THUNDERSTORM FREQUENCY OVER THE WESTERN RIFT-VALLEY AND LAKE VICTORIA REGION OF KENYA AND ITS RELATION TO AVIATION INDUSTRY

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DECLARATION

This project is my original work of research and has not been submitted in any other university for a Degree.

Signature…………………………………………………..Date…………………May,2016

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This Project Has Been Submitted With My Approval as University Supervisor:

Signature…………………………………………………..Date…………………May,2016

DR. OPIJAH F.J.

DEDICATION

I dedicate this project to my *brothers and sisters; GEORGE OTIENO, KENNEDY AGIRA, ERICK OTIENO, ZACHARY, PENINA, ROSABELL* and *KENNEDY ALUOCH* for their support throughout the entire study period.

Special dedications goes to my **parents *WILSON OGUTU* and *GRACE ATIENO*** who valued my education so much and gave the necessary support they could afford.

Step mother *ROSEMIKA*, late uncles *MICALJAMES* and *WILIAM* cannot go unmentioned for the support they gave me, RIP.

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ABSTRACT

The western Kenya is a highly risky zone in terms of lightning strikes. The aim of the study was to examine the recent trends of thunderstorm days in areas around the western rift valley and the lake region and to establish a relationship between thunderstorm frequency and aviation industry over the study region.

The data used consisted of monthly thunderstorm days for forty two (42) years from 1971 to 2012 for Kisumu, Kericho, and Nakuru, thirty years (30) for Kisii. The data was extracted manually from climatological section of Kenya meteorological services (KMS), Nairobi.

Statistical methods were used to get the mean monthly and annual thunderstorm days in every station. The frequencies showed two distinct peaks which coincide with the rain seasons of these areas: March, April May (MAM) and October, November and December (OND).the time series analysis showed an increasing trend in the thunderstorm days frequency. Thunderstorm activities were found to be most frequent in the highland areas of Kericho towards the lake basin. This could be due to orographic effect and abundant supply of moisture.

ACKNOWLEDGEMENT

I extend my sincerest gratitude to my supervisor **DR. OPIJAH F.J.** for his valuable guidance and comments throughout the entire period of this project.

I would also like to thank the entire **teaching staff** of meteorological department, university of Nairobi for their support and encouragement during the various phases of study.

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CHAPTRER ONE

1.1 Introduction

A thunderstorm (TSRA)(a storm with lightning and thunder), also known as an electric storm, a lightning storm, thunder shower or simply a storm is a form of weather characterized by the presence of lightning and its acoustic effect on the earth's atmosphere called thunder.

Thunderhead (TS) is when only the acoustic effect is heard i.e. no rainfall but may have lightening. TS and TSRA are captured on meteorological aviation reports when the thunderstorm or thunder is seen in the vicinity of the airport. Thunderstorm is usually associated with the cumulonimbus type of cloud. Thunderstorm is usually accompanied by strong winds, heavy rain, and hail (hailstorms) or there may be no precipitation at all. Thunderstorms may line up in a series or rain band call squall line.

Strong severe thunder storms may rotate and are called supercells. Thunderstorm may result from rapid upward movement of warm, moist air. They may occur inside warm moist airmasses or fronts. As the warm moist air- masses move upward, it cools, condenses and forms cumulonimbus clouds that can reach heights of 20 km. As the rising air reaches its dew point, water droplets and ice form and begins falling the long distance through the clouds towards the earth's surface as the droplets fall, they collide with other droplets and becomes larger. The falling droplets create a downdraft of air that spreads out at the earth's surface and causes strong winds associated with thunderstorms. Damages that result from thunderstorm is mainly inflicted by downbursts, large scale hailstorms etc.

During a lightning flash, the atmosphere is suddenly and intensively heated. This leads to massive expansion of air which produces sound waves that are heard as thunder. A thunderstorm day is a day on which thunder is heard at an observing station (WMO, 1992).It is recorded as such regardless of the actual number of thunderstorms heard on that day. Lightening without thunder is not recorded as thunderstorm day.

The most destructive products of thunderstorm are lightning strikes, hail, strong winds, dust-storms, heavy rain and flash flooding. Lightening causes human and animal deaths and damage by fire. Sudden momentary difference of thousand volts between the ground and the field can induce a fatal surge (sudden forceful flow) of electric current through the body. Forest fires can be started by lightning in dry season.

Hail can damage structures, fruits and plants. It can also punch holes in the body of the aircraft penetrating a thunderstorm.

Thunderstorms are hazardous for aviation operations. Very strong horizontal winds are a threat to aircrafts trying to go through it. For this reason, aircrafts are redirected towards other destination (alternative routes) thereby increasing the cost of travel.

1.2 Statement of the Problem

Aviation is the safest mode of transport and it is this fact that gives travelers confidence as they board the aircraft. Aircrafts are very expensive equipments .The lives it carries in them are also important. Hazards are natural phenomena and can never be stopped. One can only predict its occurrence and hence telling safe flight times to avoid accidents caused by the hazard – thunderstorm.

With the upgrading of Kisumu airport even more research is to be done as the frequency of flights will increase. Lots of incidences of thunderstorm effects have been reported to have taken place around the lake region and the surroundings, for instance, thunderstorm striking people at kisii and many parts of Nyanza region have been frequently reported.

1.3 Significance and Justification of the Study

The proximity of Kisumu Airport to lake Victoria which has a large water body continuously provides moisture necessary for cumulonimbus cloud formation, the geographic positioning of the lake on the equator known for its high temperatures that provide the convective energy and the fact that the airport lies in the Tropics with constant interaction with the synoptic scale systems like the ICTZ, the zonal Congo Airmass and the association of squall lines with thunderstorms makes the region viable for more research on the project.

