Student thesis series INES nr 425

Climate Change in Kenya

- *A review of literature and evaluation of temperature and precipitation data*

Marie Wigren Skogseid

2017
Department of
Physical Geography and Ecosystem Science
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden

Climate Change in Kenya – *A review of literature and evaluation of temperature and precipitation data*

Klimatförändringar i Kenya – *En litteraturstudie samt en utvärdering av temperatur- och nederbördsdata*

Bachelor Degree Thesis, 15 credits in *Physical Geography and Ecosystem Science*
Department of Physical Geography and Ecosystem Science, Lund University

Level: Bachelor of Science (BSc)

Course duration: *March* 2017 until *June* 2017

Climate Change in Kenya

- *A review of literature and evaluation of temperature and precipitation data*

Marie Wigren Skogseid

Bachelor thesis, 15 credits, in *Physical Geography and Ecosystem Science*

Supervisor: Petter Pilesjö

Course coordinator: Jonas Ardö

Exam committee:
Vaughan Philips, Lund University
Thomas Holst, Lund University

Acknowledgements
First of all I would like to give a special thanks to my supervisor, Petter Pilesjö, for his knowledge, support and guidance beyond his responsibilities during this process of thesis writing. Finally, I would like to thank my fellow classmates for many days of working, crying and drinking coffee together during this entire process.

Abstract

The world is facing serious and complex impacts with regard to climate change. Natural and human settlements on all continents are affected, and the African continent is considered as one of the most vulnerable areas due to rapid urbanization growth and high dependency on rain-fed agriculture, amongst others. This thesis focuses on climate change in Kenya. The first aim is to compare trends of climate change in East Africa and Kenya by using a literature review and analyzing temperature and precipitation data. The second aim is to investigate regional differences in Kenya by using regional temperature data. Literature about climate change in East Africa and Kenya was collected and gathered in a literature review. Climate data was analyzed on national and regional level. Main findings were that there is a general agreement about increasing temperature trends in Kenya, in literature and in the data analysis. Findings of precipitation in literature and data analysis indicate that eastern Africa and Kenya are characterized by high variability in rainfall. Literature report about drying trends of precipitation however the link to human induced climate change needs to be further investigated. Analyses of regional datasets indicate regional differences in the magnitude of increase in mean, maximum and minimum temperatures.

Key words: climate change, Kenya, East Africa, temperature trends, precipitation patterns, extreme weather

Sammanfattning

Världen står inför allvarliga och komplexa konsekvenser när det gäller klimatförändringar. Naturliga och mänskliga bosättningar på samtliga kontinenter är påverkade, och den afrikanska kontinenten anses höra till ett av världens mest utsatta områden bland annat på grund av snabb befolkningstillväxt och stort beroende av regn-bevattnat jordbruk. Denna uppsats handlar om klimatförändringar i Kenya. Det första syftet är att jämföra trender av klimatförändringar inom Östafrika och Kenya med hjälp av en litteraturstudie och en analys av temperatur- och nederbördsdata. Det andra syftet är att undersöka regionala skillnader i Kenya med hjälp av regional temperaturdata. Litteratur om klimatförändringar i Östafrika och Kenya granskades och samlades till en litteraturöversikt. Klimatdata analyserades på nationell och regional nivå. De huvudsakliga resultaten var att det finns en övergripande överenskommelse om ökande temperaturtrender i Kenya inom både litteratur och inom dataanalysen. När det kommer till nederbörd så tyder resultat i litteratur och dataanalys på att östra Afrika och Kenya kännetecknas av stor variation när det kommer till regnfall. Inom insamlad litteratur rapporteras det om att Östafrika uppvisar en minskning in nederbörd och går mot en torrare trend, dock så finns det inga bevis på att denna trend är påverkad av mänsklig aktivitet. Från analysen av regionala dataset kan man se att regionala skillnader finns i hur mycket varje regions medel-, maximi- och minimitemperaturer har ökat.
Nyckelord: klimatförändringar, Kenya, Östafrika, temperaturtrender, nederbördsmönster, extremt väder

Table of Contents

1 Introduction

The Earth is getting warmer. The last three decades have shown higher surface temperatures than any decade since the 1850's, and surface temperatures are projected to rise further during the 21st century. Looking back 1400 years in the Northern Hemisphere, no 30-year period has been warmer than the period of 1983-2012 (Houghton 2009; IPCC 2014). According to the IPCC (Intergovernmental Panel on Climate Change), more than half of the observed increase in mean global surface temperature 1951-2010 is due to anthropogenic influence (IPCC 2014).

The word climate change has several definitions. According to IPCC climate change may originate from either natural sources like change in solar cycles and volcanic eruptions or by changes in the atmosphere caused by human activity. Conversely, the United Nations Framework Convention on Climate Change (UNFCCC) is contrasting between climate change and climate variability. Climate variability is here referred to as caused by natural sources, while climate change is defined as "*a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*"(IPCC 2014 p.120).

Both natural systems and human settlements on all continents have been affected by climate change in some way. In addition to increased temperatures, also changes in extreme weather and climate related events have been observed since 1950, events like rise in sea level, warming of the world's oceans, extreme precipitation, a decrease in cold temperature extremes and an increase in warm temperature extremes. For the 21st century, IPCC predicts that surface temperatures will increase, and in addition extreme events, like the ones mentioned above, will become more intense and more frequent (IPCC 2014).

Still, African countries are among the most vulnerable when it comes to climate change and extreme events - due to lack of resilience and ability to adapt, and due to high dependency on rain fed agriculture (Awuor et al. 2008; Houghton 2009; Niang 2014). IPCC describes Africa as the poorest region in the world, and that the extended poverty results in high vulnerability to projected impacts of climate change. "The effects of climate change are expected to be greatest in developing countries in terms of loss of life and relative effects on investment and economy"(IPCC 2014).

Climate change constitutes predominantly negative implications for economic growth, human security and social welfare in Kenya and is thus seen by Awuor et al. (2008) as a major challenge that constrain development. Therefore "in view of the country's relatively limited capacity to adapt, it is important that the issue of climate change is taken seriously and given the necessary attention" (Awuor et al. 2008)p. 237). Kenya is experiencing increasing temperatures and several regions in the country are affected by climate extremes – especially flooding's – which affects both the city of Mombasa and the city of Kisumu (Awuor et al. 2008; Kebede et al. 2012).

The African climate is characterized by a varied range of climate regimes; from humid-equatorial, through arid-tropical climate to a sub-tropical Mediterranean climate and they are varying temporally in different degrees - especially when it comes to precipitation. It is a great challenge to predict temporal variations in the African climate, and especially to separate those variations originating from natural sources to those that are human induced. It is however important in the sense that it helps to understand how global climate is influenced by human activity (Hulme et al. 2001). By investigating if trends of temperature and precipitation are present, it is possible to link these to climate change. In order to get a higher understanding about how Kenya is affected by climate change, it may be interesting to see if different parts of Kenya are affected in different ways by climate change.

With background to the observations and predictions about climate change from IPCC, and its effects on developing countries, this report will focus on climate change in Kenya. Literature about climate change is studied on continental, national and regional level. The literature is focused on trends in temperature and precipitation, and will to some extent report about extreme events from regional parts of Kenya. A data analysis is performed to study climate trends in Kenya. Trends of climate change are presented in result part for literature and data, and then compared in the discussion part. The main conclusions are summarized in the final part.

1.1 Aims

Aims for this study are to:

- Compare trends of climate change in East Africa and Kenya by the use of two different methods, a literature review and an analysis of temperature and precipitation data

- Investigate regional differences of climate change in Kenya, by the use of regional temperature data

2 Background

The following part is split into four sections. In the first part, relevant definitions in the study are defined, the second part presents some views of why Africa is vulnerable for climate change, the third part gives a brief introduction to the interannual climate of east Africa and in the final part the study sites are described.

2.1 Definitions

"Climatological standard normal" ("normals"): Defined as "averages of climatological data computed for successive 30-year periods". Used as a reference point against which climate observations can be compared, and are used as a prediction of the conditions most likely to occur in a given location (WMO 2011 p.4:15-16).

"East/eastern Africa": Within the statistics division of UN, following countries and regions are included in east Africa: Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Rwanda, Somalia, South Sudan, Uganda and the united republic of Tanzania. It also includes the small Island nations of Mauritius, Seychelles, Comoros and in addition the French overseas territories of Mayotte and Réunion (UN Statistics Division). Within gathered literature Endris et al. (2013) define the east African region as the area lying within 18°N-16°S, 22°E-52°E, and (Giannini et al. 2008) define eastern equatorial Africa as the region within 10°N-10°S, 20°E-50°E.

"El Nino Southern Oscillation (ENSO): "Ocean-atmospheric condition that occurs every 2nd to 7th year and origins in the Pacific Ocean. During an El Nino event, there is a change in atmospheric pressure patterns in the Pacific Ocean. Normally, water along the equator in the Pacific Ocean is cold (and has a high pressure) in the east by the coast of South America, and warm (with a low pressure) in the west by Indonesia and Australia. During El Nino, pressure patterns are reversed, resulting in easterly winds being replaced by westerly. Thereby, the upwelling of cold water along the coast of South America stops and large number of marine life dies and this strikes hard on the regional fishing industry. The climate that normally occurs around Indonesia has been transferred to the coast of South America. In most years the event lasts for between a few weeks until a couple of months, but it may also last for more than a year during strong El Nino events. Strong El Nino events result in severe impacts in several regions. In south and eastern Africa droughts normally occur as well as for Australia, and warming of the central and eastern equatorial Pacific Ocean takes place while, in contrast, Ecuador and Peru are exposed to heavy rains (Ahrens 2013).

"Extreme (weather) events": Defined as events that are rare at a particular place and for a particular time of year, and the definition may thus vary from place to place. Events regularly referred in connection to extreme events by IPCC are: droughts, heavy rainfall, flooding's, cold temperature extremes, warm temperature extremes, cyclones, wildfires (IPCC 2014).

"Extreme climate events": When a pattern of extreme weather persists for some time –e.g. heavy rainfall over a season (IPCC 2014).

"**Heat island effect":** The expression can be explained as a "*consistent rise of surface temperatures within the urban environment" (Makokha and Shisanya 2010)*. This effect is characterized by higher temperatures in cities compared to surrounding areas (Nakayama and Fujita 2010). It originate from the changing growth of cities and emerge from reductions in vegetation and evapotranspiration, growing areas of dark surfaces and in anthropogenic warming (Stone et al. 2010)

"Intertropical Convergence Zone (ITCZ)": is a low-pressure boundary zone along the equator, which separates the northeast trade winds of the northern hemisphere with the southeast trade winds of the southern hemisphere. The boundary is characterized by warm and wet conditions; it marks the zone where a lot of air rises due to large amount of insolation, which creates vast amounts of thunderclouds.

2.2 Africa's vulnerability to climate change

The following section is meant to give a brief background on why Africa is vulnerable to climate change.

Rapid population growth

Africa is currently experiencing a high population growth - the African population has more than doubled since the 1980's, reached 1 billion in 2010 and after 2050, Africa is the only major area that will still experience a substantial growth in population (UN DESA Population Division 2015). Despite the fact that the percentage of Africans living beneath poverty line is decreasing - there is still a substantial part (47.5 % in 2008) of the population that does and will continue to do so (UNECA 2012).

High dependency on rain fed agriculture

Most of the African food production is based on small-scale farming. 70 % of the total African workforce has small-scale farming as main income (Simms and Murphy 2005) and in the sub-Saharan region, 98 % of the agriculture is rain fed (FAO 2002). Small-scale farmers have limited means to influence their options, and consequently they are stuck in the land they possess hoping for favorable weather conditions (Ochieng et al. 2016). Changes in rainfall variability and extreme weather results in food insecurity - which leads to increasing food prices (Yabi and Afouda 2012). The population of many regions is increasing - however the yields from the agricultural areas in many regions are not - leading to lower food availability per capita since the 1970's (MDG Africa Steering Group 2008). In addition, there is a lack of investment in the African agricultural sector. African governments are generally reducing the supports for agricultural development services and international organs like the EU provide, more of their funding's towards "infrastructure" or "governance" (Simms and Murphy 2005).

Rapid urbanization

In the footsteps of the rapid population growth, Africa experiences some of the world's highest urbanization rates. Consequently, many of the African cities are growing without a planning strategy - which results in a lack of housing, illegal or unplanned settlements and urban poverty (Yuen and Kumssa 2011). According to Douglas et al (2008) especially the poor people are vulnerable for climate change, since they are living in simpler conditions, located outside the city centers where locations for settlements might be unsuitable, for example on floodplains, hillsides or close to swamps. With projected increase in extreme weather and increase in mean sea level in mind - these urban dwellers are highly exposed to the projected impacts of climate change (Douglas et al. 2008).

Changes in land use and fragile ecosystems

Shifts in land use due to agricultural development, expansion of livestock grazing and fuel-wood harvesting results in changes towards a decrease in natural vegetation and natural forests (Niang et al. 2014). Along with this, there is a high agreement that changes connected to climate change are likely to affect terrestrial ecosystems with regard to biome shifts (Niang et al. 2014), and have a negative effect on biodiversity (Simms and Murphy 2005). Africa contains more than one fifth of globally known species of plants, birds and mammals, and many poor people in Africa are dependent on species biodiversity in order to support themselves with food and medicine (Simms and Murphy 2005).

