Assessing the Effects of Meteorological Parameters on Aerosols over Dar es Salaam, Tanzania

By

Isaya Kapakala

Reg no:I45/84332/2012

kapakalai@yahoo.com

University of Nairobi

Department of Meteorology

P. O. Box 30197

Nairobi, Kenya

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Declaration

This research project is my original work and has not been presented for a degree in this or any other University.

Signature

Isaya Kapakala **Date**

Department of Meteorology

University of Nairobi

This research project has been accepted for research study with our approval as University Supervisors.

Signature

Prof. J. K NG'ANG'A **Date**

Department of Meteorology,

University of Nairobi

Signature

Prof. J.M ININDA **Date**

Department of Meteorology,

University of Nairobi

Abstract

The effect of meteorology on aerosols concentration in Dar es Salaam was assessed. Meteorological data (Precipitation,temperature, relative humidity and wind speed) were obtained from Tanzania Meteorological Agency during the period from 1980-2012 and the Aerosol Optical Depth (AOD) at 550nm data was sought from the Moderate Resolution Imaging Spectro-radiometer satellite(MODIS) from 2000-2012.Time series analysis based on graphical analysis of meteorological parameters and aerosols were done. Aerosols concentrations were correlated to meteorological parameters.

Results showed that the highest concentrations for the aerosol optical depth were observed during the dry season and the lowest concentrations during the wet season. It is interpreted that reasons for the higher levels of the aerosols in the dry season are due to temperature inversions, soil dust dispersal and absence of rain wash-out. A negative correlation between AOD and relative humidity,temperature and rainfall, and positive correlation between AOD and windspeed was observed. The observed Aerosols concentration are affected by the variations in meteorological conditions such as precipitation, relative humidity,temperature and wind speed.

Overall, the study found that the aerosols response to changes in meteorlogical parameters was somewhat reasonable identifying meteorological parameters as a driver of air quality and therefore information from this study should be used to form basis for assesing the effect of meteorological factors on aerosols.

DEDICATION

This study is dedicated to my lovely parents Mr. and Mrs. Solomon Kapakala

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I would like to thank GOD for giving me strength, ability and good health throughout this research and my all studies.

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Last but not least I would like to thank my friends, Juma Hamisi and Ahmad Athuman for always being there for me during both good and bad times.

MAY GOD BLESS THEM ALL

KAPAKALA ISAYA

UNIVERSITY OF NAIROBI

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Acronyms

AOD	Aerosol Optical Depth
FMF	Fine Mode Fractions
GDAS	Global Data Assimilation System
IPCC	Intergovernmental Panel on Climate Change
JJA	June, July, August
MAM	March, April, May
MODIS	Moderate Resolution Imaging Spectral-radiometer satellite
NCEP	National Centers for Environmental Prediction
NCAR	National Centre for Atmospheric Research
PM	Particulate Matters

CHAPTER ONE

INTRODUCTION

1.1 Background of study

Since the beginning of the last century, many events of air pollution have been associated with increase in mortality. Some examples are the 1930 Meuse Valley fog killed 60 people in Belgium due to a combination of industrial air pollution and climatic conditions (Firket, 1931), Donora in 1948 that killed 20 people and sickened 7,000 more (Ciocco and Thompson, 1961) and the most famous, London smog in 1952 killed about 4000 people (Logan, 1953) and Sao Paulo City (Gonc, et. al. 2004). These episodes entirely depended on various factors including emissions, local and synoptic scale meteorological conditions, topography, and atmospheric chemical processes and the season of the year.

The temporal and spatial variability of the atmospheric concentration of Particulate Matters (PM) and its components are influenced by meteorological parameters such as rainfall, temperature, relative humidity, and air flow patterns (Bardouki et al. 2003). Aerosol particles are removed from the air by a combination of wet and dry deposition processes. Wet deposition occurs in rain events; it is a process, which is somewhat independent on the particle size, which during the wet deposition larger and smaller particles can be eliminated sequentially during a single rain event. Dry deposition is a continuous process in which the fallout of aerosol particles is strongly determined by particle size (Ozsoy and Saydam, 2000).

Aerosol concentrations are the result of interactions among local weather patterns, atmospheric circulation features, wind, topography, human activities such as transport, human responses to weather changes such as the onset of cold or warm spells which may increase heating and cooling needs and therefore energy needs (Kossmann and Sturman 2004). Some locations, because of their general climate and topographic setting, are predisposed to poor air quality because the climate is conducive to chemical reactions leading to the transformation of emissions, and topography restricts the dispersion of pollutants (Kossmann and Sturman 2004).

Certain weather situations provide the prerequisite meteorological conditions for pollution episodes. Meteorological conditions influence the chemical and physical processes involved in the formation of the secondary pollutants such as Ozone (Nilsson et al. 2001). Airflow along the flanks of anticyclonic systems can transport Ozone precursors, creating the conditions for an Ozone event

(Tanner and Law 2002). Large-scale airflows not necessarily related to anticyclonic systems can interact with local topography, sea/lake and land breezes, or mountain or valley winds to increase pollutant concentrations (Hess et al. 2003). Distant weather systems such as tropical cyclones and low pressure systems lying over coastal regions can lead to high pollutions levels (Gallardo et al. 2002).

Aerosol particles in the atmosphere consist of a mixture of natural and anthropogenic materials. Particles of aerodynamic diameter smaller than 10 µm (PM10) and those smaller than 2.5 µm (PM2.5), have been found to be associated with health problems (Pope, 2000; Afroz et al. 2003) and ambient air quality problems, such as visibility reduction (Watson, 2002). Studies indicate that air pollutants demonstrate clear seasonal cycles (Kassomenos et al. 2003; Nagedra and Khare 2003).

In an effort to provide those responsible for air quality management with potential scenarios, there exist a need to develop research on assessment of the impacts of a changing climate on regional air quality (Cheng et al. 2007; Jacob and Winner, 2009). Therefore, this research paper will address the dependence of air quality on meteorological parameters in Dar es Salaam and give better understand on the pollution levels of the urban area.

1.2 Problem statement

Recent years have seen an increase in urbanization not only in the developed country but also in developing countries. An increasing percentage of the world's population lives in urban areas. This high population density and the concentration of industry exert great pressures on local environments. The causes of air pollution episodes depend on various factors including emissions, local and synoptic scale meteorological conditions, topography, and atmospheric chemical processes. In most cases, Air pollution, from households, industry power stations and transportation (motor vehicles), is often a major problem. This has resulted to continued concern about urban air quality (Costabile et al. 2006). Poor air quality has both acute and chronic effects on human health, plants and property.

Studies indicate that air pollutants demonstrate clear seasonal cycles (Kassomenos et al. 2003). Certain weather situations provide the prerequisite meteorological conditions for pollution episodes. Moreover, meteorological conditions influence the chemical and physical processes involved in the formation of the secondary pollutants such as Ozone (Nilsson et al. 2001). With observed climate change, local to regional air quality will be affected through changes in chemical reactions rates, boundary layer heights, that affect vertical mixing of pollutants, and changes in synoptic air flow patterns that govern pollutant transport (Swart et al. 2004).

Estimation of sensitivity of air pollutants to individual weather parameters has proven particularly challenging for several reasons. For example, meteorological parameters are inherently linked, resulting in strong interdependencies. Moreover, meteorological parameters can affect pollutants through direct physical mechanisms such as the relationship with radiation and ozone or indirectly through influences on other meteorological parameters such as the association between high temperatures and low wind speed (Ordonez et al. 2005; Jacob and Winner, 2009).

Changes in meteorological conditions coupled with increasing urbanization, population growth and industrialization will be expected to worsen the effects of air pollution and thus air quality especially in urban areas.

1.3 Hypothesis

The overall hypothesis in this study is that changes in rainfall, temperature, relative humidity and winds influence the concentration of aerosols over Dar es Salaam.

1.4 Objectives of study

The overall objective of this study was to assess the effects of meteorological parameters (rainfall, temperature, relative humidity and winds) on aerosols over Dar es Salaam. The specific objectives were;

1. To determine the temporal variability of meteorological parameters and aerosols over Dar es Salaam
2. To determine the relationship between meteorological parameters and aerosols over Dar es Salaam

1.5 Justification of study

It is properly identified that concentrations of gases and aerosol particles surrounded by local air sheds are affected by meteorology (Cheng et al. 2007; Beaver and Palazoglu, 2009). This understanding has led the air quality community to recognize that air pollution is an area sensitive to projected climate change. In an attempt to give those accountable for air quality management with potential scenarios, there exist a need to develop research on assessment of the impacts of a changing climate on regional air quality (Jacob and Winner, 2009) such as estimation of the sensitivity of air pollutants to individual meteorological parameters.

With recent acknowledgement of the sensitivity of air quality to changes in climate, this necessitates site specific assessments necessary to understanding local responses affecting the relationships between meteorology and air quality (Dawson et al. 2007; USEPA, 2009). This will provide insights into pollution levels and thus information on appropriate measures to regulate and mitigate effects of air pollution. Improving air quality is a significant aspect of promoting sustainable human settlements.

1.6 Conceptual framework

Meteorology plays an important role in the formation, dispersion, transport, and dilution of air pollutants. The variations in local meteorological conditions such as wind direction, wind speed, temperature and relative humidity have a great influence in air quality (Mkoma, 2010). In this study, weather parameters (rainfall,temperaure,winds and relative humidity) when mixed up with air pollutants such as PM10 and PM2.5 in the atmosphere will result into good or bad air quality as shown in figure 1 below.

