UNIVERSITY OF NAIROBI

INVESTIGATING CONTRIBUTION OF FOG TO AIR TRAFFIC DELAY AT JOMO KENYATTA INTERNATIONAL AIRPORT

BY

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A Project Report Submitted in Partial Fulfillment of the Requirements for Award of the Postgraduate Diploma in Aviation Meteorology of the University of Nairobi.

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DECLARATION

I declare that this project is my original work and has not been submitted elsewhere for examination, award of degree or publication. Where other people's work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.

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DEDICATION

I dedicate this work to the my family and colleagues

ACKNOWLEDGEMENT

I would like to first take this opportunity to thank the Almighty God, for giving me the strength and the good health to carry out this research work.

Special thanks to my family for their support and being understanding.

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ABSRACT

Information on fog occurrence or dissipation is very useful for aircraft maneuvers. This is usually very difficult to determine either due to the absence of instruments to sense or the complexity involved in its forecasting. Most of the studies that have been carried out are on dynamics of fog formation, the various instruments that can be used to forecast fog or the fog-layer top.

This study seeks to relate fog occurrence to improved profitability. The total economic losses associated with the impact of the presence of fog on various transportation sectors such as aviation, marine and land transportation can be comparable to those of tornadoes or, in some cases, winter storms and hurricanes. During winter fog can create icing on aircraft wings and at its worst crash landing. Dense sea fog cause collision of boats, SMOG affects human health negatively therefore information on fog occurrence/formation is very crucial as it can result to fatality or serious economic losses. The number of articles including the word ‘‘fog’’ in Journals of American Meteorological Society alone was found to be about 4700, indicating that there is substantial interest in this subject. In spite of this extensive body of work, our ability to accurately forecast/nowcast fog remains limited due to our incomplete understanding of the fog processes over various time and space scales(Gultepe et al,2007).

LIST OF ACRONYMS

KMS: Kenya Meteorological Services

JKIA: Jomo Kenyatta International Airport

RVR: The greatest distance that runway lights can be seen in the direction of landing, or take- off, along the runway as seen from the Centre-line at the point of touchdown at the average eyelevel of the pilot

FOG: According to the WMO fog is defined as "A concentrated suspension of very small water droplets causing horizontal ground level visibility below 1000 meters (WMO, 1992: International Meteorological Vocabulary WMO No.182). Furthermore, the WMO reports „fog" (with symbol FG) when the visibility is less than 1000 meters

MIST: (with symbol BR) when the visibility is from 1000 meters to 9000 meters.

DELAY: A period of time when somebody or something has to wait because of a problem that makes something slow or late.

AIR TRAFFIC DELAY: refers to an arrival or departure flight in excess of the estimated time on the flight plan.

WMO: World Meteorological Organization.

TAF: Terminal Aerodrome Forecast

VISIBILITY: The greatest horizontal distance at which prominent objects can be viewed with naked eye

CEILING: The lowest layer of clouds reported as being broken or overcast, or the vertical visibility into obscuration like fog

KCAA: Kenya Civil Aviation Authority

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CHAPTER ONE

INTRODUCTION

1.0 Background of the Study

The weather conditions have a significant implication on the safety and efficiency of air traffic during all phases of flights. It is very important to detect, track and predict hazardous weather elements and provide information to pilots for easier decision making before taking off and landing (Geiz *et al*., 2012). NOAA (2004) affirmed that weather affects flight operations.

Fog that reduces visibility to the point where aircraft have to divert to another airport is not uncommon at Jomo Kenyatta International Airport (JKIA). This means that not all fog events result in diversions. Aircraft can still land with a minimum runway visual range (RVR) of 200 m and 0 m decision height, or, put another way, 0 m cloud base or vertical visibility, provided the pilots are currently qualified and the aircraft is suitably equipped. RVR is the greatest distance that runway lights can be seen in the direction of landing, or take-off, along the runway as seen from the Centre-line at the point of touchdown at the average eyelevel of the pilot (UKMO, 1994). At ADIA it is electronically measured by equipment alongside the touchdown point at each end of the runway with another sensor at the centre point. This distance is usually further than the minimum non-directional distance that can be observed with the naked eye.

Diverting flights to another airport results in considerable cost to airlines. The extra expense includes fuel used and hotel accommodation for the passengers. Flight and cabin crew can become duty time expired and by law may not fly again until they have had a specific period of time off duty.

Furthermore, passengers still have to get to their desired destinations. When inclement weather is forecast, flight crews, for their own peace of mind, are inclined to load more fuel than the legal minimum required. This results in extra weight and therefore extra fuel consumption and lower profit for the flight. If cargo carried has to be decreased as a result, this will further decrease profit (De Villiers and Van Heerden, 2007). Aviation industry plays important role in providing for the world economies. One of the main challenges facing the aviation industry is to develop capacity to meet demand; delay is one of the performance indicators. Traffic delay is experienced whether in the departure or arrival of aircrafts. If an aircraft arrives late at its destination, the delayed inbound flight may not only be delayed on its next flight leg but it may also affect other flights within the airline network (Boye**,** 2015). Many flights to JKIA originate from places up to ten hours' flight time away. Added to this the flight dispatcher does the flight planning at least an hour before departure time. As will be seen later, fog is most common about 0300 to 0900 local time (LT) (2300 to 0500 UTC).

Poor weather conditions have been shown to dramatically increase the rate of aviation fatalities. For example, under instrument flight rules (IFR),fog is defined as a cloud ceiling below 1000 feet above ground level and/or a visibility less than 3miles,about two-thirds of all general aviation accidents are fatal- a rate much higher than the overall fatality rate for all general aviation incidents(NTSB 2014).Similarly, between 1983 and 2009 over the Gulf of Mexico, 16% of helicopter accidents and 40% of the resulting fatalities were attributable to poor weather conditions(Baker et al.2011).In addition to safety, accurate predictions of ceiling and visibility have far reaching economic and traffic flow management implications.

Probabilistic forecasts for both visibility conditions and ceilings surrounding airports allow for cost-based critical decision thresholds to be created for fuel loading in accordance with airlines' planning timelines (Keith and Leyton 2007).Increasing skill at longer lead times allows for more efficient and effective planning, with potential savings of tens of millions of dollars annually via fuel cost reductions for many major airlines (Keith and Leyton 2007). The ability to adjust flight plans based on predicted ceilings and visibilities that reduce arrival and departure rates could streamline air traffic movement across the globe.

Fog is a major nuisance to travelers. Whether driving or flying, fog results in travel delays and in some cases cancellations. Accidents and/or delays caused by fog can result to huge economic losses or disruption of societal activities. Forecasting fog can be difficult, but its proper prediction is extremely important. The proper prediction of fog can have people better prepared to avoid delays and being late for work. The best preparation is to leave early for work or school. Leaving early will help avoid the travel delays or flight cancellations/diversions (JEFF HABY)

Aeronautical meteorological services have become significant to the civil aviation industry. Knowledge of weather conditions is critical to the industry since the performance and fuel consumption of an aircraft is dependent on them. Observations are used to prepare forecasts which should inform or warn a pilot in advance on what to expect.

The value of a weather forecast to a user is much more than accuracy (Keith, 2003).There is need to assess how large disruptions of air transport, caused by bad weather, can be better accommodated by improved cooperation across transport systems. The user should then utilize this opinion in an optimal way, given the relative costs of occurrence of the event and protection from the event. Weather forecasts that are accurate ensure that flights remain safe and on schedule.

Weather phenomena can be hazardous to aviation thus a clear understanding of meteorological parameters is crucial for the safety and regular operation of aircrafts .An aircraft will be affected by weather parameters like air temperatures, cloud characteristics, wind characteristics, visibility and pressure. Weather phenomena likely to occur are cloud ceiling, gusty winds, fog, thunderstorms, heavy precipitation, hail, tropical cyclones, low clouds, icing, volcanic ash cloud displacement, mountain waves and turbulence. Knowledge of these phenomena does not only contribute to safety but also on tactical maneuvering of flights when there is poor weather.

Most fog forms as a result of cooling of the air in contact with the Earth’s surface. Considering that JKIA is located on a flat inland area the two primary types of fog are advection fog(due to warmer air streaming over a colder surface) and nocturnal radiation fog (ground heat loss due to outgoing radiation, clear skies with weak winds). Other fog types are upslope, frontal and steaming fog (UKMO, 1997). The mixing of two slightly unsaturated air parcels, initially at different temperatures, is also important (Roach, 1994).

Fog is rarely produced by a single process, but rather by any combination of the above, although one of them may be dominant. Nocturnal radiation fog is most likely when surface winds are calm, or light, with a clear sky (or limited to thin, high cloud) and dry air above a moist boundary layer of about 100 m and a weak pressure gradient. Anticyclones are usually associated with the correct ingredients for the formation of radiation fog and are rarely associated with a cyclonic circulation. Dry air aloft in subsiding conditions promotes surface radiation cooling while suppressing the surface wind. A clear sky allows much more heat to escape, thereby enhancing radiation cooling. A light wind enables the correct amount of turbulent mixing to take place so not all condensation is in the form of dew, but condensation also takes place in the air (Taylor, 1917; Ricks, 1981; UKMO, 1994, 1997).

