SPATIOTEMPORAL TRENDS OF $PM_{2.5}$ CONCENTRATIONS USING SATELLITE DATA IN MEGHALAYA, INDIA

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ABSTRACT: Particulate matters, a major air pollutant, cause cardiopulmonary problems. It is vital to assess its spatiotemporal distributions and to discuss the chief influencing factors. Satellite based $PM_{2.5}$ concentrations data is used to assess the spatial and temporal trends of $PM_{2.5}$ distributions over the state of Meghalaya during the period of 2007-2016. Satellite derived aerosol optical depth (AOD) is related to $PM_{2.5}$ concentrations and used for better spatial coverage. Spatial trends in distribution of $PM_{2.5}$ concentrations is observed to increase from eastern to western part of Meghalaya. Minimum $PM_{2.5}$ concentrations is detected in Jaintia hills and maximum in West Garo Hills. Temporally, $PM_{2.5}$ levels showed a positive trend in all the districts of Meghalaya but is significant in only 2 districts namely Jaintia Hills and Ri Bhoi. Along with interior (inside Meghalaya) factors, exterior factors (outside Meghalaya) also may have influenced the accumulation of $PM_{2.5}$ levels over the state.
Keywords: $PM_{2.5}$, Aerosol optical depth, Meghalaya

INTRODUCTION

In recent decades, atmospheric particulate matters have been perceived as one of the foremost environmental problem because of its adverse impact on the environment as well as on human health (Habeebullah, 2013). Particulate matters (PM) particularly those with diameters less than 2.5 microns ($PM_{2.5}$) poses the greatest threat to human health, as they can enter deep into lungs and even to the bloodstream during inhalation process. A large number of studies have linked the pollution of particulate matters to various health problems including asthma, irregular heartbeat, heart and lung diseases (Li, Xia, & Nel, 2008; Brook et al., 2010 ;Valavanidis,Vlachogianni, Fiotakis, & Loridas, 2013).Furthermore, particulate matters are reported to be responsible for scattering of visible light and may thus play a role in reduction of visibility (Davidson, Phalen & Solomon, 2005; Zhang & Cao, 2015). In addition, these particulate matters may get carried away by winds and afterwards settle on water or soils (Wang et al., 2017). Contingent to their chemical composition, they may affect stream and soils acidity, depleting the soil and water nutrients and affecting the diversity of ecosystem (Gillette, 1977). This therefore demonstrate the necessity of studying temporal and spatial distribution of $PM_{2.5.}$

Meghalaya, located in Northeast part of India, is a small state with an area of 22,430 km² and population of 3,211,474 (Fact sheet 2014). Though the air quality of the state has reported to be far from satisfactory, however, as of late, the skyline of the state is sometimes reported to be invisible by noon as the atmosphere is loaded with smog (Shillong Times 2016). Vehicles can be attributed as the major sources of air pollution on the state especially in urban areas and places located along the highways (Anon 2012). The issue gets amplified particularly as this is the only means of transportation in the state, since rail and waterways are not accessible. Also air polluting industries such as Cement plants, stone crushing, lime kilns, ferro alloy, stone grinding, flour mills etc have been recently set up in some areas of Ri Bhoi, Jaintia, East Khasi and Garo Hills. Haphazard and unscientific mining activities, particularly mining of coal and limestone have already spread in almost all districts of the state, mostly in Jaintia Hills, East Khasi Hills and Garo Hills districts. Shifting (jhum) cultivation, solid waste disposal, infrastructure developmental activities and other non-point activities are other sources of air pollution in the state for which studies are yet to be taken up.

