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Operational Constraints on Flight Navigation due to Fog and Consequent Economic Implications at the Rajiv Gandhi International Airport, Hyderabad, Telangana, India

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Abstract: Fog is a frequent deterrent during the winter season. The reduction in horizontal visibility and other adverse conditions results in flight delays, cancellations, and flight de-route/diversions, leading to economic implications for rescheduling plans by the air-travellers. Clear skies, calm/light winds, a good amount of relative humidity, and fall in temperatures due to radiation cooling during winter nights are conducive. The intensity and duration of fog constrain flight operations. In the light of a fair number of fog occurrences compelling flight delays and diversions over Hyderabad Airport (RGIA, Shamshabad), the present study is undertaken to analyse the meteorological aspects of fog, and its frequency, duration, and economic implications.

During the period 2014-2019, 74 instances of fog occurrence were recorded over the RGIA. The majority of the incidents (45.9%) were shallow fog events. The dense fog (2) and very dense fog (1) events were rare. Maximum fog occurrences (26 out of 74 events) were reported in December. The onset of fog was observed between 1800 UTC and 0400 UTC, while most of them (43.2%) occurred between 0000 UTC and 0200 UTC. Most of the fog events lasted up to 1 hour, and there were six instances of fog lasting between 2-3 hrs.

Key words: Fog, Shamshabad, flight diversion, low visibility procedure, visibility.

Introduction

Weather phenomena such as heavy rainfall, thunderstorms, blowing snow, strong winds, turbulence, and fog significantly impact aviation safety through visibility. A clear, transparent, non-turbid atmosphere is essential for uninterrupted aviation services. Low visibility and low clouds with dense fog affect flight on-time performance. Reduced visibility makes it difficult for pilots to see beacons, landmarks, obstructions, etc. This causes flight delays, diversions, cancellations, rescheduling, and ultimate monetary loss.

The clearance of an aircraft to fly during late night and early morning hours depends on visibility. Low visibility obscures the ground. It can be due to fog, mist, haze, or smoke. Fog is an adverse weather phenomenon

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that badly affects aviation, especially during the winter months. It is present throughout the year and mainly depends on air mass at airports. Fog is a cloud of tiny droplets that form near ground level. The dense fog reduces visibility to as low as 50 m and sometimes even to zero. Visibility of less than one km is risky for aircraft operations. In addition, air pollution caused by rapid urbanization and industrialisation has a strong effect on fog, its persistence and cloud formation. During winter, stable atmospheric conditions and air pollution are conducive to the formation of fog. The conditions favourable for the formation of fog are strong subsidence, cloudlessness, calm/light winds/ low turbulence, high relative humidity, inversion of temperature/negative lapse in the few metres above the ground, calm wind speed (less than 2 ms^{-1}), and partly cloudy or a cloudless sky. Dense fog events occur when temperatures are below 0°C. It peaks during the early morning and reaches a minimum in the late afternoon to early night and fog is observed during December-February and rarely during September-November and March-April. Fog can also be classified based on environmental and thermodynamic conditions such as upslope, frontal, radiation, and advection. By duration, dense fog is categorized into light, moderate, thick, and very thick. The long-lasting period of thick fog is not more than 3-hours. Even though fog formation is a common and regular phenomenon in India, there is a scarcity of literature related to its dynamics, formation, and prediction. Most of the measuring sites related to fog events are at and near airports because of real-time information for visibility conditions. It revisits with greater frequency and intensity during winter due to Western disturbance and the associated weather conditions. However, the severity of fog is low in South India compared to North India.

Review of Literature

There are several studies on fog in regard to its meteorological aspects, the ability of models to forecast, and various facets of diagnosis and prognosis using satellites and Numerical Weather Prediction (NWP) models. Gultepe et al. (2007) made an exhaustive study on the formation of fog and its various meteorological facets. Analysis and forecasting of in-situ fog formation due to favourable meteorological conditions were studied by Mohapatra et al. (1998) (over Bangalore airport), Suresh et al. (2007) (over Chennai airport), and meteorological aspects of fog were analyzed by Kutty et al. (2018) (over Kempegowda airport, Bangalore) and Ram et al. (2008) (over Guwahati airport).