It has been noted that initial fog formation occurs when the wind at 2 m above the ground temporarily drops to 1kn or less (Findlater, 1985). Due to dry desert conditions next to the warm airport, fog formation in the JKIA is usually a combination of advection and nocturnal radiation processes. Forecasts issued in the aviation sector are short-range (Range from 2 to 24 hours). They are relied upon in planning and thus must be accurate. According to Wolfson et al (2008) strategic planning takes place daily in the national airspace system (NAS) and 2 to 6 hour forecasts are utilized. These early plans remain unaltered in only the most predictable of convective weather scenarios. A precise and timely shared picture of the current weather as well as an accurate, reliable short term forecast is required. The forecast explain how meteorological parameters are expected to change at the aerodrome, over an area or along a route.

There are aircraft operational requirements for meteorological information which should be representative of a specified area or areas around the aerodrome and its immediate vicinity (Ito, 1967). The requirements have become more and more critical with increasing size of aerodromes and upgrading of flight operations. This implies that the effects of all environmental conditions must be evaluated way ahead before an aircraft leaves an aerodrome. During take-off or landing, the weather condition or safety of runway is critical.

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1.1 STATEMENT OF THE PROBLEM

In a recent past there have been massive loss of revenue at air transport with some airlines getting out of the market like Jetlink and others like FLY540 reducing the number of flights to cut down on cost. With Kenya Airways there have been public outcries due to the number of losses incurred in the last financial year leading to workers layoff. Combined with this are other risks; Technical and mechanical that bring about losses. Airport weather conditions can cause traffic delays/cancelations/diversions/accidents due to safety problems which create economic and time losses, and they even lead to accidents and breakups. In ensuring air traffic safety and minimum delay it is also important to understand how various weather variables vary in different months of the year. Despite the past studies none seem to clearly show how fog has affected air transport at JKIA and thus the reason for this study.

1.2 JUSTIFICATION

JKIA airport is a fast growing transport link between Kenya and the rest of the world. These aerodrome operations are affected by fog which either leads to delays, accidents, cancellations or diversions of her flights therefore the need to look into how this has affected aviation profitability.

1.3 OBJECTIVES

The main objective of this study is to establish how knowledge on fog occurrence can lead to improved profitability in air transport

Specific Objectives

i. To determine the temporal variations of fog
ii. To determine the relationship between fog and delays
iii. Evaluation of loss due fog delays

1.4 Limitation of the Study

The data on flight incidents caused by weather was available only for a short period of time from 2009 up to 2014 and the analysis was only carried out for Jomo Kenyatta International Airport.

1.5 Area of Study

Jomo Kenyatta International Airport is located in Nairobi County, Kenya. It is at an elevation of 840mb above sea level, and runway measuring 4,000m in length. The geographical coordinates of this airport are: 1.19000°S, 36.55000°E. It is the nation's busiest airport, with three terminals namely cargo, domestic and international. The cargo and international terminals operate for 24 hours daily while domestic terminal runs for 16 hours daily. The JKIA airport has two runways namely runway 24 AND Runway 06.On average it serves airlines both scheduled and non-scheduled daily.

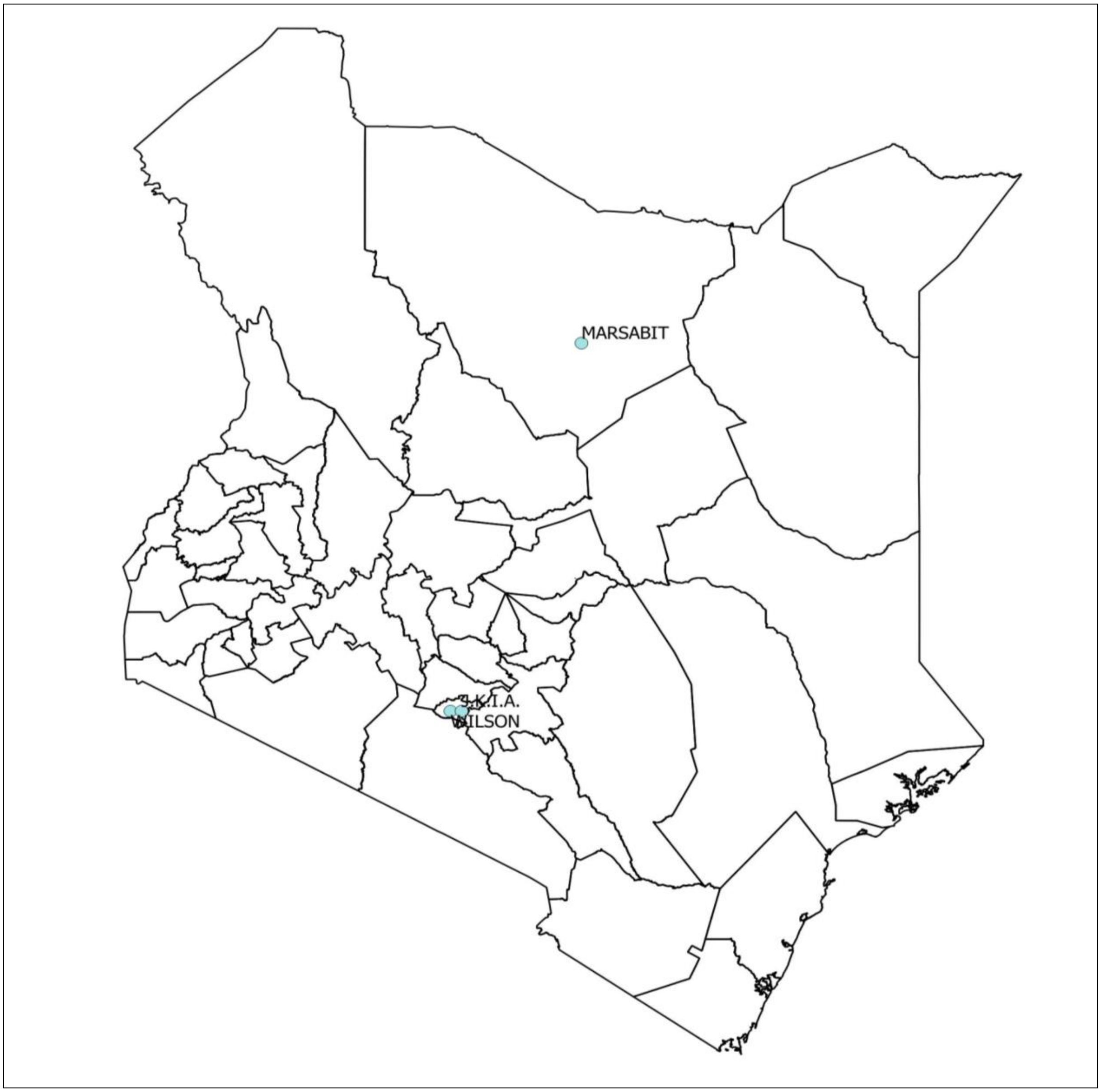

Figure 1 Map of Kenya showing the study area

1.5.1 Weather

a) Clouds cover: Clouds are always a major consideration for aviation operations. Low overcast clouds will limit vertical visibility and derail effectiveness of aerial illumination devices (Thomas *et al*, 2004).

b) Reduced visibility: Poor visibility over the runway affects the flights in landings and at take-offs (Michael *et at*, 2005). Visibility generally is near zero within a thunderstorm cloud. It also can become restricted in precipitation and dust between the cloud base and the ground.

1.5.1.1Types of Fog

There are two types of fog formation processes: cooling the surface by radiation of heat and by advection of moist air over an already cool surface. In both cases air above the surface will cool to its dewpoint (RH 100%) but the way it does that is different as are the circumstances surrounding it.

For fog to form the temperature/dewpoint (T/Td) spread must be small enough or a RH of 100% will never be reached and an abundance of condensation nuclei must to be present too. These are the main factors.

1.5.1.1.1Advection fog

This type forms when moist air moves over an already cold surface and cools from below so that the temperature reaches its dew point the air gets saturated and condensation will take place. There already is a wind moving this air so we have a mixing process taking place at the same time. The air must be stable; else the fog will develop in a stratus/Stratocumulus cloud. And as with radiation fog an inversion must exist so that the fog bank is of limited vertical extend.

They may look the same but there are a few differences between radiation and advection fog:

- Radiation fog forms over land only, where advection fog can form over sea too: cold and warm stream fog.
- Advection fog needs a surface that is already cool (water or land).
- Radiation fog disappears some time after sunrise but advection fog can persist for days, given the right conditions.
- For radiation fog a high pressure area or a col is needed in contrary to advection fog, these are favorable for lights winds.

Both have the same basic principles of formation but under quite different circumstances and events. The location where these types of fog develop can also be related to certain geographic areas, for example, advection fog formed over sea can travel inland and block airports close to the sea or situated in lower parts.

For advection fog to disperse one of the formation factors need to change: thus either less moist air, a change of wind direction or heating of the cool surface, but this might prove difficult if there is a cloud layer above.

1.5.1.1.2 Frontal fog

On the approach of a warm front, where the warm air will move overhead the heavier cold air, with light winds and any precipitation into the cold sector ahead of the warm front the cool air will cause saturation and fog / stratus development.

