Impact of Aerosols on Winter Fog of Pakistan

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Abstract

Fog is boundary layer phenomena whose formation is usually influenced by surface conditions. Fog is considered as serious hazard in Punjab and Sindh particularly during winter. Winter in Pakistan became short and intense under the changing climate. The increasing trend of fog frequencies in the last decade result in various kind of impacts on human life, irrigation network and economy of the country. The frequency of dense, Moderate and Shallow foggy days has been calculated focusing Punjab and Sindh from 2000-2010. The aim of this study is to identify the fog frequency, its density in the fog prone regions (Punjab and Sindh) of Pakistan and role of aerosols in fog formation. The maximum frequency of dense fog has been observed in Sialkot, Lahore, Bahawalnagar, Faisalabad and its adjoining areas while maximum frequency of Moderate/Shallow fog has been seen in Multan & Sukkur. The decadal analysis of surface visibility from 2001-2010 depicts fall in visibility up to 200m and on some occasions it reduces even up to 50m during dense fog period in upper Punjab. The average dry bulb temperature and relative humidity analysis reveals the fact that decrease in temperature and increase in relative humidity results in increasing frequency of foggy days in Punjab. Calm wind is observed during foggy conditions in Punjab. The ten years aerosol analyses indicate that significantly higher concentration of aerosols and rise in dense foggy days was observed in the eastern parts (Punjab) of Pakistan during the period 2008-2010. There are two major types of aerosols in Pakistan i.e. Dust blowing and Biomass burning. These trans-boundary aerosols enhanced the fog in Punjab and upper Sindh. Their impacts are not only threatening the environment but also for the human health and other living organisms in Pakistan.

Key Word: Fog, Relative humidity, dry bulb temperature, visibility and aerosols.

Introduction

Fog is a meteorological phenomenon in which a cloud (stratus) which has its base on or close to ground level and visibility reduces to < 1000 meters. There are different types of fog i.e. Radiation, Advection, Frontal and Industrial. The radiation fog is the most dominant type of fog, which occurs when the radiational cooling at night decreases the air temperatures to its dew point temperature. The favorable conditions for its development are light wind, clear sky, high moisture and lack of turbulence (Muslehuddin et al., 2004; Dejmal and Repal, 2010). In UAE the soil conditions like soil moisture and vegetation cover influence the soil thermal conductivity which plays a vital role in formation of radiation fog. This property of soil serves as a tool in satellite remote sensing in detection and monitoring of fog (Bushahab et al., 2009). Fog also forms in the environment, where there are large concentrations of aerosols characterized by a low activation super saturation (Brooks et. al., 2009).

Tiwari et al., 2010 stated that northern regions of India experience severe fog conditions during winter (Nov-Jan) every year. The high aerosols loads are an important factor contributing in severity of fog events. Mohan and Payra, 2009 further reported that urban areas in India are experiencing increase in fog frequencies due to high level of pollution, originating from variety of sources. The enhanced pollution load result in atmospheric reactions, producing the secondary pollutants that may lead to increased aerosol concentration in the atmosphere. This could cause enhanced water aerosol in the presence of favorable meteorological conditions and high relative humidity. The duration of foggy days has increased in China during the recent few years due to rapid urbanization and industrialization. The catastrophic events have been experienced because of the dense fog. The most important staple food crop of China is winter wheat, its growth and productivity is quite sensitive to temperature and fog events (Shengjie et al., 2010).

Pakistan receives heavy amount of sulfur dioxide, from the coal burning industries of India, which is adjacent to northeastern parts of Pakistan. Hussain et al., discussed, that during the foggy days in Lahore

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the concentration of sulphate were exceptionally high, and suggested that fog may be caused by the high SO_2, and it is main component of fog. These trans-boundary pollutants result in severe foggy conditions in Punjab. It creates hazardous conditions for air and road traffic, human health and agriculture. The cities under influence of this severe fog, cut off from the other regions of the country thus making problems more complex (Saeed, 2004). Fog is a phenomenon which usually appears for few hours. The source for moisture availability for fog formation in Pakistan is Indus River, Western Disturbances and Soil moisture. The plains of Punjab have shown significant increase in intensity and duration of fog events during the present decades. It has been analyzed in a study that during El Nino years the atmosphere pressure increases over the region, this high pressure increases stability and results in to favorable conditions for fog formation, particularly during winter in Pakistan (Saeed and Yonus, 2004).