Chaurasia et al. (2011) developed an algorithm to study night-time fog using Brightness Temperature Difference (BTD) between 3.9 μm and 10.75 μm bi-spectral channels. Using large-scale circulation features as analyzed from Cloud Motion Vectors (CMV), Brij Bhushan et al. (2003) devised a diagnostic tool for the formation and persistence of fog over a large area.

Kim et al. (2020) simulated by ingesting meteorological tower data using the nudging technique in Weather Research and Forecasting (WRF) and PAarameterized FOG (PAFOG) coupled models. Aditi et al. (2018) persevered to predict the occurrence of fog using NWP Models. Aditi (2019) endeavoured to study the capability of the National Centre for Medium Range Weather Forecasting (NCMRWF) known as the Unified Model (NCUM) in the prediction of radiative fog formation over Indo-Gangetic plains. Swagata Payra et al. (2014) attempted to diagnose fog occurrence using the WRF model. An objective study by statistical multiple discriminant analysis techniques was made by Roy Bhowmik et al. (2004) for studying fog at Delhi airport. Climatological perspectives of winter fog over the Indian sub-continent were studied by Sawaisarje et al. (2014). Economic impacts of fog on aviation over Delhi Airport were assessed by Kulkarni et al. (2019).

However, there are no studies available on the impact of visibility on operations at Hyderabad or Shamshabad (RGIA) Airport. Against this backdrop, this paper aims to appraise the incidence and implications of fog and visibility over Rajiv Gandhi International airport (RGIA), Hyderabad.

Location and Data Methodology

Rajiv Gandhi International airport (17.2403° N, 78.4294° E) is located in Shamshabad, about 30 km south of Hyderabad, Telangana state, India (Figure 1) at an elevation of 2,021 ft. The flight operations started from the present location in the year 2008 while previously the national and international flights were operated from Begumpet. Today, it is the sixth busiest airport in India. Hyderabad is geographically located in southern Telangana on Deccan Plateau with an average elevation of 540 metres. The Shamshabad airport is on the periphery of the Greater Hyderabad Municipal Corporation limits en route to the Mahabubnagar district. The climate of the place is characterised by hot and dry summers; humid air with moderate temperatures during the remaining months. Occasional fog is observed during the winter months.

The data used in this study mainly pertain to the Routine and Special Meteorological Terminal Aviation

