

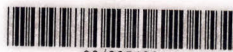
**THUNDERSTORM HAZARDS AND THEIR IMPACT  
IN THE LAKE VICTORIA BASIN OF KENYA**

**BY**

**KENNEDY OBIERO**

**A Thesis submitted in partial fulfilment of the requirements for the Degree of  
Master of Arts, Department of Geography, Kenyatta University**

Obiero, Kennedy  
*Thunderstorm hazards  
and their impact in*



98/235431

1998

**KENYATTA UNIVERSITY LIBRARY**

**ABSTRACT**

This study characterised thunderstorm hazards in the Lake Victoria Basin of Kenya. This was done by examining the relationship between thunderstorm frequency and other weather variables, analysing the storms' spatial and temporal variation, establishing the frequency characteristics of rainfall associated with the storms and assessing lightning severity in the area. The analysis involved multiple regression, coefficient of variation, Weibull formula and the lightning hazard indices respectively.

The results indicated that each thunderstorm recording station had its own multiple regression model. The coefficient of multiple determination from each station showed that the variables explained only a small fraction of the variance in thunderstorm frequency suggesting that other uninvestigated factors could be responsible for the remaining variance. Although thunderstorm frequency was high in stations adjacent to the lake, a fact attributed to relative convective activities associated with the lake, the F-test revealed no significant difference in the number of thunder days among the stations.

A monthly analysis of the storms' frequency showed each recording station had its own peak. The first peak was evident in Kisii during the month of March followed by Kericho in May. The third peak was observed in Kitale during the month of August. The least peak was evident in Eldoret.

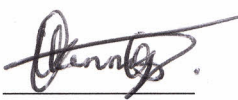
The Gumbel probability plots for annual maximum daily rainfall ( $R_{\max}$ ) from thunder days extracted from the stations revealed Kisumu to have the highest  $R_{\max}$  while Eldoret

had the lowest. This analysis has implications in the design of hydraulic structures in the area.

In assessing lightning severity in the Basin using the Lightning Hazard Index (LHI), Kisii and Nyamira Districts which have recorded the worst thunderstorm tragedies were taken as case studies. Since the LHI considered only human casualties, an adjusted index, Overall Lightning Hazard Index (OLHI) was developed to accommodate other losses such as houses, livestock and trees. Both indices showed that lightning seriousness was high in areas with high population densities such as Keumbu and Nyamira Divisions. Although there was no significant difference between the two indices, the study has recommended the use of OLHI as it considers both loss of life and property.

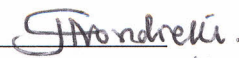
## DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signature  14/07/98

Kennedy Obiero

This thesis has been submitted with our approval as University Supervisors.

Signature   
14.07.98

Dr. Christopher Ondieki

Signature  14/7/98

Dr. Chris A. Shisanya

Department of Geography

Kenyatta University

P. O. Box 43844

Nairobi.

## DEDICATION

This work is dedicated to my dear parents; Mr. Ramesh Obiero Omare and Mrs. Alice Moraa Obiero. Their efforts enabled me to carry on my postgraduate studies at Kenyatta University. Their teachings on the value of hard work has been very central in carrying out my studies.

To my uncles and Mokubo community, whose financial support enabled me to go through high school education, I say thank you. Finally, I thank my brothers, sisters and friends for their encouragement throughout my studies.

## ACKNOWLEDGEMENTS

I am indebted to Kenyatta University for offering me a scholarship for the study. Special appreciation goes to my Supervisors; Dr. Christopher Ondieki and Dr. Chris Shisanya for their guidance and encouragement throughout this study.

I acknowledge the material support I was given by Prof. Akello and the members of the Departments of Electrical Engineering and Meteorology, University of Nairobi during the initial stages of this study. I am thankful to Mr. Gichomo N. C. of the Institute of Meteorological Training and Research (IMTR) for materials on thunderstorms. The other necessary data were obtained from Kenya Meteorological Department (KMD). I thank my research assistant Mr. Daniel Maenya for extracting the data. I am also grateful to Mr. Mochama Gori, Mr. Charles Nyangweso, Mrs. Isabellah Nyakerario and my other research assistants who collected data on lightning casualties.

Finally thanks to all my friends in Kenyatta and Nairobi universities for their encouragement. I particularly thank Mr. Gideon Mochere Motuka for his support after the expiry of my scholarship. I wish all of them God's blessings.

<b>TABLE OF CONTENTS</b>	<b>PAGES</b>
Abstract	ii
Declaration	iv
Dedication	v
Acknowledgement	vi
List of Tables	x
List of Figures	xi
List of Appendices	xiii
 <b>CHAPTER ONE</b>	
<b>1.0 INTRODUCTION</b>	<b>1</b>
1.1 Background to the study problem	1
1.2 Statement of the study problem	3
1.3 Objectives of the study	4
1.4 Research hypotheses	4
1.5 Rationale of the study	5
1.6 Scope and limitations of the study	6
1.7 Study area	8
1.7.1 Location	8
1.7.2 Topography	11
1.7.3 Climate	11
1.7.4 Drainage	13
1.7.5 Land use	14

**CHAPTER TWO**

<b>2.0 LITERATURE REVIEW</b>	15
2.1 Thunderstorm formation mechanisms	15
2.2 Global thunderstorm hazards	19
2.3 Thunderstorm studies in Kenya	22
2.4 Hailstones	23
2.5 Frequency analysis of rainfall	26
2.6 Thunderstorm risk analysis	27
2.7 Theoretical framework	27

**CHAPTER THREE**

<b>3.0 METHODOLOGY</b>	31
3.1 Data collection methods	31
3.1.1 Weather and other climatic data	31
3.1.2 Demographic data	35
3.1.3 Interview schedule	35
3.2 Data quality	36
3.2.1 Missing data	36
3.2.2 Station record consistency	36
3.3 Data analysis	37
3.3.1 Multiple correlation and regression analyses	37
3.3.1.1 Beta weights	39
3.3.1.2 Stepwise regression	40

3.3.2 The Coefficient of variation	41
3.3.3 Analysis of variance (ANOVA)	42
3.3.4 Frequency analysis	43
3.3.5 The Lightning Hazard Index (LHI)	45

## **CHAPTER FOUR**

<b>4.0 RESULTS AND DISCUSSION</b>	<b>47</b>
4.1 Thunderstorm - weather variable relationships	47
4.2 Stepwise regression	50
4.3 Spatial-temporal characteristics of the Basin thunderstorms	52
4.4 Anova Test for thunderstorm frequency	59
4.5 Frequency analysis	60
4.6 Rainfall-thunderstorm frequency significance test	61
4.7 Lightning severity in the L. Victoria Basin	64
4.8 Significance test of LHI and OLHI	68

## **CHAPTER FIVE**

<b>5.0 CONCLUSIONS AND RECOMMENDATIONS</b>	<b>69</b>
5.1 Summary of findings	69
5.2 Recommendations for policy action	71
5.3 Recommendations for further research	72
<b>REFERENCES</b>	<b>74</b>
<b>APPENDICES</b>	<b>81</b>

---

**LIST OF TABLES**

Table 1 : Lightning casualties in Bungoma District	2
Table 2.1: Details of stations in category I	33
Table 2.2: Details of stations in category II	34
Table 4.1: Results of multiple regression	48
Table 4.2: Absolute Beta weight for the eight variables	49
Table 4.3: Variables extracted for each station	50
Table 4.4: Beta weights for the extracted variables	51
Table 4.5: Highest and Lowest explained variance at each station	52
Table 4.6: Coefficient of variation for thunderstorm recording stations (1980-1995)	53
Table 4.7: Maximum 24 Hour rainfall for thunderstorm recording stations	61
Table 4.8: Correlation coefficients between thunderstorm frequency and rainfall	61
Table 4.9 Statistics for thunderstorm-rainfall a relations	63
Table 4.10 The LHI and OLHI for Kisii and Nyamira districts	64

---

## LIST OF FIGURES

Figure 1 : Frequency of cumulo-nimbus clouds in the L. Victoria Basin	7
Figure 2.1: The location of the study area in Kenya	9
Figure 2.2: The L. Victoria Basin of Kenya	10
Figure 3 : Monthly rainfall distribution for some selected stations in the study area	13
Figure 4.1: Cumulus stage in thunderstorm development	16
Figure 4.2: Mature stage of thunderstorm development	18
Figure 4.3: Dissipating stage of a thunderhead	18
Figure 5 : Global pattern of thunderdays	19
Figure 6 : Mean monthly hail frequency & tea losses in Karicho	25
Figure 7 : Hailstone frequency for thunderstorm recording stations (1980-1995)	26
Figure 8 : Resource hazard model	28
Figure 9 : Modified Rowsell model for thunderstorm analysis	29
Figure 10 : Location of the stations in the study area	32
Figure 11 : Spatial pattern of thunderstorms in March-May season	55
Figure 12 : Spatial pattern pattern of thunderstorm in July-Sept. season	56
Figure 13 : Spatial pattern pattern of thunderstorm in Oct.-Dec. season	57
Figure 14 : Annual spatial pattern of thunderstorms in the L. Victoria Basin of Kenya	58
Figure 15 : Monthly variation of thunderstorms for recording stations (1980-1995)	59

Figure 16 : Frequency of 24 hour annual maximum rainfall for thunderstorm recording stations	62
Figure 17 : Spatial variability of LHI in Kisii and Nyamira districts	66
Figure 18: Spatial variability of OLHI in Kisii and Nyamira districts	67

## LIST OF APPENDICES

Appendix 1 : Interview schedule	80
Appendix 2.1: Data for Kisumu met. station (1980-1995)	81
Appendix 2.2: Data for Kericho met. station (1980-1995)	81
Appendix 2.3: Data for Kitale met. station (1980-1995)	82
Appendix 2.4: Data for Kisii met. station (1980-1995)	82
Appendix 2.5: Data for Eldoret met. station (1980-1995)	83
Appendix 2.6: Data for Kakamega met. Station (1980-1995)	83
Appendix 3.1: Results of stepwise regression for Kisumu met. station	84
Appendix 3.2: Results of stepwise regression for Kericho met. station	84
Appendix 3.3: Results of stepwise regression for Kitale met. station	84
Appendix 3.4: Results of stepwise regression for Kisii met. station	85
Appendix 3.5: Results of stepwise regression for Kakamega station	85
Appendix 3.6: Results of stepwise regression for Eldoret station	85
Appendix 4.1: Coefficients of variation for stations in category II	86
Appendix 4.2: Mean yearly coefficients of variation for the stations	87
Appendix 5 : Thunderstorm frequency as recorded by category I stations	88
Appendix 6.1: Max. 24 hour rainfall for Kisumu 1960-95	89
Appendix 6.2: Max. 24 hour rainfall for Kitale 1960-95	90
Appendix 6.3: Max. 24 hour rainfall for Kericho 1968-95	91
Appendix 6.4: Max. 24 hour rainfall for Eldoret 1973-95	92
Appendix 6.5: Max. 24 hour rainfall for Kisii 1980-95	92
Appendix 6.6: Max. 24 hour rainfall for Kakamega,1980-95	93

Appendix 7.1: Population density and lightning casualties	
Jan 1970 - June 1996	93
Appendix 7.2: Ranking areas according to lightning severity using LHI	
in Kisii and Nyamira Districts	94
Appendix 7.3: Overall lightning casualties in Kisii and Nyamira Districts	
1970 - June 1996	94
Appendix 7.4: Population density and aggregated casualties	
1970-June 1996	96
Appendix 7.5: Ranking divisions according to lightning	
severity using OLHI	97

# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Background to the study problem

On a global scale, weather-inflicted hazards such as hurricanes, typhoons, floods, whirlwinds, tornadoes, spouts and thunderstorms occur every year (International Decade for Natural Disaster Research, 1993). Their consequences include; loss of life and property (Wescott, 1995), necessitating research for purposes of management and mitigation. This study investigated the occurrence and effects of thunderstorms and lightning in the Lake Victoria Basin.

The occurrence of thunderstorms has been differently explained, initially associated with several legends and myths (Schonland, 1950). Currently a scientific explanation about them has been advanced using satellite information (Wahlin, 1986). Globally, thunderstorms have shown a maximum concentration in Java, Central and Southern America (WMO, 1956). At any particular moment, roughly 2000 thunderstorms are in progress world-wide (Uman, 1971). In Tropical areas of U.S.A., lightning causes significant loss of life estimated to be 100 deaths per annum (Wescott, 1995).

In Africa, high thunderstorm activities are experienced in Cameroon, Nigeria and mountainous areas along the Atlantic Coast such as Fouta Djalon and Atlas. In Kenya, they have been rampant in the Lake Victoria Basin, for example in the districts of Bungoma, Kisii, Kakamega, Kericho and Kisumu. Lightning has caused havoc to

institutions such as schools where children have been killed, buildings destroyed and property lost (Akello, 1984). Table 1 is a summary of lightning casualties in Bungoma District between 1960 and 1980.

**Table 1: Lightning Casualties in Bungoma District (1960-1980)**

DIVISION	NUMBER OF CASUALTIES					
	Human	Livestock	Houses	Trees	Others	Total
Mount Elgon	18	119	56	95	7	315
Tongaren	85	98	51	66	14	314
Kimilili	197	180	111	358	25	871
Sirisia	38	194	36	113	7	388
Webuye	41	52	41	54	7	195
Kaduyi	166	354	136	217	32	905
TOTALS	565	997	431	907	92	2988

(Source: Akello, 1990)

Thunderstorms have been associated with heavy rains, which cause flooding in areas such as Kano plains and Bunyala lowlands of the Basin (Waters and Otero, 1990). In these areas life and property have been lost due to floods resulting from the thunderstorms experienced in the higher altitude of the Basin such as Nandi Hills, Kericho and Kisii highlands. An understanding of the frequency of these rains is important for the management of the floods in the Basin. Such a management plan may include evacuation of people and animals to higher ground prior to or during the floods through accurate forecasts and proper designs of flood control structures.

Lightning which is one of the characteristics of thunderstorms was investigated. Its spatial and temporal occurrence of lightning in the Basin has been investigated with a view to developing a Lightning Hazard Index for assessing the area's lightning severity. The investigation was based on casualties obtained from a number of villages and institutions, which have experienced lightning catastrophies with associated damages. The figures were collected from Kisii and Nyamira districts which have recorded some of the worst lightning tragedies (Akello, 1990).

## **1.2 Statement of the problem**

Although policies have been developed to reduce lightning tragedies through public awareness campaigns and the installation of lightning arrestors in some places (Gichomo, 1992; Akello, 1990), private homes and public buildings are still struck by lightning leading to loss of life and property. The study sought to answer to the following questions:

- (a) Is there a relationship between thunderstorm frequency and other weather variables such as vapour pressure, cloud amount and humidity?
- (b) What are the spatial and temporal features of thunderstorms in the Lake Victoria Basin of Kenya?
- (c) What are the frequency characteristics of rainfall associated with thunderstorms in the study area?
- (d) What are the levels of lightning severity in the study area?

### 1.3 Objectives of the study

---

The aim of the study was to characterise the thunderstorm and lightning activities of the Lake Victoria Basin, which may be used to plan and manage the hazards therein. The specific research objectives were:-

- (i) To examine the relationship between thunderstorm occurrence and other related weather variables.
- (ii) To analyse the spatial and temporal variations of thunderstorms in the study area.
- (iii) To establish frequency characteristics of rainfall associated with thunderstorms occurrence in the Basin.
- (iv) To analyse the levels of lightning severity using the Lightning Hazard Index (LHI) and Overall Lightning Hazard Index (OLHI).

### 1.4 Research hypotheses

The following were the hypotheses for the study:

- H1: There is no relationship between thunderstorm occurrence and other weather variables such as humidity, amount of rainfall, vapour pressure and cloud amounts.
- H2: There is no significant difference in the spatial and temporal variations of thunderstorm occurrence within the Basin.
- H3: There is no significant difference between rainfall amount and thunderstorm occurrence in the area.
-

H4: There is no significant difference in the use of LHI and OLHI in assessing the levels of lightning severity.

### **1.5 Rationale for the study**

Thunderstorms are associated with lightning, floods, hail and soil erosion (Byers and Braham, 1949). These hazards need to be predicted in the study area so as to reduce any loss of life, costs of agricultural and livestock production as well as water resources.

An examination of frequency characteristics of rainfall associated with thunderstorms is a useful tool in the design of hydraulic structures such as culverts, contour drains and storm sewers. Frequency analysis of rainfall aids in appropriate sizing of hydraulic structures. This study provides information on maximum 24-hour rainfall associated with the storms and this is a crucial input in the design of the structures.

Currently, the Ministry of Works (MOW) in collaboration with the Lightning Protection Commission have installed lightning arrestors in some public utility places where lightning phenomenon has been recorded. According to Akello (1984), arrestors were installed in those public places, which have had at least three strikes in five years. The analysis of the spatial and temporal variations of the storms in the present research provides a further scientific criterion for identifying areas where arrestors could be installed to prevent loss of life and property.

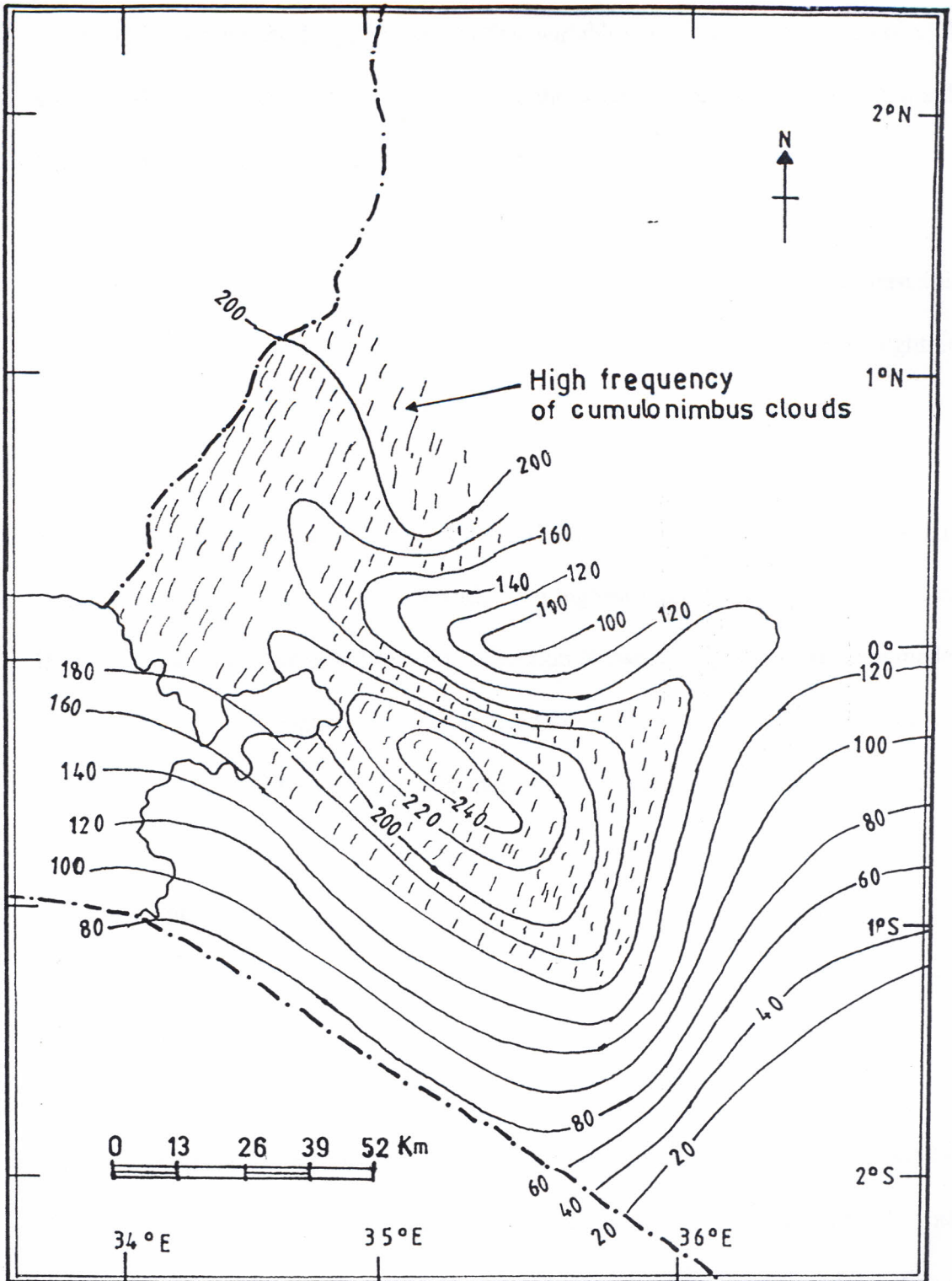
Thunderstorms have an impact on aviation (Rao, 1961). Although air-traffic is not well developed in the study area, the trend is likely to change especially with the opening of Eldoret airport and perhaps the improvement of existing Kisumu and Kakamega airport and airstrip respectively. The air traffic industry will no doubt benefit from this study since it provides an in-depth analysis of thunderstorms activity which are central in this industry. The findings of the study will assist in identifying times of the year when thunderstorms are more frequent in the area. This can help the management and control of air traffic flow to reduce risk.

The Lake Victoria Basin of Kenya has been selected for research as it is the most thundery area in Kenya (WMO, 1956). The area has the highest record of cumulonimbus clouds responsible for thunderstorm and lightning activity (Mumah and Alusa, 1981, cf. Fig. 1)

### **1.6 Scope and limitations of the study**

This study analyses thunderstorm hazards in the Lake Victoria Basin of Kenya. It does not include the physics or chemistry of upper atmospheric conditions leading to thunderstorm formation.

Figure 1: Frequency of Cumulo-nimbus clouds in the Basin .



(Source: Mumah and Alusa, 1981)

It concentrates on the relationship between thunderstorm occurrence and rainfall amounts, cloud amounts, humidity and vapour pressure. This will be helpful in predicting thunderstorm frequency once other variables are given. The analysis of the spatial and temporal variations of the storms in the Basin as well as frequency of thunder rains also falls within the scope of the research.

The major limitation of this study was lack of enough records on lightning casualties over a climatological period. This information is crucial in the derivation of lightning hazard indices for assessing lightning severity.