Fog usually forms during November to February in Pakistan. Most of the studies made Punjab as a focal point for fog formation. The areas of Sindh are equally important to study foggy events. Therefore this research will cover the investigation of dense foggy days both in Punjab and Sindh province of Pakistan from 2000-2010. The decadal analysis has been done by calculating correlation with different meteorological parameters. The analysis of poor and good visibility has also been made.

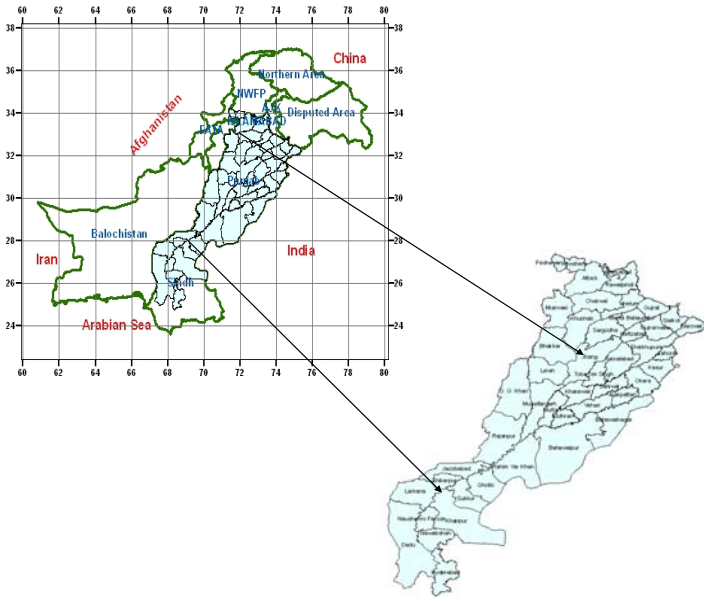

Figure 1: Study Area of Fog.

Data and Methodology

The monthly data of dry bulb temperature, relative humidity, and wind direction from 2000 to 2010 were obtained from the Climate Data Processing Center (CDPC), of PMD Karachi. The hourly data set of synoptic surface visibility, weather conditions (such as haze, fog) have been acquired from Regional Meteorological Center (RMC), Lahore. The weather condition data provide information on the number of foggy days as represented by WMO land SYNOP codes from 40 to 49 for fog at the time of observation, ,from the winter during period of 2000 to 2010. The fog data is dividing into two type's dense and Moderate/Shallow fog, following criteria of Visibility ≤ 200m as dense fog and visibility ≥ 200 m up to 999 m as Moderate/Shallow fog. Table 1 categorizes the fog according to visibility range.

Table 1: Fog types according to Visibility (m).

Fog types	General visibility ranges (m)
Shallow	999-500
Moderate	500-200
Dense	200-50
Very Dense	<50

The ten years daily mean data of Aerosol Optical Depth (AOD) at 550nm and Angstrom Exponent 470 / 660 nm of MODIS of spatial resolution 1° x 1° degree, level 3 was obtained from Goddard Earth Sciences, from Information services Center, NASA. These datasets are used in this study to examine the

effect of Aerosol on winter fog formation during the period 2001-2010 in Pakistan (Punjab & Sindh particularly).

Results and Discussion

Fog is a huge problem in Pakistan, during winter season. The eastern Pakistan, especially the Punjab and Upper parts of Sindh, suffer from widespread fog, when background meteorology is relatively calmer. Saeed et al., (2004) identified that radiation and frontal fog formed over Punjab. The study sites are located in eastern part of Pakistan, where climate categorizes from temperate-moist. The average temperature is winter 5-15°C. The study area of Sindh and Punjab are crop yield areas. The moisture availability is in abundance in this region due to passing Indus and other rivers, and irrigation canal system. Another source is the western disturbances which move from west to east.

I- Frequency of Dense and Moderate/Shallow Foggy Days

The meteorological factors are important in fog formation, fog is assumed to form when the near-surface air temperature is nearly equal or falls below the dew point temperature and ground value of ground relative humidity to be above 90% or some time reaches 100% and wind condition are calm. Figure 2 (a) illustrates the maximum frequency of dense fog in Sialkot, Lahore, Bahawalnagar, Faisalabad and its adjoining areas. The maximum foggy period depict the significant availability of moisture, either in the form of Western disturbance or vast irrigated agricultural fields. Figure 2(b) depicts that the frequency of Moderate/Shallow foggy days are higher in Sialkot, Faisalabad, Mulatn and Sukkur. Central Punjab, Upper Sindh, Dadu and Larkana also experienced the moderate and shallow fog frequency. In lower Punjab and Sindh visibility reduced due to smoke, haze and smoky weather condition during study period. Hyderabad and Nawabshah experienced minimum fog frequency due to average wind speed of 1-2 m/sec, low humidity and high temperature.