Upslope is the same as frontal fog, warm and moist air moving over a cool layer (be that an mountain or hill upslope or a cool pocket of air), it's just a different name for the same phenomena.

1.5.1.1.3 Cold stream

This type develops when a cold stream is surrounded by warm water and a light wind blows warm moist air over the cold stream, fog will develop but it will be restricted to the cold stream region.

1.5.1.1.4 Warm stream

With warm stream fog it is expected that the air above it is warm and moist. When a light wind blows this warm air over a colder surface or body of water, cooling from below will saturate the air and fog may develop.

These are some examples of advection type fog a pilot may see in their career.

CHAPTER TWO

2.0 LITERATURE REVIEW

Airport operation Fog affects very heavily airport operation (Allan et al., 2001). It is one of the weather events provoking more flight delays and cancellations (Robinson, 1989). Many airports are located in areas where fog can take place, in the flat bottoms of basins or near the coast. Typically 1% of the time fog may affect an airport. According to the USA Bureau of Transportation (2013), weather related delays are about one-half of the total delays. Statistics for individual airports report foggy conditions as one of the major disrupting events for their ordinary operation. Only few airports can operate in dense fog and not many aircraft are equipped to do so. In consequence, fog implies cancellation or severe delay of flights, also because the security delay imposed between takeoff and landing operations. Another issue, important at high latitudes in winter, is freezing fog that deposits ice on the wings and implies de-icing, an operation causing significant delay, especially in busy airports.

Generally, the weather impact is strongest during takeoff and landing. Typically, wind shear, fog, heavy snowfall and low visibility affect these stages of the flight while clear air turbulence is a characteristic enroute hazard. They generally reduce the safety margins and increase the occurrence of incidents and eventually accidents. Simultaneously, the capacity of airports is reduced by the need to increase the separation between aircraft, by the need for additional holdings, or by the closure of one or even all runways. As a result, the operational capacity of a region's entire airspace is reduced through delays, diversions and cancellations of flights – all of which have severe knock-on effects for the ordinary traveller (Sasse et al., 2003).

According to Wolfson and Clark (2006), the ability to provide accurate weather forecasts to air traffic managers and controllers plays a very important role in assuring that the nation's airliner flights will remain safe and on schedule. Weather phenomena that are likely to affect short-range forecasts have been widely studied. Indicated that fog producing reduced visibility over a distance of 1 km or less is deemed heavy enough to warrant notification to the aircrew. Weber et al (2000) states that common weather situation awareness allows terminal Approach, tower controllers and other traffic management personnel to jointly plan with confidence and safely manage more arrivals and departures with less delay. Knowledge of the location, severity and movement of hazardous weather allows dynamic adjustments to be made in routing aircraft to runways, approach and departure corridors, terminal arrival and departure transition areas (i.e. gate-posts) and other air routes.

Judy (2010) recognizes the importance of TAFs. She states that Airport terminal weather forecasts, produced in the United States by civilian and military forecasters are critical to decision making regarding aircraft movement within the National Airspace System. National Weather Service (NWS) forecasters routinely produce TAFs 4 times per day for projections up to 24 h from issuance time, with selected airports out to 30 h as of November 2008 (NWS 2008).

In addition, updates/amendments are made when weather conditions have changed or are expected to change and those changes are operationally significant to airports or aircraft. Special attention is given to forecasts that have operational significance during the critical TAF period, which is defined as 0–6 hours from the current valid time within the TAF. The TAFs contain some of the most challenging weather elements to forecast skillfully, even for the relatively short period of the TAF. Forecasts of only a few hours are often compared to persistence, that is, a forecast of exactly what the most recent observation is. At longer projections, largely because of advective and diurnal changes, some form of conditional climatology is used to deduce skill. The conditional climatology could be nothing more than the mean conditions stratified by time of day and month of year at the airport for which the forecasts are made, or can be more sophisticated with stratification by categories of existing conditions.

Wilks (2001) found out that forecast exhibiting consistent over forecasting (i.e., a low decision threshold) produce greater value for situations with low cost-loss (C-L) ratios. Wilks also found that the use of probabilistic methods achieved the greatest increase in value over climatology, with respect to perfect forecasts, for forecast probability densities typical of short-range forecasts.

Jomo Kenyatta International Airport (JKIA) in Kenya lies within the tropics; hence, humidification in the region is through radiative cooling. Fog and/or low level stratus is a common occurrence during both the northern summer (June-July-August) and southern summer (December-January-February) (Mwebesa, 1980). The study reported that at JKIA, fog occurs when air temperature is cooled to reach saturation below 16°C and in most cases occurs between 2200Z and 0700Z. Fog is of considerable socioeconomic importance, especially in terms of traffic safety, visibility and air quality (Elias et al., 2009; Gultepe et al. 2009; Niu et al., 2010; Tardif and Rasmussen, 2007). Muiruri (2011) observed that, among all the meteorological parameters causing disruption to aircraft operations at JKIA, fog is rated highly, hence it's proper and timely forecast can greatly reduce its impact on the airlines.

Mwebesa (1980), studied fog occurrence at JKIA for five years, from 1971 to 1975 to see what relative humidity, dry bulb temperature and wind direction and speed were when fog occurred. The occurrences were also examined to determine the frequencies by hour and per month. Fog seemed to have preferred temperatures (12-16 degree centigrade) and relative humidity (98-100%).Muiruri (2006) studied the influence of fog on delays at JKIA for the period 2000 to 2005. His results indicated that fog occurrence at JKIA is between 2100 to 0700 UTC and was rare between 0800 and 2100 UTC. Fog occurrence per month is highest in April, November and December, which coincides with the rainfall seasons. Results also revealed that low dew point depressions are favorable for fog formation.

Flight planning which can be climatological or pre-flight is dependent on weather conditions. This is supported by Mwebesa (1979) who states that an aircraft operates in an environment over which weather has a crucial effect. They determine the length of runway required for safe take-off and landing. Flight is planned using the forecast temperatures. Temperature affects the efficiency of the engine such that it decreases with increasing temperatures.

Flight cancellations/diversions/delays for the sake of safety, represents lost revenue for air transport operators. This factor should be carefully considered in the economic analysis of proposed equipment to be used on air routes in those parts of the world where fog may be expected.

In an EU study named Management of Weather Events in the Transport System (MOWE-IT) is assessed how large disruptions of air transport, caused by bad weather, can be better accommodated by improved cooperation across transport systems. Assessed substitution options are, retention of passengers and freight at their origin, rerouting within air travel, transfer of passengers to nearby airports, modal switch to high speed rail, and trucking (air cargo) for a selection of major hubs in Europe.(Conference Paper · Jan 2014)

The growth of aviation industry in Nigeria and the increased adoption of air transportation as one of the best means of transport have been obstructed by various weather hazards. There is a greater need for aviation weather forecasters to deliver quality forecasts. It is therefore necessary to identify the most dangerous and most common weather hazards which are detrimental to the aviation industry so as to enhance the expertise on addressing them. This paper examined various weather hazards which include thunderstorm, fog, dust haze and line squall that affect flight operation such as flight delays, diversion and cancellation. The study revealed that fog accounted for 13.2% of flight cancellation at the airport and line squall similarly accounted for 10.1% of delays, 8.4% of diversion and 20% of cancellation from 2000-2009 at the airport.(Conference Paper · Jan 2014)

For more than a century, nations have equipped themselves to provide weather, climate and hydrological information, forecasts and, more recently, remotely sensed data and early warnings to the public and private sectors, Glen Anderson et al June 2015

Almazan (1992) reported that 4 I percent of aircraft delays in 1990 were weather related, with 17 percent being avoidable (e.g., based on more accurate forecast information, unnecessary flight scheduling and routing changes could have saved time and fuel). These resulted in losses of approximately 1.7 billion dollars. These losses occur when critical thresholds of clouds and/or visibilities (including heavy fog) and various weather conditions are encountered or predicted to occur. For most aviation interests IFR and LIFR are the most significant conditions to consider because they lead to delays and cancellations (LIFR is ceilings less than 500 feet and/or visibilities less than 1 statute mile; DOC/NOAA 1994).
At the Mobile Regional Airport, Delta Airlines (the airport's largest carrier) indicated that two fIights were diverted or canceled in 1993 due to adverse weather conditions (Delta Airlines 1994). This resulted in estimated losses of up to twenty-five thousand dollars. As the occurrence of heavy fog is critical to runway operations (1/4 mile or less halts most air traffic according to Flight Service Station personnel), temporary closure of an airport may also cause significant losses to local carriers (e.g., overnight package services), impose limitations on helicopter use in medical emergencies, and delay transports to offshore oil platforms (Johnson and Graschel 1992).

Aircraft engines are designed to operate most efficiently and economically at high altitudes (Bristow, 2002). The greater the altitude, the lower the atmospheric air density, which in turn results in a lower thrust requirement to maintain the engine's optimal cruising 'revolutions per minute' (rpm). The optimal en route altitude has the best aerodynamic and engine performance qualities and result in the best fuel economy, if maintained for a large percentage of the flight (Bristow, 2002). Therefore the converse is also true: when an approaching aircraft is placed in a holding pattern by air traffic controllers, after descending to a lower altitude, and forced to delay its landing by several minutes, the operating cost of the flight increases. When inclement weather is forecast, flight crews are inclined to load more fuel than the legal minimum required.

