**Assessing the operational capacity of airports in extreme weather scenarios in the niger delta region**

**Abstract**

The aviation sector operations and efficiency are weather-elements sensitive and adverse weather such as thunderstorm is one hazard known globally for its significant effect on the transportation sector particularly the aviation sub-sector. Thus, this study examined the impact of thunderstorm on flight operations in selected airports of the Niger Delta Region of Nigeria with the view to mitigate effects of thunderstorms on flight operations. The quasi experimental design in the context of the ex-post-facto research design was adopted while both primary and secondary data were used for the study. The primary data were obtained from copies of administered questionnaire, while the secondary data included aviation operations records sourced from the archive of the Nigerian Aerospace Management Agency (NAMA), climate data (particularly thunderstorm, rainfall, temperature, wind speed and wind direction, visibility, cloud types), sourced from the archive of the Nigerian Meteorological Agency (NIMET) for the period 1989-2019. Analyses were done using analysis of variance (ANOVA) and multiple linear regressions (MLR). Results showed that mean thunderstorm for the region was 116 day/year but varied spatially at P<0.05 (Fcal-16.586; sig-0.000) and Benin recorded the highest thunder-storm/days/year of 140. Perception of respondents indicated that the manifestation of thunderstorms at the airports accounted for flight cancellation (75%), flight diversion (75%) and flight delays (100%). Recorded information showed that thunderstorm accounted for 14880 flight delays, 1657 diversions and 13558 flights cancellation for the period of inquiry. The MLR revealed an r value 0.6. The coefficient of determination of the model was 36% implying that, 36 % of the aviation operations is explicated by thunderstorm, leaving the other 64% to other weather elements, and poor aviation decision making. Furthermore, the model was significant at P<0.05 (F-4.2; SigF-0.015), this means that flights operations significantly depend on thunderstorm in the area. Respondents (75%) opined that preparedness level to handle thunderstorm effects at the airports is low. Therefore, it is recommended that, modern equipment for weather measurement and forecasting at the airports be acquired while retraining the observers should be prioritized.

Keywords: Assessment, Flight operations, Extreme weather, Thunderstorm, Hazard

**Introduction**

The aviation industry and associated operations are affected by weather (Chaudhuri., 2008; Faraji, Doust Kamian, & Safavi, 2015). Aviation operations and efficiency are weather-elements sensitive and adverse weather can have negative impacts to the sector especially thunderstorm (Fahey & Lee, 2016; Gettelman & Chen, 2013; Ghosh, Kölker, & Terekhov, 2015; Terekhov, Ghosh & Gollnick, 2015). Thunderstorm is one of the extreme weather hazards that result in many human losses globally (Klein, Craun & Lee, 2010; Kulesa, 2003; Peck & Hedding, 2014; Reynolds, Clark, Wilson, & Cook, 2012). Apart from its effects on crops and facilities, there are documented evidences that thunderstorms also affect the transportation sector particularly the aviation sub sector (Adelekan, 1998; Abdel-Aty, Lee, Bai, Li, & Michalak, 2007; Ghavidel, 2012; Hurlbut & Cohen 2014). The civil aviation practice in Nigeria has come to the front burners in recent years because of the fear to fly as a result of the countless plane crashes that have drummed up public debate on the safety of lives and property (Adelekan, 1998; Ayigbe, 2007), and one of the main challenges to the aviation industry in Nigeria is weather hazard (Mohammad-Khorshid & Ghavidel, 2006; Salahi., 2012; Dalal, *et al.,* 2012). Similarly, according to (World Meteorological Organization, 2007; Ahrens., 2013; Alijani, 2012) weather elements that affects flight operations include, lightening, thunderstorms, poor visibility (as a result of precipitation) and wind shear whereas thunderstorm is pinpointed as the most devastating weather hazards that plague the aviation industry and particularly more hazardous when it occurs at lower altitude (McGee *et al.,* 1982; Ghavidel, 2011; Farajzadeh, 2012); Ghavidel, 2012 ; Hurlbut & Cohen, 2014; Faraji, Doust Kamian, & Safavi, 2015). Terrestrial rainfall and thunderstorm clouds have affected aircrafts flights operations in term of landing or taking off, flight cancellations and delays resulting in passenger’s agitations and economic losses as it is a known fact and most times reported that Nigeria airlines are stacking millions of dollar onto the loss column of their balance sheets as a result of bad weather. Accordingly, Bernad (2019), identified severe weather element such as thunderstorm as not only a threat to aircraft flights operations but equally causes devastating damages to airports facilities, equipment and aircraft on ground. It is clear that cumulonimbus clouds with the associated thunderstorms continue to pose a hazard to air craft operations (Das, Sarkar, Das, Rahman & Islam, 2015). Despite the fact that statistics indicates that weather solely contribute up to 30% of civil aviation accident worldwide (Mohammed, 2009). It is clear that the effect of weather on flight operations have not been properly accounted. Thus, most airports are yet to be properly prepared to handle the impacts of weather on their operations which has resulted in documented accidents in the recent past. It is against this backdrop; that this study seeks to assess the capacity of airports in the Niger Delta region of Nigeria to withstand the effect of heavy rainfall and thunderstorms on flight operations.

**MATERIALS AND METHODS**

The Niger Delta with an estimated area of about 70,000 km2 is one of the World's largest deltas. The Niger Delta Region is located on latitudes 40 10’ to 60 20’ N and longitudes 20 45’ to 80 35’ E (Figure 1). It is bounded to the south by the Atlantic Ocean, to the east by the Cameroun Mountain, to the west the region is bounded by western states of Nigeria such as Osun and Ogun, while to the north the region is bounded by Kogi, Anambra and Ebonyi states. The Niger Delta is located along the Atlantic coast which forms the southern boundary of Nigeria, and it is the entrance of Rivers Niger and Benue into the ocean through a web of rivers, creeks, and estuaries. It is the largest wetland in Africa and the third largest in the world, with about 2370 square kilometres of rivers, creeks and estuaries. Its vegetation is predominantly of the forest type with 8600 square kilometres of swamp forest and about 1900 square kilometres of mangrove forests (Alagoa, 2005). The region situated in the southern part of Nigeria, is bordered in the east by the Republic of Cameroun and in the south, by the Atlantic Ocean. Within Nigeria, the region is defined geographically and politically; the latter being for revenue sharing purposes. The geographic Niger Delta includes the littoral States of Rivers, Bayelsa, Delta Cross River and Akwa- Ibom and has an area of about 67,284 square kilometres with a combined population of 16,331,000 persons. The political Niger Delta includes these and in addition, Abia, Edo, Imo, and Ondo states, with a total area of 112,110 square kilometres of land as at 2006. The region represents about 12% of Nigeria’s total surface area (NDDC, 2006).