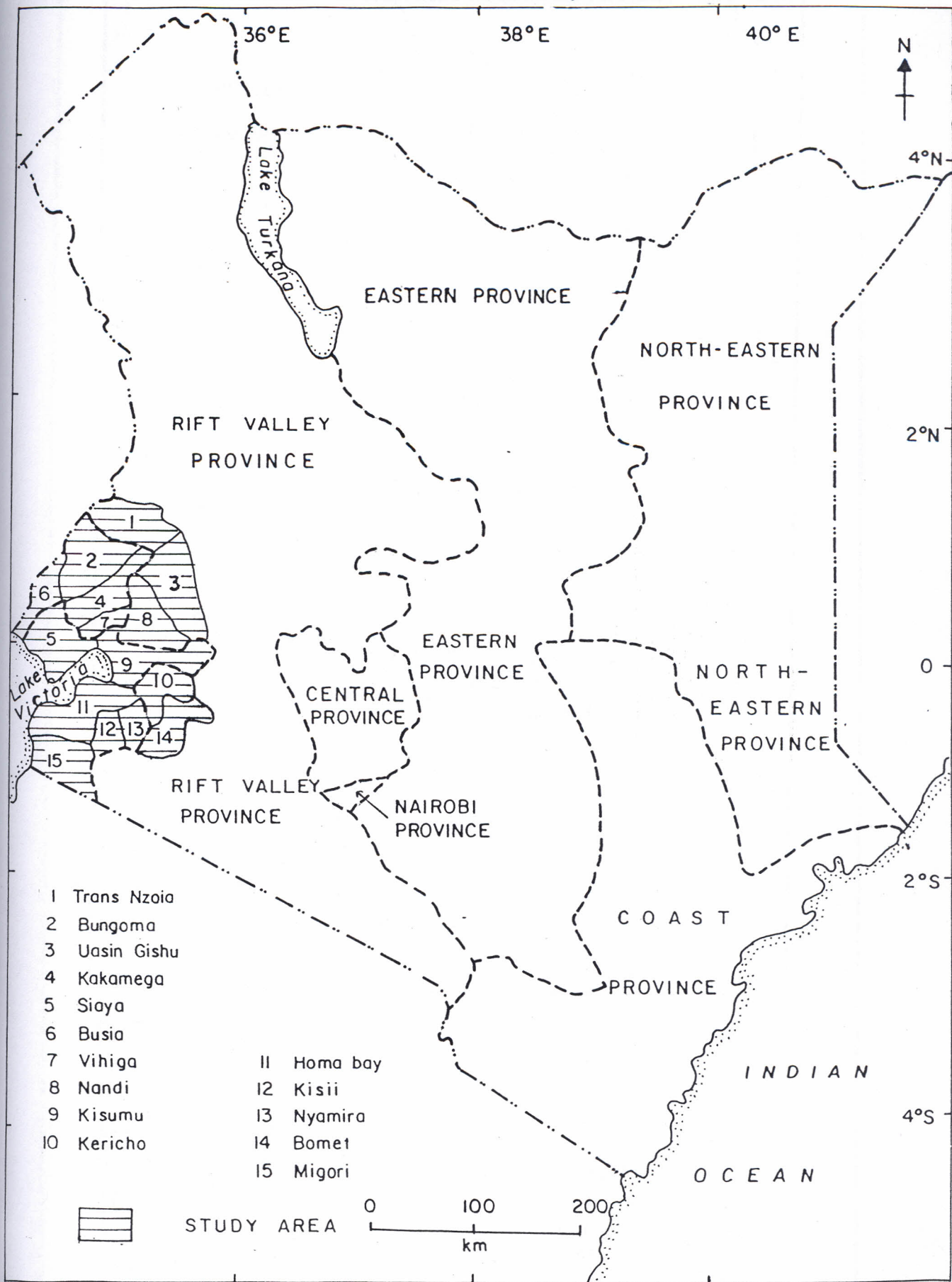
In the derivation of the LHI and OLHI, the casualty data was obtained only from Kisii and Nyamira districts, which have recorded the highest lightning incidents in the Lake Basin. The lack of a National Lightning Detection Network (NLDN) in the area made it necessary to seek information from the affected families through interview schedules. In future, the NLDN will be a necessity for more representative information.

## **1.7 The study area**

### **1.7.1 Location**

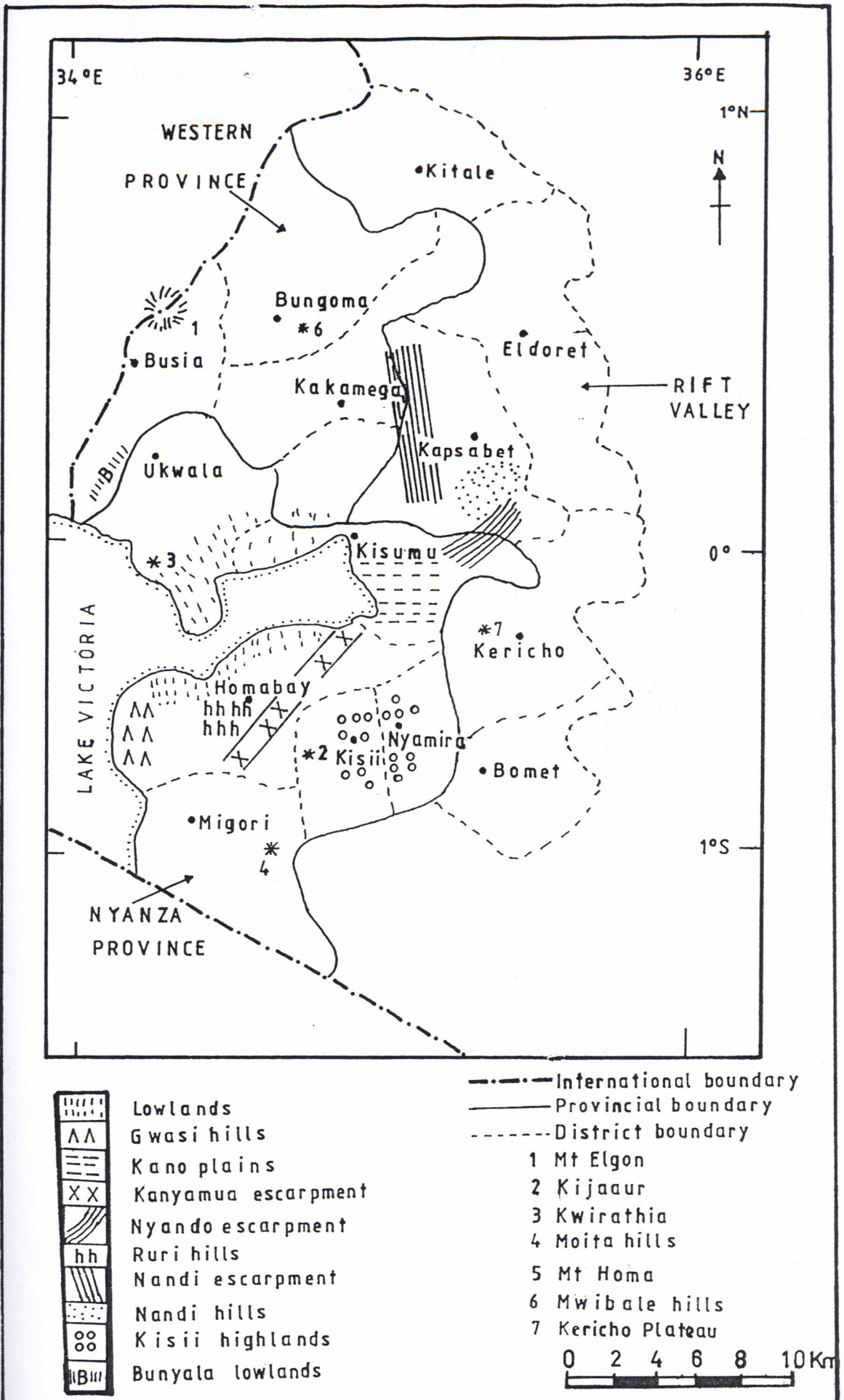
The Lake Victoria Basin of Kenya lies approximately between 34° 15' and 35° 40' East and 1° 15' N and 1° 30' S (Figures 2.1 & 2.2). To the south it is bordered by Tanzania and to the west by Uganda. It occupies an area of 38,531 Km<sup>2</sup>. The adjacent location of

Figure 2.1: The Location of the Study Area in Kenya



(Source: Kenya National Atlas, 1970)

Figure 2.2: The lake Victoria Basin of Kenya



(Source Kenya National Atlas, 1970)

this area to the largest inland water body of L. Victoria yielding convectional rains is partly responsible for its thundery nature (Chaggar, 1977).

### **1.7.2 Topography**

The area has varied topography with a variety of landforms (cf. Figure 2.2) which include hills, inselbergs, plateaus, and some scarps. The highest mountain in the area is Mt. Elgon 4313 m high with a number of scattered highlands such as Kisii highlands. Relics of large volcanoes can be observed in South Nyanza for instance Homa hills in which is L. Simbi. The orographic lifting associated with these highlands leads to condensation in moisture-laden winds. The rains resulting from orographic lifting may be accompanied with thunderstorms which partly explains the frequency of this phenomenon in highland areas of the region (Lamb, 1970). Lowland areas include; The Kano plains, Bunyala lowlands and Lambwe valley, which form part of the Kavirondo Gulf. In these areas, flooding is a notable hazard. The low altitudes of these areas make them susceptible to this hazard which results from heavy rainfall in the surrounding highland areas.

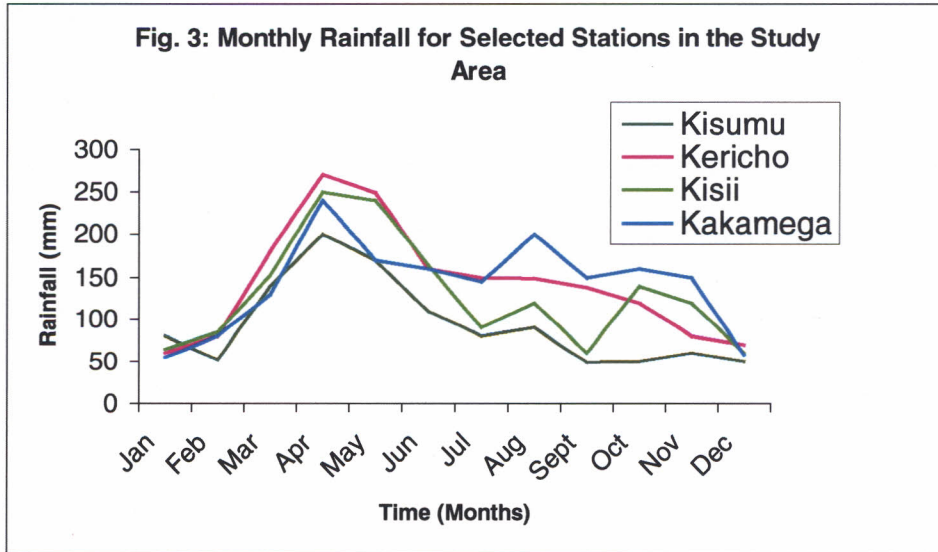
### **1.7.3 Climate**

The area has Highland Equatorial Climate (Republic of Kenya, 1993). Due to relief effects, climate varies with altitude, highland parts being cooler and receiving heavier rainfall than lowland areas. Heavy rains of upto 2000mm are experienced in April and May.

The driest months are January and February (Waters and Odero, 1990). The dry conditions are caused by the north east trade winds whose origin is in the drier continental areas of the Middle East such as the Arabian desert (Nieuwolt, 1978). The highest mean annual temperatures (28-30°C) are experienced in Kisumu while lowest mean annual temperatures (18°C) are recorded over Kericho and Uasin Gishu in the months of June-July (Waters and Odero, 1990).

Lake Victoria is well known for its dominating influence on the area's climate (Ogallo, 1980). It is responsible for lake and land breezes. During the day, the land warms up quickly than water. A low-pressure centre is created over the land and consequently moisture-laden air blows from the lake towards the land while during the night, the reverse occurs. When such air meets a mountain barrier, it rises, cools adiabatically leading to cloud formation and consequent rainfall accompanied with thunder and lightning (Republic of Kenya, 1993). Figure 3 shows monthly rainfall distribution for some selected stations in the study area.

The Congo air stream also forms part of the general circulation in the area. This air stream is moist and is responsible for the continental rains in the area during the month of July-September (Waters and Odero, 1990).



(Source: National Atlas of Kenya, 1970)

#### 1.7.4 Drainage

Due to the heavy rainfall received in the highlands almost throughout the year, the study area has many permanent rivers. These include; the Nzoia, the Sondu and the Nyando.. These rivers overflow their banks during thunder rains on the highlands causing frequent floods on the lowland areas such as Kano plains and Bunyala lowlands.

During floods, people dwelling on the lowlands move with their livestock to higher areas and often, some lives and property are lost during the floods.

### 1.7.5 Land use

The area is rich in agricultural production and densely populated. Any occurrence of a hazard may thus lead to heavy losses due to high population clusters in any one area. Livestock farming is carried out in the upper catches of the Lake Basin such as Kericho and Nandi Hills. In the lower reaches of the basin, small-scale cattle keeping is practised for purposes of supplying milk for subsistence.

Sometimes during the occurrence of the lightning , livestock is also lost. The dominant crops grown in the area are maize, coffee, tea and pyrethrum. Crops either in the farms or in stores may be lost during a lightning hazard.

## CHAPTER TWO

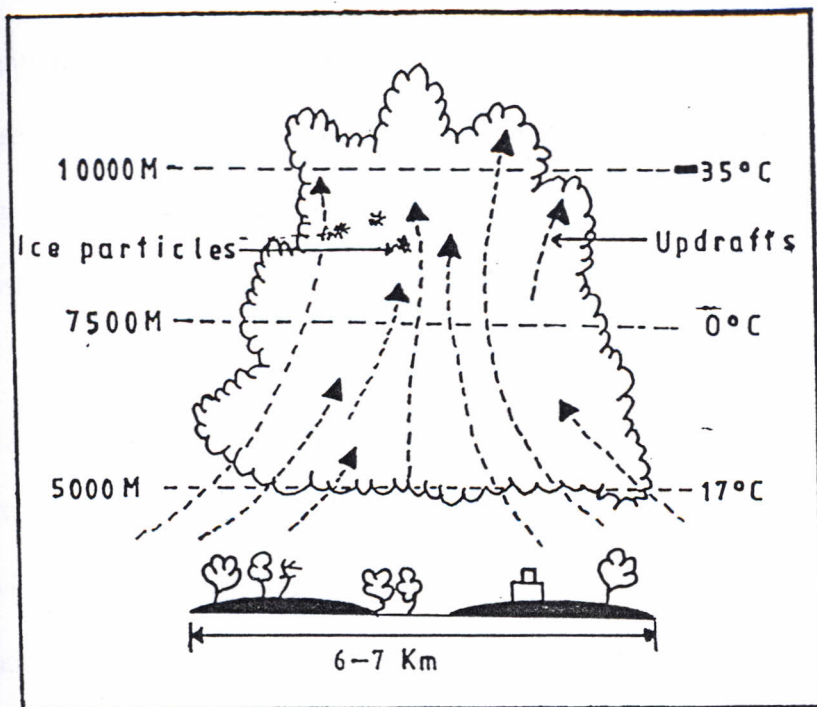
### 2.0 LITERATURE REVIEW

#### 2.1 Thunderstorm formation mechanisms.

The upper air conditions of thunderstorms can be understood through their genesis in a cumulo-nimbus cloud (Barry, 1987). The cloud is characterised by upward and downward movements of air which are the principal ingredients and motivating mechanisms in thunderstorm formation (Sutton, 1963). The cloud has regions of downdraughts and updraughts known as cells (Venkiteshwaran, 1961; Barry, 1987). A small thundercloud may have only one cell while an extensive thundercloud may have several cells in various stages of development (Byers and Braham, 1949).

The life history of a thunderstorm cell goes through three stages; cumulus, mature and dissipating (Byers and Rodebush, 1948; Viemeister, 1972). In cumulus stage, there are updraughts throughout the entire cell with the strongest updraughts taking place near the top of the cell. At this stage, there is no precipitation that falls out of the base of the cloud (Rogers, 1976). The cloud may also have tiny ice particles. The cumulus stage is shown in figure 4.1.

Figure 4.1 : Cumulus stage in the development of a thunderstorm



(Source: Viemeister, 1972)

The mature stage of the cell commences when the first rain reaches the ground (Kaplan, 1943). In this stage, the rain drops and the ice particles have become so large that they can no longer be supported by the upward air currents in the cloud. These hydro-meteors (raindrops and ice particles) start falling dragging the surrounding air along with them. They become instrumental in initiating regions of downdraughts in the cells (Rogers, 1976). The downdraughts begin in the lowest part of the cell and gradually extend to greater heights. In this stage, especially at high levels, updrafts still persist with velocities upto  $30 \text{ ms}^{-1}$ .

The hazardous nature of these storms begins at this stage. Here, heavy rains sometimes accompanied by hail occur (Barry, 1987). The cloud is also electrically active at this stage (Raman and Raghavan, 1961) with most of the positive charges at the top of the cloud due to the inductive

the inductive nature of the positively charged ionosphere. Negative charges are concentrated at the base of the cloud also due to the inductive influence of the negatively charged earth. Lightning is rampant at this stage of development hence promoting the hazardous nature of these storms. According to Kaplan (1943) and Barry (1987), the updraughts and downdraughts may influence the distribution and movement of the charges within the cloud. Figure 4.2 is an illustration of the mature stage of a thunderstorm.

When the downdraughts have spread across the lower levels of the thunderstorm cell to an extent that updraughts have become of secondary importance, the cell passes to dissipating or anvil stage (Kaplan, 1943). In this stage, there are gentle downdraughts with negligible vertical motions in higher levels. Slight downdraughts exist as long as light rain continues (Barry, 1987).

Brisk upper winds may shift the cloud top, producing the familiar anvil head. The entraining of environmental air at this stage contributes to the dying and eventual disintegration of the thunderstorm cell. By the time rain has stopped, large scale vertical motions have subsided and cell boundaries become indistinct (Byers and Rodebush, 1948). Figure 4.3 illustrates the dissipating stage of a thunderhead characterised by downdrafts throughout the cell.

Figure 4.2: Mature stage of thunderstorm development

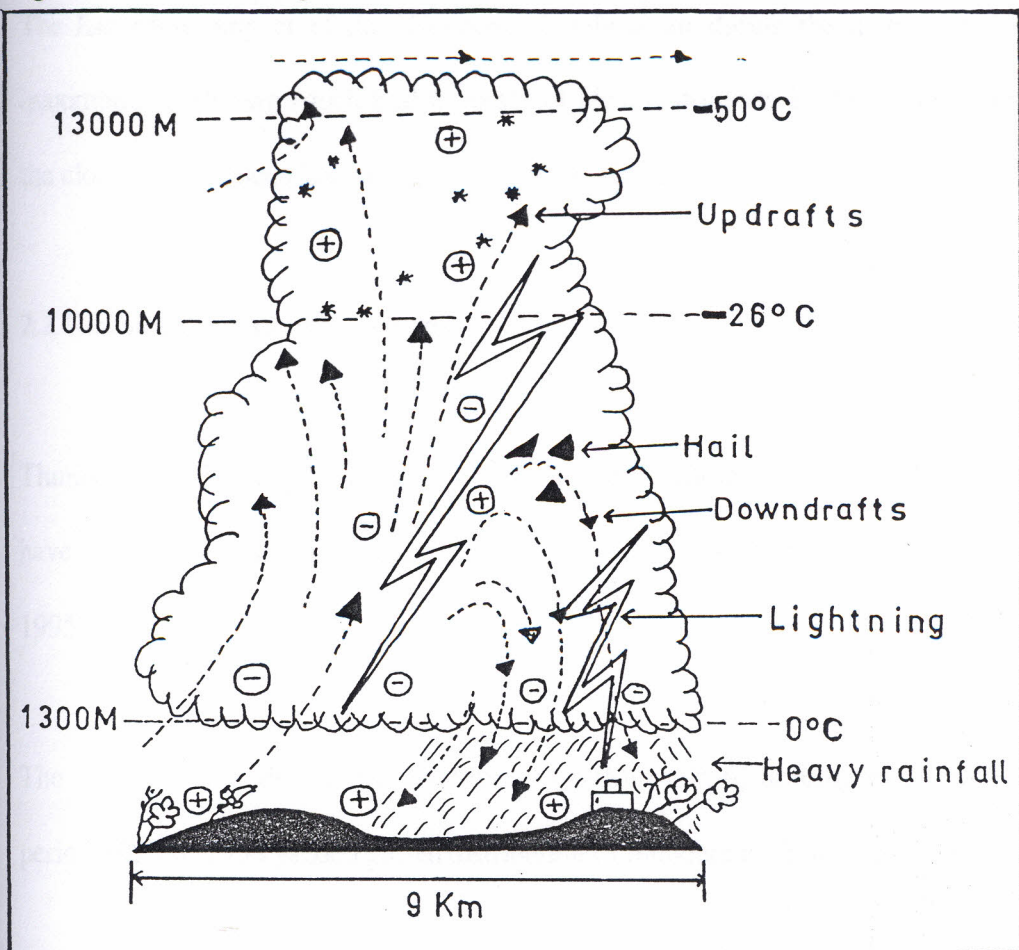
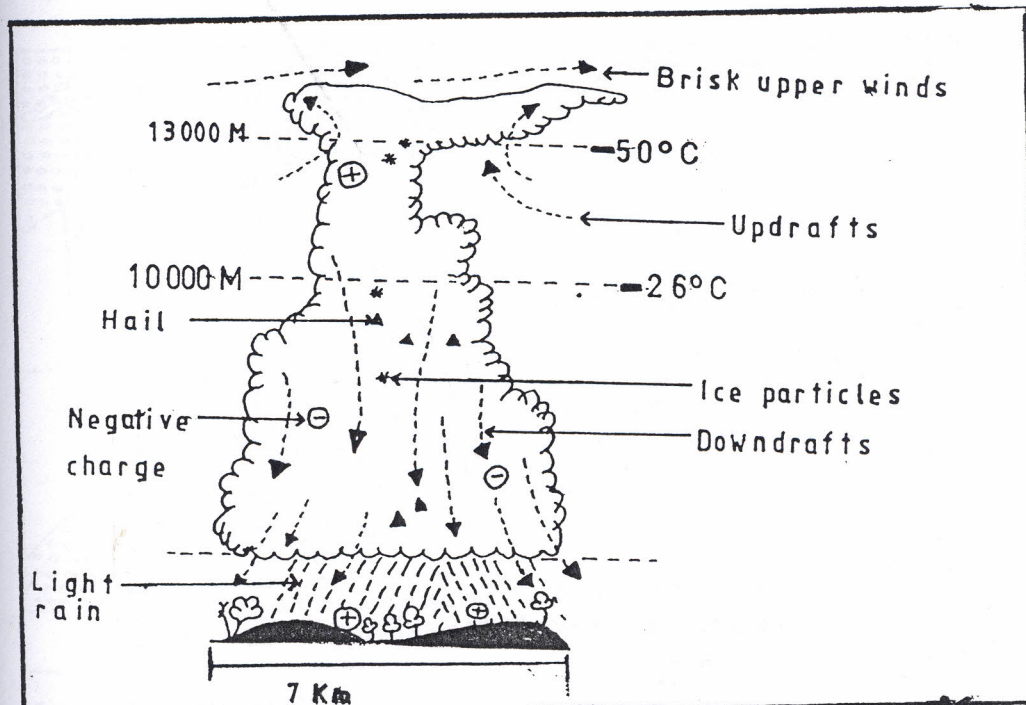


Figure 4.3 Dissipating stage of a thunderhead



(Source : Viemeister, 1972)

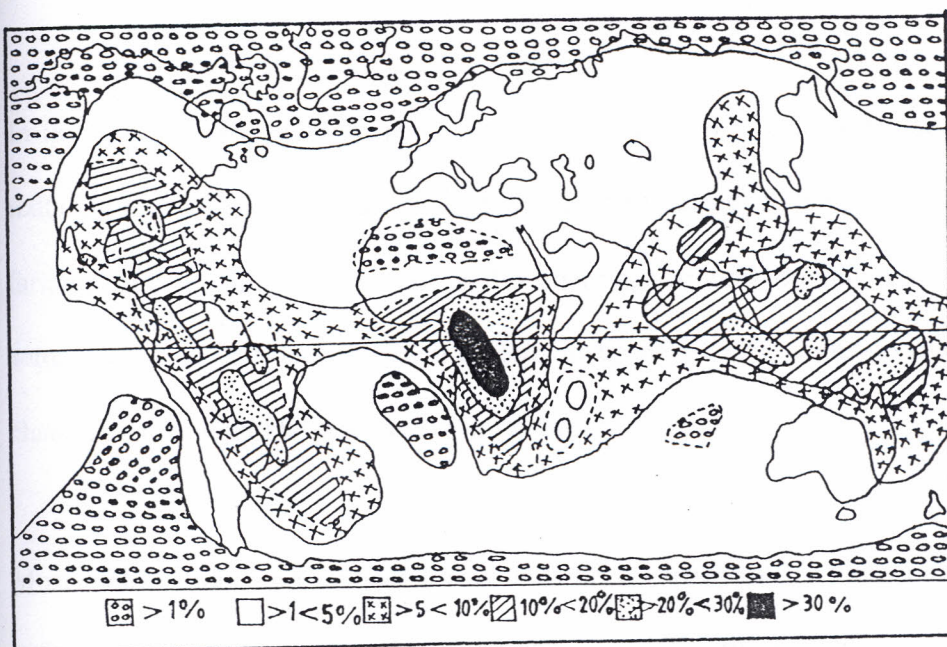
The hazardous impact of thunderstorms mainly occur during the mature stage where rainfall is maximum. Lightning which lead to losses of life and property is also at the climax at this stage as the cloud is most electrically charged (Graham, 1963).