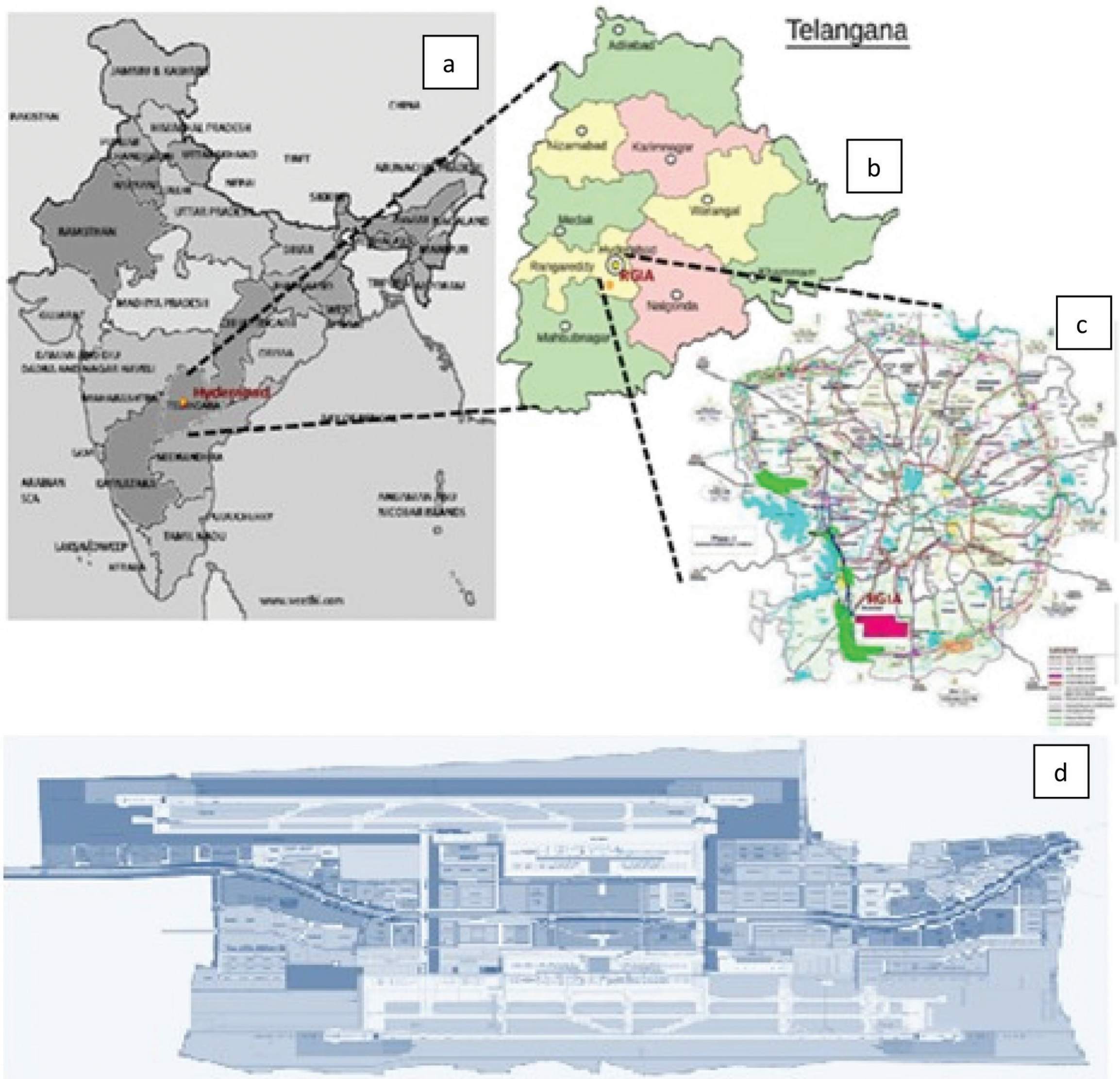

Figure 1: Geographical Location of Rajiv Gandhi International Airport (RGIA) (17.2403 °N, 78.4294 °E), (a) In India (b) Telangana State, (c) Greater Hyderabad and (d) RGIA Layout.

Reports (METAR) issued by the AMO, RGIA for its operational utilization at the ATC and outward transmission to the other airports.

The categorization of airports is done based on the airport minima as delineated in Table 1. Visibility procedures are to be followed while landing and take-off of the flights at the airports, as mentioned in subsequent paragraphs.

Table 1: Minima for landing operations under different categories of Instrument Landing System (according to International Civil Aviation Organization (ICAO) DOC 9365- AN/910)

	Decision height	*Runway visual range*
CAT I	200 ft	550 m
CAT II	100 ft	300 m
CAT III A	50 ft	175 m
CAT III B	15 ft	125 m
CAT III C	Nil	Nil

Visibility Procedures at the RGIA

The International Civil Aviation Organization (ICAO) *3rd Edition(2005) Doc 9328 AN/908, Manual of Runway Visual Range Observing and Reporting Practices* marks out the important weather phenomena that may cause a reduction or deterioration in visibility as due to Litho-meteors (smoke, dust, haze, volcanic ash, sand) and hydrometeors fog, mist and precipitation in its various manifest forms as drizzle, rain, shower, snow crystals/

pellets, snow grains, sleets, glaze, ice crystals, ice pellets and hail. The turbidity or opaqueness of the transparent air is due to the suspension of these litho-meteors and hydrometeors in the air around the observational arena.

The *sine qua non* of air navigation stipulated by the ICAO and the DGCA includes strict compliance of Low Visibility Procedures (LVP) and Low Visibility Take-offs (LVTO). LVP is applied at an aerodrome to ensure safe air operations during visibility lower than the categories specified supra. LVPs are enforced on occasions when horizontal surface visibility goes below the standard values as aforementioned may be due to low visibility or height of the low cloud base.

Operationally, fog is classified based on Meteorological Optical Range (MOR), the discernible horizontal distance (Visibility) up to which it can be seen (Table 2).