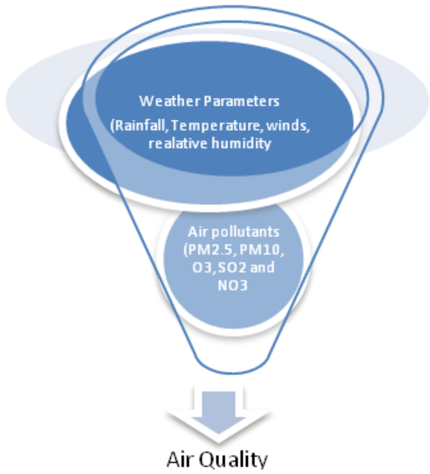

Figure 1: Conceptual Framework

1.7 Area of study

Dar es Salaam is the largest city in Tanzania. It is also the country's richest city and a regionally important economic centre. Dar es Salaam is actually an administrative province within Tanzania, and consists of three local government areas or administrative districts: Kinondoni to the north, Ilala in the center of the region, and Temeke to the south. Dar es Salaam is located at 6°48' South, 39°17' East (−6.8, 39.3). The city is situated on a massive natural harbour on the Eastern Indian Ocean coast of Africa, with sandy beaches in some areas. Administratively, Dar es Salaam is broken into 3 districts: Ilala, Kinondoni, and Temeke

Being situated so close to the equator and the warm Indian Ocean, the city experiences generally tropical climatic conditions, typified by hot and humid weather throughout much of the year. Dar es Salaam features a tropical wet and dry climate, with two different rainy seasons. Annual rainfall is approximately 1,100 mm and in a normal year there are two distinct rainy seasons: "the long rains", which fall during April and May, and "the short rains", which fall during October and November.

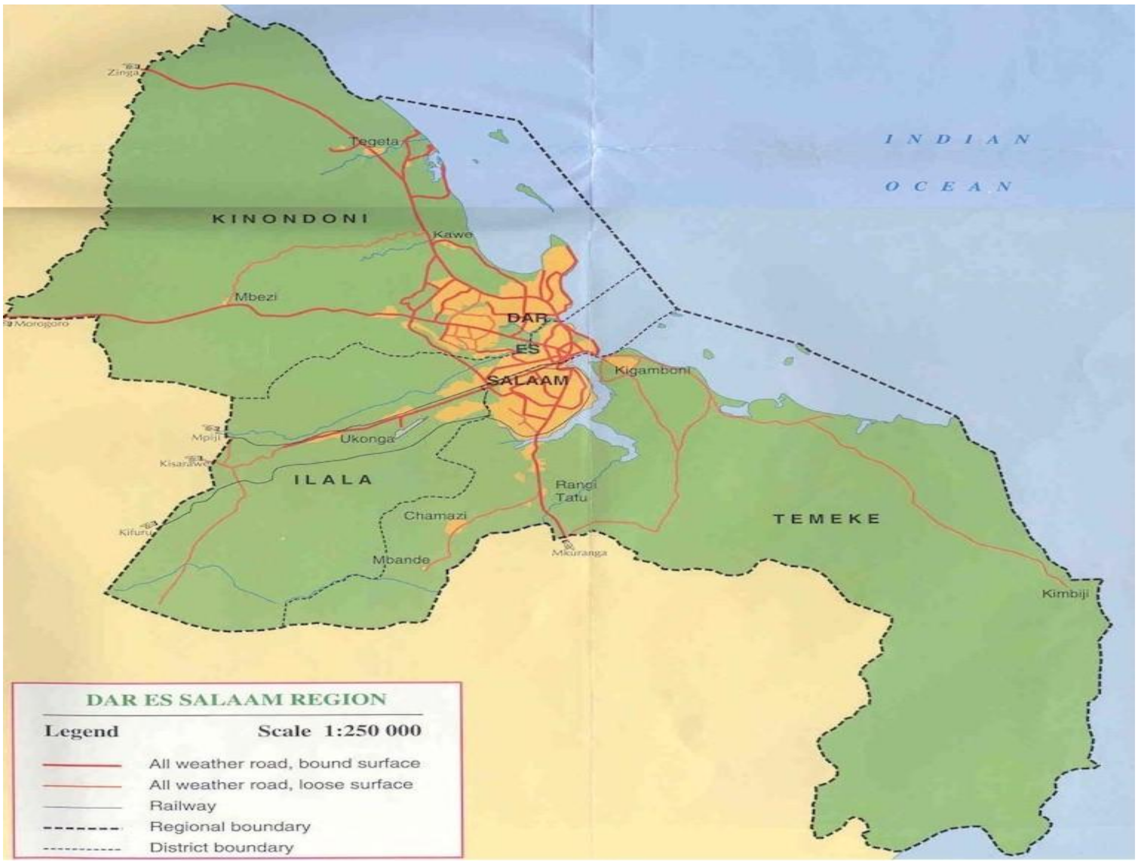

Figure 2: Map of Tanzania and Dar es Salaam showing the city municipalities (Source: Mbuligwe, 2001)

CHAPTER TWO

2 LITERATURE REVIEW

Never (1995) defines air pollution as the presence of undesirable material in air, in quantities large enough to produce harmful effects. The undesirable material may damage human health, vegetation, property or the global environment, as well as create aesthetic insults in the form of brown or hazy air or unpleasant smells. Aerosol particles in the atmosphere consist of a mixture of natural and anthropogenic materials. Studies by Pope **(**2000) and Afroz et al. (2003) found that particles of aerodynamic diameter smaller than 10 µm (PM10) and those smaller than 2.5 µm (PM2.5) are highly associated with health problems and ambient air quality problems such as visibility reduction (Watson, 2002).

According to the IPCC (2007) report, atmospheric aerosols especially the submicrometersized particles affect the Earth's climate by scattering and absorbing incoming solar radiation and outgoing terrestrial infrared radiation and by influencing the properties and formation processes of clouds. In this way, aerosols can affect the concentration and size distribution of cloud droplets. In turn, they can alter the cloud radiative properties, cloud lifetime, the nature and allocation of rain clouds and as a result they interfere with the hydrological cycle (Toon, 2000). Furthermore, aerosol particles influence many atmospheric processes, acidification of clouds, rain and fog (Khoder, 2002) and impacts on climate and ecosystems.

Mkoma (2009) investigated the influence of meteorological parameters (Precipitation, temperature, relative humidity and wind speed) on air quality for a rural background site in Morogoro, Tanzania during 2005 and 2006 wet and dry seasons. They found higher PM10 mass concentrations (45$\mu g/m^3$) during the 2005 dry season and lowest (13 $\mu g/m^3$) during the 2006 wet season. They study attributed the higher levels of the particulate matter mass in the dry season to be as a result of temperature inversions and absence of rain wash down.

Pearce et al. (2011) developed an observational relationships between locally measured individual meteorological variables and selected air pollutants in Melbourne, Australia and found that local meteorological conditions most strongly affected the daily variation associated with O_3 and NO_2 followed closely by PM10. The strongest effects for O_3 were related to temperature, boundary layer height, and radiation. The most significant variables for PM10 were temperature, wind, water vapor pressure, and boundary layer height. Temperature also displayed the strongest influence on NO_2

which was followed by wind and water vapor pressure. The remaining variables displayed some effect for each air pollutant, but the responses for these were less pronounced. These results showed percentage change in air pollutant response across the range of individual meteorological variables, and thus a clear window into how potential climate change may affect air quality.

Weather at all time scales determines the development, transport, dispersion and deposition of air pollutants, with the passage of fronts, cyclonic and anticyclonic systems and their associated air masses being of particular importance. Air-pollution episodes are often associated with stationary or slowly migrating anticyclonic or high pressure systems, which reduce pollution dispersion and diffusion (Rao et al., 2003). Airflow along the flanks of anticyclonic systems can transport ozone precursors, creating the conditions for an ozone event (Tanner and Law, 2002). Certain weather patterns enhance the development of the urban heat island, the intensity of which may be important for secondary chemical reactions within the urban atmosphere, leading to elevated levels of some pollutants (Jonsson et al., 2004)

Ground-level ozone is both naturally occurring and, as the primary constituent of urban smog, is also a secondary pollutant formed through photochemical reactions involving nitrogen oxides and volatile organic compounds in the presence of bright sunshine with high temperatures. In urban areas, transport vehicles are the key sources of nitrogen oxides and volatile organic compounds. Temperature, wind, solar radiation, atmospheric moisture, venting and mixing affect both the emissions of ozone precursors and the production of ozone (Mott et al., 2005). Because ozone formation depends on sunlight, concentrations are typically highest during the summer months, although not all cities have shown seasonality in ozone concentrations (Bates, 2005). Concentrations of ground-level ozone are increasing in most regions (Chen et al., 2004).

Concentrations of air pollutants in general and fine particulate matter (PM) in particular, may change in response to climate change because their formation depends, in part, on temperature and humidity. Air-pollution concentrations are the result of interactions between variations in the physical and dynamic properties of the atmosphere on time-scales from hours to days, atmospheric circulation features, wind, topography and energy use (Pal Arya, 2000). Some air pollutants demonstrate weather-related seasonal cycles (Eiguren-Fernandez et al., 2004). Some locations, such as Mexico City and Los Angeles, are predisposed to poor air quality because local weather patterns are conducive to chemical reactions leading to the transformation of emissions, and because the topography restricts the dispersion of pollutants (Rappengluck et al., 2000)

Studies by Scott and Diab (2000), Tanner and Law (2002) and Yarnal et al. (2001) showed that airflow along the flanks of anticyclonic systems could transport Ozone precursors, creating the conditions for an Ozone event. However, (Ma and Lyons, 2003) have shown that large-scale airflows not necessarily related to anticyclonic systems can interact with local topography, sea/lake and land breezes, or mountain or valley winds to increase pollutant concentrations. Distant weather systems such as tropical cyclones and low pressure systems lying over coastal regions can lead to high pollutions levels (Gallardo et al. 2002).

Swart et al. (2004) found that Climate change affected local to regional air quality directly through changes in chemical reactions rates at boundary layer heights (the layer of air near the ground that is affected by diurnal heat, moisture and momentum transfer to/from the surface) that affect vertical mixing of pollutants, and changes in synoptic air flow patterns that govern pollutant transport.

