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Article

The Impacts of Low Visibility on the Aviation Services of Patna Airport During the Period from 2016 to 2023

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Abstract.

Airport efficiency depends on fast reactions to circum-stances. Local weather conditions may have an impact on airport operations, which may affect the network. Local weather events and airport operations may affect the network. Low visibility due to fog, thunderstorms, rain, etc. affects Patna Airport, India's 15th busiest airport. It is one of the Airports Authority of India's lucrative airports, located in the Indo-Gangetic Plain (IGP), where fog reduces vision and interrupts traffic often in the post-monsoon and winter seasons. Because there is just one operating runway (07/25) at Jay Prakash Narayan International (JPNI) Airport, Patna, and around one hundred daily flight operations, any downtime might have a substantial monetary impact on the aviation services. Therefore, it is absolutely necessary to carry out a quantitative study of the losses that are anticipated. This was the first study of its kind that looked at the impact of low visibility (due to fog and a thunderstorm) on economic losses at Patna Airport. This research also investigates the impacts that fog has on aviation services, in addition to its frequency, duration, and characteristics that are linked. Over Patna Airport, there were a total of 726 in-stances of fog (visibility<1000m) and 171 instances of dense fog (visibility<200m) during the studied period, i.e., April 2016 and March 2023 (7 years). As a result, the tactical level of analysis that this approach offers enables the stakeholders to enhance the services and better mitigate the impacts of local weather on the effective operation of the airports.

Keywords: Fog, low visibility, aviation economy, Patna Airport.

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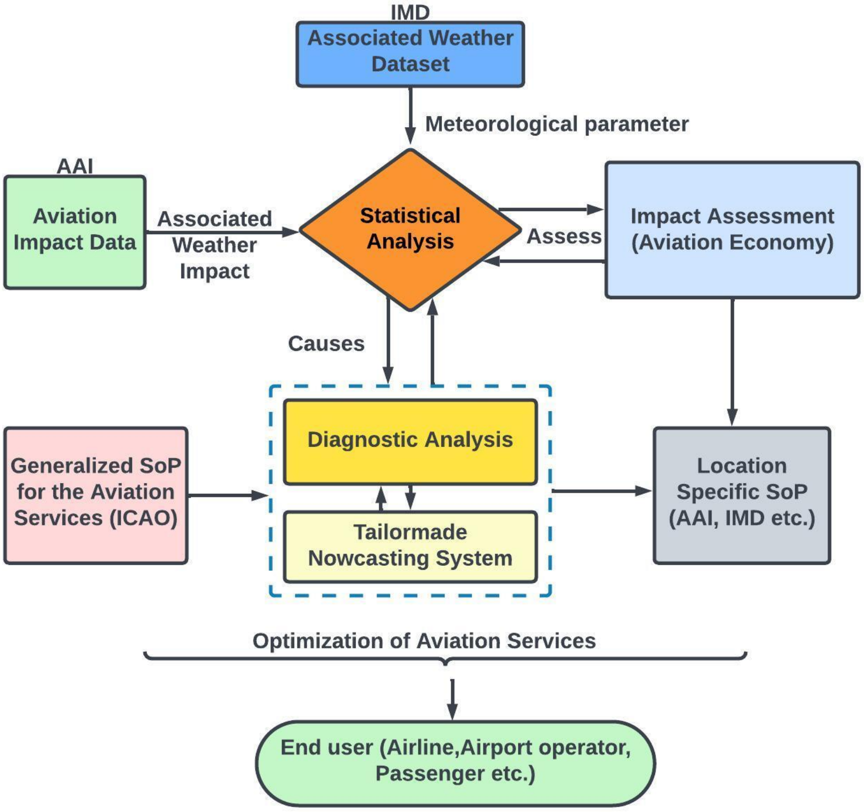
Graphical Abstract