Kericho has got orographic effect and hence acts as lifting mechanism for moisture from the lake region for cumulus cloud formation hence thunderstorm occurrence (Okoola, R.E., 1996)

1.4 Objectives of the Study

The overall objective of the study is to determine thunderstorm frequency in both time and space over the western rift valley and Lake Victoria region of Kenya and its relationship with the aviation industry.

1.4.1 The specific objectives of this study are:

- To determine the temporal and spatial variations of thunderstorm frequency over the region of study.
- Determine the frequency of delays and diversions of aircrafts at Kisumu airport.
- Correlate thunderstorms frequency with delays at Kisumu airport.

1.5 Area of the study

The region of the study is the western rift valley region and around the Lake Victoria region. The meteorological stations to be used are as shown in Table.

Kisumu airport is located in Kisumu County in the shores of Lake Victoria. Due to its strategic geographic location and the continuing expansion of the airport, it holds many regional and international meetings, lots of cargo will be transported through this airport and also many travelers takes their flights at this airport. The airport will not only act as a gateway to other parts of the region but also to other international cities e.g. Kampala.

With a surface area of approx. 6800 km^2, Lake Vitoria is Africa's largest lake by area, and is the largest tropical lake in the world and is the world's eighth largest continental lake. Lake Victoria occupies a shallow depression in the east African plateau.

ITCZ do lie over Kisumu region twice a year hence making the temperatures of this region higher. This raises the convective energy and also causes instability of the atmosphere which favors the development of cumulonimbus clouds from which thunderstorm form.

Areas within the western rift valley will include Kisumu, Kisii, Nakuru and Kericho. The following map shows the location of the places (stations to be used) under study and some other stations in Kenya;

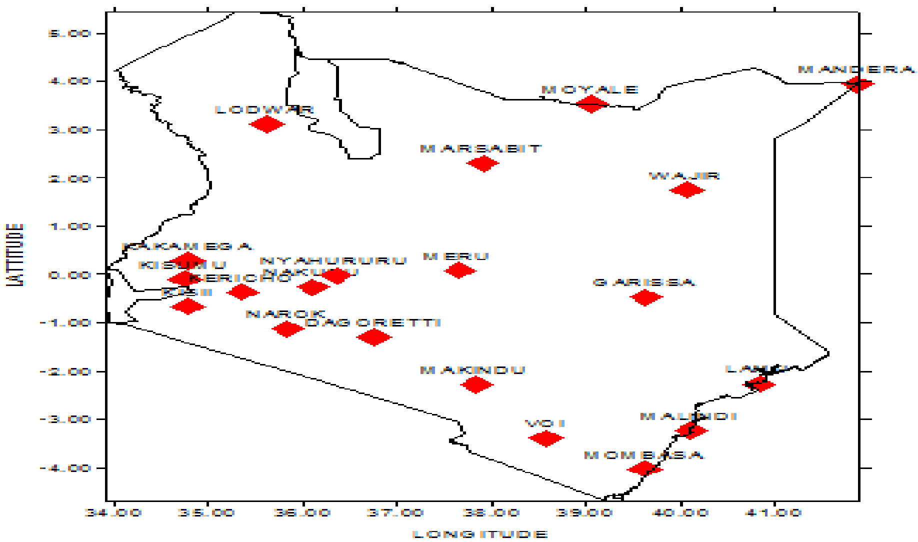


Figure 1. the location of Kisumu, Nakuru, Kisii and Kericho meteorological stations and other meteorological stations in Kenya.

Table 1.1: Stations used in the study with their elevation, latitude and longitude

STATION	ELEVATION(m)	LATITUDE	LONGITUDE
Kisumu(HKKI)	1149	0.10°S	34.58°E
Kericho(HKKR)	2182	0.37°S	35.27°E
Kisii(HKKS)	1707	0.68°S	34.78°E
Nakuru(HKNK)	1871	0.27°S	36.07°E

CHAPTER TWO

2.0 Literature Review

Thunderstorms occur much more frequently in the tropics than in higher latitudes and in the humid continental regions of the tropics, including South America (Amazon), Africa, (Congo), and South East Asia (Indonesia).Thunderstorm project (Byers and Braham, 1949) provide some basic results for thunderstorms that a thunderstorm is made up of two or more thunderstorm cells and each cell has three stages of life cycle; the cumulus stage, mature stage and the dissipation stage.

During the cumulus stage, rising warm air results into a cumulus cloud growing in moist unstable air. Updrafts in the cloud prevent precipitation from taking place. Several cumulus clouds may combine to form a single cell and takes 10-15 minutes. At mature stage, both vigorous updrafts and downdrafts occur within the cloud. If an aircraft penetrates the cloud, severe turbulence could be experienced due to the close distance of rising air and falling air. The cloud droplets may become charged with static electricity in the environment which builds up until a discharge occurs in the form of lightening flash and accompanying thunder. This mature stage lasts between 15-30 minutes. During the dissipation stage, the cold downdrafts air spreads out below the cell, the updrafts disappears, and the downdrafts extend to occupy the entire cell, but also weakens and eventually disappears (Okoola, 1996).

Lake Victoria (largest lake in tropical region) in east Africa with an approximated area of about 6800 km^2 lies in a valley between two mountain ranges with 1135m elevation. The unique orographic features and intense equatorial insolation generate intense meso-scale circulation with the intense diurnal cycle of temperatures and rainfall over Lake Victoria and neighborhood. Thunderstorm frequency in the region may come out to be the largest in the world (Asnani, 2005).

Mbindyo (2010) showed that the diurnal occurrences of thunderstorms at Kisumu airport are mainly in the afternoon and night. Maximum frequency is reached between 1400-1800 GMT. He also showed that the mean monthly frequencies have a close correlation with mean monthly rainfall. An increasing trend of thunderstorm frequencies was also observed.