Indirect effects could result from increasing or decreasing anthropogenic emissions via changes in human behavior or from altering the level of biogenic emissions because of higher temperatures and land cover change. Higher temperatures can increase emissions of isoprene, a volatile hydrocarbon and ozone-precursor emitted by woody plant species. However establishing the scale (local, regional or global) and direction of change (improvement or deterioration) of air quality is challenging (Rainham et al. 2001; Semazzi 2003).

Changes in wind patterns and increased desertification may increase the long-range transport of air pollutants. Under certain atmospheric circulation conditions, the transport of pollutants, including aerosols, carbon monoxide, ozone, desert dust, mould spores and pesticides, may occur over large distances and over time-scales typically of 4-6 days, which can lead to adverse health impacts (Kato et al., 2004). Sources of such pollutants include biomass burning, as well as industrial and mobile sources (Moore et al., 2003).

Exposure to elevated concentrations of ozone is associated with increased hospital admissions for pneumonia, chronic obstructive pulmonary disease, asthma, allergic rhinitis and other respiratory diseases, and with premature mortality (Ito et al., 2005; Levy et al., 2005). Outdoor ozone concentrations, activity patterns and housing characteristics, such as the extent of insulation, are the primary determinants of ozone exposure (Levy et al., 2005). Although a considerable amount is known about the health effects of ozone in Europe and North America, few studies have been conducted in other regions. Evidence for the health impacts of PM is stronger than that for ozone. PM is known to affect morbidity and mortality (Dominici et al., 2006), so increasing concentrations would have significant negative health impacts

CHAPTER THREE

3 DATA AND METHODS

In this chapter, data types and methods of data analysis was covered. The data sources and temporal characteristics of the remote sensed and conventional data that was used in this study was also examined.

3.1 Data

3.1.1 Atmospheric aerosol data

The atmospheric aerosol data was sought from the Moderate Resolution Imaging Spectro-radiometer satellite. Two sets of Moderate Resolution Imaging Spectro-radiometer (MODIS) level -3 (version 5) global-gridded $1^{o} \times 1^{o}$ Moderate Resolution Imaging Spectro-radiometer (MODIS) data for the period 2000 to 2012 was used. These are MODIS atmospheric aerosols products. MODIS atmospheric aerosol products include Aerosol Optical Depth (AOD) for aerosol loading (Kaufman *et al.* 1997) and the aerosol Fine Mode Fraction (FMF) to distinguish aerosol species and composition, in particular dust and smoke.

3.1.2 Weather Parameters

Meteorological data (total monthly rainfall, mean wind speed at 0600z and at 1200z, mean monthly maximum and minimum temperature, and relative humidity at 0600z and 1200z) for the period 1980 -2012 was used. These records were obtained from the Tanzania Meteorological Agency.

Data Quality Control

The quality of data may be compromised by the existence of outliers, inconsistencies and missing values. Inconsistent data can occur due to several reasons such as change of location of observing stations, change of instruments or due to human error. The need for examining data quality cannot be overemphasized; this is to ensure that the data is complete and free from outliers and to ensure correct and reliable statistical inferences can be made from the data. In this study, data quality control refers to a set of techniques applied to detect and correct inconsistencies in observed rainfall, temperature,wind and relative humidity.

In this study, short cut Bartlett test and single mass curve was used to test the homogeneity of data records and ascertain the significance of a break by testing the data time series for stability of variance. Short –Cut Bartlett's test is a test of the hypothesis that all factor standard deviations (or equivalently variances) are equal against the alternative that the standard deviations were not all equal. The sampling distribution of the Bartlett statistic is approximately chi-square when the k factor samples were from independent normal populations. This method is very sensitive to departures from this normality assumption. The method is used in analysis of variance (ANOVA) in a statistical test of the significance of an apparent break in the slope. ANOVA supposes a normal distribution of the data and therefore testing for stability of variance. This method was applied by dividing the time series data into k equal sub periods, where k > 2. In each of these sub-periods, the sample variance $S^2{}_k$ is given by Equation 1

$$S^2{}_k = \frac{1}{n}\left[\sum x^2{}_i - \frac{1}{n}\left(\sum x_i\right)^2\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1)$$

In the equation (1), n represents the summations range over the series in the sub-period k. The largest and smallest values of $S^2{}_k$ will then be selected and denoted as S_{max} and S_{min} respectively. The 95% significant points for the ratio S_{max}/S_{min} will be obtained by comparing this ratio with the values in F-distribution table at 95% significance points. In this method, the null hypothesis is rejected if the calculated F- value is less than tabulated value.

3.2 Methodology

3.2.1 Time variability of meteorological parameters and aerosols over Dar es Salaam city

A time series analysis was used to determine the temporal variability of rainfall, temperature, relative humidity and winds. Time series analysis is an examination of the temporal variations of data of some variable, measured at successive equally-spaced time intervals such as daily, weekly, monthly, and interannual time scales. Time series components include trend, cyclical and random variations. Time series analysis focusing on data observed in time scales less than annual could also have diurnal, monthly, and seasonal variations depending on time scales of data observation. Eventually trend component refers to long term movement of a time series (Ogallo 1980, Omondi 2005).Time series component that were examined in the present study were the trend and seasonal variation.

The seasonality of both the weather parameters and aerosols were studied by analyzing the monthly means.Time series analysis was sought to identify trends in the given datasets. Trend presents the long term movement of the time series. Trend patterns can be derived from graphical and statistical techniques (Omondi 2010). When evaluating the trend component in any time series, detection of whether a time series is stationary or non-stationary can be deduced and when it's non-stationary it can be classified as either linear or non-linear. Trend analysis was done through graphical method and statistical method.

Graphical method which involved plotting various variables against time was used to determine the temporal variability of meteorological parameters and aerosols over Dar es Salaam city. The scatter diagram shows neighboring points connected to generate a time versus data points graph. At times, a time series can be smoothed out with the intention of showing the natural trend of the center of mass of the data. Smoothing always involves some form of local averaging of data such that the non-systematic components of individual observations cancel out. The most common technique is the moving average smoothing which replaces each element of the series by either the simple or weighted average of *n* surrounding elements, where *n* is the width of the smoothing window (Nicholson 2000). Medians can be used instead of means. The main advantage of median as compared to moving average smoothing is that its results are less biased by outliers.

By using statistical method under long- term trend analysis, the data was divided into two groups; 1980 to 1996 (group 1) and 1997 to 2012 (group 2). The statistical methods were used to determine whether there were significant trend of meteorological parameters over the whole period (1980 to 2012). In determining the trend: means from each group was calculated

Note that, if:

$$|\bar{X}_1 - \bar{X}_2| \approx 0$$

It implies that$\bar{X}_1 \approx \bar{X}_2$, then there is no trend, otherwise there is a trend.

$\bar{X}_1$ is the mean for group 1

$\bar{X}_1$ is the mean for group 2

The standard error of estimate(S) was then computed using equation below

$$S = \sqrt{\frac{{\sigma_1}^2}{N_1} + \frac{{\sigma_2}^2}{N_2}}$$

Whereby: S = standard error of estimate, ${\sigma_1}^2$ is the variance for group 1, ${\sigma_2}^2$ is the variance for group 2, and N_1, N_2 is number of data points for each of the groups. The student t- test which is computed as shown by the formula below was used to test the significant of the trend

$$t = \frac{\bar{X}1 - \bar{X}2}{s}$$

This gives the t-computed or the t- statistic. Then using student t- distribution table at 5% significance level and N-2 degrees of freedom i.e. t-tabulated or critical value the null (H_0) and alternative (H_1) hypotheses were defined so as to be able to decide the trend of the time series and they were:

H_0: there is no significant of trend.

H_1: there is significant of trend

The value of t-computed was compared with the value of t-tabulated; if t-computed would be found to be less than t-tabulated the null hypothesis would be accepted, implying that there had no significant of trends.

3.2.2 Relationship between meteorological parameters and aerosols over Dar es Salaam city

Correlation analysis was used to investigate the relationship between meteorological parameters and aerosols. This method provides the degree of relationship between variables. The correlation coefficient *r* is a measure of the linear relationship between two attributes or columns of data. The correlation coefficient is also known as the Pearson product-moment correlation coefficient. The value of *r* can range from -1 to +1 and is independent of the units of measurement. A value of *r* near 0 indicates little correlation between attributes; a value near +1 or -1 indicates a high level of correlation. Simple correlation coefficient *r* between meteorological variable and the air pollution data was calculated. The value of *r* was evaluated using Equation 3.

Simple correlation was used to determine the degree of relationship between any pair of variables.

The simple correlation coefficient between variable X and Variable Y is given by the formula;

$$r_{XY} = \frac{\frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})(Y - \bar{Y})}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})^2 . \frac{1}{n}\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \quad \text{......(3)}$$

Where; r_{xy} is the correlation coefficient.
n is the sample size.
X_i and Y_i are the variables being correlated.
$\bar{x}$ and $\bar{y}$ are the mean values of variables being correlated.

The computed correlation values was tested for statistical significance at 95% and 99% confidence level using the table of critical values for Pearson correlation.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

This chapter addresses the results obtained as per the objectives of the study using the methods outlined in the preceding chapter. The quality of the data used was examined first to ascertain the validity and consistency of data used for further analysis.

4.2 Data Quality Control

Homogeneity of meteorological data used in the study was tested using Short-Cut Bartlett test and single mass curve. Using Short-Cut Bartlett test, it was possible to find out the significance of a break by testing the time series for stability of variance. These results were based on significance points of 95%. The F statistics value and F critical represented the computed and tabulated F distribution sample variances respectively. In this study, rainfall, temperature, wind and relative humidity datasets from all the stations used were homogeneous. Figure 3 shows the graphical representation of sample variances for different meteorological parameters over Dar es Salaam city.