 Figure 1: Study area: Niger Delta Region of Nigeria

The purposive sampling technique was adopted to select 4 airports from the airports and airstrips in the region that must have operated for up to 31 years or more based on the number of years of establishment to meet the climate normal or sequence approved by the World Meteorological Organization. Consequently, the airports displayed in Table 1 were selected.

**Table 1: Selected Airports/airstrip in the Niger Delta region**

|  |  |  |  |
| --- | --- | --- | --- |
| States | Number of operational air ports & strips | Year of establishment | Remark  |
| Ondo | 1 | 1986 | Selected |
| Edo | 1 | 1956 | Selected |
| Rivers | 1 | 1987 | Selected  |
| Calabar | 1 | 1983 | Selected  |
| Total  | 4 |  |  |

Additionally, while climate data particularly thunderstorm, rainfall, temperature, wind speed, wind direction, visibility, cloud types for 31 years were sourced from the archives of the Nigerian Meteorological Agency (NIMET), aviation operations data relating to daily flights operations including (number of flights lifted, cancelled, diverted, delayed or crashed) at the different flight carriers in the sampled airports were sourced from Nigerian Aerospace Management Authority (NAMA). Since it is the only body saddled with the responsibility to archive such data because of its sensitivity. The data for this study were presented in tables and statistical diagrams while the analyses were done using analysis of variance and the multiple linear regressions (MLR) using the statistical package for social sciences (IBM/SPSS) version 22. The mathematical formula for ANOVA is given by the formula below (Akuezuilo & Agu, 2002):

ANOVA Equation

TES = $\sum\_{}^{}x^{2}-\frac{\left(\sum\_{}^{}x\right)^{2}}{N}$ ---- ---- ---- 1

ESS = $\frac{\left(\sum\_{}^{}x\_{1}\right)^{2}}{n\_{1}}+\frac{\left(\sum\_{}^{}x\_{2}\right)^{2}}{n\_{2}}+\frac{\left(\sum\_{}^{}x\_{3}\right)^{2}}{n\_{3}}+\frac{\left(\sum\_{}^{}x\_{4}\right)^{2}}{n\_{4}}-\frac{\left(\sum\_{}^{}x\right)^{2}}{N}….. 2$

WSS = TSS – BSS ---- ---- 3

Where: TSS = Total Sum of Squares

 BSS = Between Sample Sum of Squares

 WSS = Within Sample Sum of Squares

 n1 … n3 = Number of Samples means being compared

 N = Total items of all groups.

**Results:**

**Table 2: Annual thunderstorm values in the study area**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Years | Benin  | Port Harcourt | Calarbar  | Akure | Niger Delta Region |
| 1989 | 125 | 88 | 83 | 104 | 100 |
| 1990 | 148 | 91 | 96 | 105 | 110 |
| 1991 | 160 | 88 | 94 | 113 | 114 |
| 1992 | 142 | 95 | 91 | 111 | 110 |
| 1993 | 149 | 96 | 87 | 97 | 107 |
| 1994 | 154 | 103 | 97 | 91 | 111 |
| 1995 | 165 | 83 | 99 | 101 | 112 |
| 1996 | 154 | 90 | 94 | 100 | 110 |
| 1997 | 155 | 93 | 93 | 108 | 112 |
| 1998 | 130 | 85 | 92 | 98 | 101 |
| 1999 | 155 | 106 | 123 | 117 | 125 |
| 2000 | 134 | 95 | 132 | 92 | 113 |
| 2001 | 152 | 77 | 148 | 93 | 118 |
| 2002 | 157 | 86 | 145 | 106 | 124 |
| 2003 | 110 | 81 | 153 | 84 | 107 |
| 2004 | 143 | 92 | 148 | 105 | 122 |
| 2005 | 145 | 79 | 117 | 96 | 109 |
| 2006 | 114 | 97 | 129 | 110 | 113 |
| 2007 | 160 | 141 | 131 | 117 | 137 |
| 2008 | 144 | 138 | 106 | 106 | 124 |
| 2009 | 148 | 98 | 60 | 102 | 102 |
| 2010 | 137 | 102 | 57 | 111 | 102 |
| 2011 | 93 | 104 | 91 | 96 | 96 |
| 2012 | 160 | 105 | 78 | 114 | 114 |
| 2013 | 157 | 109 | 197 | 111 | 144 |
| 2014 | 130 | 142 | 179 | 122 | 143 |
| 2015 | 141 | 137 | 189 | 103 | 143 |
| 2016 | 135 | 121 | 197 | 102 | 139 |
| 2017 | 141 | 67 | 186 | 82 | 119 |
| 2018 | 117 | 143 | 164 | 102 | 132 |
| 2019 | 102 | 107 | 114 | 80 | 101 |
| Mean  | 140 | 101 | 122 | 103 | 116 |