1. Introduction

Changes in short-term severe weather, such as thunderstorms in the summer and fog in the winter, are among the complex weather factors that impact the smoothness of airport traffic [1]. Other adverse weather conditions that may hinder visibility also play a role. More than any other mode of transportation, thunderstorms, strong winds (squalls and wind shear), fog, and thick dust haze, as well as temperature and pressure extremes, have a significant impact on aviation services. As a result, weather has the potential to affect every stage of flight [2, 3]. Low clouds, fog, and other types of atmospheric impediments make it impossible for flights to take off or land in a safe manner unless the sky is completely clear of these types of obstacles. When there is poor visibility, it is more difficult for pilots to identify hazards, landmarks, and other navigational aids. As a consequence, flights are delayed, diverted, cancelled, and rescheduled, and airlines lose money [4, 5]. Depending on visibility, an aeroplane may be permitted to fly or not. There-fore, visibility is the primary criteria for landing and taking off. There are a number of factors that might contribute to low horizontal visibility. Some of these factors include fog, mist, haze, and smoke. As a result, situations with limited visibility (such as fog, dust, smoke, or haze, among other things) pose challenges for the operations of aircraft, especially at crucial landing and takeoff times. Therefore, flight delays, cancellations, and diversions are common outcomes when dense fog interferes with airport flight operations [4, 6, 7]. As a result, travellers are put through inconvenience, and airlines experience significant financial losses.

The Indian aviation industry has largely recovered from the COVID-19 epidemic [8], as air traffic flow rose to 327.28 million in FY23 from 188.89 million in FY22. According to the International Aviation Transport Indus-try Association (IATA), India will replace China and the US as the world's third-largest air passenger market by 2030. The Indian civil aviation business has grown rapidly in the past three years. India's aviation industry was the world's third largest in terms of domestic traffic on June 30, 2023. Domestic traffic accounts for 69% of South Asian airline traffic, and India's airport capacity will accommodate 1 billion passengers by 2023. Patna, one of Eastern India's megacities, serves the aviation services for the populous state of Bihar in India, which is situated in the Indo-Gangetic Plain (IGP). The dense winter fog in the Indo-Gangetic Plains (IGP) region of northern and northeastern India is well known. Recent research on fog in India has generated substantial socio-economic difficulties due to the worrisome increase in fog and pollution and the persistence of fog in the IGP over the winter [9, 10]. It displays substantial seasonal variability depending on a confluence of meso- and mac-ro-scale weather factors [11, 12]. Significant low-level inversions cause a lower-level ridge line to form over these areas, which creates stable, clear weather and lower surface temperatures [13]. This makes it easier for fog to form and stick around in these areas. In reality, such periods of fog may be the world's fastest in onset, largest in area, and longest in duration compared to fog reported in other parts of the world. It's possible that many physical factors contribute to the genesis of fog events [14]. Also, growing urbanisation and industrialization contribute greatly to air pollution, which in turn has a major impact on fog, its longevity, and fog formation. Fog tends to form or begin when there is a combination of factors, including strong subsidence, cloudlessness, calm or light winds, low turbulence, high relative humidity, an inversion of temperature, and a negative lapse in the few metres above the ground. The months of November through February are the fog-prone months in the studied areas. It peaks in the early morning and reaches a minimum in the late afternoon or early evening. The details of the studied areas are presented in Figure. 1.

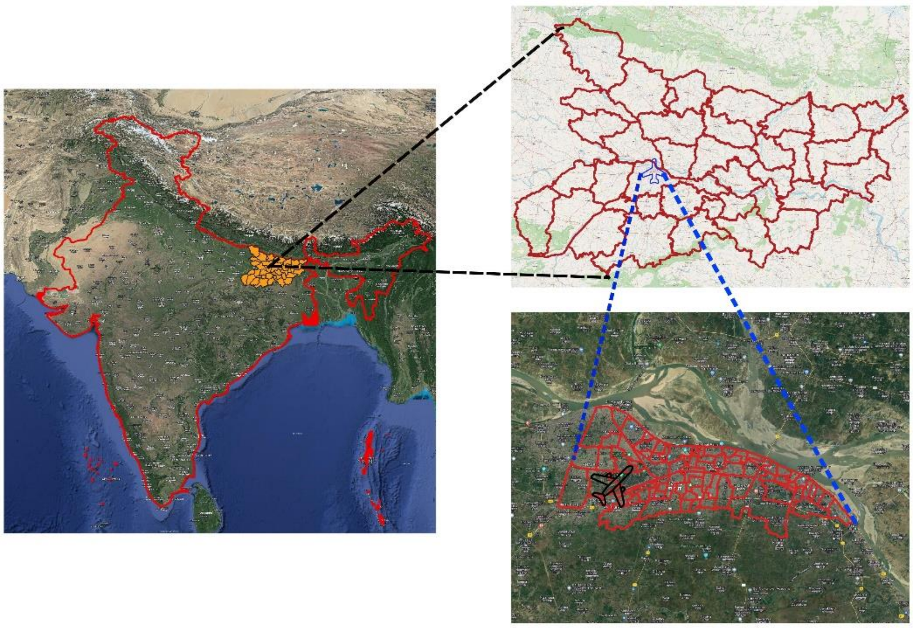


Figure. 1: The geographical location of Jay Prakash Narayan International Airport Patna (a) India (b) Bihar (c) Capital Cities of Patna