2.3 Interannual climate of east Africa

Dominating climate types in east Africa are Aw (equatorial savannah) Bs (arid steppe) and Bw (arid desert) (Kottek et al. 2006). Seasons of eastern Africa and Africa, as anywhere, are the result from interactions between atmosphere, land and ocean, and how different surfaces respond to insolation (Giannini et al. 2008). Eastern Africa generally contains complex topography and is characterized by different rainfall regimes. Local conditions, like differing terrain and differences in land cover, as well as climate mechanisms at larger scale, contributes to the various spatial rainfall patterns that characterizes the whole region (Endris et al. 2013). As land and ocean surfaces are heated up by sun radiation, the near-surface-air will become warmer and thus less dense than surrounding air, which results in rising of air parcels. Rising air results in cooling, and as condensation occurs most of the original water vapor returns to the surface in the form of rainfall. The process of convection – when air parcels rise and sink exchanging energy – characterizes *atmospheric instability* and results in tropical precipitation (Giannini et al. 2008). The precipitation patterns might however be interrupted by the opposite to instability – *atmospheric stabilization*. This is done for example by warming at higher levels in the tropical atmosphere – which then level out the differences between near surface temperature and temperature at higher altitudes (Giannini et al. 2008).

The seasonal rainfall patterns of east Africa are strongly connected and generally controlled by the north-south movement of the Intertropical Convergence Zone (ITCZ) (Giannini et al. 2008; Endris et al. 2013; Ogwang et al. 2014). Along this zone a lot of humid air rises which results in high rainfall amounts in this area. Air rises along the equator and sinks again along lat. 30, and some of the sinking air moves back towards the equator. The ITCZ straddles the equator in April and October, in June-August it moves gradually towards northern African and towards southern Africa in Jan-Feb. Consequently, east Africa experience rainy seasons in March-May and Oct-Dec, and dry seasons in Jan-Feb and June-Sep (Giannini et al. 2008), and the ITCZ is thus a controlling factor of the interannual rainfall patterns (Ogwang et al. 2014). Precipitation patterns in eastern Africa are however also influenced by other large scale factors, which contribute to the high degree of variability in both space and time (Giannini et al. 2008; Endris et al. 2013). There is an additional component that dominates the interannual rainfall variability of equatorial eastern Africa; ENSO. The direct impact of ENSO over Africa is strongly connected to the warming trend that starts the stabilization mechanism. If warming occurs in one part of the tropical atmosphere the warming will be efficiently distributed horizontally throughout the tropic region. Heating on higher altitudes over the Indian Ocean would then reduce the atmospheric instability and thus suppress precipitation. During a strong ENSO-event, heating of the equatorial Pacific in turn result in warming of the entire tropical troposphere. The following stabilization of the atmosphere leads to declining precipitation in several regions, eastern Africa included (Giannini et al. 2008).

2.4 Study Area

The study focuses on Kenya and four cities in Kenya; Nairobi, Mombasa, Kisumu and Garissa. Kenya is located in eastern equatorial Africa and is a good example of one of several countries that are affected and vulnerable for the many effects that follows with changes in climate, which will be seen in following sections of the report.

Kenya

Kenya (5 °N-5 °S, 34 °- 42 °E) is located on the border to the Indian Ocean and neighboring countries are Ethiopia in the north, Somalia in the east, Tanzania in the south and Uganda in the west, along with Lake Victoria in the southwest. The country covers an area of 591 971 km^2 and is divided into 47 administrative counties (Kenya National Bureau of Statistics 2015). Since the 1950's, Kenya's population growth has increased dramatically due to rising birth rates and declining mortality rates. In 2017 the population was estimated to 48 million (Central Intelligence Agency 2017; Worldometers.info 2017).

Service sector, agriculture, industries and tourism are important economic sectors and dominating contributors to the country's GDP. Agriculture constitutes the second largest contributor for Kenya's GDP and for 80 % of the population agriculture is the main or part-time income source. The dominating part of the agricultural outputs (75 %) originates from rain-fed, small scale farming or livestock production (Central Intelligence Agency 2017). Industrial activities are dominated by food-processing of agricultural products, consumer goods manufacturing, aluminum, steel and cement. Industrial activities are gathered around the three major urban centers, Nairobi, Mombasa and Kisumu (Central Intelligence Agency 2017).

Kenya's physical geography is characterized by the East African Rift Valley which bisects the country in North-South-facing direction. As a result, the land is gradually rising in altitude from the coast towards the inland, creating a high plateau in the central and western parts of the country, before the land is once again leveling off when approaching the shores of Lake Victoria in the south west (Landguiden.se 2016; United Nations Development Programme 2017). Kenya's climate is characterized by several climate types on different locations. The dominating climate types are Aw, Bs and Cf-climate, according to the Köppen Climate Classification (IVPH 2017). Aw-climate refers to an equatorial savannah with dry winters, which apply to the western inlands. The north-eastern parts are dominated by arid steppe-climate (Bs-climate) and the south western parts towards the shores of Lake Victoria is dominated by tropical to warm temperate/fully humid (Cf and Af) climate (Kottek et al. 2006). Kenya, as the rest of eastern equatorial Africa, experiences two rain seasons and two dry seasons per year. The longer rain season occurs from March/April to May/June, and the shorter occur from October to November/December (Ochieng et al. 2016; United Nations Development Programme 2017).

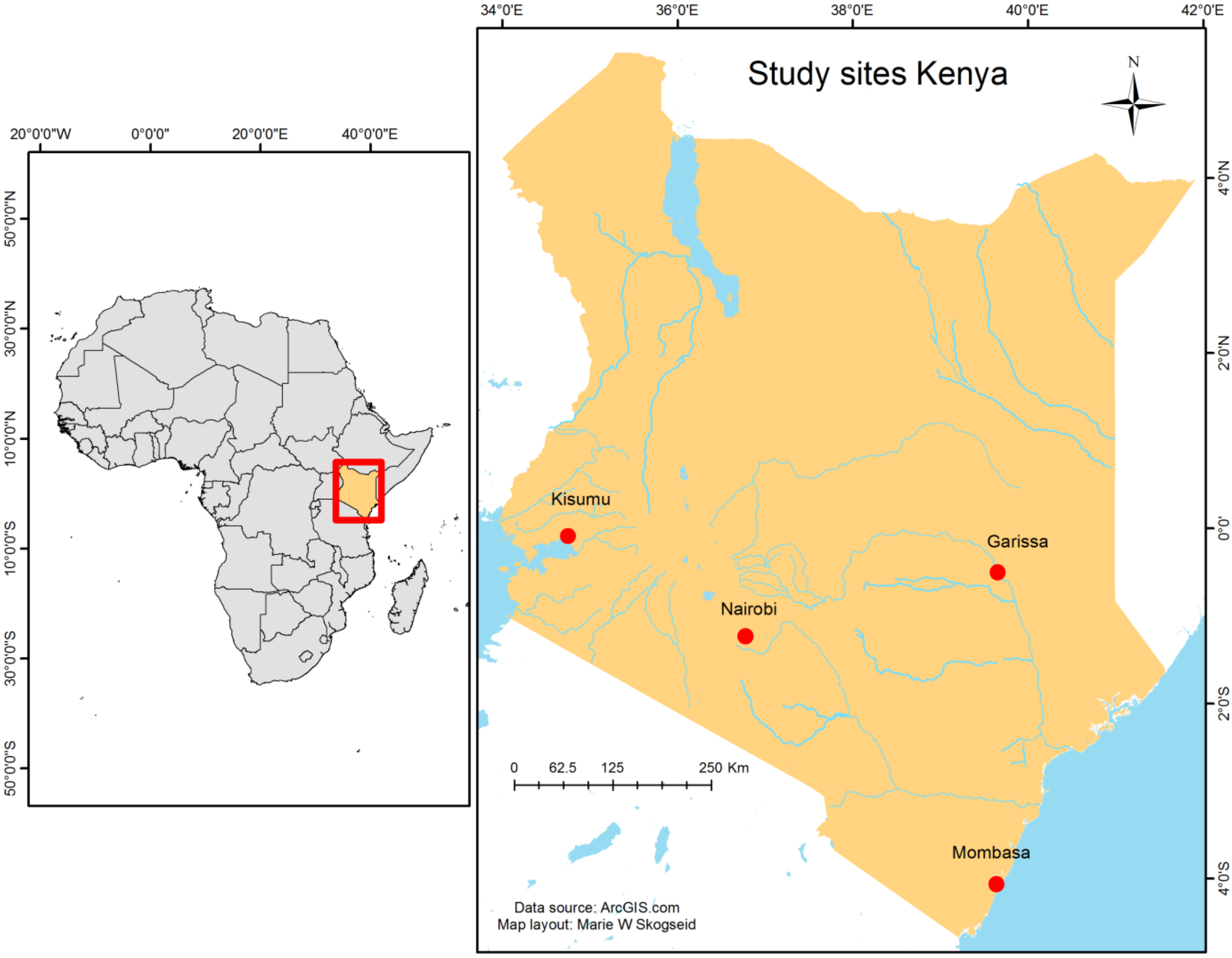

Figure 1: Location of study; Kenya located in the eastern equatorial Africa on the border to the Indian Ocean. Regional temperature is studied in the four cities Mombasa, Nairobi, Kisumu and Garissa.

Nairobi

Nairobi (1°17'S, 36°48'E) is the capital of Kenya and had in 2009 a population of 3 million people (Kenya National Bureau of Statistics 2009). Just like Kenya in general, the city experienced an increase in population starting from the 1960's. The rapid population growth has resulted in Nairobi being the most densely populated region of the country, and location of the second largest slum in Africa. The high population density of Nairobi has resulted in high demand on housing, employment, transport services and energy (Shisanya and Khayesi 2007). Nairobi is located 140 km south of the equator and 480 km from the Indian Ocean. The city is located about 1700 m a.s.l. (1500 in the East to 1900 in the West) which influences temperature and rainfall and gives the city a cool, sub-tropic climate. The mean annual temperature is 19 °C and annual rainfall varies from 800 mm in the East to above 1000 mm in the west, see **figure 2** (Makokha and Shisanya 2010; Climate-data.org (A) 2017). Average min and max temperatures are 11 °C and 26 °C. Rain seasons stretches from March-May and the shorter from October-December. The dry period of Jan-Feb is characterized by hot and dry climate while the dry period June-August is typically dry and cold (Egondi et al. 2012).

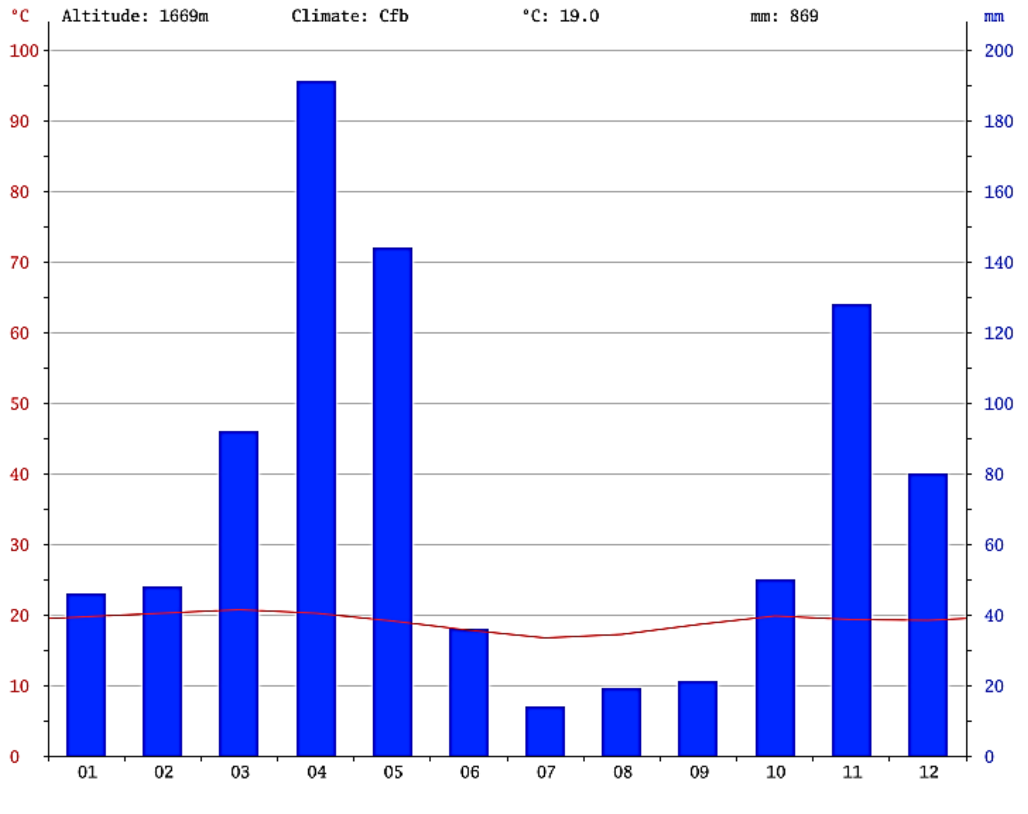

Figure 2: Average climate in Nairobi. Figure from Climate-data.org (A) (2017).

