BASIN RAINFALL

The Blue Nile River drainage basin is approximately 324,530 km^2 (Peggy and Curtis, 1994). The Upper Blue Nile River Basin (Figure 1) is 176,000 km^2 in area (Conway, 2000). The major tributaries in Ethiopia are Gilgel Abbay, Megech, Ribb, Gumera, Beshlo, Woleka, Jemma, Muger, Guder, Chemoga, Fincha, Dedessa, Angar, Dura and Beles. Figure 3 depicts the Upper Blue Nile River Basin and its tributaries in Ethiopia. The Upper Blue Nile Basin is relatively wet with annual mean rainfall of 1423 mm (1960-2002) with standard deviation of 125 mm. The rainfall statistics is based on 32 rainfall stations with varying length of record (Abtew et al., 2008). Conway (2000) reported a mean annual rainfall of 1421 mm based on 11 gauges for a period of record of 1900-1998. The Upper Blue Nile Basin annual rainfall is depicted in Figure 4. Out of the nine driest years (1984, 1962, 2002, 1986, 1982, 1965, 1995, 1961 and 1994) all occurred during El Niño years except 1984 and 1962. 1984 followed strong El Niño years of 1982-1983. Out of the 12 wettest years (1973, 1964, 1971, 1977, 1993, 1975, 1974, 1998, 1978, 1967, 1996 and 1988) ten occurred during La Niña years except in 1977 and 1993. Conway (2000) reported that dry years show a degree of association with low values of SOI (El Niño). Eldaw et al.,(2003) reported that the July to October flows of the Nile are correlated to the Pacific SST and Guinea rainfall. Other studies that relate El Nino events to Ethiopian droughts are reviewed in Gissila et al. (2004). Jury et al. (2002) have shown that African rainfall variation is related to El Niño-Southern Oscillation Indices (ENSO).

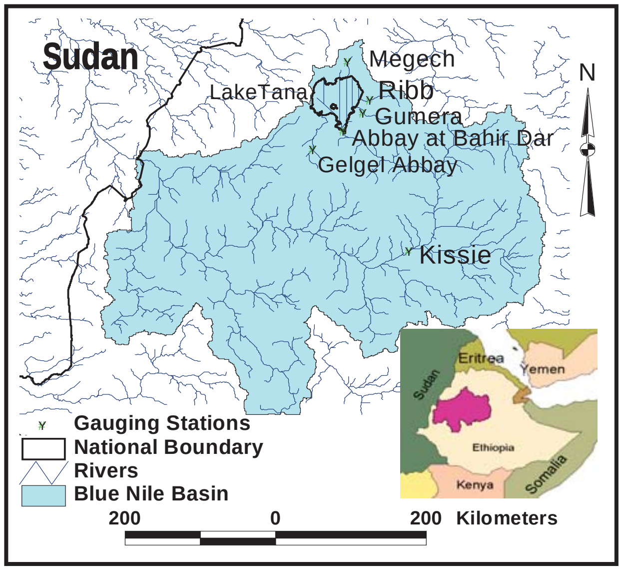

Figure 3. The Upper Blue Nile Basin in Ethiopia.