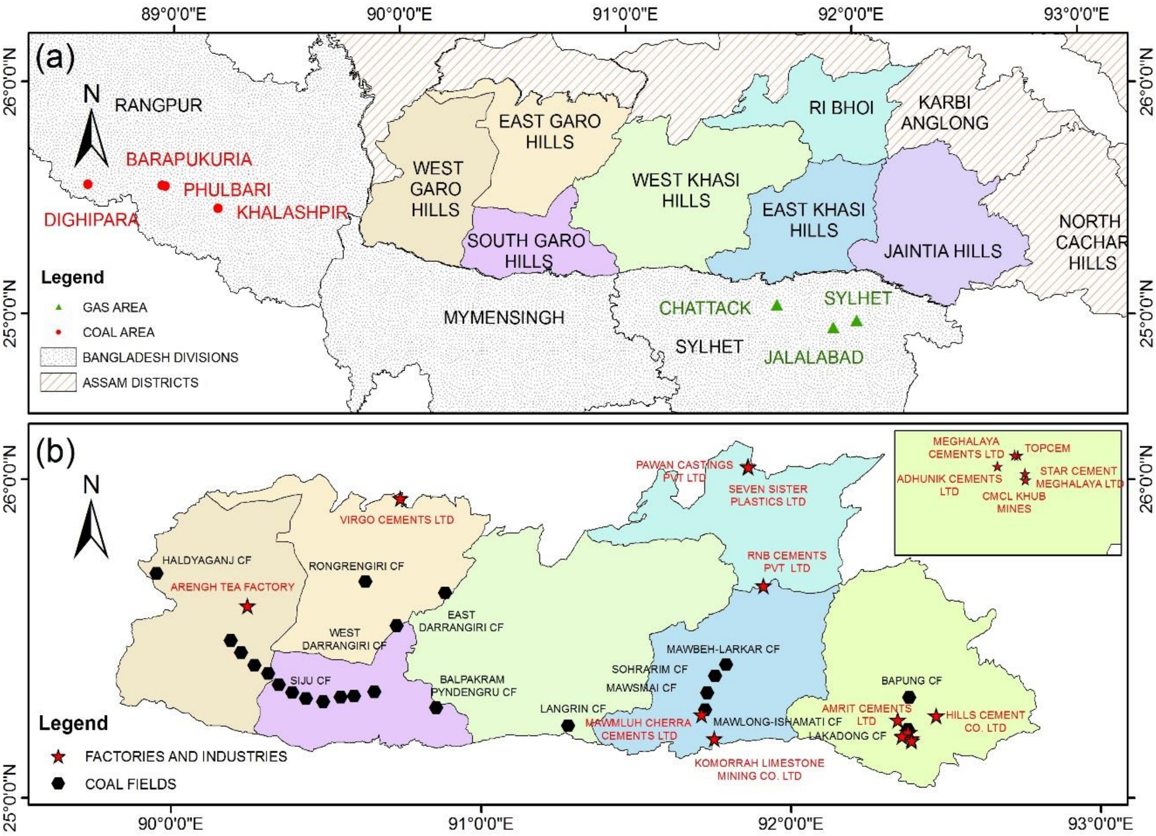

Fig 1: Study area (State Meghalaya consisting of 7 districts shown with 7 different colors) with 3 Bangladesh divisions and 5 Assam districts sharing common boundaries with Meghalaya. (a) The red circle and green triangle symbols denote the coal and gas areas respectively in Bangladesh, which are near to Meghalaya. (b) The black hexagons and red star symbols denote the coal fields (CF) and major factories and industries in Meghalaya.

Like other states in India, Meghalaya State Pollution Control Board have set up some localities Viz. at Tura, Dawki, Shillong, Byrnihat, Khliehriat, Nongstoin, Lumpyngngad and Police bazar in the state to monitor air pollutants present in the air (MSPCB 2018). The measured data from these air quality stations can be utilize for various purposes such as, in determining whether the air quality of a region is within the permissible limits and in locating the air pollutants hotspots. However, the primary downside is that, these stations are only providing data at a particular stationary point. To give a full spatial statistic about the air quality of a large expansive area, there is a requirement for an immense system, which requires a colossal amount of resources. On the other hand, remote sensing devices can serve as a tool to aid in monitoring air quality over a large spatial scale (Duncan et al., 2014). Remote sensing images along with Geographic Information System (GIS) have been successfully implemented and proved to be useful in implementation of flood analysis, land use and crop analysis etc. (Ogunbadewa, 2012) Therefore, in the present study, a satellite derived data set Viz. Aerosol Optical Depth (AOD) (Van Donkelaar,2018) which is highly related to fine particulate matter ($PM_{2.5}$) was used to study the spatial and temporal distributions of $PM_{2.5}$ from 2007-2016 across various districts of Meghalaya. AOD is attained from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) and Multi-angle Imaging Spectroradiometer (MISR) and the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) satellites. It is discussed in detail in methodology. The data exclude the influence of dust and sea salt on $PM_{2.5}$. These data are available in GeoTIFF format and are provided with WGS 84 projection. The study area is shown in fig 1 with adjacent Assam districts and three Bangladesh divisions that share border with Meghalaya. The figure highlights the factors (both external and internal to Meghalaya) that influence the $PM_{2.5}$ concentrations over Meghalaya. Meghalaya is a landlocked state and does not include any major sandy terrain. Thus, the satellite data that focusses on generation of $PM_{2.5}$ from anthropogenic sources by excluding dust and sea salt, are used in the study. Also map showing changes in $PM_{2.5}$ concentrations between 2007-2016 was generated to visually demonstrate the spatial trends of annual $PM_{2.5}$ concentrations between the study period.

