Variability in Rainfall, Temperature and Relative Humidity at Bahir Dar City Areas, Ethiopia

Habtamu Yitayew and Gelana Amente*

Haramaya University, College of Natural and Computational Sciences, P O Box 138, Dire Dawa, Ethiopia

Abstract: This study was conducted to assess change in rainfall, temperature and relative humidity at Bahir Dar city in relation to global climate change. The study focused on analyzing changes in meteorological data, specifically temperature, rainfall and relative humidity. Bahir Dar city was selected due to its proximity to Lake Tana and its rapid urbanization over the past few decades. Debre Markos city (with no lake nearby) was selected for comparison, to assess the thermal inertia effect of the lake on Bahir Dar. The assessments in this study showed that Bahir Dar city has experienced mean temperature change of about 0.4 ^oC per decade, which is higher than the global average (0.08 ^oC per decade) and a decrease in rainfall of about 30 mm per decade. Monotonic increment of minimum temperature (0.60 ^oC decade^{-1}) surpassed that of maximum temperature (0.25 ^oC per decade) and this was further confirmed by a decrease in change of diurnal temperature range of -0.34 ^oC per decade. The increase in temperature at Bahir Dar over the global average is attributed to rapid urbanization (urban heat island effect). Comparison between Bahir Dar and Debre Markos showed slight influence of thermal inertia of the lake on Bahir Dar's minimum temperature. Greater lake effect was observed with the change in relative humidity, which showed a reduction of only 0.4% per decade at Bahir Dar compared to 3.8% at Debre Markos. The cyclic pattern of temperature clearly manifested the long cycle of Pacific Decadal Oscillation (PDO) while the short cycle PDO was slightly subdued perhaps due to the local effect. Rainfall cycle modestly followed the pattern of the Sahel.

Keywords: Climate Change; Lake Effect; Rainfall; Relative Humidity; Thermal Inertia; Urban Heat Island Effect

1. Introduction

Climate change is a global phenomenon that takes place at several places on earth. This change among other things is manifested in terms of increasing temperature and change in intensity and pattern of rainfall (NMA, 2007), both of which are attributed to global warming.

As in many other places on earth, climate change is of major concern in Ethiopia. Recurrent drought, which is partly attributed to shortage and erratic nature of rainfall and other factors such as deforestation and erosion (NMA, 2007), has forced the country to focus more on environmental issues more than ever.

There are several studies on climate change at a global scale, but issues addressing regional and local problems are required to understand the problems more (Yarnal, 1998; Smit and Pilifosova, 2003). Specific issues responsible for local conditions are required to get better picture of climate change of an area on top of global factors since such factors may have the impact of either mitigating or enhancing the global effects.

The reason why this study focused on Bahir Dar city is first, due to its proximity to Lake Tana and secondly, because of its rapid urbanization especially over the past few decades. The presence of water body such as lake has a moderation effect on a climate factor such as temperature on account of its thermal inertia. Urbanization on the other hand, has the effect of creating urban heat island (UHI), which increases rejected waste heat that has been created from different sources.

Rapid economic development, population increase and high degree of urbanization enhance human activities and increase energy consumption. With increase in energy consumption, the amount of waste heat also increases along with water vapor and pollutants (Anne *et al.,* 2012). Urban infrastructures such as roads, pavements and buildings absorb solar radiation in substantial amount (due to their reduced albedo) and this is gradually released in the form of longwave radiation (thermal energy). Heat energy produced from urban traffic, electrical power utilized by different household appliances and even heat emitted from human population as a by-product of metabolism, all contribute to UHI and have effect on temperature variability (Parker, 2006). Both thermal inertia and UHI effects are considered as local effects. They are acting side by side and that makes it unclear which one dominates. In line with this, the objectives of this study were first, to determine changes in temperature and relative humidity at Bahir Dar in order to investigate how the lake and urbanization have affected the two parameters. This was done by comparing the changes of the two parameters at Bahir Dar and Debre Markos. Second, changes in the maximum, the minimum and the average temperatures and the variability in rainfall intensity and pattern were assessed in relation to global climate change.

*Corresponding author. E-mail: amentegelana@yahoo.com

ISSN 1992-0407

2. Materials and Methods

2.1. Descriptions of the Study Sites

The main research site was Bahir Dar the capital city of the Amhara National Regional Stat. However, Debre Markos town was also considered for the purpose of comparison. Bahir Dar is a city in northwestern Ethiopia situated on the southern shore of Lake Tana, the source of the Blue Nile (Figure 1). Lake Tana is the largest lake in Ethiopia. It has average surface area of 2,156 km^2. Bahir Dar is located 565 km to the northwest of Addis Ababa. It has latitude of 11^o 59' N, longitude of 37^o 39' E and an average altitude of 1840 meters above mean sea level. The city has an area of a little over 213 square kilometers and its population has almost doubled (grown from 94,235 to 182,676) between 1994 and 2004 (CSA, 1994, 2008).

Debre Markos is also located in the northwest of Addis Ababa, at a distance of 300 km. A distance of 265 km separates Debre Markos from Bahir Dar. It is located at latitude of 10^o 20' N and longitude of 37^o 43' E. It has average elevation of 2446 m above mean sea level. The population of the town was 49,297 in 1994 and has increased to 62,469 in 2004 (CSA, 1994, 2008). The city was also considered in this study, because it has weather data of comparable duration with Bahir Dar. It is also a town which has shown (though not as fast) population increment and urban growth as Bahir Dar. However, the primary purpose of its selection was because of absence of water body close-by to moderate its temperature and its relative humidity. Difference in altitudes between the two locations was not of a major concern since the study dealt with changes rather than absolute values.

Figure 1. Amhara National Regional State (shaded) shown with Lake Tana (gray area within the shaded region).

2.2. Data Collection

The data used in this study were obtained from National Meteorological Agency, Bahir Dar Branch. The data set consisted of time series of daily maximum and minimum temperatures and rainfall observed between 1961 and 2010, both at Bahir Dar and Debre Markos stations. For relative humidity, a 23 year data (1988-2010) obtained for the two stations were also used in this study.

