ABSTRACT

PM2.5, PM10 (particulate matter smaller than 2.5μm and 10μm respectively) and AOD 550 nm (Aerosol Optical Depth at 550 nm) are the extensively studied aerosol parameters that represent the particulate matter (PM) surface concentration and integral of total extinction of light by aerosol respectively. The surface concentration of PM2.5 and PM10 is largely influenced by meteorological forcing variables- air temperature (AT), wind speed (WS), relative humidity (RH) and surface pressure (Ps), and planetary boundary layer height (PBLH) through several feedback mechanisms (interactions). The surface concentration of PM2.5 and PM10 and their interactions with meteorological variables as well as PBLH varies in space and time, as PBLH and meteorological parameters are intrinsically anisotropic to surface topography and dynamics of atmospheric processes.

Owing to the topographical orientation and the terrain complexity (surrounded by hills ranges and mountains in three directions and open to the fourth), and as well as being the sink to the long-range transported aerosol from Indo-Gangetic plains, Bay of Bengal and west Asia, the Brahmaputra valley (BV) has its significance for aerosol studies. Meta-analysis shows surface concentrations of PM2.5 and PM10 and their interactions with meteorological variables as well as PBLH for BV at the valley-site scale are rarely studied.

Analysis of spatio-temporal variation in PM2.5, AOD 550 nm and meteorological forcing variables AT, WS, RH, Ps and PM2.5-Meteorology PM2.5-AOD 550 nm relationships, diurnal analysis of PBLH and PM2.5, and the nature and strength of their (PM2.5-PBLH) relationship, estimation of PM10 surface concentration using Geographic Weighted Regression (GWR) model over BV at the valley-site scale form the core of investigation of this work.

A continuous spatial and temporal dataset of aerosol, meteorological parameters, and PBLH over a large spatial domain is an essential requirement for a comprehensive analysis. The inadequate number, unavailability at a high temporal scale, and disproportionate distribution of ground-based stations (considered the most accurate data source) have been major limiting factors for the valley-site scale aerosol studies over BV. Research worldwide shows that this limitation can be addressed by integrating satellite, reanalysis and ground-based data. In this context, the present study explored multiple data sources, assessed the performance (efficacy and uncertainty) of the satellite and reanalysis

data (with reference to ground-based data for the studied parameters), and assessed the GWR model performance and validation over the complex terrain of BV.

This thesis is organized into the following five chapters:

Chapter 1: Introduction

Based on analytical appraisal and synthesis of the relevant research literature, this chapter introduces the topic, highlights the importance of the study, identifies the research gap, and outlines the objectives and the scopes. The overall goal of this chapter is to set the framework for the research work.

The objectives of the thesis are:

1. Analysis of the spatio-temporal variation in PM2.5, AOD 550 nm and meteorological parameters, and their relation over the BV at the valley-site scale.
2. Analysis of the boundary layer height variation and its interaction with PM2.5 surface concentration at diurnal and seasonal scale over BV at the valley-site scale.
3. Estimation of PM10 surface concentration using Geographic Weighted Regression model by integrative assimilation of surface PM10, AOD 550 nm, and meteorological variables.

Chapter 2: Variation and relationship of PM2.5, AOD 550 nm and meteorological parameters over Brahmaputra Valley at the valley-site scale

Both PM2.5 and AOD 550 nm are amongst the most widely used parameters for aerosol studies. PM2.5 are particulate matter smaller than 2.5µm in aerodynamic diameter, and AOD 550 nm represents the columnar aerosol concentration. PM2.5, AOD 550 nm are closely related to meteorological parameters. PM2.5, AOD 550 nm and meteorological parameters vary in time and space over a large geographic area.

As mentioned earlier BV has significance for aerosol studies. Meta-analysis shows that there is a lacuna in the analysis of spatio-temporal variation of PM2.5, AOD 550 nm and meteorological parameters at the valley-site scale over BV. So is for the PM2.5-meteorology and PM2.5-AOD 550 nm relationships.