The studied airport, i.e., Patna Airport, is currently the fifteenth busiest airport in India in terms of domestic traffic (during the period of April 2022 to March 2023). Severe fog has a significant impact on the operations of this airport. A total of 23 flights had to be rerouted in December 2017, the highest in a single calendar month, owing to low visibility during the day, costing airlines more money than usual because the extreme fog lingered over these airports for four days (December 27th to December 31st, 2017). The airlines lose more money when the onset of fog occurs between sunrise and sunset as compared to when it sets at midnight. Therefore, the persistent nature of early warning helps in the scheduling of aircraft. Even though it is common knowledge that fog can have a detrimental influence on the aviation economy, it is essential to undertake a quantitative evaluation of the expected losses. The arrival of fog has two effects: (1) a decrease in ground traffic due to slower taxiing speed; and (2) an increase in runway occupancy time (ROT). Additionally, JPNI Airport's capacity may decrease by as much as 30 to 40%, and air traffic controllers (ATCs) must lengthen the gap between landing and takeoff aircraft to maintain safe operations (runway vacation time increases by 30 to 90 seconds). Moreover, air traffic controllers have a responsibility to protect landing system signals for aircraft within two nautical miles of the runway. The areas impacted by previous arrivals and departures must be cleaned in order to take appropriate safety measures. Because of this, flights may be delayed at the airport of departure, rerouted back to the airport of origin, or even cancelled, as presented in Figure. 2.

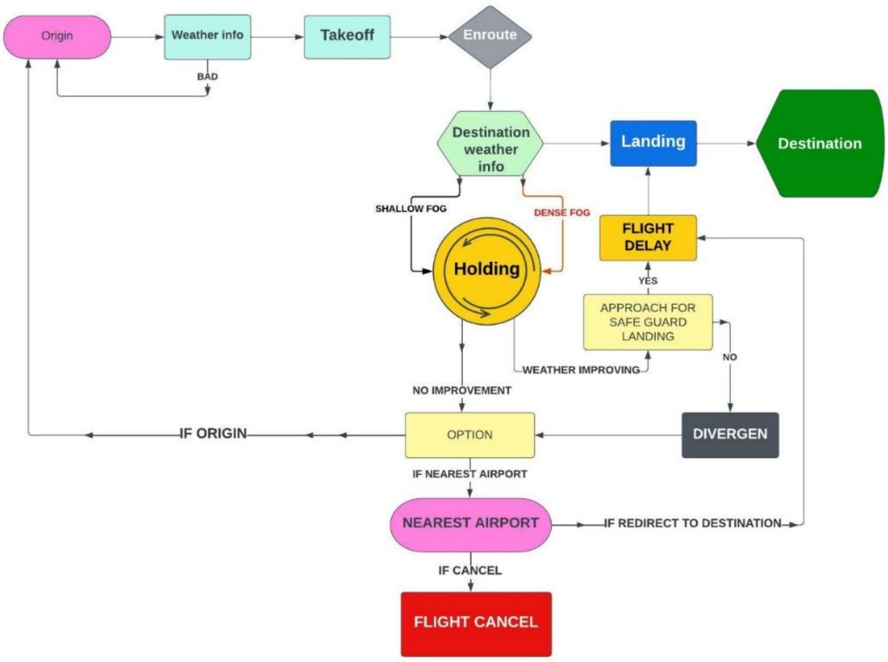


Figure. 2. Schematic of Flight Operations at Airports during Low Visibility and Schematic of Possible Impacts of Adverse Weather on the Operations of Flight

The main objective of this study was to ascertain how much money JPNI Airport Patna lost as a direct result of flight diversions brought on by the dense fog between April 2016 and March 2023. Additionally, the frequency, consequences, and low visibility issues that frequently occur at Patna airport are investigated in this study as well. As per the knowledge of the authors, this kind of analysis has never been done before for any airport in eastern India that is located within the IGP.

