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Trends of climate parameters over Tanzania

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Abstract. Analysis of the climate parameters over Tanzania were done for period 57-61 years. Rainfall and wind speed had greater variability than air temperatures. Positive significant trend of dry air temperature, maximal and minimal air temperatures were detected almost for all weather stations. As well positive trends of wind speed were detected just for stations Dodoma, Arusha, Mtwara and Mwanza. While rainfall trend analysis just for station Mtwara showed negative significant trend. In absolute values wind speed increased by 0.7-1.1 m/s, rainfall decreased by 89.3-136.1 mm, dry air temperature rise up 0.5-1.0 °C, maximal and minimal air temperatures values have grown by 2.0-3.6 °C.

1. Introduction

Tanzania is a country located in East Africa within the African Great Lakes region. It is bordered by Kenya and Uganda to the north, Rwanda and Burundi and the Democratic Republic of the Congo to the west (figure 1), Zambia, Malawi and Mozambique to the south and by the Indian Ocean to the east [1]. Country has two rainfall patterns which are bimodal and unimodal. In bimodal rainfall regime the first rainfall season started on March to May (MAM), and the second rainfall season started on October to December (OND), the rainfall amount are not the same for both seasons [2]. The OND season shows large interannual fluctuations and strongly related to large scale circulation anomalies in the Indian and Pacific oceans compared to the MAM season [3-6]. Even if the MAM season has not large interannual variability compared to OND season, MAM season contribute a large amount of the annual rainfall over Kenya and Tanzania compared to OND season [7, 8] and the unimodal rainfall regime started from November to April.

Variability of rainfall was associated with other factors, such as monsoon winds [9, 10], equatorial westerlies over the western Indian ocean and southeast trade winds over the south Indian Ocean [11], intraseasonal variability [8], Indian Ocean Dipole [12], Madden Julian Oscillation [13], Quasi-biennial Oscillation [14], Congo air mass [7, 9], Indian Ocean zonal mode [15], African jet streams [14], pressure gradient between Atlantic and Indian oceans, regional and local effects, tropical cyclones, easterly waves and westerly waves and sub-Tropical Anticyclones over the Indian ocean and Atlantic ocean [14]. Kruger and Shongwe [16] in their study of temperature trends in South Africa were used temporal and spatial trends for the period 1960 to 2003, shown that days and nights with relatively high temperatures have increased while the days and nights with relatively low temperature have decreased. Some studies related these changes with El Nino and la Nina events [17, 18, 19], whereby



during El Nino years, temperatures seem to be higher than during the La Nina years. However, other studies did not relate it with El Nino and La Nina events [16].



Figure 1. Location of Tanzania in Africa and its bordering.

Source: a) [20]; b) [21].

According to World Meteorological Organisation [22], the year 2013 was the warmest year on the continent since at least 1950 with more than above temperatures in most of the regions; however, Eastern Africa recorded almost average temperature in the same year. At the global scale, the annual mean surface air temperature indicated that year 2013 was the sixth warmest year since global records of temperatures began in 1850, and this warming among other reasons is due to the long-lived greenhouse gases, which is the strongest and the most certain warming effect on the climate [22]. Rainfall, temperature and wind are important variables in the climate studies. Increased temperature and changes in rainfall patterns as results of climate change were recognised in many areas include Tanzania [9, 23, 24, 25, 26]. Climate change has more effects in sub-Saharan Africa, where by the important economic activities is agriculture [27].

Weather and climate information are vital for protecting life and property during the severe rainfall and drought over Tanzania and Africa in general. However, many studies of the past and present patterns of climate over Tanzania have been derived from temperature and rainfall alone, this study attempt to fill this gap and use more parameters to investigate a long-term trend analysis of air temperature, maximum temperature, minimum temperatures, rainfall and wind speed over Tanzania.

2. Materials and methods

Data about rainfall, wind speed, dry, maximal and minimal air temperatures, and location of weather station was obtained from Tanzania Meteorological Agency (TMA) for whole period of observation.

Nine long-term weather stations were selected for this study based on location, length and completeness of the records. The primary goal for the station selection was to represent as far as possible and as well as possible the variety of geographical areas in Tanzania. Instrumental records on the weather data in Tanzania for selected weather stations were available since 1950 up to nowadays. In average each weather station has data for 57-61 years. Just Kigoma station has data for 33 years due to its relocation in 1981-1982. Among methods were used data screening, infilling missing rainfall data and linear regression method.

3. Results and discussion

3.1. Long-term average

Verified and reconstructed data were used for calculation of the long-term average climate data (table 1). Such long-term average data gives an understanding about the average climate characteristic

over the study region. As rule the use of the whole data set available gives the most proper values of data, hence it longest and includes different climate cycles. For comparison of how is the long term average could change was calculated other averages for 10, 20, 30, 40, 50 and 60 years.

Table 1. Long-term average climate data.