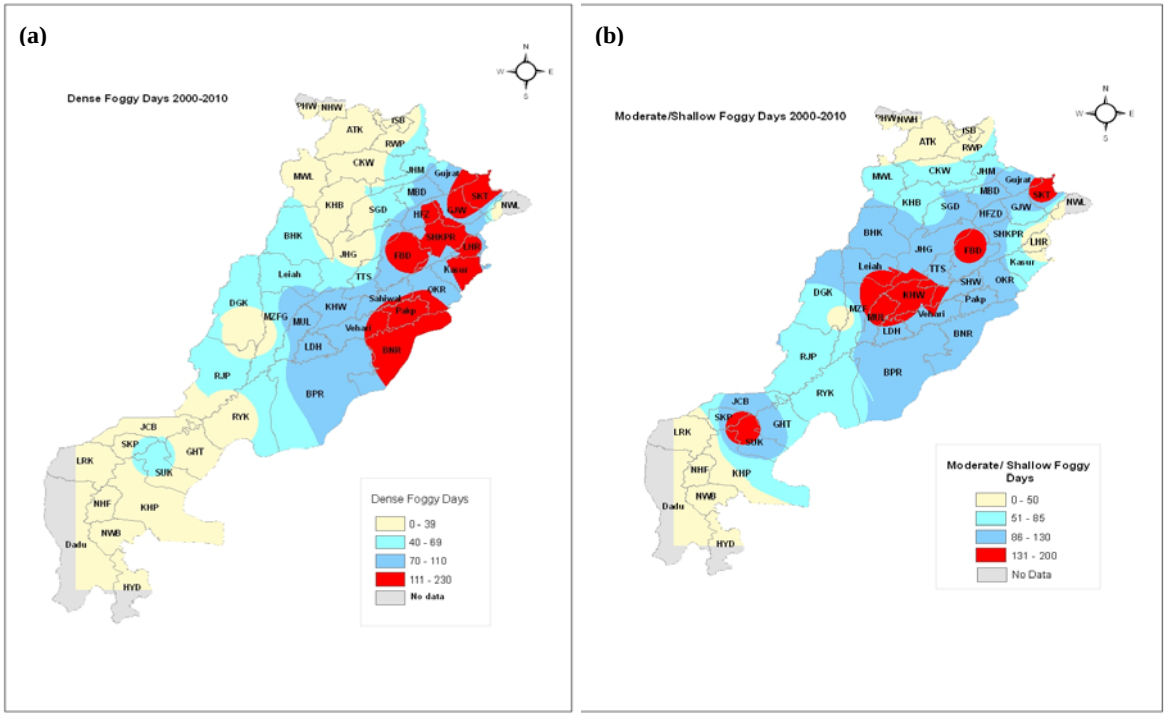

Figure 2: Frequency of **(a)**, dense foggy days, **(b)**, Moderate / Shallow foggy days 2000-2010

II- Synoptic Surface Visibility in Foggy Days

The surface visibility is an important factor while analyzing fog. Therefore decadal analysis of surface visibility from 2001-2010 has been done. Figure 3 shows that the hourly synoptic surface visibility during foggy days. It has been observed that the normal visibility during winter season is >10,000m in Punjab and Sindh. The results show that the visibility fall up to 200m during dense foggy days in upper Punjab (Lahore, Faisalabad, Sialkot and Bahawalnagar) some times it reduces even up to 50m. This reduced visibility highly affects these areas of Punjab and is considered as hazards for transportation and health. The photosynthesis process is also retarded during dense foggy days as sunlight does not reach the earth properly. Hence dense foggy days have very bad impacts on crops growth of these areas as well. The lower elevated stations of Punjab (Multan, Rahim Yar Khan and Bahawalpur) indicate the visibility range in foggy days, around 900m. The visibility in lower Punjab is much better as compared to the upper Punjab. It is therefore expected that upper Punjab is more prone to casualties and catastrophe during dense foggy days.