METHOD

Global annual gridded data of particulate matter with aerodynamic diameter of 2.5 µm or less ($PM_{2.5}$) during the period 2007-2016 is obtained from data of NASA Moderate Resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging SpectroRadiometer (MISR) and the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) satellites (*http://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-gwr-pm2-5-modis-misr-seawifs-aod*). The dataset comprises of annual concentrations (micrograms per cubic meter) of ground-level $PM_{2.5}$ at spatial resolution of 0.01 degrees, excluding the dust and sea salt (van Donkelaar et al., 2018). Thus, it emphasizes on the anthropogenic sources of the particulate matter $PM_{2.5}$. The dataset associates retrievals of Aerosol Optical Depth (AOD) using passive retrieval algorithms from multiple satellites mentioned above and this total measure of aerosol is related to the near-surface Particulate Matter concentrations ($PM_{2.5}$) using the GEOS-Chem chemical transport model. Geographically Weighted Regression (GWR) is used to anticipate and amend for the residual $PM_{2.5}$ bias in these satellite derived estimated values (van Donkelaar et al., 2016).Using ArcMap, the spatial distributions of $PM_{2.5}$ concentrations, over the state Meghalaya, are extracted for the mentioned study period (2007-2016). The mean values are computed for each of the seven districts of the state.

In order to quantify the temporal trends of $PM_{2.5}$ across different districts of Meghalaya during the 10 years of study period (2007-2016), present study first used the nonparametric Mann-Kendall test to detect the existence of increasing or decreasing trend (Kendall, 1975; Mann, 1945), then followed by nonparametric Sen's method to estimate the magnitude of the trend (Sen, 1968). The Mann-Kendall test statistic (S) is calculated using the formula 1.1, which is nothing but the number of positive differences minus the number of negative differences.

$$S = \sum_{i=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_i) \qquad (1)$$

where x_j and x_k denotes the annual $PM_{2.5}$ values in years' *j* and *k* respectively, and *j* > *k*.

$$sgn(X_j - X_i) = \begin{Bmatrix} 1,\ if\ (X_j - X_i) > 0 \\ 0\ \ if\ (X_j - X_i) = 0 \\ -1\ if\ (X_j - X_i) < 0 \end{Bmatrix} \qquad (2)$$

i.e., if S = 0, then it shows that there is no increasing or decreasing trend in the data, If S < 0, then it means that there is a decreasing trend, whereas if S > 0, then there is an increasing trend in concentration of $PM_{2.5}$, over the chosen time interval.

Sen slope estimator is then estimated using the formula as per equation 3.

$$f(t) = Q(t) + B \qquad (3)$$

Here, B is a constant, whereas Q represent the slope which is calculated as per equation 4.

$$Q_i = \frac{X_j - X_k}{j-k} \qquad (4)$$

In case if there are *n* values of x_j in the $PM_{2.5}$ time series, we get as many as *N = n(n-1)/2* slope estimates *Qi*. The *N* values of *Qi* are then ranked from the smallest to the largest and the Sen's slope estimator is then the median of these *N* values of *Qi* (equation 5).

if N is odd:

$$Q = \frac{1}{2}(Q_{\left[\frac{N}{2}\right]} + Q_{\left[\left(\frac{N}{2}\right)/2\right]}$$

(5)

if N is odd:

$$Q = Q_{\left[\frac{N+1}{2}\right]} \quad (6)$$

RESULTS

Spatial distribution

Figure 2 shows the spatial distribution of $PM_{2.5}$ across all the districts of Meghalaya from 2007 to 2016. District wise magnitudes of $PM_{2.5}$ concentrations are indexed in Table 1. Although the concentrations per grid cell varied each year, it can be observed that the trend is similar in all the years.