Mombasa

Mombasa (4°3'S, 39°40'E) is the second largest city in Kenya with approximately 1.1 million inhabitants in 2015 (Central Intelligence Agency 2017). Dominating income sources for the local population are small scale agriculture, livestock production, fishing, import/export of commodities and industries such as cement manufacturing. Mombasa is located at the coastline to the Indian Ocean, and is the largest seaport in East Africa. The city plays an important role in the region's economy since it functions as the center of import and export of commodities to the inland countries of Africa. It is located on a coastal plain which lies on altitudes between 0 to 45 m a.s.l. The low altitude and proximity to the coastline makes Mombasa vulnerable to climate change, since parts of the city and the neighboring area are likely to get inundated during a rise in sea level. A rise of sea level with as little as 0.3 meters is estimated to cause flooding's on 17 % of the city which is equal to 4600 hectare of land area. This would result in negative impacts on many activities like agriculture, industry, human residences, damage to water supply and ecosystem functions (Awuor et al. 2008). Mombasa has a tropical climate with average temperature of 27 °C and annual precipitation of about 1200 mm (see **figure 3**) (Climate-data.org (B) 2017).

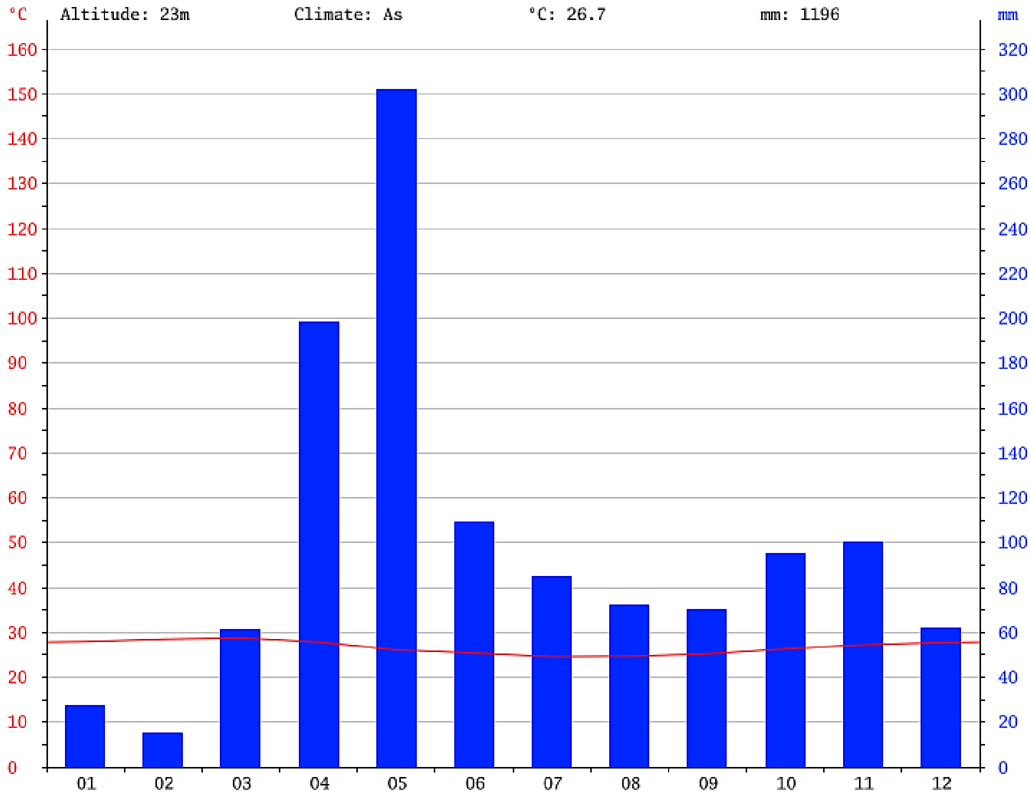

Figure 3: Average climate in Mombasa. Figure from Climate-data.org (B) (2017).

Kisumu

Kisumu (0°6 S, 34°45'E) the third largest city in Kenya, is located in the west close to the shores of Lake Victoria. The whole of Kisumu district had according to the 2009 census a population of about 600 000 inhabitants but the city itself around 400 000 (Kenya National Bureau of Statistics 2009). The dominant income sources are agriculture and livestock production. The altitude of the region varies between 1100 m a.s.l. to 1800 m a.s.l. (Okere and Kodiwo 2012). The region shares the same climate as Lake Victoria, which is tropical to warm temperate climate, and experiences mean annual rainfall between 600 to 1600 mm, and temperatures are varying between 18 °C and 34°C (Ajuang et al. 2016). Average temperature is however around 23 °C (see **figure 4**) (Climate-data.org (C) 2017).

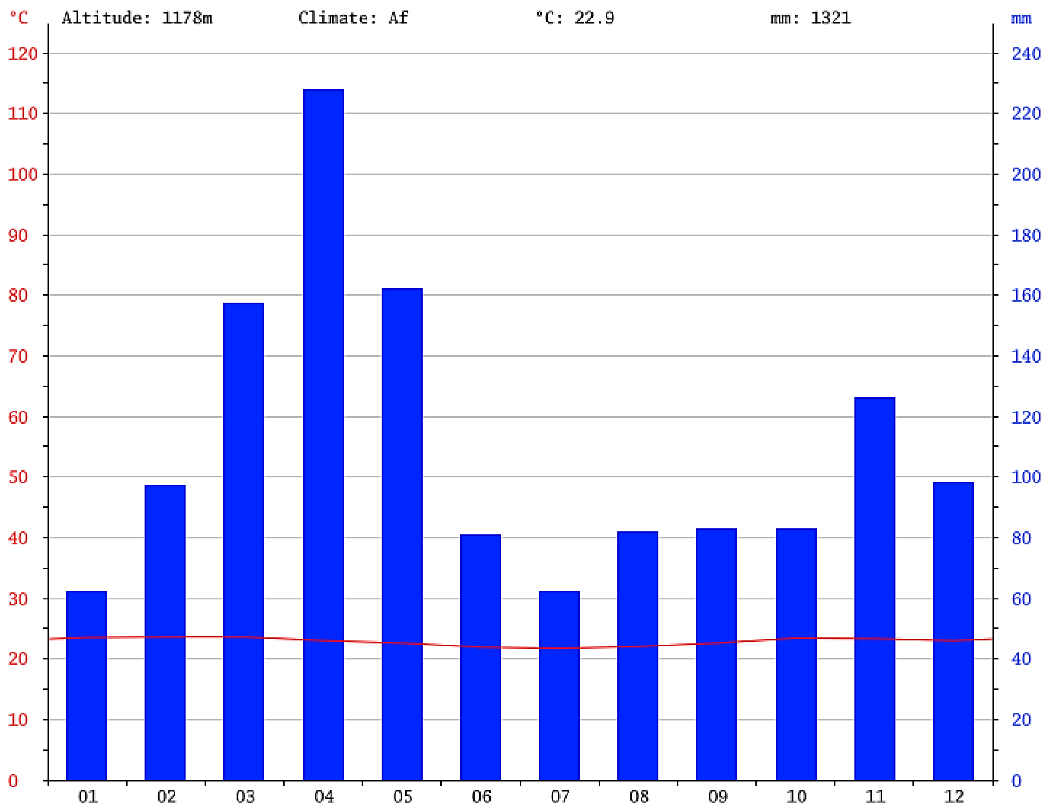

Figure 4: Average climate in Kisumu. Figure from Climate-data.org (C) (2017).

Garissa

Garissa (0° 27'S, 39°39'E) is located in the northeast, in a semiarid part of Kenya. According to the 2009 census, the city has about 117 000 inhabitants (Kenya National Bureau of Statistics 2009) and the region about 623,060 inhabitants. Livestock production is one of the largest income sources for the region's economy. The altitude of the county ranges from 70 m a.s.l. to 400 m a.s.l. (Nanyingi et al. 2017). The climate in this region is according to Köppen's climate classification Bwh- or Bsh-climate, characterized by arid-desert/steppe (IVPH 2017). The average temperature is relatively high (29 °C) and the level of precipitation per year is very low (see **figure 5**) (Climate-data.org (D) 2017) but in times of heavy rainfall the area may easily get flooded (Nanyingi et al. 2017).

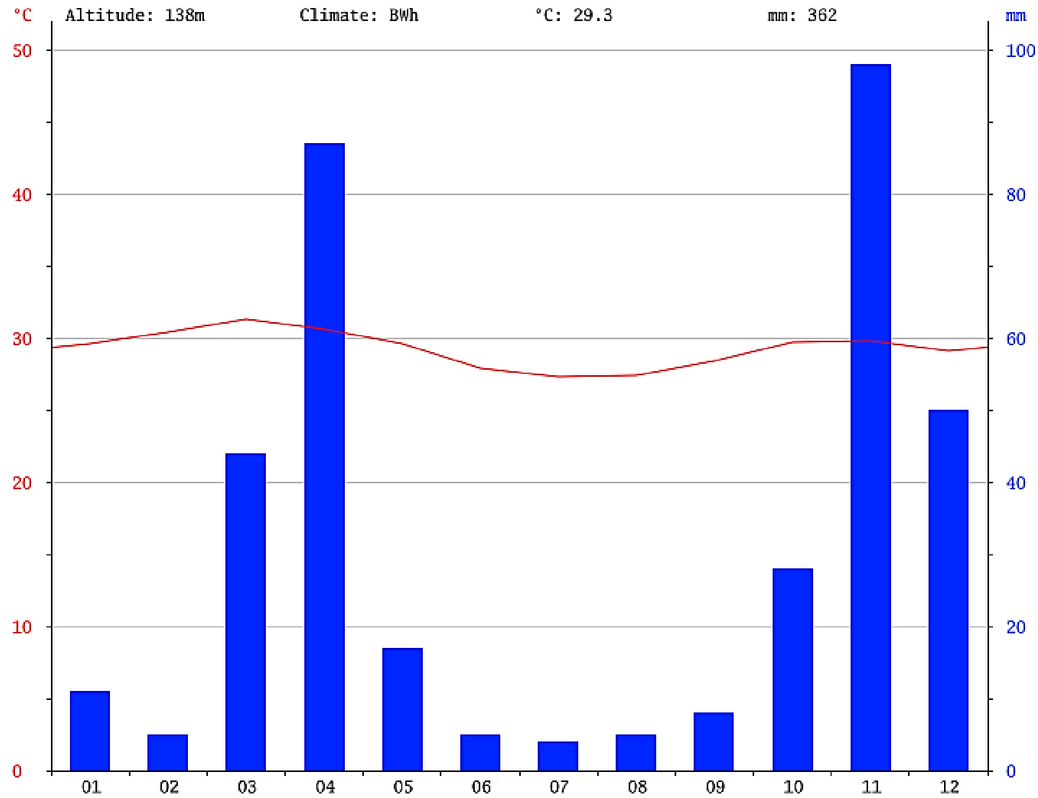

Figure 5: Average climate in Garissa. Figure from Climate-data.org (D) (2017).

3 Data and Methodology

The results are based on findings from two sources - literature and climate data. Literature on actual temperature trends on local scale was limited which motivates that the data analysis is focused on a more local scale.

3.1 Literature

Literature about climate was focused on East Africa, Kenya and regional level to some extent. Findings from relevant journals and literature were gathered, studied and noted down as a literature review. The findings start on larger scale (Africa, East Africa) and then focus down on Kenya.

3.2 Data

The data analysis was based on climate data (rainfall and temperature) on both national and regional scale in Kenya.

3.2.1 Data Source

<u>National data</u>

The national data were obtained from sdwebx.worldbank.org (2017), which is a climate change-knowledge portal created by the World Bank. The aim of this portal is to provide online data access for global, regional and national datasets related to development and climate change (The World Bank Group 2017). The data are based on quality-controlled temperature and rainfall data from weather stations. They contain complete monthly averages of mean temperature and precipitation, between 1900 and 2012. The datasets are produced by Climatic Research Unit (CRU) of University of Anglia (EUA) and reformatted by International Water Management Institute (IWMI).

<u>Regional data</u>

The regional climate data were derived from Hothaps-Soft – which is a software tool used to present climate variables by the use of publicly available weather stations, and data recordings are available from 1980 (Climatechip.org 2016). Therefore the time span of the regional data only stretches from 1980-2014. From this source, regional datasets for 17 different cities were available; however none of them were 100 % complete. The four cities with the most complete datasets were thus chosen; Nairobi, Mombasa, Kisumu and Garissa. The regional data were used in order to analyze temperature trends for the four cities. The data consist of daily measurements of minimum, maximum and mean temperatures.

3.2.2 Data analysis

The levels of completeness were varying between the four cities. Some of the years also had a slight difference in number of recordings per year in mean, maximum and minimum temperatures. According to World Meteorological Organization (WMO) *"normals or period averages of temperature, should be calculated only when values are available for at least 80 % of the years of record, with no more than three consecutive missing years"* (WMO 2011) (p. 4-17). Further, WMO recommend that monthly average values *"should not be calculated if more than ten daily values are missing, or five or more consecutive daily values are missing"* (WMO 2011).

The quality of the data was seen as suitable to use to analyze temperature trends, since most of the years had recordings for more than 90 % of a full year. However, some years had months with a number of recordings below 80 % = 25 days. Gap-filling of missing days was advised in order to reach more complete datasets. The gap-filling for one missing day were made by calculating the average between the day before and the day after the missing day, as advised by Holst (2017).

In order to make sure that each month had at least 25 days, and each year at least 95 % of recordings – gap-filling was done in order to reach a more complete dataset.