Weather station	Annual dry air temperature, °C	Annual min air temperature, °C	Annual max air temperature, °C	Annual sum of rainfall, mm	Annual wind speed, m/s
	1951-2015*	1953-2015*	1953-2015*	1950-2015*	1955-2015*
Dodoma	23.5	16.8	29.0	563	4.8
Dar es Slaam	27.8	21.3	30.9	1096	4.2
Arusha	21.2	14.3	25.8	811	3.8
Songea	22.8	15.8	26.9	1096	4.1
Mtwara	27.2	21.1	30.2	1093	5.6
Mbeya	19.9	11.1	23.9	913	4.3
Kigoma	24.5	18.9	28.9	929	3.6
Tabora	24.7	17.1	29.7	944	3.0
Mwanza	24.1	17.6	28.0	1090	4.3

* - period of averaging.

Analysis of the results shows that most affected by choice of the period for averaging can be wind speed and rainfall. While the dry, maximal and minimal air temperatures remain almost unchanged. Due to that in order to get the correct data for analysis of the wind speed and rainfall the data need to be used for whole period of observations. Otherwise the averaged data could be 5-10% less or more than the norm.

3.2. Trend estimation

Distribution of the studied parameters in historical perspective show that it varied from year to year. Some long-term fluctuations could be ordinary and do not demonstrate any tendencies. Others could show the different slope and direction. In order to differentiate between ordinary fluctuations and fluctuations with significant slope was used parameter a in equation $y=ax+b$ and p -value <0.005 (table 2). Results show that positive significant trend of maximal air temperatures was detected for all selected weather stations in Tanzania. As well dry air temperature and minimal air temperature also shows similar positive trend. While for wind speed some positive tendencies were detected just for stations Dodoma, Arusha, Mtwara and Mwanza. In rainfall trend analysis just one station (Mtwara) had negative significant trend.

Table 2. Parameter a and trend significance.

Weather station	V, m/s	X, mm	Tdry, °C	Tmax, °C	Tmin, °C
Dodoma	0.023	0.513	-0.002	0.021	0.008
Dar es Slaam	0.003	-1.416	0.015	0.023	0.018
Arusha	0.024	-1.617	0.021	0.019	0.016
Songea	0.006	-3.041	0.016	0.002	0.016
Mtwara	0.020	-1.940	0.014	0.008	0.008
Mbeya	0.006	-0.251	0.017	0.014	0.017
Kigoma	0.000	-0.167	0.014	0.003	0.014
Tabora	-0.009	0.301	0.019	0.019	0.018
Mwanza	0.012	2.085	0.017	0.001	0.021

Note: V - wind speed; X – Rainfall; Tdry - Dry air temperature; Tmin - minimal air temperature; Tmax - maximal air temperature. Values in bold and italic show significant trend.

Additionally was estimated trend size in absolute and relative values. The difference was calculated between first 10 years and last 10 years of the studied elements (ΔN_{10}). This case can reflect the maximal increment or reduction of studied parameters. As well was calculated difference between

average values in first 20 (30) years and last 20 (30) years (ΔN_{20} and ΔN_{30}). Such difference could show more appropriate results as it is based on averaged data for longer period of years at beginning and end of the study period. Difference between data in first 10 (20 and 30) years and in last 10 (20 and 30) years was calculated (ΔN_{10} , ΔN_{20} , ΔN_{30}).

Table 3. Calculated trend.