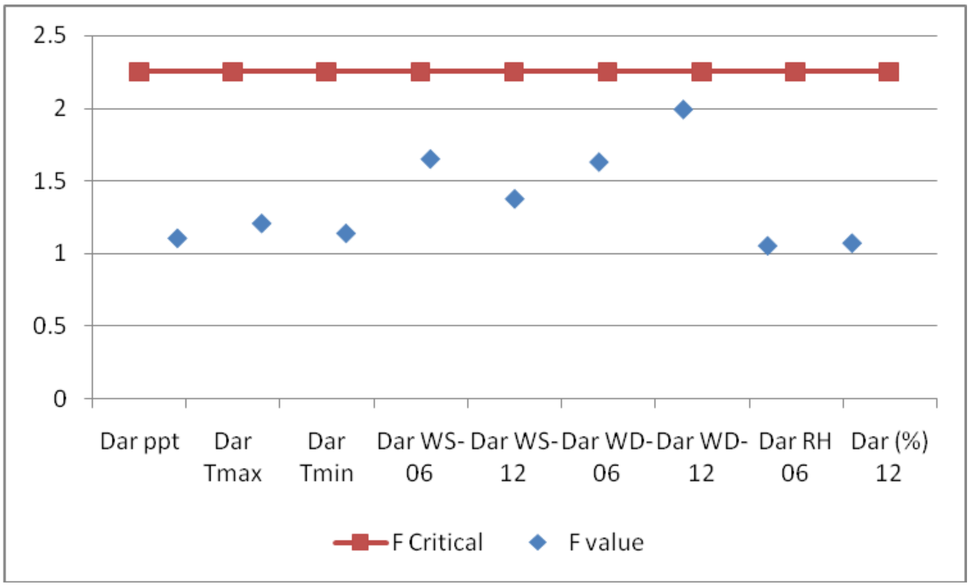

Figure 3: Sample variance for selected meteorological parameters over different stations

The figure 3 showed that at 5% (0.05) significance level, the computed variance (F-value) was less than the tabulated variance (F critical) for rainfall, temperature, wind and relative humidity, records in all stations used in the study. This meant that the variance were the same for all meteorological parameters used from the selected stations. Therefore, the null hypothesis in this probability distribution which stated that all factor standard deviations (or equivalently variances) were equal accepted i.e. the rainfall, temperature, wind and relative humidity records used were homogeneous and useful for further studies. The single mass curve, which is a plot of cumulative meteorological data against time, was also used to test for homogeneity. R showed goodness of fit of the points. The trend line has no breakage on the time for all the parameters used in the study thus indicating homogeneity.

