Recent precipitation and temperature changes in Djibouti City

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ABSTRACT

A dataset of derived indicators has been compiled to clarify whether the frequency and / or the severity of rainfall and temperature extremes changed over the last decades in the city of Djibouti in East Africa. This study uses the only current available coverage of homogenous daily series which can be used for calculating any significant change in rainfall and temperature in recent years. It covers the 1980–2011 period for precipitation and the 1966–2011 period for what regards maximum, minimum and mean temperature. We used a set of 23 indicators of extreme climatic events.

Results show that the annual total precipitation, the annual total of wet days (with daily rainfall >= 1mm) and the frequency of very wet days (defined as the 95th percentile) have strongly declined over the last 32 years. Yet, since 2007, mean yearly rainfall meets a 73% deficit when compared to the 30-year average, a situation that is much worst than what was observed in the early 1980s.

For what regards temperatures, the average increase recorded during the 1966–2011 period is of +0.28°C per decade, a far higher value than the global rising temperature. Heatwaves characterized by daily maximum temperatures ≥ 45°C (that is the 99th percentile) have become 15 times more frequent than in the past (comparing the 1966–75 and 2002–2011 periods) while extremely cool nights (<18.7°C, that is the 1st percentile in minimum temperature) have almost disappeared.

Although the database should be extended to improve the global picture of recent climate changes in Djibouti, it seems very likely that rainfall shortages and increasing temperature extremes have already impacted the people of the Republic of Djibouti, especially the water availability and health sectors.

Adaptation strategies are urgently needed since the global warming process is not likely to decline in the next decades.

Keywords: Extreme precipitations; Extreme temperatures; Indices; Trend analysis; Climate change; Republic of Djibouti.

I. INTRODUCTION

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.

According to the Climate Research Unit of the University of East Anglia (Jones, 2012), the period 2001-2010 (0.44°C above 1961-90 mean) was 0.20°C warmer than the 1991–2000 decade (0.24°C above 1961-90 mean). The warmest year of the entire series has been 1998, with a temperature of 0.55°C above the 1961–1990 mean. After 1998, the next nine warmest years in the series are all in the decade 2001–2011. During this decade, 2008 was the coldest year of the 21st century although it was the 13th warmest year of the whole record.

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007), most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. The observed widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is extremely unlikely that global climate change of the past 50 years can be explained without external forcing and very likely that it is not due to known natural causes alone. During this period, the sum of solar and volcanic forcings would likely have produced cooling, not warming.

Some extreme weather events have received increased attention in the last few years within the perspective of climate change. Studies show that they have changed in frequency and/or intensity over the last 50 years. Yet, it is very likely that cold days, cold nights and frosts have become less frequent over most land areas, while hot days and hot nights have become more frequent. It is also likely that heatwaves have become more frequent over most land areas, that the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas, and that the incidence of extreme high sea level has increased at a broad range of sites worldwide since 1975 (IPCC, 2007).

In addition to the climate change impacts, population and infrastructure continue to develop in areas that are vulnerable to extremes such as flooding, storm damage, and extreme heat or cold. Furthermore, land use change can often further increase vulnerability by creating more potential for catastrophic impacts from climate extremes, such as flooding due to extreme precipitation events.

Although the frequency, the intensity and the impacts of extreme weather events are well documented in most parts of the world, there has been a paucity of information on trends in daily extreme rainfall events in Africa (New *et al.,* 2006). The lack of long-term daily climate data suitable for analysis of extremes is the biggest obstacle to quantifying whether extreme events have changed over the last decades, either continental or on a more regional basis (Easterling *et al*., 1999). We took a systematic review of the literature to find relevant studies dealing with the variability of recent climate in the Republic of Djibouti, searching the Scopus abstract and citation database of research literature and quality web sources (www.scopus.com). The search extended from 1991 to 2012 but found no result, neither on precipitation nor on temperature. The present study aims to fill in this gap. In this paper, evidence for changes in the intensity of extreme daily rainfall and temperature events in Djibouti City during the last decades is assessed. Our database is briefly described; then, results of the tendency analysis of extreme climate indices based on daily precipitation are discussed.

II. DATA AND METHODS

Database

For the analysis of recent trends of extreme precipitation and temperatures, data were made available for the synoptic station of Djibouti City (Lat: 11.55 N; Long: 43.15 E; altitude: 13 m asl) located near the international airport of Djibouti from the “Agence Nationale de la Météorologie (ANM) de Djibouti”. The database includes daily precipitation data from January 1980 to December 2011 and maximum, minimum and mean daily temperatures from January 1966 to December 2011. There were no missing data, so the database can be used for trend analysis (Klein Tank et al., 2002).