Table 2: Classification of fog

S. No.	*Type of fog*	*Range of horizontal visibility (metres)*
1	Shallow fog	500-1000
2	Moderate fog	200-500
3	Dense fog	50-200
4	Very dense fog	<50

The RGIA, Shamshabad is equipped with CAT-I Instrumental Landing System (ILS). Advanced Surface Movement Guidance and Control System (ASMGCS) can also be marshalled for operational use. The Runway (RWY) and the Taxiway (TWY) have centreline illuminations that can be used during LVP. There are two Runway Visual Range (RVR) transmissometers of the ‘Drishti’ system at the Touch Down Zone (TDZ) and the End Point (END). The reference RVR value for clearance and cancellation of the flight to conform to the LVP shall lower the TDZ and the END RVR. The CAT-I ILS allows a decision height of 60 metres and with either visibility of not less than 800 m or RVR of not less than 550 m. At the RGIA, the safeguarding procedure is initiated when (1) The RVR is less than 1200 m or visibility is forecast to deteriorate to 750 m or less; and/or (2) The cloud ceiling is 400 ft (120m) and forecast to fall to 200 ft (60m) or less. Then the Watch Supervisory Officer (WSO) will inform Airport Operations Coordination Centre (AOCC) to coordinate with all the connected agencies to implement LVTO. The LVP for departures shall be implemented when RVR reduces to 750 m or less and/or the cloud ceiling is less than 200 ft (60 m). Notwithstanding that LVP is enforced when RVR is less than 750 m, ILS CAT-I operates until TDZ RVR is not less than 550 m.

Data pertaining to horizontal visibility for the period 2014-2019 are obtained from the India Meteorological Department station at the site for January-March and September-December for the study period. In the remaining months, the occurrence of fog is rare due to strong winds, turbulence, cloud coverage, monsoonal regime, convective weather, and tropical weather systems. As given by IMD, the present weather codes are used for identifying fog hours and meteorological phenomena. The collected data are analysed for monthly frequency of fog, onset and duration of fog, and frequencies of critical variability. The meteorological parameters such as dew point temperature, wind speed, and wind direction are also considered for analysis

Results and Discussion

A fog event is defined in the present study as visibility from the ground in to the sky (that is, vertical visibility) of less than one km. The occurrence of fog is quite significant during September-December and in a few instances during January-March. Out of 74 events during the reference period, a high occurrence is observed in 2014 with a maximum occurrence of 26 days, and a minimum in 2016 with only 3 days (Figure 2). The monthly frequency during 2014-2019 has been tabulated and analysed (Table 3). Out of six years, the maximum occurrence was observed in December, followed by November, October, and September in that order. In the year 2017, however, the maximum occurrence recorded was during March, September, and

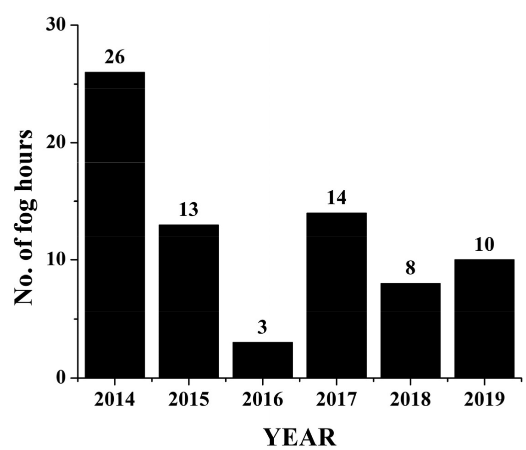

Figure 2: Annual frequency of fog over Hyderabad airport during the period 2014-2019, zero visibility associated with fog at this site.

Table 3: Month-wise fog frequency during 2014-2019 at the study site

Year	*Jan*	*Feb*	*Mar*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
2014	2	5	1	0	6	8	4	26
2015	1	0	0	5	0	0	7	13
2016	3	0	0	0	0	0	0	3
2017	1	1	3	3	1	2	3	14
2018	0	0	2	0	0	0	6	8
2019	0	0	0	0	2	2	6	10
Total	7	6	6	8	9	12	26	74

December in that order. From the observations, it is clear that the most favourable month for fog formation over Hyderabad airport is December.

The frequencies of minimum visibility during fog events are summarized in Table 4 and Figure 3. In 45.9% of fog days, the minimum visibility is 501-800, and in 21.6% of cases, the range of visibility is 301-500 m. Out of 74 total cases, three cases of visibility less than 100 m are reported. 1 out of 3 is less than 50 m that occurred in the transitional month of March. There was no case of zero visibility associated with fog at this site.

