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Trends in winter fog events in the Terai region of Nepal

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ABSTRACT

Winter fog events of the Indo Gangetic plain (IGP) including the Terai area of Nepal are considered to be one of the important public concerns due to their effect on people's health, transportation, and agriculture. Unlike the IGP area of India, Pakistan and Bangladesh there are only very few fog related studies reported about the Terai region of Nepal. This study is carried out to study the occurrence of fog in the Terai region of Nepal by analysing the historical visibility data from 1980 to 2015 at four airports in the region (Nepalgunj, Bhairahawa, Simara and Biratnagar). It was found that the fog events in the Terai start in the month of November, reach the peak in December/January and end by the end of February. The average number of foggy days ranged from 24 days to 56 days per annum and average number of day-time foggy hours varied from 71 to 169 in the study. Visibility during winter is decreasing at all stations during the study period. The Man Kendall test indicated fog related parameters such as foggy days, foggy hours, dense foggy days, dense foggy hours have increasing trends at least at 0.1 level of statistical significance during the study period. The increasing trend of foggy days and daytime foggy hours may reduce winter crop production and negatively affect the food security of the Terai region of Nepal.

1. Introduction

Winter fog events have been a regular phenomenon in the North Indian Indo-Gangetic Plain (IGP), including the southern Nepalese Terai plain area, since 1990 (Manandhar, 2006). Increased fog events not only reduce Photosynthetically Active Radiation (PAR), but also reduce the air temperature with an observed increase in cold waves, which were found to be statistically significant in the Terai area of Nepal (Manandhar et al., 2011). As the Terai is considered to be the food basket of Nepal, the effect of fog on crop production is not only important for the livelihood of farmers in the Terai, but also the food security of the country. Here we study trends in fog events in the Terai over the last three decades and develop a simple empirical model to estimate fog events based on routinely collected meteorological data.

Fog is defined as a suspension of very small, usually microscopic, water droplets in the air that reduce visibility to less than 1000 m at the Earth's surface (WMO, 1975). Atmospheric pollution has a direct relationship with fog occurrence because particles emitted to the atmosphere act as Cloud Condensation Nuclei (CCN), which are essential for the formation of fog. Air pollution is considered to be a key environmental issue for South Asian countries *viz.* India, Pakistan, Nepal, Bangladesh and Afghanistan (UNEP and DA, 2014). The impact of air pollution has become severe in this region due to very high levels of particulate matter in the atmosphere, resulting in 40 South Asian cities being among the 100 most polluted cities in the world (WHO, 2016). The effects of air pollution is not only limited to urban centres, it has become a regional as well as global problem due to the long range transport of aerosols (Ramanathan and Feng, 2009). MODIS imaging has revealed aerosol loading has a significant impact on fog/low cloud occurrence during winter across the Indo Gangetic Plain (IGP) ranging up to 3000 km in length (spreading from Pakistan in the west to Bangladesh) and 400 km wide, including the plain area of Nepal and Northern India (Gautam et al., 2007).

Fog records at Hisar, India (western IGP), from 1992 to 2008 clearly indicate fog event occurrence is increasing at the rate of 2 days per season during that period (Singh and Singh, 2010). Based upon analysis of observational fog occurrence data in south Asia during 1976–2010, Syed et al. (2012) reported fog frequency increased by 3 times during the last 35 years. Similarly, analysis of fog characteristics over the Indian IGP from 1971 to 2010, found the frequency of fog occurrence increased significantly during December and January over the last four decades (Srivastava et al., 2016). Syed et al. (2012) analysed visibility data from 82 IGP stations across India, Pakistan and Bangladesh for December, January and February during 1976–2000 and found the Western IGP (Punjab, Haryana and Uttar Pradesh) was most affected by fog with more than 18% of winter days being foggy during the study period. Syed et al. (2012) also found the trend in fog occurrence in the region increased in 3 steps: step 1 (1976–1989) with a mean fog

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fraction of 6.1%; step 2 (1990–1997) with a mean fog fraction of 10.1%; and step-3 (1998–2010) with a mean fog fraction of 19.5%. By using the Mann-Kendall test, Srivastava et al. (2016) concluded that there is an increasing trend of fog occurrence in the entire IGP with 95% confidence level.

The increasing trend in dense fog events in winter in the IGP has negatively impacted the day-to-day life of millions of people living in the region through frequent flight / train delays due to poor visibility (Jenamani, 2007). Along with reduced visibility, the increased fog events have changed meteorological conditions in winter with a decrease in day-time temperature and an increase in night-time temperature (Aslam, 2012), due to fog reducing solar radiation at the surface during day-time and absorbing night-time long-wave radiation emitted from the surface. Analysing monthly cloud data over the IGP, Sathiyamoorthy et al. (2016) found that fog episodes exerted significant radiative cooling in the IGP, even up to 50 Wm^{-2}. The increase in fog events in the north western plains of India has also been reported to affect the growth and development of the wheat crop due to reduced, or no, photo-synthetically active radiation (PAR), cold stress and congenial conditions for disease and insect pest development (Singh and Singh, 2010).