Extreme rainfall indices

In this study, 12 rainfall indices were calculated over the January to December period and are listed in Table 1. These are the annual total precipitation (PTOT); the annual total of wet days (with daily rainfall ≥ 1mm, Rd); the simple day intensity index (SDII) was calculated as the average rainfall from wet days; the annual maximum rainfall recorded during 1 day (Rx1d); and the number of heavy precipitation (rainfall ≥ 10 mm, R10mm) and very heavy precipitation (rainfall ≥ 20 mm, R20mm) days. Other six indices are based on the 95th and 99th percentiles which define a very wet day and an extreme rainfall event, respectively (Manton *et al*., 2001; Griffiths *et al*., 2003; Haylock *et al*., 2006). These percentile values were calculated from daily rainfall data over the 1981–2010 period. For the station of Djibouti City, the thresholds calculated from percentiles are 46.9 mm and 108.1 mm to define a very wet day and an extreme rainfall event, respectively. Based on these percentiles, two extreme precipitation indices were chosen. Very wet day and extreme rainfall frequency are based on the annual count of days when rainfall ≥ 95th and 99th percentiles of 1981–2010 (R95p and R99p). Very wet day and extreme rainfall intensity correspond to the annual total precipitation recorded from days when rainfall ≥ 95th and 99th percentiles of 1981–2010 (R95pSUM and R99pSUM) and give an indication on the rain received from very wet or extreme rainfall. Very wet day and extreme rainfall proportion are the percentage of the annual total precipitation recorded from days when rainfall ≥ 95th and 99th percentiles of 1981–2010 (R95pTOT and R99pTOT) and measure how much of the total rain comes from very wet or extreme events.

Table 1: Rainfall indices with their definitions and units.

ID	INDICATOR NAME	DEFINITION	UNIT
PTOT	Precipitation total	Annual total precipitation	[mm]
Rd	Rainfall days	Annual total of wet days (rainfall ≥ 1mm)	[days]
SDII	Simple day intensity index	Average rainfall from wet days	[mm/day]
Rx1d	Maximum 1-day rainfall	Annual maximum 1-day rainfall	[mm]
R10mm	Number of heavy precipitation days	Annual count of days when rainfall ≥ 10 mm	[days]
R20mm	Number of very heavy precipitation days	Annual count of days when rainfall ≥ 20 mm	[days]
R95p	Very wet day frequency	Annual count of days when rainfall ≥ 95th percentile of 1981-2010	[days]
R99p	Extreme rainfall frequency	Annual count of days when rainfall ≥ 99th percentile of 1981-2010	[days]
R95pSUM	Very wet day intensity	Annual precipitation from days when rainfall ≥ 95th percentile of 1981-2010	[mm]
R99pSUM	Extreme rainfall intensity	Annual precipitation from days when rainfall ≥ 99th percentile of 1981-2010	[mm]
R95pTOT	Very wet day proportion	Percentage of annual precipitation from days when rainfall ≥ 95th percentile of 1981-2010	[%]
R99pTOT	Extreme rainfall proportion	Percentage of annual precipitation from days when rainfall ≥ 99th percentile of 1981-2010	[%]

Extreme temperature indices

The analysis of minimum, maximum and mean temperatures is based on 11 indices calculated over the January to December period (Table 2). Three of then are based on the annual average value of daily minimum, maximum and mean temperatures (ATN, ATX and ATM) in order to analyse the global trends in temperatures. All other indices are based on the 1st, 5th, 95th and 99th percentiles which define 'extremely cool', 'cool', 'warm', and 'extremely warm' nights (using Tmin) and days (using Tmax), respectively (adapted from Aguilar et al., 2005; Zhou & Ren, 2011). These percentile values were calculated from daily rainfall data over the 1971–2000 period. Threshold temperature values calculated from percentiles are presented in Table 2, but note that, in Djibouti, an extremely cool night is characterized by minimum temperatures ≤ 18.6°C while an extremely warm day is defined when maximum temperatures are ≥ 45.0°C.

Table 2: Temperature indices with their definitions and units.