Flohn $ Fraedrich (1996) studied the wind regime over Lake Victoria. They described a diurnal circulation system and demonstrated that rainfall over the lake surface is essentially controlled by the convergence associated with the nocturnal land breeze component of this system. The land breeze regularly a giant cumulonimbus cluster lasting until 10:00 or 11:00 hours. The cluster is centered during its mature phase over the central and western part of the lake, due to the prevailing easterly winds at the 300-700 mb layer. Consequently, on Victoria's north and west shores, most rains occurs at night, generally in association with strong thunderstorms. During the afternoon, the daytime lake breeze diverges and clouds disappear from the lake surface. The fact that the lake breeze regularly produces cumulonimbus clusters and thunderstorms is related to the thermal instability of the atmospheric boundary layer.

The lake, which acts as a storage reservoir of radiational heat, has an average temperature (25.4˚c) that is about 3.5°c higher than the average air temperature at the surrounding coastal stations. This steep lapse rate destabilizes the lower boundary layer. This circulation system is extremely sensitive to change in temperature difference between land and water (Flohn $Burckhardt, 1985)

CHAPTER THREE

3.0 Data and Methodology

3.1 Data Type and source

Weather data (monthly) i.e. data concerning thunderstorm occurrences at the various areas of study was extracted from 40 year meteorological aviation reports (METARs), from the Kenya meteorological department, climatological section.

It includes all the available years from 1971 to 2013.it is only kisii whose data was available from 1982 to 2012.

Data on aircraft diversion at Kisumu airport were obtained from Kenya civil aviation authority and it included data for Kisumu for the period 200-2009.

3.2 Data validation

The missing for this research was less than 1% in all the stations and was filled with the long term mean which was obtained using the arithmetic mean method. This is a technique provided by World Meteorological Organization provided the missing data is 10% of all the data.

$$x = \frac{1}{\mathbf{n}} \sum_{i=0}^{n} x_i$$

X=long term mean of thunderstorm days

n=number of years (1971-2012)

x_i = thunderstorm day

3.3 Homogeneity test

This is to test for the consistency of data .Inconsistency was done using the single mass curve method. A plot of time against cumulative values of thunderstorm days from 1971 to 2012 was done for each station.

It was noted that accumulated thunderstorm days were consistent for all the study stations throughout the period. There were no outliers in the mass curves and therefore the thunderstorm frequency data was fit for use in the study.

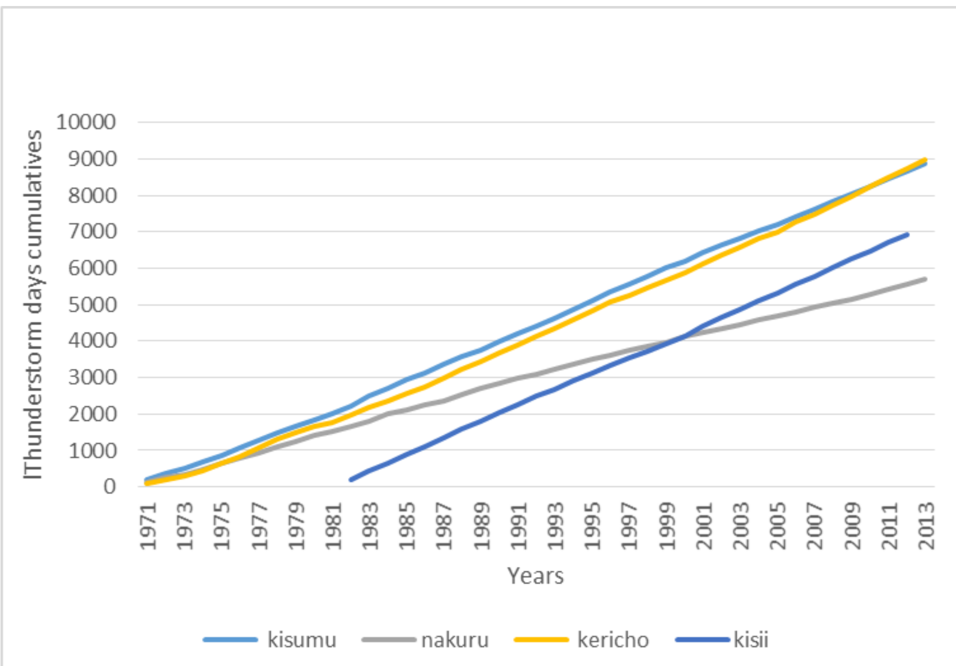


Fig.2: Single mass curve for thunderstorm days cumulative against time for Kisumu, Kisii, Kericho and Nakuru

CHAPTER FOUR

4.0 Methodology

4.1 Thunderstorm frequency analysis

The following steps were used to determine the variation with time of thunderstorm frequency for each station:

Mean monthly thunderstorm days were computed to determine the months with the highest frequency of thunderstorm for each station. Annual frequencies of thunderstorm days were computed to determine the years with the highest number of thunderstorm for each station.

4.2 Trend Analysis

Trend analysis is the process of collecting information and attempting to spot a pattern (trend) in the information. Data was divided into two equal parts for all stations in order to examine whether there is a difference between the two means then t-test was used to test the significance of the trends. The following was presented:

- Time series displaying the observed data (thunderstorm days) over time.
- The trend over the years for each station.

4.3 Spatial Distribution

A bar graph and line graph was used to map mean monthly thunderstorm frequency for each station in order to establish the distribution of thunderstorm days over the area of study.

CHAPTER FIVE

5.0 Results and Discussions

The results for each station was discussed as below and figures used to reinforce the information.

5.1 Results for Kisumu Region

Mean monthly thunderstorm variation at Kisumu airport

This is one of the areas surrounding Lake Victoria and is the second most thundery place in western Kenya with an annual average of 207 thunderstorm days during the study period which is an average estimate of 17 thunderstorm days in a month .the highest peak is in May with an average of 23 days and second peak is in September with an average of 22 days as shown in the figure below.