2. Materials and Methodology

Patna's airport has the coordinates 25.5947°N and 85.0908° E and is situated at an elevation of 52 metres in the alluvial plains of the Ganga basin. It is positioned on the Ganga River's southern bank. Since 1950, public aviation services have been provided. The region has a temperate winter, a hot and dry summer, and a hot and humid monsoon season. Summers are hot and dry, but the rest of the year is mild and humid. Fog can be noticed on occasion throughout the winter months. From November through February (winter), this area is prone to radiation and advection fog due to the Western Disturbance (WD) [15]. In this section, datasets and the methodology will be discussed in detail.

2.1 Dataset

Within the scope of our research, we concentrated primarily on the quantity of flights diverted from April 2016 to March 2023, as well as the resulting financial losses as a result of the low visibility that the weather factors presented. The dates of the flights and aircraft that were diverted were taken from the Airport Authority of India. And in correspondence with visibility and meteorologic data obtained from the Aerodrome Meteorological Office (AMO), which is situated at the Patna airport (also accessible from the portal at https://dsp.imdpune.gov.in/). The monthly aircraft that were diverted at the Patna airport are presented in Table 1. Out of the total 147 flights diverted, a total of 76.2% were diverted because of the bad weather associated with the poor visibility. And remaining diversion with the technical issues like the non-availability of parking, technical glitches, etc. The corresponding total number of fog and dense fog hours is presented in Table 2.

Table 1: Details of the monthly number of flights diverted at Patna Airport because of bad weather and associated poor visibility and technical issues.

Year/Month/Diverted	2016-17		2017-18		2018-19		2019-20		2020-21		2021-22		2022-23		Mean	
	Bad Weather	Technical Issues	Bad Weather	Technical Issues	Bad Weather	Technical Issues	Bad Weather	Technical Issues	Bad Weather	Technical Issues	Bad Weather	Technical Issues	Bad Weather	Technical Issues	Bad Weather	Technical Issues
Apr	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0.29	0.00
May	0	0	1	0	1	0	0	1	2	0	0	0	1	0	0.71	0.17
Jun	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0.29	0.17
July	0	0	11	0	0	3	0	0	0	0	2	0	0	0	1.86	0.50
Aug	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0.29	0.00
sept	0	0	0	0	0	0	5	3	1	0	1	0	0	0	1.00	0.50
Oct	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0.43	0.17
Nov	0	0	9	0	3	0	3	0	0	0	2	0	0	0	2.43	0.00
Dec	2	0	21	6	0	0	1	0	9	4	0	0	3	0	5.14	0.83
Jan	0	0	1	0	0	0	0	1	9	1	5	0	8	3	3.29	0.83
Feb	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0.29	0.17
Mar	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0.00	1.67

Table 2. Monthly total number of low-visibility fog (visibility< 1000 m) hours and dense fog (visibility<200 m) hours

Year/Month/Diverted	2016-17		2017-18		2018-19		2019-20		2020-21		2021-22		2022-23		Mean	
	Net Fog hours	Net dense Fog hours	Net Fog hours	Net dense Fog hours	Net Fog hours	Net dense Fog hours	Net Fog hours	Net dense Fog hours	Net Fog hours	Net dense Fog hours	Net Fog hours	Net dense Fog hours	Net Fog hours	Net dense Fog hours	Mean Fog hours	Meandense Fog hours
Apr	0	0	2	0	0	0	1	0	3	0	2	0	0	0	1.00	0.00
May	0	0	1	0	1	0	0	0	2	0	0	0	1	0	0.63	0.00
Jun	0	0	0	0	0	0	1	0	0	0	1	0	2	0	0.50	0.00
July	0	0	3	0	0	0	0	0	1	0	1	0	1	0	0.75	0.00
Aug	0	0	1	0	2	0	1	1	1	0	4	0	3	0	1.63	0.14
sept	0	0	0	0	1	0	2	0	1	0	4	0	0	0	1.00	0.00
Oct	0	0	7	1	7	0	11	0	1	0	0	0	0	0	3.25	0.14
Nov	50	2	11	0	7	0	37	1	0	0	17	0	7	0	16.25	0.43
Dec	287	75	157	33	49	1	97	19	115	25	10	0	149	4	110.38	22.43
Jan	94	10	316	78	86	3	142	36	172	65	133	15	185	35	145.50	34.57
Feb	43	6	24	2	8	0	8	2	40	5	27	6	10	0	20.25	3.00
Mar	1	0	0	0	3	0	1	0	0	0	0	0	1	0	0.75	0.00

Net low visibility hours, i.e., <1000m and <200 m, vary across the months presented in Table 2. January 2018 and December 2016 were the worst in terms of the number of hours of low visibility at Patna airports. The fog was mainly concentrated in the four months, i.e., November to February, of which December and January were the peak fog months. Also, there is a large variation in low visibility across the different years. It also depends on the seasonal rainfall. If there is less or no rainfall in these months, then widespread, long-lasting low visibility will occur along with the pollution. Rainfall, which settles pollution levels, plays an important role in the onset and dissipation of low visibility.