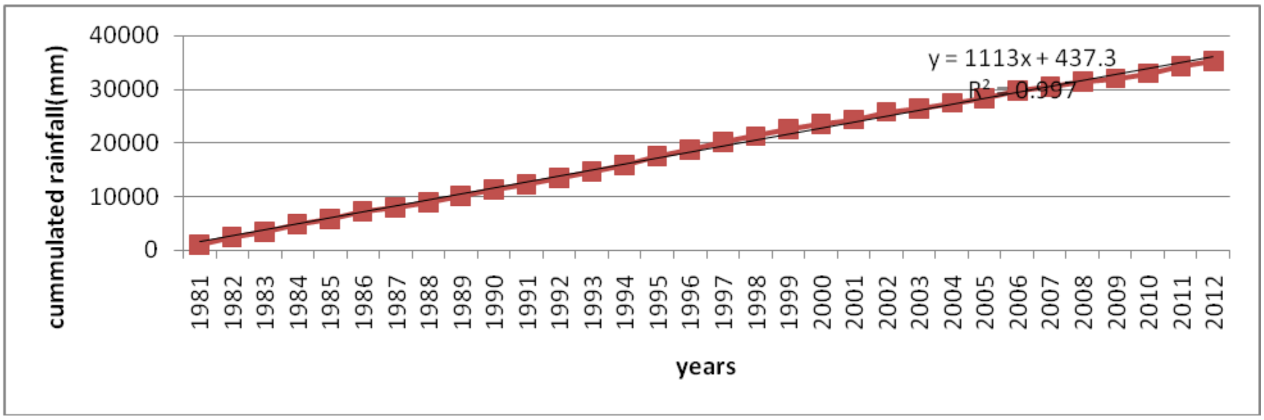

Figure 4: single mass curve for rainfall

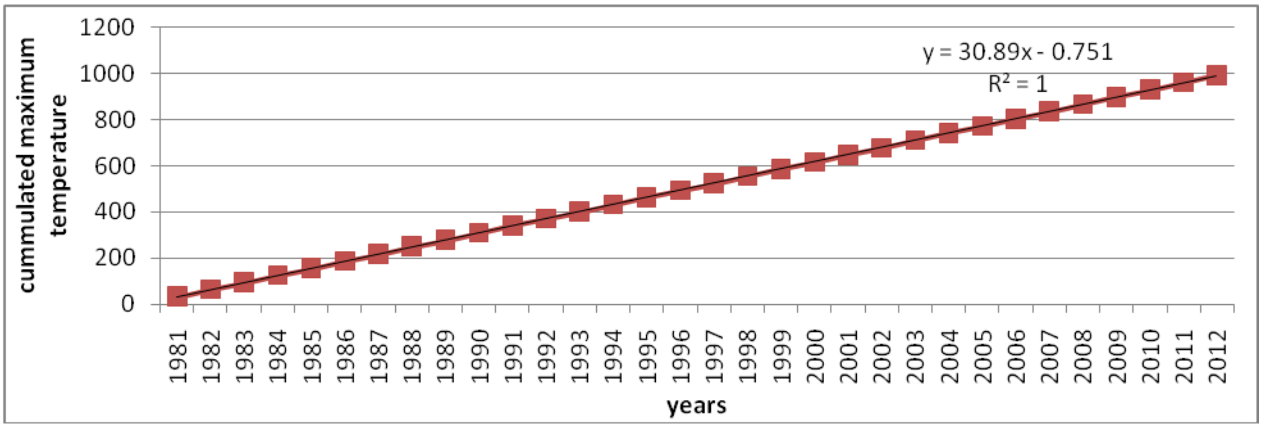

Figure 5: single mass curve for maximum temperature

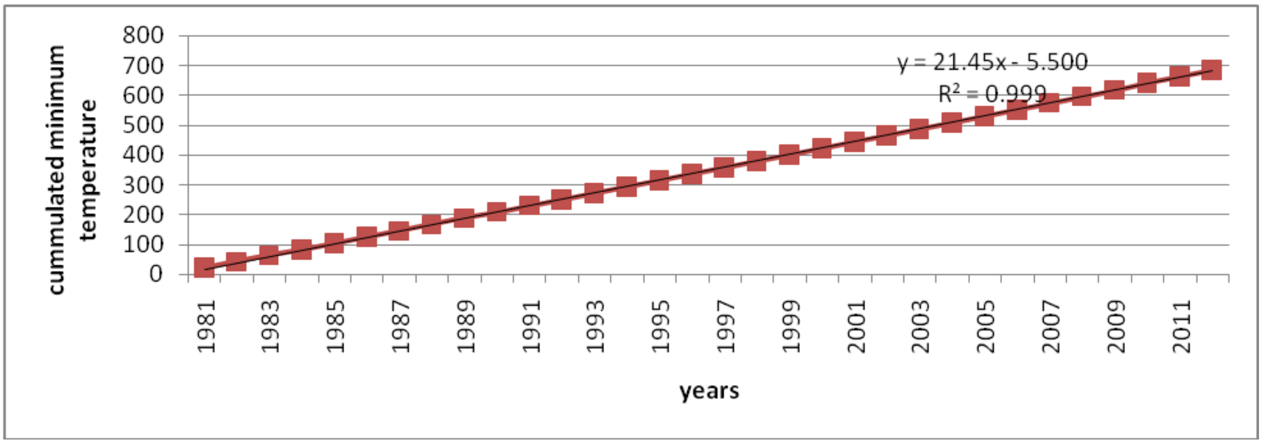

Figure 6: single mass curve for minimum temperature

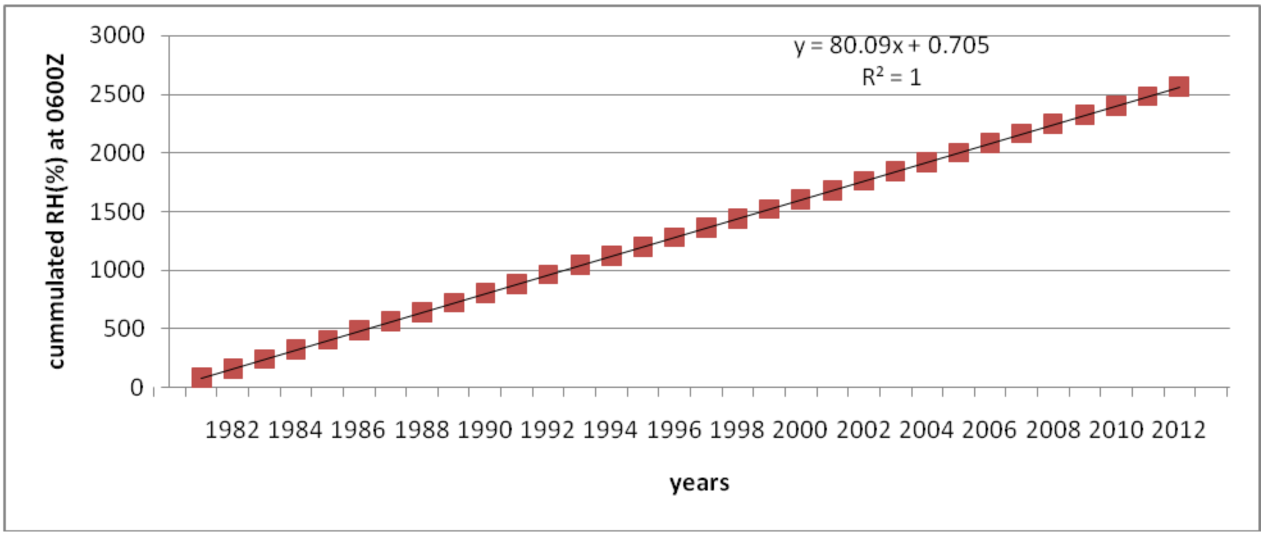

Figure 7: single mass curve for relative humidity at 0600z

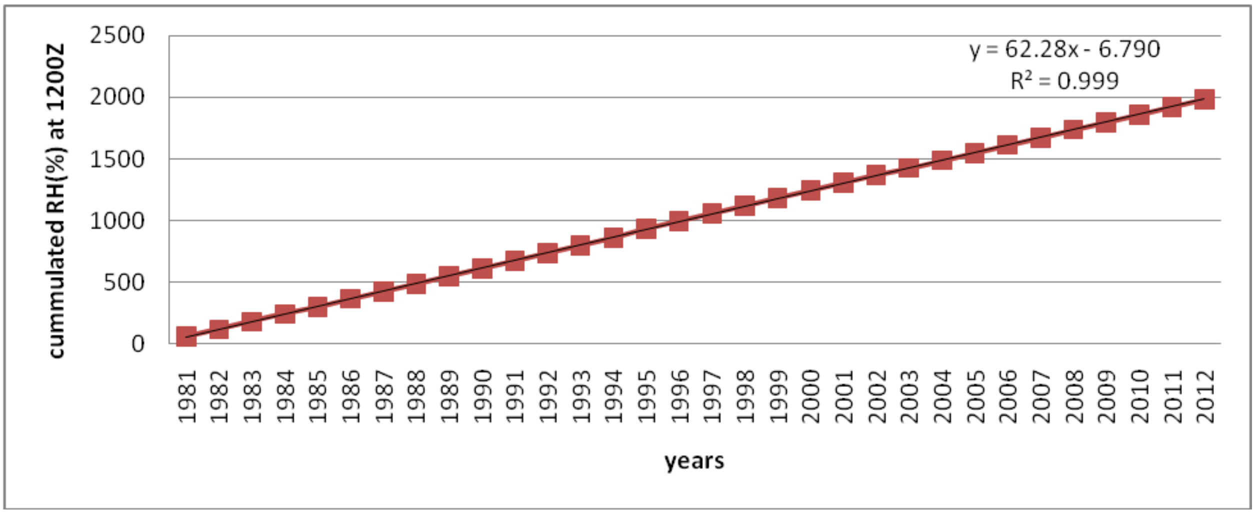

Figure 8: single mass curve for relative humidity at 1200z

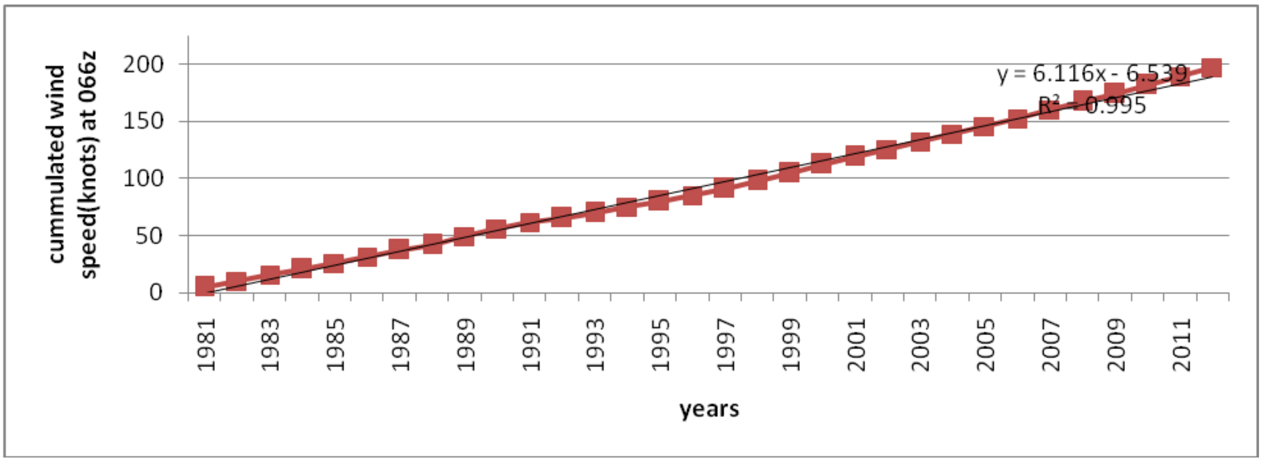

Figure 9: single mass curve for wind speed at 0600z

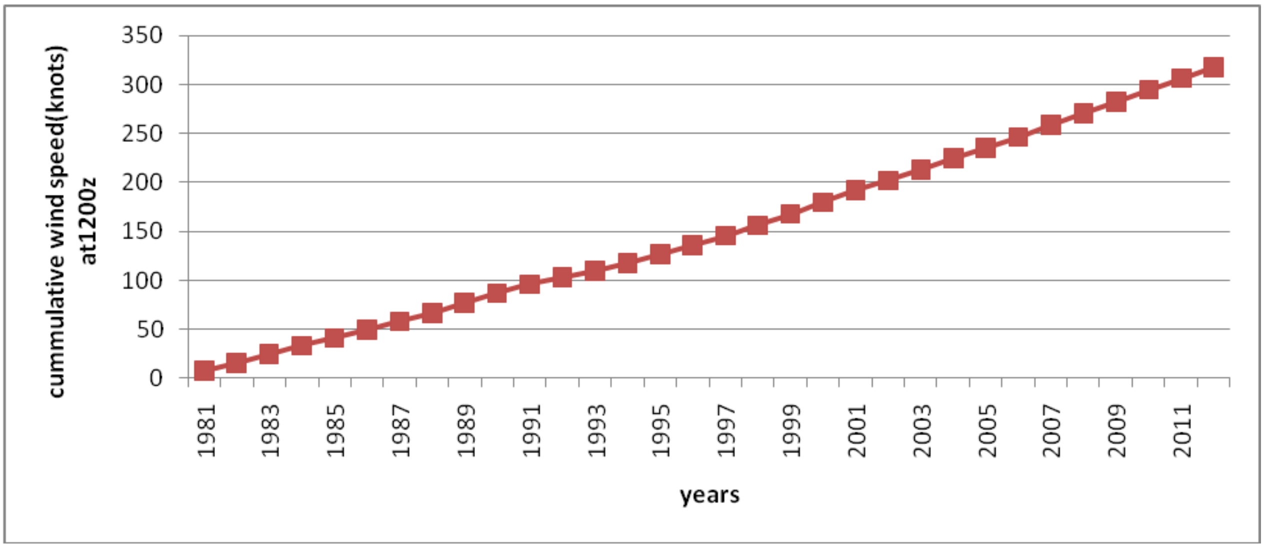

Figure 10: single mass curve for wind speed at 1200z

4.3 Temporal Variability of Meteorological Parameters and Aerosols over Dar es salaam City in Tanzania

This section presents the results from the analysis of the temporal variability of meteorological parameters (Rainfall, Wind speed, Maximum and Minimum Temperature and Relative Humidity) and aerosols (Aerosol Optical Depth at 550nm over Dar es Salaam city.

4.3.1 Results from Rainfall trend analysis

The temporal variation of rainfall over Dar es Salaam city is presented in figure 11.From the figure it can be seen that the rainfall has been decreasing over time.

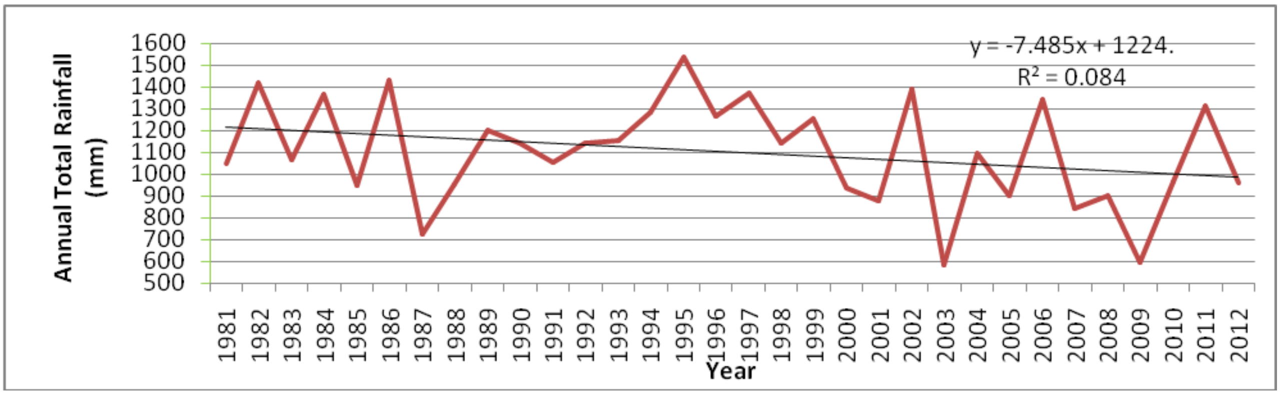

Figure 11: Time series of Rainfall over Dar es Salaam.

4.3.2 Wind speed

The temporal variation of Wind Speed over Dar es Salaam city is presented in figures 12(a) and

12(b) **.** The figures 12(a) wind speed at 0600z and 12 (b)wind speed at 1200z shows time series analysis of wind speed over station used in the study, from the figures it can be seen that both wind speed at 0600z and wind speed at1200z has been increasing over time.