2.3. Data Analysis

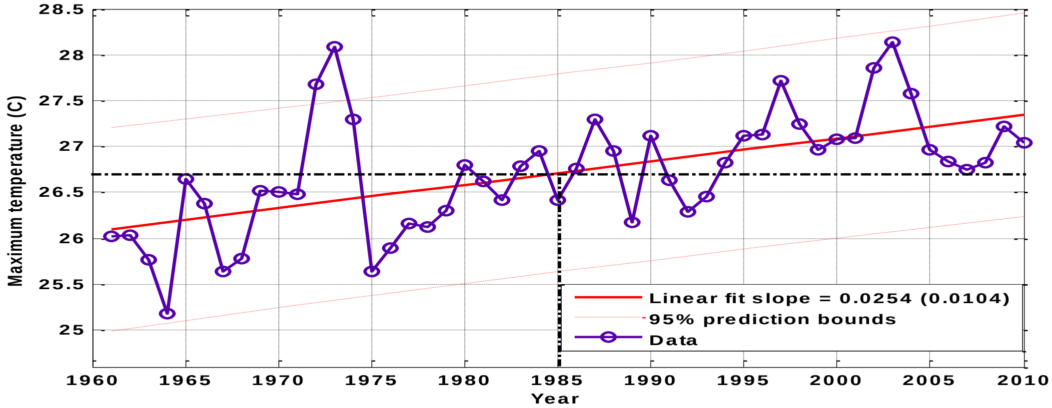
The data of different parameters were analyzed using MatLab software (R2010a version). Time series variability of maximum and minimum temperatures was analyzed in order to investigate the changes in relation to global trends. Differences between maximum and minimum temperatures were analyzed in order to determine diurnal temperature range (DTR) since it, along with maximum and minimum temperatures, serves as an index of global climate change and gives more information about temperature variability of an area better than using mean temperature alone (Braganza *et al.,* 2004). Statistical descriptions like mean, standard deviation, percentage, and regression analyses were carried out to study changes and trends of temperatures, rainfall and relative humidity of Bahir Dar in relation to global trends. For determination of the lake effect, changes in temperature and relative humidity of Bahir Dar were compared with those of Debre Markos.

3. Results and Discussion

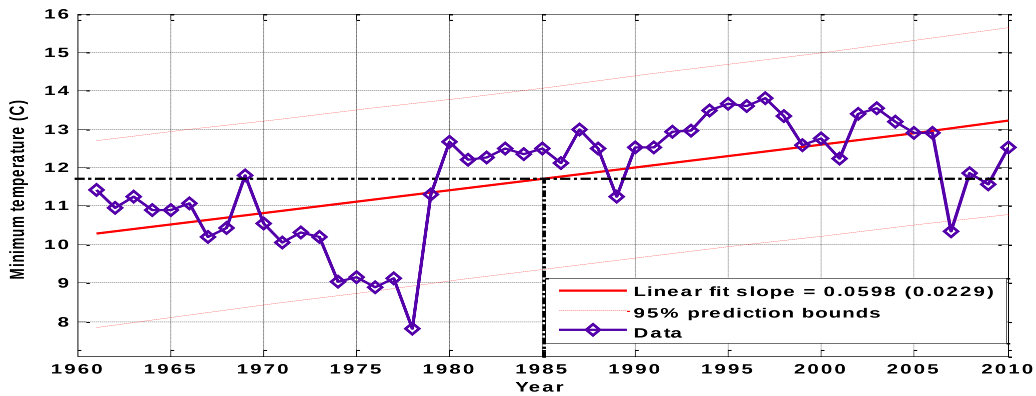
3.1. Maximum and Minimum Temperatures and DTR at Bahir Dar

Extreme temperatures (maximum and minimum) are important in order to understand climate anomalies such as drought and extreme low temperature at night times. Therefore, in this study, maximum and minimum temperatures were analyzed before the average temperature. Maximum temperature of an area is indicative of how hot it gets and it influences daytime relative humidity and evaporation. The minimum temperature, which generally occurs at night, is indicative of cold trends that have impact on certain crops. Diurnal temperature range is needed to know how fast the minimum temperature is changing with respect to the maximum temperature. It is important to know which of the two is contributing more to the change of the average temperature.

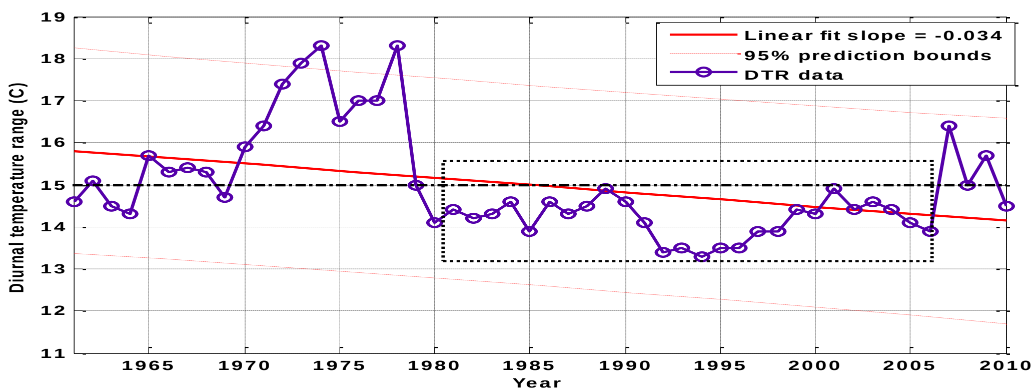
Average of maximum temperature is depicted by the dash-dot horizontal line that crossed the slope line in 1985 (Figure 2a). Before 1985, maximum temperature in excess of the average occurred only six times (25% of the time). After and including 1985, the maximum temperature crossed below the average line only five times. Despite fluctuations, the overall trend of maximum temperature over the last fifty years showed an increase of 0.025 ^{o}C per year or 0.25 ^{o}C per decade. For this temperature, the cyclic pattern of the extremes showed periods of 3–8 years. When the temperature extremes were close to each other (repeated every 3 to 4 years), maximum temperature at the extreme was not that much high as when they occurred after relatively longer periods (repeated every 7 or 8 years).



(a)



(b)



(c)

Figure 2. Time series of (a) maximum and (b) minimum temperatures and (c) DTR at Bahir Dar, 1961-2010. The trend lines are shown as slopes of regression lines and indicate changes of respective temperatures per year.

The average line of the time series of the minimum temperature also crossed the slope line in 1985 (Figure 2b). Between 1961 and 1979 none of the years experienced minimum temperature in excess of the average (11.7 ^{o}C). The year 1978 was exceptionally cold with minimum temperature below the range of the 95% prediction bound. After 1985, minimum temperatures below average were observed only three times (12% of the time), i.e., most of the minimum temperatures were indicative of warm nights. As shown in Figure 2b, the years 1974–1978 experienced unusually low minimum temperatures. Actually, 1978 was the dividing year between the years of overall declining minimum temperatures (before 1978) and the years of overall increasing minimum temperatures (after 1978).