In Table 2, the thunderstorm values over the past thirty years for the study area is presented and the mean thunderstorm days for the region were observed to be 116. On the other hand, mean thunderstorm days for Port Harcourt for the period under review were 101 representing the area with the lowest record of thunderstorm days in the study area. This is closely followed by Akure with mean thunderstorm days 103, while Benin and Calabar are the places with the highest thunderstorm days in the area with mean thunderstorm days of 140 and 122 respectively. Three factors are responsible for the formations and spatial variations in the thunderstorm days across the region and are; moisture-to form clouds and rain, unstable air-relatively warm air that can rise rapidly, lift-fronts, sea breezes and mountains are capable of lifting air to help form thunderstorms. These enumerated factors are present in the region of study. Also worthy of note in Table 2 is the fact that there are also annual variations in the thunderstorm days in the study area. In 1989 the Benin (125) recorded the highest number of thunderstorm days in the region compared to the other areas an average of which implies that the area had 100 thunderstorm days in the area. This is rampant and implies far reaching effects for the aviation industry. The following five years after the first year (1989), Benin continue to experience increasing number of thunderstorm days with the highest within this period occurring in 1991 (160 TSD/year). However, the other areas continued to experience increase in the number of thunder storm days but in 1992 thunderstorm days in Akure dwindled and 91 thunderstorm days were recorded. In 1995 the mean thunderstorm days for the region was 112 but Benin yet recorded the highest number of thunderstorm days in the region with 165 days per year. Amid the year 1995 and 2005 the thunderstorm days undulated in the region and in all the locations, although Benin continued to record the higher number of thunderstorm days. From the year 2005 and 2019 thunderstorm data revealed that the places in the study region continued to experience 1 thunder strike in every 3 days in Benin and Calabar. In Akure and Port Harcourt it was 1 thunder strike in every four days. The reasons for the high thunderstorm days in the study area can be explained by several factors. First, the area is a tropical environment which is characterized by the preconditions for thunderstorm to take place, i.e. moisture-to form clouds and rain, unstable air-relatively warm air that can rise rapidly, lift-fronts, sea breezes and mountains are capable of lifting air to help form thunderstorms (Tyagi, Krishna, Satyanarayana, 2011; Ghavidel, 2012; Yamane, Hayashi, Kiguchi, Akter & Dewan, 2012; Hurlbut & Cohen 2014).

**Table 3: Flights cancelled, delayed, diverted or crashed as a result of thunderstorm over airports in the Niger Delta Region of Nigeria during the past 31years**

|  |
| --- |
| **Total for Airports Sampled in the Niger Delta Region** |
| **Decades** | **Delays**  | **Diverted**  | **Cancelled**  | **Crashed**  |
| 1989-1998 | 2457 | 421 | 2104 | 0 |
| 1999-2008 | 4789 | 673 | 4213 | 0 |
| 2009-2019 | 7634 | 563 | 7241 | 0 |
| Average  | 4960 | 552 | 4519 | 0 |
| Total | 14880 | 1657 | 13558 | 0 |
|  **Calabar** |
| **Decades** | **Delays**  | **Diverted**  | **Cancelled**  | **Crashed**  |
| 1989-1998 | 590 | 81 | 503 | 0 |
| 1999-2008 | 976 | 139 | 1095 | 0 |
| 2009-2019 | 1453 | 139 | 1453 | 0 |
| Average  | 1006 | 118 | 1017 | 0 |
| Total | 3019 | 359 | 3051 | 0 |
| **Port Harcourt** |
| **Decades** | **Delays**  | **Diverted**  | **Cancelled**  | **Crashed**  |
| 1989-1998 | 891 | 173 | 743 | 0 |
| 1999-2008 | 1787 | 264 | 1502 | 0 |
| 2009-2019 | 2893 | 189 | 2752 | 0 |
| Average  | 1857 | 209 | 1667 | 0 |
| Total | 5571 | 626 | 4997 | 0 |
|  **Benin** |
| **Decades** | **Delays**  | **Diverted**  | **Cancelled**  | **Crashed**  |
| 1989-1998 | 762 | 98 | 613 | 0 |
| 1999-2008 | 1261 | 168 | 1211 | 0 |
| 2009-2019 | 2254 | 146 | 2104 | 0 |
| Average  | 1426 | 137 | 1309 | 0 |
| Total | 4277 | 412 | 3928 | 0 |
|  **Akure** |
| **Decades** | **Delays**  | **Diverted**  | **Cancelled**  | **Crashed**  |
| 1989-1998 | 214 | 69 | 245 | 0 |
| 1999-2008 | 763 | 103 | 405 | 0 |
| 2009-2019 | 1034 | 89 | 932 | 0 |
| Average  | 1426 | 137 | 1309 | 0 |
| Total | 3437 | 398 | 2891 | 0 |

**Source: Aviation Safety Network (2020)**

Table 3 shows the data for flights cancelled, delayed, diverted or crashed as a result of thunderstorm over airports in the Niger Delta Region of Nigeria during the past 31 years. In the table, the total number of flights that have been delayed as a result of thunderstorm accounted for 14880 trips, while flights that got diverted accounted for 1657 trips. The number of the flights cancelled for the period accounted for 13558 flights and the number of planes crashed as a result of thunderstorm over the past thirty one years accounted for zero crashes. The effects of thunderstorm on aviation operations are lucid in the region, although the increasing number may not necessarily by as a result of climate change influenced thunderstorm alone but also because the number of people flying has increased and the fleet has also increased as well. Nevertheless, there has also been spatial variation in the effects of thunderstorm on aviation operations across the region looking at the data presented in Table 3, and several reasons account for this. First is the air travel demand per cities which is traceable to the function the city plays too. In this case there is a difference between Akure and Benin which plays different functions economically, in the country and hence would have variation in the demand for flights and consequently on the number of flights affected by thunderstorm as well. There are also environmental factors that account for the variation in the thunderstorm effects on aviation in the region. For example, the build-up of thunderstorm in Akure would be different from that of Port Harcourt since the elevations, presence of water bodies and the environmental heating levels are different. In the first decade the number of delays recorded as a result of thunderstorms in Calabar was 590 flights, while Akure encountered only 214 delays in flights as a result of thunderstorm. However, the number of diverted flights was higher at the Port Harcourt airport with a total number of 625 flights diverted for thunderstorms alone, while Akure (398) recorded the lowest number of diverted flights. Overall, Port Harcourt happened to be the area where flight operations have been mostly hit by thunderstorms over the past 31 years.

**Table 4: dependence of flight operations on thunderstorm**

| **Model Summaryb** |
| --- |
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Change Statistics | Durbin-Watson |
| R Square Change | F Change | df1 | df2 | Sig. F Change |
| 1 | .563a | .317 | .241 | 1.66953 | .317 | 4.182 | 3 | 27 | .015 | 1.533 |
| a. Predictors: (Constant), cancelled, diverted, delays |
| b. Dependent Variable: thunderstorm |

The regressions model result for the dependence of flight operations on thunderstorms in the study area presented in table 4. In the table it is evident that the regression model produced a relationship of R-0.6 between flight operations and thunderstorm. The coefficient of determination of the model is 32% implying that, 32 % of the aviation operations can be explained by thunderstorm, leaving the other 68% to other weather elements, and poor aviation decision making. Furthermore, the model was significant at P<0.05 (F-4.2>Sig-0.015), this means that the earlier stated hypothesis “Flights cancelled, delayed and diverted do not significantly depend on thunderstorms in the Niger Delta Region of Nigeria during the past 31years” is rejected and the alternative hypothesis is accepted. This implies that, flights cancelled, delayed, and diverted significantly depend on thunderstorms in the Niger Delta Region of Nigeria during the past 31years.