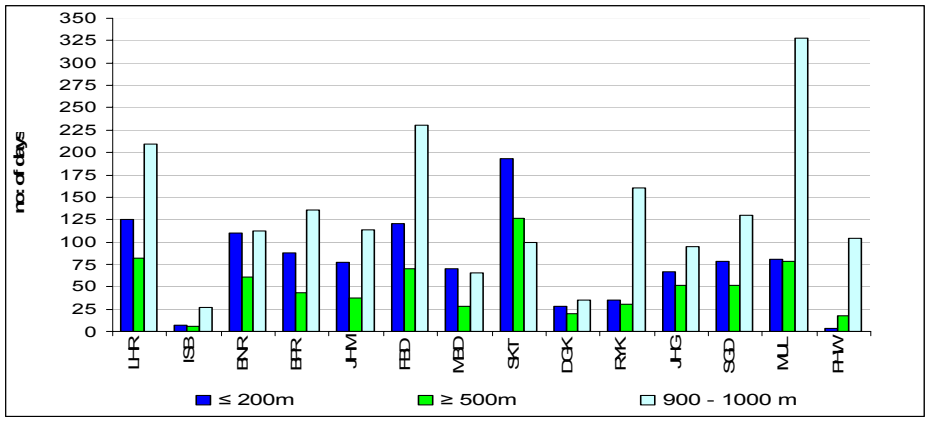

Figure 3: Synoptic Surface Visibility (m) of Punjab 2000-2010

III- Dry Bulb Temperature & Relative Humidity in Foggy Days

The mean monthly dry bulb temperature and mean relative humidity have been calculated from 2000 to 2010 for the months of November, December, January and February during the study. The average dry bulb temperature and relative humidity in the morning generally ranges between 9-15°C and RH as 70-90% during November and February. Due to this shallow frequency of fog is formed as shown in Figure 4(a) & (b). In case of entire winter (December to January) average temperature falls between ranges 5-11°C and average humidity ranges from 80-92%. December and January are the coldest months and more fog form, especially in eastern Punjab (Muslehuddin et al., 2004). On the contrary the minimum frequency of fog has been found in Dera Ghazi Khan and Hyderabad due to higher temperature and lower relative humidity. The graph shows that the decrease in temperature and increase in relative humidity results in increasing frequency of foggy days in Punjab as compared to Sindh.

Fog often forms after sunset as the air and ground surface begin to cool and condensation replaces the evaporation (Aruan et. al., 2010). The monthly average of temperature ranges from 15-25°C in upper Punjab and 15-30°C in lower Punjab including Sindh stations (Sukkur, Nawabshah and Hyderabad) during November and February as shown in Figure 5(a)&(b). The temperature ranges 10-20°C at higher elevated foggy stations and 15-25°C at lower elevated stations in winter seasons. Similarly the average relative humidity ranges between 40-60% during the study period. The temperature drop and increase humidity at night time are favorable conditions for the formation of radiation fog. The study region is the major crop yield region of the Pakistan and the irrigated soil provide the moisture for fog formation.