Comparison of the maximum and minimum temperature plots showed a delay of three years for the onset of increasing trend after the falling trend (1974-1978) in the case of the minimum temperature. Perhaps this was due to the thermal inertia of the lake. During the three years the lake was cooler and could still suppress the thermal energy absorbed during the daytime. This shows thermal inertia of the lake took about three years (Figure 6).

Both the maximum and the minimum temperatures have shown increasing trends because of UHI effect. From among the three major heat sources, i.e., building sector, transportation sector and human metabolism (Sailor and Lu, 2004), the building sector is assumed to be the main contributor at Bahir Dar. Building heat is associated with heat generated from electrical lighting and use of other electrical and cooking appliances. Modification of urban land (i.e., change in albedo, moisture, roughness and thermal storage) was responsible for absorption of more solar radiation during day times, which were gradually released thereby increasing both daytime and nighttime temperatures (Sailor and Lu, 2004). Compared to the heat emitted from buildings, heat emission from vehicular traffic was not significant at Bahir Dar because of the relatively low vehicle population. Contribution from human metabolism was generally very low since it is of the order of 5% even for cities with population of 10,000 persons/km^2 (Sailor and Lu, 2004), which was more than ten times that of Bahir Dar.

The minimum temperature showed a cyclic behaviour as the maximum temperature. For instance, years 1967–1978 (11 years) could be seen as one period, 1978–1989 (11 years) another period, 1989–2001 (11 years) as the third period and so on.

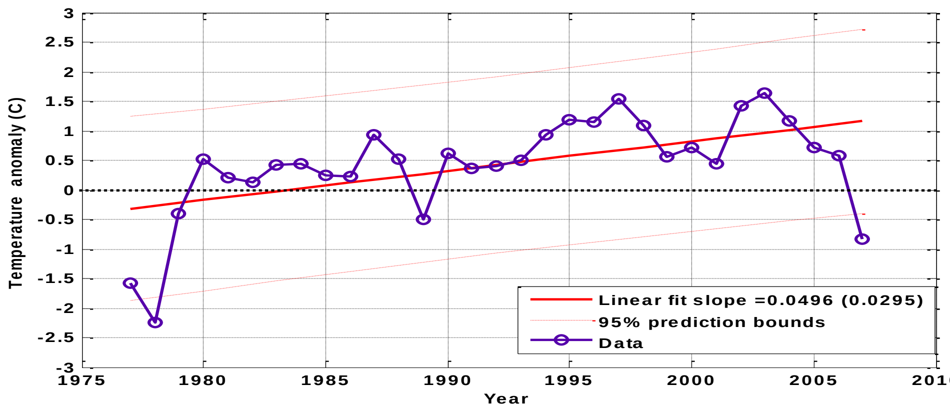
The trend line of the minimum had larger slope of 0.060 ^{o}C (0.6 ^{o} per decade) than that of the maximum temperature of 0.25 ^{o}C per decade (Table 2). This is in agreement with what was observed globally over the past half a century (Price *et al.,* 1999; New *et al.,* 2000; Kalnay and Cai, 2003; Braganza *et al.,* 2004). DTR, which is a suitable index of climate variability and provides additional information of the attributes of recent observed climate change (Braganza *et al.,* 2004) also, depicted a negative slope at Bahir Dar (Figure 2c). It meant that the minimum temperature was monotonically increasing at a faster rate than the maximum temperature thereby contributing more to the average temperature. Even though the trend was similar to global trend as mentioned earlier, the DTR decline observed at Bahir Dar (-0.34 ^{o}C per decade) differed from the global value of about -0.08 ^{o}C per decade (Stone and Weaver, 2002; Braganza *et al.,* 2004). It reflected narrowing of the DTR (faster warming at night) and signalled anthropogenic forcing of recent climate change (Easterling *et al.,* 1997; Stone and Weaver, 2002).

A decrease in DTR worldwide over the past fifty years is claimed on cloud cover and moisture (Dai *et al.,* 1999). Clouds in association with soil moisture and precipitation can reduce DTR by as much as 25-50% as compared to clear days (Dai *et al.,* 1999). Clouds have dual effects when it comes to air temperature on land mass. During daytime they tend to reflect more of the incoming shortwave radiation (on account of their increased albedo) and this tends to reduce the daytime maximum temperature. At night, clouds reflect back to earth the outgoing longwave (thermal) radiation, which ultimately increases nighttime (minimum) temperature (Dai *et al.,* 1999). Soil moisture on the other hand has the effect of evaporative cooling, which takes predominantly during daytime and is significant especially during dry seasons. This tends to reduce daytime temperature more than nighttime temperature. Precipitation is associated with soil moisture since it increases the soil moisture. The three together indicate intensification of the hydrologic cycle. In this study, precipitation showed a decreasing trend and no appreciable change (data analysis not shown here) has been observed for the cloud cover in terms of sunshine hours. Despite the two facts, reduction in the value of DTR can be explained using rainfall pattern at Bahir Dar during the past fifty years (Figure 4). For instance, between 1979 and 2006 variability in DTR was relatively low compared to the periods before and after. Referring to Figure 4, before 1978 rainfall at Bahir Dar was above average, which means during this period cloud cover, rainfall and soil moisture were higher and all of these have contributed to higher DTR reduction. Similar argument could be given for the period after 2006 even though this period was relatively shorter.

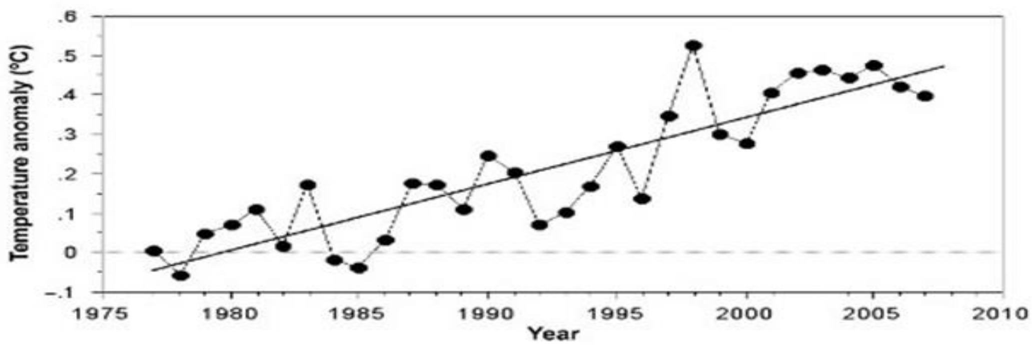
3.2. Change in Average Temperature at Bahir Dar and Global Temperature Trend

For comparison of change in average temperature at Bahir Dar with the change in global average temperature, identical years were selected (1977-2007) and two plots were shown (Figures 3a and 3b) in terms of temperature anomalies.

