Seasonal Variability of Aerosol Optical Depth over Indian Subcontinent

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Abstract- Ganga basin extends 2000 km E-W and about 400 km N-S and is bounded by Himalayas in the north. This basin is unequivocally found to be affected by high aerosols optical depth (AOD) (>0.6) throughout the year. Himalayas restricts movement of aerosols toward north and as a result dynamic nature of aerosol is seen over the Ganga basin. High AOD in this region has detrimental effects on health of more than 460 million people living in this part of India besides adversely affecting clouds formation, monsoonal rainfall pattern and Normalized Difference Vegetation Index (NDVI). Severe drought events (year 2002) in Ganga basin and unexpected failure of monsoon several times, occurred in different parts of Indian subcontinent. Significant rise in AOD (18.7%) over the central part of basin (Kanpur region) have been found to cause substantial decrease in NDVI (8.1%) since 2000. A negative relationship is observed between AOD and NDVI, magnitude of which differs from region to region. Efforts have been made to determine general distribution of AOD and its dominant departure in recent years spatially using Moderate Resolution Imaging Spectroradiometer (MODIS) data. The seasonal changes in aerosol optical depth over the Indo-Gangetic basin is found to very significant as a result of the increasing dust storm events in recent years.

Index Terms- MODIS, Aerosols, Ganga basin.

I. Introduction

THE Ganga basin is one of the largest basins in world. It is bounded by the Himalayas in the north, the Aravalli mountains in the west, the Vindhyans and Chhotanagpur Plateau in the south and the Brahmaputra ridge in the east. It is traversed by Ganga river and its major tributaries. Ganga basin is densely populated (~460 million) primarily due to presence of numerous small and big rivers and fertile soil that make this region highly productive. Large scale uncontrolled urbanization and industrial development in this region have caused high pollution levels in air, water and land. Aerosol pollution level has risen tremendously in this region since 2000 causing degradation in air quality and other indirect effects. Efforts are made here to study growth of population in this region since 1990 and rise of aerosols optical depth (AOD) season wise. We have found that increase of aerosol concentration especially during summer season (pre-monsoon season) is alarming. Seasonal spatial variability of aerosols is studied since 2000 [6] [8]. Aerosols are responsible for lowering of land surface temperature i.e. cooling effect which restricts warming effect of Greenhouse gases over Indian region. Higher aerosol loading is causing substantial decrease in sunlight reaching to the surface thereby affecting vegetation which depends on sunlight for their growth. Efforts are made to study effect of aerosols on Normalized Difference Vegetation Index (NDVI) in this region. Indo-Asian aerosols have impact on radiative forcing that cause negative forcing (cooling) at surface and positive effect (warming) at top of atmosphere [1], [4], [7], [10], [12]. Satellite sensor data can be used for urban air quality assessment and monitoring [2], [3], [5], [13]. Changes in precipitation, soil moisture, NDVI and aerosols have been studied in central Ganga basin where aerosol pollution pool is found to be persistent in regional context.

II. Data Used

Aerosol optical depth have been obtained using Level-3 MODIS (Moderate Resolution Imaging

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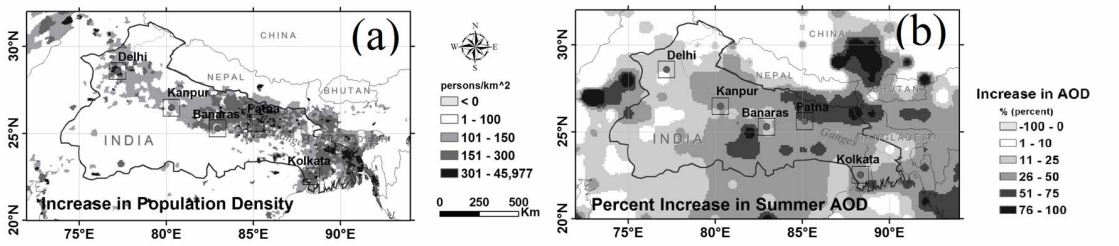

Fig. 1 Increase in population density (2000) since year 1990 (1.a.). Percent Increase in summer AOD 2004 compared to year 2000 (1.b.).