Criteria for a complete year:

- 95 % of days included (347 days)
- Each month should contain minimum 80 % of recordings (25 days)
- Each year should have the same number of recordings for mean, maximum and minimum temperature – in order to be more comparable

Procedure of gap-filling

Gap-filling was done by identifying those months that had the lowest number of recordings (less than 25). First, gaps of only one day was chosen as far as possible – then two days and so on. No trend has more than five days missing in a row – following the guidelines from WMO (above). Months containing recordings below 25 days were gap-filled until the threshold was reached. If a year had lower than 95 % of recordings (347 days) these days were gap-filled so that the year would reach 95 % of recordings. If a year was complete up to 95 %, and all months contained 25 days each - no gap-filling was needed (see **table 1**). Finally, a few missing records for maximum and minimum temperatures were calculated so that each year had the same number of recordings for all of the three temperatures. Some years were excluded since they had too many days in a row missing to be able to gap-fill them. No regional temperature trend had more than three years excluded from the dataset.

Microsoft Excel (2010) was used for all data analyzes. The national data constituted by monthly averages were summarized into yearly averages and then plotted in graphs. After gap-filling of the regional data was done – monthly averages were calculated and summarized to yearly averages. Mean, maximum and minimum temperatures were thus all calculated by taking the average per month and these are represented as the average mean temperature, the average maximum temperatures and the average minimum temperatures per month and then per year in the graphs.

Interpreting the results

A simple linear regression trend was applied in order to show the annual trends in the climate data (the regression line describes the relationship between x and y). The linear change in temperature over time was calculated by using the trend line and the R^2-value (*coefficient of determination)* was computed from the regression model, since it gives the proportion of the variation in the y data explained by the regression model.

The F-distribution may be used to find if the regression line explains more of the variation in y than expected by chance alone (Rogerson 2011). The F-distribution was therefore chosen to see whether the R^2-value was significant or not.

Formula used to calculate F.

$$F = \frac{r^2\,(n-2)}{1-r^2}$$

The critical F-value was looked up in a table for the F-distribution. If the F-value exceeds the critical values, the explained variation is significant with a confidence level of 95 %.

Table 1: Display temperature data from Mombasa, Kenya. An example of how numbers of recordings per year are varying within the regional dataset. As for Mombasa, years of 1992, 1993 and 1998 (in orange) were excluded due to too many missing consecutive days. Years marked in green had days that were calculated manually in order to reach the decided threshold on 95 % to be considered as complete.

year	Mean	Min	Max	year	Mean	Min	Max
1980	327	325	327	1998	232	231	231
1981	351	351	351	1999	342	342	342
1982	350	350	350	2000	358	358	358
1983	355	355	355	2001	360	360	360
1984	355	355	355	2002	361	361	361
1985	361	361	361	2003	362	362	362
1986	361	361	361	2004	361	361	361
1987	363	363	363	2005	345	345	345
1988	363	363	363	2006	365	365	365
1989	355	355	355	2007	364	364	364
1990	337	337	337	2008	365	365	365
1991	325	325	325	2009	365	365	365
1992	316	316	316	2010	354	354	354
1993	284	284	284	2011	363	363	363
1994	357	355	357	2012	366	366	366
1995	365	365	365	2013	362	362	362
1996	364	364	364	2014	365	365	365
1997	360	359	360				

4 Results

In following section results from gathered literature and the data analysis are presented.

4.1 Literature analysis

The literature analysis is meant to give a review on gathered literature on climate change in Africa, Kenya and regional parts of Kenya. The gathered material includes observed trends of temperature and precipitation, a smaller section about regional impacts followed by a brief section on projected future trends.

4.1.1 Temperature

Africa as a continent is warmer than it was 100 years ago (Hulme et al. 2001). According to Niang et al. (2014) it is very likely that mean annual temperature for dominating parts of the African continent has increased since the 1900's. There are different meanings about the rate of warming. Hulme et al. (2001) state the rate of warming in Africa since the 1900's has been at about 0.5 °C per century. Hussein (2011) argues that Africa experienced an overall warming of 0.7 °C during the same period. In general, minimum temperatures show a more rapid increasing trend than maximum temperatures (Niang et al. 2014). For the equatorial and southern parts of East Africa, significant increases in temperature are reported since the 1980's by Anyah and Qiu (2012). Also Williams et al. (2012) indicate that during the last 50 years, an increase in seasonal mean temperature has been observed in many areas of the eastern equatorial countries - Kenya - amongst others. Further, Vincent et al. (2011) report that for countries adjacent to the western Indian Ocean, increases in the near surface temperatures have been observed, as well as an increase in the frequency of extreme events, between 1961 and 2008.

Focusing on Kenya, especially the central part is pointed out as an area where recent and predicted trends in temperature and rainfall has resulted in already affected and continued changes in climate. From analyzes on temperature data for the long rain-season (March-June) between 1960 and 2009 coherent patterns of climate change was reported by Funk (2010) as it could be seen during the period in both rainfall and temperature data. It was found that between March-June the temperature had increased significantly with 1 °C between 1960 and 2009. The country has experienced a substantial warming during 50 years, and in addition the frequency of the dry years is increasing. Further, Funk (2010) states that Kenya's plateaus and mountain ranges are likely to remain cooler compared to the surrounding lowlands, and stay relatively cool while the rest of the country is experiencing increasing temperatures.

Based on data from Kenya Meteorological Department (KMD) the government of Kenya agrees on the reported findings above, and states that extended areas of the country has experienced increasing temperatures. Minimum and maximum temperatures show a warming trend, especially for the minimum temperatures which show a steeper trend than the maximum temperatures (Government of Kenya 2010).

In a report from Makokha and Shisanya (2010) which focuses on minimum and maximum temperatures in Nairobi – both maximum and minimum temperatures between 1966 and 1999 show increasing trends. In addition, it was found that the annual minimum temperature trends show a stronger increase and higher R^2-values compared to the annual maximum temperature trends. According to the study, this may be an effect of so called "urban heat islands" and state that the difference between an urban and rural environment is largest during nighttime – indicating that minimum temperatures are the most affected by this phenomenon (Makokha and Shisanya 2010).

4.1.2 *Precipitation*

There is a lack in complete long-term rainfall data from the past century in many African regions, which makes it hard to state any conclusions about annual precipitation trends during this time. In addition there are many regional datasets that show dissimilarities when compared to each other (Nikulin et al. 2012; Sylla et al. 2012; Kim et al. 2014). In those regions in East Africa that have complete long-term data, precipitation patterns show an increasing trend. However as mentioned before, precipitation patterns in east Africa are highly characterized by temporal and spatial variability due to several components (Giannini et al. 2008; Niang et al. 2014).

Looking at more recent decades, Nicholson et al. (2000) state that trends of increasing aridity are seen since 1970's in rainfall over the Sahel area. This trend is supported by Williams and Funk (2011) who report that rainfall in East Africa has decreased during the long rain period (March-May/June) during the last three decades. Also Lyon and DeWitt (2012) indicate that the seasonal rainfall during the same period has decreased in East Africa. One possible explanation for this drying trend is suggested to be rapid warming of Indian Ocean (Williams and Funk 2011), and this warming trend is believed to further enhance the drying impact that warm ENSO events have on the region (Giannini et al. 2008). It is also possible that global warming has resulted in the increased frequency and persistency of strong ENSO events that has been observed in recent years (Giannini et al. 2008). Nicholson et al. (2000) however states that this trend should not be seen as a continuous large-scale trend towards aridness - but rather points out those historical fluctuations in precipitation are common. To what degree human influenced changes in land cover and human induced climate change contribute to the variations in the African precipitation are still uncertain (Hulme et al. 2001; Giannini et al. 2008).

When focusing on Kenya, Funk (2010), reports about substantial declines in rainfall 1960-2009, (during the long-rain-season, March to June) and argues that if these observed changes would last until 2025 – extensive parts of Kenya would experience more than a 100 mm decline in the long-rain-season-precipitation. Also the Government of Kenya reports that amount of precipitation for the long-rain-season are lower in recent years in comparison to the amount in the early 1960's (Government of Kenya 2010).

4.1.3 *Extreme weather events*

As mentioned above, an increase in extreme weather events has been observed globally and is likely to increase further during the 21st century (IPCC 2014). There are several studies (Awuor et al. 2008; Shongwe et al. 2011; Williams and Funk 2011; Lyon and DeWitt 2012) reporting about increases in the frequency of extreme events like droughts and heavy rainfall over the last 30-60 years in Eastern Africa. Williams and Funk (2011) report that successive warming of the Indian Ocean has resulted in a higher frequency of East African droughts in spring and summer season during the past 30 years. Lyon and DeWitt (2012) however state that it is not certain if the mentioned changes are due to human influence or natural variability.

In Kenya, as well as for the rest of East Africa, floods are the major climatic disaster (UNDP: International Strategy for Disaster Reduction 2009) and much of the flooding's in Africa has been related to global warming (Awuor et al. 2008; IPCC 2014). Some parts of Kenya have experienced major incidents related to flooding's during the last couple of decades, and most affected are low-lying areas close to coastlines (Awuor et al. 2008).

The city of Mombasa has experienced direct and indirect impacts of extreme climate change events – especially floods, droughts and strong winds (Awuor et al. 2008; Kebede et al. 2012). These events constitute threats to the citizen's life and well-being, they prevent development and causes damage to the existing infrastructure of the city. Similarly Kebede et al. (2012) state that floods cause damages almost every year, and especially refer to the extreme rain-induced flooding in 2006 - where 60 000 people were affected. Also in the western parts of Kenya - in parts of the Kisumu district amongst others, floods are becoming a more frequent matter which leads to negative impacts on social and economic aspects of development (Okayo et al. 2015). The Kisumu region experiences, just as Kenya and East Africa in general, mainly two extreme weather events - floods during wet periods and droughts during dry periods (Ajuang et al. 2016).

4.1.4 Projected trends

Below follows a brief review on future projections for temperature and precipitation.

Temperature

Based on predictions made from models, Hulme et al. (2001) suggest that the overall warming of the African continent will proceed and in several scenarios intensify. According to the predicted scenarios, the continent's temperature could increase with between 2-6 °C during the next 100 years. During the 21st century, Africa is predicted to undergo a more rapid increase in mean annual temperature than the global average, especially in the arid regions (Niang et al. 2014). Minimum and maximum temperatures for equatorial eastern Africa, are towards the end of the 21st century projected to show a significant increase in the number of days exceeding 2 °C above the average temperature for 1981-2000 (Anyah and Qiu 2012). FEWS NET (Famine Early Warning System Network) of the United States Agency for International Development, estimates that progressing warming of Kenya between 1975 and 2025 will be equal to an increase with more than 1°C, which is a considerable change in the country's underlying climate (Funk 2010).

Precipitation

Projections for precipitation do not have the same degree of certainty as projections for temperature trends. Hulme et al. (2001) state "*while [these] predictions of future warming may be relatively robust, there remain fundamental reasons why we are much less confident about the magnitude, and even direction, of regional rainfall changes in Africa*" (Hulme et al. 2001 p.165). IPCC (2014) however, projects that during the 21^{rst} century, mean annual precipitation will likely decrease in the north and south part of Africa, but will likely increase in the eastern part (Niang et al. 2014). Similarly, Shongwe et al. (2011) indicate that Eastern Africa by the end of this century will have a wetter climate with more intense wet seasons and less severe droughts.

4.2 Data Analysis

Below results from data analysis will be presented, starting with temperature trends followed by precipitation trends.

4.2.1 Temperature

As described in the method section, temperature data were analyzed for mean temperatures on national level and for mean, minimum and maximum temperatures on regional level.

Kenya

Long-term mean temperature for Kenya is displayed in **figure 6**. Between 1901 and 2015, the coldest year was 1968 with a mean temperature of 23.5 °C and the warmest year was 2009 with a mean temperature of 25.6 °C. The mean temperature trend follows an increasing trend as seen below, and according to the trend line, the long-term temperature has increased with 0.6 °C during this 115-year period. The R^2-value, which is significant, gives a value of 0.26, indicating that 26 % of the variation can be explained.