Comparison between global average temperature anomaly (Figure 3b) and average surface temperature anomaly at Bahir Dar (Figure 3a) during the same period (1977-2007) shows a global average temperature change of about 0.5^{o}C in thirty years compared to 1.5±0.9 ^{o}C at Bahir Dar. Average temperature anomaly at Bahir Dar was higher than the global anomaly because of UHI effect. Energy consumption of cities is very high (about 70%) in proportion to their areal coverage, which is only about 2% (WEO, 2008). More consumption of energy means production of more waste heat that has the ability to affect temperature, humidity, and air quality (Anne *et al.,* 2012). Waste heat emission increases near surface circulation and improves near surface turbulent activity, which is stronger at night than daytime (Chen *et al.,* 2009).



(a)



(b) Source: IPCC (2007)

Figure 3. Comparison of (a) time series average temperature anomaly at Bahir Dar, 1977-2007 and (b) average global surface temperature anomaly, 1977–2007.

Globally, seven of the eight warmest years occurred within a period of 2000-2007 (IPCC, 2007) while within the same period Bahir Dar had experienced three of the eight warmest years. The 1997-1998 El Nino was a major contributor to the 1998 high temperature globally (Glebushko, 2004) during which Bahir Dar also experienced one of the warmest temperatures on record (1997). During the same period the rainfall at Bahir Dar was also very low (Figure 4) even though the year was not one of the driest. One has to note that the global temperature average is the average of several locations on the globe some of which experienced large temperature increment like Bahir Dar, while others were of modest temperature changes. Average temperature of Bahir Dar was also higher than the national average of 0.46 ^{o}C computed using data from 1952 to 1998 (MoWR and NMSA, 2001).

The Earth's surface temperature undergoes a thirty year cyclic change of cool and warm temperatures because of the effect of Pacific Decadal Oscillation (PDO) (Compo and Sardeshmukh, 2009). PDO is a climatic index, which is based on the surface temperature of the North Pacific (Mantua *et al.,* 1997) and it is important in the understanding of global warming. It is a long-lived pattern, which is similar to El Nino of Pacific climate variability in pattern but with different time scales (Mantua and Hare, 2000; Biondi *et al.,* 2001). It is a large-scale interaction between the ocean and the atmosphere (Glebushko, 2004). Unlike El Nino, which takes place every three to six years and usually lasts 9-12 months or at times even 18 months, PDO has cycles of longer duration (Biondi *et al.,* 2001; Glebushko, 2004). Based on PDO, the period from 1945-1975 was a cool period, whereas 1976-2005 was a warm period (Compo and Sardeshmukh, 2009). The temperature pattern at Bahir Dar reflected this pattern especially, between 1961 and 1978 (cool cycle, Figure 6), during which all temperatures remained below average (19.2 ^{o}C shown by dash-dot line). Between 1980 and 2005 was a warm cycle during which all temperatures (except 1989) remained above average.

A Quasi-Decadal Oscillation (QDO) has a period ranging from 8-12 years and it is considered as a high frequency PDO that seems to be related to the sunspots (Compo and Sardeshmukh, 2009**)**. A sunspot is the solar activity that takes place on the surface of the sun and affects the amount of electromagnetic radiation reaching the earth (Foukal and Lean, 1990). Even though the dark sunspots impede the free flux of energy from the sun's interior and tend to have the cooling effect, the bright faculae (bright and extremely hot spots) around the sunspots increase the solar activity and compensate the loss due to the sunspots and create surplus irradiance thereby increasing earth surface temperature (Foukal and Lean, 1990). QDO was not clearly observed at Bahir Dar but one could assume the period between 1978 and 1989 and between 1990 and 2000 as two such cycles with periods of eleven years each.

3.3. Rainfall Pattern at Bahir Dar

The rainfall pattern at Bahir Dar (Figure 4) has shown monotonic decline over the years as indicated by the regression line (solid line with slope = -3.24±4.40). This decline amounts to about 160 mm, a reduction in average rainfall in 2010 compared to the average value in 1961. On top of the decline, the rainfall has shown high variability as observed from the high deviation of the fitted line (± 4.40). The rainfall has also shown cyclic pattern even though the cycles did not have the same duration. For instance, between 1966 and 1977 (the first dotted rectangle in Figure 4), Bahir Dar experienced above average rainfall (horizontal dash-dot line in the same figure marked I). This was followed by duration of below average rainfall, i.e., 1978-1988 (dotted rectangle marked II). Each of these two cycles lasted an average of eleven years. The next two cycles (III and IV) each lasted only about five years, which was nearly half the duration recorded for I and II.

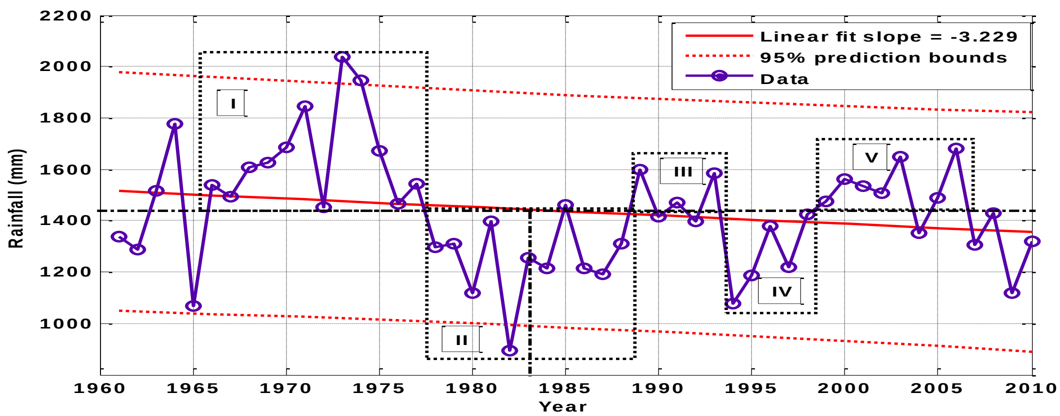


Figure 4. Rainfall pattern at Bahir Dar, 1961-2010. The dash-doted horizontal line indicates the average rainfall (1435 mm) of 50 years.