## 2.2 Global thunderstorm hazards

Thunderstorm hazards have been in existence throughout the ages (Schonland, 1950) and they have impact on aviation, agriculture, life and other property (Wallace, 1975; McEver & Orville, 1995).

The first global study on thunderstorms by WMO (1956) utilising data on thunderdays for the period 1925 to 1954 yielded global distribution of thunderdays is shown in Figure 5.

**Figure 5: Global pattern of thunderdays expressed in percentage (1925-1954)**



(Source: WMO 1956)

Kolokolov and Pavlova (1974) attempted to map thunderstorm distribution in Russia using an empirical formula that utilises lightning discharges recorded by weather stations. Such data is however lacking in many stations including the Lake Victoria Basin.

Uman (1971) evaluated the seriousness of lightning in U.S.A and indicated that it causes more direct deaths than any weather inflicted phenomenon. In his analysis, he found that 70% of the fatalities of lightning accidents involve one person, 15% two persons and the remainder involve three or more with 75 to 85% of all lightning deaths and injuries being males, hence the seriousness of this environmental catastrophe in thunderly areas.

In Western U.S.A. thunderstorms giving rise to lightning are a major weather hazard and have prompted various studies such as those by Macmillan and Orville (1993), Curran et al (1995), Silver and Orville (1993), MacEver (1995) and Wescott (1995) who investigated cloud-to-ground lightning.

In India, Rao (1961) and Asnan (1961) have examined thunderstorm activity with a view of reducing aircraft accidents and enhancing agricultural development. In many parts of India, farmers depend on seasonal storms for their agricultural operations although these storms sometimes lead to flooding which sweeps away crops. An understanding of their frequency characteristics would help reduce their damage.

Most of the studies on thunderstorms have been carried out in temperate regions where their activities are rather low (WMO, 1956) unlike the tropics where basic data and pertinent research

are minimal (Akello, 1984).

Some areas within the continent such as the Republic of Congo and the Lake Victoria Basin have high isokeramic levels of thunderstorms (Akello, 1984). Isokeramic levels refer to thunderstorm frequencies of over 100 days. Thunderstorms have claimed lives and led to loss of property through lightning (Duclos and Sanderson, 1990) and flooding on lowlands areas (Rowell, 1986). Their havoc has occurred both in Kenya (Akello, 1990) and other countries in Africa such as Zimbabwe (Karimanzira et al, 1987).

As an advancement on the work carried out by WMO (1956), Chaggar (1977) investigated and developed thunderstorm distribution patterns in the Eastern Africa region. His work, reveals Lake Victoria Basin of Kenya as one of the most thunderly places of the earth. In his study, isobronts were used to show the spatial patterns of the storms. The isobronts were derived using mean yearly thunderdays as per the weather stations in the study area. Chaggar's approach has been used by Spain (1970) in an attempt to map thunderstorm risk in Zambia.

The high frequency of thunderstorms in Tropical Africa (Brook, 1925), prompted Patnaik and Chaggar (1987) to evaluate some of the climatic features of the storms in Eastern Africa including the rest of tropical Africa. Their studies employed the Kolokolov and Pavlova formula (Kolokolov & Pavlova, 1974) which use lightning flashes per unit area in mapping thunderstorm phenomenon. They also showed that the Lake Victoria basin of Kenya is thunderly. The application of the Kolokolov-Pavlova formula, is however limited due to lack of data on lightning discharges in the study area hence the need for approaches of examining their spatial variability using readily available data especially their coefficients of variation.

In Niger, Saloum (1996) has established the rainfall characteristics of the storms using recorded climatological data. Although the storms support farming activities in Niger, the high intensity storms sometimes lead to flooding and erosion.

The alarming reports of lightning deaths in Zimbabwe in 1985 by the Electricity Supply Commission prompted Karimanzira (1987) to study the lightning hazard in Zimbabwe. He reviewed the lightning phenomenon in two seasons 1984/1985 and 1985/1986. The main aspects reviewed in his work centered on the distribution of thunderdays, areas of high lightning victims as well as the vulnerability of rural huts to lightning hazard. Inference on long term trends of the hazard casualties was however not easily discernable.

### **2.3 Thunderstorm studies in Kenya.**

Kenya's position within the tropics and at the Equator, along with the presence of Lake Victoria as well as other small lakes make it more susceptible to convective activities that give rise to thunderstorms. The high frequency of the storms especially in the western part has attracted a number of research works.

Basing his work on Matari (1990), Gichomo (1992) has examined the thunderstorm phenomenon in Kenya using simple regression with a view of seeking existence of any correlations between thunderstorm frequency and humidity. High correlation coefficients were observed in L. Victoria region which has high levels of humidity. Low frequency of thunderstorms was however obtained from the coast despite high levels of humidity there. This

discrepancy was attributed to the lack of a topographic factor to trigger orographic lifting, leading to adiabatic cooling of humid air and thunderstorm formation (Lamb, 1970).

Mumah and Alusa (1981) have analysed annual and monthly frequency of the number of days with cumulo-nimbus clouds in the L. Victoria basin of Kenya. Their study emanated from the fact that the convective activities that occur within these clouds leads to thunderstorm occurrence (Brooks, 1925; Byers and Braham, 1949).

Akello (1984, 1990) has identified that lightning is a natural hazard within the country. His work in collaboration with the Lightning Protection Commission led to the installation of lightning arrestors in a number of places. By 1990, due to his work, 200 arrestors had been installed in ten districts within western Kenya.

Akello's work was significant in this research as it provided part of the required secondary information. The Lightning Hazard Index (LHI) and Overall Lightning Hazard Index (OLHI) which Akello has not employed in his work were used in the present study to identify risk-prone areas by ranking the areas according to lightning severity on the basis of casualties and population density.

## **2.4 Hailstones**

Hail is one of the most destructive weather phenomena along with tornadoes, typhoons, and hurricanes (Salau, 1993). This is essentially due to their higher frequency and distribution (Alusa, 1986).

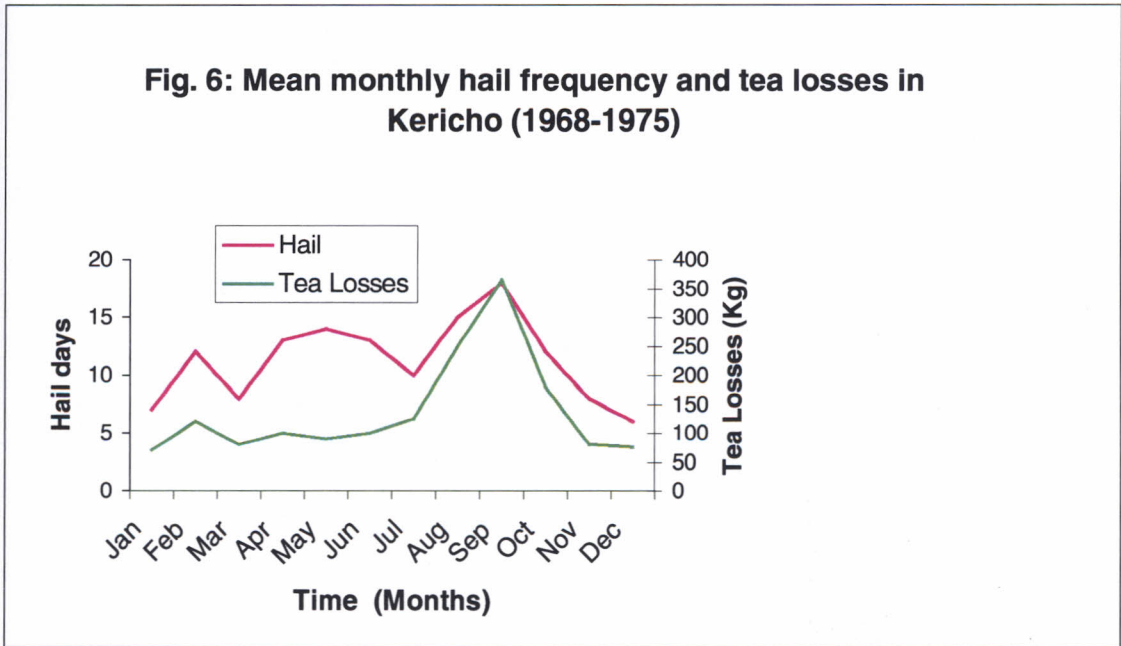
Hailstones are associated with thunderstorms (Henderson, 1968) causing substantial damage to agricultural crops which on a global scale, according to American estimates amounted to \$ 1,000 million annually (Breuer, 1976).

The most hailstone prone areas include the Po valley of North Eastern Italy (Morgan, 1973) and Illinois in U.S.A.(Changnon, 1967). In these areas, losses attributable to the hazard are high especially in agriculture and this has led to cloud seeding experiments as a remedial measure using Silver iodide crystals (Marwitz, 1972).

In Kenya, high hailstone frequency has been detected in Kericho and Nandi Hills area (Sansom, 1961). In this region, over 100 hail days are experienced each year (Alusa, 1986). The phenomenon causes damage to tea, an important cash crop, among other crops in the area (Sansom & Gichuiya, 1969). According to Henderson (1969), tea losses attributed to hail damage amount to 700,000 kilograms per annum. This is a big loss to the economy as tea and coffee exports account for over 33% of the total export earnings of Kenya (Waters and Odero, 1990).

According to studies carried out by Henderson (1968) and Alusa (1986 a & b), 70% of thunderstorms in Kericho and Nandi Hills result in hail. The mean number of days per year with thunder in Kericho is about 200 days (Chaggar, 1977) and 172 of these days experience hail (Alusa, 1986). This means that the hailstone hazard is closely associated with thunderstorms.

The results on hailstone frequency by Alusa (1986) showed that the highest hail frequency was experienced in the months of August and September. This was also accompanied by heavy tea losses. Figure 6 shows how hail frequency influences tea losses.

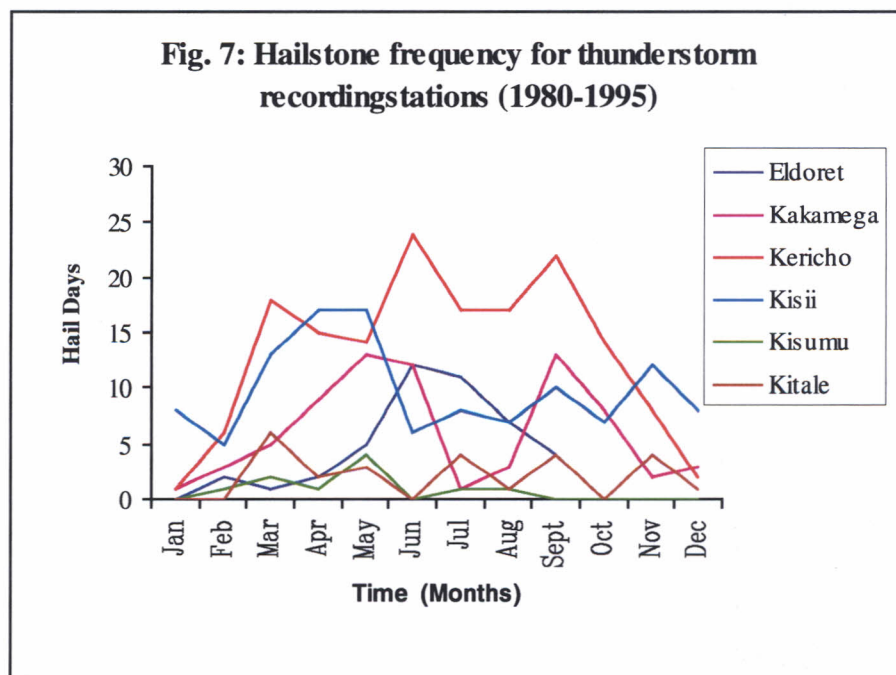


(Source: Alusa, 1986)

Due to the seriousness of this hazard in Kericho, as elsewhere upto today (Curic, 1996), studies were carried out to assess possibilities of carrying out cloud seeding, a measure that was assumed would reduce or eliminate hail damage (Sansom, 1961). The Kenya Growers Association in 1967, contracted Atmospherics Incorporated to seed the storms in the area using Silver Iodide crystals and assess the effectiveness of the cloud seeding in the area (Sansom, 1965b).

The mean monthly hailstone frequency for some six thunderstorm recording stations in the study area are presented in Figure 7. The figure shows that hailstone frequency is still high in

Kericho. Least hailstone frequency is evident in Kisumu due its low altitude. High frequency of hailstone is also experienced in Kisii.



## 2.5 Frequency Analysis of rainfall

Frequency analysis of rainfall particularly intensity duration frequency (I.D.F) has been carried out in East Africa (Mureithi, 1973). In his analysis he related rainfall intensity with other parameters such as duration in minutes ( $t$ ), return period in years ( $T$ ) and regional coefficients ( $c$ ,  $m$ ,  $n$  and  $d$ ).

Jackson (1989) has pointed out that a relationship exist between intensity ( $I$ ), duration ( $t$ ), return period ( $T$ ) and rainfall totals in mm. He used logarithmic expressions to derive the mentioned

parameters. He used data from Zambia where rainfall events recording upto 100 mm from all days whether or not a thunderstorm event was experienced were considered. The frequency analysis of upper extreme values of rainfall, are important to engineers, landscape architects and geomorphologists for drainage design and other related projects (Riggs, 1985).

## 2.6 Thunderstorm risk analysis

Smith (1993), has quantified lightning risk using the Lightning Hazard Index (LHI). This index is capable of ranking places or states or divisions according to lightening severity. In his application of the index, he has succeeded in ranking the lightening severity for the states of U.S.A. with Wyoming ranking top in lightning severity while Alaska has taken the last position.

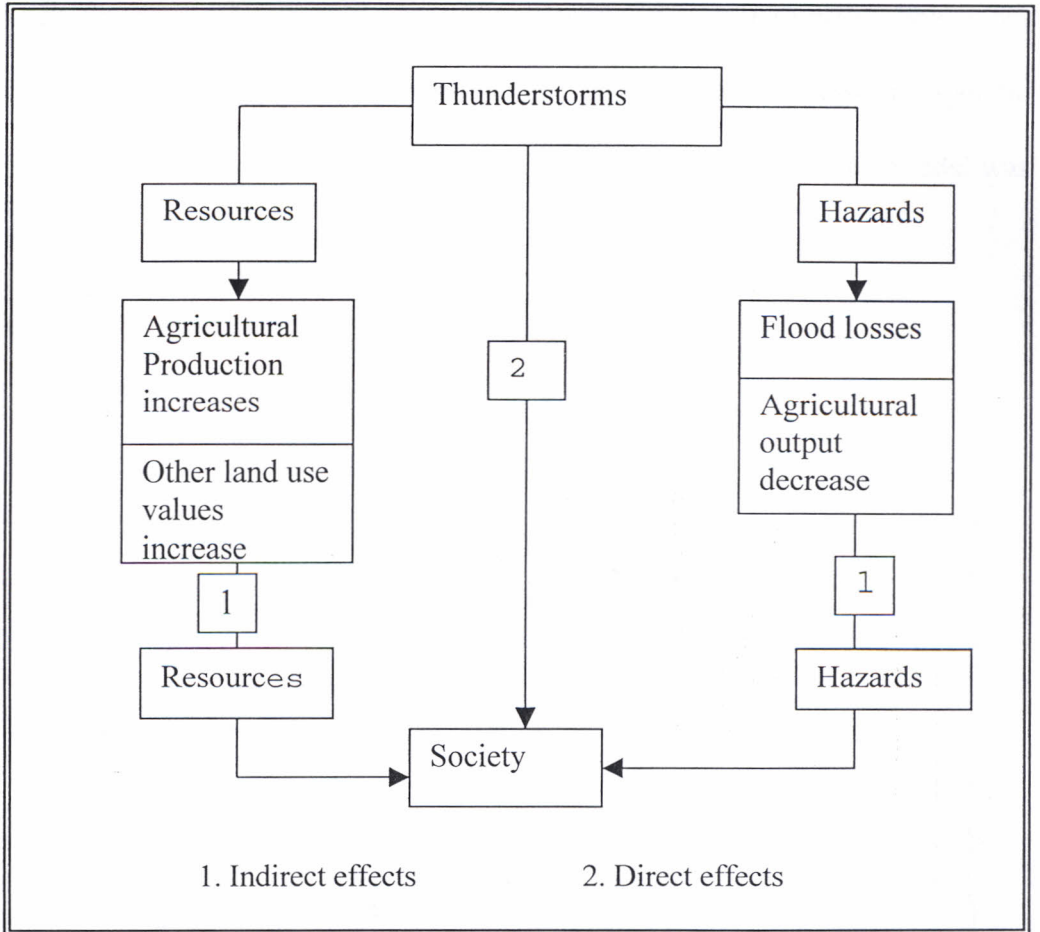
Most thunderstorm studies (Rao, 1961; Asnan, 1961; Wescott, 1995 and McEver & Orville, 1995) have concentrated in temperate regions with little emphasis on the tropics. The tropical areas especially the Equatorial and specifically the L. Victoria Basin of Kenya still need some applied research and data on thunderstorms.

## 2.7 Theoretical framework

The Resource Hazard Model (cf. Figure 8) borrowed from Rowsell (1986) explains the inter-relationships between resources and the environmental hazards such as thunderstorms, hail and floods. According to the model, an environmental phenomenon, may qualify both as a resource and a hazard. For thunderstorms, they cause floods which may sweep away crops and other

properties. On the other hand, the storms provide moisture required by agricultural crops and other plants in general.

Figure 8 : Resource Hazard Model



(Source: Rowsell, 1986)

Kates (1970), defines resources as beneficial outcomes of environmental use while hazards are resistances or barriers that interfere with resource exploitation. Although thunderstorms have hazardous effects such as lightning, soil erosion and floods (Waters & Odero, 1990), they provide precipitation needed by crops and animals.

The effects of thunderstorms are both direct and indirect. The storms affect society directly for example through lightning which may kill people. Hailstones which accompany thunderstorms may also injure people hence causing direct impact. Indirect effects include reduced agricultural production through floods and hailstones. The Rowsell model does not directly show other hazards related to thunderstorms such as hail and lightning. It also does not show any specific property destroyed by thunderstorms or its associated hazards. For these reasons, the model was modified by the author as shown in Figure 9.