**Table 5: Monthly predominant cloud cover and types across the study area**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Years** | **Jan** | **Feb**  | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
| **1989** | 7 |  7 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **1990** | 6 |  7 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **1991** | 7 |  7 |  8 | 5 | 8 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **1992** | 7 |  8 |  8 | 7 | 5 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **1993** | 7 |  8 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **1994** | 7 |  7 |  7 | 7 | 5 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **1995** | 7 |  7 |  7  | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **1996** | 7 |  7 |  6 | 6 | 3 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **1997** | 7 |  7 |  7 | 7 | 5 | 7 | 7 | 7 | 7 | 8 | 7 | 7 |
| **1998** | 7 |  7 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **1999** | 7 |  8 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2000** | 7 |  7 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2001** | 7 |  7 |  8 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2002** | 7 |  7  |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2003** | 7 |  7 |  7 | 7 | 8 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2004** | 7 |  7  |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2005** | 7 |  7 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2006** | 7 |  7 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2007** | 7 |  7 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2008** | 7 |  6  |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2009** | 7 |  7 |  6 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2010** | 7 |  7 |  7 | 8 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2011** | 7 |  7 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 8 | 7 | 7 |
| **2012** | 7 |  7 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2013** | 7 |  7  |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2014** | 7 |  7 |  3 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2015** | 7 |  7  |  7 | 7 | 7 | 7 | 7 | 7 |  7 | 7 | 7 | 7 |
| **2016** | 7 |  7 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2017** | 7 |  7 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2018** | 7 |  7 |  5 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **2019** | 7 |  7 |  7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **PD**  | Ci |  Ci | Ci/st | Cu/St | Cu | Cu | Cu  | Cu/St | Cu/N | Ci/St | Ci/St | Ci |

 **N:B: the following in the table refers as follows: PD-predominant cloud type; Ci-cirrus; Ci/st-Cirro-stratus; Cu/st-Cumulostratus; Cu/N-Cumulonimbus**

Table 5 presented the mean monthly cloud formation in Oktas and the predominant types happen to be Cirrus, Cirrostratus, Cumulostratus and Cumulonimbus. In the table it is evident that the Cirrus cloud type prevails in the drier months while the cumulus cloud types are predominant in the wet periods of the year. This also followed the seasons reflecting the relationship between the seasons, rains and cloud types.

**Table 6: Wind speed, wind direction and visibility characteristics in the study area**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| PRMT | Months | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| W/S in M/S  | PHC | 1.08 | 1.11 | 1.11 | 1.1 | 1.03 | 1.18 | 1.37 | 1.45 | 1.26 | 1.02 | 0.81 | 0.9 |
| Benin | 0.99 | 1 | 1.05 | 1.08 | 1.01 | 1.13 | 1.32 | 1.39 | 1.17 | 0.92 | 0.73 | 0.85 |
| Akure | 1.07 | 1.17 | 1.3 | 1.35 | 1.2 | 1.23 | 1.43 | 1.46 | 1.13 | 0.9 | 0.82 | 0.94 |
| Calabar | 1.87 | 2.18 | 2.39 | 2.42 | 2.45 | 2.87 | 3.16 | 3.21 | 2.9 | 2.51 | 2.04 | 1.74 |
| PRMT | Months | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| W/DIn 0 | PHC | 233 | 195 | 180 | 179 | 163 | 174 | 191 | 191 | 195 | 167 | 140 | 214 |
| Benin | 231 | 193 | 178 | 177 | 161 | 172 | 189 | 189 | 193 | 165 | 138 | 212 |
| Akure | 241 | 203 | 188 | 187 | 171 | 182 | 199 | 199 | 203 | 175 | 148 | 222 |
| Calabar | 228 | 190 | 175 | 174 | 158 | 169 | 186 | 186 | 190 | 162 | 135 | 209 |
| PRMT | Months | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| V/SIn KM | PHC | 8.9 | 7.7 | 17.9 | 22.3 | 21.1 | 18.8 | 15.2 | 16.7 | 18.9 | 20.7 | 20.4 | 16.0 |
| Benin | 7.5 | 10.3 | 14.3 | 16.5 | 16.0 | 14.9 | 12.8 | 13.4 | 14.6 | 15.7 | 13.5 | 8.5 |
| Akure | 8.7 | 17.2 | 17.8 | 19.6 | 18.9 | 17.9 | 16.7 | 17.1 | 17.4 | 18.3 | 14.0 | 5.7 |
| Calabar | 4.8 | 6.1 | 7.4 | 7.5 | 8.0 | 8.0 | 6.5 | 6.5 | 7.6 | 8.1 | 6.3 | 3.9 |

***N/B: PRMT refers to parameter; W/S refers to wind speed in meter per seconds; W/D refers to wind direction in 0; V/S refers to visibility in kilometres.***

The mean monthly wind speed, predominant wind direction and visibility values of the study area are shown in table 6. It is evident in the table that the wind speed of the area ranges between 0.81 to 3.21 meter/seconds. The individual stations showed wind speed is higher in the rainy periods than at the drier periods. The reason for this relates to the influence of the Atlantic Ocean to the south of the region which also produced the cumulus, strato-cumulus and nimbus clouds that results in thunderstorms and rains in the area. However, the wind speed in Calabar is higher than in the other places in the study region with wind speed that ranged between 1.74 m/s in December and 3.21 m/s in August. The condition of wind speed in Benin City shows that the area is further away from the influence of the Tropical maritime air mass (mT) and also the spate of development in the area of the airport there. Nevertheless the wind speed characteristics in the area shows that it is mostly influenced by the rainy season and the season also reflects higher thunder storms in the area and as such the period to look out for mostly when it comes to thunder storm influence on aviation in the area.