This results in extra weight which results in extra fuel consumption and lower profit for the flight (De Villiers and Van Heerden, 2007). Burger (2006) determined that the estimated cost for diverting a narrow body aircraft in South Africa was R39, 000 per hr for a Boeing 737-800 carrying 160 passengers. In 2009 the direct aircraft operating costs for scheduled U.S. passenger airlines due to delays, were estimated at 6.1 billion US dollars. This estimate does not take the average cost to passengers into consideration arising from lost productivity, wages and goodwill (Airport Transport Association, 2010).

CTIA is the second largest airport in South Africa and the third largest in Africa (World Airports, 2010). In 2009 there were nearly 48 000 aircraft arriving at the airport and it hosts more than 15 international airlines (ACSA, 2010). According to the International Civil Aviation Organization (ICAO) takeoff and landing of aircraft under visual flight rules (VFR) is not allowed when the visibility is less than 5000m and the cloud base is 1500ft or less. These rules are adjusted according to the experience of the pilot, the type of aircraft and the instrumentation at an airport. For instance at CTIA, with a Category IIIB Instrument Landing System (ILS) (World airports, 2008) aircraft with suitable equipment and qualified pilots can land with a minimum runway visual range (RVR) between 75-200m and 0m decision height, or a cloud base and vertical visibility of 0m (Civil Aviation Authority, 2007).

However, aircraft diversions and delays at CTIA as a result of reduced visibility due to fog are not uncommon. During the autumn and winter months of 2009, 15 weather related aircraft diversions occurred of which all were as a result of fog (SAWS, 2009). Improved knowledge of the circumstances under which fog occurs or does not occur, will result in more accurate forecasts and fewer false alarms. This will result in improved flight planning by airlines, increased profit and improved preparedness by airport authorities (De Villiers and Van Heerden, 2007).

CHAPTER THREE

3.0 DATA AND METHODOLOGY

The data and the methods used in this study to achieve the objectives are presented in this chapter. This study predominantly relied on secondary data collected over a period of forty years from 2009 up to 2014.

3.1 DATA

The fog data was extracted from the aviation routine weather reports (METAR) database available in the Kenya Meteorological Department Data Archive and at the Jomo Kenyatta International Airport. The METAR data are reported hourly at the stations. The data used in this research is from 2009 to 2014.The flights delayed data was obtained from KCAA.The data sets included:

i) Fog occurrence: This covers the monthly fog occurrence for selected years

ii) Number of flight incidences: Daily number of flights affected by fog and were either delayed/on hold or diverted

3.2 DATA QUALITY CONTROL

Designed to ensure that meteorological data meets required standards and will involve looking for errors that involve data inhomogeneity or inconsistency. With the implementation of quality management in all meteorological aviation weather providers the quality of the data is guaranteed due to examination for completeness and consistency before transmission and storage for future use (ICAO Annex3).

3.2.1 HOMOGENEITY TEST

Single mass curve will be used to check for consistency of fog and flights affected. They will be plotted against time. A near straight line indicates good quality of data. The single mass curve method was used to test the quality of weather parameters data. It also entailed checking for inconsistencies (heterogeneous records) and also providing a correction factor to these data. The single mass curve analysis involved plotting cumulative data for a given location against time. A straight line obtained signified consistency in the data while a change in slope lasting for more than five continuous points indicated heterogeneity in data sets.

The single mass curve can also be used to interpolate or extrapolate the data beyond the existing length of records and similarly it can be used to estimate any of the missing data by generating the correction factor.

1- For the larger slope: multiplying every point with the ratio of $\frac{a_c}{a_1}$ brings down the slope.
2- For the smaller slope: the slope is raised by multiplying every point with the ratio of $\frac{a_c}{a_2}$

Where:

a_c = slope for homogeneous regression line.

a_1 = slope for non-homogeneous regression line below the homogeneous one.

a_2= slope for non-homogeneous regression line below the homogeneous one.

3.2.2 TIME SERIES ANALYSIS

Graphs of cost and fog data will be plotted against time**.** These graphical analysis will show how these parameters have evolved with time and thus used to infer the future.

3.2.3 CORRELATION ANALYSIS

In this study, the correlation analysis is used to get the relationship between fog and delays, cancellations, diversions. The coefficient of correlation "r" will be measured to show the strength of the relationship between the variables. This was done according to the Pearson's correlation coefficient given by the following relation

Equation 1 correlation coefficient

$$r_{xy} = \frac{\frac{1}{n}\sum_{i=1}^{n}[(x_i-\bar{x})(y_i-\bar{y})]}{\left[\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2 . \frac{1}{n}\sum_{i=1}^{n}(y_i-\bar{y})^2\right]^{\frac{1}{2}}} \text{.................. (1)}$$

Where, r_{xy} is the correlation between x and y

x_i , y_i are the individual data points for variable x and y respectively

$\bar{x}$,$\bar{y}$ are the mean of x and y respectively, and

n is the total number of observations

The test statistic for significance of computed correlation coefficient was done using the t test at 95% confidence level according to the formula;

Equation 2 Test statistic using t test

$$t_{(n-2)} = r\sqrt{\frac{(n-2)}{(1-r^2)}} \qquad \text{...................} \ (2)$$

Where:

n - 2 is the degrees of freedom

r is the correlation between y and the x

r^2 is the coefficient of determination and tells us how strong the fit is.

3.2.4 Computer Software

R Statistical Tool, Excel and Word were used

3.3 Methodology

The methods used in the study included time series analysis, correlation analysis and regression. A time series (trend and seasonality) analysis was used to assess the temporal variation of weather parameters at the airports. Techniques that were utilized include graphical analysis and coefficient of variation for the trend analysis. Many methods have been used to study trends in climatologically data. These methods may be grouped into several categories, some of which are: graphical, polynomial, and statistical methods e.g. Student t test. The study also used correlation and regression analysis to identify fog as a weather hazards responsible for flight incidents and identify the degree and nature of the relationship, which exists between the fog and flight operations at the airport.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.0 Results from Various Analyses

The results obtained from the data analysis are illustrated and discussed in this chapter.

4.1 Results from data quality control

4.1.1 Single mass curves analysis

The single mass curves for fog days showed the data sets for the chosen period were homogeneous. This was depicted by the straight-line graphs as showed in figure 4.1