**Figure 9: Modified Resource Hazard model for thunderstorm analysis**

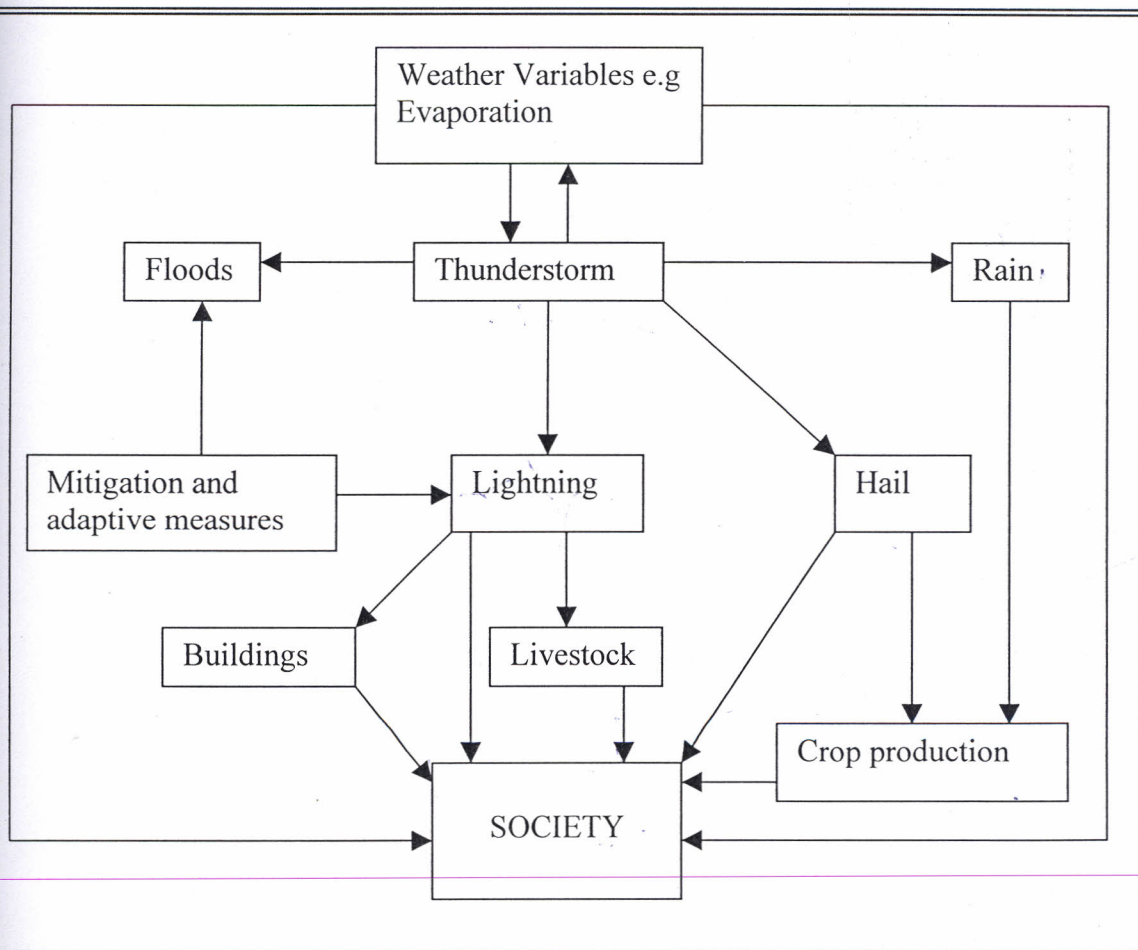


Figure 9 shows the relationship between thunderstorm phenomenon and society. It indicates ways in which the phenomenon affects people and it illustrates that weather variables may have a relationship with thunderstorms.

Thunderstorm occurrences affect society directly through lightning and hailstones. The framework shows that thunderstorms may lead to floods. Thunderstorms are not always a hazard but also a resource hence complying with the Rowsell's Resource Hazard model. Thunderstorms as a resource provides water for crop production and livestock keeping but the emphasis in this study was on the hazardous nature of thunderstorms.

## CHAPTER THREE

### 3.0 METHODOLOGY

This chapter presents the methodology that was used to collect and analyse data. The first two sections deal with data acquisition and quality control while the third section deals with analytical techniques.

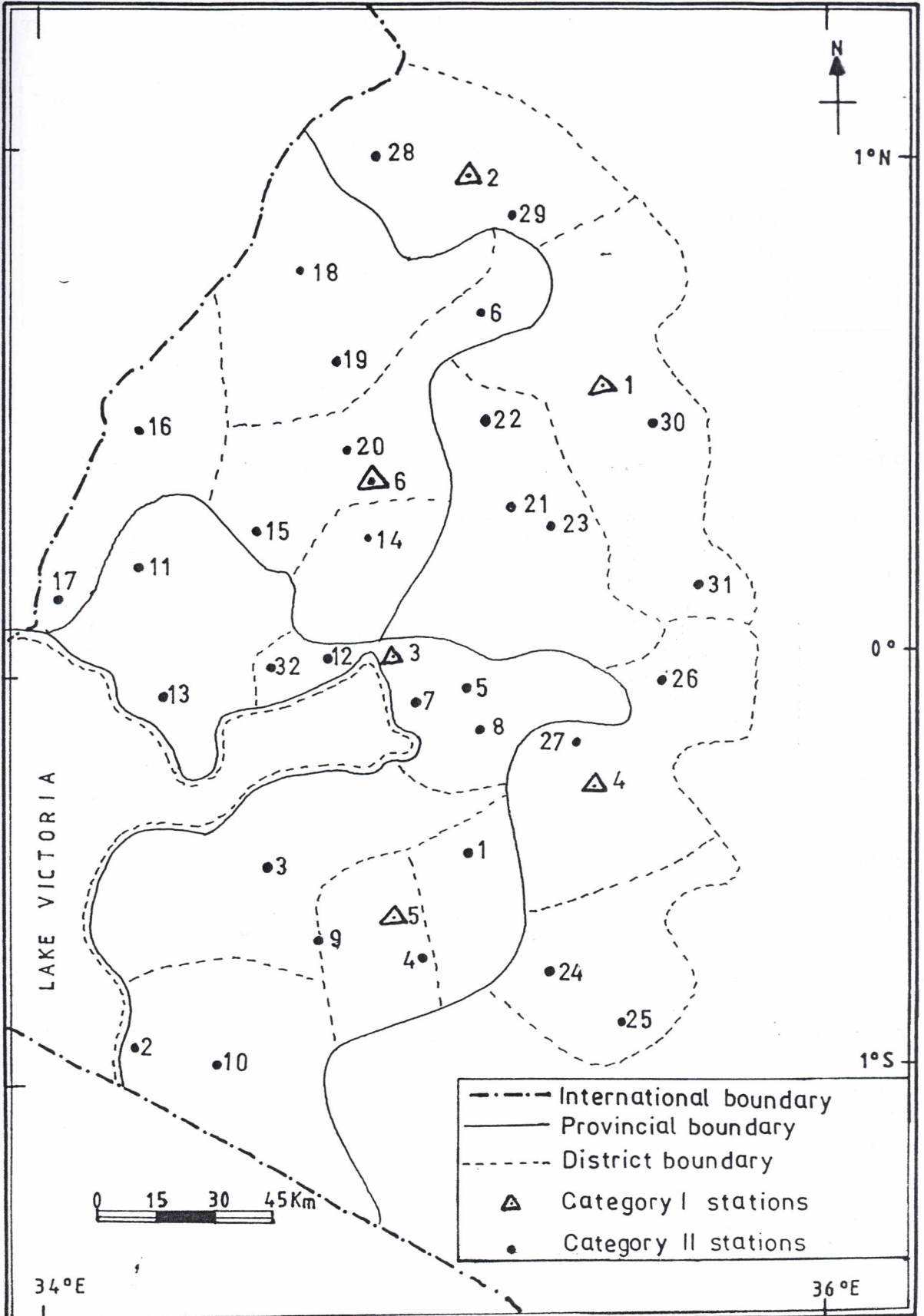
#### 3.1 Data collection methods

Basically, the secondary data collection involved library search of documented materials on the study area, climatological and weather information from the Kenya Meteorological Department (KMD), demographic data from Central Bureau of Statistics (CBS) and primary data on lightning casualties through interview schedules.

##### 3.1.1 Weather and other climatic data

The Kenya Meteorological Department maintains a network of stations throughout Kenya. However, not all stations in the network record thunderstorm information. In this study, the stations recording thunderstorm information among other variables have been classified as category I stations and those that record only rainfall as a common variable as category II (Fig 10). The standard station codes, names and altitudinal details for the two categories are given in Tables 2.1 and 2.2 respectively.

Figure 10: Location of the stations used in the study



(Source KMD,1995)

**Table 2.1 Details of Stations in category I**

Station No. (cf. Fig.10)	Station code.	Station name	Altitude (M)
1	8935181	Eldoret	2120
2	8834098	Kitale	1890
3	9034025	Kisumu	1149
4	9035279	Kericho	2182
5	9034082	Kisii	1707
6	8934096	Kakamega	1600

(Source: KMD, 1995)

From the stations in category I, the following weather variables were collected; number of thunder days, relative humidity, vapour pressure, mean temperature, cloud amounts, amount of rainfall, open water evaporation, number of rain days and hail days. The data was for the period 1980-1995 when all these stations were in operation.

The number of thunder days, hail days, rain days, evaporation and amount of rainfall were recorded once in a 24-hour period. The average of the maximum and minimum temperatures recorded by Mercury and Alcohol thermometers were computed to obtain daily temperatures. The daily relative humidity was obtained from relative humidity values recorded at 6.00 a.m., 9.00 noon and 3.00 p.m. An average value of cloud cover was obtained from cloud values taken at 9.00 a.m. and 3.00 p.m. All these data were summarised on monthly basis before yearly values could be computed. From stations in category II, mean monthly rainfall data were collected and used to estimate thunder days by employing regression relationships derived from the former stations. This was possible

since the former stations recorded rainfall and thunder days.

**Table 2.2 Details of stations in category II**

Station No. (cf. Fig. 10)	Station code	Station name	Altitude (M)
1	9034046	North Mugirango F.C	1710
2	9034059	Macalder Mine	1218
3	9034084	Homabay	1218
4	9034044	Keroka	1500
5	9035274	Chemelil	1229
6	8935170	Turbo Forest	1829
7	9034086	Ahero (Kano)	1219
8	9035148	Koru	1706
9	9034005	Kamagambo	1500
10	9134010	Migori Agr. Office	1370
11	8934127	Ukwala Dist. Office	1256
12	9034021	Maseno	1234
13	9034036	Bondo Water Supply	1219
14	8934103	Vihiga Maragoli	1585
15	8934040	Butere H.C.	1433
16	8934105	Busia Cotton Stn.	1220
17	8933026	Port Victoria	1250
18	8934093	Kimilili Forest	2073
19	8934023	Bungoma Vet. Stn.	1370
20	8934028	Kakamega Forest	1676
21	8935018	Kapsabet	1998
22	8935152	Kapsabet Kapyet	1828
23	8935152	Nandi Hills	1999
34	9035013	Sotik	1824
25	9035227	Bomet Dist. Office	1920
26	9035068	Lumbwa	1931
27	9035007	Fort Ternan	1768
28	8834009	Mt. Elgon Forest Stn.	2225
29	8934008	Kimini G. Vale	1829
30	8935010	Kaptagat Forest	2438
31	8935022	Timboroa	2743
32	9034081	Kibos	1171

(Source : KMD, 1995)

For frequency analysis, thunder days from stations in category I were selected. From the days, one maximum rainfall value for 24-hour period was obtained from each year for the various periods.

### **3.1.2 Demographic data**

In order to derive the Lightning Hazard Index and the Overall Lightning Hazard Index, demographic data from the two districts population densities at divisional level was collected for Kisii and Nyamira districts which have had some of the worst thunderstorm tragedies in the recent times.

### **3.1.3 Interview schedules**

In addition to the secondary data obtained above, an interview schedule (see Appendix 2) was conducted in Kisii and Nyamira districts. The schedule was administered to the families and institutions (schools) already affected by thunderstorm catastrophe as they had the information at hand either in record or in memory.

The data on lightning casualties in the two districts was accomplished with the assistance of research assistants recruited from respective divisions in the two districts. Their information was summarised at divisional level. The data collected covered the scattered lightning incidents in the districts for the period 1970 to June 1996 and was similar to

Akello's (1990) survey in Bungoma district. This provided details required in deriving the Lightning Hazard Index (LHI) and the Overall Lightning Hazard Index (OLHI).

## **3.2 Data quality**

One of the concerns of climatological studies is the quality of data used. Climatological data are extremely sensitive to erroneous values (Baker et al, 1995). The following criteria were used in data quality control.

### **3.2.1 Missing data**

Missing data was filled using correlation and regression techniques. In correlation analysis, inter-station variable correlations were first obtained. The station that was highly correlated with the one missing data was chosen for filling missing data. A regression relationship was also developed between the stations, which were closely related using concurrent data, and then one of them was used to estimate the missing data for the other station.

### **3.2.2 Station record consistency**

The weather data were checked for consistency by Double Mass Curve (Searcy & Hudson, 1960: 33; Dunne & Leopold, 1978) technique. The technique plots cumulative total of a given weather variable at a station against the period or the cumulative average of nearby

stations against the cumulative totals of one station.

### 3.3 Data Analysis

The methods that were used included multiple correlation and regression analyses, the use of the coefficient of variation, Gumbel probability plots and the Lightning Hazard Index analysis.

#### 3.3.1 Multiple correlation and regression analyses

These methods were used to determine the relationship between thunderstorm frequency and other weather variables (vapour pressure, relative humidity, cloud cover, evaporation, amount of rainfall, number of rain days, temperature and number of hail days). A multiple regression equation has been defined by Johnston (1978) as:

$$Y_i = a + b_1x_1 + b_2x_2 + \dots + b_nx_n + e_i \dots\dots\dots (1)$$

Where:

$Y_i$  = the dependent variable which in this study is the thunderstorm frequency from each of the stations in category I,

- a = the regression constant,
- $b_1 \dots b_n$  = the partial correlation coefficients,
- $x_1 \dots x_n$  = the independent variables such as relative humidity, vapour pressure, evaporation and temperature.
- $e_i$  = error term for station i

Multiple correlation and regression analyses were used to determine the degree and nature of relationships between thunderstorm frequency which is the dependent variable (Y) and the independent variables {vapour pressure ( $x_1$ ), relative humidity ( $x_2$ ), cloud cover ( $x_3$ ), evaporation ( $x_4$ ), rainfall ( $x_5$ ), number of rain days ( $x_6$ ), temperature ( $x_7$ ) and hail days ( $x_8$ )}.

The analysis was carried out for the collected data (see appendix 2.1 to 2.6) using the SPSS computer program (Marija, 1990). The following statistics were computed in multiple regression:

- (i) The coefficient of multiple correlation (R)
- (ii) The coefficient of multiple determination

$$R^2 = \frac{SS_{Reg}}{SS_y} \dots\dots\dots (2)$$

where:

R = is the coefficient of multiple correlation

$SS_{Reg}$  = Sum of squares due to regression,

$SS_y$  = Sum of squares due to regression residuals.

Regression residuals refer to the scatter of points around the regression model.  $R^2$  is a measure of the percentages of the total variation in thunderstorm frequency, explained statistically by the independent variables in each of the stations.

The significance of the relationships were assessed by using the Beta weights. This was done by testing the null hypothesis that there is no significant relationship between thunderstorm frequency and the other weather variables.

### 3.3.1.1 Beta weights

The respective partial correlation coefficients from the multiple regression relationships were converted to beta weights so as to standardize them since they were measured in different units which make direct comparisons difficult (Shaw and Wheeler, 1985). A Beta weight is defined as:

$$\beta_i = b_i (S_{x_i} / S_y) \dots\dots\dots(3)$$

where:

$\beta_i$  = is the Beta weight,

- $S_{x_i}$  = is the standard deviation of the independent variable under consideration,  
 $S_y$  = is the standard deviation of the dependent variable,  
 $b_i$  = is the partial correlation coefficient pertaining to  $x_i$ .

Beta weights are actually standardized partial correlation coefficients (Shaw & Wheeler, 1985). The weights provide one way in which the separate effects of individual variables in a regression equation can be assessed.

The independent variables may however be dependent upon each other hence creating the multicollinearity problem. To eliminate this, stepwise regression was used.

### 3.3.1.2 Stepwise regression

Stepwise regression particularly backward stepping was carried out using SPSS computer program (Marija, 1990). In the first stage, it involved entering all the independent variables (vapour pressure, relative humidity, cloud cover, evaporation, rainfall, number of rain days, temperature and number of hail days) in the multiple regression model and assessing their overall influence on the dependent variable Y (thunderstorm frequency).

In the subsequent stages, the independent variables were eliminated depending on their relative significance on the dependent variable. The least significant variable was the first

one to be eliminated. The process was repeated until the most significant variables were obtained for each station in category I. This was done using the F statistic. With this statistic, the most significant variables could be detected when it is highest. For each station, a significant model was developed linking the dependent variable (thunderstorm frequency) with the independent variables. Apart from the individual station variable relationships to thunderstorm frequency, it was necessary to investigate the spatial and temporal characteristics of thunderstorms.

### 3.3.2 The Coefficient of Variation (CV)

The coefficient of variation was used to determine the spatial and temporal variability of thunderstorm frequency in the study area. It is expressed as:

$$CV = \left(\frac{s}{\bar{X}}\right) \times 100 \dots\dots\dots(4)$$

where:

- s = is the sample standard deviation of thunderstorm frequency,
- $\bar{X}$  = mean thunderstorm frequency for each station.

The CV statistic was computed for each of the 38 stations for the period 1980-1995. The stations used were classified into two categories. Category I was composed of those stations that record actual thunderstorm data and rainfall. Category II comprised of stations that

record rainfall. Isobronts (lines of equal thunderstorm days) were drawn to show the spatial pattern of thunderstorm frequency in the area.

The process of drawing isobronts involved plotting the calculated coefficients for each of the stations used in this study. The isobronts were then drawn using the coefficient of variation to join stations with equal coefficients. This was done for the three rainfall seasons; March-May, July-September and October-December in the area (Davies et al, 1985 and Kenworthy, 1964). The statistic has the advantage of being standardized and it is also not affected by extreme values in any set of data (Shaw & Wheeler, 1985).

### **3.3.3 Analysis of variance (ANOVA)**

This was used to test the null hypothesis that there is no significant difference in the spatial and temporal variation of thunderstorm frequency because of its ability to determine whether there is any significant difference in the spatial pattern of thunderstorms in the study area. The following steps were followed in this process of analysis:

1. Calculation of variance among sample means was computed. This statistic is known as Between Column Variance (BCV),
2. Calculation of variance within samples. The statistic obtained is known as Within Column Variance (WCV),

3. Calculation of F-statistic was also carried out. The F statistic in F-test was tested for significance using the F table at 0.01 and 0.05 levels. The F-statistic is a relationship between (1) and (2) above.

It is defined by the equation:

$$F = \frac{BCV}{WCV} \dots\dots\dots (5)$$

The ANOVA technique was preferred due to its ability to show if a significant difference exists among means obtained from more than one sample.

### 3.3.4 Frequency analysis

This was used to determine the frequency of rainfall associated with thunderstorms. The Weibull formula (Dandekar & Sharma, 1991), was used. It was preferred because of its simplicity as well as its requirement of little data input. It takes the form;

$$F = \frac{M}{n+1} \times 100 \dots\dots\dots(6)$$

where:

- F = frequency which represents the percentage of years during which rainfall equaled or exceeded the rainfall of order M,
- M = the order of a given amount of rainfall either in increasing or decreasing order.

$n$  = the number of years of observation.

From the above, the return period (T) in years for rainfall associated with thunderstorms was calculated using the formula:

$$T = \frac{I}{F} \dots\dots\dots(7)$$

The hypothesis that there is a significant difference between rainfall amount and thunderstorm frequency was tested using correlation analysis. A correlation coefficient (r) was calculated using the equation;

$$r = \frac{\sum xy}{\sqrt{\sum x^2 \sum y^2}} \dots\dots\dots (8)$$

where:

$r$  = the correlation coefficient

$$x = X - \bar{X} \quad \text{and} \quad y = Y - \bar{Y}$$

$\bar{X}$  and  $\bar{Y}$  are mean values of the variables

$X$  = independent variable (rainfall amount)

$Y$  = dependent variable (thunderstorm frequency)

Significant tests in correlation analysis were carried out using t-test. The statistic was preferred since it is easy to compute. The following equation defines the statistic:

$$t = \frac{r\sqrt{(n-2)}}{\sqrt{1-r^2}} \dots\dots\dots (9)$$

where:

t = the statistic,

r= correlation coefficient,

n= number of observations and

r<sup>2</sup> = coefficient of determination

The Null hypothesis was to be rejected whenever the computed value was greater than the critical value for the test at both 0.01 and 0.05 significance levels. This was meant to reduce the chances of committing either type I or II errors.

### 3.3.5 The Lightning Hazard Index (LHI)

The LHI was used to assess the severity of lightning. The index has been defined by Smith (1993) as:

$$LHI = \frac{C}{P} \times 100 \dots\dots\dots(10)$$

where:

LHI = Lightning hazard Index,

C = Number of casualties and

P = Population density.

The casualties refer to injured or dead people due to lightning accident taken over the divisions. The LHI was modified to include livestock, trees and houses and called Overall Lightning Hazard Index (OLHI) given as;

$$OLHI = \frac{AC}{P} \times 100 \dots\dots\dots(11)$$

where:

- AC = Aggregated Casualties,  
 P = Population density.

The aggregated casualties were computed as:

$$AC = H_i + L_i + H_{ii} + T_i \dots\dots\dots (12)$$

where:

- $H_i$  = Human casualties  
 $L_i$  = Livestock casualties  
 $H_{ii}$  = Houses burned or damaged by lightning  
 $T_i$  = Trees burned or damaged by lightning

The null hypothesis that there is no significant difference in the use of LHI and OLHI in assessing the levels of lightning severity was tested using correlation analysis and the t-test described above.

## CHAPTER FOUR

### 4.0 RESULTS AND DISCUSSION

This chapter presents and discusses the results of the study. The results are centred on the objectives and hypotheses of the study.

#### 4.1 Thunderstorm - weather variable relationships

Table 1 shows the results of the relationship between thunderstorm frequency and other weather variables. It indicates that in each of the stations, the eight variables (Appendix 2.1 to 2.6) had a high correlation coefficient of over 0.50 with corresponding thunderstorm frequency. The best correlation coefficient of 0.93 was observed in Kakamega. The least coefficient of 0.67 was obtained in Kericho. This means that the eight variables explained, to a large extent, the occurrences of thunderstorms in the stations.

The variance in thunderstorm frequency explained by the eight variables differed from one station to another. It was highest in Kakamega (87%) and least in Kericho (44%). This is an indication that the eight variables explained only a fraction of thunderstorm frequency. Other variables not considered in this study such as altitude and atmospheric pressure may play a significant role in thunderstorm frequency. Upper air condition would also be responsible for the unexplained variance by the eight variables (Ardis, 1961 and Githungo, 1990).

**Table 4.1: Results of multiple regression**

Stations	Multiple regression equations	R	R <sup>2</sup>
Kisumu	$796-252X_1+45X_2+107X_3+1.00X_4-0.15X_5+0.45X_6+34X_7+8.3X_8+e_i$	0.78	0.61
Kisii	$-249-56X_1+6.8X_2+35X_3+0.1X_4+0.02X_5+0.40X_6+21X_7+0.10X_8+e_i$	0.86	0.74
Kitale	$1132+21X_1-11X_2-52X_3-0.21X_4-0.30X_5+2X_6-6X_7-2X_8+e_i$	0.74	0.55
Kericho	$-4000+455X_1-37X_2+11X_3+0.10X_4-0.7X_5+11X_6+0.67X_7-0.46X_8+e_i$	0.67	0.44
Eldoret	$-90-4.7X_1+1.0X_2+29X_3+0.02X_4+0.04X_5+0.28X_6+3.9X_8+e_i$	0.71	0.50
Kakamega	$64-145X_1+17X_2-2X_3+0.11X_4+0.01X_5+0.05X_6+48X_7-0.75X_8+e_i$	0.93	0.87

The high correlation coefficients agree with findings by Gichomo (1992) who argued that variables such as relative humidity played a significant role in influencing thunderstorm frequency. On a world scale, Wallen (1970) points out that warm humid air is a valuable factor in influencing thunderstorm frequency. This fact is true of the L. Victoria Basin stations considered in this study. The large amount of water vapour from the lake contributes a lot to the latent heat of the atmosphere which gives rise to thunderstorms (Rogers, 1976).