It could be observed that the time of onset of fog (Table 5) is between 1800 and 0400 UTC, which manifests the role of radiational cooling. The most preferred time for the formation of fog is between 0000 and 0200 UTC. 43.2% of fog events were reported during this period. This is when oblique rays of the Sun penetrate the lower atmosphere through a stable layer and churn the pollutants trapped there. In about 13.5% of the cases, the first fog was observed between 2200 and 0000 UTC, indicating the stable atmosphere's trapped pollutants even before the churning mechanism. The duration of fog (Figure 4 and Table 6) varied

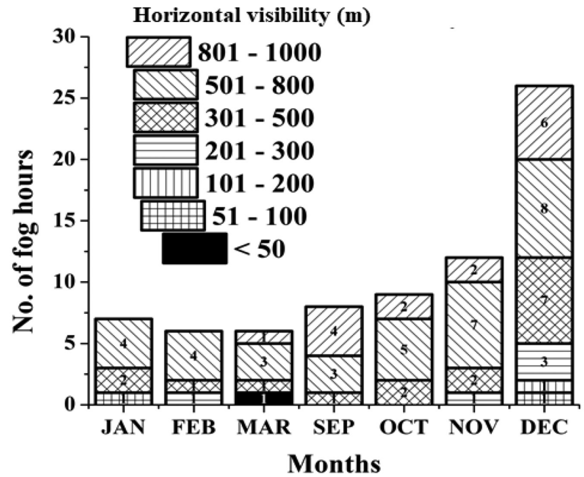

Figure 3: Frequencies of minimum visibility month-wise during the study period.

between 60 and 180 minutes at this location. In about 58.3% of cases, fog duration was about 1 hour, and in 12.5 % of cases, the duration lasted up to 3 hours.

Dew point temperature (Figure 5a) represents the amount of moisture in the air. The higher the dew points, the higher the moisture content in the air. The moisture must be removed if the air cools through condensation. This leads to the formation of fog. Low temperatures combined with moisture and low wind speed result in inversion. Light wind speed (5 m/s) interspersed with calm conditions favours fog formation (Figure 5b). Low wind speeds tend fog formation through turbulent mixing, which spreads cooling vertically, thereby deepening the fog layer. Figure 5c shows that the predominant wind direction is east-south-easterly during fog formation, and wind speed during fog events is below 4 m/sec. In 32.3% of fog events, the dew point temperature is either low or moderate and in the remaining 67.7% of events, it is high.

Table 4: Frequencies of Minimum Visibility during the study period

Month	*Visibility in metres*							*Total no. of events*
	≤ 50	*51-100*	*101-200*	*201-300*	*301-500*	*501-800*	*801-1000*	
JAN	0	1	0	0	2	4	0	**7**
FEB	0	0	0	1	1	4	0	**6**
MAR	1	0	0	0	1	3	1	**6**
SEP	0	0	0	0	1	3	4	**8**
OCT	0	0	0	0	2	5	2	**9**
NOV	0	0	0	1	2	7	2	**12**
DEC	0	1	1	3	7	8	6	**26**
TOTAL	1	2	1	5	16	34	15	**74**

Table 5: Time of onset/formation of fog

TIME in UTC	*JAN*	*FEB*	*MAR*	*SEP*	*OCT*	*NOV*	*DEC*	*TOTAL*
1000-1200	0	0	0	1	1	0	0	**2**
1200-1400	1	0	0	0	1	0	0	**2**
1600-1800	0	0	0	0	0	1	0	**1**
1800-2000	0	0	1	0	1	1	0	**3**
2000-2200	0	0	1	0	3	3	1	**8**
2200-0000	0	3	0	3	1	2	1	**10**
0000-0200	3	2	3	3	2	5	14	**32**
0200-0400	2	1	1	0	0	0	9	**13**
0400-0600	1	0	0	0	0	0	1	**2**
0600-0800	0	0	0	1	0	0	0	**1**
TOTAL	7	6	6	8	9	12	26	**74**