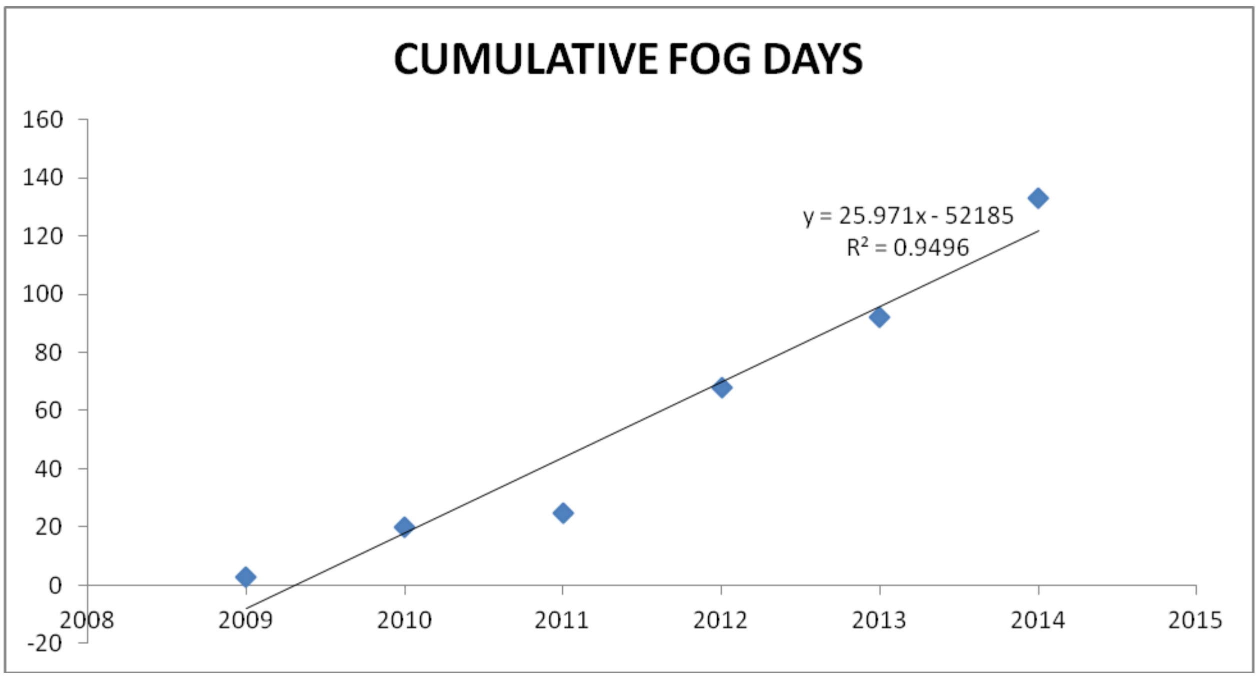

Figure 2 Single Mass curve for fog days

4.2 Analysis of the annual cycle of Weather elements

4.2.1 Result from analysis of fog

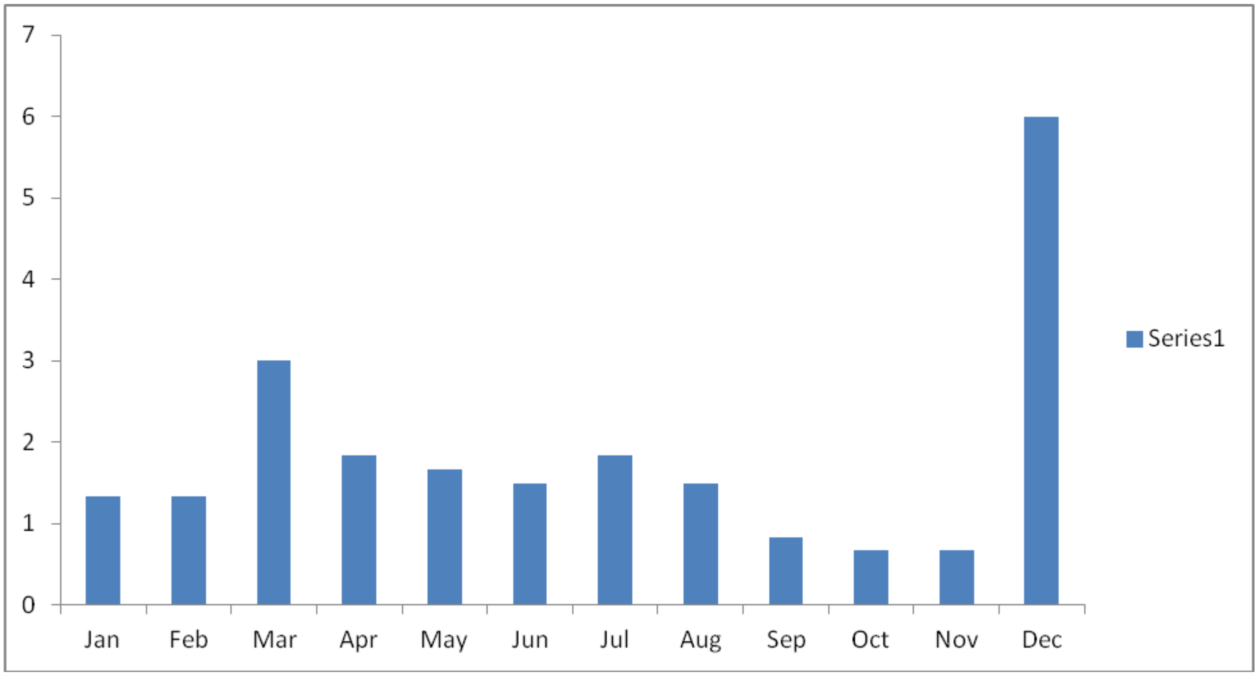

Figure 3 Mean monthly distribution of fog

Muiruri (2006) studied the influence of fog on delays at JKIA for the period 2000 to 2005. His results indicated that fog occurrence at JKIA is highest in April, November and December, which coincides with the rainfall seasons. Results also revealed that low dew point depressions are favorable for fog formation. This study shows a slight shift from April to March.

Fog occurs when the vapor pressure within the layer in contact within the ground surface is greater than the saturation water vapor pressure. Fog can also be formed in presence of high concentration of condensation nuclei under 100% of Relative Humidity. Radiation Fog is formed when there is drop in temperature up to dew point temperature, which is the effect of terrestrial radiation cooling, formed in the lower atmospheric layer in contact with the ground surface.

Radiation fog formation is favored by the following conditions:

- Sky clear
- High Humidity
- Light wind

- Anticyclones' pressure field
- Radiation process dominate

It has a nocturnal peak; the locale-scale processes are more important

This type of fog is the most commonly observed in JKIA in dry season. An inversion in temperature occurs through radiation cooling overnight consequently the atmospheric lower layer directly in contact with the ground is cooled up to its water vapor pressure is greater than its saturation water vapor pressure.

Advection fog occurs when moist air passes over a cool surface and is cooled. If the wind blows in the right direction, then sea fog can become transported over coastal land areas. Warmer moist air moves over a colder surface that has been cooled overnight through radiation cooling.

Conditions for the occurrence of advection fog

- Large water body
- Large scale transport of moist air

It is not necessarily a nocturnal phenomenon. The radiation process is secondary.

This moisture available enough for advection fog formation and even evaporation/warm fog.

4.2.2 Result from analysis of Mean monthly distribution of flights delayed

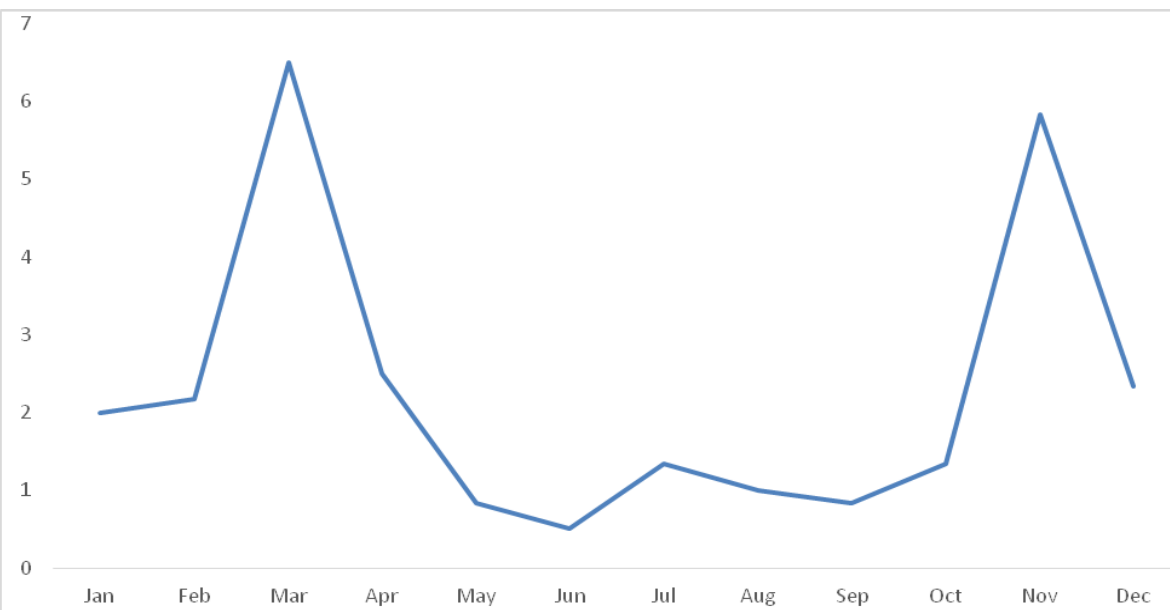

Figure 4 Mean monthly distribution of flights delayed

4.2.3 Results of analysis of annual variability of fog days

This shows an increasing trend meaning the conditions are becoming for favorable for fog formation

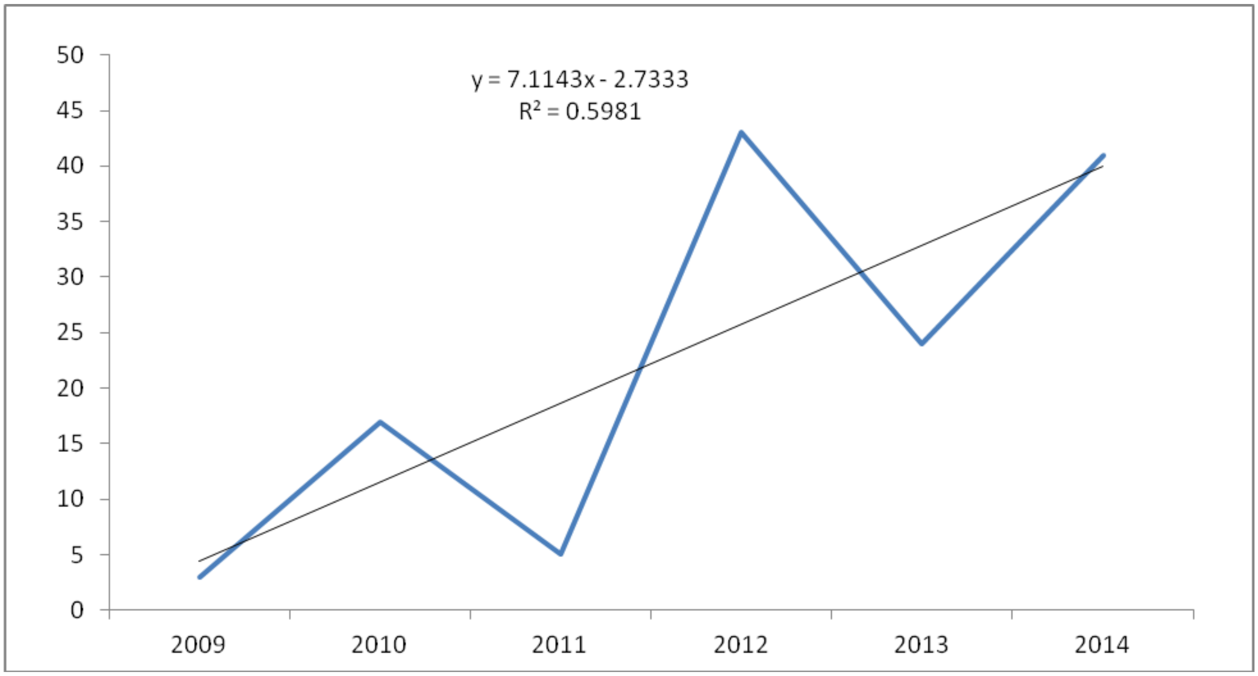

Figure 5 Annual variability of fog days

Annual Fog Distribution

According to Mwebesa, 1980 fog is seen to occur during Southern Summer (December-January-February)