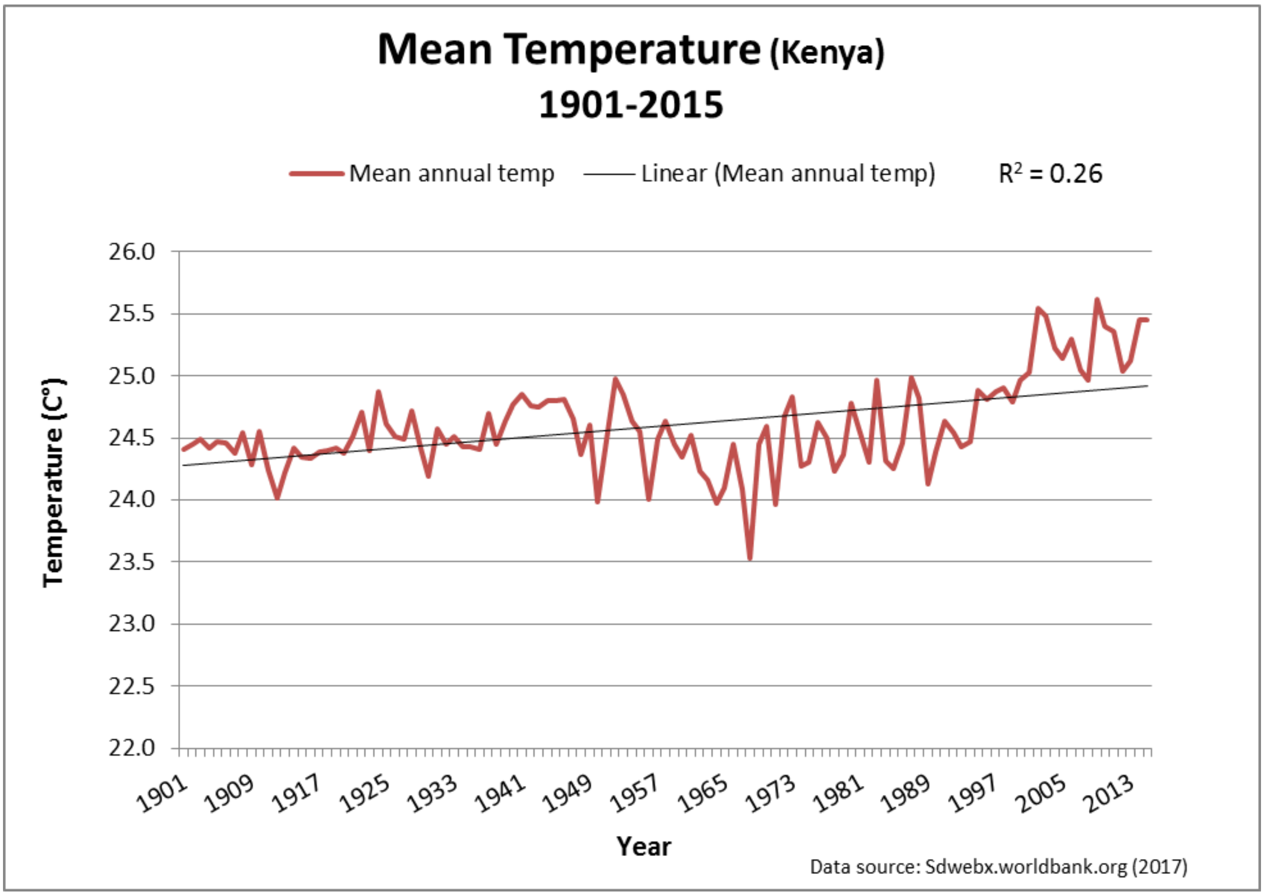

Figure 6: Mean temperature for Kenya, 1901-2015. During these 115 years a linear increase of 0.6 °C was estimated. The R^2-value is significant and indicates that 26% of the variation is explained.

Since a higher increase in mean temperature can be seen towards the end in **figure 6**, the time span between 1985 and 2015 was analyzed as well (**figure 7**). The temperature range varies between 24.13 °C (1989) and 25.62 °C (2009). Between 1985 until 2015 the temperature increased with 1 °C during these 30 years following the trend line. The R^2-value is significant and indicates that 65 % of the variation is explained by the regression model.

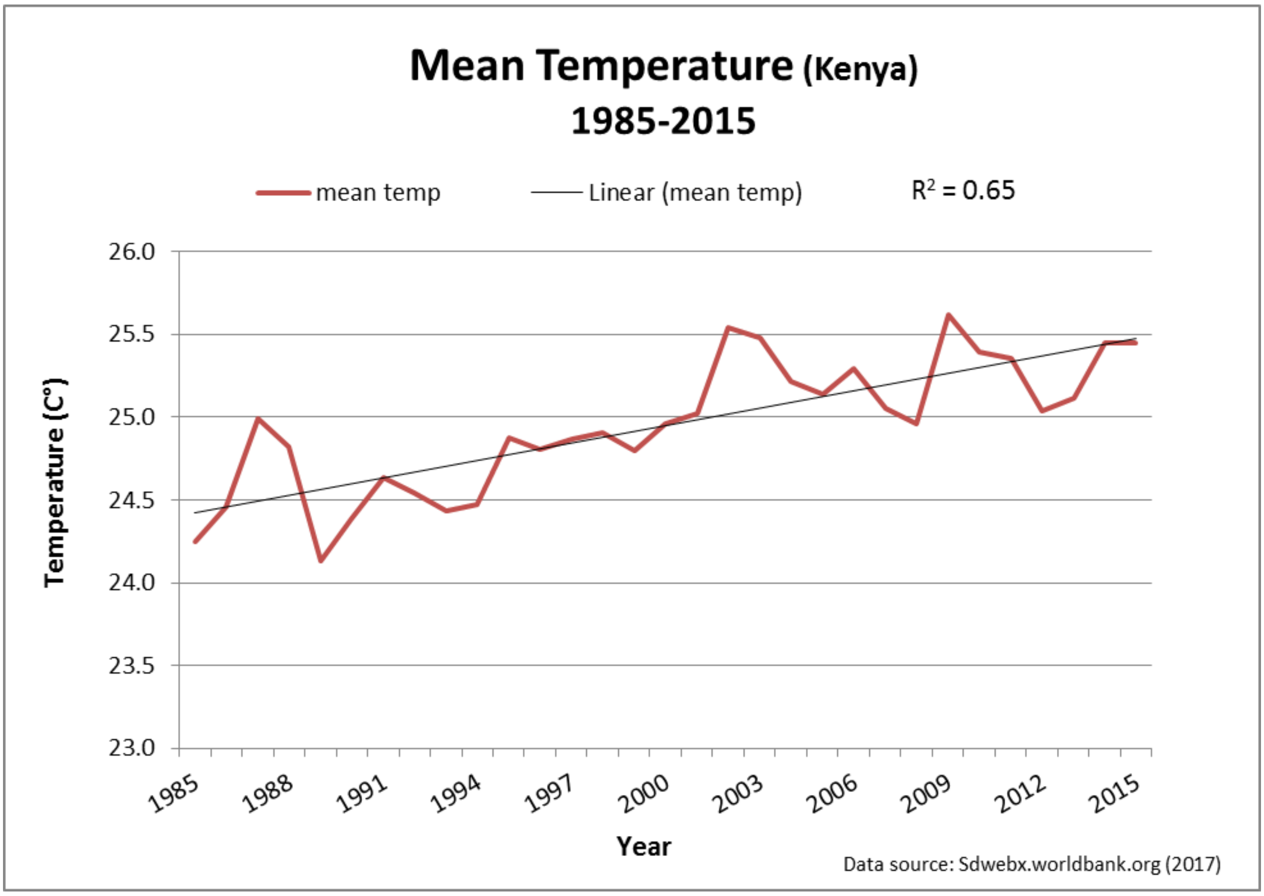

Figure 7: Mean temperature trend over a 30-year time span. The R^2-value is significant and indicates that 65 % of the variation is explained by the graph.

NAIROBI

Results and temperature trends for Nairobi are seen in **figure 8** and **table 2**. For Nairobi, two years (1992 and 1993) were excluded. M**aximum temperatures** are ranging from 24.6 °C (1989) to 26.5 °C (1987), and no strong indication of a temperature trend can be seen. The R^2-value indicates that 9 % of the variation can be explained, and the trend line gives a temperature increase of 0.4 °C during this time span. For the **mean temperatures** the lowest temperature during this time span was 18.2 °C (1989) and highest mean temperature was 19.8°C (2011). The trend line gives that the overall increase during this time period was 1 °C. The R^2-value indicates that more than 50 % of the variation is explained and the trend is significant. **Minimum temperatures** are ranging from 12.3 °C (1980) to 14.5 °C (2011). They indicate the strongest temperature trend, with a R^2-value of 0.76 and a significant trend. An overall increase of 1.6 °C during this period can be calculated by the trend line.

Table 2: Gives resulting R^2–values, linear increases and if the trends are significant or not for temperature trends in Nairobi.

Nairobi			
Trend	**R2**	**F-distribution gives**	**Linear temp increase 1980-2014 (C°)**
Max	0.09	not significant	0.4
Mean	0.56	significant	1
Min	0.76	significant	1.6

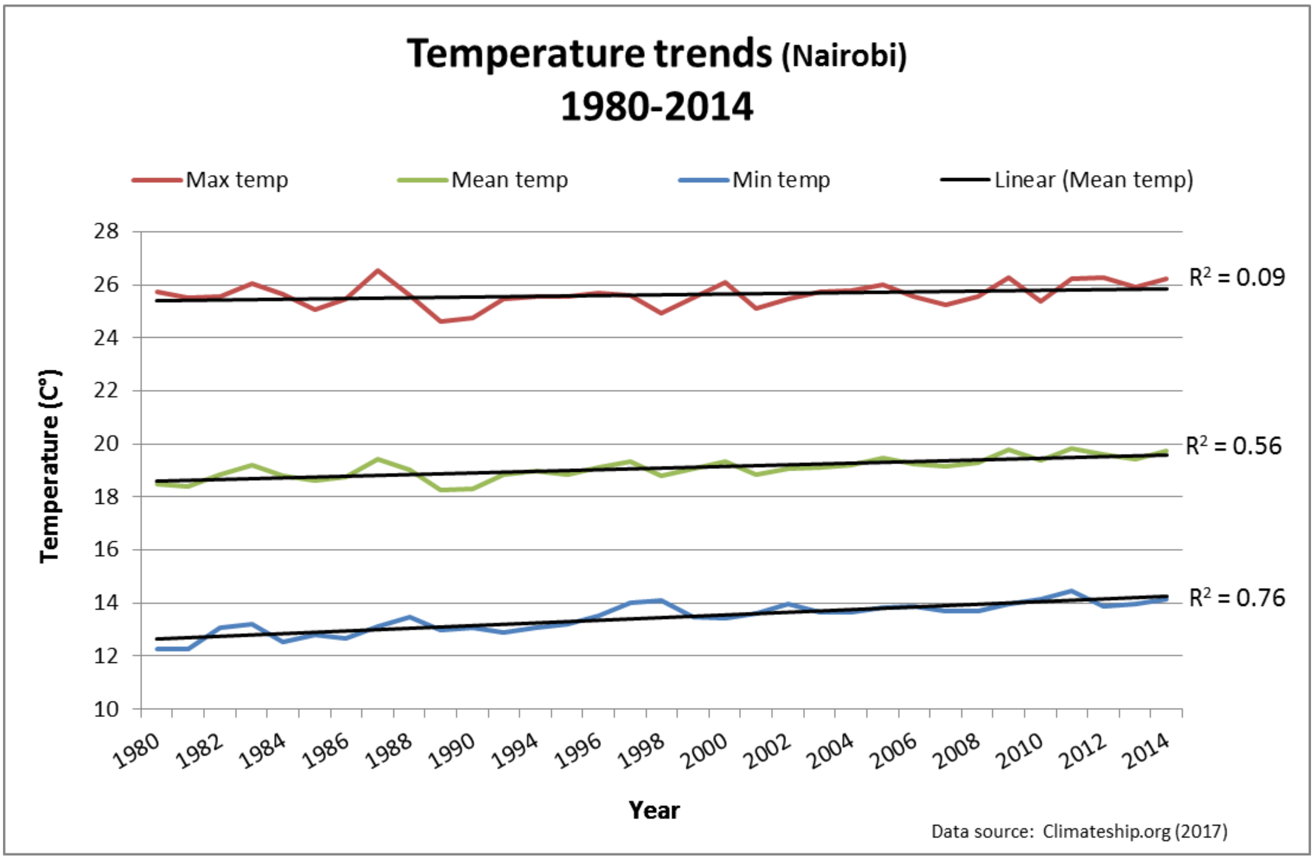

Figure 8: Trends of maximum, mean and minimum temperature in Nairobi, 1980-2014.

MOMBASA

Figure 9 displays the mean, maximum and minimum temperature trends for Mombasa, and results from the trends are seen in **table 3.** Three years (1992, 1993 and 1998) were excluded. **Maximum temperatures** show an increasing trend with a R^2-value of 0.59 and a significant trend. Temperatures are varying between 29.6 °C (1989) and 30.6°C (2014). Following the trend the increase for maximum temperature is 1°C in this time span. The **mean temperatures** show an increasing trend with a R^2-value of 0.66, and a significant trend. The mean temperature ranges from 25.6 °C in 1984 to 26.9 in 2009. Following the trend line, an increase with 1 °C can be calculated during this time span. The **minimum temperatures** are ranging from 20.74 °C (1996) to 23.43 °C (2011). A total increase of 1 °C can be calculated according to the trend line. The R^2-value indicates that 21 % of the variation is explained and the trend is significant.

Table 3: Gives resulting R^2–values, linear increases and if the trends are significant or not for temperature trends in Mombasa.