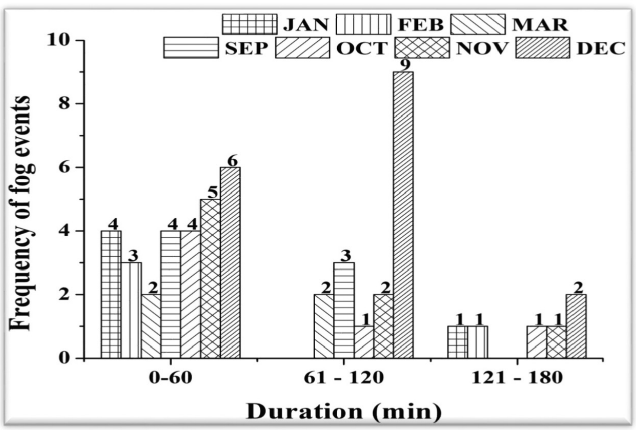

Figure 4: Month-wise duration of fog hours.

Table 6: Duration of fog hours

Duration (in minutes)	*Number of time slices*
0-60	28
61-120	17
121-180	6

The Impact of Fog on Flight Diversions, Economic Costs, and Other Problems

The operational problems of flight navigation are often due to meteorological conditions besides the technical snags and other unforeseen /impending dangers. There are many instances of flight delays and diversions (Table 7) due to adverse weather like severe weather in association with thunderstorms and allied phenomena like lightning, heavy rains, turbulence in the cloud, and squally weather. The weather events that enforce flight diversions also include deteriorating visibility in association with the above occurrences and poor visibility due to atmospheric turbidity from fog and mist. The number of hours of reduced visibility that hinders aircraft movement indicates the cost burden on the air carrier besides the troubles to the passengers.

The longer the duration of the fog, the greater its economic impact on the **air carriers** due to de-tour, diversion, fuel costs, passenger accommodation and amenities and other inputs. **Airports** have to keep longer watches, levy Aeronautical Service charges like Route Navigation Facility Charges (RNFC) for domestic and international flights for overflying/stationary hovering for clearance during adverse weather. P**assengers** have to reschedule their plans, and these unforeseen changing schedules can spoil their once-in-lifetime chances.

Improvements and Possible Actions to Adopt

The airport at Shamshabad experiences mostly shallow fog events and the incidence of fog is also not as frequent and as dense as it is seen in the northern airports in the country. The techniques of fog dispersal are not economical either. The fog forewarning is also not possible using satellite as the area is not a sufficiently larger region enveloped by dense fog. Synoptic analysis, empirical methods, and study by stability analysis from aerological soundings of morning and evening GPS-sonde ascents will give a peep view of the depth of the thermal inversion layers, the possibility of persistence of fog, and hence of the ability to forecast and forewarn the aviation service providers to reschedule flights on short notice. Accordingly, the economic costs are imminent and inevitable. However, the costs can be minimised with an improved aviation micro-scale forecast topped by synoptic analysis with the deployment of fog monitors to measure the drop