2.2 Visibility Procedure at Patna Airport

The primary contributors to the poor visibility are lithometers (e.g., dust, pollution, etc.) and hydrometers(e.g., microdroplets). The turbidity or opaqueness of the transparent air is a direct result of the lithometeors and hydrometeors that are suspended in the air close to the airport's observation area. The ICAO and the DGCA have established that stringent compliance with low visibility procedures (LVP) and low visibility take-offs (LVTO) is an absolute necessity for safe air navigation. LVP and LVTO are implemented at an airport to provide safe aviation operations during periods of visibility that are lower than those stated in the preceding list. On those rare occasions when horizontal surface visibility drops below the standard values—which may be the case when there is low visibility or when the height of the low cloud base is low—LVPs are enforced. The CAT-I Instrumental Landing System (ILS) is installed at the JPNI Airport in Patna. During LVTO or LVP, the lights of the runway (RWY) and taxiway (TWY) illuminate the runway for better visibility. The FSM is operational at the RWY 25/07 TDZ, and the Drishti transmissometer is operational at the RWY 25 TDZ . The TDZ and the END RVR must be lower than the reference RVR value for clearance and cancellation of the movement of the aircraft to adhere to the LVP or LVTO. The CAT-I ILS provides for a decision height of 60 metres and either RVR or visibility of at least 1000 metres. When (1) the RVR is less than 1200 m or visibility is predicted to decrease to 750 m or less, or (2) the cloud ceiling is 400 ft (120 m) and is predicted to fall to 200 ft (60 m) or less, the safeguarding procedure is started at the JPNI Airport. The batch in charge will then notify the Airport Traffic Management (ATM) to work with other related authorities to implement LVTO. When RVR drops to 750 m or below and/or the cloud ceiling is lower than 200 ft, the LVP for departures must be used. ILS CAT-I is in operation until TDZ RVR is not less than 550 m, despite the fact that LVP is imposed when RVR is less than 750 m. The India Meteorological Department's Aerodome Metrological Office (AMO) provides accurate information through observation and prediction of visibility to ensure safe operations at Patna Airport.

2.3 Optimal performance of the airports(loss of revenue)

Depending on how long the dense fog occurrence lasts, an aircraft may be delayed, diverted, or cancelled when visibility is extremely low. As a result, such an event burdens airlines with economic costs they have to pay. The economic costs either reimburse the passengers or impose additional costs on them in the form of ground handling and parking fees, Route Navigation Facilities Charges (RNFCs), fuel surcharges for extra hold space, and fees for passenger meals and lodging on both domestic and international flights. The economic loss for the diverted flights is presented in Table 3.

Table 3. Breakdown of charges for domestic flight operations as per the Centre for the Asia Pacific Association

Diverted Flight	
Content	Cost in Rupees (in INR)
Extra fuel Cost	2,00,000
Landing Charges	12000
Ground Hnadling (for atleast 5 hour)	45000
RNFC	4620
Parking Charges	13000
Food Charges	500/person
Accommodation Charge	1000 INR/person/night
Total Cost	About 5,00,000