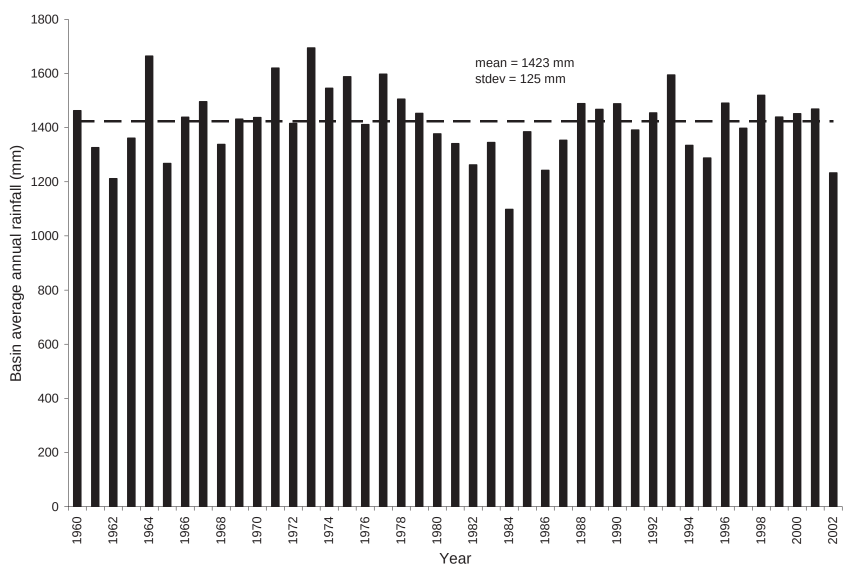

Figure 4. Upper Blue Nile Basin average annual rainfall (1960-2002).

In this study, a scatter plot of cumulative annual ENSO index and annual Upper Blue Nile Basin rainfall deviations shows that wet years are more likely to occur in La Niña years and dry years occur during El Niño years (Figure 5). In 27 years out of 42 years of record, below average rainfall corresponded with El Niño years and above average rainfall occurred during La Niña years. A test of significance of a binomial proportion can be applied to show that the events are not random (Snedecor and Cochran, 1980). With an assumed probability of 0.5 that correspondence of ENSO events to rainfall deviations in a year is a random event as the null hypothesis, Chi square (χ^2) test of goodness of fit can be performed. The following equation expresses the test (Eq. 1).

$$\chi^2 = \frac{\sum (f - F)^2}{F} = \frac{(r - np)^2}{np} + \frac{(r - np)^2}{nq} \qquad (1)$$

Where n is the number of years of analysis (42); f is observed number of years where annual rainfall deficit corresponds to ENSO event (r=27); n-r is the number of years where rainfall deficit does not correspond to ENSO event (n-r=15); F is expected frequency of random correspondence assuming a probability of 0.5 (np=21); F is also expected number of years rainfall deficit not corresponding with any ENSO events (nq=21). The computation results in $\chi^2 = 3.41$. Compared to the expected (χ^2 Table) value at 1 degree of freedom, the null hypothesis that the rainfall deficit has 50/50 chance to correspond to any ENSO event is rejected at 0.10 significant test level.

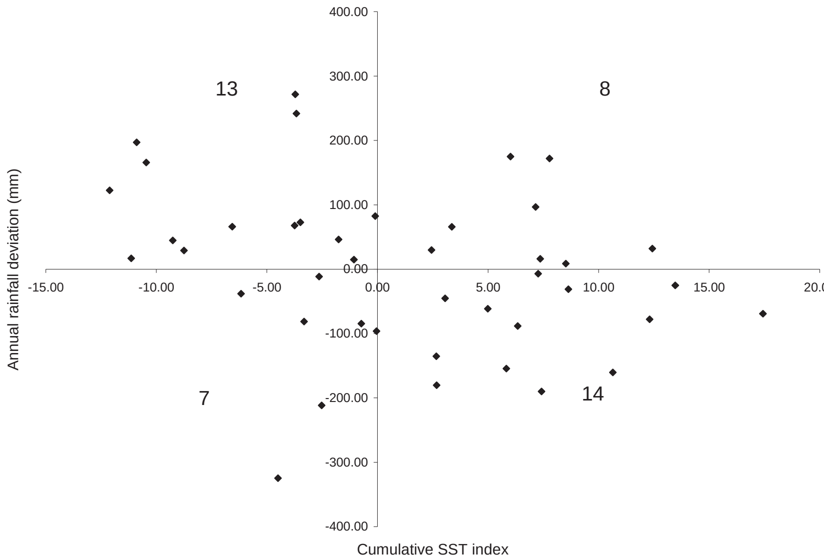

Figure 5. Relationship of cumulative annual ENSO Indices and Upper Blue Nile Basin annual rainfall deviations.