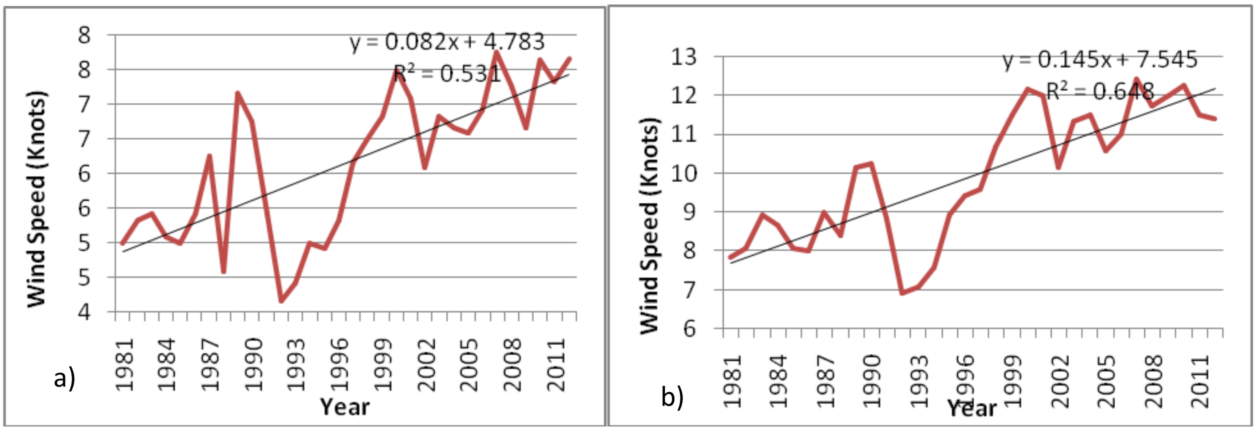

Figure 12: Time series of Wind speed (a) at 0600z and (b) 1200z over Dar es Salaam.

4.3.3 Maximum and Minimum temperature

The figures 13(a) minimum temperature and 13 (b) maximum temperature show time series analysis of temperature over Dar es Salaam. From the figures it can be seen that both maximum and minimum temperature has been increasing over time.

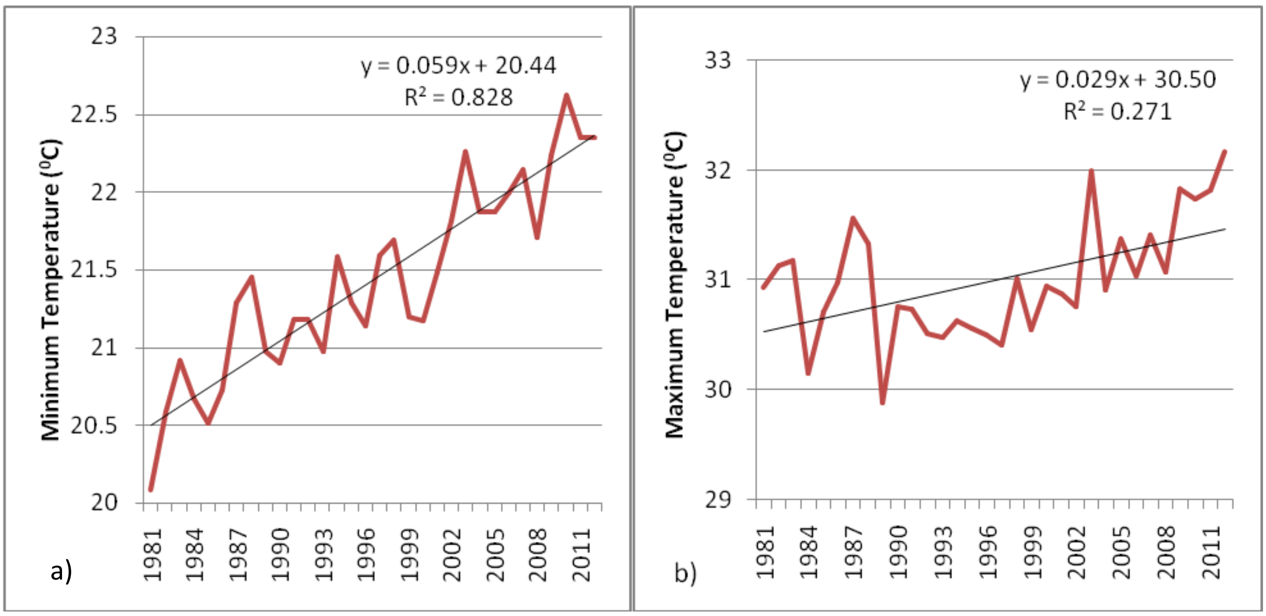

Figure 13: Time series of (a) Minimum and (b) Maximum temperature over Dar es Salaam

4.3.4 Relative Humidity

The figures 14(a)relative humidity at 0600z and 14 (b)relative humidity at1200z show time series analysis of relative humidity over Dar es salaam. From the figures it can be seen that both relative humidity at 0600z and relative humidity at 1200z has been increasing over time.

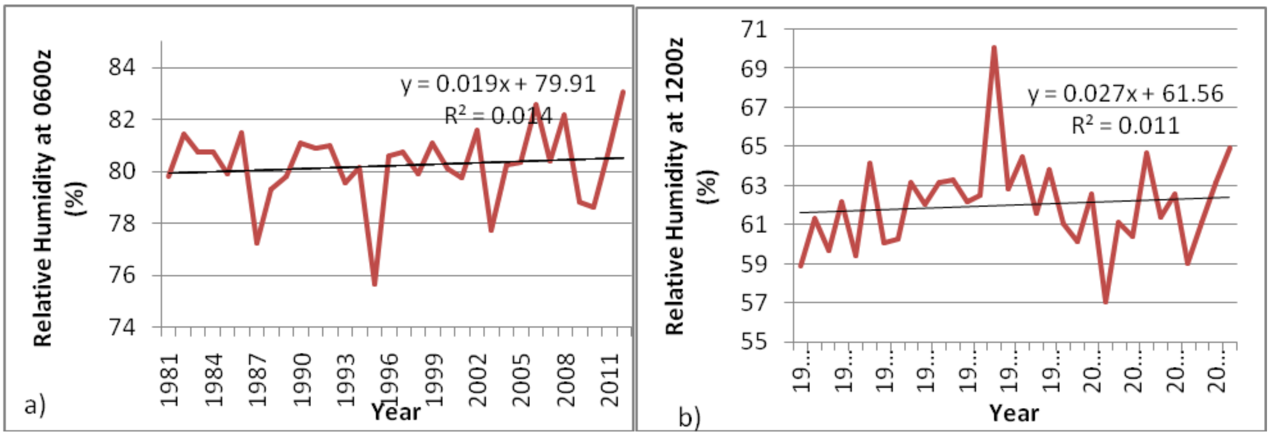

Figure 14: Time serious of Relative Humidity at (a) 0600z and (b) 1200z over Dar es Salaam.

4.3.5 Aerosols

The temporal variation of aerosols over Dar es Salaam city is presented in figure 15.From the figure it can be seen that the aerosols has been slight increasing over time.

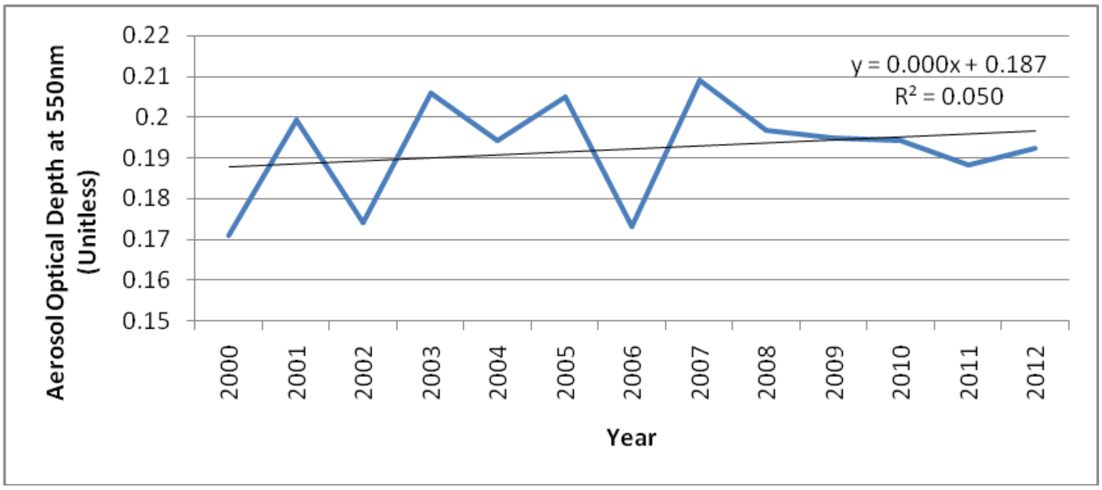

Figure 15: Time series of aerosols optical depth at 550nm over Dar es Salaam.

4.3.6 Results from statistical test of the significance of the trends

Table 1 shows the computed and tabulated t-value of for the test of the significance of the trends. From the table it can be seen that the entire trend were significant except for rainfall, relative humidity at 1200z and aerosols optical depth (AOD).

Table 1: t-test result at 95% confidence interval of **meteorological parameters and AOD concentration**

Variable	Difference in mean	Trend	t-computed	t-tabulated	Significance of the trend
Tmax	0.45	There is trend	2.65	2.04	significant
Tmin	0.93	There is trend	6.57	2.04	significant
Rainfall	142.21	There is trend	1.73	2.04	Not significant
Wind speed at 0600z	2.0	There is trend	6.43	2.04	significant
Wind speed at 1200z	2.0	There is trend	8.70	2.04	significant
RH at 0600z	0.53	There is trend	2.74	2.04	significant
RH at 1200z	0.38	There is trend	0.45	2.04	Not significant
AOD	0.001	There is trend	1.49*10^-4	2.269	Not significant

The results of the trend analysis for aerosols optical depth and meteorological parameters showed an increasing trend except for rainfall which showed a decreasing trend. Statistical test was done to test the trend and significance of the trend and it was observed that all the trend were significant except for rainfall, relative humidity at 1200z and aerosols optical depth (AOD).