Table 1. Time series rainfall parameters and their values at Bahir Dar; 1961-2010.

Parameters	Values
Available sample years	50
Average (mm)	1435
Median (mm)	1441
Standard deviation (mm)	226
Minimum (mm)	895 (in 1982)
Maximum (mm)	2037 (in 1973)
Skewness coefficient	0.26

The cycles during which there were above average rainfall (I, III, and V) were followed by cycles of below average rainfall (II and IV). On average, the long duration cycles took about 10 to 11 years (I, II, and V), while the short duration cycles took 4 to 5 years (III and IV). Extremes (maximum of above average or minimum of below average cycles) that occurred with the cycles that took longer duration were generally higher than extremes that occurred within the short cycles.

Those cycles with above average rainfalls were characterized as wet years and were favorable for crops but there might have been floods during those periods. Such cycles were also favorable for recharge of lakes and ground water. Region V was more in line with the Sahel that has experienced a shift to wetter regime since 2000 (Nicholson, 2005). On the other hand, the decade of 1990-2000 was the year of drought for Sahel (Nicholson, 2000) and a portion of the period (IV) was a dry period for Bahir Dar as well. Most of the wet and dry times experienced by Sahel, for instance, major droughts of 1972-73 and 1983-84 (Bobee *et al.,* 2012) were also experienced at Bahir Dar (e.g., a sharp drop in rainfall in 1972 and region II, respectively). According to Tschakert (2007), years 1976-1988 marked dry period for Sahel and this overlapped with region II shown in Figure 4, which has experienced the lowest cumulative rainfall at Bahir Dar since rainfall recording started.

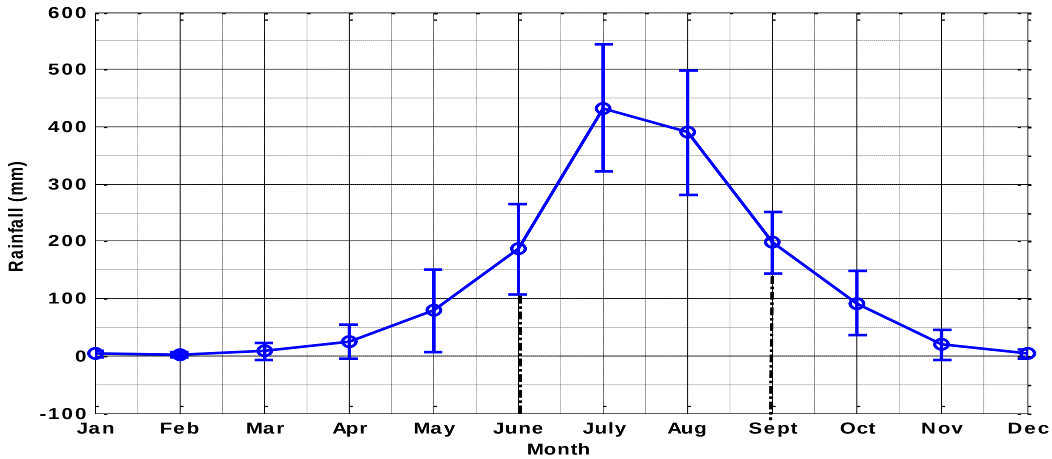


Figure 5. Variability of monthly-averaged rainfall at Bahir Dar, 1961-2010.

Monthly variability of rainfall (Figure 5) at Bahir Dar indicated that, 84% of the mean took place between June and September, with skewness of 1.3. The figure showed maximum rainfall in July (30%) followed by August (27%). June and September had nearly identical contributions of 13 and 14%, respectively. Even though the total rainfall has shown a decline of 160 mm over fifty years, the decline of the four months' total was smaller (only 96 mm or 60% of the total decline). This indicates that the decline had less effect on the growing season.

3.4. Comparison of Temperature Changes at Bahir Dar with that of Debre Markos

Regression lines fitted to temperature data of the two locations (BD and DM) indicated slopes which were the same within margins of error (Table 2), which means both locations showed similar temperature changes over the fifty years. This happened despite differences in altitude, topography, and climate patterns of the two areas. The slope line and the average (19.2 ^{o}C) line at Bahir Dar crossed each other around 1984, while at Debre Markos (average temperature of 16.1 ^{o}C), the crossing occurred about two years later (shown by the two vertical dotted lines). Besides, Bahir Dar also showed more temperature fluctuations with respect to the fitted line. For instance, Bahir Dar showed more average temperature variability and this was manifested in its slope variability of ±0.014 ^{o}C compared to Debre Markos that showed slope variability of ±0.009 ^{o}C. Details are shown in Table 2.

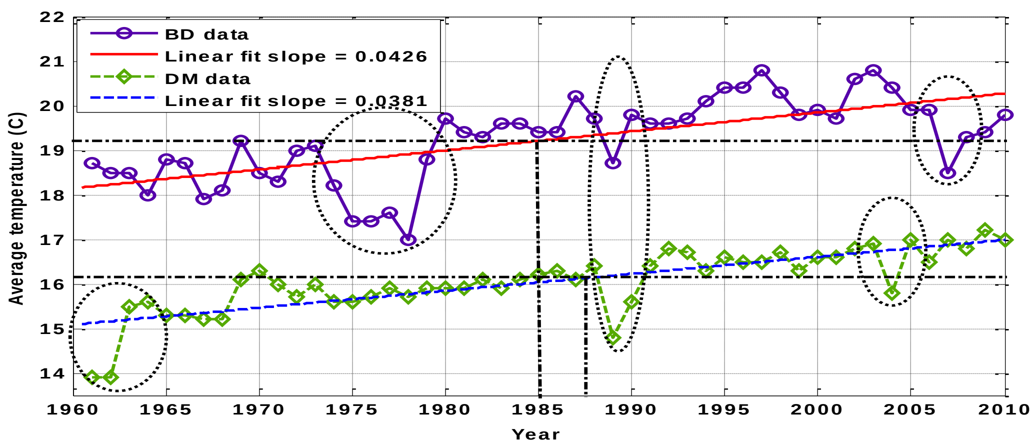


Figure 6. Time series average temperatures at Bahir Dar (BD) and Debre Markos (DM), 1961-2010.