To address the extant lacuna this chapter, therefore, (a) evaluates PM2.5 surface concentration based on MERRA-2 aerosol components; (b) analyse the spatial, seasonal and inter-annual variation of PM2.5, AOD 550 nm and meteorological parameters viz. AT, WS, Ps and RH; (c) examine the strength of the relationship between PM2.5 and AOD 550 nm, PM2.5 and meteorological parameters for the period 2016 to 2020.

MERRA-2 (Modern-Era Retrospective Analysis for Research and Application version 2) major aerosol components, ERA5 ECMWF (European Centre for Medium-Range Weather Forecasts), and MODIS (Moderate Resolution Imaging Spectroradiometer) Terra and Aqua were used for PM2.5 surface concentration, meteorological parameters (AT, Ps, RH, WS) and AOD 550 nm respectively. For the chosen parameters, these data sources were validated with reference to ground-based data of MAPAN (Modelling of Atmospheric Pollution and Networking), IMD (Indian Meteorological Department) and AERONET (Aerosol Robotic Network). ERA5 meteorological parameters and MERRA-2 aerosol components were extracted, collocated, validated, and re-gridded using Gaussian process regression to the desired spatial and temporal grid size for the generation of variability map and correlation analysis. Total PM2.5 surface concentration was calculated using the MERRA-2 major aerosol components black carbon (BC), dust (DU2.5), sea salt (SS2.5), sulfate (SO_4), and organic carbon (OC) surface concentration.

Pronounced east-west trending asymmetry was observed in the spatial variation of PM2.5 $\mu g/m^3$ and AOD 550 nm, and the meteorological parameters over BV. For PM2.5 surface concentration, the eastern part of BV showed notably lower surface concentration compared to that of the central and western parts. Seasonally, the cleanest environment was observed during monsoon. High PM2.5 concentration areas were found to coincide with high AOD 550 nm in all seasons except for pre-monsoon The inter-annual variation in AT, RH, Ps, AOD 550 nm and PM2.5 is small over BV. Moderate to strong negative PM2.5-AT, PM2.5-RH relationship and positive PM2.5-Ps, PM2.5-WS and PM2.5-AOD 550 nm relationship was observed over BV. PM2.5-RH negative association reflected the predominance of non-hygroscopic organic precursors and carbonaceous aerosols in PM2.5 concentration. Except for WS, all the ERA5 meteorological products AT, RH and Ps are well-represented the ground-based observations. Whereas, PM2.5 estimated from MERRA-2 major aerosol components moderately represented the surface observations. ERA5 meteorological products were effective in overcoming the spatial and temporal data limitation challenges over the complex topography of BV.

Chapter 3: Boundary layer dynamism and PM2.5-PBLH interaction over Brahmaputra Valley at the valley-site scale

PBLH is a fundamental parameter that characterizes the vertical mixing between the earth's surface and free atmosphere through the PBL. The convective and turbulent processes (vertical mixing) within PBLH are complex and vary on a wide range of parameters like space, time scales and terrain. PBLH variability is influenced by the diurnal and seasonal cycle of the atmospheric processes, especially over heterogeneous terrain. The variability in PBLH has a pronounced influence on PM2.5 surface concentration.

As mentioned earlier BV is surrounded by mountains and hills, the topographical orientation of the valley has a cumulative effect on the diurnal and seasonal evolution of PBLH, which in turn, plays a significant role in the accumulation of local and long-range transported aerosol and its residence time. Despite the importance, the diurnal variation of PM2.5 and PBLH and their relationship at the valley-site scale over BV is still a research gap.

In bridging the gap, this chapter, therefore, investigates (a) the variability of PBLH and surface PM2.5 concentration at the spatial and diurnal scale; (b) seasonality of PBLH, PM2.5 and AOD 550 nm; and (c) the association of PBLH with surface PM2.5 concentration in different seasons over BV at the valley-site scale.