For purposes of comparison, on the relative importance of the variables, Beta weights were sought. The computed beta weights after all the eight independent variables were taken into account are shown in Table 4.2.

For Kericho, vapour pressure, relative humidity and rain days were closely associated as shown by the high values of the corresponding Beta weights. For

Kisumu, the vapour pressure and relative humidity were the important variables. Kitale however indicated that the relative humidity and evaporation were closely linked variables. Kakamega.

**Table 4.2 Absolute Beta weights for the eight variables**

Stations	Magnitude of Beta weights							
	$\beta_1$	$\beta_2$	$\beta_3$	$\beta_4$	$\beta_5$	$\beta_6$	$\beta_7$	$\beta_8$
Kisumu	5.70	6.05	0.76	0.37	0.61	0.20	0.88	0.16
Kisii	1.14	1.15	3.70	0.06	0.36	0.40	0.40	0.40
Kitale	0.29	1.36	0.32	1.30	0.24	0.86	0.04	0.11
Kericho	5.67	5.12	0.80	0.35	0.54	3.62	0.27	0.12
Eldoret	0.19	0.34	0.53	0.21	0.44	0.25	-	0.66
Kakamega	5.29	5.00	0.02	0.02	0.25	0.04	0.79	0.27

depicted vapour pressure and relative humidity as the important variables while Kisii exhibited vapour pressure, relative humidity and cloud cover to be closely linked. All these indicate that the water content of the atmosphere is vital in influencing thunderstorm occurrence (Gichomo, 1992; Schwerdtfeger 1976 and Arakawa, 1969). The stations had different values for beta weights. This showed that the relative importance of the independent variables, varied from one station to another. This was due to differences in the relative location of the stations. Kisii and Kericho were on a higher ground, Eldoret and Kitale on a medium ground while Kisumu stood on the lowest ground. For details on data used for multiple regression see appendices 2.1 to 2.6.

## 4.2 Stepwise regression

Table 4.3 gives a summary of the variables extracted for each of the stations using the F-statistic. The respective Beta weights for the extracted variables are presented in Table 4.4. It is evident from Table 4.3 and 4.4 that the variables extracted provided an explained variance ranging from 35% in Kitale to 82% in Kakamega. The unexplained variance would be accounted for by other factors not considered in this study such as topography (Lamb, 1970; Nieuwold, 1977), atmospheric pressure (Schwerddfeger, 1976) and other upper air conditions (Githungo, 1990; Ardis, 1971). The detailed process of stepwise regression is provided in appendices 3.1 to 3.6.

**Table 4.3: Variables extracted for each station**

Stations	Multiple regression equations	R	R <sup>2</sup>
Kisumu	$720-229X_1+41X_2+94X_3-0.15X_5 \pm e_i$	0.67	0.45
Kisii	$-533+32X_3+0.28X_5+0.38X_6+22X_7 \pm e_i$	0.85	0.73
Kitale	$508-6X_2-0.11X_4-2 \pm e_i$	0.59	0.35
Kericho	$-650+31X_1+0.12X_4+16X_7 \pm e_i$	0.60	0.36
Eldoret	$-62+21X_3+0.03X_5+0.27X_6+3X_8 \pm e_i$	0.62	0.38
Kakamega	$155-154X_1+18X_2+0.01X_7-0.91X_8 \pm e_i$	0.91	0.82

#### 4.4 Beta weights for the extracted variables

Stations	Multiple regression equations	R	R <sup>2</sup>
Kisumu	$720-5\beta_1+6\beta_2+0.67\beta_3-0.41\beta_5 \pm e_i$	0.67	0.45
Kisii	$-533 + 0.33\beta_3 + 0.37\beta_6 + 0.35\beta_7 + 0.42\beta_8 \pm e_i$	0.85	0.73
Kitale	$508-0.70\beta_2+0.70\beta_4+0.73\beta_5 \pm e_i$	0.69	0.35
Kericho	$-680+0.38\beta_1 +0.45\beta_4+ 0.40\beta_7 \pm e_i$	0.60	0.36
Eldoret	$-62+0.38\beta_1+0.38\beta_3 +0.31\beta_5+0.25\beta_6 + 0.53\beta_8 \pm e_i$	0.69	0.47
Kakamega	$155-6\beta_1+5\beta_2+0.23\beta_7-0.29\beta_8 \pm e_i$	0.91	0.82

A comparison between highest and lowest explained variances in thunderstorm frequency is shown in Table 4.5. The value of R<sup>2</sup> ranged between 14% and 87%. The highest explained variance for each station was provided by the eight variables explained only a maximum of 87% of thunderstorm variance.

When the highest R<sup>2</sup> and the lowest R<sup>2</sup> for the stations were subjected to t-test,  $t_{calc}$  was found to be 2.7 while  $t_{tab}$  was 2.015 and 2.571 at 0.01 and 0.05 levels of significance respectively. The t-test provides a simple way of assessing the relative significance of two variables. In both levels of significance, the null hypothesis that there is no significant relationship between the highest R<sup>2</sup> and lowest R<sup>2</sup> was accepted. This is because the  $t_{calc}$  was outside the acceptance region.

**Table 4.5 : Highest and Lowest explained variance in each station**

Station	Highest R <sup>2</sup> (%)	Lowest R <sup>2</sup> (%)
Kisumu	61	18
Kericho	47	14
Kisii	74	36
Eldoret	50	38
Kitale	55	35
Kakamega	87	82

### 4.3 Spatial and temporal characteristics of the thunderstorms

The spatial pattern of thunderstorms was mapped using the coefficient of variation of their frequencies of occurrence. On the basis of these coefficients, isobronts were drawn for data pertaining to the period from 1980 to 1995. The patterns of the storms were classified into three rainfall seasons; March-May, July-September and October-December.

The thunderstorm frequencies and their coefficients of variation are shown in Table 4.6 and Appendix 4.1. A close examination of Table 4.6 indicates that the lowest thunderstorm frequency was recorded in Eldoret during Oct.-Dec rainfall season. This station had the highest coefficient of variation during the period. Generally, it was observed that stations with lower thunderstorm frequencies had high coefficients of variation. The lowest coefficient of variation, representing a high thunderstorm frequency according to the table was Kisii station during March-May rainfall season.

(Table 2.2).

Figures 11, 12 and 13 show the spatial variability of the storms during the three rainfall seasons over the period 1980-1995. From the figures it is clear that stations adjacent to the lake had almost the same coefficient of variation (28-29%) during the three rainfall seasons. The low coefficients of variation recorded by these stations represented high thunderstorm frequency as illustrated in Table 4.6 which may be attributed to the daytime convective activities and warm humid conditions from the lake (Wallen, 1970). Patnaik and Chaggar (1977) also showed high thunderstorm frequency using lightning discharges. Stations situated far from the lake such as Eldoret and Kitale with their adjacent stations in category II had high coefficients of variation representing low thunderstorm frequencies in all the three seasons.

Table 4.6 and Appendix 4.1 were used to derive yearly coefficients of variation for the stations (Appendix 4.2). On the basis of Appendix 4.2, Figure 14 has been drawn to show the spatial pattern of thunderstorms in the area on a yearly basis. The figure shows that the lowest thunderstorm frequency, denoted by high coefficients of variation, are observed in Kaptagat, Kapsabet, Nandi Hills and Eldoret. These stations are located far from Lake Victoria whose convective activities give rise to thunderstorms (Lamb, 1970). High thunderstorm frequency was observed in Kisumu, Kisii and Kakamega. These stations' proximity to the L. Victoria makes them susceptible to convective activities arising from the lake that generate thunderstorms. In Kisii and Kakamega, thunderstorms are reinforced by orography.

Figure 11: Spatial pattern of thunderstorms in March-May rainfall season (1980-1995)

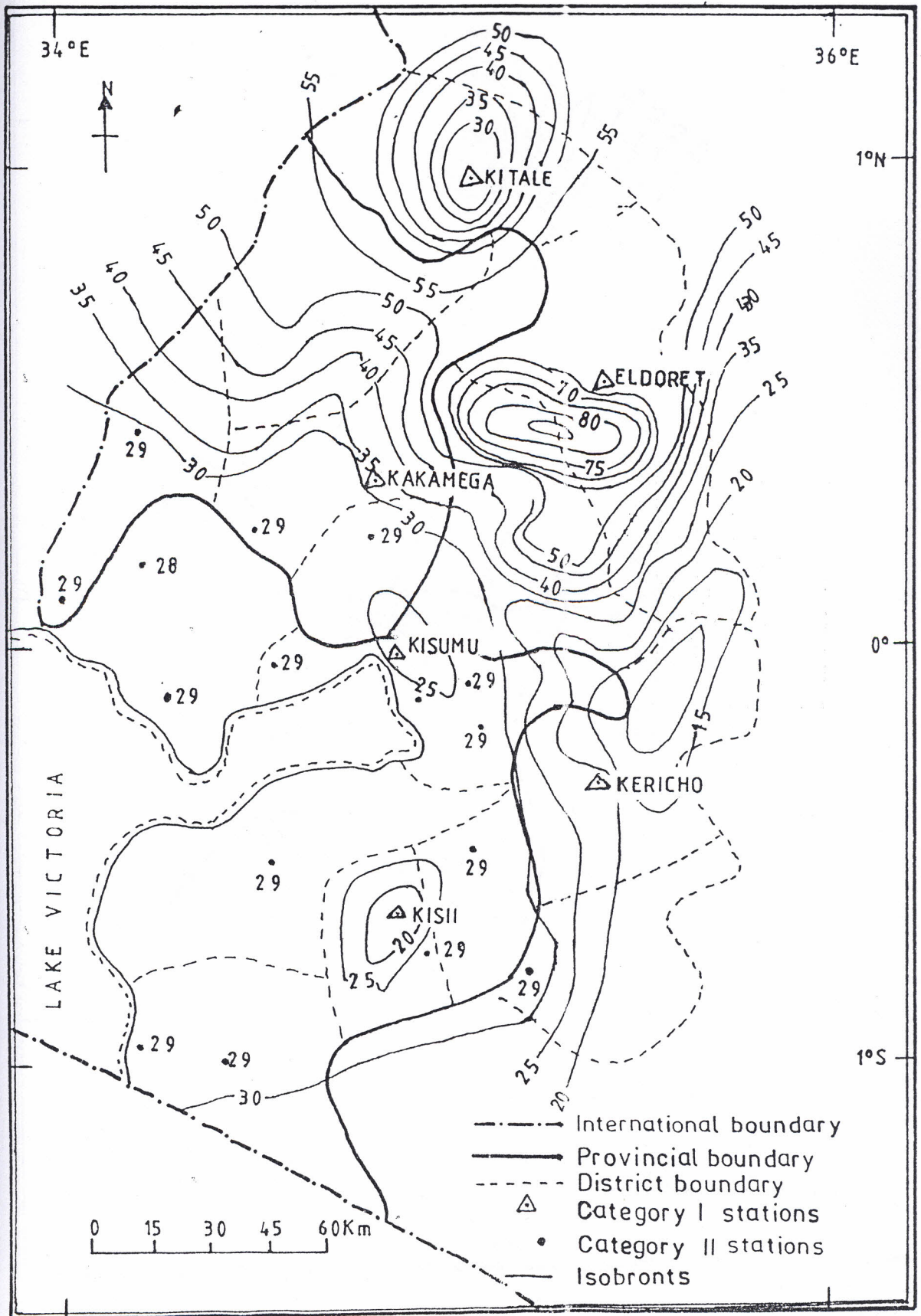


Figure 12: Spatial pattern of thunderstorms in July-Sept rainfall season

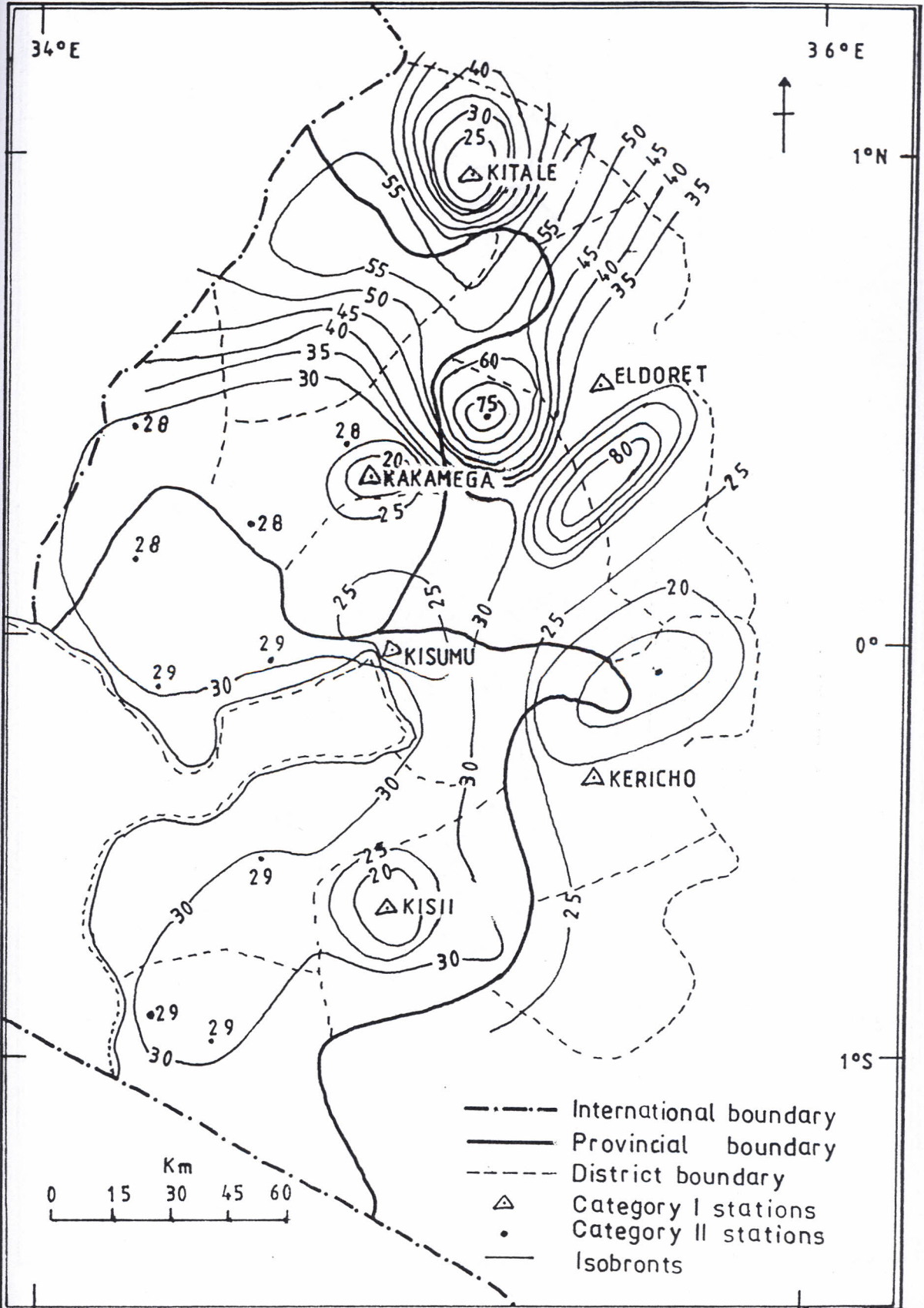


Figure 13: Spatial pattern of thunderstorms in Oct.-Dec. rainfall season

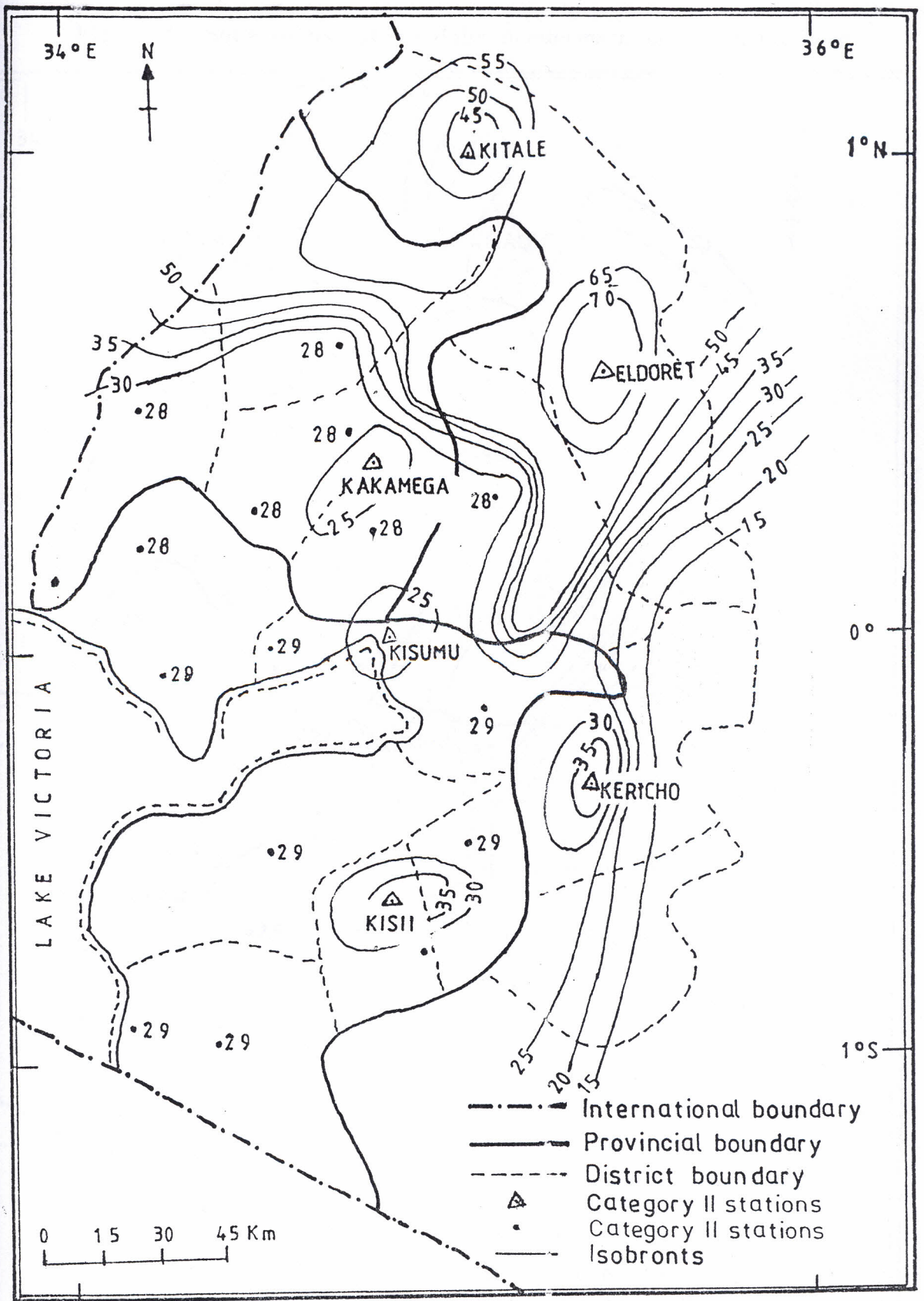
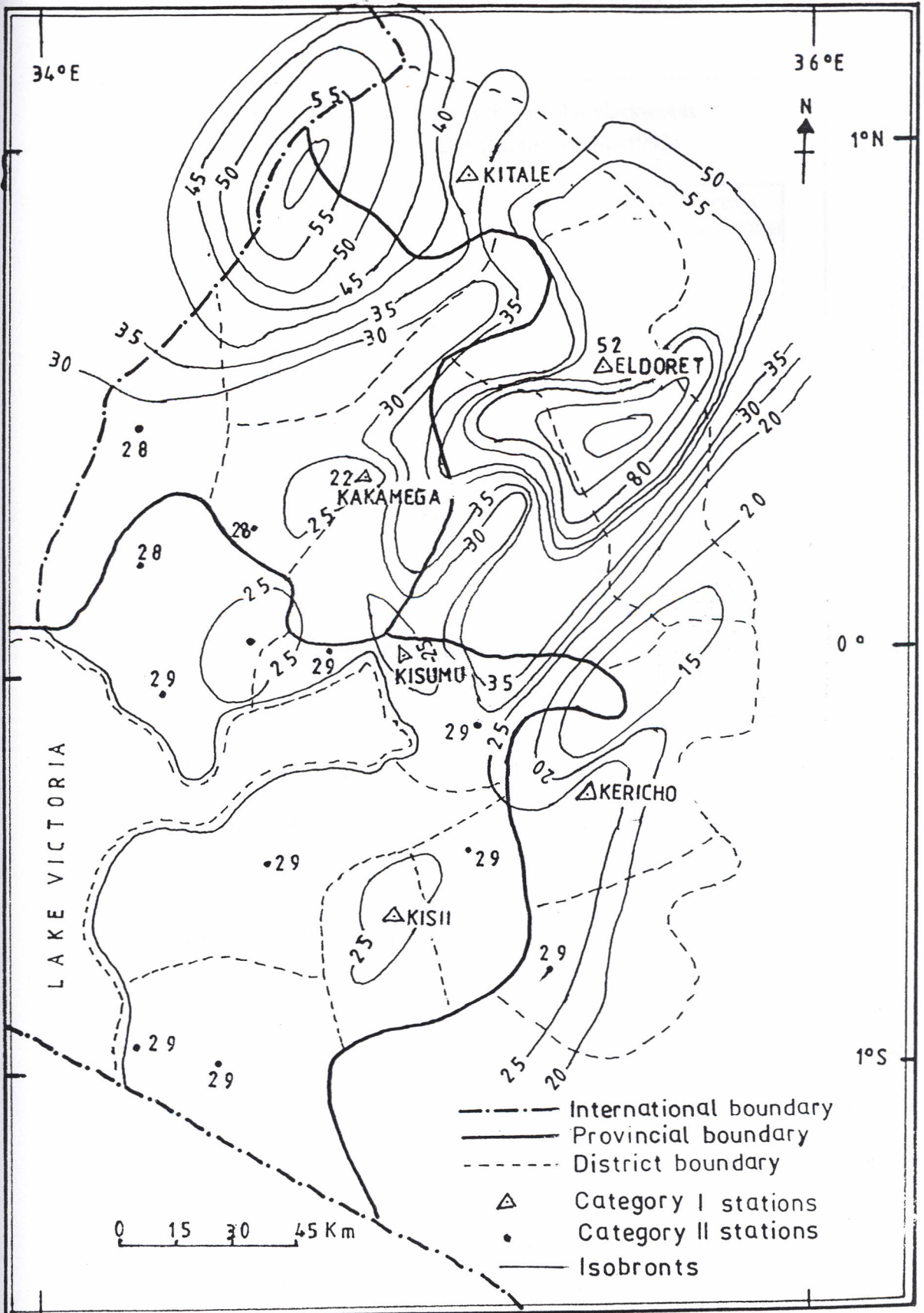
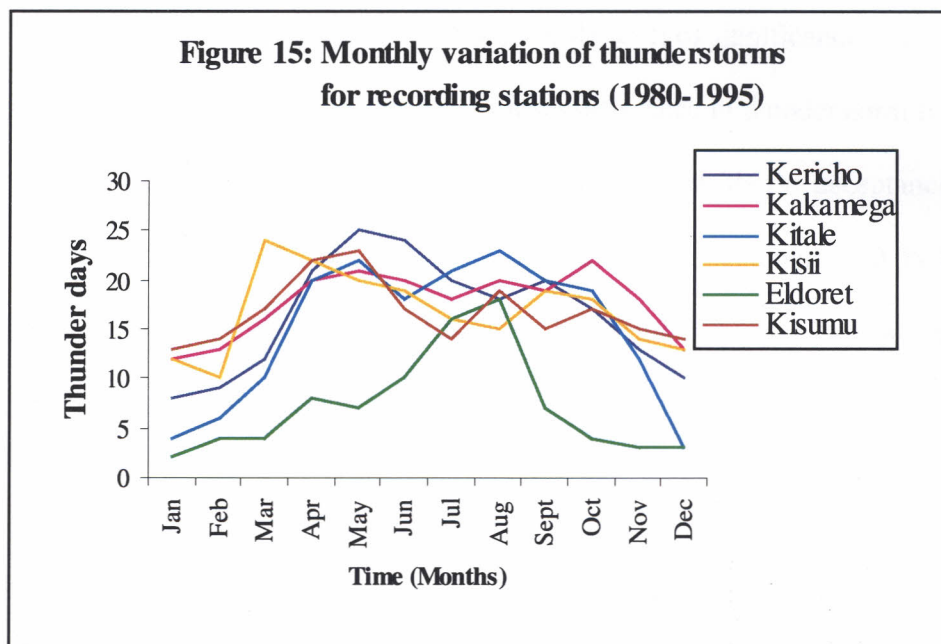


Figure 14: Annual spatial pattern of thunderstorms in the L. Victoria Basin



The monthly variation of thunderstorms in recording stations is presented in Figure 15. The figure shows different thunderstorm peaks for each station. The first peak is



depicted in Kisii in the month of March followed by Kericho in May. The third peak is observed in Kitale during the month of August. It is also evident that Eldoret has low thunderstorm frequency for most of the months except August which depicts a high peak. Kakamega has least thunderstorm frequency in July.