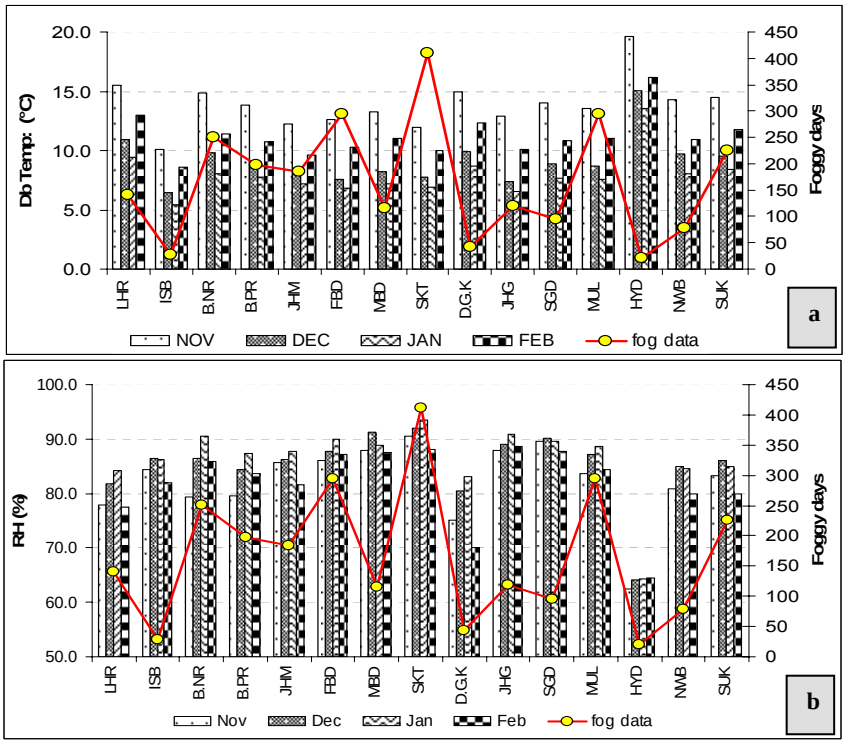

Figure 4: (a) Average Dry Bulb Temperature 0000 UTC
(b) Average Relative Humidity 0000 UTC Nov-Feb 2000-2010

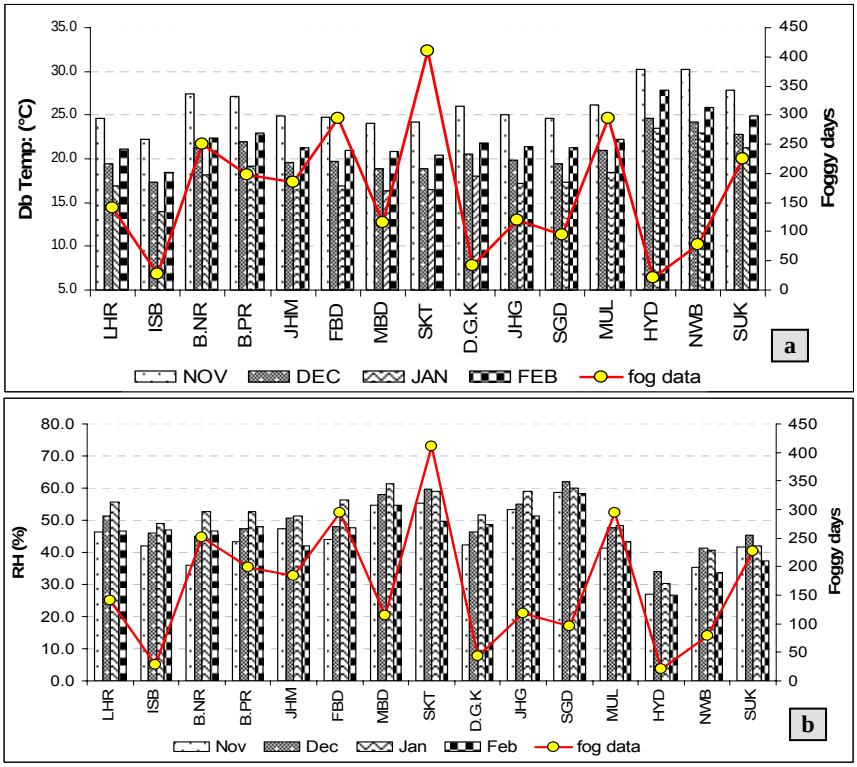

Figure 5: (a) Average dry bulb temperature 1200 UTC
(b) Average relative humidity 1200 UTC Nov-Feb 2000-2010.

Aruan et, al., 2010 stated that the soil moisture flow above the ground in winter and below in summer months due to temperature gradient and its upward movement contributes to moisture availability at low level and this enhances the radiation fog. The higher concentration of rivers, canals reservoirs and local water bodies may also contribute the rising of humidity of these cities.

Rasul et, al., 2011 discussed the behavior of minimum temperatures of agricultural plains of the country results show the increasing trend of minimum temperature during the recent ten years over the agriculture plains of all the provinces of Pakistan. The maximum and minimum temperatures of the foggy regions have also been investigated by Syed et, al., 2004; Maida and Rasul, 2011. They reported significant increase in maximum and minimum temperatures of all the foggy stations.

IV- Role of Wind Direction in Foggy Days

Fog is more likely to occur when wind is calm. Figure 6 depicts that the wind pattern of different cities are mostly similar during both normal and foggy days. But it has been observed that in Lahore, Sialkot and Faisalabad more than 80% winds are usually calm and north-west direction pattern is dominant. The western disturbance is a low pressure system which move west to east (Dimri, 2007), and it gives the winter precipitation to upper Punjab. After rain, moisture in air transform into Fog. The topography of fog affected areas and lighter wind speed 1-3 knots causes the moisture stagnant in this region for longer time (Muslehuddin et al., 2004, Saeed and Youns, 2004). The fog persistence for longer period mostly depends upon lower temperature, high value of relative humidity and calm wind conditions.