Fundamental atmospheric fields from GPS radiosonde, ERA5 ECMWF BLH and MERRA-2 PBLH were used for PBLH. Vertical gradient profiles of the 8 fundamental atmospheric fields were generated and examined to identify the best indicator of PBLH. ERA5 ECMWF BLH (Boundary Layer height) and MERRA-2 PBLH were validated with reference to radiosonde PBLH estimates. All the data sources were geo-referenced, collocated in space and time, validated and re-gridded to desired grid size. MERRA-2 PBLH and MERRA-2 major aerosol components were used to calculate the day-time and night-time PBLH and PM2.5 respectively over BV.

MERRA-2 PBLH outperformed ERA5 ECMWF BLH when compared with radiosonde PBLH estimates for the Dibrugarh station. PBLH and PM2.5 showed a remarkable diurnal variation and synergism. Deeper day-time PBLH coincides with lower PM2.5 surface concentration; whilst shallower night-time PBLH co-existed with higher PM2.5 surface concentration. PBLH was deepest in the per-monsoon. The depth of PBLH decreased in the monsoon and post-monsoon and increased in the winter. The diel and seasonal changes in PBLH reflected changes in PM2.5 surface concentrations and AOD 550 nm. PBLH-PM2.5 relationship revealed an unusual weak to strong positive relationship over BV. The rough eastern BV topography evinced a relatively strong positive relationship compared to that of the western and central parts. Turbulence and valley wind circulation generated within the PBL is effective at lowering PM2.5 surface concentration

Chapter 4: Estimation of PM10 over Brahmaputra Valley using Geographic Weighted Regression model

PM10 one of the major contributors to air pollution is related to PBLH and meteorological variables over a region. GWR, a spatial regression model, is globally applied to estimate PM10 surface concentration. GWR is also effective in modelling spatially varying relationships of the dependent with the explanatory variables.

GWR model, known for its efficiency in capturing spatial heterogeneity in relations and estimation, and widely applied for varieties of terrains and climatic zones, has not yet been applied for estimation of PM10 surface concentration over the complex terrain of BV. This study (a) estimates PM10 surface concentration using GWR model based on MODIS AOD 550 nm and reanalysis derived AT, PBLH explanatory variables over the BV for the period 2016-2018; (b) explores the relationship between PM10 and the explanatory variables of AOD 550 nm, AT and PBLH height across the valley (c) analyse the spatial distribution of PM10 surface concentration, AOD 550 nm, AT and PBLH over BV.

Ground-based PM10 surface concentration data, ERA-Interim AT and PBLH, and MODIS AOD 550 nm were used for PM10 surface concentration estimation. For GWR model fitting, the monthly mean of PM10 surface concentration (dependent variable) was spatio-temporally collocated with the monthly mean of explanatory variables AOD 550 nm, PBLH, and AT for 10 different sampling stations of PM10. The performance of the GWR model was evaluated using 10-fold cross-validation method, Moran's I index, Variance Inflation Factors (VIF) and Local R^2 value. PM10-AOD 550 nm and PM10-meteorology relationship was analysed based on the model generated regression coefficient (β).

The estimated PM_{10} $\mu g/m^3$ surface concentration was slightly underestimated as compared to the observed PM_{10} $\mu g/m^3$ surface concentration across the sampling stations. The GWR model performed well for the estimation of PM10 surface concentration with R^2 (Coefficient of determination) and RMSE (Root Mean Square Error) values of 0.62 and

22.74 μg/m^3 respectively over BV. The R^2= 0.62 and the RMSE =22.74 μg/m^3 obtained from the GWR model fitting, decreased by 0.09 (R^2= 0.53), and 0.14 μg/m^3 (RMSE= 22.60) in cross-validation analysis. β The PM10-AOD 550 nm showed a strong positive to negative relationship from the west to east of BV. Strong west-east spatial heterogeneity in β values was observed in PM10-PBLH (β_2= -0.011 to 0.0041) and PM10-AT relationship (β_2= -0.011 to 0.0041). A higher mean value of PM10 surface concentration and AOD 550 nm was observed in the western and central parts of BV than in the eastern valley. Guwahati, the largest city in Northeast India, had the highest PM10 concentration among all the sampling stations.

Chapter 5: Conclusion

This chapter discussed the major findings of the current research work as well as carries concluding remarks. The latter section outlines the areas which are the future scope of research.