ID	INDICATOR NAME	DEFINITION	UNIT
ATN	Average annual Tmin	Annual average value of daily minimum temperature	[°C]
ATX	Average annual Tmax	Annual average value of daily maximum temperature	[°C]
ATM	Average annual Tmean	Annual average value of daily mean temperature	[°C]
TN1p	Extreme cool night	Annual count of days when Tmin ≤ 1th percentile of 1971-2000 (18.6°C)	[days]
TN5p	Cool night	Annual count of days when Tmin ≤ 5th percentile of 1971-2000 (20.2°C)	[days]
TN95p	Warm night	Annual count of days when Tmin ≥ 95th percentile of 1971-2000 (32.2°C)	[days]
TN99p	Extreme warm night	Annual count of days when Tmin ≥ 99th percentile of 1971-2000 (33.6°C)	[days]
TX1p	Extreme cool day	Annual count of days when Tmax ≤ 1th percentile of 1971-2000 (27.5°C)	[days]
TX5p	Cool day	Annual count of days when Tmax ≤ 5th percentile of 1971-2000 (28.5°C)	[days]
TX95p	Warm day	Annual count of days when Tmax ≥ 95th percentile of 1971-2000 (43.9°C)	[days]
TX99p	Extreme warm day	Annual count of days when Tmax ≥ 99th percentile of 1971-2000 (45.0°C)	[days]

Trend analysis

In the analysis, trend coefficients are determined using linear regression modelling, which represent the increasing or decreasing rate of the given index during 1980–2011 period for precipitation and 1966–2011 period for temperatures. Each slope (positive or negative) was categorized in six classes indicating significant, moderate or non-significant trends. The regression procedure supplies a Student-t test and its resulting significance p-level to analyse the hypothesis that the slope is equal to 0. This p-level was used as a criterion to define the class boundaries. The trends, for each index, were labelled as "significant" if the p-level exceeded 0.05 for the one-tailed t-test, "moderate" if the p-level is ranged between 0.05 and 0.1 and otherwise “non significant” if the p-level is up to 0.1 (adapted from Hountodji *et al.*, 2006).

III. RESULTS

Precipitation

Time series of several precipitation indices can be seen in Figure 1. All indices show decreasing trends although most are statistically nonsignificant (Table 3). Yet, the annual total precipitation (PTOT), the rainfall days (Rd), the annual maximum rainfall recorded during 1 day (Rx1d), and the very wet day rainfall intensity (R95pSUM) decrease in a moderate way. Only the very wet day frequency (R95p) and the very wet day proportion (R95pTOT) present a significant decline. It is likely that the extreme rainfall events (R99p) decline may be significant but it is difficult to make statistics on a sample of four data.

Table 3: Trend analysis for 1980-2011 for rainfall (base period 1981-2010) indices.

ID	UNIT	AVERAGE 1981-2010	TREND UNITS / DECADE	SIGNIFICANCE (p-level)	TREND % / DECADE
PTOT	[mm]	164	-38.0	**0.10**	-17.4
Rd	[days]	14.1	-2.3	**0.07**	-13.5
SDII	[mm/day]	11.1	-0.5	0.70	-4.2
Rx1d	[mm]	56.4	-15.6	**0.09**	-19.5
R10mm	[days]	3.9	-0.5	0.38	-10.7
R20mm	[days]	2.1	-0.5	0.27	-16.7
R95p	[days]	0.70	-0.39	**0.03**	-30.2
R99p	[days]	0.13	-0.07	0.26	-29.7
R95pSUM	[mm]	59.7	-31.4	**0.07**	-29.1
R99pSUM	[mm]	21.3	-11.5	0.28	-29.5
R95pTOT	[%]	23.4	-14.2	**<0.01**	-31.3
R99pTOT	[%]	5.8	-3.7	0.20	-32.1

The most significant rainfall shortage is found over the last five years (see Fig. 1). Yet, since 2007, the yearly rainfall average is 44 mm, which is an extreme rainfall deficit of near 75% when compared to the 1981-2010 average (164 mm). During this same recent period, the synoptic station of Djibouti City did not record any extreme rainfall nor very wet day events. The maximum rainfall recorded during 1 day was 46 mm over the last five years.

These data are of the highest importance in terms of vulnerability evolution as well as for what regards future adaptation strategies to natural hazard reduction, especially concerning floods. This aspect will be discussed in the next section.