Although there have been several fog related studies in the Indian and Pakistan sections of the IGP, there are few results reported for the Terai section of the IGP in Nepal. Analysing 36 years of daily temperature records (from 1971 to 2006) in Nepal, Baidya et al. (2008) found that the minimum value of daily maximum temperature trend in the plain area of Nepal is different to that in the hill and mountain regions. In the Terai, the minimum value of maximum temperature and the diurnal temperature range were found to have decreasing trends during winter. In the IGP area of the Koshi basin, the maximum temperature in winter and the pre monsoon season was found to have a statistically significant decreasing trend with an increasing number of cold days in winter between 1975 and 2010 (Shrestha et al., 2016). Baidya et al. (2008) mentioned that decreasing trend of maximum temperature and diurnal temperature in winter in the Terai stations could be due to the increased occurrence of fog events in the Terai region in recent decades. Manandhar (2006) observed that in the Terai continuous fog events with brief openings during winter blocked solar radiation reaching the ground and resulted in the maximum temperature in the afternoon remaining low and near to the minimum temperature, which creates a cold wave situation. Cold waves are one of the important disaster events that occur in Nepal during winter. It is reported that there have been 821 deaths due to cold waves in Nepal since 1990, of which 724 are reported in the Terai region, with the death rate increasing after 2002 (DesInventor, 2015). Similarly, fog is reported as unmeasured weather events in Terai which have considerably affected plant growth during winter over last fifteen years (Smadja et al., 2015). Increased winter fog has become an important issue due to its enormous effect on the health, agriculture, transport and livelihood of the people of the Terai region of Nepal. To better understand the change in meteorological conditions in the Terai during winter, there is a need for a systematic study of fog events in this region. This study aims to analyse past fog events in the Terai region of Nepal and search for a relationship between meteorological conditions and fog events in this region. In Nepal, systematic fog related data have not been collected, so developing a relationship between fog events and meteorological parameters is expected to help assess fog behaviour from more readily available meteorological observations.

2. Methodology

2.1. Study Area

The Terai region of Nepal is a narrow plain area extending from east to west along the foothills of the Himalaya (Fig. 1) and is considered to be an extension of the Gangetic plain of India (GON, 2011). The elevation of the Terai region ranges from 60 m to 200 m and it has a sub-tropical climate. The average monthly maximum temperature, minimum temperature and rainfall of selected stations in the Terai are presented in Fig. 2. Most rainfall (more than 80%) occurs in the monsoon season (June–September) in Nepal. With flat land and the availability of irrigation facilities, agriculture is the major economic activity in the Terai, with rice, wheat, maize, lentil, and sugarcane as the major crops. The 2001 and 2011 census data indicated that the population growth rate in the Terai was higher (1.71%) than in the Hill Districts (1.06%) and Mountain Districts (0.54%) during 2001–2011, which was mainly due to increased migration from the hill and mountain districts to the Terai (CBS, 2016). Even though the Terai region occupies only about 17 percent of the land area of Nepal, it is considered to be a very important region of Nepal as it is home to more than 50 percent of the Nepalese population and is the food basket of the country (CBS, 2015).

2.2. Data and methods

Weather reports in Meteorological Terminal Air Report (METAR) format are recorded in major airports of the Terai and are utilised mainly for aviation purposes. Apart from other regular meteorological information, visibility is also recorded in METAR datasheets. The database of METAR observations is not maintained systematically in Nepal. Historical meteorological and visibility data from METAR datasheets at four representative stations in the Terai, as listed in Table 1, were collected by the lead author from the Nepalese Department of Hydrology and Meteorology (DHM) and transcribed to electronic form for this study. Trained meteorologists are involved in recording and monitoring meteorological data (including visibility data) at airports in Nepal and the METAR report follows a standard protocol to obtain consistent quality data (personal communication with DHM Officials). Transcription of visibility data from each METAR record sheet to electronic form was cross-checked entirely to eliminate mistakes. METAR visibility observations at 3 h intervals (0:0 UTC, 3:0 UTC, 6:0 UTC, 9:0 UTC and 12:0 UTC; local time is UTC + 5:45) were used to study fog events during winter months (November, December, January and February) at these four stations. The time of sun rise and sun set in the study months were calculated based on Meeus (1999). The time of civil dawn (sun 6 degrees below the horizon) and civil dusk (sun 6 degrees below the horizon) was calculated in winter months at each station to discard poor visibility data recorded during night-time hours. Accordingly, the visibility data recorded at 0:0 UTC and 12:0 UTC at each station under study were omitted from the analysis. In the study area the poor visibility during the study period is assumed to be only due to fog because other recorded reason of low visibility such as smoke, dust storm etc. was not found to be reported so far. Based on the visibility data, fog events and dense fog events were identified as occurring when visibility was less than 1000 m and 200 m respectively. The number of foggy hours and dense foggy hours in a day were estimated by assuming that if it was foggy at the observation time, then the fog persisted from 1.5 h before the observation time to 1.5 h after. Therefore a maximum of 9 foggy hours was assigned to the day light hours over the winter period.

The Mann Kendall test, as described by Gilbert (1987), was applied to determine whether statistical trends in visibility/opacity, foggy days and dense foggy days during winter months existed at the four Terai stations. This nonparametric test performs well, even with missing values and outliers, and is widely used in trend analysis of environmental data (Connor et al., 2012, Guerreiro et al., 2014; Salmi et al., 2002) and has been successfully used in trend analysis of fog in India (Srivastava et al., 2016). In the Mann Kendall test the trend is assumed to be monotonic and there should be no seasonal cycle in the data. To avoid the seasonal/monthly cycle, only the opacity, foggy days and dense foggy days in each month during winter and over the whole winter season were analysed. In this test, the null hypothesis (H_o) is that there is no trend in visibility, foggy days, dense foggy days, foggy hours and