Mombasa			
Trend	**R2**	**F-distribution gives**	**Linear temp increase 1981-2014 (C°)**
Max	0.59	significant	1
Mean	0.66	significant	1
Min	0.21	significant	1

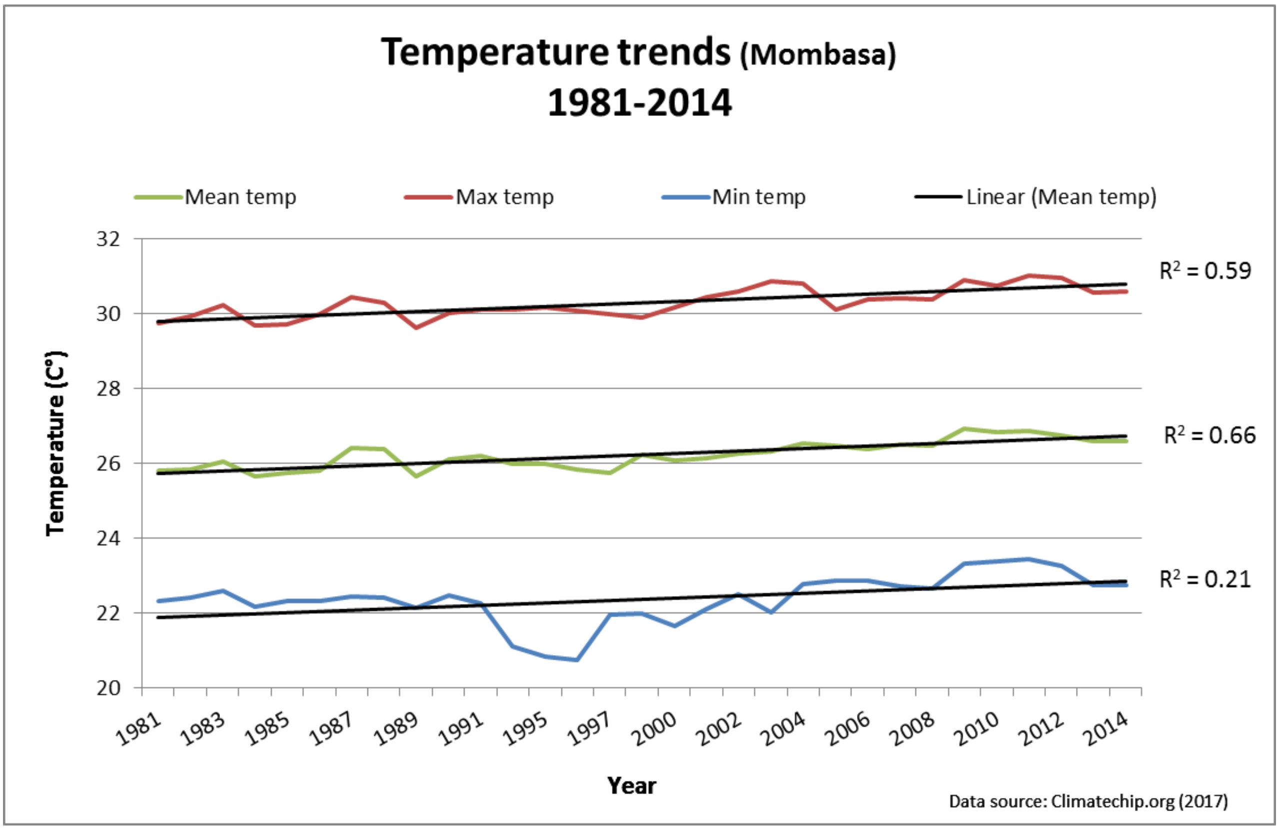

Figure 9: Trends of maximum, mean and minimum temperature in Mombasa, 1981-2014.

GARISSA

Temperature trends and results for Garissa are displayed in **figure 10** and **table 4**. Two years (1993 and 2010) were excluded. No distinct trend can be seen in the **maximum temperatures**. The R^2-value is 0.02 and the trend is not significant. Temperatures are ranging from 33.5 °C (1989) to 35.4 °C (1983) during this period. Following the trend line a temperature increase of 0.2 °C can be calculated. **Mean temperatures** for Garissa are ranging from 27.6 °C (1989) to 29.1°C (2005). R^2-value indicates that 29 % of the variation is explained by the regression model and the trend is significant. The trend line gives an overall temperature increase of 0.6 °C during this period. **Minimum temperatures** are ranging from 21.6 °C (1982) to 24 °C (2014). The R^2-value indicates that 46 % of the variation is explained and the trend is significant. A temperature increase of 1°C is calculated during this time period.

Table 4: Gives resulting R^2–values, linear increases and if the trends are significant or not for temperature trends in Garissa.

Garissa			
Trend	**R2**	**F-distribution gives**	**Linear temp increase 1982-2014 (C°)**
Max	0.02	not significant	0.2
Mean	0.29	significant	0.6
Min	0.46	significant	1

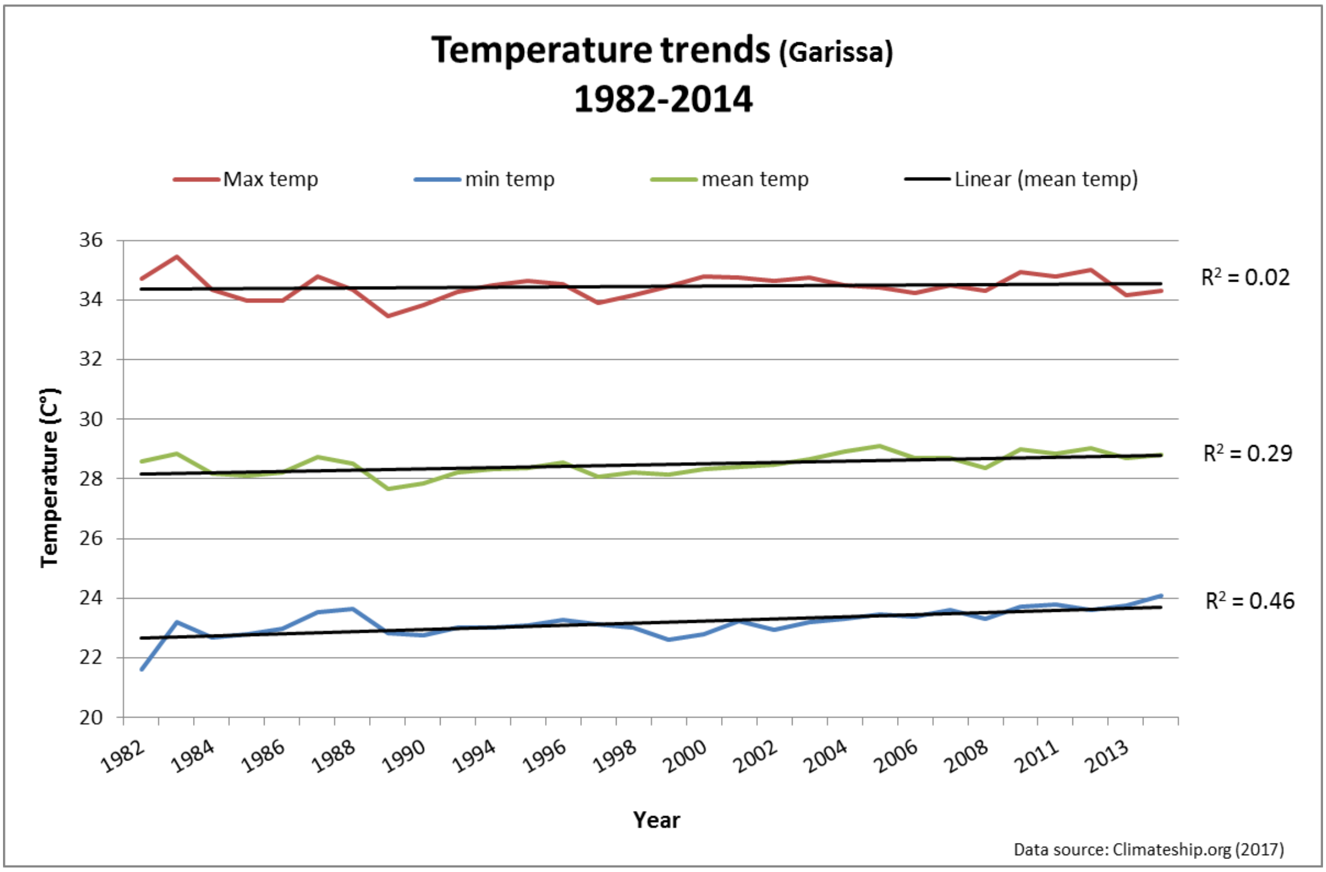

Figure 10: Trends of maximum, mean and minimum temperature in Garissa, 1982-2014.

KISUMU

Temperature trends and results for Kisumu are displayed in **figure 11** and **table 5**. Two years (1992 and 2010) were excluded. **Maximum temperatures** for Kisumu are ranging from 29.6 °C (1981) to 30.5 °C (2005). The linear trend gives a temperature increase of 0.2 °C during this time span. The R^2-value indicates that only 4 % can be explained and the trend is not significant. The **mean temperatures** are ranging from 22.6 °C (1989) to 23.8 °C (2009). Following the trend line a temperature increase of 0.4 °C can be calculated in this time span. The R^2-value indicates that 18 % of the variation is explained and the trend is significant. **Minimum temperatures** for Kisumu are ranging from 17.2 °C (1981) and 17.9 °C (2011). When using the linear trend a temperature increase of 0.3°C can be calculated in this time span. The R^2-value indicates that 8 % of the variation is explained and the trend is not significant.

Table 5: Gives resulting R^2–values, linear increases and if the trends are significant or not for temperature trends in Kisumu.

Kisumu			
Trend	**R2**	**F-distribution gives (P<0.05)**	**Linear temp increase 1981-2014 (C°)**
Max	0.04	not significant	0.2
Mean	0.18	significant	0.4
Min	0.08	not significant	0.3

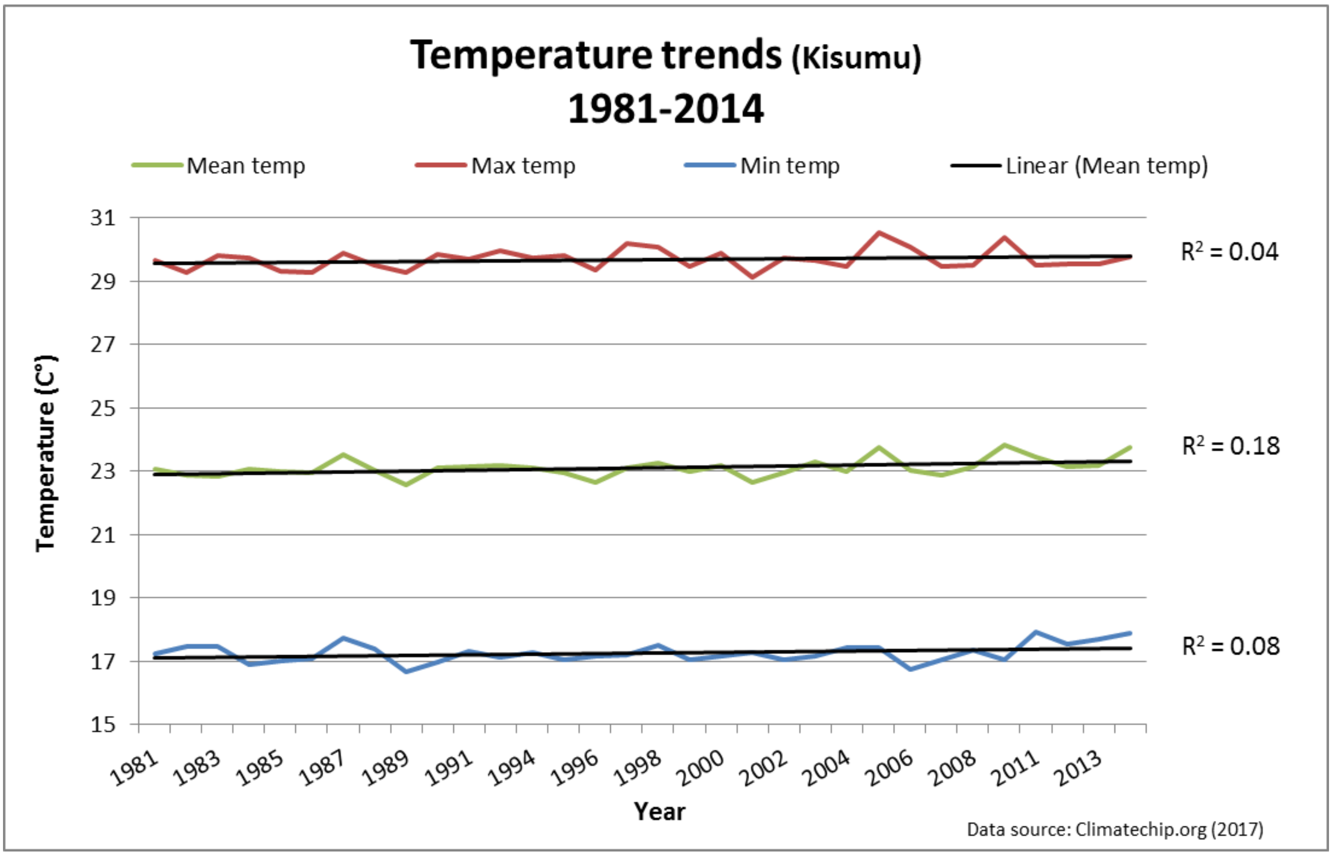

Figure 11: Trends of maximum, mean and minimum temperature in Kisumu, 1981-2014.

4.2.2 Precipitation

Figure 12 display average precipitation for Kenya on national level, 1901-2015. The graph shows high variation in rainfall over the century, the amount of precipitation ranges from 36.8 mm (1921) to 88.4 mm (1961). The R^2-value is very low with a value of 0.003, and also the trend line indicates that no actual trend can be seen in the long-term precipitation. The short-term precipitation trend is displayed in **figure 13.** The R^2-value is 0.02, indicating that very little of the variation can be explained. Over the 30-year period there is a slight precipitation increase of 5 mm.