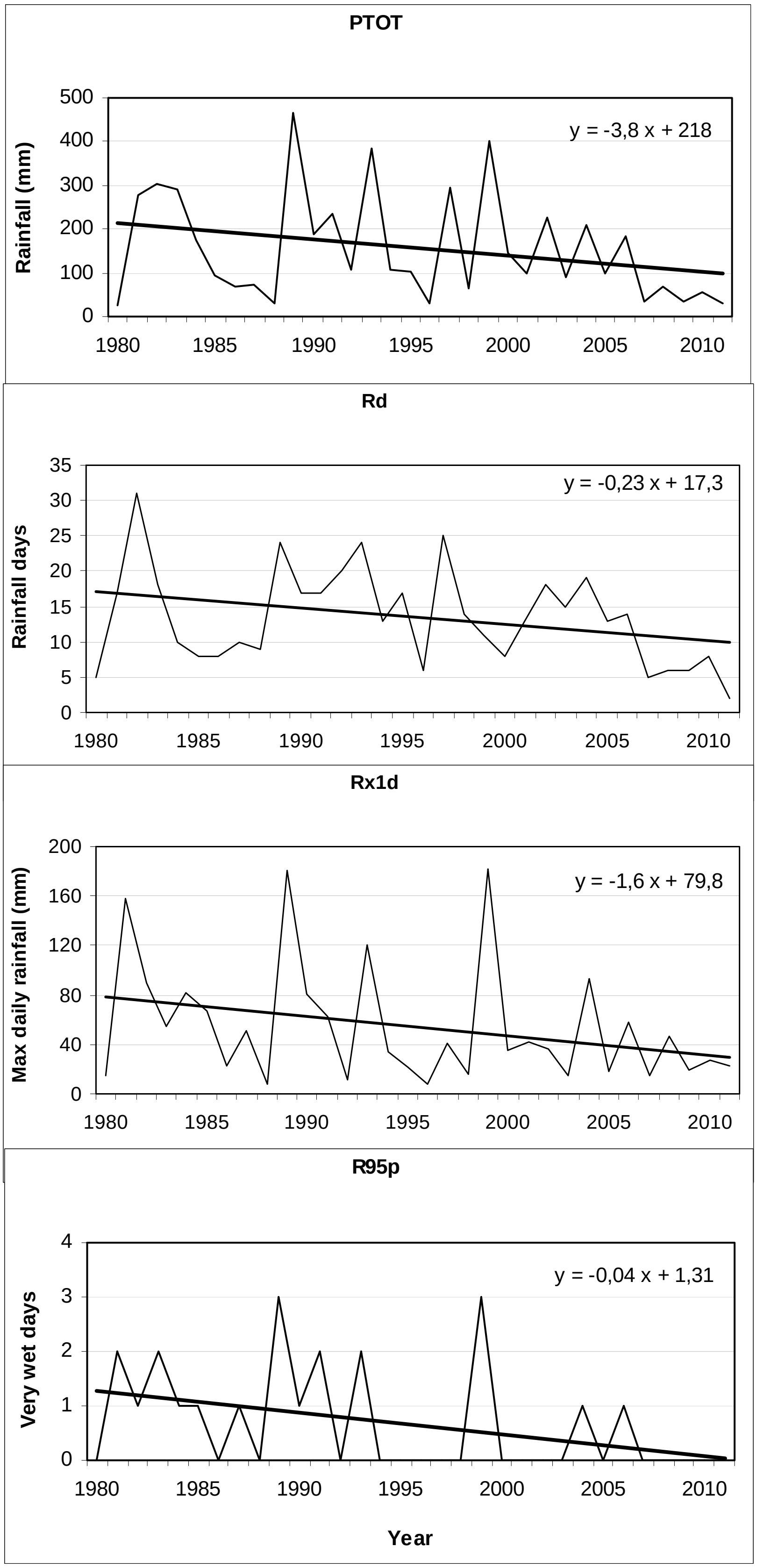

Figure 1: Evolution and trends of PTOT, Rd, Rx1d and R95p in Djibouti City (1980-2011).

Temperature

The analysis of the annual time series of the temperature indices indicates that changes in temperature extremes over the 1966–2011 period reflect warming for the Djibouti City area. The trends in annual average minimum, maximum and mean temperatures (ATN, ATX and ATM) presented in Figure 2 and given in Table 4 show a very significant increase of the three indices. Mean temperature increased by 1.24°C during the 1966–2011 period. The warmest year of the entire series was 2010 with mean temperature of 31.3°C, which is 1.18°C above the 1971–2000 mean. The ten warmest years of the whole record are registered since 1998. The period 2001-2011 was 0.66°C warmer than the 1971–2000 mean.