Muiruri, 2011 observed that among all the meteorological parameter causing to aircraft operations at JKIA, fog is rated highly, hence its proper and timely forecast can greatly reduce its impact on the airlines. Fog is of considerable socioeconomic importance, especially in terms of traffic safety, visibility and air quality (Elias et al., 2009; Gultepe et al. 2009; Niu et al., 2010; Tardif and Rasmussen, 2007).

Oundo (2015) observed that accurate and timely forecasting of fog and low level stratus is of importance; it helps to minimize the impacts associated with their occurrence in the airports.

This behavior will be relied upon in the process of producing a forecast and for aircrew profitable planning purposes. The persistence of the observed values was blended with what could be deduced. The results show an inventory on fog events: Inter-annual patterns of delays/diversions/cancellations/accidents caused by fog.

4.2.4 Results of analysis of Monthly time series of fog days

Below are the monthly analysis fog days for a period of six years

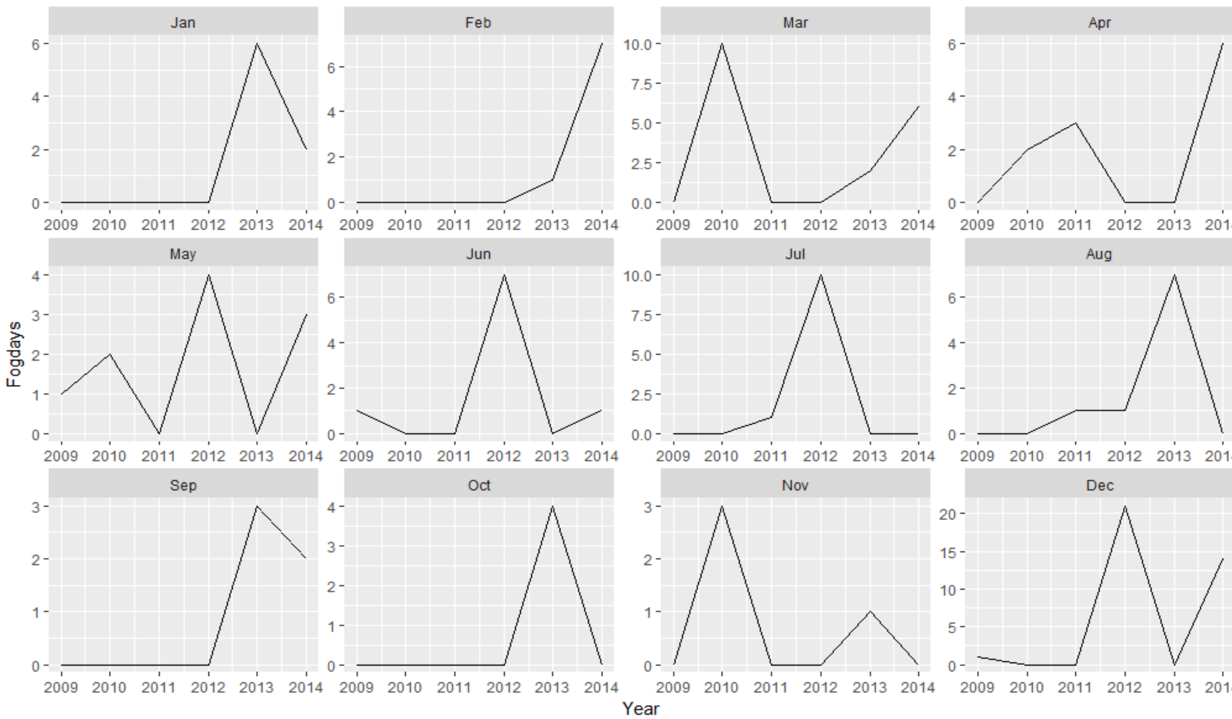

Figure 6 Monthly time series of fog days

4.2.5 Results of analysis of annual flights delayed

The figure below shows total number of flights delayed and it shows a decreasing trend

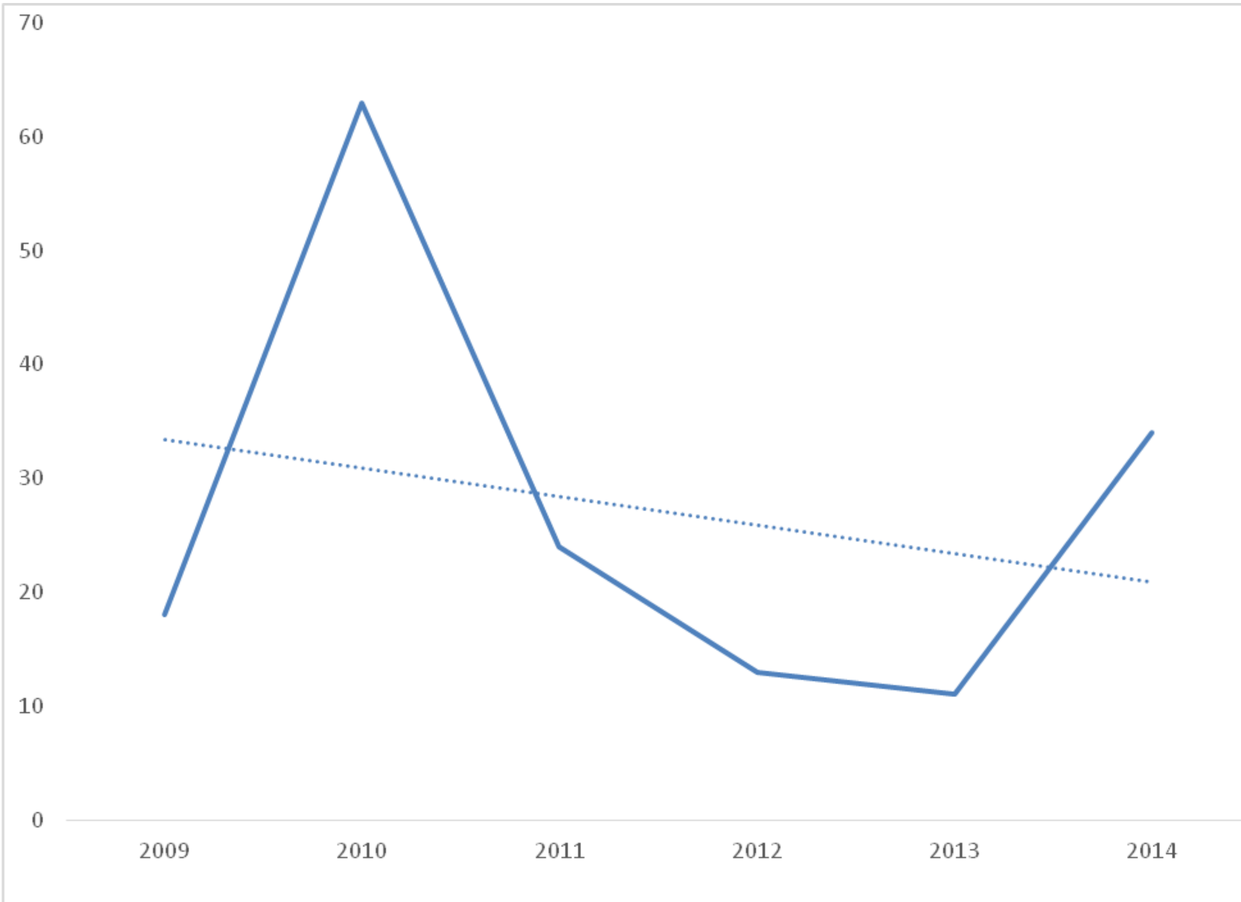

Figure 7 Time series of annual flights delayed

4.2.6 Results of analysis of monthly flights delays

Flight delays with June showing the least and November the highest.