This frequency coincides with March-April-May (MAM) season of long rains and the other with October-November-December (OND). The lowest frequency is an average of 12 thunderstorm days a month. The thunderstorm frequency peak during March-May is due to lying of ITCZ (intertropical convergence zone) over the region during this period. The lake water is therefore warm and hence sufficient supply moisture. Low level convergence winds enhances convective development hence the formation of cumulonimbus clouds from which thunderstorms form.

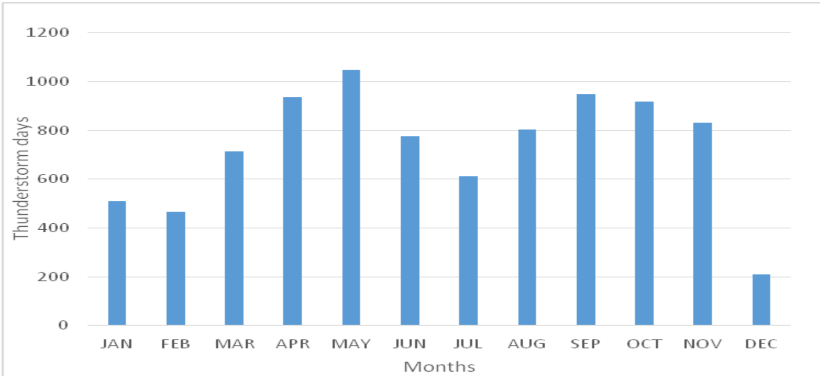


Fig.3 (a): the mean monthly distribution of thunderstorm frequency in Kisumu from 1971-2012

5.1.1 Annual variation and trends analysis

The figure above shows mean monthly variation thunderstorm days in Kisumu region from 1971 to 2012.the variation has maximum in October November December and march April May seasons. This is because this is when there is effects of ITCZ which causes maximum insolation hence more evaporation hence maximum supply moistures which is necessary for cumulonimbus cloud formation from where thunderstorm forms.

Thought the entire period (1971 to 2012), the trend was is increasing. When the period was divided into two and trend analysis conducted, three was persistence in the climatology of the region as shown in figure 3C below:

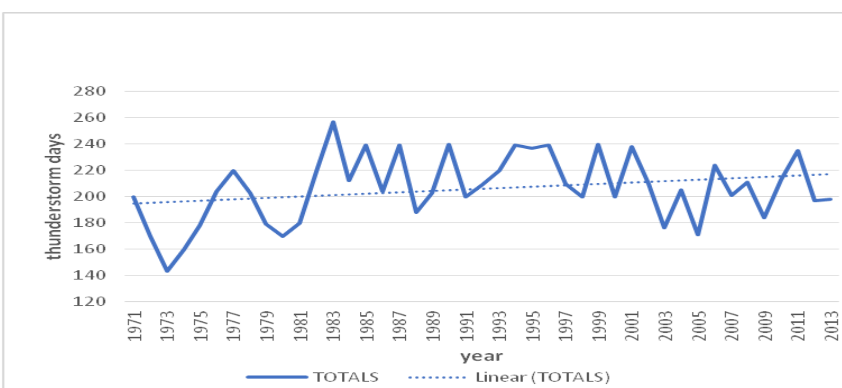


Fig.3 (b): thunderstorm frequency time series and trends in Kisumu from 1971-2012

The trend shows a gradual increase in thunderstorm days over the study period. The frequency of the first 20 years (1971-1992) is a mean of 17 days of thunder which increased to 18 in the period (1992-2012).the two means vary with 1 thunderstorm day hence a slight change. This may have been attributed to climate variability as can be observed in the season of long rains (March-May) and short rains (September-December) as depicted by the seasonal trend diagram below:

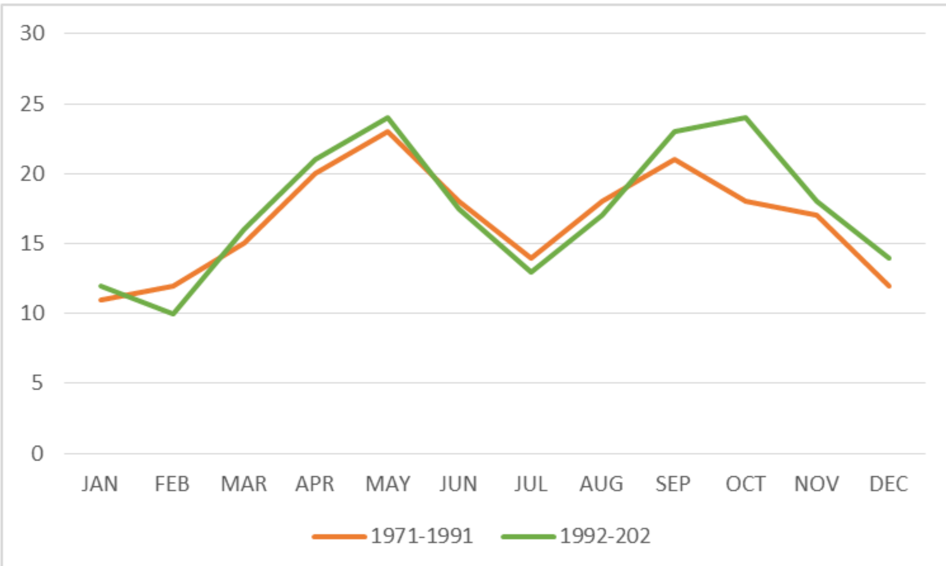
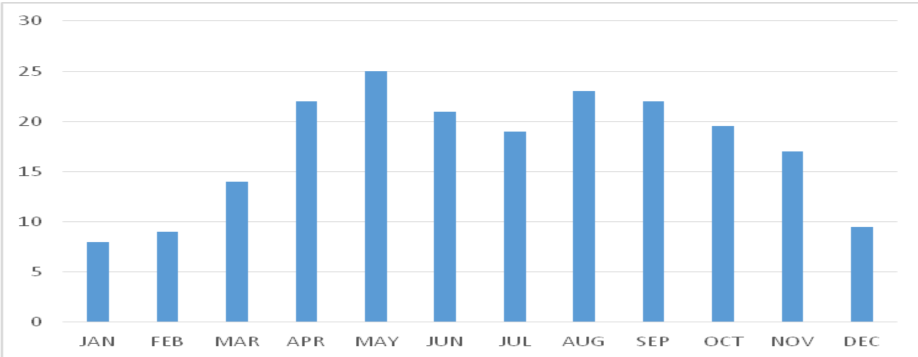