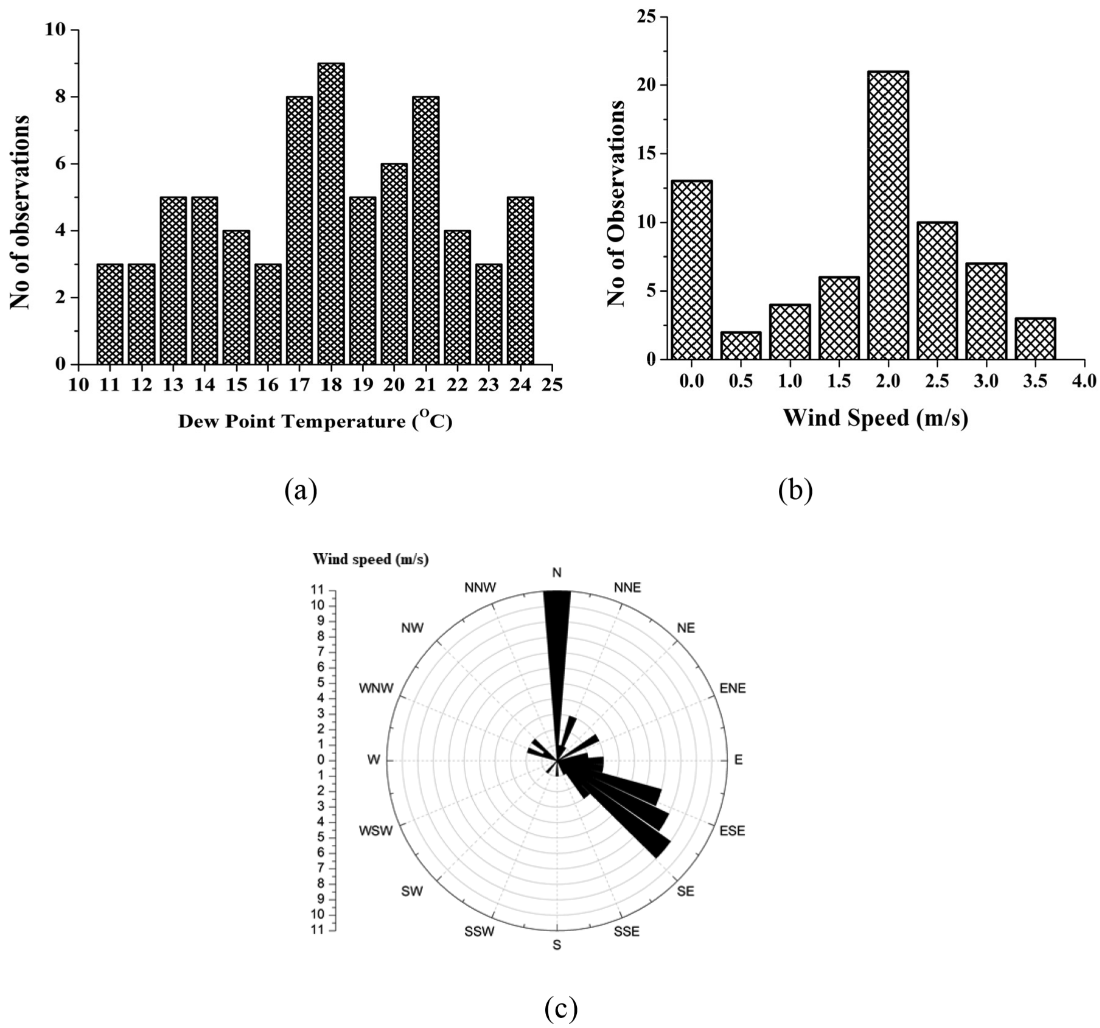

Figure 5: Conducive meteorological conditions during foggy days (a) Dew point temperature (b) wind speed (c) wind direction.

Table 7: Flight diversions during (Jan-March and Sep-Dec) months of 2014-2019 due to fog and thunderstorms and other weather events

Year	*Number of flight diversions due to bad weather at RGIA*		*Number of events of bad weather at other areas that prompted flight diversion to the RGIA*	
	Fog	*Thunderstorm and other events*	*Fog*	*Thunderstorm and other events*
2014	12	01	–	–
2015	12	07	13	09
2016	07	11	19	07
2017	06	00	18	09
2018	26	04	25	38
2019	18	27	15	45

count of the fog, microwave radiometer to measure mixing ratio, cloud water content and a Radio Acoustic Sounding System (RASS) to analyse the vertical profiles of virtual temperature and wind. Timely dissemination with concerted and coordinated action of the involving agencies and the airport authorities is needed to ensure this.

Conclusions

Hyderabad airport is susceptible to light to moderate fog, however, a few instances of thick and one instance of very thick fog were also observed. Fog occurrence is observed during September-December, and chances of the event from January to March cannot be ruled out. Mostly, light fog is predominant during September-December. Thick fog is seen in December and January, indicating the possible role of inversion conditions, low temperatures, and radiative cooling in the winter months. Very thick fog is observed in March. The highest frequency of fog events occurred in 2014 and in December months during 2014-2019. Most fog events fall in 1 hr duration, and events lasting more than 2 hrs are infrequent. As radiative cooling aids in fog formation, its onset between 1800-0400 UTC is observed. Meteorological factors such as dew point temperature, wind speed, and predominant east-southeast wind contributed to fog formation during the study period. In most fog events, calm conditions prevailed, and wind direction is between (E-SE). The longer the duration of the fog, the greater are economic costs for the **air carriers** due to de-tour, diversion, fuel costs, passenger accommodation and amenities. **Passengers** have to bear the costs of changing their schedules.

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