Table 1. $PM_{2.5}$ ($\mu g/m^3$) concentration across various districts of Meghalaya

Year	East Garo Hills	East Khasi Hills	Jaintia Hills	RiBhoi	South Garo Hills	West Garo Hills	West Khasi Hills
2007	33.04	27.25	24.09	24.20	38.81	39.69	30.90
2008	34.67	28.28	25.30	25.71	39.73	39.72	31.66
2009	40.72	32.81	29.88	32.16	46.08	47.63	37.17
2010	32.42	26.41	24.31	25.90	35.71	37.90	29.76
2011	34.27	28.08	24.85	26.17	40.04	39.30	31.46
2012	39.89	32.19	28.24	29.79	45.41	46.91	36.17
2013	34.67	28.01	25.31	27.14	38.05	39.22	31.26
2014	39.19	31.23	28.70	29.08	45.37	45.62	35.90
2015	40.68	33.46	29.84	30.03	46.41	46.68	37.34
2016	36.64	31.02	27.63	28.19	41.48	42.25	34.02
Mean	36.62	29.87	26.81	27.84	41.71	42.49	33.56

In general, the amount of $PM_{2.5}$ levels increased from Jaintia to West Garo Hills (east to west part of Meghalaya). The lowest magnitudes are observed in the extreme eastern part of Meghalaya including parts of Jaintia Hills, East Khasi Hills and Ri Bhoi. In the southern part of Jaintia Hills, there are two coal CF (Coal Fields) and seven major cement industries as shown in fig 1, but their influences in $PM_{2.5}$ concentrations are not significant in major part of the district, though a narrow zone of moderate $PM_{2.5}$ concentrations is observed in extreme south of Jentai Hills (Fig 2). $PM_{2.5}$ are very small in size (10^{-6} m; 3-5% of diameter of human hair) and therefore, winds help in carrying of these fine particles away from the sources of its generation. Thus, it can affect places, hundreds of miles away from where it was produced (Louie et al., 2005; Perrone et al., 2013; Wang et al., 2017). The nearby districts of Assam namely North Cachar Hills and Karbi- Anglong (Fig 1) are mostly covered with forestry and inhabited with rural tribal communities namely, Karbis, Kacharis and Dimasa (Roy, Das, & Naidu, 1991). Their livelihood is connected with forest regions very intricately (Kar & Borthakur, 2008; Rout, Sajem, & Nath, 2012; Tamuli & Saikia, 2010). As there is no significant industrial zone in these places, this might be a possible reason of low $PM_{2.5}$ concentrations over the extreme western Meghalaya. The concentrations increased along the border of Bangladesh and reached its maximum value in extreme southern part of West Garo Hills. As shown in Figure 1, two cement factories and 4 major CFs are there in East Khasi Hills with 1 CF in West Khasi Hills (Langrin CF) and 2 CFs in East Garo Hills (Siju and Balpakram Pyndengru CF). Langrin, Siju and Balpakram Pyndengru CFs are among the major CFs in Meghalaya and have collective reserves of more than 225 million tons of coal (Dikshit & Dikshit, 2013). In the central part of Meghalaya, there are three CFs (Rongrengiri, East and West Darrangiri CF) and 1 CF and two industries in the western part of the state. Darrangiri CF has coal reserve of over 120 million tons and is one of the major CF in the state (Dikshit & Dikshit, 2013). These industrial units and CFs have influenced the major part of continuing increment in $PM_{2.5}$ concentrations from east to west of Meghalaya. In addition, the immediate Bangladesh divisions south to Meghalaya are Mymensingh and Sylhet. Mymensingh division was carved out of Dhaka division in the year 2015. It is the second most densely populated division after Dhaka (Bangladesh Bureau of Statistics, 2011).