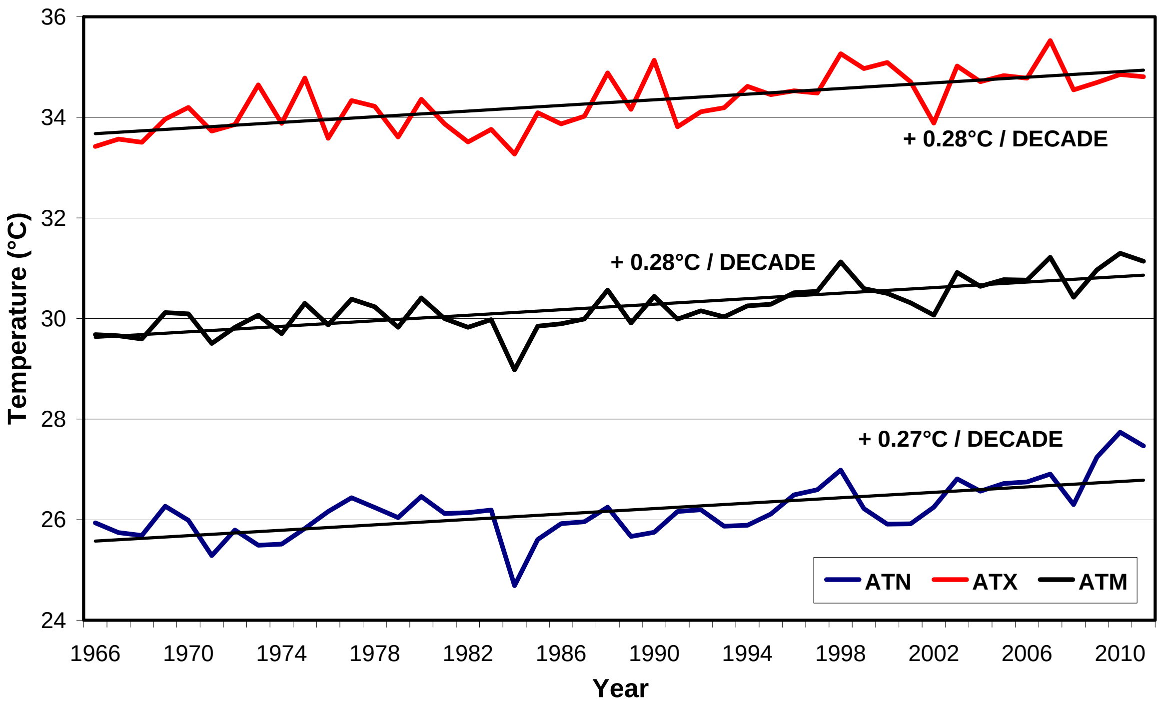

Figure 2: Evolution and trends of ATN, ATX and ATM in Djibouti City (1966-2011).

Table 4: Trend analysis for 1966-2011 for temperature (base period 1971-2000) indices.

ID	UNIT	AVERAGE 1971-2000	TREND UNITS / DECADE	SIGNIFICANCE (p-level)	AVERAGE 2001-2011
ATN	[°C]	26.0	+0.27	**<0.01**	26.8
ATX	[°C]	34.2	+0.28	**<0.01**	34.8
ATM	[°C]	30.1	+0.28	**<0.01**	30.8
TN1p	[days]	3.7	-1.2	**0.01**	1.4
TN5p	[days]	19.1	-4.8	**<0.01**	9.2
TN95p	[days]	18.8	+6.3	**<0.01**	38.3
TN99p	[days]	3.8	+2.8	**<0.01**	13.3
TX1p	[days]	4.0	-1.2	**<0.01**	2.1
TX5p	[days]	21.9	-9.0	**<0.01**	6.6
TX95p	[days]	19.0	+3.8	**<0.01**	28.5
TX99p	[days]	4.7	+2.7	**<0.01**	11.5

The annual number of warm and extremely warm days and nights, analyzed through the TX95p, TX99p, TN95p and TN99p indices, has significantly increased. Extremely warm days and nights were 11.5 and 13.3 on average during 2001-2011, a much higher figure than the average of 4.7 and 3.8 recorded during the 1971-2000 reference period (Table 4). Conversely, the number of cool and extremely cool nights and days, analyzed through TN5p, TN1p, TX5p and TX1p, has decreased significantly. These trends are shown in Figures 3 to 6.