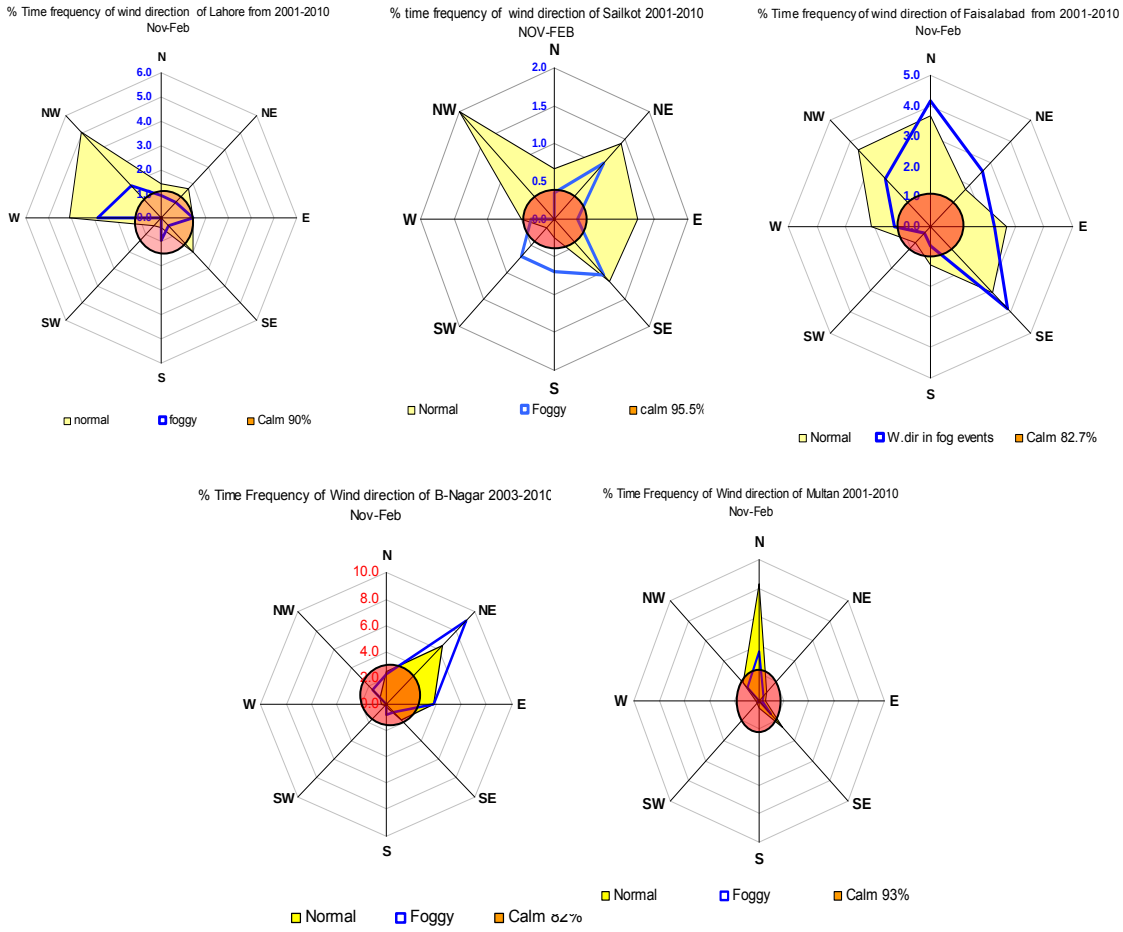

Figure 6: Wind directions in Foggy days from Nov-Feb 2001-2010.