After 1985, both Bahir Dar and Debre Markos experienced low average temperatures (lower than their respective averages shown with dotted and solid ellipses, respectively) two times in cycle of 18 years at Bahir Dar and 15 years at Debre Markos. The relatively lower average temperatures experienced at Bahir Dar between 1974 and 1979 (shown in doted circle) were due to unusually colder temperatures during those years at that location. The next below average temperature occurred after nearly 13 years, in 1989. The cold spell at Debre Markos before 1989 occurred 27 years earlier (1961/1962) shown in dotted circle.

Table 2. Temperature variability observed at Bahir Dar (BD) and at Debre Markos (DM), 1961-2010.

Parameter	Mean	SD*	Median	Maximum	Minimum	Slope	R^{2**}	50y***
T_{max} (°C), BD	26.7	0.7	26.7	28.1 (2003)	25.2 (1964)	0.025±0.010	0.33	0.75 – 1.75
T_{min} (°C) , BD	11.7	1.5	12.2	13.8 (1997)	7.8 (1978)	0.060±0.023	0.36	1.85 – 4.15
T_{avg} (°C) , BD	19.2	0.9	19.4	20.8 (2003)	17.0 (1978)	0.041±0.014	0.41	1.35 – 2.75
T_{max} (°C), DM	22.5	0.5	22.4	23.5 (2005)	21.6 (1962)	0.021±0.008	0.39	0.65 – 1.45
T_{min} (°C) , DM	9.7	1.0	10.0	11.1 (2010)	6.2 (1962)	0.054±0.012	0.64	2.10 – 3.30
T_{avg} (°C) , DM	16.1	0.7	16.1	17.2 (2009)	13.9 (1962)	0.038±0.009	0.62	1.45 – 2.35
DTR (C), BD	15.0	1.3	14.6	18.3 (1974)	13.3 (1994)	-0.034±0.023	0.15	-2.85 – 0.55
RH (%), BD	58.4	1.7	58.7	61.4 (1993)	55.3 (2006)	-0.052±0.011	0.04	-3.15 - -2.05
RH (%), DM	58.5	3.5	58.0	64.3 (1993)	50.8 (2009)	-0.378±0.155	0.55	-26.65 - -11.15

** SD = Standard deviation; **R^2= Regression coefficient; *** Change observed in 50 years; RH = Relative humidity with 23 years data; DTR = Diurnal temperature range; and the numbers in parentheses are years during which the maxima or the minima occurred.*

Maximum temperatures at both locations showed reduction from June to September (Fig. 7) because of cloud covers, which reduced the amount of direct radiation or beam reaching the surface of the earth. This in turn minimized the amount of radiation absorbed by the earth's surface and consequently reduced the air temperature. Slight reduction from December to February was due to low nighttime temperatures that suppressed average daytime temperatures. Minimum temperatures at the two locations experienced maximum values from May to September. This was due to cloud cover at night that reduced outflow of longwave radiation at night. Besides, the soil had more moisture during these months and could suppress daytime temperature through evaporative cooling. At Bahir Dar, the large lake area was capable of capturing direct radiation, which was absorbed by the water body and was not readily released to the air at night. It contributed to the depression of nighttime (minimum) temperature compared to that at Debre Markos.

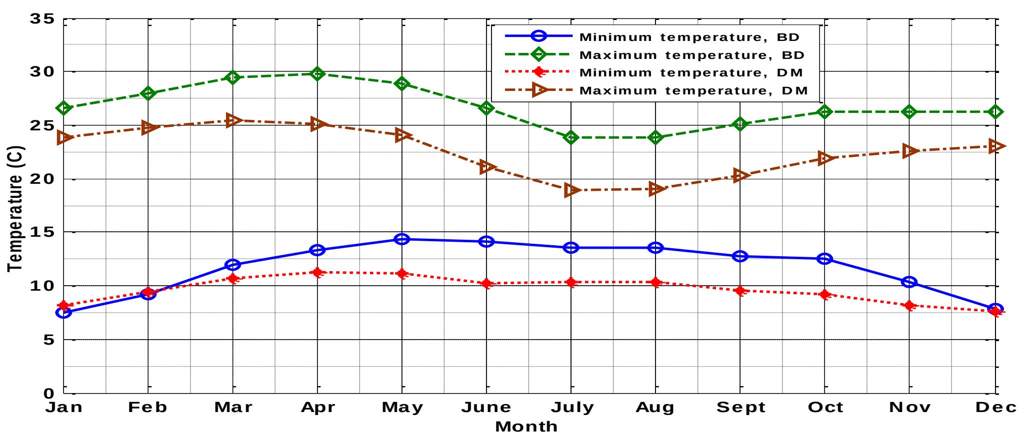


Figure 7. Average monthly variability of maximum and minimum temperatures at Bahir Dar (BD) and at Debre Markos (DM), 1961-2010.

3.5. Comparison of Relative Humidity of Bahir Dar with that of Debre Markos

Both Bahir Dar and Debre Markos have experienced nearly the same average relative humidity (58.6±2.0% and 58.5±3.4%, respectively, Figgure 8) commonly shown with a dotted horizontal line). However, Debre Markos experienced greater decline in relative humidity (slope = -0.378 ± 0.155) compared to Bahir Dar, which observed a decline of only -0.052±0.108. The slopes indicate a decline of about 8.7% at Debre Markos and only 1.2% at Bahir Dar over the twenty three years. The average line and the slopes of the two locations had a common intersection that occurred in 1999 (dotted vertical line). Relative humidity patterns of both locations were identical except in 1989 and 2006 (shown in dotted ellipses).