Furthermore, the wind direction of the area is predominantly southwest, south and southeast in origin as displayed in (Figure 2-5). This also shows that, the mT air mass has the most influence on winds and cloud formation in the area. However, visibility in the area is poorer in the months of December and January. The prevalence of the Tropical continental air mass (cT) in the area at this time of the year partly explains the poor visibility. The hazy conditions occasioned by the harmattan winds, coupled with the foggy and smog developments at this time of the year account for the poor visibilities in the study area. Also, evidence from table 5 shows that the months of June, July August (in all the stations) experienced a slight drop in the visibility conditions signifying the influence of the clouds type developed in the area at this period of the year (cumulus, nimbus, and stratocumulus clouds) since they cast darkness over visibility.

**Figure 2: Monthly predominant wind direction in Port-Harcourt**

Figure 2 -5 portray the predominant wind direction for Port Harcourt, Calabar, Benin and Akure. The figures shows that the area is mostly influenced by the southwest, south, and Southeast winds emanating from the Atlantic Ocean otherwise known as the tropical maritime airmass (mT). However, the wind permeates the area more from the southwest area of Port Harcourt. This finding is also supported by the findings of Alagoa, (2005); Nwilo & Badejo, (2005) and Mmom, (2010). Albeit, the closeness of the area to the Atlantic Ocean, the angle of intrusion of the area, relative to the Atlantic, partly explains the preponderant wind direction in this area.

**Figure 3: Monthly preponderant wind direction in Calabar**

**Figure 4: Monthly predominant wind direction in Benin**

**Figure 5: Monthly predominant wind direction in Akure**

**Table 7: Annual rainfall and temperature values in the study area**

|  |  |  |
| --- | --- | --- |
| Year  | Rainfall  | Temperature |
| Portharcourt | Calabar | Akure | Benin | NDR | Calabar | Portharcourt | Akure | Benin | NDR |
| **1989** | 1864.9 | 2765.6 | 1455.5 | 1969.9 | 2014.0 | 26.5 | 26.7 | 25.8 | 27.3 | 26.6 |
| **1990** | 2482.7 | 2729.1 | 1577.9 | 2470.2 | 2315.0 | 27.2 | 27.1 | 26.3 | 27.6 | 27.1 |
| **1991** | 2094.4 | 2658.3 | 1909.3 | 2577.6 | 2309.9 | 27.1 | 26.8 | 25.8 | 27.3 | 26.7 |
| **1992** | 2227.4 | 2896.4 | 1470.7 | 1966.8 | 2140.3 | 26.6 | 26.8 | 25.7 | 27.2 | 26.6 |
| **1993** | 2639.4 | 2511.3 | 1273.3 | 1849.8 | 2068.5 | 26.9 | 27.0 | 26.4 | 27.3 | 26.9 |
| **1994** | 2422.8 | 2904.6 | 1160.8 | 2532.5 | 2255.2 | 26.6 | 26.8 | 26.1 | 27.3 | 26.7 |
| **1995** | 2490.9 | 3825.5 | 1709.9 | 2669.8 | 2674.0 | 26.7 | 27.2 | 26.4 | 27.6 | 27.0 |
| **1996** | 2419.5 | 3321.8 | 1366.2 | 2549.6 | 2414.3 | 26.5 | 27.1 | 26.4 | 27.8 | 26.9 |
| **1997** | 1924.2 | 3492.4 | 1516.2 | 2200.8 | 2283.4 | 26.6 | 27.0 | 26.0 | 27.5 | 26.8 |
| **1998** | 2569.1 | 2771.5 | 1453.6 | 2057.7 | 2213.0 | 27.2 | 27.6 | 26.7 | 28.0 | 27.4 |
| **1999** | 2499.6 | 2983.9 | 1408.9 | 2253.5 | 2286.5 | 26.4 | 26.8 | 26.3 | 27.3 | 26.7 |
| **2000** | 1994.3 | 2807.4 | 1490.2 | 2240.0 | 2133.0 | 27.2 | 27.0 | 26.5 | 27.6 | 27.1 |
| **2001** | 2150.0 | 3202.0 | 1026.4 | 2285.3 | 2165.9 | 27.0 | 26.8 | 26.4 | 27.6 | 27.0 |
| **2002** | 2097.0 | 2797.7 | 1549.4 | 2544.2 | 2247.1 | 27.3 | 27.0 | 26.2 | 27.5 | 27.0 |
| **2003** | 2501.6 | 2657.7 | 1068.5 | 1838.1 | 2016.5 | 27.4 | 27.3 | 26.6 | 27.8 | 27.3 |
| **2004** | 2263.3 | 2371.8 | 1482.5 | 2317.7 | 2108.8 | 27.4 | 27.2 | 26.2 | 27.7 | 27.1 |
| **2005** | 2053.0 | 3702.0 | 1317.1 | 2012.5 | 2271.2 | 27.2 | 27.3 | 26.4 | 29.2 | 27.5 |
| **2006** | 2572.0 | 2893.8 | 1381.0 | 1717.8 | 2141.2 | 27.0 | 27.5 | 26.3 | 27.9 | 27.2 |
| **2007** | 2823.5 | 3428.9 | 1506.9 | 2654.6 | 2603.5 | 27.1 | 27.3 | 26.2 | 28.0 | 27.2 |
| **2008** | 2006.2 | 3060.8 | 1470.2 | 2651.0 | 2297.1 | 27.1 | 27.1 | 26.1 | 27.8 | 27.0 |
| **2009** | 2564.0 | 2527.4 | 1309.6 | 2102.5 | 2125.9 | 27.4 | 27.5 | 26.5 | 27.8 | 27.3 |
| **2010** | 2166.2 | 3072.0 | 1397.8 | 2800.3 | 2359.1 | 27.4 | 27.7 | 26.9 | 28.2 | 27.6 |
| **2011** | 1758.3 | 3472.2 | 1512.8 | 2004.2 | 2186.9 | 27.0 | 27.4 | 26.6 | 27.7 | 27.2 |
| **2012** | 2287.4 | 3787.9 | 1389.3 | 2464.7 | 2482.3 | 27.1 | 28.3 | 26.3 | 27.4 | 27.3 |
| **2013** | 2280.1 | 3563.7 | 1663.2 | 2595.9 | 2525.7 | 26.9 | 27.0 | 26.6 | 27.5 | 27.0 |
| **2014** | 2470.8 | 3280.1 | 1407.2 | 1713.8 | 2218.0 | 26.6 | 27.3 | 26.9 | 27.6 | 27.1 |
| **2015** | 2141.7 | 3361.0 | 1217.8 | 2353.4 | 2268.5 | 26.9 | 27.0 | 26.9 | 27.5 | 27.1 |
| **2016** | 2273.9 | 2555.3 | 1568.5 | 2026.3 | 2106.0 | 27.4 | 27.5 | 27.1 | 28.3 | 27.5 |
| **2017** | 2649.3 | 3093.4 | 868.2 | 2347.8 | 2239.7 | 27.4 | 27.4 | 27.1 | 28.2 | 27.5 |
| **2018** | 2249.0 | 2901.0 | 1531.4 | 2155.6 | 2209.3 | 27.3 | 27.3 | 26.6 | 28.2 | 27.3 |
| **2019** | 3114.8 | 3547.7 | 2131.4 | 3106.7 | 2975.2 | 27.3 | 27.5 | 26.8 | 28.0 | 27.4 |
| **Mean** | 2324.2 | 3062.7 | 1438.4 | 2291.3 | 2279.2 | 26.5 | 26.7 | 25.8 | 27.3 | 26.6 |