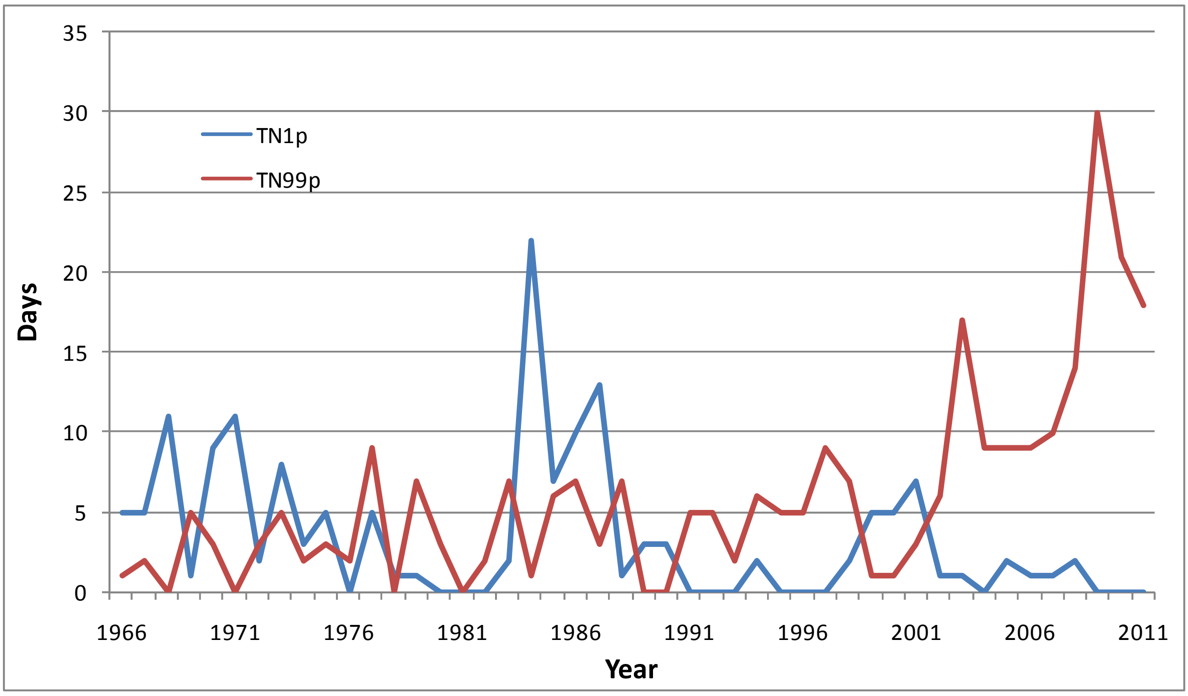

Figure 3: Evolution of extremely cool (TN1p) and warm (TN99p) nights in Djibouti City (1966-2011).

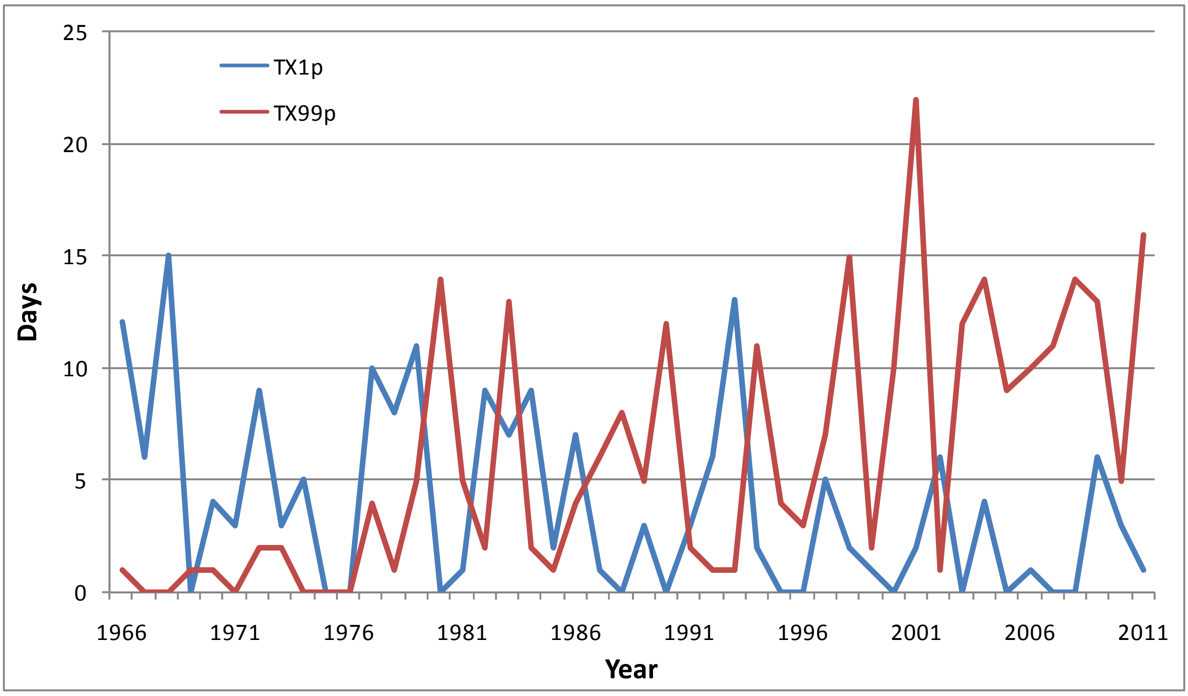

Figure 4: Evolution of extremely cool (TX1p) and warm (TX99p) days in Djibouti City (1966-2011).