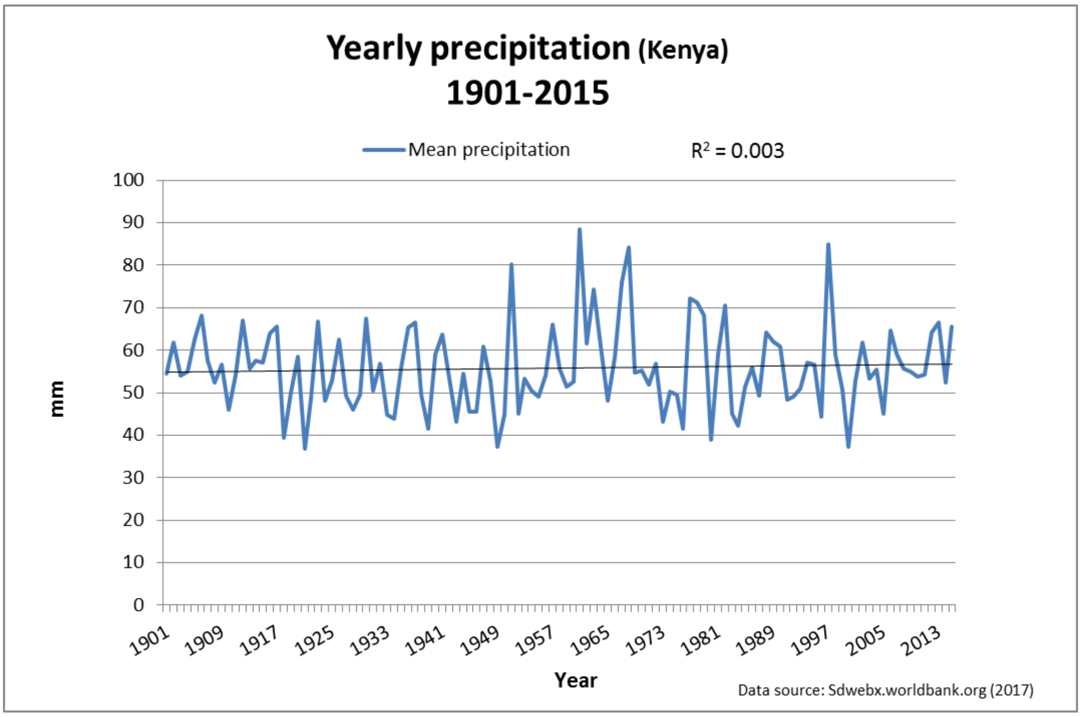

Figure 12: Average yearly precipitation for Kenya, 1901-2015. A very slight linear increase of 1.96 mm was estimated for this 115 year-period.

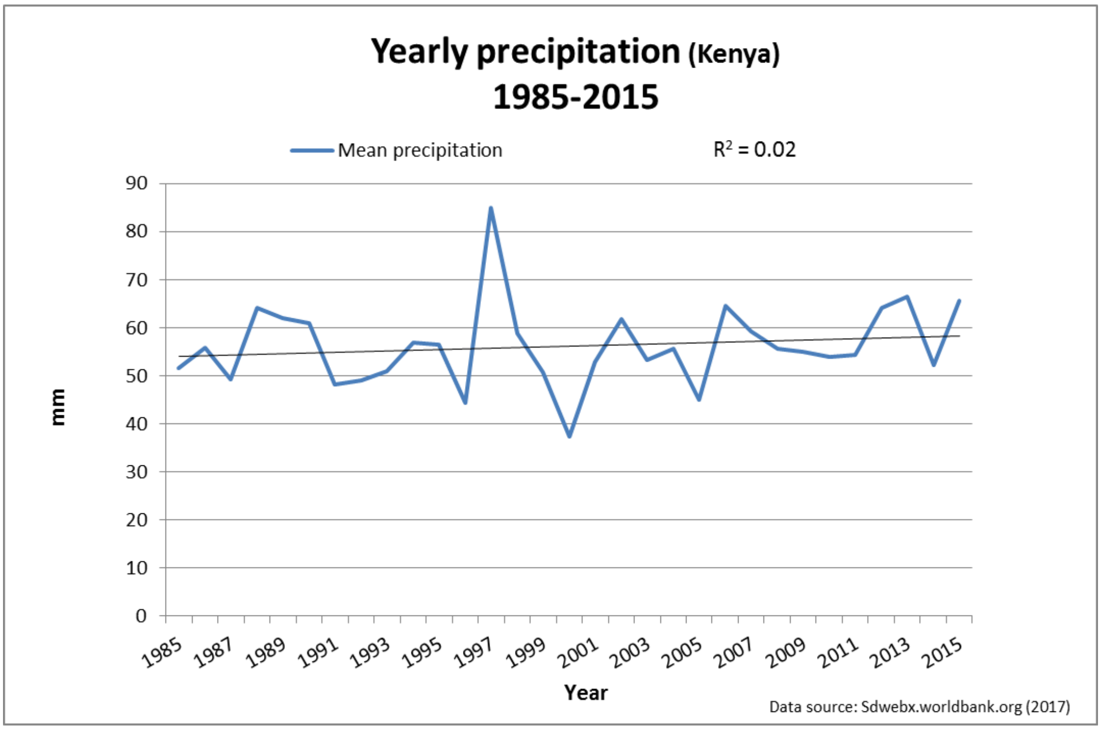

Figure 13: Yearly precipitation for the shorter time period of 1985-2015. A slight linear increase of 5 mm was estimated for this 30-year period.

5 Discussion

Below the findings about temperature and precipitation from literature and data analysis are compared and discussed in relation to each other, followed by limitations and improvements and a brief section about further studies.

5.1 Temperature

Increasing temperature trends are apparent in literature on both African and East African scale. Comparing the trends for mean temperature in literature with the national long-term temperatures for Kenya **(figure 6)** it can be seen that the computed temperature increase when following the linear trend is 0.6 °C. This is just in between the reported increases in temperature indicated by Hulme et al. (2001) who reported an increase of 0.5 °C and Hussein (2011) who reported an increase of 0.7 °C for Africa. The short term national trend **(figure 7)** however exceeds the reported long-term changes in literature and show a more distinct increasing trend than the long-term trend in the data analysis. Both the long-term and short-term trend show significant increase in temperature. From information discussed above it can be derived that literature on continental level and the data analysis on national level agree about observed increasing trends in temperature. Focusing on East Africa –significant increases in temperature are reported since about 1980 – which corresponds to significant increases in the short term national trend **(figure 7)**. For the regional parts of Kenya, for mean, maximum and minimum temperatures - 8 out of 12 regional temperature trends show significant increasing trends. For three out of four regions, minimum temperature trends displayed a higher increase than maximum temperatures – which followed the findings in literature. Thus, also regional short-term temperature trends agree with findings in literature about reported increasing trends in Kenya, however; it needs to be considered that also for some of the significant regional trends the R^2-values were very low.

5.2 Regional differences

The average temperature is, as reported the in background section, differing quite a lot between the four regions – due to different locations and altitudes which results in different climate types. Mombasa (**figure 9**, **table 3**) show significant increases in all three temperatures (mean, maximum and minimum temperatures), with a linear trend of 1 °C increase in all of them. However, Mombasa is the only city in which the minimum temperatures do not show a stronger increase than the maximum temperatures, which then contradicts the statements in the literature. For Nairobi (**figure 8**, **table 2**) two significant trends can be seen for the minimum and maximum temperatures. The minimum trend shows a stronger increase than the maximum trend – just as described by Makokha and Shisanya (2010) where minimum temperatures are increasing more rapidly due to the *urban heat island effect* as a result of urbanization. Garissa (**figure 10**, **table 4**) shows significant temperatures changes for minimum and mean temperatures and also here does minimum temperatures increase more rapidly than maximum temperatures. Kisumu (**figure 11**, **table 5**) generally shows the smallest trends of climate change, where only the mean temperature displays a slight significant increasing trend. Kisumu is, as mentioned before, located on higher elevations (between 1100 and 1800 m a.s.l.) and this fact could be compared to the statement of Funk (2010) who states that Kenya's highlands are expected to stay cooler while the rest of the surrounding lower lands will increase in temperature. However, this statement does not coincide with temperature trends for Nairobi, which is located even higher than Kisumu but where two of the temperatures show relatively strong significant trends.

Projected future trends indicate temperature increases between 2-6 °C (Hulme et al. 2001), or 2 °C until the 21st century (Anyah and Qiu 2012) and of 1 °C until 2025 (Funk 2010). Considering the observed temperatures in literature and the increasing trends in the data analysis – there are some indications that temperature trends might be approaching the projected values in the future.

5.3 Precipitation

As already mentioned in the background, interannual precipitation in eastern Africa is controlled and influenced by several factors. Both gathered literature and results from the data analysis indicate that east African rainfall is characterized by high variability. Both the long-term trend (**figure 12**) and the short-term trend (**figure 13**) have very low R^2-values. Influences from ENSO-related events make it complicated to draw conclusions about how precipitation patterns are altered by changes in climate. Within gathered literature several sources (Nicholson et al. 2000), (Williams and Funk 2011; Lyon and DeWitt 2012), report about drying trends over eastern Africa due to warming over the Indian Ocean, and a general warming of the oceans are also reported by the IPCC (2014). According to (Giannini et al. 2008) the warming of the Indian Ocean is also understood to further enhance the drying impacts of warm ENSO-events, which then indicate that global warming may have resulted in drying trends in regions of eastern Africa. However, the connection to human induced climate change has not been proven and needs further investigation.

5.4 Extreme events

An incline in the number of extreme events is reported by several studies; (Awuor et al. 2008; Kebede et al. 2012; Williams et al. 2012) as a very likely effect of climate change. For East Africa and Kenya, floods constitute the biggest problem and affects especially low-lying areas. Due to limitations within data, literature findings could not be supported by a data analysis. However gathered literature can provide a small insight to how local regions may be affected by these events, and thus argue that local regions are as well affected by climate change - related incidents.

5.5 Limitations and Improvements

Contemplating on the chosen methodologies – there are several improvements that can be made. For the *literature analysis*, improvements would be to collect literature with more focus on actual estimations of temperature trends and a more down-scaled focus – on national and regional level in order to collect findings even more comparable to the regional data. However, due to lack of time the number of articles and the time spent on collecting had to be narrowed down.

For the *climate data* there are several improvements for further studies;

First of all a higher number of regions included in the analysis is interesting when studying regional differences. The optimal case would be to have more distributed regions - covering especially more of the northern parts of Kenya.

For the temperature data it is important to note that the regional datasets for temperature – as mentioned in the methodology section – are not 100 % complete. This might affect the results, and has to be considered before stating conclusions about the findings.

Regarding precipitation – there was a lack of available data which limited the analysis to national precipitation. Regional precipitation patterns could not be studied in order to lack of data, however, a regional approach would have been interesting also for rainfall, even if it is more complicated to draw any conclusions at all about regional precipitation patterns.

Finally, gap-filling was done to some extent for the regional temperature data – as suggested by Holst (2017). This will however affect the results, and by gap-filling data by taking the average between two days - information about outliers and unexpected values will be lost, which thus changes the results Discussions on whether to gap-fill missing data-values or not is a topic which is frequently discussed, and must always be considered when conclusions are drawn about the results.

Suggestions for further studies

Suggestions for further studies are presented below;

- ❖ Include a higher number of regions in order to further investigate if, how and why different regions are affected differently when it comes to changes in temperature and precipitation.
- ❖ Impacts of ENSO-related events on the east African climate is only touched briefly upon in this report, and there is a great need of investigations of how changes in climate and global warming may impact ENSO and ENSO-related events in eastern Africa and Kenya.
- ❖ The influence of climate change-related events on social, economic and natural values in Kenya needs to be further explored.
- ❖ Finally, different ways of gap-filling methods could be investigated on the same datasets, or perform an analysis without any gap-filling at all.

6 Conclusions

Trends of progressing climate change in Kenya have been studied by a literature review and a climate data analysis. There is a general agreement about observed increases in temperature within literature and climate data. Reports from literature and observations in climate data indicate a more rapid increase in recent years. Regarding precipitation, findings in literature as well as in the data analysis indicate that precipitations patterns in eastern Africa are characterized by high variability. Declining trends in precipitation are reported within literature however the link to human induced climate change has not been proven. Regional datasets that were analyzed indicate trends of climate change, and indicate differing trends in mean, maximum and minimum temperatures between regions. The data analysis indicates thus that the magnitude of increase in temperatures might be different between the four analyzed regions.

7 References

Ahrens, C. D. 2013. *Meteorology today : an introduction to weather, climate, and the environment*. Brooks/Cole, Cengage Learning.

Ajuang, C. O., P. O. Abuom, E. K. Bosire, G. O. Dida, and D. N. Anyona. 2016. Determinants of climate change awareness level in upper Nyakach Division, Kisumu County, Kenya. *SpringerPlus* 2016. DOI: 0.1186/s40064-016-2699-y

Anyah, R. O., and W. Qiu. 2012. Characteristic 20th and 21st century precipitation and temperature patterns and changes over the Greater Horn of Africa. *International Journal of Climatology,* 32**:** 347-363. DOI: DOI: 10.1002/joc.2270.

Awuor, C. B., V. A. Orindi, and A. O. Adwera. 2008. Climate change and coastal cities: the case of Mombase, kenya. *Environment & Urbanizaiton,* 20**:** 231-242.

Central Intelligence Agency. 2017. The World Factbook. Retrieved 13 May 2017, from https://www.cia.gov/library/publications/the-world-factbook/geos/ke.html.

Climate-data.org (A). 2017. Climate: Nairobi. Retrieved 15 May 2017, from https://en.climate-data.org/location/541/#climate-graph.