FIG.3(c): Seasonal trends of thunderstorm days from 1971-1991 and 1992-2012 for Kisumu

5.2 Results for Kericho region

Mean monthly thunderstorm frequency variation in Kericho

Kericho region received an average of 208 days during 1971-2012 period hence the most thundery place in western Kenya. Thunderstorm activities in this region are uniformly distribute between April to October with the peak being in April (with an average of 25 thunderstorms days).thunderstorm activities were minimal between December to (February with an average of 8 thunderstorms days).the distribution is shown in figure 4(a) below:



4(a): A graph showing the mean monthly distribution of thunderstorm days in Kericho from 1971-2012

The figure above shows mean monthly variation thunderstorm days in Kericho region from 1971 to 2012.the variation has maximum in October November December and march April May seasons. This is because this is when there is effects of ITCZ which causes maximum insolation hence more evaporation hence maximum supply moistures which is necessary for cumulonimbus cloud formation from where thunderstorm forms. Orography in the region acts as lifting mechanism.

Thought the entire period (1971 to 2012), the trend was is increasing. When the period was divided into two and trend analysis conducted, three was persistence in the climatology of the region as shown in figure 4C below:

The enhanced thunderstorm activities in Kericho are attributed to high altitude of this area (2182M) adequate supply of moisture from the lake region. The high region favors forced uplifting of moist air from the lake region hence cumulonimbus development; which is associated with thunderstorm occurrence. The trend of thunderstorm days in Kericho is increasing significantly. The highest peak was 2010 with a total of 261 thunderstorm days while the lowest frequency was in 1973 with 88 thunderstorm days. This is shown in figure (4b) below:

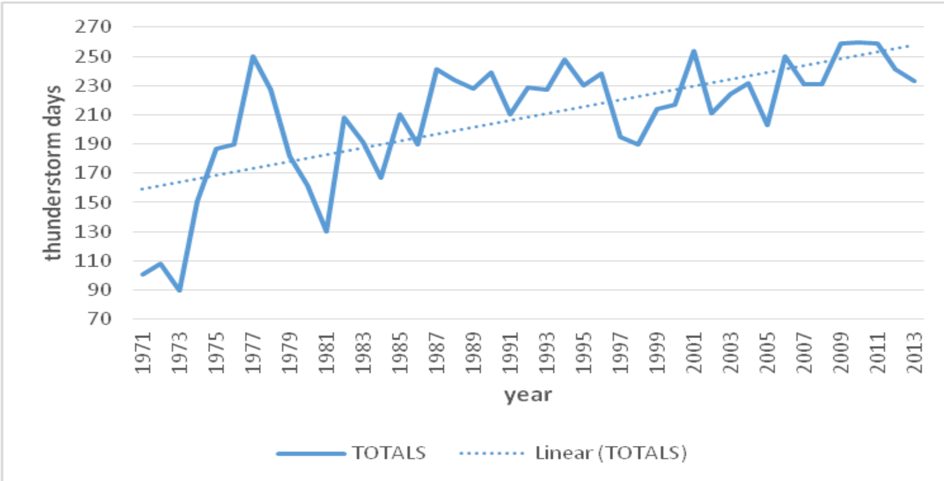


Fig.4 (b): thunderstorm frequency time series and trends in Kericho from 1971-2012

The seasonal trend for this area was done. The first 20 years (1971-1991) had a mean of 14 days and the second 20 years (1992-2012) had a mean of 17days .the difference between the two means was 3 thunderstorm days increase which shows variability over the period. This increase in trend may be attributed to climate change. The seasonal trend was as shown below:

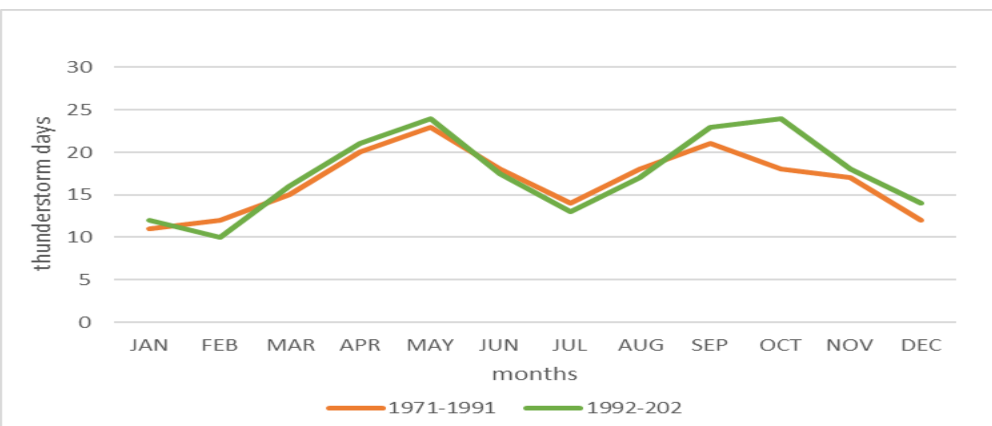
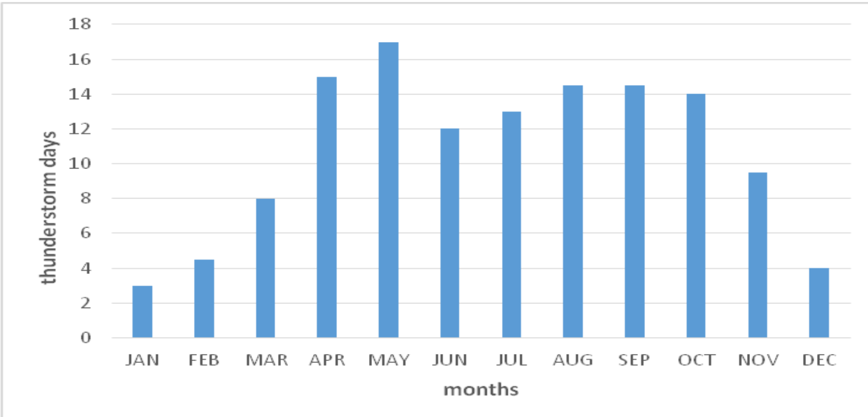