#### 4.4 Anova test for thunderstorm frequency

A test of significance was carried out to determine whether there was a significant difference in thunderstorm frequency. This was done using data from stations that recorded actual thunderstorm data. These were those stations in category I for the period 1980-1995.

In carrying out the analysis, equation 8 was used. The Between Column Variance (BCV) was found to be 31168. The Within Column Variance was found to be 70. The F-ratio based on equation 5 was 445 to 1. The calculated F-statistic ( $F_{calc}$ ) was 445. The F-statistic from the F-table ( $F_{tab}$ ) at 0.01 level of significance was 3.35. The null hypothesis ( $H_0$ ) that there is no significant difference in thunderstorm frequency among the stations was accepted since the  $F_{calc}$  was outside the acceptance region which ranged from -3.35 to 3.35. Similar results were obtained at 0.05 level of significance whereby the  $F_{tab}$  was 2.30. This would be true since the stations are in proximity to L. Victoria. Detailed data for this hypothesis is shown in appendix 5.

#### 4.5 Frequency Analysis

Table 4.7 shows the maximum 24 hour rainfall  $R_{max}$  recorded in each station and its respective frequency and return period (T). It is evident from Table 4.7 that  $R_{max}$  differs from one station to another. It was highest in Kisumu and least in Eldoret. Using extreme value probability paper (Gumbel, 1958), the 24 hour annual maximum rainfall in each of the six stations were plotted against the return periods (T) as shown in Figure 16. Appendices 6.1 to 6.6 provides the detailed data. From Figure 16, it is evident that rainfall amounts for return periods ranging from 1.01 and 100 years can be approximated.

**Table 4.7: The Max. 24 hour rainfall and their frequency characteristics for thunderstorm recording stations**

Station	Period	Year of $R_{\max}$	$R_{\max}$ (mm)	F	T (yrs)
Kisumu	1960-1995	1970	128.6	1.7	37
Kitale	1960-1995	1966	99.5	2.7	37
Kericho	1968-1995	1975	121.4	3.4	29
Eldoret	1973-1995	1976	72.6	4.0	24
Kisii	1980-1995	1988	74.5	5.9	17
Kakamega	1980-1995	1990	96.0	5.9	17

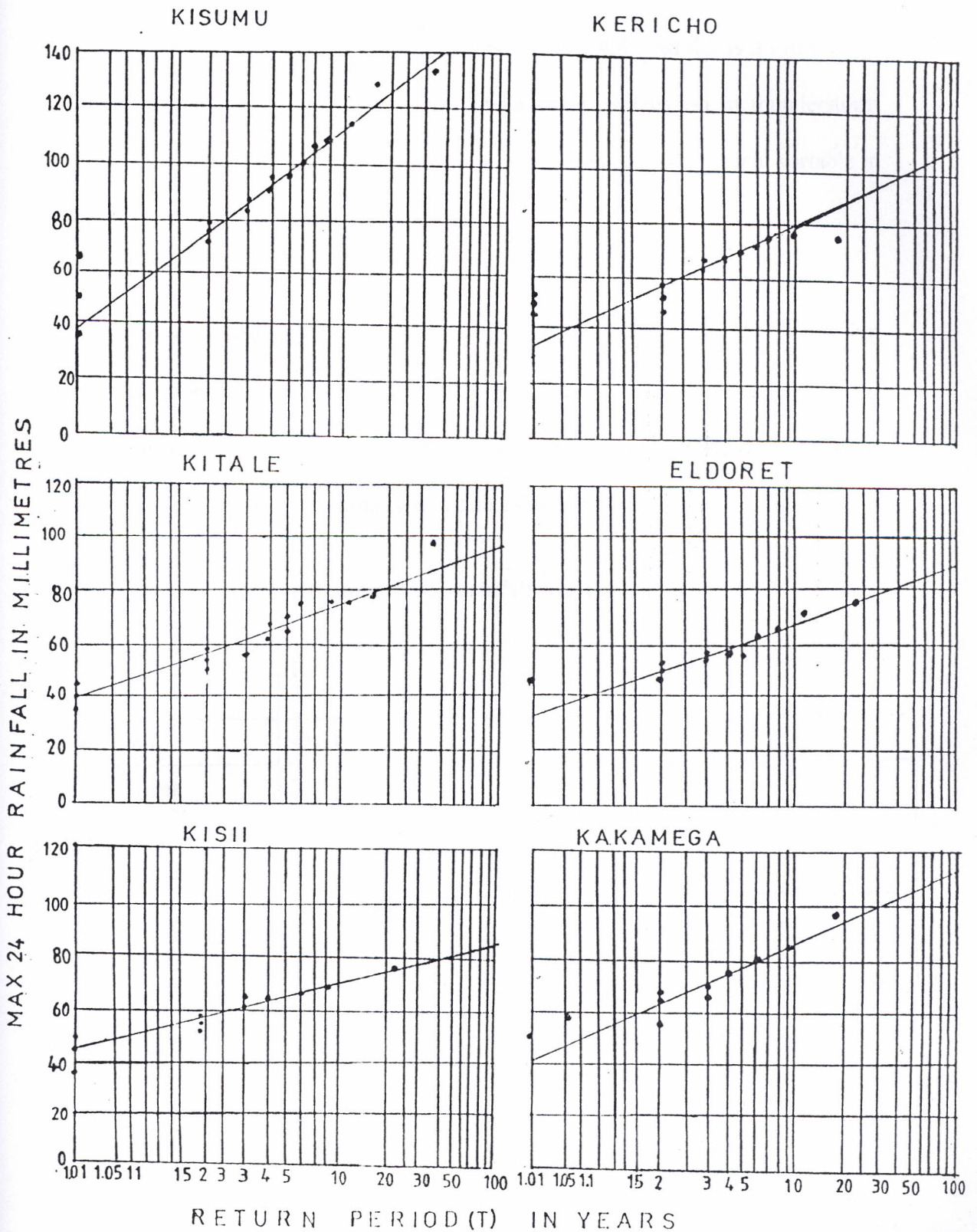
#### 4.6 Rainfall-thunderstorm frequency significance test

A test of significance was performed to see if there was a correlation between rainfall ( $X_5$ ) and thunderstorm frequency ( $Y$ ). This was carried out for each of the six stations in category I. The results are shown in Table 4.8.

**Table 4.8: Correlation coefficients between thunderstorm frequency and rainfall**

Station No. (cf. Fig. 10)	Station name	Correlation coefficient (r)
1	Eldoret	0.09
2	Kitale	0.15
3	Kisumu	-0.04
4	Kericho	-0.14
5	Kisii	0.60
6	Kakamega	0.33

Figure 16: Frequency of 24 hour annual maximum rainfall for thunderstorm recording station in the study area



From Table 4.8, positive correlation coefficients between thunderstorm frequency and rainfall were obtained in all the stations except Kisumu and Kericho. This is an indication that most of the rainfall received in the area results from thunderstorms. The strongest correlation coefficient was observed in Kisii. The low correlation coefficients in this table compared to Tables 4.1, 4.2, 4.4 and 4.5 is an indication that the variable on its own, provides only a small explanation in thunderstorm variation. It is therefore necessary to consider more than one independent variable in explaining thunderstorm frequency.

From the t-test, the null hypothesis ( $H_0$ ) that there is no significant relationship between thunderstorm frequency and rainfall was rejected at 0.01 level of significance. The  $t_{\text{calc}}$  values were within the acceptance region defined by the  $t_{\text{tab}}$  values for each station as summarised in Table 4.9.

**Table 4.9: Statistics for thunderstorm-rainfall relations**

Station	$R_{\text{tr}}$	$T_{\text{calc}}$	$T_{\text{tab}}$
Kisumu	-0.04	-0.14	2.14
Kakamega	0.33	1.30	2.14
Kericho	-0.14	0.53	2.14
Kitale	0.15	-0.56	2.14
Kisii	0.60	2.80	2.14
Eldoret	0.09	0.32	2.14

$R_{\text{tr}}$  : Correlation coefficient between thunderstorm frequency and rainfall.

At 0.05 level of significance, the  $t_{\text{tab}}$  value ranged between -2.14 to 2.14. The null hypothesis was rejected in all stations except for Kisii whose  $t_{\text{calc}}$  value was 2.8 found outside the acceptance region. This was because of the strong correlation between rainfall and thunderstorm frequency. The 0.01 level of significance was preferred as it produced uniform results.

#### 4.7 Lightning severity in the L. Victoria Basin

From the Smith's LHI, Kisii and Nyamira Districts had the OLHI developed for other casualties including human beings. Data on population densities and lightning casualties was used in deriving LHI and OLHI. Table 10 shows the results for the two indices on the basis of divisions in the two districts.

**Table 4.10: The LHI and OLHI for Kisii and Nyamira districts**

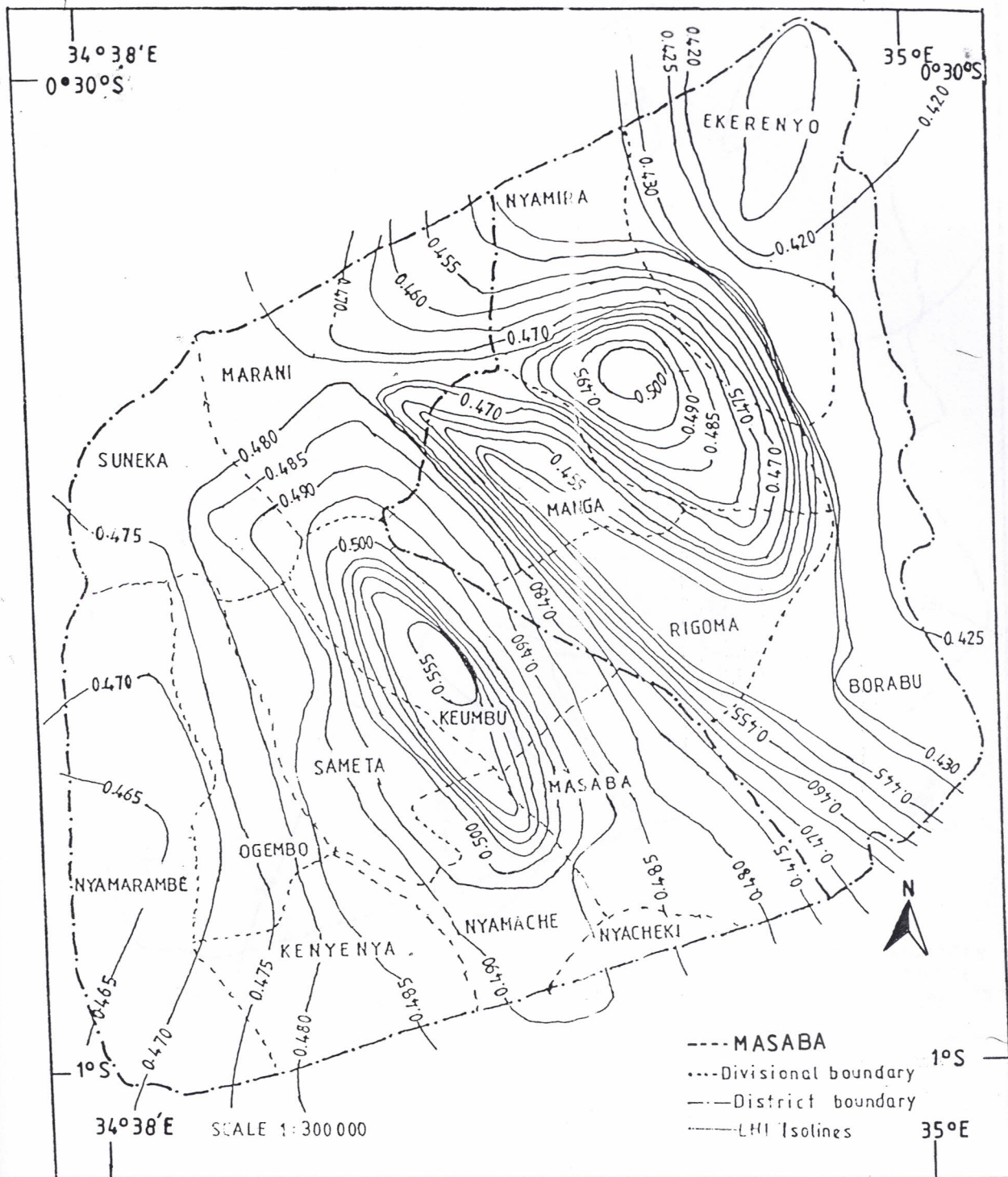
District	Division	LHI	Rank	OLHI	Rank
Kisii	Nyamarambe	0.462	12	1.923	11
	Suneka	0.477	9	1.802	15
	Nyamache	0.495	3	2.064	4
	Nyacheki	0.466	11	1.977	9
	Sameta	0.491	4	2.060	5
	Kenyenya	0.481	7	2.026	8
	Ogembo	0.476	10	2.045	6
	Keumbu	0.562	1	2.511	1
	Masaba	0.482	6	1.960	10
	Mosocho	0.489	5	2.297	2
	Marani	0.480	8	2.035	7
Nyamira	Nyamira	0.504	2	1.830	13
	Ekerenyo	0.418	16	1.810	14
	Borabu	0.429	15	1.870	12
	Rigoma	0.433	14	2.200	3
	Manga	0.448	13	1.780	16

Table 4.10, indicates that the LHI ranges from 0.418 in Ekerenyo Division in Nyamira District to 0.562 in Keumbu Division in Kisii District. The latter index assumes higher values than the former due to its inclusion of the other casualties; animals, trees and houses. The differences among the divisions is explained by population densities. From Figure 17, it is evident that high values of LHI are observed in and around Keumbu and in Kisii District.

The OLHI ranges from 1.780 in Manga Division to 2.511 in Keumbu Division in Kisii and Nyamira districts respectively. This is attributed to their high population densities. High indices are in most densely populated areas (Smith, 1993 and Curran et al, 1995).

The OLHI values are also high in Keumbu Division as shown in Figure 18. It is still evident that the north eastern part of the Nyamira district has low OLHI value of 1.80. It is followed by the north western part. The south western and south eastern parts of the area have almost similar OLHI values.

Figure 17: Spatial variability of LHI in Kisii and Nyamira districts





#### 4.8 Significance test for LHI and OLHI

A test of significance of the two indices has been carried out using t-test. This has been done to find out whether a significant difference exist between the two indices. A high correlation coefficient of 0.61 was found. Using equation 9, the  $t_{\text{calc}}$  value was found to be 2.9. The  $t_{\text{tab}}$  value at 0.01 level of significance was 2.921. This meant the null hypothesis that no significant difference exists between the two indices was accepted. This means that any of the two indices can be used in evaluating the severity of lightning in an area. At 0.05 level of significance, the  $t_{\text{tab}}$  was found to be 2.120 meaning that the  $t_{\text{calc}}$  value of 2.9 falls outside the acceptance region. This was an indication that the indices were different and each should be applied as appropriate. Appendix 7.1 to 7.5 shows the data that was used in the assessment of lightning severity.

## CHAPTER FIVE

### 5.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter summarises the main research findings and gives recommendations for implementation and for further research.

#### 5.1 Summary of research findings

The study has shown that there are significant relationships between thunderstorm and some of the climatic variables. The relationships seem to be complicated and non-linear for some of the variables.

The variance in thunderstorm frequency explained by the eight variables differed from one station to another owing to differences in the location of these stations. The unexplained variance in thunderstorm frequency is attributed to other factors not considered in this study such as atmospheric pressure, topography and other upper air conditions.

Stepwise regression extracted the most significant variables for each of the thunderstorm recording stations. These factors differed from one station to another due to differences in their altitude, topography, latitude and longitude. The variance explained by the significant variables extracted by stepwise Regression was less than that provided by the eight variables.

There was also no uniform multiple regression model that could explain the relationship between thunderstorm frequency and the predictor variables for all the stations. In order to explain thunderstorm frequency, more than one weather variable should be used. A combination of variables explaining the phenomenon at one station may not be necessarily the same elsewhere.

The coefficient of variation of thunderstorm occurrences identified areas with high thunderstorm risk or frequency. Stations located near the lake such as Kisumu had low coefficients of variation during the three rainfall seasons and hence high thunderstorm frequency. Stations located far from the lake such as Kitale had high coefficients of variation indicating low thunderstorm frequency. Convective activities responsible for thunderstorms decrease as one moves away from the lake. ANOVA at 0.05 and 0.01 levels of significance indicated no significant difference in the spatial and temporal variations of thunderstorms in the area due to the stations' proximity to the lake.

Frequency analysis showed that Kisumu had the highest maximum daily rainfall and Kitale had the least. Frequency characteristics varied from station to station depending on the number of thunderstorm years considered and not on the rainfall amounts. In all the thunderstorm-recording stations, there was a positive significant correlation between thunderstorm frequency and rainfall at 0.05 and 0.01 levels of significance. This meant that most of the rainfall in the area result from thunderstorms. The correlation coefficient was highest in Kisii.

In relation to lightning severity, both the LHI and OLHI respectively, ranked areas with high population densities such as Keumbu and Nyamira divisions in Kisii and Nyamira districts. With their high population densities, it means more people and property are likely to be exposed to the lightning catastrophe.

The t-test revealed that there was no significant difference between the LHI and OLHI in assessing the lightning risk. Despite this fact, the latter index, which takes all casualties into account, should be preferred.

## **5.2 Recommendations for policy action**

- (1) There is need to increase the network of stations recording thunderstorms and other weather variables so as to provide adequate and spatially representative data for research and other needs.
- (2) Public awareness campaigns on lightning risks should be increased and lightning arrestors be installed in areas with high LHI and OLHI values so as to reduce lightning casualties.
- (3) The design of hydraulic structures should take into account the extreme rainfall events and their frequencies.
- (5) There is need to reduce lightning severity in densely populated zones such as Keumbu and Nyamira divisions in Kisii and Nyamira districts respectively.

Steps to be taken should include:

- (i) Use of warning systems such as radars (Battan,1972) to detect lightning before it strikes. A weather radar installed in a densely populated area could help reduce casualties resulting from lightning by timely forecasts of the thunderstorms.
- (ii) Discourage the sheltering of all family members in one house during rains. This could reduce casualties in case of lightning. Students should also be discouraged from sheltering in one classroom during rains. This would reduce casualties in case one block or classroom is struck.
- (iii) A National lightning Detection Network (NLDN) should be set up to record lightning fatalities and injuries whenever they occur. This would be helpful in building a database for research and implementation.
- (iv) Since thunderstorm accidents cannot be completely eliminated, first aid for thunderstorm victims should be taught in lightning prone areas. Such first aid methods should include artificial respiration (resuscitation) because the respiratory system of a lightning victim may be temporarily paralysed during a strike (Gardener and Roylance, 1972).

### **5.3 Recommendations for further research**

- (1) The current study investigated the relationship between thunderstorm frequency and eight weather variables readily measured by the recording

stations. Upper air conditions before, during and after a thunderstorm should be investigated using radiosonde data.

- (2) In developing regression models relating thunderstorm frequency and other weather variables, annual data has been used. Models for shorter time periods such as daily, weekly or monthly values should be explored.
- (3) Spatial lightning mapping using lightning flashes in the Basin showing areas with high flash densities should be attempted. Combined with the thunderstorm frequency coefficients of variation, the LHI and OLHI, high-risk prone areas should be delineated.
- (4) The derivation of LHI and OLHI, done for Kisii and Nyamira districts should be extended to other districts in the Basin. This would provide more details and a spatially representative scenario of lightning in the study area.
- (5) The vulnerability of the pointed wooden loads on top of grass thatched houses to lightning hazard should be assessed in the area.