**Source: Author’s compilation (2019)**

The rainfall and temperature values of the study area are presented in Table 7 and it clearly shows that the area is predominantly a tropical one which is as classified by Koppens (1918). Therefore, convective heating and the development of cumulus and cirrostratus clouds are rampant in the area. Also, sea breeze which develops from the coastal belts and the deflective capabilities of the undulating hill and out crops of rocks (for example Akure and parts of Calabar) forces uplift of warm air and the formation of cloud resulting in rainfall and exacerbated temperatures. Nevertheless, mean rainfall for Port Harcourt was 2324 mm, while the mean temperature recorded for the same area was 26.7 0C. The mean rainfall for Calabar was 3062.7 mm, while the mean temperature recorded for the same area was 26.5 0C. In Akure the mean rainfall was 1438.4 mm, while the mean temperature recorded for the same area was 25.80C. The mean rainfall for Benin was 2279.2 mm, while the mean temperature recorded for the same area was 27.3 0C. However, the mean rainfall for the whole region was 2279.2 mm while the temperature was 26.6 0C. Generally, the findings in table 7, which can also be visualised in figure 4-5, suggest that rainfall and temperature are increasing in the area. It therefore partly explains the high number of thunderstorm days recorded in table 1. This is because majority of the rains that fall in the region are convective in origin (Ayoade, 2004). Figure 5 presents the rainfall and temperature information for Port Harcourt for the period 1989-2019. In the figure 1989 had the lowest amount of rain fall with the annual amount of rainfall being 1425 mm. The area experienced an increase in the rainfall amount in 1990 with annual rainfall of 1950 mm of rainfall. However, the rainfall of the area first peaked in the year 1998 with rainfall amount of 2500 mm from that point the rainfall amount decreased and continued to hover around 2000 mm to 1435mm until the year 2006 where the rainfall amount was 2300 mm.

**Figure 6: Rainfall and temperature patterns in Port Harcourt**

In the year 2012 the highest amount of rainfall was recorded for the period under review and the amount of rainfall was 3000mm. The rainfall of the area hovered around 1500mm to 2250mm between the year 2013 and 2019 of which the year 2019 had annual rainfall of 2250mm. on the other hand the temperature of the area ranged between 270C and 28.40C. The information from temperature data shows that the temperature of the area is actually increasing in contrast to the rainfall. Also indicated is that the change in the temperature of the area has been sustained and suggestive of a change created by anthropogenic activities which shroud the area. Figure 6 presents the rainfall and temperature information for Calabar for the period 1989-2019. In the figure 2004 had the lowest amount of rain fall with the annual amount of rainfall being 2205 mm. The area experienced an increase in the rainfall amount in 1995 with annual rainfall of 3600 mm of rainfall. However, the rainfall of the area first peaked in the same year 1995 with rainfall amount of 3600mm from that point the rainfall amount decreased and continued to hover around 3200mm to 2205 mm until the year 2005 where the rainfall amount was 3705 mm.

**Figure 7: Rainfall and temperature patterns in Calabar**

In the year 2012 the amount of rainfall recorded was 3000 mm. The rainfall of the area hovered around 3200mm to 2550 mm between the year 2013 and 2019 of which the year 2019 had annual rainfall of 3200 mm. on the other hand the temperature of the area ranged between 26.4 0C and 27.4 0C. The information from temperature data shows that the temperature of the area is actually increasing in contrast to the rainfall. Also indicated is that the change in the temperature of the area has been sustained and suggestive of a change created by anthropogenic activities which dots the area. Figure 6 presents the rainfall and temperature information for Akure for the period 1989-2019. In the figure 1984 had the lowest amount of rain fall with the annual amount of rainfall being 800 mm. The area experienced an increase in the rainfall amount in 1998 with annual rainfall of 1650 mm of rainfall. However, the rainfall of the area first peaked in the year 2012 with rainfall amount of 1850 mm from that point the rainfall amount decreased and continued to hover around 1850 mm to 1355 mm until the year 2014 where the rainfall amount was 1645 mm. the years 2016 and 2017 recorded 1925 mm of rainfall respectively.

**Figure 8: Rainfall and temperature patterns in Akure**

On the other hand the temperature of the area ranged between 25.8 0C and 27.3 0C. The information from temperature data shows that the temperature of the area is actually increasing. Also indicated is that the change in the temperature of the area has been sustained and suggestive of a change created by anthropogenic activities which dots the area. Figure 8 presents the rainfall and temperature information for Benin for the period 1989-2019. In the figure 1982 had the lowest amount of rain fall with the annual amount of rainfall being 1300 mm. The area experienced an increase in the rainfall amount in 2005 with annual rainfall of 3000 mm of rainfall. However, the rainfall of the area first peaked in the year 1998 with rainfall amount of 1850 mm from that point the rainfall amount decreased and continued to hover around 1250 mm to 1655 mm until the year 2010 where the rainfall amount was 1655 mm. the yeas 2016 and 2017 recorded 1905mm of rainfall respectively.