Parameter	DOM	ARU	SONG	MTW	MBY	KIG	TAB	DAR	MWZ
Wind speed (V, m/s)									
ΔV_{10} , m/s	0.9	1.1	0.2	1.1	0.1	0.0	-0.2	0.3	0.7
ΔV_{10} , %	24	28	5	20	4	-1	-7	6	16
ΔV_{20} , m/s	+0.9	+1.1	+0.3	+0.8	+0.2	-0.1	-0.2	+0.2	+0.6
ΔV_{20} , %	+20	+30	+6	+15	+5	-2	-6	+4	+14
ΔV_{30} , m/s	+0.9	+0.7	+0.2	+0.7	+0.3	+0.0	-0.7	+0.0	+0.2
ΔV_{30} , %	+20	+21	+4	+13	+7	+1	-20	+0	+5
Rainfall (X, mm)									
ΔX_{10} , mm	+12.2	+41.1	-92.7	-70.8	+34.5	+28.6	+95.6	-66.8	+245.5
ΔX_{10} , %	+2	+5	-8	-6	+4	+3	+11	-6	+26
ΔX_{20} , mm	+30.7	-94.4	-131.9	-113.8	+4.5	-3.9	+34.2	-107.4	+46.2
ΔX_{20} , %	+6	-11	-12	-10	+0	-0	+4	-9	+4
ΔX_{30} , mm	+38.4	-89.3	-136.1	-69.8	-12.9	-10.0	-8.1	-36.8	+64.6
ΔX_{30} , %	+7	-10	-12	-6	-1	-1	-1	-3	+6
Dry air temperature (Tdry, °C)									
ΔTd_{10} , °C	+0.0	+1.0	+0.6	+0.7	+0.9	+0.5	+0.7	+0.9	+0.6
ΔTd_{10} , %	+0	+5	+3	+3	+5	+2	+3	+3	+3
ΔTd_{20} , °C	+0.0	+0.9	+0.7	+0.6	+0.7	+0.7	+0.9	+0.7	+0.8
ΔTd_{20} , %	+0	+5	+3	+2	+3	+3	+4	+2	+3
ΔTd_{30} , °C	-0.4	+0.8	+0.7	+0.5	+0.6	+0.5	+0.7	+0.5	+0.6
ΔTd_{30} , %	-2	+4	+3	+2	+3	+2	+3	+2	+3
Maximal air temperature (Tmax, °C)									
$\Delta Tmin_{10}$, °C	+1.1	+0.7	-0.2	+0.3	-0.2	+0.3	+0.7	+1.3	+0.2
$\Delta Tmin_{10}$, %	+6	+5	-1	+1	-2	+2	+4	+6	+1
$\Delta Tmin_{20}$, °C	+1.0	+0.8	+0.2	+0.5	+0.7	+0.1	+0.9	+0.9	-0.1
$\Delta Tmin_{20}$, %	+6	+6	+2	+2	+6	+1	+6	+4	-1
$\Delta Tmin_{30}$, °C	+0.6	+0.7	+0.2	+0.2	+0.8	-0.1	+0.7	+0.8	-0.3
$\Delta Tmin_{30}$, %	+4	+5	+1	+1	+7	-1	+4	+4	-2
Minimal air temperature (Tmin, °C)									
$\Delta Tmax_{10}$, °C	+0.4	+0.6	+0.7	+0.3	+0.9	+0.6	+0.5	+1.1	+0.7
$\Delta Tmax_{10}$, %	+1	+2	+3	+1	+4	+2	+2	+3	+2
$\Delta Tmax_{20}$, °C	+0.3	+0.7	+0.7	+0.4	+0.7	+0.7	+0.8	+0.8	+1.1
$\Delta Tmax_{20}$, %	+1	+3	+3	+1	+3	+2	+3	+3	+4
$\Delta Tmax_{30}$, °C	+0.2	+0.6	+0.5	+0.3	+0.5	+0.4	+0.8	+0.5	+0.7
$\Delta Tmax_{30}$, %	+1	+2	+2	+1	+2	+1	+3	+2	+3

Where V - wind speed; X – Rainfall; Tdry - Dry air temperature; Tmin - minimal air temperature; Tmax - maximal air temperature.

Results of the wind speed trend estimation (table 3) show that at the beginning of the studied period (first 10, 20 or 30 years) the wind speed was significantly lower than at the end of it (last 10, 20 and 30 years). Largest values in increment of the wind speed (table 3) were detected for weather stations with positive significant tendencies (table 2) such as Dodoma, Arusha, Mtwara and Mwanza. On average the values of the wind speed in last half of observed period has been increased by 0.7-1.1 m/s (13-30%).

Some decreasing trends of rainfall were received for stations Arusha, Songea and Mtwara. On average in last 20-30 years areas received 89.3-136.1 mm (10-12%) of rainfall less than in 1950s-1970s. Tabora and Mwanza had an opposite trend of rainfall in first 10 and last 10 years, while in 20-years and 30-years period such trend become insignificant, hence not present in historical period.

Dry air temperature has grown by 0.5-1.0 °C in all weather stations. In relative values that number corresponds just for 2.0-5.0% (table 3) but those changes are significant and stable (table 2). Maximal and minimal air temperatures values have grown by 0.4-0.6% (2.0-3.6 °C). The information of climate change and its effects has been reviewed by Kruger and Shongwe [16], King'uyu et al. [18], Craparo et al. [26] and Levira [28] and showed significant increasing in temperature at several locations over Tanzania and Africa. Particularly Christy et al. [17] suggested that increase in minimum temperature might be due to the significant human development of the surface.

4. Conclusion

Results show that the positive significant trends of air temperatures of all selected weather stations have been detected. If relative values of the dry air temperature increase just by 2.0-5.0% in absolute values it become 0.5-1.0 °C. Maximal and minimal air temperatures values have grown even more than dry air temperature in absolute values 2.0-3.6 °C. Such value of air temperature grow can have negative effect on agriculture activities which vital in Tanzania. Trends of the wind speed demonstrate significant increment in relative values (13-30%) and on average it grew by 0.7-1.1 m/s. While rainfall trends revealed some reduction (89.3-136.1 mm) for stations Arusha, Songea and Mtwara. The results based on data 57-61 years indicated that climate become unfavorable for agricultural activities in Tanzania. If air temperature continue to grow, wind speed strengthen and rainfall just decrease it can reduce crop's yield and animal's production.

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