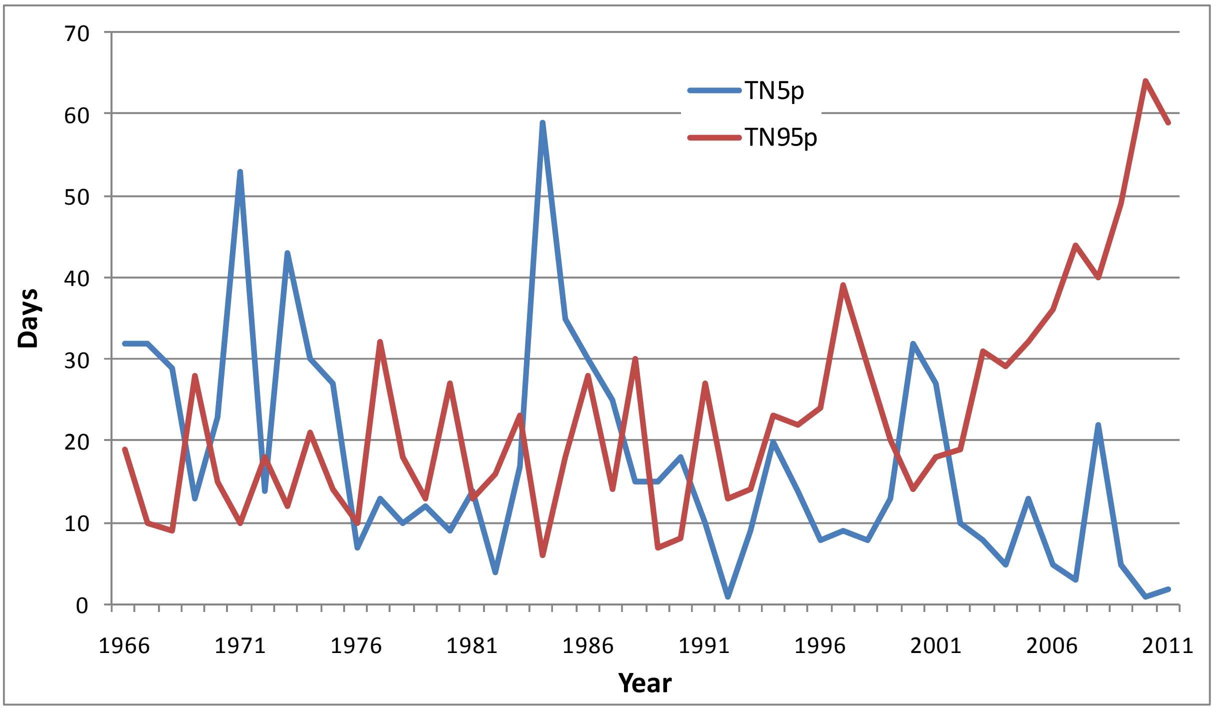

Figure 5: Evolution of cool (TN5p) and warm (TN95p) nights in Djibouti City (1966-2011).