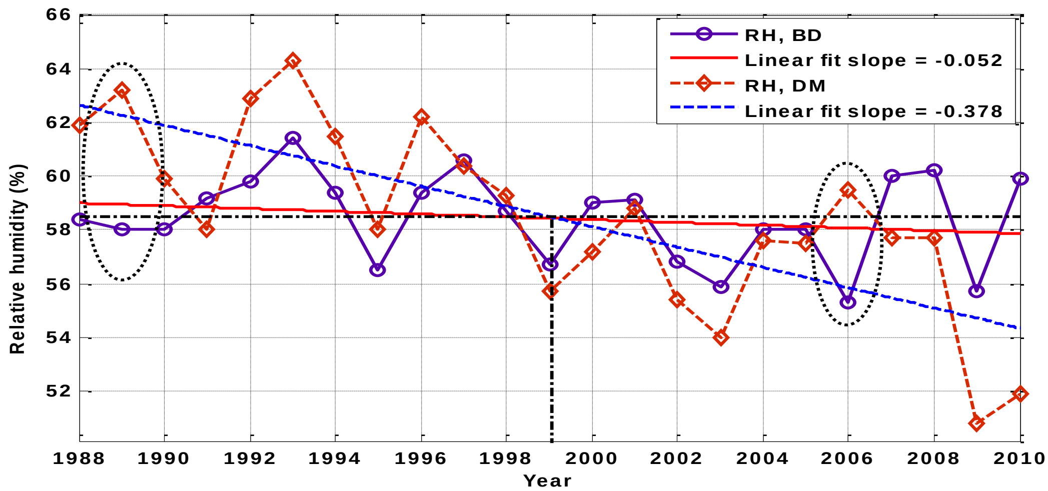


Figure 8. Time series in relative humidity of Bahir Dar (BD) and Debre Markos (DM), 1988-2010.

Between 1988 and 1997 Debre Markos experienced relatively larger relative humidity than Bahir Dar. From 1989 to 2005 the situation reversed i.e., Debre Markos showed decline in relative humidity since then (Figure 8). This must have been due to reduction of evaporation from the soil and transpiration from plants especially during the rainy seasons. This can be due to reduction in total plant population or lack of vegetation cover of the soil. On the other hand, there was no substantial reduction in relative humidity at Bahir Dar. The difference between the two must be due to the effect of the lake. The lake has contribution to relative humidity in a number of ways. First, there is direct evaporation from the body of water. Second, plants that are within the vicinity of the lake do not suffer from shortage of water and thus are capable of transpiring throughout the year thereby contributing to the relative humidity of the location even during dry months. In addition, in areas where the water table is close to the surface, suction of the soil can bring some amount of water close to the soil surface such that significant soil evaporation could take place.

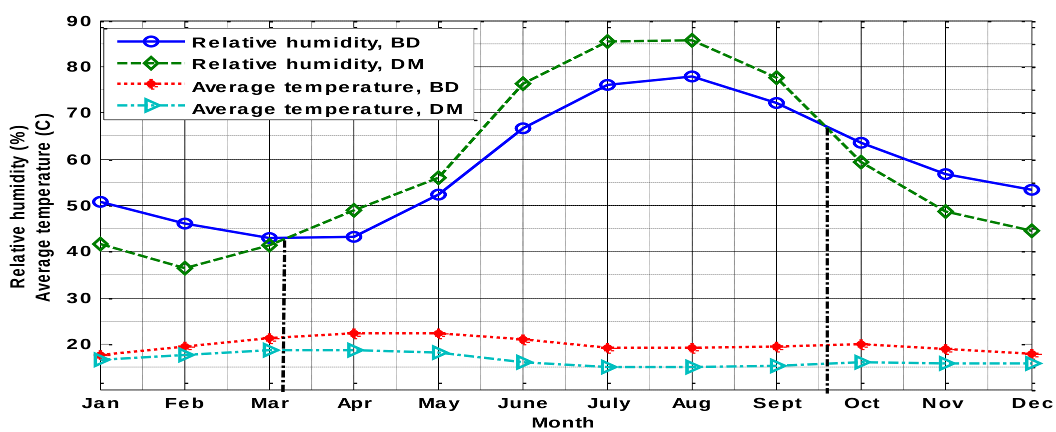


Figure 9. Monthly variability of relative humidity in relation to average temperature at Bahir Dar (BD) and at Debre Markos (DM), 1988-2010.

Monthly variability in relative humidity was due to variability in average temperature and moisture content of the atmosphere (Figure 9). During the rainy season (June to September) both areas experienced higher relative humidity. This was partly due to the presence of ample moisture in the atmosphere that has been contributed from transpiration from plants and vegetation and evaporation from the soil. The other reason is due to reduction in average temperature primarily due to cloud cover and hence less direct solar radiation reaching the surface. Since saturated vapor pressure is related to average temperature exponentially, the saturated vapor pressure increased during the rainy season because of reduced temperature. Hence, for the same vapor pressure in air, relative humidity increased during this time compared to the dry season.

Debre Markos had greater relative humidity during this time compared to Bahir Dar. The two crossing points of the relative humidity plots, after the first week of March and the second week of September (shown in the Figure 9 by dash-dot vertical lines) were indicative of changes in atmospheric behaviors. Between October and March the average temperatures of BD and DM approached each other (nearly touching each other in December and January). In 1993, when both locations had maximum relative humidity, the relative humidity of Debre Markos exceeded that of Bahir Dar by a substantial amount especially during the rainy season (June-September). The contribution of these months compared to the other months was almost equal to that of the other months. Contribution of identical months at Bahir Dar was only about 42% of the total. The difference between the two emphasized the fact that the average annual relative humidity at Debre Markos had strong contribution of the rainy season, whereas that of Bahir Dar had modest contribution from dry months as well. This was only possible because of the presence of the lake at Bahir Dar.

The year 1993 was a year during which average relative humidity were highest (Figure 8) at both locations (BD RH = 61.4±10.0 and DM RH = 64.3±19.3). During this year, DM had high slightly above average temperature that must have contributed to higher transpiration while BD had average temperature (Figure 6) and hence, had normal transpiration. This was assumed to be due to the lake effect. During the year 2009 both areas had low relative humidity (BD RH = 55.7±14.8 and DM RH = 50.8±18.1). Contribution of the lake to the RH of BD was mainly after the rainy season (September to December). Again, in this case as well, it was the rainy season that majorly contributed to the relative humidity of DM. The year 2009 was one of the years during which both areas had low relative humidity. During this year, even if Bahir Dar did not have high contribution in June and July, it managed to maintain relatively high relative humidity up to December.

4. Conclusions

This study tried to analyze changes in temperature and rainfall at Bahir Dar with respect to global changes and changes in temperature and relative humidity of Bahir Dar with those of Debre Markos. Over the last fifty years Bahir Dar has shown increment in average temperature of about 2 ^{o}C and a decrease in rainfall of about 160 mm. Despite the cyclic nature of both temperature and rainfall, increase in temperature over global average was attributed to rapid urbanization. Reduction in rainfall was more in line with the rainfall pattern of the Sahel.