In recent times, urbanization and industrialization have rapidly increased in this region, like for instance, BSCIC area of Mymensingh town (Zakir & Hossain, 2016). Moreover, there are numerous brickfields in Mymensingh division that unceasingly burns coal, wood, plastic and even tires that produces fine particulate matters, GHGs etc (Sajan et al.,

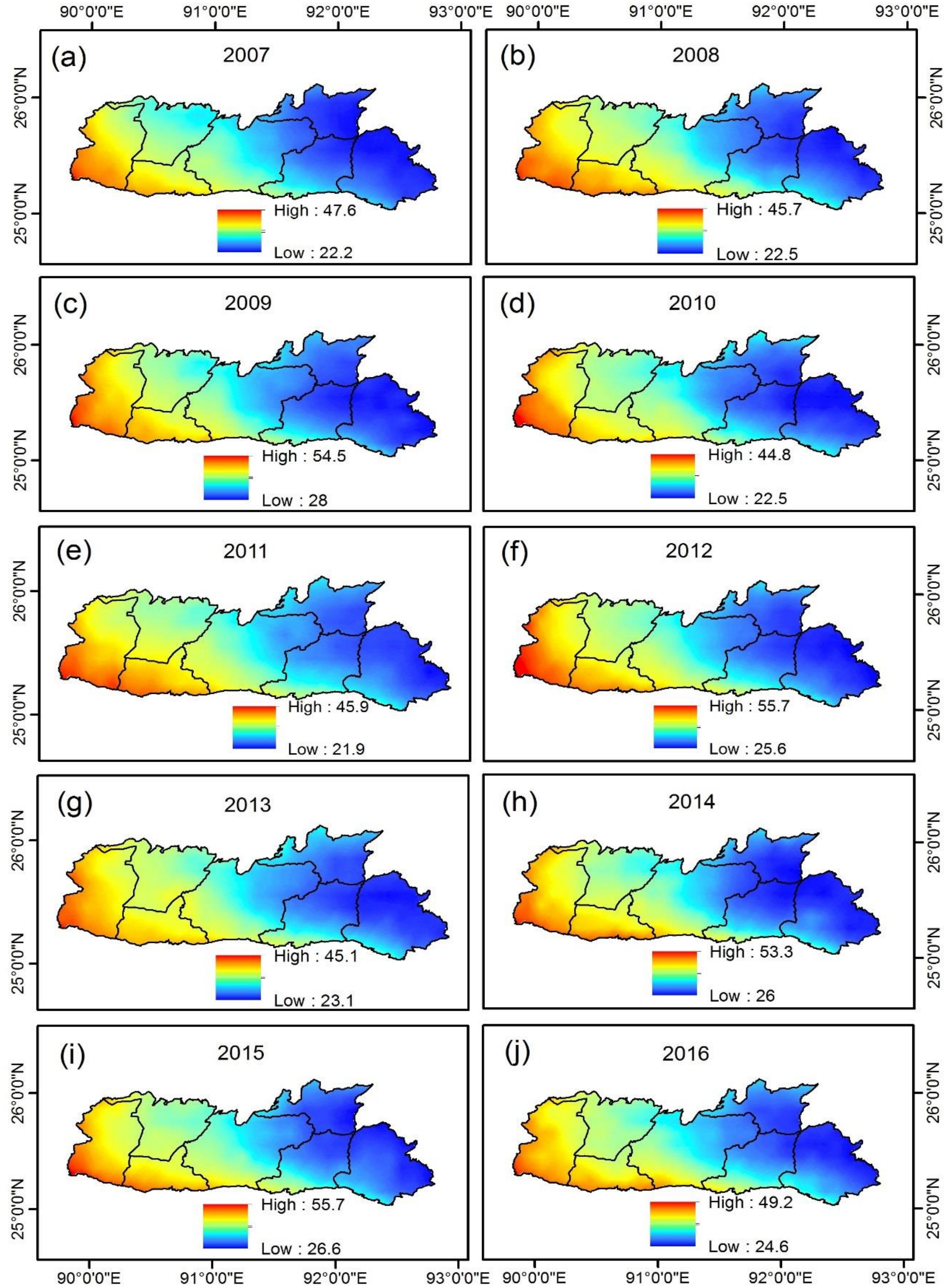

Fig 2: Spatial Distribution of $PM_{2.5}$ concentrations (a-j) over 7 districts of state Meghalaya in India.

2017).