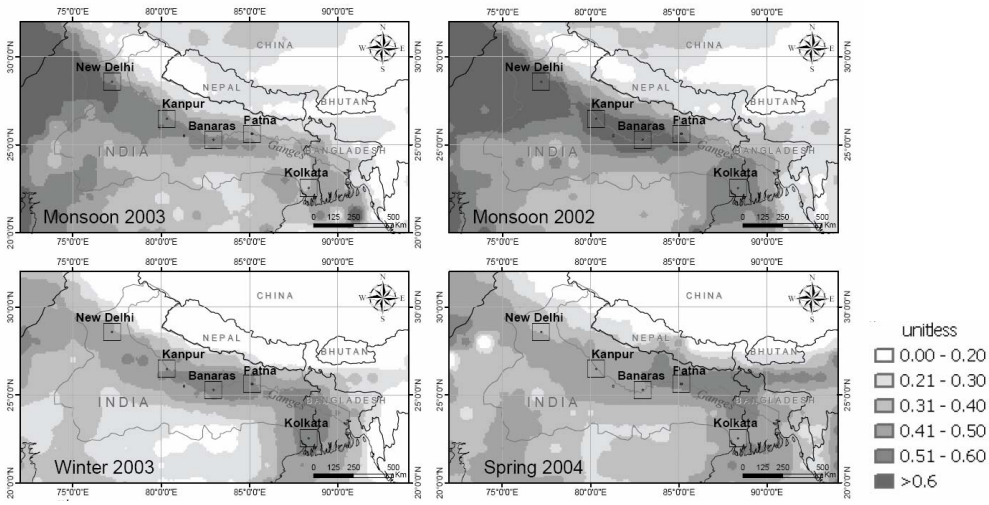

Fig. 2. AOD variation in Ganga basin for monsoon season 2002, 2003 (average of July, August, September and October months), winter season 2003 (average of November, December, January and February months) and spring season 2004 (March month only).

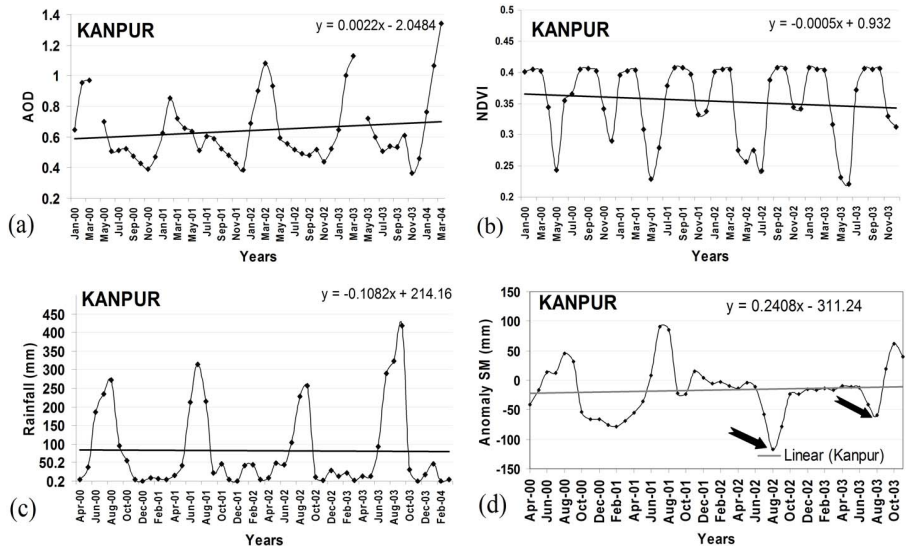

Fig. 3. AOD (a), NDVI (b), Rainfall (c) and Soil moisture (SM) (d) anomaly in Kanpur region (Central Ganga basin) since 2000. Arrows mark SM during drought year 2002 and normal rainfall year 2003.