Climate-data.org (B). 2017. Climate: Mombasa. Retrieved 15 May 2017, from https://en.climate-data.org/location/915/.

Climate-data.org (C). 2017. Climate: Kisumu. Retrieved 20 May 2017, from https://en.climate-data.org/location/715071/.

Climate-data.org (D). 2017. Climate: Garissa. Retrieved May 18 2017, from https://en.climate-data.org/location/923/.

Climatechip.org. 2016. ClimateCHIP.org,. Retrieved 15 March 2017, from www.ClimateCHIP.org.

Douglas, I., K. Alam, M. Maghenda, Y. McDonnell, L. McLean, and J. Campbell. 2008. Unjust waters: climate change, flooding and the urban poor in Africa. *Environment & Urbanizaiton,* 20**:** 187-205.

Egondi, T., C. Kyobutungi, S. Kovats, K. Muindi, R. Ettarh, and J. Rocklöv. 2012. Time-series analysis of weather and mortality patterns in Nairobi's informal settlements. *Global Health Action,* 5**:** 19065. DOI: 10.3402/gha.v5i0.19065

Endris, H. S., P. Omondi, S. Jain, C. Lennard, B. Hewitson, L. Chang'a, J. L. Awange, A. Dosio, et al. 2013. Assessment of the Performance of CORDEX Regional Climate Models in Simulating East African Rainfall. *Journal of Climate***:** p8453-p8475.

FAO. 2002. *World Agriculture: Towards 2015/2030. Summary Report. Food and Agriculture Organization of the United Nations (FAO).* Rome, Italy

Funk, C., 2010. A climate trend analysis of Kenya, August 2010. U. S. Geological Survey : Reston, VA, United States, Report 23276916, United States. [in Swedish, English summary]

Giannini, A., M. Biasutti, I. M. Held, and A. H. Sobel. 2008. A global perspective on African climate. *Climatic Change,* 90**:** 359-383. DOI: DOI: 10.1007/s10584-008-9396-v.

Government of Kenya. 2010. National Climate Change Response Strategy.

Holst, T. 2017. Personal communication. Institution for Dept. Physical Geography.

Houghton, J. T. 2009. *Global warming : the complete briefing*. Cambridge: Cambridge University Press.

Hulme, M., R. Doherty, T. Ngara, M. New, and D. Lister. 2001. African climate change: 1900-2100. *Climate Research,* 17**:** 145-168.

Hussein, M. A. 2011. Climate Change Impacts on East Africa. In *The Economic, Social and Political Elements of Climate Change,* ed. W. Leal Filho, 589-601. Climate Change Management series. New York and Heidelberg: Springer.

IPCC. 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]*. Geneva, Switzerland: IPCC

IVPH. 2017. World maps of Köppen-Geiger climate classification. Retrieved 13 May 2017, from http://koeppen-geiger.vu-wien.ac.at/present.htm.

Kebede, A. S., R. J. Nicholls, S. Hanson, and M. Mokrech. 2012. Impacts of Climate Change and Sea-Level Rise: A Preliminary Case Study of Mombasa, Kenya. *Journal of Coastal Research,* 278**:** 8-19. DOI: 10.2112/jcoastres-d-10-00069.1

Kenya National Bureau of Statistics. 2009. The 2009 Kenya Population and Housing Census

Kenya National Bureau of Statistics. 2015. Kenya Facts and Figures. Retrieved 13 May 2017, from http://www.knbs.or.ke/index.php?option=com_phocadownload&view=category&id=20&Itemid=1107.

Kim, J., D. E. Waliser, C. A. Mattmann, C. E. Goodale, A. F. Hart, P. A. Zimdars, D. J. Crichton, C. Jones, et al. 2014. Evaluation of the CORDEX-Africa multi-RCM hindcast: systematic model errors. *Climate Dynamics,* 42**:** p1189-p1202.

Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel. 2006. World Map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift,* 15**:** 259-263. DOI: 10.1127/0941-2948/2006/0130

Landguiden.se. 2016. Kenya - Geografi. Retrieved 14 May 2017, from https://www.ui.se/landguiden/lander-och-omraden/afrika/kenya/geografi/.

Lyon, B., and D. G. DeWitt. 2012. A recent and abrupt decline in the East African long rains. *GEOPHYSICAL RESEARCH LETTERS*.

Makokha, G. L., and C. A. Shisanya. 2010. Trends in Mean Annual Minimum and Maximum Near Surface Temperature in Nairobi City, Kenya. *Advances in Meteorology,* 2010**:** 6.

MDG Africa Steering Group. 2008. *Achieving the Millennium Development Goals in Africa. Recommendations of the MDG Africa Steering Group.* New York, USA: United Nations.

Nakayama, T., and T. Fujita. 2010. Cooling effect of water-holding pavements made of new materials on water and heat budgets in urban areas. *Landscape and Urban Planning,* 96**:** 57-67. DOI: 10.1016/j.landurbplan.2010.02.003

Nanyingi, M. O., G. M. Muchemi, S. M. Thumbi, F. Ade, C. O. Onyango, S. G. Kiama, and B. Bett. 2017. Seroepidemiological Survey of Rift Valley Fever Virus in Ruminants in Garissa, Kenya. *VECTOR-BORNE AND ZOONOTIC DISEASES,* 17**:** 141-146. DOI: 10.1089/vbz.2016.1988

Niang, I., O. C. Ruppel, M. A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart. 2014. *Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Nicholson, S. E., B. Some, and B. Kone. 2000. An analysis of recent rainfall conditions in West Africa, including the rainy seasons of the 1997 El Nino and the 1998 La Nina years. *Journal of Climate,* 13**:** 2628-2640.

Nikulin, G., C. Jones, F. Giorgi, G. Asrar, M. Bu¨Chner, R. Cerezo-Mota, O. B. Christensen, M. De´Que´, et al. 2012. Precipitation climatology in an ensemble of CORDEX-Africa regional climate simulations. *Journal of Climate,* 25**:** 6057-6078. DOI: .DOI: 10.1175/JCLI-D-11-00375.1.

Ochieng, J., L. Kirimi, and M. Mathenge. 2016. Effects of climate variability and change on agricultural production: The case of small scale farmers in Kenya. *NJAS - Wageningen Journal of Life Sciences,* 77**:** 71-78. DOI: 10.1016/j.njas.2016.03.005

Ogwang, B. A., H. S. Chen, X. Li, and C. J. Gao. 2014. The Influence of Topography on East African October to December Climate: Sensitivity Experiments with RegCM4. *Advances in Meteorology,* 2014**:** pp. 1-14.

Okayo, J., P. Odera, and S. Omuterema. 2015. Socio-economic characteristics of the community that determine ability to uptake precautionary measures to mitigate flood disaster in Kano Plains, Kisumu County, Kenya. *Geoenvironmental Disasters,* 2**:** 26. DOI: 10.1186/s40677-015-0034-5

Okere , F., and M. Kodiwo. 2012. Analysis of spatial and temporal changes in the correlation between agricultural land-use intensity and land degradation. *Modern Soc Sci* 1**:** 21–43.

Rogerson, P. A. 2011. *Statistical methods for geography: A student's guide*. SAGE Publications.

Shisanya, C. A., and M. Khayesi. 2007. How is climate change perceived in relation to other socioeconomic and environmental threats in Nairobi, Kenya? *Climatic Change,* 85**:** 271-284. DOI: 10.1007/s10584-007-9321-9

Shongwe, M. E., G. J. van Oldenborgh, B. van den Hurk, and M. van Aalst. 2011. Projected Changes in Mean and Extreme Precipitation in Africa under Global Warming. Part II: East Africa. *Journal of Climate,* 24**:** 3718-3733. DOI: 10.1175/2010JCLI2883.1

Simms, A., and M. Murphy. 2005. Africa – Up in smoke? The second report from the Working Group on Climate Change and Development. *Oxfam Policy and Practice: Climate Change and Resilience, ,* Volume 1**:** pp. 58-101.

Stone, B., J. J. Hess, and H. Frumkin. 2010. Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities. *Environmental Health Perspectives* 118**:** pp. 1425–1428.

Sylla, M. B., A. T. Gaye, and G. S. Jenkins. 2012. On the Fine-Scale Topography Regulating Changes in Atmospheric Hydrological Cycle and Extreme Rainfall over West Africa in a Regional Climate Model Projections. *International Journal of Geophysics***:** 981649. DOI: DOI: 10.1155/2012/981649.

The World Bank Group. 2017. Climate Change Knowledge Portal. Retrieved 26 Apr 2017, from http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisRegion=Africa&ThisCCode=KEN.

UN DESA Population Division. 2015. World Population Prospects: The 2015 Revision, Key Findings and Advance Tables. . ed. P. D. Department of Economic and Social Affairs. New York: United Nations.

UN Statistics Division. Standard Country or Area Codes for Statistical Use: The "M49 standard". Retrieved 9 June 2017, from https://unstats.un.org/unsd/methodology/m49/.

UNDP: International Strategy for Disaster Reduction. 2009. Building Disaster Resilient Communities: Good Practices and Lessons Learned; A Publication of the "Global Network of NGOs" for Disaster Risk Reduction. Geneva.: United Nations.

UNECA, A., AfDB, and UNDP,. 2012. Assessing Progress in Africa toward the Millennium Development Goals: MDG Report 2012. Emerging Perspectives from Africa on the Post-2015 Development Agenda.**:** 160 pp.

United Nations Development Programme. 2017. About Kenya, Statistics. . Retrieved 13 May 2017, from http://www.ke.undp.org/content/kenya/en/home/countryinfo.html.

Vincent, L. A., E. Aguilar, M. Saindou, A. F. Hassane, G. Jumaux, D. Roy, P. Booneeady, R. Virasami, et al. 2011. Observed trends in indices of daily and extreme temperature and precipitation for the countries of the western Indian Ocean, 1961-2008. *Journal of Geophysical Research-Atmospheres,* 116.

Williams, A. P., and C. Funk. 2011. A westward extension of the warm pool leads to a westward extension of the Walker circulation, drying eastern Africa. *Climate Dynamics,* 37**:** 2417-2435. DOI: DOI: 10.1007/s00382-010-0984-y.

Williams, A. P., C. Funk, J. Michaelsen, S. A. Rauscher, I. Robertson, T. H. G. Wils, M. Koprowski, Z. Eshetu, et al. 2012. Recent summer precipitation trends in the Greater Horn of Africa and the emerging role of Indian Ocean sea surface temperature. *Climate Dynamics,* 39**:** 2307-2328. DOI: DOI: 10.1007/s00382-011-1222-y.

WMO. 2011. Guide to Climatological Practices, 3rd Edition. *WMO,* 100.

Worldometers.info. 2017. Kenya Population. Retrieved 14 May 2017, from http://www.worldometers.info/world-population/kenya-population/.

Yabi, I., and F. Afouda. 2012. Extreme rainfall years in Benin (West Africa). *Quaternary International,* 262**:** pp 39-43.

Yuen, B., and A. Kumssa. 2011. Climate Change and Sustainable Urban Development in Africa and Asia. *Springer Science***:** 270 pp.

Institutionen för naturgeografi och ekosystemvetenskap, Lunds Universitet.

Examensarbete (Seminarieuppsatser). Uppsatserna finns tillgängliga på institutionens geobibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på LUP student papers (https://lup.lub.lu.se/student-papers/search/) och via Geobiblioteket (www.geobib.lu.se)

The student thesis reports are available at the Geo-Library, Department of Physical Geography and Ecosystem Science, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden. Report series started 1985. The complete list and electronic versions are also electronic available at the LUP student papers (https://lup.lub.lu.se/student-papers/search/) and through the Geo-library (www.geobib.lu.se)

410 Ying Zhou (2016) The link between secondary organic aerosol and monoterpenes at a boreal forest site
411 Matthew Corney (2016) Preparation and analysis of crowdsourced GPS bicycling data: a study of Skåne, Sweden
412 Louise Hannon Bradshaw (2017) Sweden, forests & wind storms: Developing a model to predict storm damage to forests in Kronoberg county
413 Joel D. White (2017) Shifts within the carbon cycle in response to the absence of keystone herbivore *Ovibos moschatus* in a high arctic mire
414 Kristofer Karlsson (2017) Greenhouse gas flux at a temperate peatland: a comparison of the eddy covariance method and the flux-gradient method
415 Md. Monirul Islam (2017) Tracing mangrove forest dynamics of Bangladesh using historical Landsat data
416 Bos Brendan Bos (2017) The effects of tropical cyclones on the carbon cycle
417 Martynas Cerniauskas (2017) Estimating wildfire-attributed boreal forest burn in Central and Eastern Siberia during summer of 2016
418 Number reserved for BSc thesis
419 Clara Kjällman (2017) Changing landscapes: Wetlands in the Swedish municipality Helsingborg 1820-2016
420 Raluca Munteanu (2017) The effects of changing temperature and precipitation rates on free-living soil Nematoda in Norway.
421 Neija Maegaard Elvekjær (2017) Assessing Land degradation in global drylands and possible linkages to socio-economic inequality
422 Petra Oberhollenzer, (2017) Reforestation of Alpine Grasslands in South Tyrol: Assessing spatial changes based on LANDSAT data 1986-2016
423 Femke, Pijcke (2017) Change of water surface area in northern Sweden
424 Alexandra Pongracz (2017) Modelling global Gross Primary Production using the correlation between key leaf traits
425 Marie W Skogseid (2017) Climate Change in Kenya - A review of literature and evaluation of temperature and precipitation data