**Figure 9: Rainfall and temperature patterns in Benin**

On the other hand the temperature of the area ranged between 27.5 0C and 29 0C. The information from temperature data shows that the temperature of the area is actually increasing. Also indicated is that the change in the temperature of the area has been sustained and suggestive of a change created by anthropogenic activities which dots the area.

**Discussion**

An inquiry into flights cancelled, delayed, diverted or crashed as a result of thunderstorm over airports in the Niger Delta Region of Nigeria during the past 31 years revealed that flights that have been delayed as a result of thunderstorm accounted were 14880, while flights that got diverted accounted for 1657 trips. The number of the flights cancelled for the period accounted for 13558 flights and the number of planes crashed as a result of thunderstorm over the past thirty years accounted for zero crashes. The effects of thunderstorm on aviation operations is lucid in the region, although the increasing number may not necessarily by as a result of climate change influenced thunderstorm alone but also because the number of people flying has increased and the fleet has also increased as well. Nevertheless, there were also been spatial variation in the effects of thunderstorm on aviation operations across the region, and several reasons were accountable for this. First is the air travel demand per cities which is traceable to the function the city plays too. In this case a difference can be spotted between Akure and Benin which plays different functions economically, in the country and hence would have variation in the demand for flights and consequently on the number of flights affected by thunderstorm as well. There are also environmental factors that account for the variation in the thunderstorm effects on aviation in the region. For example, the build-up of thunderstorm in Akure would be different from that of Port Harcourt since the elevations, presence of water bodies and the environmental heating levels are different (Ghavidel, 2012; Hurlbut & Cohen 2014; Iranpour, Yazdanpanah & Hanafi, 2015). The regressions model result for the dependence of flight operations on thunderstorms in the study area produced a relationship of R-0.6 between flight operations and thunderstorm. The coefficient of determination of the model is 36% implying that, 36 % of the aviation operations can be explained by thunderstorm, leaving the other 64% to other weather elements, and poor aviation decision making. Furthermore, the model was significant at P<0.05 (F-4.2>SigF-0.015), this means that the earlier stated hypothesis “Flights cancelled, delayed and diverted do not significantly depend on thunderstorms in the Niger Delta Region of Nigeria during the past 31years” is rejected and the alternative hypothesis is accepted. This implies that, flights cancelled, delayed, and diverted significantly depend on thunderstorms in the Niger Delta Region of Nigeria during the past 31years (Ghavidel, 2012; Hurlbut & Cohen 2014; Iranpour, Yazdanpanah & Hanafi, 2015).

Thunderstorm values over the past thirty years for the study area revealed mean thunderstorm days to be 116, signifying and average of a thunderstorm day in every three days; while mean thunderstorm days for Port Harcourt for the period under review were 101 representing the area was the lowest in terms of recorded thunderstorm days in the region. This was closely followed by Akure with mean thunderstorm days 103, while Benin and Calabar were the places with the highest thunderstorm days in the area with mean thunderstorm days of 140 and 122 respectively. Also annual variations in the thunderstorm days in the study area varied particularly in 1989 Benin (125) recorded the highest number of thunderstorm days in the region compared to the other areas an average of which implies that the area had 100 thunderstorm days in the area. This is rampant and implies far reaching effects for the aviation industry. Furthermore, the ANOVA statistics established that thunderstorm varied spatially in characteristics in the study area and the model was significant at P<0.05(Fcal-16.586; sig-0.000). This implies that the null hypothesis stated earlier is rejected and the alternate hypothesis accepted. Rainfall and temperature characteristics of the study area revealed a tropical type and typified the environmental characteristics capable of producing thunderstorms. The rainfall and temperature characteristics examined, showed that the area is predominantly a tropical one which is as classified by Koppens (1918). Therefore, convective heating and the development of cumulus and cirrostratus clouds are rampant in the area. Nevertheless, mean rainfall for Port Harcourt was 2324 mm, while the mean temperature recorded for the same area was 26.7 0C. The mean rainfall for Calabar was 3062.7 mm, while the mean temperature recorded for the same area was 26.5 0C. In Akure the mean rainfall was 1438.4 mm, while the mean temperature recorded for the same area was 25.8 0C. The mean rainfall for Benin was 2279.2 mm, while the mean temperature recorded for the same area was 27.30C. However, the mean rainfall for the whole region was 2279.2 mm, while the temperature was 26.6 0C.

An inquiry into flights cancelled, delayed, diverted or crashed as a result of thunderstorm over airports in the Niger Delta Region of Nigeria during the past 31 years revealed that flights that have been delayed as a result of thunderstorm accounted were 14880, while flights that got diverted accounted for 1657 trips. The number of the flights cancelled for the period accounted for 13558 flights and zero crashes have been recorded as a result of thunderstorm for same period. Nevertheless, there were also been spatial variation in the effects of thunderstorm on aviation operations across the region, and several reasons were accountable for this. The regressions model result for the dependence of flight operations on thunderstorms in the study area produced a relationship of R-0.60 between flight operations and thunderstorm. The coefficient of determination of the model was 36% implying that, 36 % of the aviation operations can be explained by thunderstorm, leaving the other 64% to other weather elements, and poor aviation decision making. Furthermore, the model was significant at P<0.05 (F-4.2>SigF-0.015), this means that the earlier stated hypothesis “Flights cancelled, delayed and diverted do not significantly depend on thunderstorms in the Niger Delta Region of Nigeria during the past 31years” is rejected and the alternative hypothesis is accepted. This implies that, flights cancelled, delayed, and diverted significantly depend on thunderstorms in the Niger Delta Region of Nigeria during the past 31years.