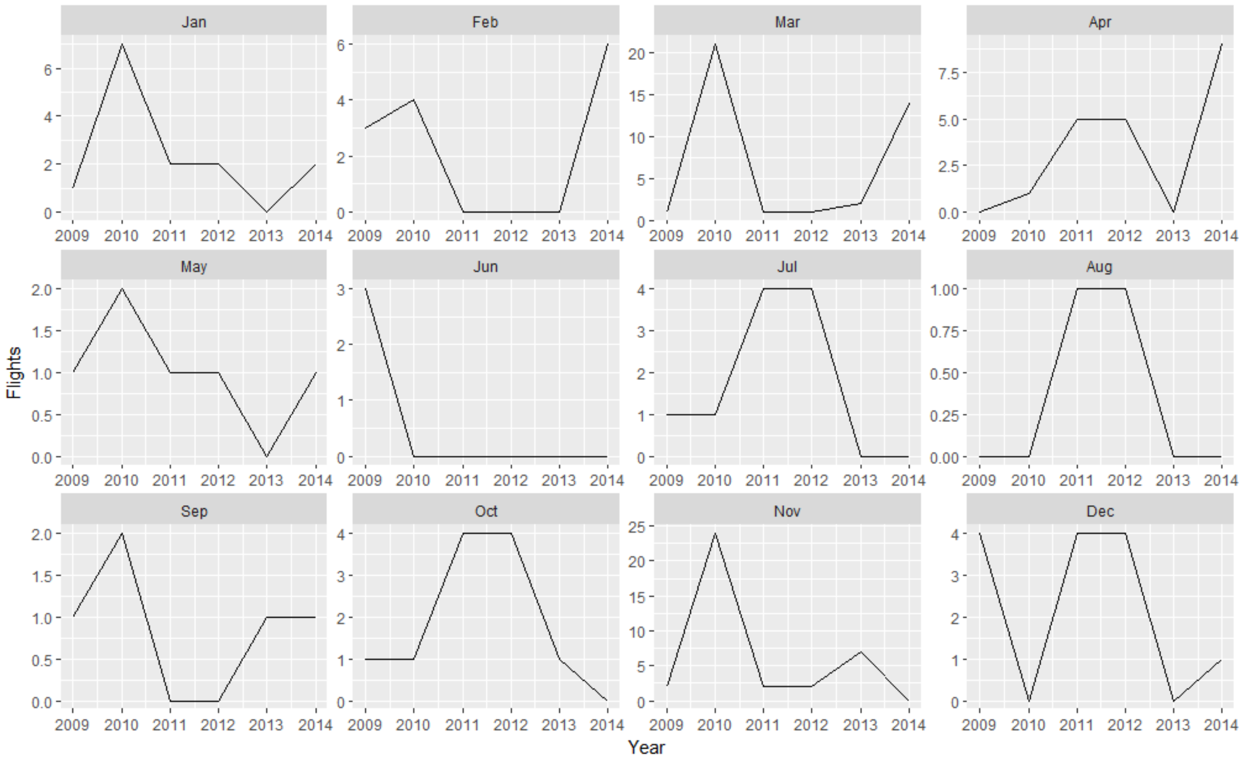

Figure 8 Monthly time series of flight delays

4.2.7 Results of analysis of annual flights delays

The figure below shows total number of flights delayed and it shows a decreasing trend but not very significant according to R=0.2315.

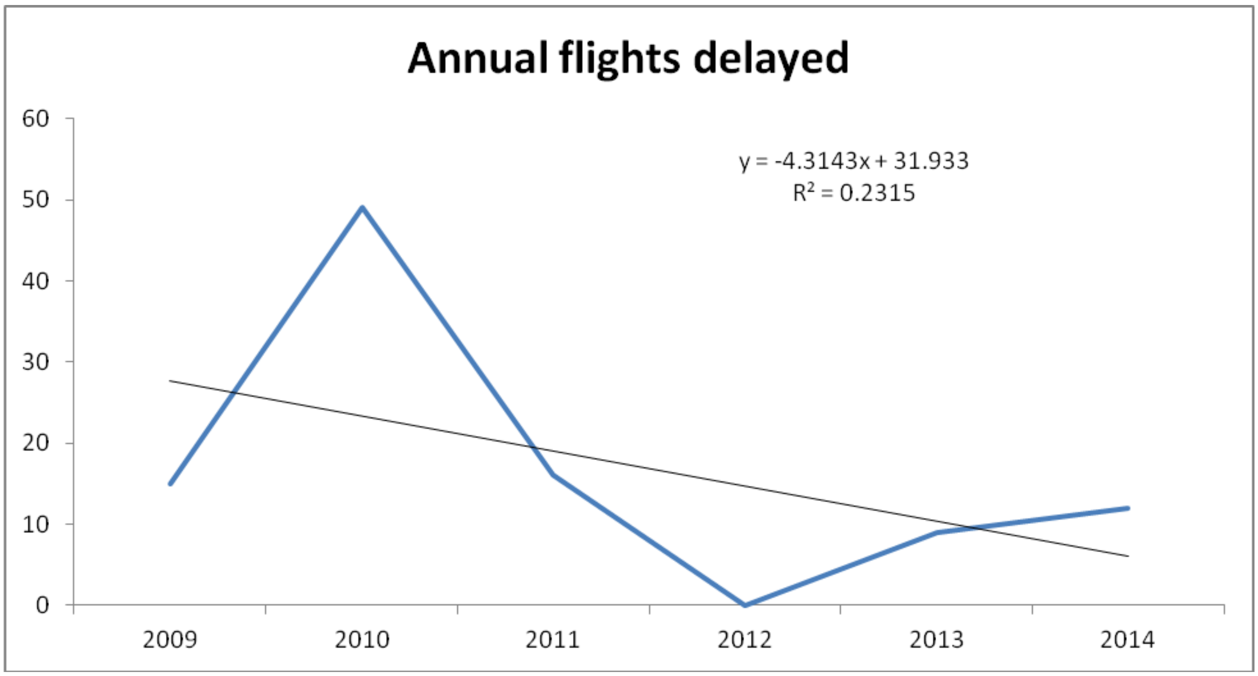

Figure 9 Annual flights delayed

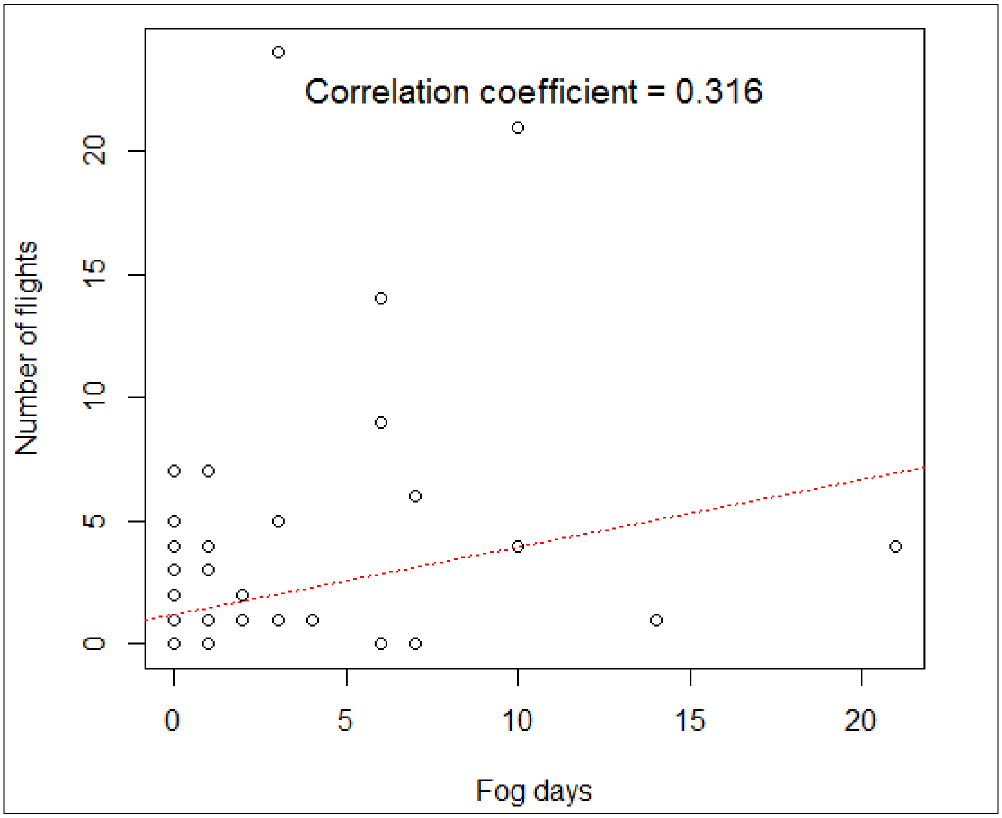

Figure 10 Scatterplot of the number of flight incidents versus the number of fog days

The correlation was not significant by 5% but at 15% as indicated from Students T-test.

Correlation coefficient = 0.316

This implies there is moderate positive correlation between the two variables and confirms the results reached by visual examination of the scatter plot.