Anecdotal records of Ethiopian droughts correspond to ENSO events. The great Ethiopian famine of 1888-1892 (Pankhurst, 1966) corresponds to one of the strong El Niño years, 1888. In recent years, 1965, 1972-73, 1983-84, 1987-88 and 1997 were drought years with low agricultural production and impacts on millions of people and the environment (Seleshi and Zanke, 2004). Years 1965, 1972, 1983, 1987 and 1997 correspond to strong El Niño years. Analysis of the Nile flows at Aswan from 1872 to 1972 showed correspondence of high flows with negative SST and low flows with positive SST anomalies for the months of September, October and November (Eltahir, 1996).

BLUE NILE FLOW AT BAHIR DAR

Flow data with some missing data and few questionable data was available for the Blue Nile flow at Bahr Dar for the period 1961-2003. Questionable data and missing data were estimated by interpolation and filling with flows of similar pattern months in other years. An example of questionable data is data where the mean is less than the minimum. The annual flow ranged from a maximum of 6,489 million m^3 to a minimum of 975 million m^3. The mean annual flow is 3,850 million m^3 and the standard deviation is 1,353 million m^3. Figure 6 depicts annual flow of the Blue Nile at Bahir Dar. Seventy one percent of the flows are from July through November while 70 percent of the rainfall at Bahir Dar occurs between June and September. Seventy three percent of the Upper Blue Nile Basin areal average rainfall occurs between May and September. Comparison of annual flow deviations with cumulative Nino 3.4 sea surface temperature index shows that wet years are likely to occur during La Niña years and dry years are likely to occur during El Niño years (Figure 7). Seven of the nine highest annual flow years occurred during La Niña years (1964, 1999, 1988, 2000, 2001, 1975 and 1962). Also, seven of the driest nine years occurred during El Niño years (1964, 1999, 1988, 2000, 2001, 1975 and 1962.

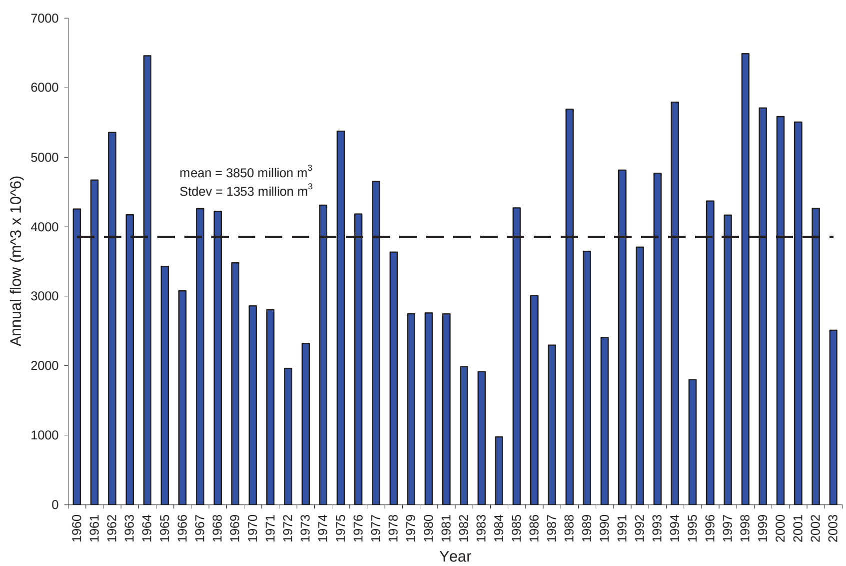

Figure 6. Blue Nile annual flows at Bahir Dar.

The Chi square value based on equation (1) with n, r, F values of 43, 29, 21.5 is 5.25. This test is significant at 5 percent level indicating that below average flows correspond to El Niño years and above average flows correspond to La Niña years. Figure 8 shows comparison of monthly flows of the Blue Nile at Bahir Dar with three months moving average ENSO (SST). El Niño events occur when sea surface temperature deviation is greater or equal to +0.50 ^{0}C and La Niña events occur when sea surface temperature deviation is less than or equal to -0.50 ^{0}C. Average flows during La Niña years are 25% higher than flows during El Niño and neutral years.