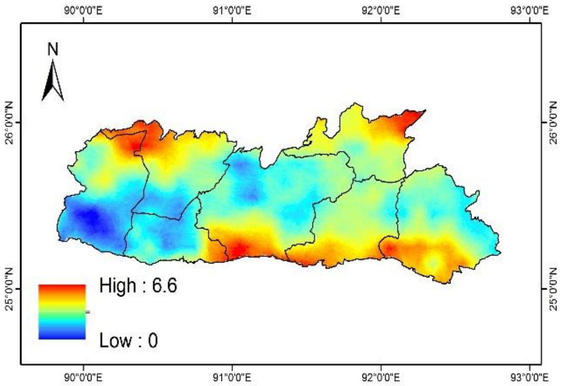

Fig 3. Spatial distribution of difference in $PM_{2.5}$ concentrations between 2007 to 2016

As can be seen in figure 1, three gas areas in Sylhet division and four coal areas in Rangpur Division are in proximity of south-eastern Meghalaya and western Meghalaya respectively. Domestic coal supply is projected to increase in Bangladesh whereas it would decrease in case of domestic natural gas supply by 2030 (Ministry of Power, 2011). Fine particles emitted in these areas can influence the neighbouring Indian territory, mostly Meghalaya. These external (exterior to Meghalaya territory) and internal factors (interior to Meghalaya territory) may elucidate the increasing trend from eastern to western expanse and its maximum presence in the south-western part of Meghalaya. Further, the difference in $PM_{2.5}$ concentrations between 2007 and 2016 is shown spatially across Meghalaya in fig 3 to display the portions experiencing increased and decreased $PM_{2.5}$ concentrations. Surprisingly, all grids have shown positive change denoting the fact that $PM_{2.5}$ concentrations increased everywhere. Note that we have taken the two extreme years of our 10-years study period to show the actual final change that happened spatially over Meghalaya, excluding the in-between variations among the years. As it can be perceived, not much change has come from 2007 to 2016, since the range of change in concentrations is just 6.6 $\mu g/m^3$. Few red patches indicating maximum increases in $PM_{2.5}$ are found in northern parts of West Garo Hills, north-western parts of Ri Bhoi and along the border with Bangladesh (mainly extreme southern parts of West Khasi, East Khasi and Jaintia Hills). Ri Bhoi shares border with Kamrup metropolitan district in Assam which is the second most densely populated district (Directorate of Census Operations, ASSAM, & Census of India, 2011) and includes Guwahati city that is the largest urban zone and hub of north-east India. Heavy urbanization in nearby district of Assam and along with 2 industries in the northern Ri Bhoi region can be the major reasons of $PM_{2.5}$ increments. The increments in southern part are may be due to increased industrialization and urbanization in Bangladesh divisions bordered with Meghalaya and heavy coal mining within Meghalaya, as discussed above. The increase in the upper northern part of West Garo hills can be justified by the illegal and detrimental use of several brick kilns in Rangpur district of Bangladesh as documented by Talukdar & Ishtiaq (2016) along with the coal areas in the same division.

Temporal distribution

Temporal trends of $PM_{2.5}$ ($\mu g/m^3$) across various districts of Meghalaya are shown in Fig 4. Here, the slope indicates the magnitude of trend (whether positive or negative) per year, whereas * depicts significant trend at $p < 0.1$. The district with no * signify no existence of significant trend. In Fig 4, the solid black colour line denotes the slope, whereas the dash line and round black dotted lines denotes the 95% maximum and minimum confidence interval. It is observed that all the districts showed positive trends of $PM_{2.5}$ concentrations. The increase in number of vehicles may be one of the primary reasons for these positive trends. As shown in Fig 5, the total numbers of vehicles in the state increased tremendously from the year 2007 to 2016. There is a dominant increase in the numbers of trucks and cars during this period, which may pose significant threat to air quality. Also due to increase in population and thus economic demands (Chakraborty, 2006; Fact sheet 2014), more load had been imposed in the existing industries of the state, which ultimately led to augmentation of their outputs. These may be the key reasons for the observed increasing trends in all the districts.

Overall, the slope was found to be steepest in West Khasi Hills (0.70 $\mu g/m^3$/year), but in spite of this, the trend was still observed to be less significant in this district. This may be due to the fact that the values of $PM_{2.5}$ concentrations in West Khasi Hills in the years 2010 and 2013 were low and very close to the $PM_{2.5}$ value of the year 2007 as observed in Table 1. However, positive trend was observed to be significant in