3. Results and Discussion

3.1 Economic Impact

In addition to technical issues and other unforeseen or imminent threats, meteorological conditions frequently contribute to operational issues with flight navigation (impacts highlighted in Table 1,2). Adverse weather conditions owing to low visibility, including severe weather associated with thunderstorms and associated phenomena like lightning, heavy rainfall, cloud turbulence, and squally weather, frequently cause aircraft delays, diversions, and cancellation. In addition to the aforementioned meteorological conditions, other weather phenomena also cause flight diversions, including deteriorating visibility owing to poor visibility brought on by atmospheric turbidity from fog and mist. The number of hours when poor vision prevents aircraft from moving around costs the airline money in addition to causing problems for the passengers. During November to February, fog is a common occurrence, but in the remaining months, it is occasionally formed for a few hours, mainly attributed to falls in visibility because of the formation and intensification of thunderstorms. The highest number of fog and dense fog hours seen were 522 and 114 in 2017–18 and the lowest in 2021–22, being 199 and 21 presented in Figure.3(a). The subsequent economic losses from dense fog are presented in Figure. 3(b), which signifies that there is a direct correlation between the number of dense fogs and economic losses. The mean number of diversions because of bad weather in December (5.14) was greater than January (3.29) and November (2.43); however, the mean number of dense fog hours in January (33.4) is greater than December (22.4) and November (0.43), which were periods of intense spells of fog. This signifies that the end users(airport operators and airlines) in the onsetting of fog are less aware and sensitive about the impacts of low visibility and stick to the routine, but after using the foreacs of IMD, etc., they rationalise their flight movements in the months of January. It also shows that the fog in the months of December is highly variable in nature, but in January it becomes persistent in nature. Due to rescheduling, diversion, fuel expenses, passenger accommodations and amenities, and other inputs, the longer the fog lasts, the greater its economic impact on the air carriers. In order to clear aircraft during bad weather, airports must keep ex-tended watches and impose aeronautical service fees like Route Navigation Facility Charges (RNFC) for domestic and international flights. Passengers must postpone their plans because of unforeseen schedule changes, which can ruin their once-in-a-lifetime opportunities.

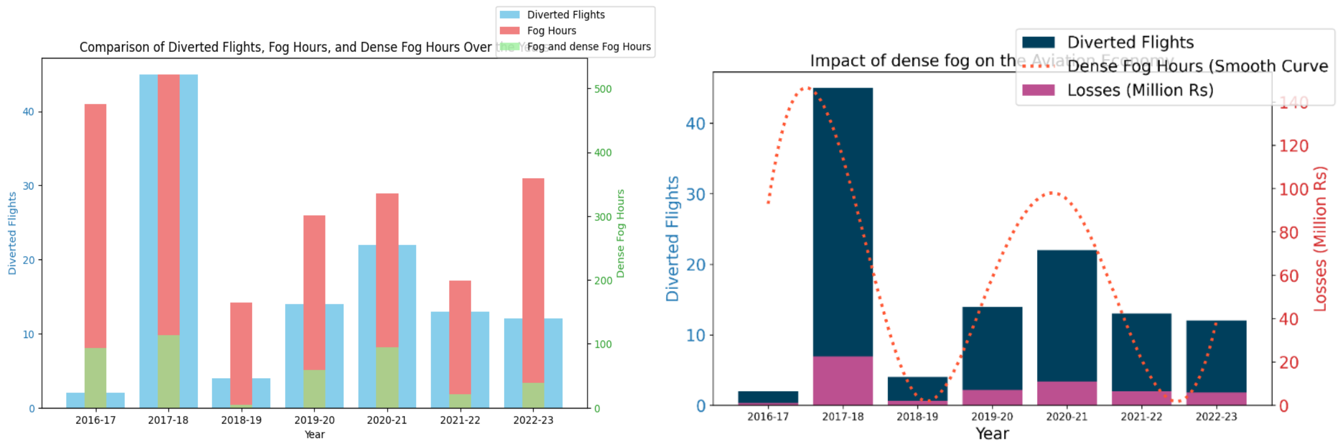


Figure. 3(a) shows the number of total flights diverted (light blue), the total number of fog hours (red), and the total number of dense fog hours (light green) for the studied period (b). Total economic losses due to dense fog hours (orange dotted line) and subsequent losses In million rupees (pink) and the number of flights diverted (deep blue) for the studied period, i.e., 2016–17 to 2022–23.

3.2 Background of the Onset and Dissipation of Fog

During November to February, the onset of fog events at these airports is frequent and the impacts in terms of diversion are significant. There-fore, the machine learning (ML)-based tailor-made quick forecasting of fog patterns, which emphasises the local conditions (or those specific to the IGP regions) [16], may be suitable based on synoptic analysis, empirical methods, and stability analysis from an atmospheric sounding and pollution perspective. These methods will give a peep into the depth of the thermal inversion layers and the possibility of fog persistence. The resulting economic losses are therefore impending and unavoidable. The costs can be reduced, though, with the use of monitoring and diagnostics of fog events . Also, to make timely predictions about the efficient operation of the airport for the different stakeholders, The physical process of the onsetting and dispersal of fog is the key to any fog-forecasting system. Here, the thresholds and range of the favourable meteorological parameters responsible for the onsetting (Figure. 4) and dipersal (Figure. 5) are presenting . In Figure. 4(a), the dry bulb temperature (DB), dew point temperature (DP), and relative humidity (RH) are explained through the box whisker diagram, and Figure. 4(b) shows the wind roses. Similary, the favourable consequences of the dispersion of Fog are presented in Figure. 5(a) (b). This clearly demonstrates that the wind plays an important role in the onset(higher number of calm winds) and dissipation(lower number of calm winds) responsible for fog. But sometimes fog also sets with the prevailing wind. It clearly shows that Patna airports face mainly radiation(associated with the calm winds), advection(associated with the mostly low winds, etc.), and the combination of these two fog types.