4.4 Seasonal Variation of Meteorological Parameters and Aerosols over Dar es Salaam

Seasonal variation of aerosols and meteorological parameters (rainfall, relative humidity and wind speed and temperature) are discussed in the following subsections.

4.4.1 Seasonal variation of Rainfall and Aerosol Optical Depth

A graph of seasonal variation of rainfall and aerosol optical depth is presented in figure 16. From the figure it shows that in March, April, May (MAM) when there is high amount of rainfall there is low concentration of AOD and in June, July, August (JJA) when there is low amount of rainfall there is high concentration of AOD.The low level of aersols concentration could be due to the presence of rain wash-out and high concentration of aerosos could be due to absence of rain wash-out

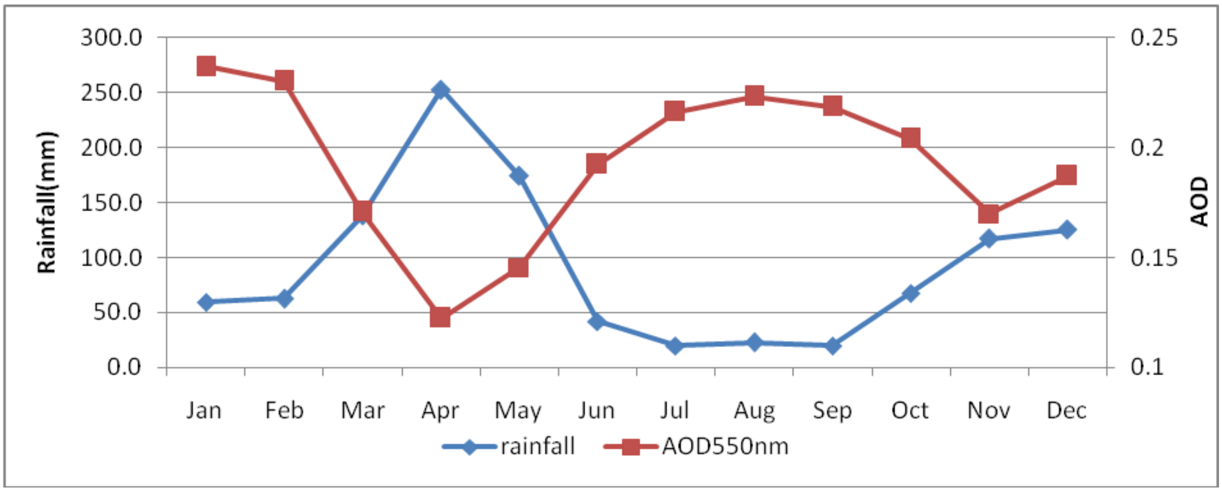

Figure 16: Seasonal variability of Rainfall and AOD550nm over Dar es Salaam

4.4.2 Seasonal variation of Wind speed and Aerosol Optical Depth

Figure 17 and 18 present the seasonalvariation of wind speed at 0600z and 1200z and aerosols.From the figure it shows that when there is low wind speed there is high concentration of aerosols in the atmosphere and when there is high wind speed there is also high concentration of aerosols in the atmosphere this could be due to reason that low wind speed lead to the build-up of high local pollutant concentrations because it inhibit dilution while high wind speeds it causes suspension in the atmosphere due to action of mobilizing the dust particle from land.

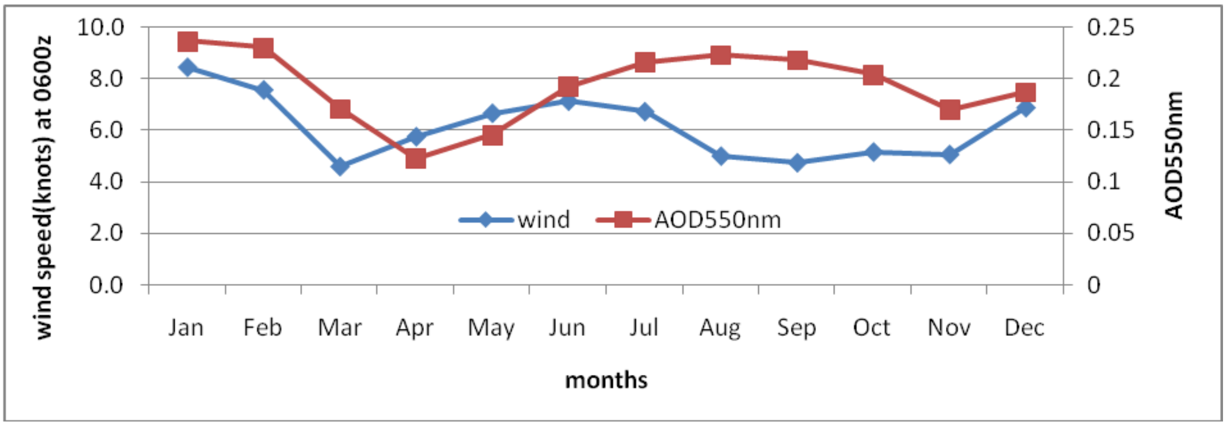

Figure 17: Seasonal variability of Wind speed at 0600z and AOD550nm over Dar es Salaam

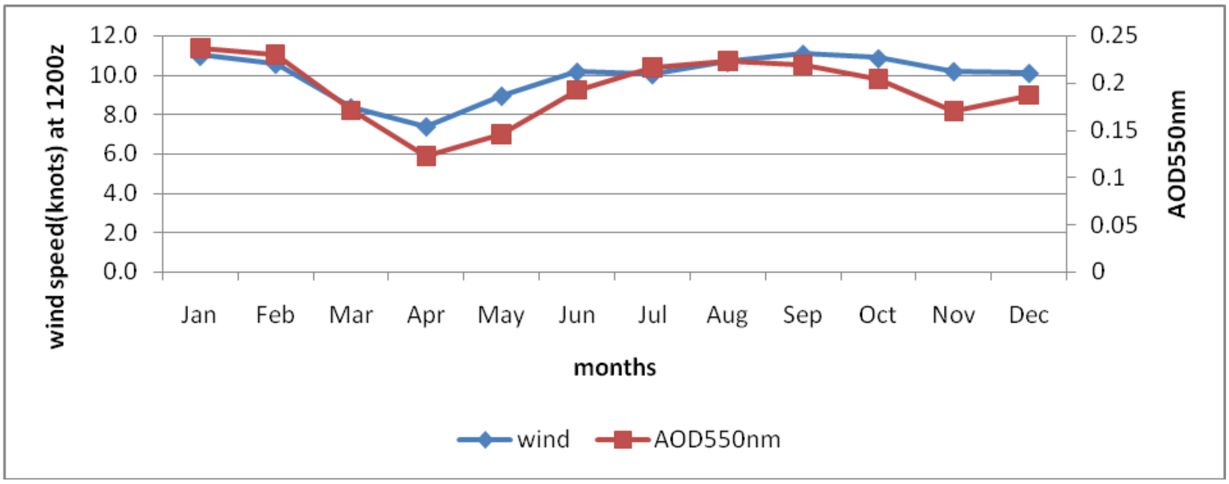

Figure 18: Seasonal variability of Wind speed at 1200z and AOD550nm over Dar es Salaam

4.4.3 Maximum and Minimum Temperature and Aerosols Optical Depth (AOD)

A plot of maximum and minimum temperature presented in the figures 19 and 20 shows the seasonal variation of maximum and minimum temperature and AOD. From the figures it shows that high concentration of AOD was observed when temperature was low and low concentration of AOD was observed when temperature was high.The increase in AOD concentration at low temperatures could be due to temperature inversions which make the atmosphere to be stable.The low AOD concentration might be influenced by high temperature because high temperaure could result into increase in mixing depth and dilute the concentration of aerosols in the atmophere. The vice- versa also is true that atmospheric aerosols could also affect the temperature by scattering and absorbing incoming solar radiation and outgoing terrestrial infrared radiation which could result into increase or decrease in temperature.