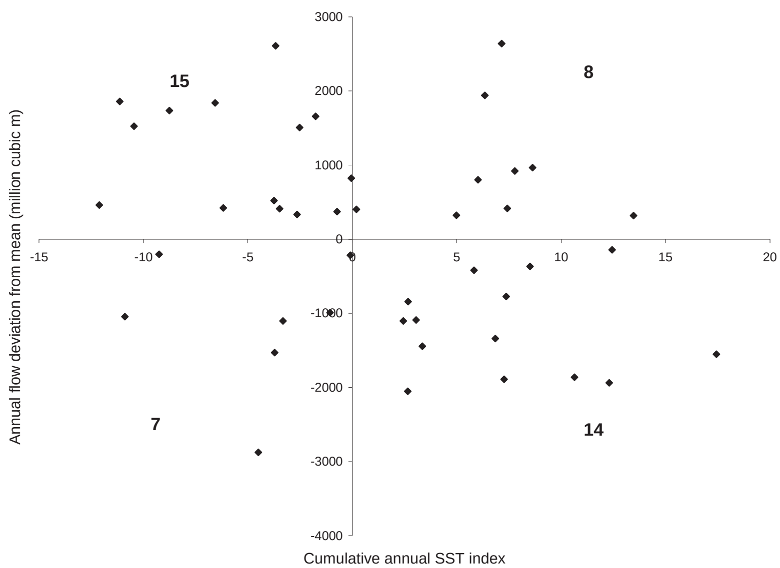

Figure 7. Relationship of cumulative annual ENSO Index and Blue Nile at Bahir Dar annual flow deviations.

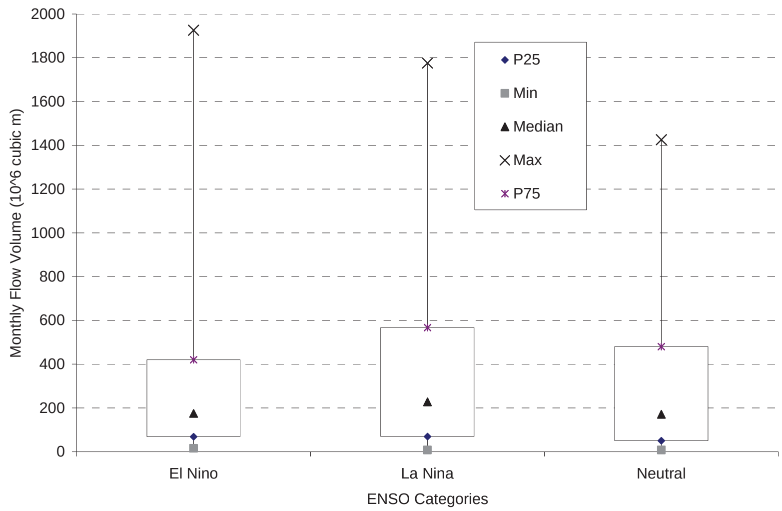

Figure 8. Relationship of month moving average ENSO (SST) index and Blue Nile at Bahir Dar monthly flow.

SUMMARY

Climatic teleconnections to the Blue Nile hydrology was evaluated using basin average rainfall and Blue Nile flows at Bahir Dar. The El Niño Southern Oscillation index (ENSO) relationship using sea surface temperature anomalies in region Niño 3.4 and variation in air pressure between the western and eastern tropical pacific was used for analysis. The analysis indicates that the Blue Nile Basin rainfall and flows are connected to the ENSO index. High rainfall and high flows are likely to occur during La Niña years and dry years are likely to occur during El Niño years. Extreme dry years are highly likely to occur during El Niño years and extreme wet years are highly likely to occur during La Niña years. The prediction of El Niño and La Niña relatively has higher certainty than predicting basin rainfall and runoff. Identifying teleconnections to a region's hydrology has practical applications for water resources management. In this paper a new approach is proposed on how to classify the strength of ENSO events. A cumulative SST index value ≥ 5 and cumulative southern oscillation index value of ≤ -7 indicate strong El Niño. A cumulative SST index value of ≤ -5 and cumulative southern oscillation index of ≥ 7 indicate strong La Niña.

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