FIG.4(c): Seasonal trends of thunderstorm days from 1971-1991 and 1992-2012 for Kericho

5.3 Results Nakuru Region

Mean monthly thunderstorm frequency variation in Nakuru

Nakuru received an annual average of 124 thunderstorm days during 1971-2012 which is an average of 10 thunderstorm days a month. Most thunderstorm activities were observed during April-may (monthly average of 14 thunderstorm days).minimum thunderstorm activity is experienced between December and March (monthly average of 3 thunderstorm days).



5(a): A graph showing the mean monthly distribution of thunderstorm days in Nakuru from 1971-2012

The figure above shows showing the mean monthly distribution of thunderstorm days in Nakuru from 1971-2012.nakuru has peaks highest in MAM and OND seasons.

This the only region with slightly decreasing trend of thunderstorm days. Thunderstorm activity was in its highest peak during 1977 with a frequency of 168 days while the lowest frequency was 2009 with 72 thunderstorm days. Thunderstorm activity is very low in this region. Is may be due to low moisture supply. This is well illustrated in the figure below:

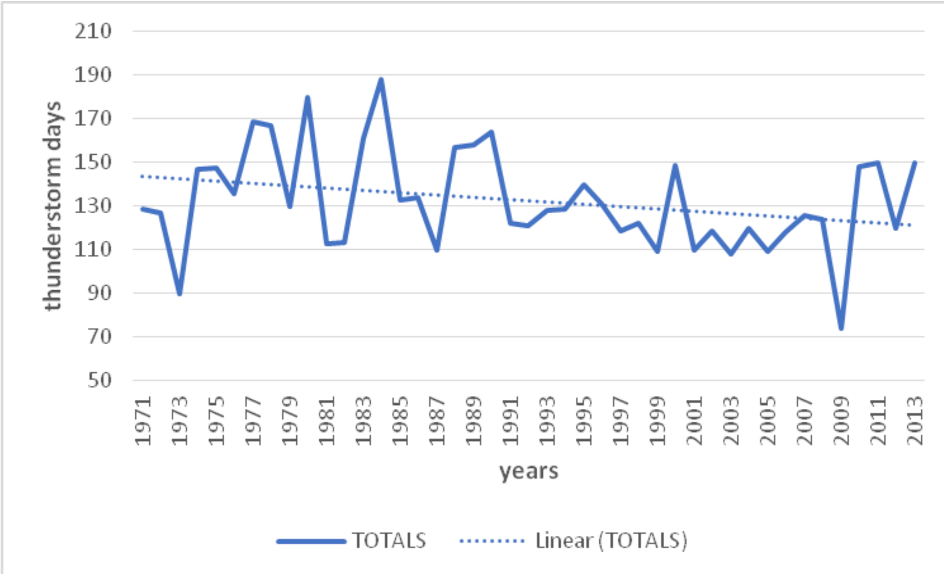


Fig.5 (b): thunderstorm frequency time series and trends in Nakuru from 1971-2012

There was variability in reducing trends. From 1971-1991 the mean was 11 days while from 1992-2012 the trend had a mean of 10 days hence a difference of only 1 day hence less significant. The trend in this region is decreasing gradually. The peak of thunder activities is 1989 with 137 thunderstorm days and lowest frequency in 1971 and 2012 with 56 and 57 thunderstorm days respectively. This can be attributed to seasonal change in weather e.g. decreased moisture supply from the surrounding water bodies e.g. lake Nakuru and from Lake Victoria. The figure below shows Seasonal trends of thunderstorm days from 1971-1991 and 1992-2012 for Nakuru.