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Spectroradiometer) gridded atmosphere monthly global product 'MOD08_M3' (http://daac.gsfc.nasa.gov/MODIS/Terra/atmosphere/MOD08_M3.shtml) at spatial resolution of 1 degree by 1 degree [6], [8]. Population density 2000 and 1990 (units: persons per square kilometer) is obtained from Gridded Population of the World (GPW) dataset available from Center for International Earth Science Information Network (http://sedac.ciesin.columbia.edu/gpw). NDVI data (unitless) have been obtained from SPOT VEGETATION having spatial resolution of 1 km^2 for period from 2000 to 2004 (http://free.vgt.vito.be/). Rainfall data (units: mm) is obtained from Tropical Rainfall Measuring Mission (TRMM) Precipitation Product 3B43 (V6) (ftp://lake.nascom.nasa.gov/data/TRMM/Gridded/3B43/). Soil Moisture (SM) data have been taken from NOAA NCEP CPC (National Oceanic and Atmospheric Administration's, National Centers for Environmental Prediction, Climate Prediction Center) Global Monthly Soil Moisture Dataset (http://iridl.ldeo.columbia.edu/SOURCES/NOAA/.NCEP/.CPC/) (units: mm).

III. Aerosol Pollution Pool

The major growth in population can be seen concentrated along the course of the Ganga river (Fig. 1a). Ganga basin shows very high level of aerosol optical depth due to accumulation of aerosols in this plain which is a topographic low. Very high AOD (>0.6) is observed over whole basin south of Himalayan mountain range during summer season. Increase in summer AOD 2004 compared to summer AOD 2000 is very high (Fig. 1b.). In Monsoon 2002, very high AOD (>0.6) is observed in western part of Ganga basin and >0.5 to >0.6 in central region due to failure of monsoon in year 2002 (Fig.2, monsoon 2002). Eastern zone comparatively shows lower AOD range of 0.4 to 0.5. There is a gradual lowering of AOD from western to eastern zone of Ganga basin in a normal monsoon year 2003 as monsoon rain washes away most of the aerosols from troposphere (Fig 2, monsoon 2003). In winter season, western zone shows low AOD values and it gradually increases to >0.5 in eastern zone (Fig 2, winter 2003). This shows a reversal in AOD distribution pattern as observed for Monsoon season. Spring season AOD distribution shows a relatively low AOD of 0.4-0.5 for most regions of basin (Fig. 2, spring 2004). Unequivocally very high AOD is present over Ganga basin through out the year (Fig. 2). Towering Himalayas in north, lower plain topography (<100m to 250m above mean sea level) and wind direction favour accumulation of aerosols in this region. Dust storms coming from deserts west of Ganga basin during summer season (pre-monsoon) bring mostly coarser aerosol particles. Dust storms cause very high level of AOD (>0.6) over entire Ganga basin during summer. A normal rainfall distribution washes out most of the aerosols from troposphere especially from eastern part of basin. However there is increase in failure of monsoon in recent years and it can be clearly seen on aerosol concentration map (Fig.2, Monsoon 2002).

IV. Adverse impact of high AOD

High levels of aerosols are highly detrimental to health of 460 million people living in this basin. High level of suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM) have been reported in urban areas. RSPM (size <10μm, particulate matter PM-10) can enter into respiratory tracts and SPM (size <2.5 μm, PM-2.5) can enter into lungs and cause respiratory problems for masses. Besides, high level of aerosols is causing increased upward scattering at top of the atmosphere causing rise in temperature in atmosphere and reducing amount of solar radiation reaching surface. This cause abnormal cooling effect on land surface and reduced incoming photosynthetically absorbed radiation is having direct effect on vegetation. It has been found that aerosols have increased by ~18.7% in Kanpur region (central Ganga basin) and NDVI has decreased by ~8.1% since year 2000. There is a negative relationship between aerosol concentration and NDVI which vary from region to region. Frequent failure of monsoon in Ganga basin since 2000 compared to relatively stable period in 1990's can be attributed to be due to these high aerosol loading in recent years. Aerosols are known to be an important variable in cloud microphysics causing changes in precipitation [11]. Aerosol induced additional heating and cooling affects tropical rainfall patterns and disturbs hydrological cycle [1], [4], [9].

V. Conclusion

Alarming level of aerosols is found in Ganga basin throughout the year. Increasing aerosol pollution is affecting health of 460 million people living in this basin causing respiratory problems and affecting visibility in urban areas. Adverse impact of aerosols is found over vegetation besides frequent failure of monsoon in this region. Though aerosols are offsetting effects of greenhouse warming in this

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region, but this abnormal cooling effect on surface and heating effect in atmosphere is inducing disturbances in hydrological cycle as evident from severe drought and flood events in this basin in recent years. Aerosol pollution is a regional phenomena and comprehensive approach is required to control anthropogenic source of aerosols.

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