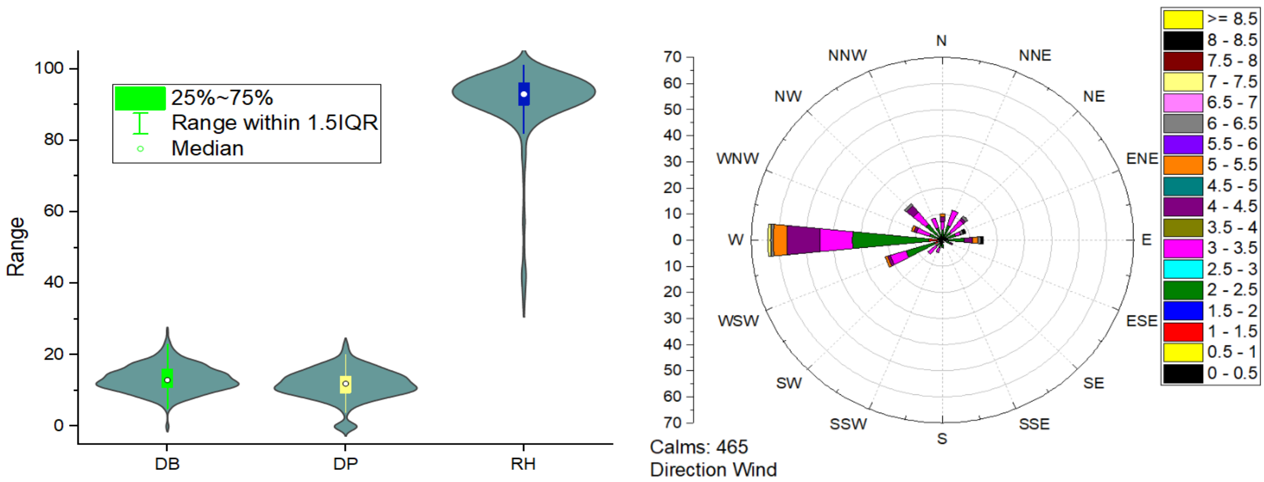


Figure. 4(a): Favourable meteorological conditions (DB-Dry Bulb Temperature, DP-Dew Point Temperature, Realtive Humidity (RH)) (b) favourable wind conditions for the onset of fog

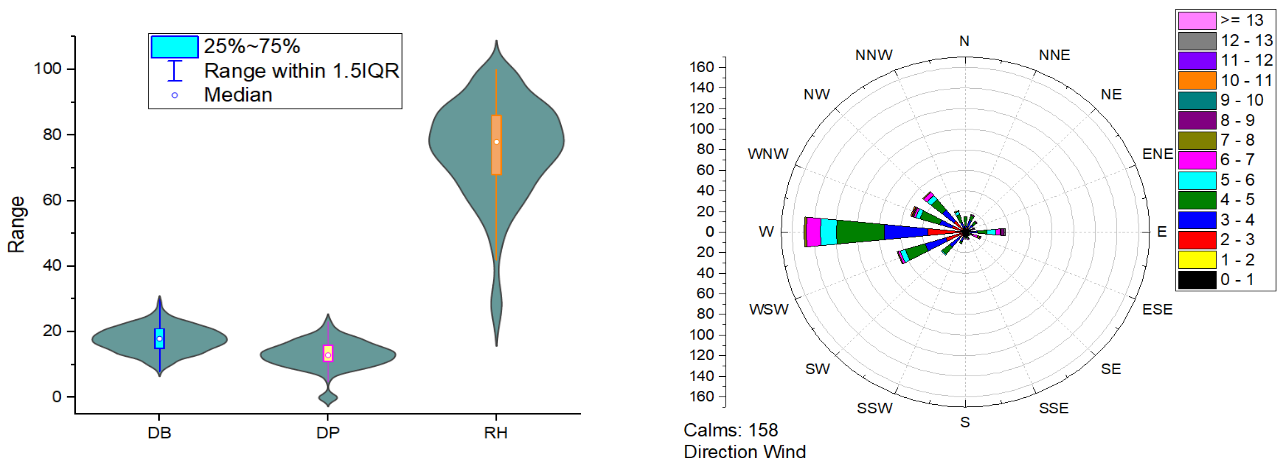


Figure. 5(a): Favourable meteorological conditions(DB-Dry Bulb Temperature, DP-Dew Point Temperature, Realtive Humidity (RH)) (b) favourable wind conditions for the dissipation of fog