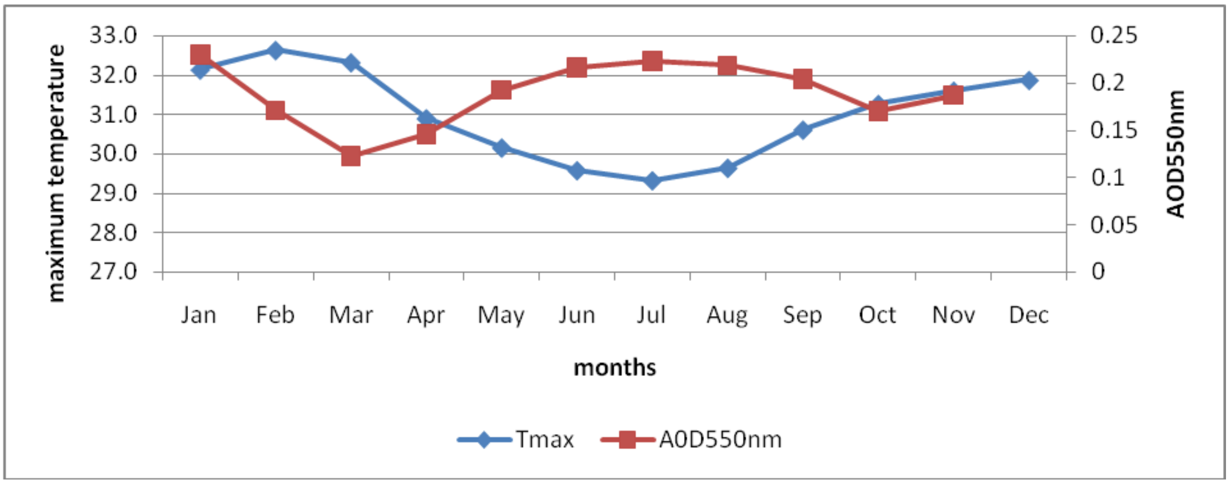

Figure 19: Seasonal variability of maximum temperature and AOD550nm over Dar es Salaam

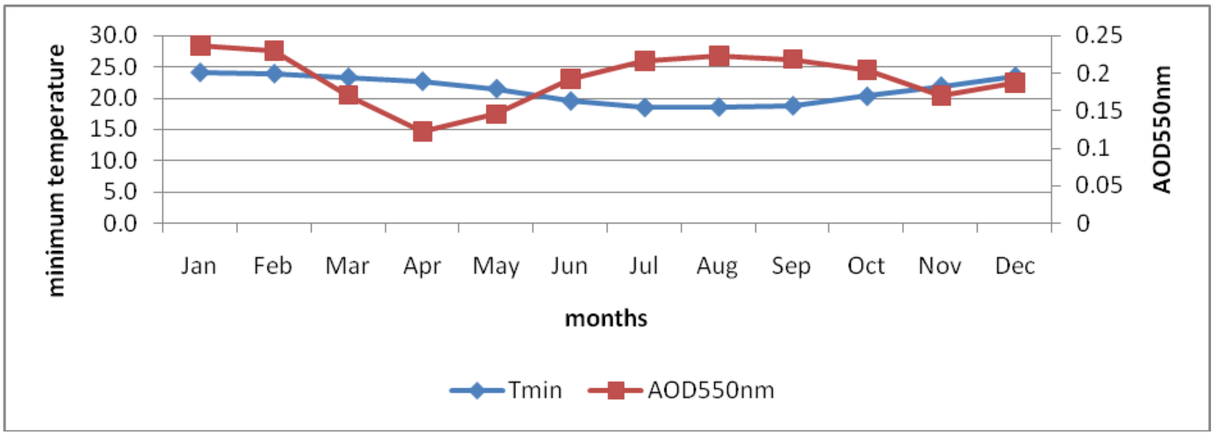

Figure 20: Seasonal variability minimum temperature and AOD55 over Dar es Salaam

4.4.4 Relative Humidity and Aerosols Optical depth

A plot of seasonal variation of relative humidity and aerosol optical depth is presented in the figure 21 and 22.From the figures it shows that during March, April, and May (MAM) there is increase in relative humidity and decrease in AOD concentration while during June, July and August (JJA) there is decrease in relative humidity and increase in AOD concentration. The reason for low concentration of aerosols during MAM could be due to the fact relative humidity associate with rainfall and has great infuence in condensation process that reduce the number of particle in the atmosphere.

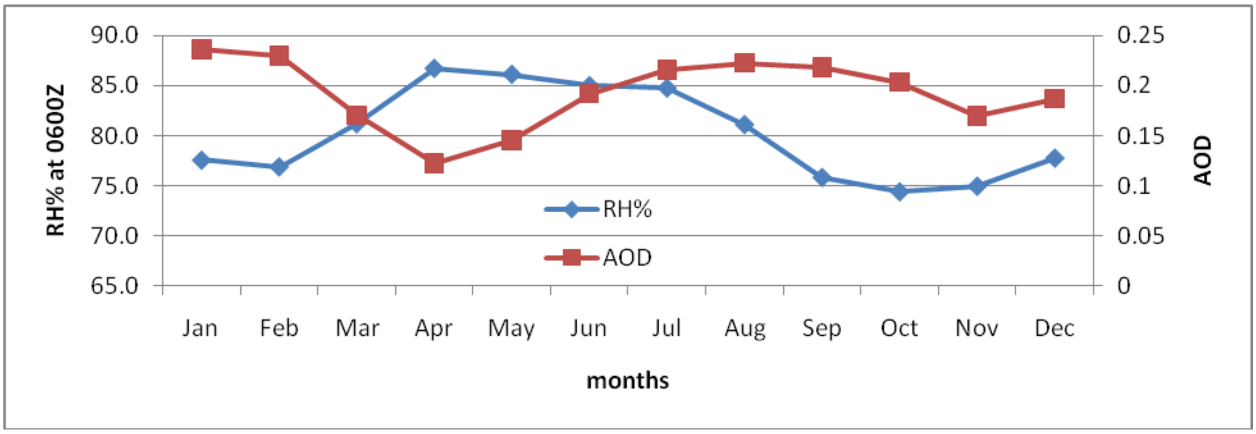

Figure 21: Seasonal variability of relative humidity and AOD over Dar es Salaam.

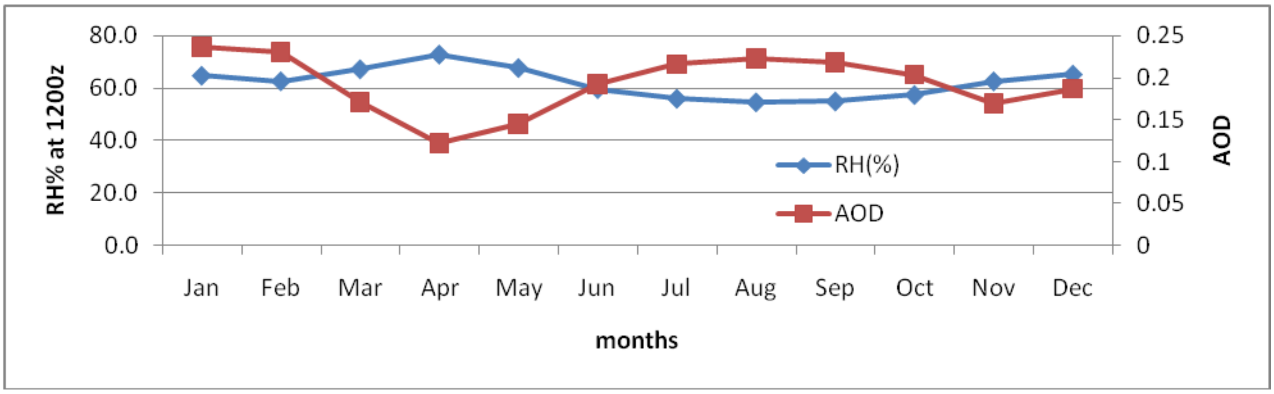

Figure 22: Seasonal variability of relative humidity and AOD over Dar es Salaam.

4.5 Correlation between Meteorological Parameters and Atmospheric Aerosols over Dar es salaam City in Tanzania

Results of correlation analysis presented in the table 1 below showed that a negative correlation between AOD and relative humidity, temperature and rainfall, and positive correlation between AOD and windspeed was observed. Based on the test using table of critical values for Pearson correlation maximum and minimum temperature, precipitation and relative humidity showed significant relationship indicated by the magnitude of correlation(**r)** greater than the 0.159 and 0.205 at 5% and 1% significance level respectively .Note that:

Table 2: Correlation analysis

(* shows significant at 5%;** shows significant at 1%)

Variable	AOD550nm
Tmax	-0.18*
Tmin	-0.21*
Precip	-0.19*
WS-0600z	0.09
WS-1200z	0.12
RH (%) 0600z	-0.01
RH (%) 1200z	-0.29**

CHAPTER FIVE

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter provides the summary, conclusions that were drawn from the various results of the study together with recommendations for future research work for a better understanding of effect of weather parameters on aerosols.

Summary

The effect of meteorology parameters on air quality in Dar es Salaam was assessed. Meteorological data (Precipitation,temperature, relative humidity and wind speed) were obtained from TMA during the period from 1980-2012 and the atmospheric pollution data was sought from the Moderate Resolution Imaging Spectro-radiometer satellite (MODIS) from 2000-2012. Homogeneity of meteorological data used in the study was tested using Short-Cut Bartlett test and single mass curve which showed that these datasets were homogeneous and thus consistent and valid for further studies. Trend analysis results showed that meteorological parameters had an increasing trend except rainfall which showed a decreasing trend.

Analysis of seasonal variability of meteorological parameters and AOD showed that during March, April May (MAM), relative humidity increased while AOD concentration decreased. During June, July and August (JJA) there was a decrease in relative humidity and an increase in AOD concentration.

The variation of AOD with temperature showed that high concentration of AOD was observed when temperatures were low and low concentrations of AOD were observed when temperatures were high. The variation of AOD with wind speed showed that during both low and high wind speeds, high concentration of aerosols in the atmosphere were observed. The variation of AOD with rainfall showed that during increased rainfall, AOD concentration decreased.

In this study Aerosols concentration and relative humidity,temperature, rainfall was observed to have a negative correlation and a positive correlation with windspeed.

Conclusion

The study showed significant trend in most of meteorological parameters an indication of shift in the mean suggesting climate change.

Seasonality was evident in all meteorological parameters together with AOD which suggest interaction between meteorological parameters and aerosols

Significant correlation observed between meteorological parameters and AOD demonstrated that meteorogical parameters have effect on air quality. These results provide evidence regarding the behavior of aerosols under varying meteorological condition and general insight into the role of meteorology on air quality.These findings suggest that if changes in meteorlogical condtion occur they may have effect on air quality.

Recommendations

Results from the present study indicated that there existed relationship between meteorological factors and aerosols concentration and therefore information from this study should be used to form basis for assesing the effect of meteorological factors on aerosols.

In this study sources of air pollution was not identified and therefore it is recomended that other studies should include it.

In this study wind direction and other meteorological factors was not included and therefore it is recomended that other studies should work on it.

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