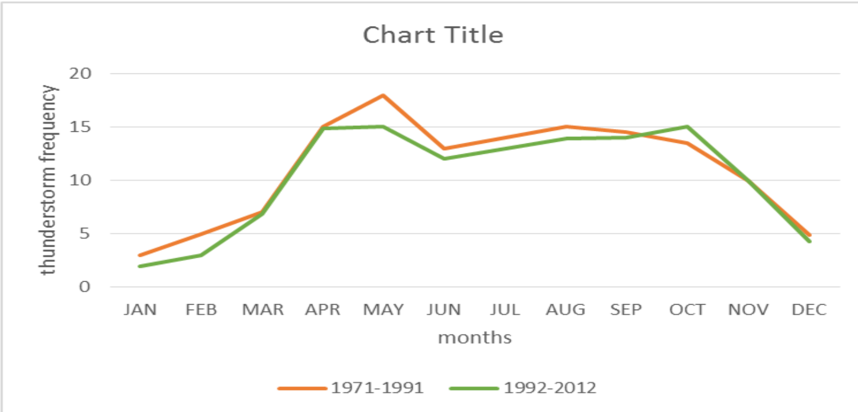
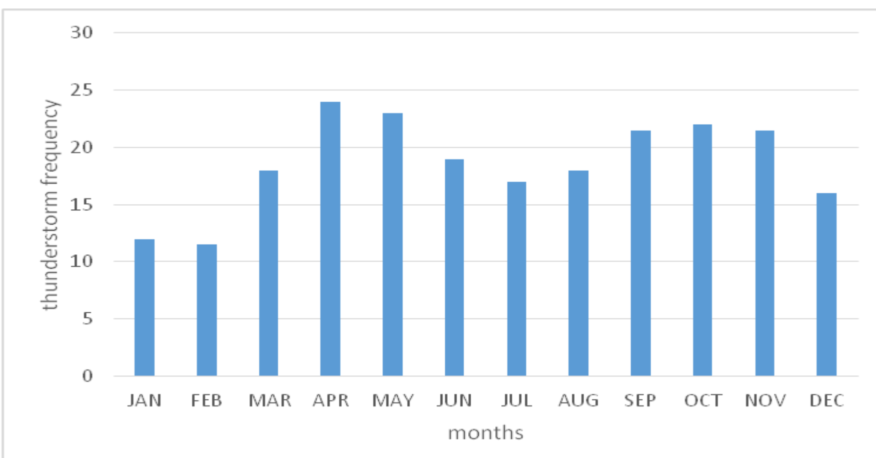


FIG.5(C): Seasonal trends of thunderstorm days from 1971-1991 and 1992-2012 for Nakuru

5.4 Results For Kisii Region

Mean monthly thunderstorm frequency variation in Kisii

The figure below shows mean monthly distribution of thunderstorm days in Kisii from 1982-2012



6(a): mean monthly distribution of thunderstorm days in Kisii from 1971-2012

The thunderstorm days are nearly uniformly distributed from March to December. High thunderstorm frequency is experienced in Kisii throughout the year. The highest peak is during April-May with an average frequency of 24 days followed by October November with 22 days frequency. The two peaks coincide with short and long rains in Kenya (October-November-December and March-April –May) seasons respectively.

5.4.1 Annual variation of thunderstorms and trends in Kisii

The thunderstorm trend in Kisii is decreasing. The peak is 2001 with 265 thunderstorm days. The lowest frequency was 1995 with 166 thunderstorm days. This is well illustrated by the graph below:

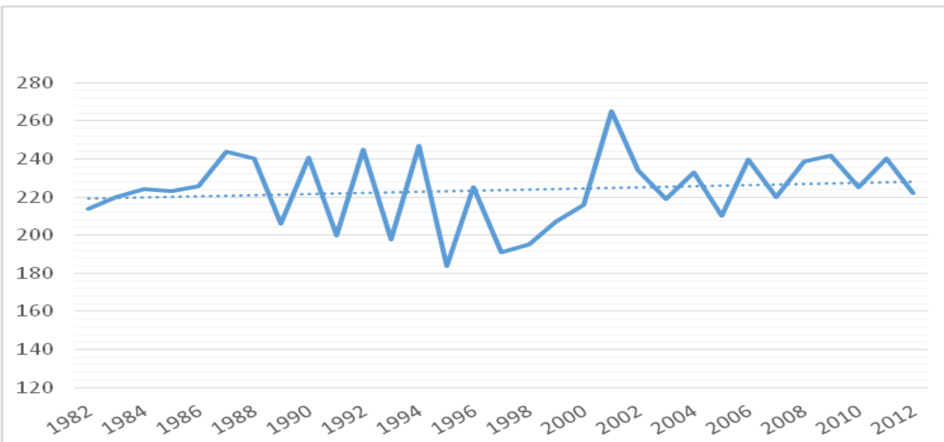


Fig.6 (b): thunderstorm frequency time series and trends in kisii from 1982-20112

CHAPTER SIX

6.0 Spatial Variation of Thunderstorm Days

The graph below shows the spatial distribution of thunderstorm days in parts of western Rift Valley and around the Lake Victoria for the period 1971 to 2012.

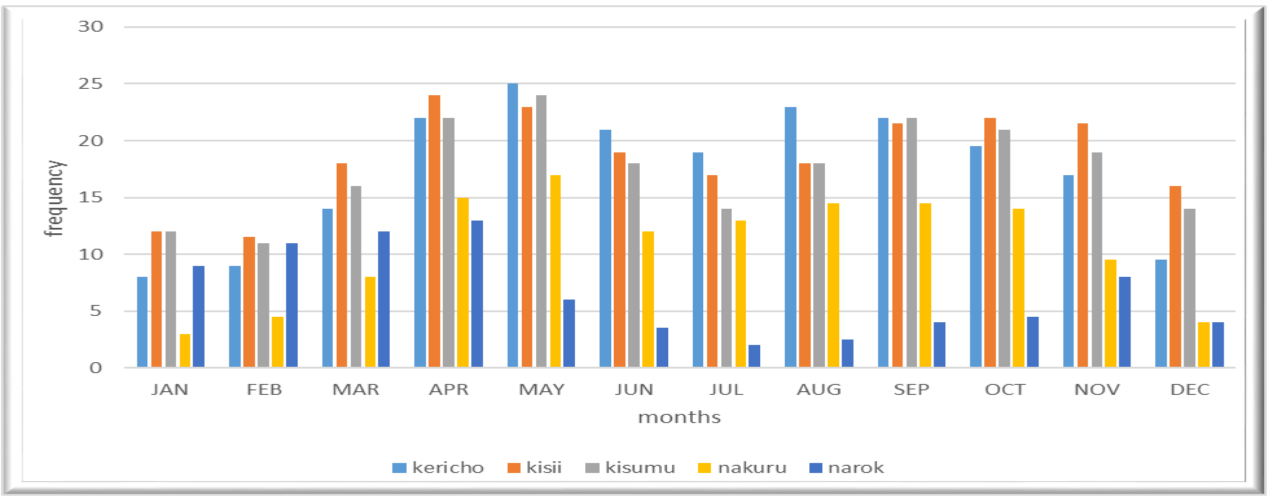


FIG.8: spatial distribution of thunderstorm days in parts of western Rift Valley and around the Lake Victoria for the period 1971 to 2012