4.3 Analysis of the evaluation of losses caused by fog

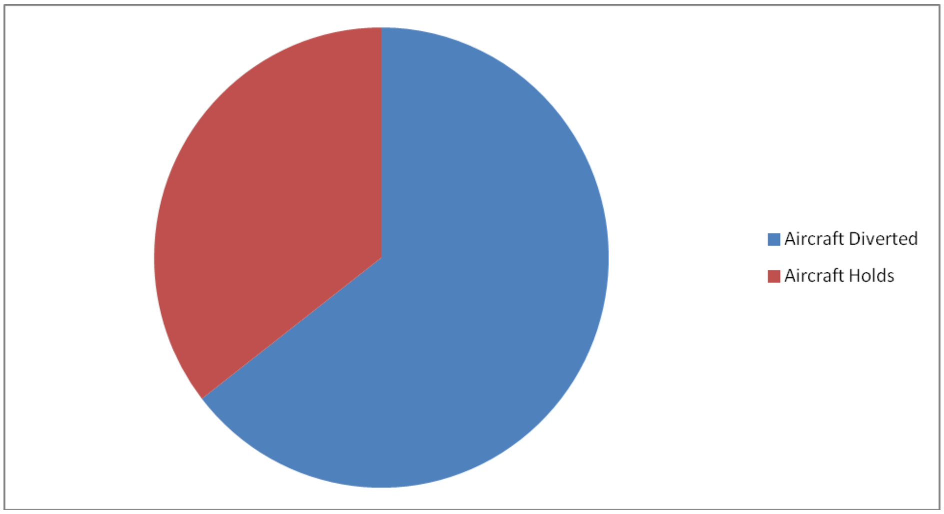

Figure 11 Flights delayed

Table 1 Percentage of flights delayed

Aircraft Diverted	Aircraft Holds	
64.50%	35.50%	

Table 1

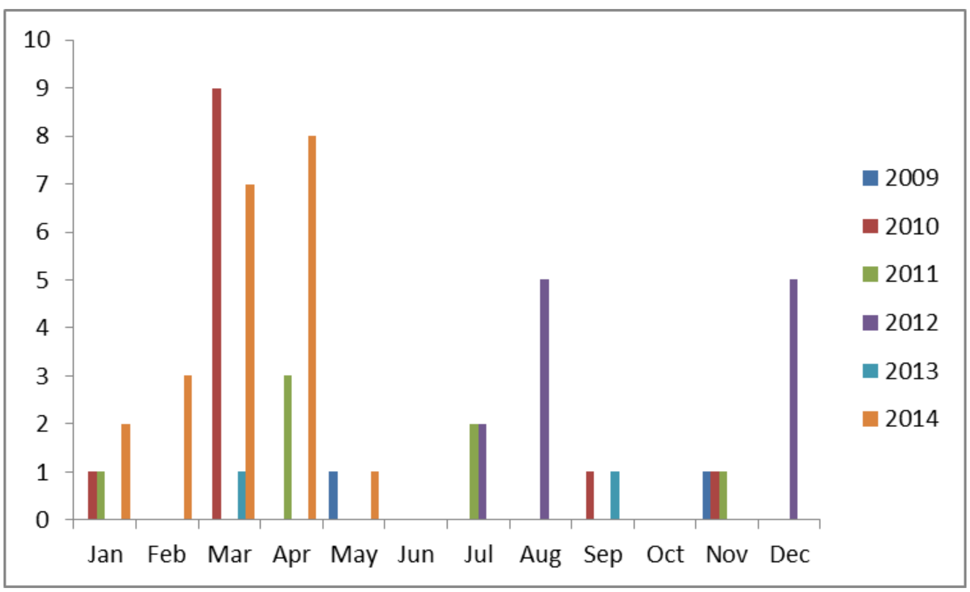

Figure 12 Monthly distribution of flights on hold

Fig 4:11 Monthly distribution of flights on hold

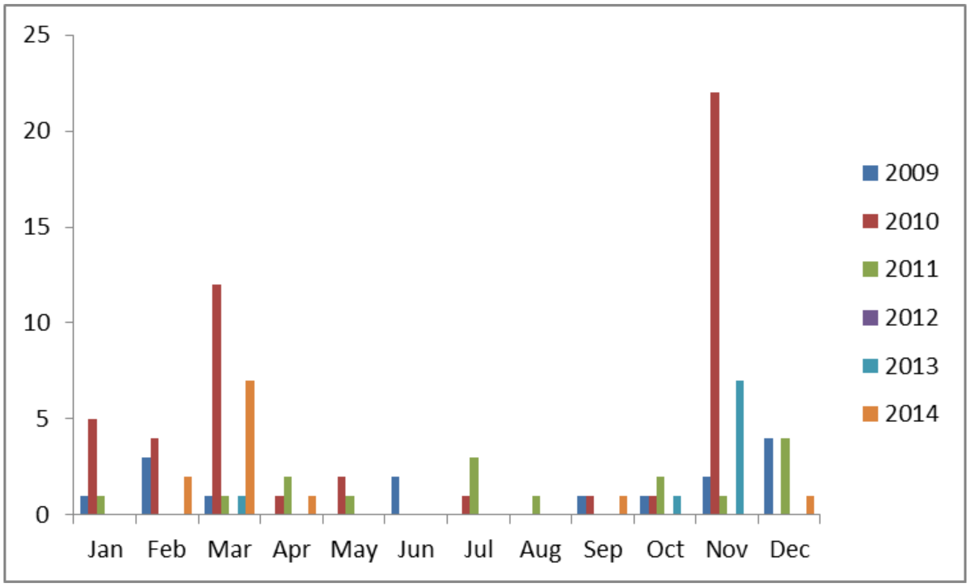

Fig 4:12 Monthly distribution of flights diverted

Total flights hours through diversion and on being hold was 9180hours and the amounted to $522,653.1 according to (Allan et al, 2001).

They fog occurrences was also be converted in monetary terms to evaluate the costs incurred by airlines due to fog. We find that improved decision making by the New York FAA users of ITWS provides an annual delay reduction of over 49,000 hours per year with a monetary value of over $150,000,000 per year.(Allan et al,2001).

CHAPTER 5

SUMMARY AND CONCLUSION

5.0 Introduction

This chapter provides a brief summary of the findings, conclusions and recommendations of the study.

5.1 Summary of the study

The main objective of the study was to determine the effects of fog on flight incidents. To achieve the main objective, the study was conducted in four parts mentioned below:

• Data quality control

• Analysis of fog

• Analysis of fog-flight delays

• Analysis of the relationship between fog and flight delays

Data used in this study was discussed in chapter 3; Simple mass curve was used to test its homogeneity.

Time series analysis of weather parameters was performed to determine weather variability (Periodic and non-periodic).

To determine the relationship between fog and flight delay, Pearson

Correlation method was used. The significance of correlations between the dependent variable and the independent variables and also between the two independent variables was determined by Pearson's method.

5.2 Summary of the results

- It is noted that fog occurred in the months of March and November with a higher frequency as compared to other months.
- This can be associated to the onset of MAM where in March the skies are still not fully covered with clouds, calm winds and enough moisture.
- Mainly this is radiation fog due to high temperatures and rains(100% moisture is key in fog formation) where cold nights are favorable condition for formation of this type of fog

- In November when the rains have already started so plenty of moisture and conditions favor evaporation fog
- More flights were cancelled in November this is also reflected in the number of flight that were diverted. This shows the severity/persistence/intensity of fog compared to other months. Advection fog is characterized by its long period of occurrence.
- Months like December show the highest number of fog days but this fog was not as intense as November thus less number of affected flights and most of them being on hold and land after fog clearance. The type of fog that clears after sunrise is radiation fog which is common in this month.
- May has the most consistent fog days while February has the least fog days

5.3 CONCLUSION

Apart from fog there are several factors that contribute to flight delays. It divided the causes of flight delays in several categories: air carrier, saturation of airport capacity, reactionary delays, passenger and cargo, VIP movement, extreme weather, National Aviation System (NAS), late-arriving aircraft, other unpredictable disruptions (eg. Strikes) and security. The category air carrier as explanation for delay is interesting, because many airlines argue that flight delays are outside their control. Flight carriers can influence some circumstances, like aircraft cleaning, while other categories of flight delays are not controllable by the flight carrier. Also, Borenstein and Rose (2007) identified some disruptions, like weather conditions, congestion externalities and inefficient infrastructure investments that cause flight delays.

Delays can be reduced by the use of Instruments Landing Systems and Elevation of airports to CATIII for ease of aircraft navigation.

Study of other delays caused by other factors other than fog eg, stormy weather in destination/enroute aerodromes (Gate delay, Taxi-out delay, airborne delay and Taxi-in delay)

How the fog affects customers' satisfaction.

Flight delays, cancellations/reschedules, diversions, closure due to bad weather could lead to loss of business opportunities and unbudgeted expenditure to passengers while those on transit could miss their connection flight.

5.4 Recommendations/ Suggestion for further work

- Fog contributes significantly to aircraft delay in JKIA; I recommend that further studies be carried out to determine losses caused using more data.
- A study to verify whether the number of delays was reduced due to aircraft being upgraded to CATIII and use of Instrument Landing.
- A study to verify whether the number of delays was reduced due to better forecasting skills and/or improved service delivery.
- All flight incidents data should be well archived at the Kenya Civil Aviation Authority, for future use.
- Prototype studies of other airports could be carried out at JKIA to determine how construction as well as planting trees could affect the fog formation in future
- Determine possible ways of fog mitigation: eg fog harvesting feasibility studies can be used to determine economic viability

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