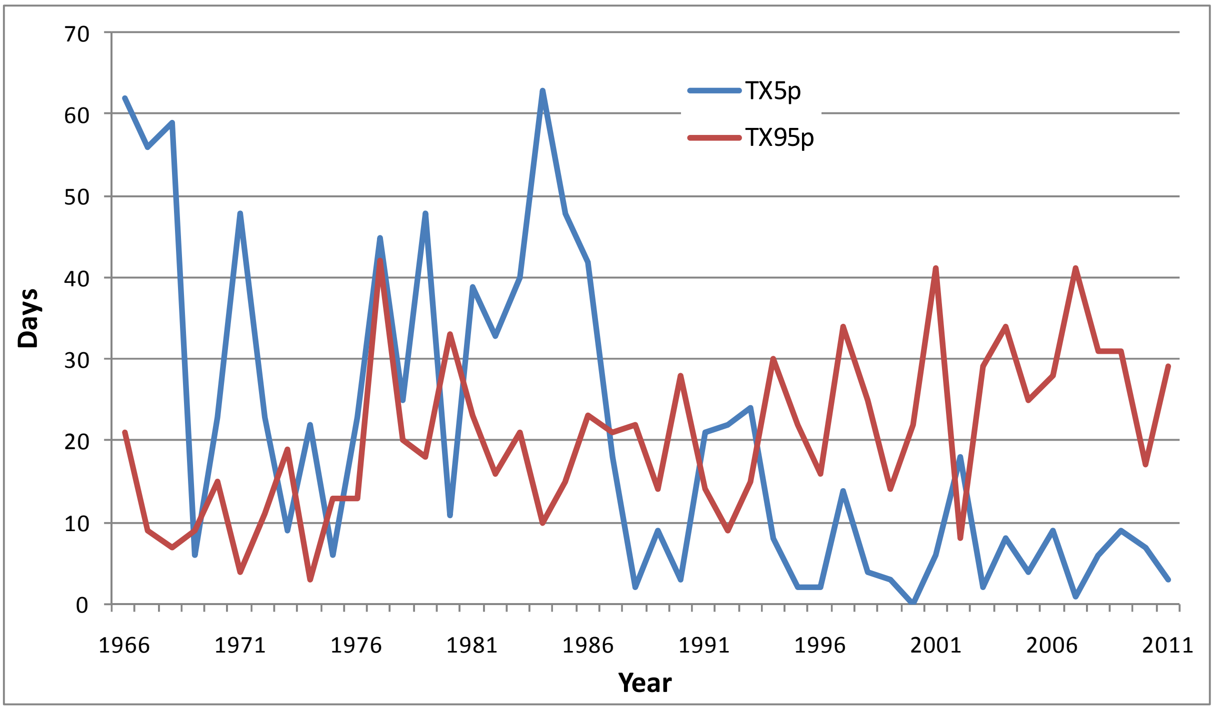

Figure 6: Evolution of cool (TX5p) and warm (TX95p) days in Djibouti City (1966-2011).

IV. DISCUSSION AND CONCLUSION

As mentioned previously, lack of long-term climate data suitable for analysis of extremes is the biggest obstacle to quantifying whether extreme events have changed over the last decades in

Africa. This paper presents, for the first time, the analysis of extreme precipitation and temperatures in Djibouti.

Results show that all rainfall indices, including the annual total precipitation, the annual total of wet days and the frequency of very wet days have declined over the last 32 years. The decrease in wet days is confirmed in most parts of Africa independently from the trend in annual total precipitation (Ozer & Ozer, 2005; Bewket & Conway, 2007; Frappart et al., 2009; Ozer et al., 2009; Hountondji et al., 2011). In addition, since 2007, mean yearly rainfall (44 mm) meets a 73% deficit when compared to the 30-year average (164 mm), a situation that is much worst than what was observed in the early 1980s and that continues (ICPAC, 2012). This clearly impacts the well-being and, in some cases, the survival of the inhabitants of the Republic of Djibouti, especially rural population whose migration towards Djibouti City has increased in recent years. By the end of 2011, near 19 million people were declared food insecure in East Africa, among which 140,000 people in the Republic of Djibouti (Sivakumar, 2011).

Drought is one of the main factors of migration to Djibouti City (Chiré, 2012). These new informal settlements continue to grow in the south and west of the city avoiding the restrictions put by the state and may be at risk (Chiré, 2012). Limited access to risk knowledge may lead to settlements in risk-prone areas. Yet, the maximum daily rainfall recorded over those last five years was 46 mm in 2008. But we showed here that extreme daily rainfall events are characterized by an amount over 108 mm. They occurred in the past, they will occur in the future. In addition, the fourth the latest IPCC report states that precipitation extremes are projected to increase worldwide (IPCC, 2007). Uncontrolled urbanization process may turn into catastrophic hazard in case of heavy and extreme rainfall as it has been seen elsewhere in Africa (Sene & Ozer, 2002; Tarhule, 2005; Ould Sidi Cheikh et al., 2007; Atedhor et al., 2011). The latest dramatic flood that impacted Djibouti occurred in 2004, affecting 100,000 people and killing 51. But the country also experienced killing floods in 1981, 1989 and 1994, systematically affecting over 100,000 people (Preventionweb, 2012). The risk of flooding is therefore real. Local authorities should pay attention to this specific hazard within urban planning policies.

All trends of temperature indices indicate a serious significant warming in Djibouti. Mean temperature increased by 1.24°C during the 1966–2011 period and the period 2001-2011 was 0.66°C warmer than the 1971–2000 mean. This increase in temperature is much higher than the global warming (Jones, 2012) and is consistent with other studies carried out in Africa (New et al., 2006; Aguilar et al., 2009; Elagib, 2010; Kruger & Sekele, 2012). Heatwaves characterized by daily maximum temperatures ≥ 45°C have become 15 times more frequent than in the past (comparing the 1966–75 and 2002–2011 periods) while extremely cool nights (<18.7°C) have almost disappeared. These impressive changes are observed at the global level (IPCC, 2007). Such increase in heatwaves clearly has an impact on human health (McMichael et al., 2012). The greater absolute burden of adverse health impact from heatwaves is in the general community, but workers in various heat exposed workplaces, both outdoors and indoors (if unventilated), are particularly vulnerable. The impact is therefore also economical. Considering this increasing threat, the health sector of the Republic of Djibouti should play a central role: to communicate the health risks of heatwave, to initiate studies on the real impact of such high temperatures on mortality and morbidity, and to promote, lead and evaluate a range of adaptive strategies. On its side, the National Agency of Meteorology of Djibouti should develop a heatwave early warning system in order to alert the population when weather conditions pose risks to health as it has been done elsewhere (Ebi et al., 2004).

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