6.0.1 Discussion for Spatial Distribution.

The result from the data shows that the distribution of thunderstorm days has a bi-modal pattern which mostly coincides with the season of long rains and short rains in these areas. April and may are the months with the maximum thunderstorm frequency at nearly all the stations. The large number of thunderstorm days may be due to ITCZ which lies over this region during this period and therefore the lake water is very warm and this means ample supply of moisture. Also the low level convergence of winds enhances vertical motion and this results in the formation of unstable type of clouds (cumulonimbus) from which thunderstorm form. In all the station, the trend of thunderstorm days is increasing except in Nakuru.

This may be attributed to climate change. Nakuru also has development of geothermal activities and this has modification of climate of this area through introduction of aerosols into the atmosphere.

Thunderstorm activity was found to increase towards the lake basin and the highest frequency was found to be Kericho mainly due to orographic effect. Nakuru experienced relatively less number of thunderstorm days compared to other study stations because they are further away from the Lake Victoria.

6.2 Relationship between thunderstorm and aviation industry

The following graph shows monthly occurrence of thunderstorm against aircrafts for Kisumu airport based on data for the period 2000-2009.

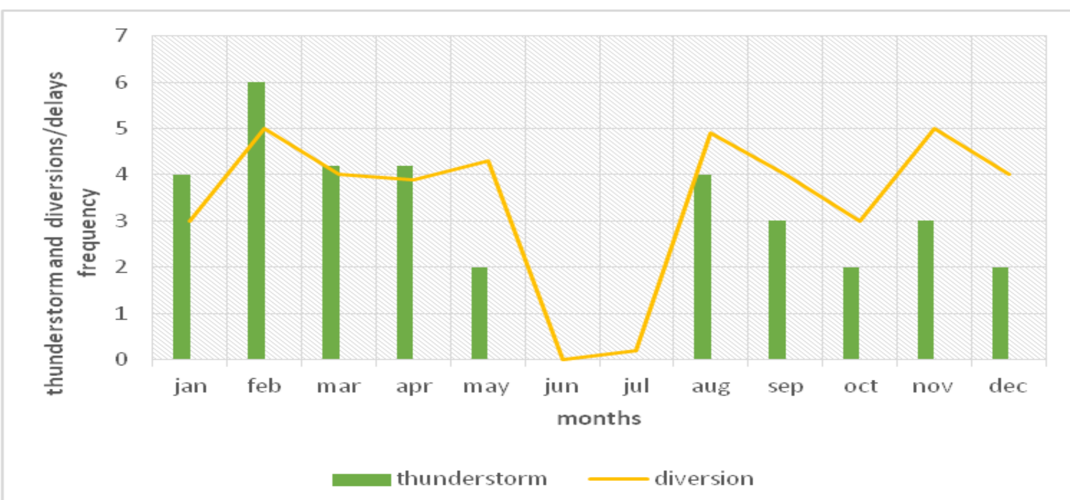


FIG.9: monthly occurrence of thunderstorm against aircrafts delays and diversions for Kisumu airport based on data for the period 2000-2009.

A correlation analysis was done to investigate if diversions/delays frequency is related with thunderstorm occurrence in Kisumu airport.

The following are the results from correlation analysis

Table 2: correlation of thunderstorm with aircraft delays and diversions for Kisumu airport for the period 2000-2009

	thunderstorm	Aircraft affected
Thunderstorm	1	0.7211231976976
Aircraft affected	0.7211231976976	1

There was a correlation of 0.72 between thunderstorm and aircraft affected.

6.3 Summary

The results from the data shows that the distribution of thunderstorm days has a bi-modal pattern which mostly coincides with the season of long and short rains in these areas April and may are the months with the maximum thunderstorm frequency at nearly all the stations. The cause for the large number of thunderstorm days may be that ITCZ is approximately lying over this region during this period and therefore the lake is very warm and this means ample supply of moisture. Also the low level convergence of winds enhances vertical motion and this results in the formation of unstable type of clouds (cumulonimbus) from which thunderstorm form.

In all the stations the trend of thunderstorm days is increasing except in Nakuru. This may be attributed to climate change .the development of geothermal activities around Nakuru has a modification to its climate through the introduction of aerosols into the atmosphere.

Thunderstorm activity was found to increase towards the lake basin and highest frequency was found to be Kericho mainly due to orographic effect. Nakuru experienced relatively less number of thunderstorm days compared to other study stations because they are further away from Lake Victoria and the influence of the lake is not evident. Moisture is necessary for the formation of cumulonimbus clouds from which thunderstorm form.

CHAPTER SEVEN

7.0 CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

7.1 Conclusion

From the analysis of the data, the results showed that the distribution of thunderstorm days has a bi-modal pattern and an increasing trend in all the stations.

The frequency of thunderstorm days increases as one moves towards the Lake Region and areas with the influence of orography experiences enhanced thunderstorm activity as seen in Kericho.

Thunderstorm activity has a great impact on aviation industry. This is shown by the big correlation coefficient of 0.7211231976976 in Kisumu international airport.

7.2 Suggestions for Future Work

i. Scientific study on the thunderstorm days should be extended to cover other stations in the country.
ii. Means should be developed so that information such as the intensity and duration of the thunderstorm are also included in the thunderstorm frequencies record.
iii. There is need to establish prediction model in view of the relationship between thunderstorm frequencies and aircrafts delays at Kisumu international airport and also to help the community around to know the times when the frequency is at its peak to take necessary pre

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