To sum up, minimum temperature change at Bahir Dar was slightly affected by the thermal inertia of the Lake. However, the effect of the lake was not that much observable with the maximum and average temperatures. Average temperatures appeared to follow slightly different patterns for the two areas. The differences in the patterns were again assumed to be due to the lake effect at BD. Debre Markos showed decline in relative humidity higher than Bahir Dar over the years. The difference between the two emphasized the fact that the average annual relative humidity at Debre Markos was from strong contribution of the rainy season, whereas that of Bahir Dar had substantial contribution from dry months as well.

The result obtained from this study has shown Bahir Dar to be similar to most other urban areas in the world experiencing UHI effect and this effect was more apparent than the lake effect when it comes to average temperature change. Temperature cycles of long duration at Bahir Dar seem to follow PDO pattern. But since climate change is wide and complex phenomenon and fifty years though it may seem a long time may not be sufficient to give conclusive results of oscillation patterns. Hence, it is important to have data that covers greater time span to give conclusive results on temperature oscillations.

5. Acknowledgement

The authors are grateful to the National Meteorological Agency, Bahir Dar Branch Office for providing the meteorological data used for the study.

6. References

Anne, K., Quah, L. and Roth, M. 2012. Diurnal and weekly variation of anthropogenic heat emissions in a tropical city, Singapore. *Atmospheric Environment* 46: 92-103.

Bobee, C., Ottle, C., Maignan, F., de Noblet-Ducoudre, N., Maugis, P., Lezine, A.M. and Ndiaye, M. 2012. Analysis of vegetation seasonality in Sahelian environments using MODIS LAI, in association with land cover and rainfall. *Journal of Arid Environment* 84: 38-50.

Biondi, F., Gershanov, A. and Cayan, D.R. 2001. North Pacific decadal climate variability since AD 1661. *Journal of Climate* 14(1): 5-10.

Braganza, K., Karoly, D.J. and Arblaster, J.M. 2004. Diurnal temperature range as an index of global climate change during the twentieth century. *Geophysics Research Letters.* 31: L13217

Chen, Y., Jiang, W.M., Zhang, N., He, X.F. and Zhou, R.W. 2009. Numerical simulation of anthropogenic heat effect on urban boundary layer structure. *Theoretical and Applied Climatology* 97: 123-134.

CSA (Central Statistical Agency). 1994. Census Conducted by the Central Statistical Agency, Addis Ababa, and Ethiopia.

CSA (Central Statistical Agency). 2008. Summary and Statistical Report of the 2007 Population and Housing Census. FDRE Population and Census Commission, 2008. Addis Ababa, Ethiopia.

Compo, G.P. and Sardeshmukh, P.D. 2009. Oceanic influences on recent continental warming. *Climate Dynamics* 32: 333-342.

Dai, A., Trenberth, K.E. and Karl, T.R. 1999. Effects of Clouds, Soil Moisture, Precipitation and Water

Vapor on Diurnal Temperature Range. *Journal of Climate* 12(8): 2451-2473.

Easterling, D.R., Horton, B., Jones, P.D., Peterson, T.C., Karl, T.R., Parker, D.E., Salinger, M.J., Razuvayev, V., Plummer, N., Jamason, P. and Folland, C.K. 1997. Maximum and minimum temperature trends for the globe. *Science* 277(5324): 364-367.

Foukal, P. and Lean, J. 1990. An empirical model of total solar irradiance between 1874 and 1988. *Science* 247: 556-558.

Glebushko, K. 2004. CSA Discovery Guides: The El Niño Phenomenon: From Understanding to Predicting. http://www.csa.com/discoveryguides/discoveryguides-main.php. (Accessed on June 30, 2012)

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. The Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report. Cambridge University Press, Cambridge.

Kalnay, E. and Cai, M. 2003. Impact of urbanization and land-use change on climate. *Nature* 423: 528-531.

Mantua, N.J. and Hare, S.R. 2000. The Pacific Decadal Oscillation (PDO). *Journal of Oceanography* 58: 35-44.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M. and Francis, R.C. 1997: A Pacific inter-decadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society* 78(6): 1069-1079.

MoWR and NMSA (Ministry of Water Resources National Meteorological Service Agency). 2001. Initial National Communication of Ethiopia to the UNFCCC. Addis Ababa, Ethiopia.

New, M., Hulme, M. and Jones, P. 2000. Representing twentieth century space-time climate variability. Part II: development of 1901-96 monthly grids of terrestrial surface climate. *Journal of Climate*. 13: 2217-2238.

Nicholson, S. 2000. Land surface processes and Sahel climate. *Reviews of Geophysics* 38: 117-139.

Nicholson, S. 2005. On the question of the "recovery" of the rains in the West African Sahel. *Journal of Arid Environment* 63: 615-641.

NMA (National Meteorological Agency). 2007. Climate Change National Adaptation Programme of Action (NAPA) of Ethiopia. Ministry of Water Resources National Meteorological Agency. NMA Addis Ababa, Ethiopia.

Parker, D. E. 2006. A demonstration that large-scale warming is not urban. *Journal of Climate*. 19: 2882-2895.

Price, C., Michaelides, S., Pashiardis, S. and Alpert, P. 1999. Long-term changes in diurnal temperature range in Cyprus. *Atmospheric Research*. 51: 85-98.

Sailor, D.J. and Lu Lu. 2004. A top-down methodology for developing diurnal and seasonal anthropogenic heating profile for urban areas. *Atmospheric Environment* 38: 2737-2748.

Smit, B. and Pilifosova, O. 2003. From Adaptation to Adaptive Capacity and Vulnerability Reduction, *In*: Smith, J.B., Klein, R.J.T. and Huq, S. (eds.), Climate Change, Adaptive Capacity and Development, Imperial College Press, London.

Stone, D.A. and Weaver, A.J. 2002. Daily maximum and minimum temperature trends in a climate model. *Geophysics Research Letters*. 29(9): 1356.

Tschakert, P. 2007. News from the vulnerable: understanding climatic and other stressors in the Sahel. *Global Environmental Change* 17: 381-396.

WEO (World Energy Outlook). 2008. World Energy outlook 2008, the authoritative source of energy analysis and projections, Paris.

Yarnal, B. 1998. Integrated regional assessment and climate change impacts in river basins. *Climate Research* 11:65-74.