V- Role of Aerosols in Foggy Conditions

It is well understood that aerosols have serious regional implications. Gautam et al., 2007 defined aerosols in the shape of liquid or solid particulates primarily suspended in troposphere and stratosphere. The origin of atmospheric aerosols are both natural and anthropogenic, smoke from natural wild-land forest fires, dust lifted from desert and sea salt from ocean, while soot and sulfates particles from fossil-fuels and bio-fuels emissions are considered as anthropogenic (human made) aerosols. Aerosols particularly those near the surface impact the climate of the region, its environment, air quality, visibility and on human health. North-eastern part of Pakistan is dominated by fine mode aerosols. These types of aerosols are transported from Indo-Gigantic Plains. Abish and Kumar, 2011, stated that the IGP and surrounding are the major source of fine mode aerosols. The occurrence of Aerosol is due to transport of aerosol from biomass burning in IGP associated with wind direction from NE and E during October to November. Basically different type of aerosols and typically range in size from 0.001 μm to 10 μm in diameter, divide into three range < 0.1 μm are Aitkin nuclei mode, diameter ≤ 2.5 μm considered as "Fine mode" or accumulation mode and > 2.5 μm are coarse mode (Sharma, 1994, Kelly, 2011). Biomass burning and urban aerosols which are dominated by fine mode accumulation particles formed by combustion and condensation, process and desert dust are dominated by coarse mode particles originate from primary emission such as wind blown dust, sea salt, fly ash, and road dust (Eck et al., 1999). Increased concentration of Aerosols Optical Depth over the north western IGP in the month of October are associated with crop residue burning, while bio fuels and fossil fuels are both of the sources of fine mode aerosols in agricultural areas (Sharma et al., 2010 Kakaoutis et al., 2011). Figure 7, shows that the crop burning activity at Pak-Indo border and adjoining areas from mid October to November 2010 {source (FIRMS Global Fires Alerts-UN-FAO/UMD/NASA)} is responsible for origination of fine mode aerosols to take part for the fog and hazy/smoky days in this region.

Figure 7: Fire activities at Pak-Indo border

Two major source of aerosols in Pakistan are, dust blowing from deserts either local or neighbor countries like Iran, Afghanistan and northern Africa, and other is biomass burning activity across Pak-India trans-boundary especially in later half of the dry season. The Trans boundary effects of this pollutant have threaten the environment, humans and other living organisms in the Pakistan region. High Aerosols concentration over northern part of India travel towards Pakistan is associated with wind direction from NE to E during the period October-November, which is due to transport of aerosol from biomass burning in IGP. Aerosols serve as cloud condensation nuclei (CCN) for cloud formation, and are hygroscopic in nature. It seeks water vapour when humidity is high and reduced the visibility (Parameswaran and Vijay Kumar, 1994; Kotchenruther et al., 1999). The aerosols are contributing to global dimming, decrease the sunlight reached the earth surface.

In this study, it has been observed that the trans-boundary aerosols enhanced the fog in Punjab and upper Sindh. Shengjie et al; (2009) stated that the relation between the aerosols and fog are dual, it can promote the fog formation. It has been noted that fog formed due to pollution as well as meteorological factors. Aerosols are accelerating and intensifying the fog formation because fog droplets are formed by the condensation of water vapors on to the aerosols particles in the presence of relative humidity (Mircea et al; 2002, Mohan and Payra, 2009). The mean daily aerosols optical depth

used in this study is obtained from the MODIS level 3 (L3) 1°×1° equal angel grid data product years of 2001-2010 (November to February). AOD retrieved at different wavelength such as 340, 440, 500, 675, 870 and 1020 nm (Alam et al: 2011; Dey et al: 2004). This study discusses the Angstrom exponent (ALPHA) (470-660 nm) and it determined from the spectral dependence of the measured optical depth. Liu et al; 2008" and Alam et al; 2011: stated that the angstrom exponent is a good indicator for aerosol size. High value of Alpha indicates the dominance of fine particles, while its low value indicates dominance of coarse particles.

Figure 8, shows the year-to-year variation of aerosols, with the help of angstrom exponent here identified the fine particles, the magnitude of AE are relatively high indicating the greater contribution of fine particles to extinction in the region. According to results the high aerosols concentrations exists over northern part of India and travel towards Pakistan. Lahore and adjoining areas, hazy and smoky days, significantly start after massive rice straw is burning in the area from mid October to November almost every year. It is noted that from 2008 to 2010 significantly higher concentration of Aerosol in is the Eastern parts of Pakistan. It also increased the dense foggy days from 2008 to 2010 in this region. The study conducted by SUPARCO reported exceptionally high SO_4^{-2} concentrations during the foggy days in Lahore (Lodhi et al., 2009). It has been observed that the mean Angstrom exp. value range from 0.4-0.8 for the duration 2001-2008(February), and 0.8-1.4 from 2008(November) to 2010(February).

