論 文 の 内 容 の 要 旨

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論文題目

Long term change of sunshine duration in Nepal as influenced by the atmospheric brown clouds and biomass burning
（大気の茶色雲とバイオマス燃焼によって生じたネパールにおける日照時間の長期的変化）

Chapter 1. Introduction: Background and objectives of study.

Solar radiation (SR) at earth's surface is the primary energy source for life on our planet. Over the past decades, there had been significant reduction in SR referred to as 'global dimming' in regions with high concentrations of anthropogenic aerosols such as India and China. These aerosols are produced as a result of large scale combustion of fossil fuels and biomass burning and have significant impacts on hydrological cycle, monsoon circulation and regional climate change.

Nepal, with the Himalayas in the north, acts as a barrier that separates a region of abundant aerosols in the Indo-Gangetic plains (IGP). These aerosols transform into thick, persistent layers of haze known as 'Atmospheric Brown Clouds' (ABC) and are transported to as far as the Himalayas. In addition to the trans-boundary air pollution, local pollution has increased drastically in major urban cities of Nepal. Despite such evidences of local and regional air pollution, no study on change in SR has been reported for Nepal. In this thesis, I elucidated long term changes in SR by analyzing temporal changes in sunshine duration (SSD) over an extended period in Nepal and identified the major drivers of the observed changes in SSD. I also identified the sources contributing to the major drivers with particular focus on aerosol emissions from different combustion sources and the influence of trans-boundary air pollution.

Chapter 2. Long term trends of sunshine duration in Nepal for the period 1987-2010.

In this chapter, I analyzed temporal changes of sunshine duration (SSD) in Nepal across its three physiographic regions: plains, low-hills (LH) and high-hills and mountains (HHM) for the period 1987-2010 with the records at 13 meteorological stations. I found declining trends in SSD, i.e. solar dimming, across the country at a rate of -0.20% per year with the highest decline in post-monsoon season (-0.33% per year) followed by pre-monsoon season (-0.24% per year). A close look at the individual stations indicated that the declines in pre-monsoon and post-monsoon seasons are common regional phenomena. By region, the dimming was pronounced (-0.56% per year) in the plains at 0-300 m a.s.l. and gradually diminishes with an increase in elevation. The decline in the stations in the plains closely matched the decreasing trends observed at the stations lying in IGP confirming the persistence of dimming over the region.

Chapter 3. Possible drivers of the decline in sunshine duration in Nepal.

In this chapter, I identified the major drivers of the decline in SSD by analyzing trends in SSD on clear day (S_clear) to understand the role of aerosols and trends in SSD on cloudy days (S_cloudy) to understand the influence of clouds across the period 1987-2007. A significant decline was found in S-clear trends at a rate of 0.42% per year, with intense dimming at the stations located in the plains and Kathmandu, suggesting direct effect of aerosols. Seasonally, the decline in S-clear was evident in all the dry seasons (October to May) in the plains, with highest dimming at a rate of -1.27% per year in the winter season. On the other hand, the trends in S_cloudy showed intense dimming at a rate of 3.27% per year with strong decline in all the three regions. Seasonally, the highest decline in S-cloudy occurred in monsoon followed by pre-monsoon season

The 8 times higher decline in S_cloudy compared to S_clear indicated that clouds play much larger role in the observed dimming than aerosols which could be likely due to the increasing trends in cloud amount. Trends in total rainfall (R) did not show any significant increase which could explain an increase in cloud amount rather a significant decline was observed in total number of rainy days (NRD). Analysis of light rainfall events (R<=10mm, NRD<=10mm) and heavy rainfall events (R>=45mm, NRD>=45mm) revealed significant decline in light rainfall events while moderate increase was observed in heavy rainfall events. Such anomalies in light and heavy rainfall events suggested the role of indirect effect of aerosols, in which the aerosols could interact with the clouds to suppress light rainfall from shallow clouds but could increase the rainfall from deep clouds in the later stage. The aerosol induced increase in shallow and deep clouds as reflected by the decrease in light rainfall events and increase in heavy rainfall events could be the most plausible explanation for the high dimming observed in S_cloudy in Nepal.