## REFERENCES

- AKELLO, R.J. (1984): Investigation of lightning in the Republic of Kenya, **National Conference for Science and Technology Report No. NCST/SEZ/440051**, Nairobi
- \_\_\_\_\_ (1990): Lightning problems in Tropical Zones-An overview  
**Proceedings of the first National Teaching of sciences in Kenya's System**, Commission for Higher Education, Nairobi.
- ALUSA, A.L. (1974): Weather Modification Activities in East Africa, **International Tropical Meteorological meeting**, Jan-Feb 1974, Met. Dept. Nairobi, pp 302-307
- \_\_\_\_\_ (1986): Some characteristics of Hailstorms in Kericho and Nandi Hills, **Research Report No. 2/8**, IMTR, Nairobi.
- \_\_\_\_\_ (1986a): Towards the Forecasting of Hailstones in Kericho area of Kenya, **Research Report No.5/86**, Kenya Met. Dept., Nairobi.
- \_\_\_\_\_ (1986b): Some synoptic pattern associated with Hail occurrence in Kericho-Nandi Hills Area, **IMTR Report No.3/186**, Kenya Met. Dept., Nairobi.
- ARAKAWA, H., (1969): **Climates of Northern and Eastern Asia**, Elsevier, New York.
- ARDIS, C. V., (1961): An Objective method for forecasting thunderstorms at Madison-Wisconsin, **Bulletin of American Meteorological Society Vol.42, No. 3**, pp. 166-174.
- BAKER, B. C., KARL, T. R. & DIAZ, F., (1995): **Quality Control of Long-term Climatological Data using Objective Data Analysis**, National Climate Data Centre, Asheville.
- BARRY, R.G., (1987): **Atmosphere, Weather and Climate**, Fifth Edition, Methueni, London.
- BATTAN, L.J., (1969): **Harvesting the Clouds**, Doubleday, New York.
- BREUER, G. (1976): **Weather Modification**, Cambridge University Press, London
- BROOK, C. E. P. (1925): The distribution of thunderstorms over the Globe, **Geophysical Memoirs, No. 24**, Met. Office, London.

- BYERS, H. R. & BRAHAM G., (1949): The Thunderstorm, **Journal of Weather Bureau**, Dept. of Commerce, New York.
- \_\_\_\_\_ and RODEBUSH, H.R., (1948): Causes thunderstorms of Florida Pensula, **Journal of Meteorology**, Vol. 5, No.6, pp. 275-280.
- CERRILO, M., (1943): Commission Impulsora Co-ordinating de la investigation: in SILBERG, F., (1965): **Problems of Atmospheric Space and Electricity**, Elsevier, Amsterdam.
- CHAGGAR, T.S., (1977): Geographical Distribution of Monthly and Annual Frequency of Thunderstorm Days over Africa, **Tech. Mem. No. 26**, Kenya Met. Dept., Nairobi.
- CHANGNON, S.A. (1973): Precipitation Modification by major urban areas, **Bulletin of American Met. Soc.**, 54, pp. 1220-1232
- CURRAN, E.B., HOLLE, R.L. and LOPEZ, R.E., (1995): **Lightning Casualty and Damage Climatology for U.S.A 1959-1990**, National Weather service, Texas.
- CURIC, M., (1996): **Numerical simulation of hail suppression efficiency**, Institute of Meteorological University, Belgrade, Yugoslavia.
- DANDEKAR, M. N., (1991): **Water Power Engineering**, Vikas, New Delhi.
- DAVIES, T. D., VINCENT, C. E. & BERESFORD, A. K. C. (1985): July-August Rainfall in West Central Kenya, **Journal of Climatology**, Vol. 5, pp. 17-33.
- DUCLOS, P.J. and SANDERSON, L.M. (1990): An Epidemiological Description of Lightning related deaths in U.S.A, **International Journal of Epidemiology** 19, pp. 673-679.
- DUNNE, T. and LEOPOLD, L.B., (1978): **Water in Environmental Planning**, Freeman and co., New York.
- GARDENER, A. W. & ROYLANCE, P. J., (1972): **New Essentials of First Aid**, Pan Books, London
- GICHOMO, N.S., (1992): **Relationship between Thunderstorm Frequency and some Weather Parameters**, IMTR, Nairobi.
- GITHUNGO, W.N., (1990): Forecasting Thunderstorms by Stability Index in Nairobi, **Tech. Conf. No. 2/1990**, KMD, Nairobi, pp. 20-21
- GRAHAM, S., (1963): **The Physics of Lightning**, English University Press, London

- GUMBEL, E. J., (1958): **Statistics of Extremes**, Columbia University, and New York.
- HENDERSON, T.J., (1968): The Kericho Nandi-Hills Hail Suppression Programme, 1967-1968, **Report to teaGrowers of Kenya**, Met. Dept., Nairobi
- HOLLE, R.L., LOPEZ, R.E., ORTIZ, R., PAXTON, C.H., DECKER, D.M. and SMITH, D.L., (1993): The Local Meteorological Environment of Lightning Casualties in Central Florida, **17Th Conference on Severe Local Storms**, American Met.Soc. Boston, 779-784
- INTERNATIONAL DECADE FOR NATURAL DISASTER RESEARCH (IDNDR), (1993): **Stop Disasters**, IDNDR No. 16/Nov-Dec. pp. 1019-1050
- JACKSON, I. J., (1989): **Climate, Water and Agriculture in the Tropics**, Longman, London.
- JOHNSTON, R. J., (1978): **Multivariate statistical Analysis in Geography**, Longman, London
- KARIMANZIRA, R.P., MURAH, T. and MARTIN, A., (1987): **Lightning Hazard in Zimbabwe during 1984-1986 Seasons**, Dept. of Met. Services, Harare, Zimbabwe.
- KATES, R. W. (1970): Natural Hazards in Human Ecological Perspective: Hypothesis and Models, **National Hazard Research Paper No. 14**, Toronto, Department of Geography, University of Toronto.
- KAPLAN, H. G. (1943): Mechanisms of thunderstorm downdrafts  
**Bul. Amer. Met. Soc.** 24, pp. 54-59
- KENWORTHY, M., (1964): Rainfall and Water Resources of East Africa in STEEL, R. W. & PROTERRA, R. M. (eds.) **Geography & Tropics**, London.
- KENYA METEOROLOGICAL DEPARTMENT (1995): **List of Weather stations in Kenya**, KMD, Nairobi.
- KOLOKOLOV, V.P. and PAVLOVA, G.P. (1974): Relations between some Thunderstorm Parameters, **Studies in Atmospheric Electricity**, Israel Programme for Scientific Translation, Jerusalem, pp 33-35
- LAMB, F.C., (1970): Topographical influence on Thunderstorm Activity near L.Victoria, **Weather, Vol., 25**, pp. 404

- MACMILLAN, R. S. & ORVILLE, R. E., (1993): **A classification of Texas thunderstorms according to Cloud to Ground Lightning characteristics**, A&M University, College Station.
- MARIJA, J. N. (1990): **Statistical Package for Social Sciences (SPSS)**, SPSS inc., Chicago.
- MARWITZ, J. D., (1972): The structure and motion of severe hailstorms, **Journal of Applied Meteorology**, pp. 166-179.
- MATARI, E. (1990): Relationship between Thunderstorm Frequency and Rainfall in Tanzania, **Tech. Conf. No 2/1990**, KMD. pp. 42-45.
- Mc Ever, G. D., and ORVILLE, R. E., (1995): **Summer Lightning over South East Texas and adjacent Waters**, Co-operative Institute for Applied Meteorology, Texas.
- MORGAN, W. T. W. (1973): **East Africa**, Longman, London.
- MUMAH, P. D. and ALUSA, A. L. (1981): **An Analysis of Annual and Monthly Mean Frequency of Number of days with Cumulo-nimbus Clouds in Western Kenya**, Kenya Met. Dept., Nairobi.
- MUREITHI, F. M., (1973): **Rainfall Intensity Duration Frequency Relations for some Selected Stations in Kenya**, Unpublished Msc. Thesis, University of Nairobi.
- NEUBAUER, H. N., (1937): **Physik**, 106, 474
- NIEUWOLT, T. S. (1978): **Tropical Climatology**, John Wiley & Sons, New York.
- OGALLO, L. J. A., (1980): **Time Series Analysis of Rainfall in East Africa**, (Unpub. Ph.D. Thesis), University of Nairobi.
- ORVILLE, R. E. (1983): Coastal Lightning Detection Network, **Bul. of American Met.Soc.** **64**, pp. 1029-1037.
- \_\_\_\_\_ (1987): Cloud-to-Ground Lightning Flash Characteristics from June 1984-May 1984, **Journal of Geophysics**, 92, pp. 5640-5644 .
- \_\_\_\_\_ (1993): **Cloud-to-Ground Lightning in the Blizzard of 1993**, 20, 13, American Met. Soc., Texas, pp. 1367-70.
- PATNAIK, J. K. & CHAGGAR, T. S., (1987): Some climatic features of thunderstorms of East Africa and Tropical Africa, **Tech. Conf. No. 1/87**, K. M. D, Nairobi, pp. 202-207

- RAMAN, P. K. and RAGHAVAN, K., (1961): Diurnal Variations of Thunderstorms in India during different seasons **Indian Journal of Meteorology and Geophysics** Vol. 12, No. 1-4, India Met. Dept., New Delhi, pp. 323-328.
- RAO, P.R.K. (1961): Thunderstorm Studies In India, **Journal of Meteorology and Geophysics**, Vol. 12, Indian Met. Dept. New Delhi, pp. 420-426.
- REPUBLIC OF KENYA, (1993): **Kisii District Development Plan**, Government Printer, Nairobi.
- RIGGS, H. C., (1985): **Developments in Water Science**, 22, Elsevier, New York.
- ROGERS, R.R., (1976): **A Short Course in Cloud Physics**, Pergamon, New York
- ROWSELL, E .C., (1986): **Floods and Drainage**, Allen and Unwin, London.
- SALAU, O. A., (1993): **Spatial and temporal variation of hailstorms in Nigeria**, Department of Geography, Port Harcourt University, Port Harcourt.
- SALOUM, M., (1996): **Estimation of rainfall based on climatological aspects of Thunderstorms over Niger**, Service Meteorologique National B. P. 218, Niamey Niger.
- SANSOM, H. W., (1961): The occurrence of Hailstones in British East Africa, **Nubila**, 4, pp. 34-51.
- \_\_\_\_\_ (1965): A Preliminary Report on hail suppression in Kenya, **Proceedings of the International Conference on Cloud Physics**, Tokyo and Sapporo, pp. 449-453
- \_\_\_\_\_ (1968): A Four-Year hail Suppression Experiment using Explosive Rockets, **Proceedings of The International Conference on Cloud Physics** Tokyo, pp. 768-772.
- \_\_\_\_\_ and GICHUIYA, S., (1969): Hailstorm in Kericho area, Memorandum **No.22**, E.A. Met. Dept., Nairobi.
- SCHONLAND, B. F.J. (1950): **The Flight of Thunderbolts**, Oxford University Press, London.
- SCHWERDTFEGER, W., (1976): **Climates of Central and South America**, Elsevier, New York,

- SEARCY, J. K. and HARDISON, C.H., (1960): **Double Mass Curves** Manual of Hydrology, Geological Survey Water Supply Paper 1541-B, Washington.
- SHAW, G. and WHEELER, D. (1985): **Statistical Techniques in Geographical Analysis**, John Wiley and Sons, New York..
- SILBERG, J., (1965): **Problems of Atmospheric and Space Electricity**, Elsevier, Amsterdam, 430.
- SILVER, F. and ORVILLE, E., (1993): Climatology of Cloud-to-Ground Lightning for the Contiguous U.S.A 1992-1993, **Ninth Conference on Applied Climatology 1995**, Dallas, Texas.
- SMITH, S.B., (1993): Comments on Lightning Ground Flash Density in U.S.A. 1989, **Monthly Weather Review**, 121, 72-73.
- SPAIN, E.S. (1970): **Investigation into Thunder Days in Zambia**, Met. Dept., Lusaka.
- SUTTON, G., (1963): **Physics of Lightning**, English University Press, London
- UMAN, M. A., (1971): **Understanding Lightning**, Westhouse Research Lab., Pittsburgh.
- VENKITESHWARAN, S. P. (1961): Vertical Currents in a Thunderstorm observed with F-Type Radiosonde **Indian Journal of Meteorology and Geophysics**, Vol.8, Indian Met. Dept., New Delhi, pp. 323-326.
- VIEMEISTER, P. E., (1972): **The Lightning Book**, Mit Press, Massachusetts.
- WAHLIN, L., (1986): **Atmospheric Electrostatics**, John Wiley and Sons, New York.
- WALLACE, J.M. (1975): Diurnal Variations in Precipitation and Thunderstorm Frequency Over U.S.A **Monthly Weather Review**, 109, pp. 406-419.
- WALLEN, C. C., (1970): **Climates of Northern and Western Europe**, Elsevier, New York.
- WATERS, G. & ODERO, J. (1990): **Geography of Kenya and the East African Region**, Macmillan, London.
- WESCOTT, N. E., (1995): Spatial Trends in Lightning Frequency in and around major Midwest cities, Illinois, 61820.
- WMO, (1956): **World Distribution of Thunder Days**, WMO, Geneva, No.21.

## APPENDIX 1

### INTERVIEW SCHEDULE

#### I: Introduction

I am a researcher from Kenyatta University. I am carrying out a study on Thunderstorm and Lightning problems. I request you to answer these questions which are chiefly for academic purpose. All the information that you give will be treated confidentially

#### II: Instructions

Fill or mark as appropriate.

Interview schedule No. -----

Name of interviewer -----

Name of respondent -----

#### III: LIGHTNING/THUNDERSTORM PROBLEMS IN THE DISTRICT.

1. Has a thunderstorm event ever occurred in your family/institution?

Yes( )

No ( )

2. If yes, state the following:

District -----

Division -----

Location -----

Sublocaion -----

Village -----

3. State the year, month and time of occurrence

(a) Year -----

(b) Month -----

(c) Time of the day (i) Morning ( )

(ii) Afternoon ( )                      (iii) Night ( )

4. State the number of casualties

(a) Who died -----

(b) Who were injured -----

5. Did you lose any property due to this calamity?

Yes ( ) No ( )

6. If yes, state the following:

(a) Number of livestock lost -----

(b) Number of houses/classrooms destroyed -----

(c) Number of trees burned/destroyed-----

(d) Any other property. Specify-----

APPENDIX 2.1 : Data for Kisumu Met. Station for the period 1980-95

YR/V 19'	Y	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	X <sub>6</sub>	X <sub>7</sub>	X <sub>8</sub>
80	168	17.6	63	5.0	2206.4	1114.1	96	23	1
81	196	20.0	78	4.4	2209.0	1105.7	102	24	1
82	223	18.2	69	4.5	2107.7	1451.3	107	23	1
83	254	18.1	67	4.8	2300.2	1145.0	91	24	2
84	233	17.6	64	4.8	2206.2	1231.1	128	23	0
85	235	18.0	66	5.2	2173.9	1359.0	96	23	2
86	231	18.1	67	5.3	2228.1	1225.1	96	23	1
87	238	18.4	67	4.9	2306.3	1301.7	85	27	0
88	197	18.4	67	5.5	2031.6	1636.5	98	23	1
89	205	18.2	68	5.2	2013.1	1347.7	145	23	0
90	238	18.4	67	5.0	2044.7	1075.7	102	24	0
91	201	18.3	60	4.9	1953.1	1267.5	94	23	0
92	209	16.8	67	5.0	2397.0	1257.1	118	24	0
93	94	18.1	54	4.8	2088.5	1353.5	83	24	1
94	228	16.1	67	4.9	2112.2	1503.1	109	24	1
95	244	17.9	59	4.9	1840.3	1470.0	81	24	0

APPENDIX 2.2 : Data for Kericho met. station for the period 1980-1995.

YR/V 19'	Y	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	X <sub>6</sub>	X <sub>7</sub>	X <sub>8</sub>
80	170	13.8	66	5.8	1663.3	1781.1	179	17	21
81	151	14.1	69	5.3	1276.8	2207.5	195	18	7
82	198	14.0	67	5.2	1597.5	2280.4	201	16	0
83	192	14.0	68	5.1	1541.3	2041.0	218	17	0
84	209	14.0	68	5.3	1533.1	2164.0	212	16	4
85	213	14.0	68	5.4	1487.6	2286.8	211	16	15
86	185	13.7	64	5.3	1505.6	1682.3	173	16	26
87	240	14.5	73	5.2	1626.0	2032.8	187	18	4
88	242	14.6	75	5.7	1449.3	2107.7	203	17	6
89	224	14.6	74	5.4	1361.9	2060.6	182	17	13
90	237	14.5	73	5.3	1510.1	1920.8	191	17	17
91	213	14.0	67	5.3	1478.2	2008.7	172	17	9
92	226	13.8	66	5.5	1524.9	1881.1	206	18	11
93	224	13.5	63	5.3	1576.7	1706.2	182	18	7
94	243	13.7	65	5.5	1618.3	1895.6	195	17	12
95	234	13.8	65	5.4	1480.7	1732.7	177	18	6

Notes:

V = Variable

Y = The dependent variable

X<sub>1</sub>..X<sub>8</sub> = Independent variables

Appendix 2.3 : Data for Kitale Met. Station for the period 1980-1995

YR/V 19'	Y	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	X <sub>6</sub>	X <sub>7</sub>	X <sub>8</sub>
80	94	14.0	71	5.5	1519.9	951.7	125	19	1
81	132	14.4	73	5.2	1511.1	1573.3	143	19	4
82	202	14.5	76	5.1	1366.3	1318.4	161	19	0
83	227	14.6	76	5.1	1470.2	1572.7	162	19	1
84	222	14.0	71	5.2	1595.9	1309.2	176	19	0
85	187	14.2	72	5.1	1371.2	1335.8	138	18	8
86	183	14.3	73	5.3	1373.8	881.0	130	19	0
87	180	14.2	72	5.3	1395.2	1176.2	120	19	2
88	221	14.6	75	5.8	1186.5	1265.5	151	19	4
89	219	14.6	76	5.7	1114.2	1300.6	150	18	1
90	221	14.6	75	5.5	1164.0	1332.4	141	19	0
91	220	13.4	66	5.3	1601.0	1364.6	152	19	0
92	208	13.4	66	5.4	1703.0	1370.6	144	19	0
93	189	13.2	64	5.4	1688.3	1224.6	128	19	0
94	205	13.5	66	4.9	1955.4	337.1	147	19	3
95	205	13.4	65	5.4	1708.3	1250.1	141	19	1

Appendix 2.4 : Data for Kisii Met. station for the period 1980-1995

YR/V 19'	Y	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	X <sub>6</sub>	X <sub>7</sub>	X <sub>8</sub>
80	236	13.6	67	5.5	1775.9	1827.1	188	20	9
82	209	13.7	68	5.5	1691.7	1975.6	179	20	4
83	215	13.6	68	5.4	1606.8	1809.1	188	20	0
84	221	13.7	68	5.4	1547.2	1976.1	197	21	0
85	222	13.6	67	5.4	1617.4	2001.3	205	20	2
86	224	13.4	66	5.5	1686.8	2026.0	204	20	18
87	229	13.5	67	5.1	1773.8	1889.4	188	20	24
88	246	13.3	66	5.1	1772.8	2491.7	189	21	8
89	241	13.7	69	5.8	1542.1	1585.0	201	21	6
89	208	13.7	68	5.4	1527.5	1822.0	174	20	6
90	243	13.6	68	5.4	1658.6	2146.0	190	20	9
91	204	13.0	63	5.2	1638.5	1603.3	188	20	5
92	249	12.9	62	5.5	1630.5	2252.0	206	20	9
93	198	12.8	61	5.3	1699.3	1675.0	163	21	3
94	232	13.0	63	5.5	1641.4	2241.6	188	21	10
95	223	13.0	63	5.3	1705.6	1860.8	149	20	9

Notes:

V = Variable

Y = The dependent variable

X1..X8 = Independent variables

Appendix 2.5 : Data for Eldoret Met. for the period 1980-1995

YR/V 19'	Y	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	X <sub>6</sub>	X <sub>7</sub>	X <sub>8</sub>
80	116	13.0	62	5.4	2039.0	945.4	85	17	7
81	129	13.8	69	5.3	1954.4	1007.7	109	17	4
82	109	13.6	67	4.8	1710.1	942.4	132	17	1
83	113	13.7	68	4.8	1838.5	1383.5	128	17	0
84	107	12.6	67	4.8	1840.0	1182.4	120	17	1
85	86	13.2	64	4.8	1832.5	980.3	105	17	1
86	89	13.3	65	4.8	1303.0	784.9	97	17	0
87	93	13.3	65	4.6	1601.6	1137.5	125	17	0
88	101	13.8	69	5.1	1734.9	999.7	126	17	3
89	101	13.8	69	4.9	1827.9	806.0	119	17	5
90	112	13.7	69	4.8	1794.2	1018.6	118	17	4
91	130	13.6	67	4.8	1946.8	980.4	119	17	5
92	125	12.6	59	5.1	1914.2	992.3	122	17	7
93	121	12.2	57	5.5	1631.6	688.1	96	17	4
94	118	12.2	56	5.2	1814.2	1203.2	123	17	0
95	89	12.4	57	5.2	1898.5	975.4	113	17	3

Appendix 2.6 : Data for Kakamega Met. station for the period 1980-1995

YR/V 19'	Y	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	X <sub>6</sub>	X <sub>7</sub>	X <sub>8</sub>
80	220	13.4	66	4.9	1857.1	1977.7	203	21	3
81	236	13.1	63	4.7	1820.2	2070.2	165	21	0
82	232	14.3	74	4.8	1882.1	2225.8	189	20	0
83	235	14.4	74	5.0	1819.6	1927.7	188	21	0
84	222	14.0	70	5.2	1800.4	1626.0	194	21	0
85	209	14.1	71	5.0	1787.6	2210.0	180	21	8
86	213	14.2	72	4.8	1669.6	1767.9	158	21	18
87	248	14.4	74	4.7	1856.5	2066.5	171	21	5
88	232	14.5	75	5.1	1795.1	2608.3	187	21	1
89	203	14.5	74	4.5	1750.6	1972.9	173	20	5
90	194	14.5	75	4.5	1783.1	2053.2	177	20	5
91	211	13.5	66	4.9	1966.0	2066.1	160	20	10
92	226	13.3	65	4.9	1862.3	1933.6	179	20	9
93	225	13.0	63	4.7	1860.5	1544.3	158	21	7
94	237	13.3	65	4.9	1856.1	1944.7	178	21	8
95	247	13.3	65	4.9	1657.0	2861.2	191	21	4

Notes:

V = Variable Y = The dependent variable

X<sub>1</sub>..X<sub>8</sub> = Independent variables

**APPENDIX 3.1 Results of Stepwise Regression for Kisumu station  
for the period 1980-1995**

Step	Variables included	F	R <sup>2</sup>	R
1	X <sub>1</sub> , X <sub>2</sub> , X <sub>3</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub> , X <sub>8</sub>	1.3	0.61	0.78
2	X <sub>1</sub> , X <sub>2</sub> , X <sub>3</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub>	1.7	0.60	0.77
3	X <sub>1</sub> , X <sub>2</sub> , X <sub>3</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>7</sub>	2.2	0.59	0.77
4	X <sub>1</sub> , X <sub>2</sub> , X <sub>3</sub> , X <sub>5</sub> , X <sub>7</sub>	2.4	0.55	0.74
5	X <sub>1</sub> , X <sub>2</sub> , X <sub>3</sub> , X <sub>7</sub>	2.3	0.45	0.67
6	X <sub>1</sub> , X <sub>2</sub> , X <sub>7</sub>	1.8	0.31	0.55
7	X <sub>1</sub> , X <sub>2</sub>	2.2	0.25	0.50
8	X <sub>1</sub>	3.1	0.18	0.43

**Appendix 3.2 Results of Stepwise Regression for Kericho station  
for the period 1980-1995**

Step	Variables Included	F	R <sup>2</sup>	R
1	X <sub>1</sub> , X <sub>2</sub> , X <sub>3</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub> , X <sub>8</sub>	0.70	0.44	0.67
2	X <sub>1</sub> , X <sub>2</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub> , X <sub>8</sub>	0.89	0.44	0.66
3	X <sub>1</sub> , X <sub>2</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub>	1.16	0.44	0.66
4	X <sub>1</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub>	1.27	0.39	0.62
5	X <sub>1</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>7</sub>	1.63	0.37	0.61
6	X <sub>1</sub> , X <sub>4</sub> , X <sub>7</sub>	2.25	0.36	0.60
7	X <sub>4</sub> , X <sub>7</sub>	1.99	0.24	0.48
8	X <sub>7</sub>	2.29	0.14	0.37

**Appendix 3.3 Results of Stepwise regression for Kitale for the period 1980-95**

Step	Variables included	F	R <sup>2</sup>	R
1	X <sub>1</sub> , X <sub>2</sub> , X <sub>3</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub> , X <sub>8</sub>	1.05	0.55	0.73
2	X <sub>1</sub> , X <sub>2</sub> , X <sub>3</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>8</sub>	1.37	0.55	0.74
3	X <sub>2</sub> , X <sub>3</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>8</sub>	1.79	0.54	0.74
4	X <sub>2</sub> , X <sub>3</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub>	2.33	0.54	0.73
5	X <sub>2</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub>	2.83	0.51	0.71
6	X <sub>2</sub> , X <sub>4</sub> , X <sub>5</sub>	3.67	0.48	0.69
7	X <sub>4</sub> , X <sub>5</sub>	3.64	0.36	0.60
8	X <sub>5</sub>	7.43	0.35	0.59

**Appendix 3.4 Results of stepwise regression for Kisii met. station for the period 1980-1995.**

Step	Variables Included	F	R <sup>2</sup>	R
1	X <sub>1</sub> , X <sub>2</sub> , X <sub>3</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub> , X <sub>8</sub>	2.47	0.74	0.86
2	X <sub>1</sub> , X <sub>2</sub> , X <sub>3</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub> , X <sub>8</sub>	3.20	0.74	0.86
3	X <sub>2</sub> , X <sub>3</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub> , X <sub>8</sub>	4.00	0.73	0.85
4	X <sub>3</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub> , X <sub>8</sub>	5.30	0.73	0.85
5	X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub> , X <sub>8</sub>	4.97	0.64	0.80
6	X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub>	4.79	0.54	0.74
7	X <sub>5</sub> , X <sub>6</sub>	5.71	0.47	0.68
8	X <sub>5</sub>	7.87	0.36	0.60

**Appendix 3.5 Results of stepwise regression for Kakamega met. station for the period 1980-1995**

Step	Variables Included	F	R <sup>2</sup>	R
1	X <sub>1</sub> , X <sub>2</sub> , X <sub>3</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub> , X <sub>8</sub>	5.62	0.87	0.93
2	X <sub>1</sub> , X <sub>2</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>7</sub> , X <sub>8</sub>	7.33	0.87	0.93
3	X <sub>1</sub> , X <sub>2</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>7</sub> , X <sub>8</sub>	9.58	0.86	0.93
4	X <sub>1</sub> , X <sub>2</sub> , X <sub>5</sub> , X <sub>7</sub> , X <sub>8</sub>	12.63	0.86	0.93
5	X <sub>1</sub> , X <sub>2</sub> , X <sub>7</sub> , X <sub>8</sub>	12.52	0.82	0.91

**Appendix 3.6 Results of stepwise regression for Eldoret Met Station for the period 1980-1995**

Step	Variables Included	F	R <sup>2</sup>	R
1	X <sub>1</sub> , X <sub>2</sub> , X <sub>3</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>8</sub>	1.15	0.5	0.71
2	X <sub>2</sub> , X <sub>3</sub> , X <sub>4</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>8</sub>	1.47	0.49	0.70
3	X <sub>2</sub> , X <sub>3</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>8</sub>	1.87	0.48	0.70
4	X <sub>3</sub> , X <sub>5</sub> , X <sub>6</sub> , X <sub>8</sub>	2.42	0.47	0.68
5	X <sub>3</sub> , X <sub>5</sub>	3.08	0.44	0.66
6	X <sub>5</sub>	3.94	0.38	0.61

**Appendix 4.1: Coefficients of variation of thunderstorm occurrences for stations in category II for the period 1980-1995**

Station No. on Fig. 10	Season one March-May		Season two July-Sept.		Season three Oct. - Dec.	
	Rain (mm)	CV	Rain (mm)	CV	Rain (mm)	CV
1	242	29	148	29	152	29
2	155	29	45	29	107	29
3	190	29	64	29	101	29
4	246	29	164	29	153	29
5	157	29	164	29	155	29
6	126	55	175	54	47	55
7	160	29	63	29	62	29
8	188	29	107	29	132	29
9	197	29	108	29	135	29
10	187	29	62	29	131	29
11	204	28	107	28	141	28
12	205	29	126	29	148	29
13	141	29	74	29	99	29
14	234	29	137	28	148	28
15	240	29	155	28	118	28
16	226	29	127	28	151	28
17	153	29	40	29	64	29
18	199	54	150	55	105	55
19	196	28	133	28	114	28
20	239	29	188	29	118	28
21	173	28	154	28	78	28
22	140	81	160	81	77	82
23	177	81	151	81	117	81
34	157	29	112	28	91	29
25	182	16	56	14	97	15
26	132	15	137	15	81	15
27	155	16	122	15	69	15
28	132	55	148	55	70	55
29	144	55	146	55	68	55
30	155	81	128	81	78	82
31	119	15	164	16	48	15
32	181	29	86	29	105	15

**Appendix 4.2: Mean yearly coefficients of variation of thunderstorm occurrence for the stations for the period 1980-1995**

Station	CV Season 1 March-May	CV Season 2 July-Sept.	CV Season 3 Oct.-Dec	Mean CV
Category I Stations				
1	56	28	72	52
2	27	23	45	32
3	22	23	21	22
4	23	22	35	27
5	16	19	35	23
6	21	22	22	22
Category II Stations				
1	29	29	29	29
2	29	29	29	29
3	29	29	29	29
4	29	29	29	29
5	29	29	29	29
6	55	54	55	29
7	29	29	29	29
8	29	29	29	29
9	29	29	29	29
10	29	29	29	29
11	28	28	28	28
12	29	29	29	29
13	29	29	29	29
14	29	28	28	28
15	29	28	28	28
16	29	28	28	28
17	29	29	29	29
18	54	55	55	55
19	28	28	28	28
20	29	29	28	29
21	28	28	28	28
22	81	81	82	81
23	81	81	81	81
24	29	28	29	29
25	16	14	15	15
26	15	15	15	15
27	16	15	15	15
28	55	55	55	55
29	55	55	55	55
30	81	81	82	81
31	15	16	15	15
32	29	29	15	24

**Appendix 5: Thunderstorm frequency as recorded in category I stations for the period 1980-1995**

Station/ Year	Kisumu	Kaka-mega	Kitale	Kisii	Eldoret	Kericho
1980	168	220	94	236	116	170
1981	196	236	132	209	129	151
1982	223	232	202	215	109	198
1983	254	235	227	221	113	192
1984	233	222	222	222	107	209
1985	235	209	187	224	86	213
1986	231	213	183	229	89	185
1987	238	248	180	246	93	240
1988	197	232	221	241	101	242
1989	205	203	219	208	101	224
1990	238	194	221	243	112	237
1991	201	211	220	204	130	213
1992	209	226	208	249	125	226
1993	94	225	189	198	121	224
1994	228	237	205	232	118	243
1995	244	247	205	223	89	234
Mean	212	224	195	225	109	213

## Appendix 6.1 Max. 24 Hour (HR) Rainfall for Kisumu for the period 1960-1995

YEAR	MAX. 24 (HR) RAINFALL	M	F	T
1960	55.6	30	81.1	1
1961	128.3	2	5.4	19
1962	71.4	23	62.2	2
1963	81.5	14	35.2	3
1964	76.7	21	56.8	2
1965	105.0	5	13.5	7
1966	90.5	9	24.3	4
1967	93.3	8	21.6	5
1968	77.3	19	51.4	2
1969	50.0	34	91.9	1
1970	66.8	25	67.6	1
1971	115.7	3	8.1	12
1972	61.0	28	75.7	1
1973	51.5	32	86.5	1
1974	50.6	33	89.2	1
1975	60.4	29	78.4	1
1976	128.6	1	2.7	37
1977	89.0	10	27.0	4
1978	77.9	18	48.6	2
1979	76.9	20	54.1	2
1980	39.2	35	94.6	1
1981	81.5	14	35.1	3
1982	113.6	4	10.8	9
1983	86.4	12	32.4	3
1984	38.4	36	97.3	1
1985	95.7	7	18.9	5
1986	54.7	31	83.8	1
1987	68.1	24	64.9	2
1988	78.5	16	43.2	2
1989	62.2	27	73.0	1
1990	87.3	11	29.7	3
1991	77.9	17	45.9	2
1992	62.9	26	70.3	1
1993	79.9	15	40.5	2
1994	100.2	6	16.2	6
1995	72.6	22	59.5	2

## Notes:

F = Frequency which represents the percentage of years during which rainfall equalled or exceeded the rainfall of order M  
M = The order of a given amount of rainfall T = Return period

## Appendix 6.2 Max 24 Hour (HR) Rainfall for Kitale for the period 1960-1995.

YEAR	MAX. 24 HR RAINFALL	M	F	T
1960	35.6	35	94.6	1
1961	70.1	7	18.9	5
1962	40.6	31	83.8	1
1963	73.3	5	13.5	7
1964	42.5	30	81.1	1
1965	33.5	36	97.3	1
1966	99.5	1	2.7	37
1967	78.0	2	5.4	19
1968	49.6	23	62.2	2
1969	57.6	13	35.1	3
1970	65.0	8	21.6	5
1971	54.2	21	56.8	2
1972	48.3	25	67.6	1
1973	37.6	33	89.2	1
1974	46.9	26	70.3	1
1975	48.7	24	64.9	2
1976	44.9	27	73.0	1
1977	72.1	6	16.2	6
1978	55.4	18	48.7	2
1979	56.0	17	46.0	2
1980	43.0	29	78.4	1
1981	75.9	4	10.8	9
1982	60.1	10	27.0	4
1983	57.3	15	40.5	2
1984	53.0	22	59.5	2
1985	55.4	18	48.7	2
1986	54.7	20	54.1	2
1987	58.2	12	32.4	3
1988	44.2	28	75.7	1
1989	64.4	9	24.3	4
1990	77.9	3	80.1	12
1991	56.6	16	43.2	2
1992	35.9	34	91.9	1
1993	57.3	14	37.8	3
1994	58.6	11	29.7	3
1995	39.2	32	86.5	1

Notes: See Appendix 6.1

## Appendix 6.3 Max 24 Hour (HR) Rainfall for Kericho for the period 1968-1995

YEAR	MAX. 24 HR RAINFALL	M	F	T
1968	59.5	14	48.3	2
1969	70.0	6	20.7	5
1970	57.8	17	58.6	2
1971	55.5	18	62.1	2
1972	69.7	7	24.1	4
1973	48.0	24	82.8	1
1974	45.7	26	89.7	1
1975	121.4	1	3.4	29
1976	59.2	16	55.2	2
1977	62.2	12	41.4	2
1978	64.9	9	31.0	3
1979	61.2	13	44.3	2
1980	53.8	19	65.5	2
1981	67.2	8	27.6	4
1982	46.1	25	86.2	1
1983	70.6	5	17.2	6
1984	39.9	28	96.6	1
1985	63.2	11	37.9	3
1986	75.1	4	13.8	7
1987	49.3	23	79.3	1
1988	76.0	3	10.3	10
1989	63.5	10	34.5	3
1990	51.8	21	72.4	1
1991	59.2	15	51.7	2
1992	43.0	27	93.1	1
1993	52.0	20	69.0	1
1994	77.1	7	6.9	15
1995	50.3	22	75.9	1

Notes: See Appendix 6.1

**Appendix 6.4 Max 24 Hour (HR) Rainfall for Eldoret for the period 1973-1995**

YEAR	MAX. 24 HR RAINFALL	M	F	T
1973	48.1	18	75.0	1
1974	48.2	16	66.7	2
1975	68.8	3	12.5	8
1976	72.6	1	4.0	24
1977	69.9	2	8.3	12
1978	56.1	10	41.7	2
1979	56.5	8	33.3	3
1980	48.1	18	75.0	1
1981	49.0	15	62.5	2
1982	40.8	24	95.8	1
1983	59.2	6	25.0	4
1984	62.8	4	16.7	6
1985	50.5	14	58.3	2
1986	42.5	22	9.2	1
1987	55.4	9	37.5	3
1988	43.5	23	95.8	1
1989	53.6	13	54.2	2
1990	49.2	17	70.8	2
1991	61.3	5	20.8	1
1992	53.9	12	50.0	5
1993	55.1	11	45.8	2
1994	58.9	7	29.2	3
1995	46.7	21	8.8	1

**Appendix 6.5 Max. 24 Hour (HR) Rainfall for Kisii for the period 1980-1995**

YEAR	MAX. 24 HR RAINFALL	M	F	T
1980	52.8	10	58.8	2
1981	59.7	7	41.2	2
1982	57.8	8	47.1	2
1983	45.5	15	88.2	1
1984	35.2	16	94.1	1
1985	47.6	13	76.5	1
1986	67.2	3	17.6	6
1987	49.9	11	64.7	2
1988	74.5	1	5.9	17
1989	56.0	9	52.9	2
1990	63.9	4	23.5	4
1991	61.4	6	35.3	3
1992	46.7	14	82.4	1
1993	47.7	12	70.6	1
1994	71.2	2	11.8	9
1995	62.2	5	29.4	3

Notes: See Appendix 6.1

**Appendix 6.6 Max. 24 Hour (HR) Rainfall for Kakamega for the period 1980-1995**

YEAR	MAX. 24 HR RAINFALL	M	F	T
1980	66.7	6	35.3	3
1981	59.2	11	64.7	2
1982	56.6	14	82.3	1
1983	60.6	10	58.8	2
1984	65.1	7	41.2	2
1985	80.1	3	17.6	6
1986	58.9	12	70.6	1
1987	53.2	16	94.1	1
1988	85.8	2	15.4	9
1989	64.3	8	47.1	2
1990	96.0	1	5.9	17
1991	68.5	5	29.4	3
1992	56.5	15	88.2	1
1993	58.7	13	76.5	1
1994	75.6	4	23.5	4
1995	60.9	9	52.9	2

Note: See Appendix 6.1

**Appendix 7.1 Population density and lightning casualties for the period 1970 to June 1996.**

Division	1970-1979		1980-1993		1994		1994-Jun. 1996	
	PD*	C*	PD*	C*	PD*	C*	PD*	C*
Nyamarambe	621	35	1190	79	1233	7	1323	10
Suneka	316	19	605	39	627	2	672	9
Nyamache	124	8	237	15	246	2	264	3
Nyacheki	316	13	381	22	394	3	423	5
Sameta	152	9	291	19	301	2	323	4
Kenyenya	264	15	506	34	524	2	563	7
Ogembo	456	26	837	52	904	9	971	11
Keumbu	783	45	1508	100	2015	66	2163	25
Masaba	627	36	1200	79	1244	7	1335	16
Mosocho	422	24	802	53	537	6	898	11
Marani	680	38	1301	86	1348	8	1447	17
Nyamira	429	25	738	40	761	3	809	9
Ekerenyo	295	15	501	27	523	3	558	6
Borabu	114	5	196	12	202	2	215	1
Rigoma	369	21	633	34	653	4	694	7
Manga	429	28	739	38	762	3	810	10
Mean	424	24	805	52	852	10	944	11

Notes:

PD\* = Population Density

C\*= Casualties

**Appendix 7.2 Ranking areas according to Lightning Severity using the LHI in Kisii and Nyamira Districts**

DISTRICT Division	C* 1970-Jun. 1996	Average C*	Average Pop. Density	LHI	Rank
<b>KISII</b>					
Nyamarambe	131	5.04	1092	0.462	12
Suneka	69	2.65	555	0.477	9
Nyamache	28	1.08	218	0.495	3
Nyachekei	43	1.65	354	0.466	11
Sameta	34	1.31	267	0.491	4
Kenyenya	58	2.23	464	0.481	7
Ogembo	98	3.77	792	0.476	10
Keumbu	236	9.08	1617	0.562	1
Masaba	138	5.31	1102	0.482	6
Mosocho	94	3.62	740	0.489	5
Marani	149	5.73	1194	0.480	8
<b>NYAMIRA</b>					
Nyamira	87	3.45	864	0.504	2
Ekerenyo	51	1.96	469	0.418	16
Borabu	20	0.78	182	0.429	15
Rigoma	66	2.54	587	0.433	14
Manga	79	3.04	679	0.448	13

Notes:

C\* = Casualties

**Appendix 7.3 Overall Lightning Casualties in Kisii and Nyamira Districts 1970-June 1996.**

**(i) Humans and Livestock**

Divisions/ Casualties	1970-1979		1980-1993		1994		1995- Jun. 1996	
	H	L	H	L	H	L	H	L
Nyamarambe	35	56	79	125	7	11	10	16
Suneka	19	28	39	64	2	7	9	11
Nyamache	8	10	15	26	2	3	3	5
Nyachekei	13	20	22	34	3	4	5	10
Sameta	9	13	19	31	2	3	4	6
Kenyenya	15	22	34	55	2	4	7	9
Ogembo	26	41	52	81	9	18	11	19
Keumbu	45	71	100	159	66	136	25	40
Masaba	36	56	79	125	7	12	16	5
Mosocho	24	85	53	82	6	9	11	19
Marani	38	62	86	138	8	13	17	20
Nyamira	25	38	40	64	3	6	9	13
Ekerenyo	15	26	27	42	3	5	6	10
Borabu	5	11	12	17	2	1	1	4
Rigoma	21	33	34	55	4	5	7	9
Manga	26	36	38	65	1	5	10	10

Notes: H = Humans      L = Livestock

## (ii) Trees and Houses

DISTRICT Divisions	1970-1979		1980-1993		1994		1995- Jun. 1996	
	T	HS	T	HS	T	HS	T	HS
<b>KISII</b>								
Nyamarambe	42	16	93	36	9	3	8	7
Suneka	2	8	47	19	5	2	9	3
Nyamache	8	3	19	7	2	1	3	2
Nyacheki	15	5	25	10	3	1	6	3
Sameta	11	2	22	10	3	2	4	3
Kenyenya	18	7	39	15	4	2	8	4
Ogembo	30	12	61	23	14	6	13	5
Keumbu	52	20	119	46	101	31	30	14
Masaba	42	16	94	36	8	4	19	6
Mosocho	28	11	62	24	7	3	12	5
Marani	45	17	102	39	9	4	20	7
<b>NYAMIRA</b>								
Nyamira	29	12	47	18	5	2	10	4
Ekerenyo	20	7	31	13	4	1	8	3
Borabu	8	4	12	5	2	1	2	1
Rigoma	24	11	40	16	4	2	9	4
Manga	28	12	48	16	6	3	8	3

Notes: T = Trees

HS = Houses

Appendix 7.4 Population density and aggregated casualties for the period 1970- June 1996  
per division

DISTRICT Divisions	1970-1979		1980-1993		1994		1995- Jun. 1996	
	PD*	AC*	PD*	AC*	PD*	AC*	PD*	AC*
<b>KISII</b>								
Nyamarambe	621	149	1190	333	1233	30	1323	41
Suneka	316	57	605	159	627	16	672	32
Nyamache	124	29	237	67	246	8	264	13
Nyacheki	216	53	381	91	394	11	423	24
Sameta	152	35	291	82	301	10	323	17
Kenyenya	264	62	506	143	524	12	563	28
Ogembo	456	109	837	217	904	47	971	48
Keumbu	783	188	1508	424	2015	334	2163	109
Masaba	627	150	1200	334	1244	31	1325	46
Mosocho	422	148	802	222	837	25	898	47
Marani	480	162	1301	365	1348	34	1447	70
<b>NYAMIRA</b>								
Nyamira	429	96	738	169	761	16	809	36
Ekerenyo	295	68	501	112	523	13	558	27
Borabu	114	28	196	46	202	6	215	8
Rigoma	369	89	633	145	653	15	694	29
Manga	429	102	739	167	762	15	810	31

Notes: PD\* = Population density AC\* = Aggregated casualties (H+L+T+H)  
H = Houses L = Livestock T=Trees H=Houses

## Appendix 7.5 Ranking divisions according to Lightning severity using OLHI

DISTRICT Divisions	AC* 1970- Jun. 1997	AAC*	APD*	OLHI	Rank
<b>KISII</b>					
Nyamarambe	553	21.0	1092	1.923	11
Suneka	264	10.0	555	1.802	15
Nyamache	117	4.5	218	2.064	4
Nyacheki	179	7.0	354	1.977	9
Sameta	144	5.5	267	2.060	5
Kenyenya	245	9.4	464	2.026	8
Ogembo	421	16.2	792	2.045	6
Keumbu	1055	40.6	1617	2.511	1
Masaba	561	21.6	1102	1.960	10
Mosocho	442	17.0	740	2.297	2
Marani	631	24.3	1194	2.035	7
<b>NYAMIRA</b>					
Nyamira	325	12.5	684	1.830	13
Ekerenyo	221	8.5	469	1.810	14
Borabu	88	3.4	182	1.870	12
Rigoma	278	10.7	487	2.200	3
Manga	315	12.1	679	1.780	16

Notes:

AC\* = Aggregated Casualties

AAC\* = Average Aggregated Casualties

APD\* = Average population density

KENYATTA UNIVERSITY LIBRARY