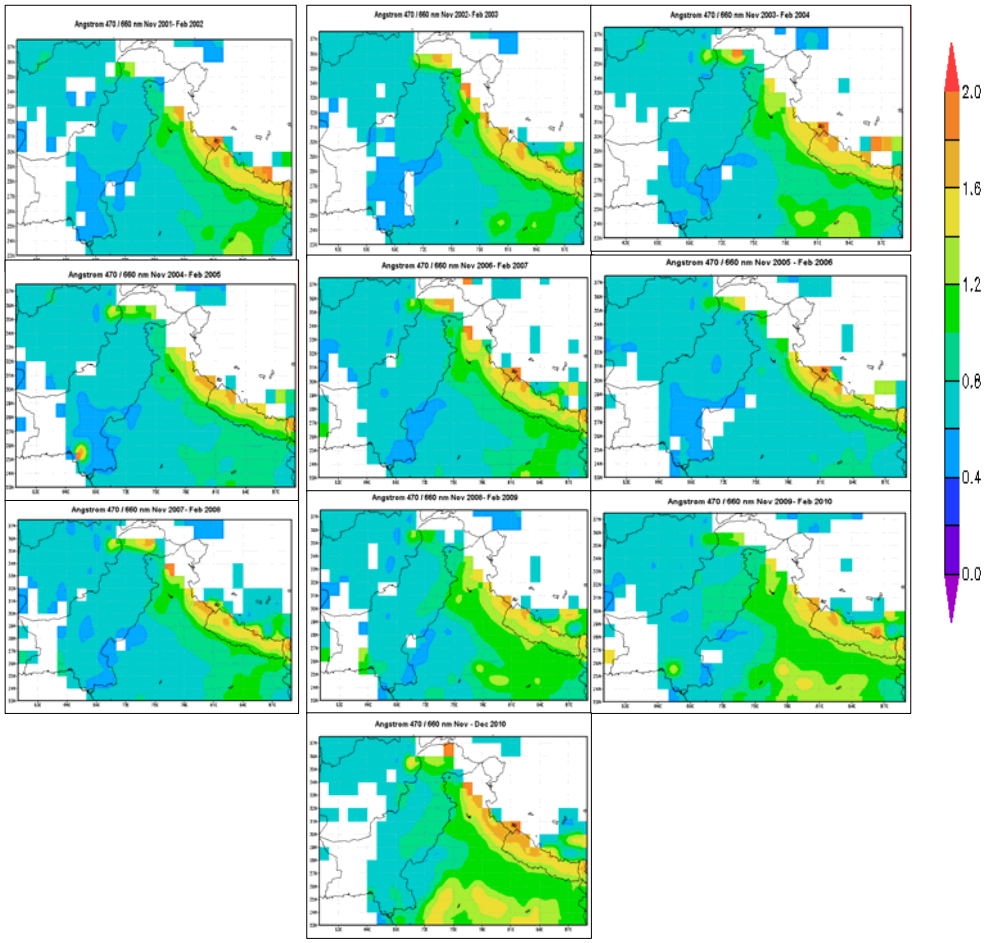

Figure 8: Spatial variations of Aerosols yearly basis from 2001-2010 (Nov-Feb).

Conclusion:

The frequency of fog formation over Punjab and Sindh has been analyzed for the period 2000-2010. On the basis of results it is concluded that the fog is a local phenomena, and the process of fog formation is controlled by a complex combination of meteorological factors like dry bulb temperature, relative humidity, wind speed and direction. But aerosols also play vital role in fog formation as it contains cloud condensation nuclei which are hygroscopic in nature; they trap more moisture and affect visibility. The persistence of fog duration is mainly associated with the effect of air pollution. The huge amount of CCN enhances the of smaller cloud droplet concentration. Fog is generally formed when atmospheric conditions are stable in upper level. The regions of Punjab and Sindh comprise of major agricultural fields in the country which also take part in fog formation as soil conditions have important role in radiation fog formation. The aerosols analysis reveals that the north-eastern part of Pakistan has been dominant by fine mode aerosols most probably due to its transport from biomass burning in Indo-Gigantic Plains (IGP) from October to November. This burning produce large amount of smoke aerosols with high optical depth. During study period, it has been observed that the mean Angstrom exp. value range from 0.4-0.8 for the duration 2001-2008(February), and 0.8-1.4 from 2008(November) to 2010(February). It has been analyzed that the higher concentration of aerosols enhances the fog frequency/intensity in Pakistan from 2008-2010. The higher concentration of aerosols amplifies the duration/intensity of fog in Pakistan but only under favorable meteorological conditions. It has been noted that the transboundary pollutants have adverse impacts on the environment of Pakistan, and causes the dense fog formation in the agricultural areas of Punjab and Sindh.

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