3.3 Possible actions to adopt.

Enhancements in aviation services have the potential to yield advantages for both passengers and the aviation industry at large. There are several potential measures that can be taken to improve aviation ser-vices. These include updating and improving the standard operating procedures that are specific to airports in order to meet safety regulations and protocols. This can be achieved through a diagnostic study of the local conditions at the airport, as well as through the implementation and capacity building of various stakeholders such as airlines, airport operators, and meteorological service providers. Furthermore, enhancing communication on precise weather forecasting and monitoring crucial meteorological variables enhances the efficiency of airport operations. The techniques of fog dispersal are not economical either. Fog fore-warning is possible using the satellite as well as products of numerical weather models. Tailor-made forewarning, real-time monitoring through synoptic analysis, empirical methods, and stability analysis from atmospheric soundings of morning and evening GPS-sonde as-cents will give a peep view of the depth of the thermal inversion layers, the possibility of persistence of fog, and hence the ability to forecast and forewarn aviation service providers . Therefore, the costs can be minimised with an improved, machine-learning, tailor-made micro-scale forecasting system topped by synoptic analysis and the deployment of fog monitors, etc [16]. In order to maximise the use of the enhanced weather conditions, it is imperative to streamline the check-in and boarding processes. The effective utilisation of air traffic management in the aviation industry plays a crucial role in mitigating congestion and minimising delays. The authors furthermore propose the implementation of comprehensive crisis management and con-tingency strategies in order to proficiently address unforeseen events, thereby guaranteeing safety and instilling trust in passengers. Utilise data analytics techniques to facilitate enhanced demand forecasting capabilities and optimise operational efficiency. By implementing these measures to enhance aviation services, the potential outcomes include enhanced safety, increased operational efficiency, and improved customer satisfaction, thereby yielding advantages for both the aviation sector and its passengers.

4. Conclusion

Due to its location in the fog-prone Indo-Gangetic plain, JPNI Airport Patna is prone to intense fog in the later parts of the post-monsoon and winter seasons. Therefore, it is important to assess the impact of fog on the aviation economy and how fogcasting systems and standard operating procedures for low visbility, specific to airports, and advancements in landing systems prevent large losses. Fog is frequent from December to February . Inversion layers, low temperatures, or radiative cooling are all potential causes of fog. Between 2014 and 2023, January 2018 had the most fog-prone months. CAPA reports breakdown charges to assess the economic costs of diversions. Dense fog at Patna Airport cost air-lines 35 million Indian rupees in 2017–18 during 522 hours and 114 hours of dense fog, respectively. Radiative cooling causes fog between 1800 and 0600 UTC. Dew point temperature, wind speed, and the dominant westerly wind affected fog development during the studied period. Most fog events take place during the calm and with E-SE winds. The diagnostic approach outlined above may help generate effective airport mobility by using tailor-made nowcasting techniques. Also, reliable fog forecasts based on diagnostic approaches from IMD are crucial, along with airport-specific standard operating procedures for efficient management of air traffic to reduce economic losses. It also optimises aeroplane scheduling at the busiest airport. Both the airport operator and the airline will use it. It will optimise airport operations and airline scheduling.

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Data Availability

The National Data Centre, Climate Research Station of the India Mete-orological Department, provided hourly METAR data (or synoptic hourly data) of weather parameters at JPNI Airport Patna, which can be found at https://dsp.imdpune.gov.in/. Impact statistics in terms of di-version and aircraft incidents were collected from the Airports Author-ity of India. Also, data can be supplied after a request.

Contributions

Conceptualization, A.S.; methodology,A.S.; software,A.S.; validation, A.S.; data curation, A.S.; writing—original draft preparation, A.S.; writing—revised draft, A.S., R.K.G.; supervision, R.K.G.; all authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

Abbrebiations

This manuscript employs the following abbreviations:

JPNI Airport	Jay Prakash Narayan International Airport Patna
RVR	Runway Visual Range
IGP	Indo Gangetic Plain

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