**Conclusion and Recommendations**

Thunderstorm has been affecting and will continue to affect the aviation sector not only in Nigeria but globally. As such efforts continue to build in essence to mitigate the effects of thunderstorm and other weather elements on the industry. This study is one of such efforts to cushion the effects of thunderstorm on the aviation industry in Nigeria. Arising from the findings of the study, the following recommendations were made: evaluation of weather monitoring equipment by airport authorities for reliable information generation on thunderstorm and other weather elements forecasts due to global climate change, approvals to be given to only weather vagaries compliant aeroplanes to fly in airspace, constant training of weather observers at the airports for accurate weather information reporting and effective working synergy between aviation related agencies for improved result oriented services.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

**References**

1. Abdel-Aty, M., Lee, C., Bai, Y., Li, X. and Michalak, M., (2007). Detecting periodic patterns of arrival delay, *Journal of Air Transport Management*, 13 Pp355-361.
2. Adelekan, 1.O. (1998) Spatio-Temporal Variation in Thunderstorm Rainfall over Nigeria. International Journal of Climatology 18, Pp1273 — 1283.
3. Ahrens., C. D. (2013). *Meteorology today: an introduction to weather, climate, and the environment*. Brooks/Cole, Cengage Learning, Belmont
4. Akuezuilo, E. O., & Agu A. (2002). *Research and Statistics in Education and Social Sciences. Method and Applications*. Awka: Newl Centi Publishers and Academic Press Ltd, pp. 131- 132.
5. Alijani B (2012) Synoptic climatology, 5nd edn. Samt Publications (in Persian), Tehran
6. Ayigbe, F. (2007, January 9). Challenges of the Aviation Sector. New Nigerian Newspaper, p. 7.
7. Ayoade, J.F. (2004). Introduction to climatology for the tropics. Ibadan: Spectrum Books Ltd.
8. Chaudhuri., S. (2008). Identification of the level of downdraft formation during severe thunder-storm/days: a frequency domain analysis. *Meteorological Atmospheric Physics,* 102 Pp123–129.
9. Dalal, S., Lohar, D., Sarkar, S., Sadhukhan, I. and Debnath, G.C. (2012) Organizational modes of squall-type mesoscale convective systems during premonsoon season over eastern India. *Atmospheric Research.,* 106 Pp120–138
10. Das, S., Sarkar, A., Das, M.K., Rahman, M.M. & Islam M.N. (2015). Composite Characteristics of Nor'westers based on Observations and Simulations. *Journal of Atmospheric Research,* 58 Pp158– 178.
11. Fahey, D.W. & Lee, D.S. (2016). Aviation and Climate Change: A Scientific Perspective. *Carbon Climate Law Rev*iew 10, 97–104.
12. Faraji, A., Doust Kamian, M., and Safavi, Z. (2015) Synoptic analysis of spatial and temporal patterns of rainfall and thunderstorms (a case study of Zanjan). Quarterly Geography and Environmental Studies 14:41–66.
13. Gettelman, A. & Chen, C.(2013). The climate impact of aviation aerosols. *Geophysical Research Lett*er 40, 2785–2789.
14. Ghavidel, Y. (2012) Synoptic analysis of thunderstorms of April 23rd and 24th 2010 thunderstorm in Tabriz. *Geography and Planning*, 42 Pp223–238
15. Ghosh, R. and Terekhov, I. (2015). Future passenger air traffic modelling: Trend analysis of the global passenger air travel demand network. In Proceedings of the 53rd AIAA Aerospace Sciences Meeting, Kissimmee, FL, USA, 5–12 January 2015
16. Ghosh, R.; Kölker, K.; & Terekhov, T. (2015). Future passenger air traffic modelling: A theoretical concept to integrate quality of travel, cost of travel and capacity constraints. In Proceedings of the 19th World Conference of the Air Transport Research Society (ATRS), Singapore, 2–4 July.
17. Hurlbut, M.M., and Cohen. A.E. (2014) Environments of northeast U.S. severe thunderstorm events from 1999 to 2009. *Weather Forecasting*, 29 Pp3–22.
18. Iranpour F, Yazdanpanah H, and Hanafi A (2015). Synoptic and thermodynamic analysis of thunderstorms in Hamedan meteorology stations. *Geography and Environmental Hazards*, 13 Pp115–131
19. Klein, A., Craun, C. & Lee, R.S., (2010). Airport delay prediction using weather-impacted traffic index (WITI) model, Digital Avionics Systems Conference (DASC), 2010 IEEE/AIAA 29th. IEEE.
20. Kulesa, G., (2003). Weather and aviation: How does weather affect the safety and operations of airports and aviation, and how does FAA work to manage weather-related effect? The Potential Impacts of Climate Change on Transportation, Washington, D.C., U.S.A. Mohammad-Khorshid D. A, and Ghavidel, Y. (2006). The application of digital atmosphere 2000 software in spatial analysis of Iran climatic phenomena. *Quarterly Geographical Journal of Territory* (in Persian) 12:48–58.
21. Muhammad, H. (2009). Air Safety: Weathering the Weather Factor. Retrieved from Daily Trust, the online edition September 13, 2009, from dailytrust.com National
22. Peck, L. & Hedding, D.W. (2014). Tourist perceptions of air travel and climate change: an assessment of the polluters pay principle in South Africa, *African Journal of Hospitality, Tourism and Leisure,* 3(1), Pp 12.31
23. Reynolds, D.W., Clark, D.A., Wilson, F.W. and Cook, L., (2012). Forecast-based decision support for San Francisco International Airport: A NextGen prototype system that improves operations during summer stratus season, Bulletin of the American Meteorological Society, 93(10), Pp1503-1518.
24. Salahi., B. (2012). Statistical characteristics and synoptic review of thunderstorms of Ardabil. *Physical Geography Research Quarterly* (in Persian) 72 Pp129–141.
25. Terekhov, I.; Ghosh, R., & Gollnick, V. A (2015). Concept of forecasting origin-destination air passenger demand between global city pairs using future socio-economic development scenarios. In Proceedings of the 53rd AIAA Aerospace Sciences Meeting, Kissimmee, FL, USA, 5–9 January 2015.
26. Tyagi, B., Krishna, V.N. and Satyanarayana, A.N.V. (2011) Skill of thermodynamic indices for forecasting pre-monsoon thunderstorms over Kolkata during storm pilot phase 2006–2008. *Natural Hazards*. 56, Pp681–698.
27. Yamane. Y., Hayashi, T., Kiguchi, M., Akter, F. and Dewan, A.M. (2012) Synoptic situations of severe local convective storms during the pre-monsoon season in Bangladesh. *International Journal of Climatology,* 33, Pp725–734
28. World Meteorological Organization (WMO), (2007), Aviation hazards, education and training programme ETR-20, Geneva, Switzerland