Hence, both direct and indirect effects of aerosols have been identified as the major driver of the dimming in plains while aerosol indirect effect plays a crucial role in the dimming in LH and HHM.

Chapter 4. Influence of biomass burning and long-range transport of pollutants on aerosol variations in Nepal.

As aerosols were identified as the major driver of the decline in SSD, major sources of aerosols were sought out in this chapter. Among the two major divisions of aerosol sources: biomass burning and fossil fuel combustion, the emissions from biomass burning were estimated to be approximately three times the emissions from fossil fuel combustion, contributing on average to 74% of the total emissions (black carbon and SO2) in Nepal. To understand aerosol variations and its relation to biomass burning, Moderate Resolution Imaging Spectroradiometer (MODIS) derived firecounts and Aerosol optical depth (AOD) were analyzed for the period 2005-2010. The highest mean AOD values (0.495) and maximum firecounts (53% of total firecounts) both occurred in April and were found to be in peak values in pre-monsoon season. Acute pollution (AP) events characterized by significant increase in AOD values were identified for two locations: Simara and Kathmandu. A coupling of air mass backward trajectory analysis with MODIS firecounts identified 55% of the AP events in Simara and 60% of the AP events in Kathmandu, respectively, to be influenced by biomass burning referred to as 'BB pollution events'. Regional frequency of firecounts for different seasons during BB pollution events suggested that biomass burning occurring in Nepal could strongly influence the occurrence of highest AOD in pre-monsoon season, while trans-boundary biomass burning was dominant in all the other seasons.

Cluster analysis of air mass backward trajectories arriving at Kathmandu showed that air masses from highly polluted IGP were carried by the prevailing winds, and caused peak AOD in the winter season. The peak AOD in the pre-monsoon season was significantly contributed by air masses originating in the North-eastern states of India, Meghalaya, dominated by slash and burn agriculture; and air masses from Punjab, characterized by wheat residue burning. The air masses originating in the Bay of Bengal indicated the pathway of the Indian summer monsoon (ISM) circulation, which brings pollutants in early monsoon causing peak AOD in June. Weakening of ISM, known as 'break' periods, dominated by westerly circulations also contributed to peak AOD in June. The polluted smoke of rice residue burning occurring on a large scale in Punjab of the northern IGP caused peak AOD in post-monsoon season despite its negligible contribution in total trajectories.

Chapter 5. Synthesis and implications.

In this chapter, I synthesized the findings from previous chapters. A significant decline was observed in SSD trends particularly in the plain regions of Nepal. Seasonal analysis of the trends revealed intense dimming in plains in all the dry seasons under clear days. While intense dimming under cloudy days occurred in all the three regions particularly in the monsoon season. Aerosols released from biomass burning during pre-monsoon season in Nepal and transport of air pollutants from Indian subcontinent were identified as the major determinants of peak AOD in Nepal.

The observed dimming and peak AOD concentrations will have large implications on agriculture in Nepal. The main growing season (November to April) of wheat and dry season rice in the plains, coincides with the peak AOD values and significant dimming in S_clear, observed in the winter and pre-monsoon seasons. Similarly the significant dimming observed in S_cloudy in monsoon season coincides with the rice growing season (July to October) in both plains and LH. The observed reduction in SR would significantly reduce the photosynthetic rate of the crops and other vegetation (forests, grasslands and shrublands) and lowers productivity, influencing the livelihood and food security of a large population base.

Such impacts of dimming and the ABC on agriculture calls for immediate action to mitigate aerosol emissions both at national and international levels. The mitigation efforts could include controlled fires in protected areas, use of improved cooking stoves, and awareness about the implications of forest fires to reduce emissions from biomass burning. A larger international collaboration and cooperation will be required to fix the problem of trans-boundary air pollution. It is important to understand that the mitigation efforts to reduce aerosol emissions represent a rewarding step for the food security and regional climate.