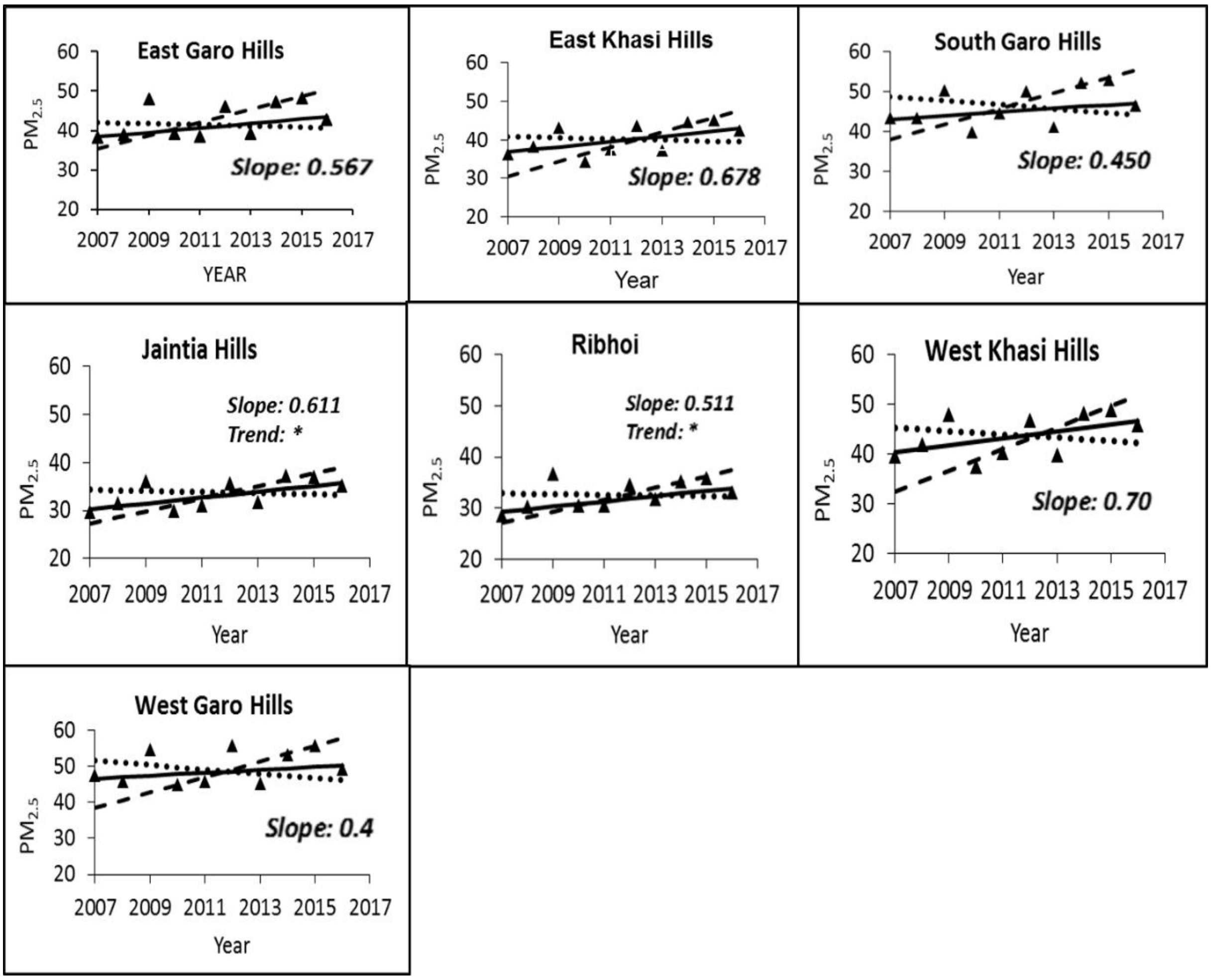

Fig 4. Temporal trend of PM2.5 (µg/m3) across various districts of Meghalaya

Ribhoi and Jaintia Hills districts. As for these set up at Umiam in Ri Bhoi and the unscientific rampant coal mining in Jaintia Hills as well as the two districts, pollution from the industrial units establishment of a large number of cement factories (as shown in Study area) may be the reasons that contribute to the significant positively trend in these two districts (Das Gupta, Tiwari, & Tripathi, 2002). In fact, according to the report published by Meghalaya State Pollution Control Board on the impact of water and air pollution on the quality of life of Meghalaya, the industrial units at Umiam, mostly mineral-based, do not have the dispersion and assimilative capacity of the air-sheds, which is mandatory for a healthy environment (The Telegraph 2014).

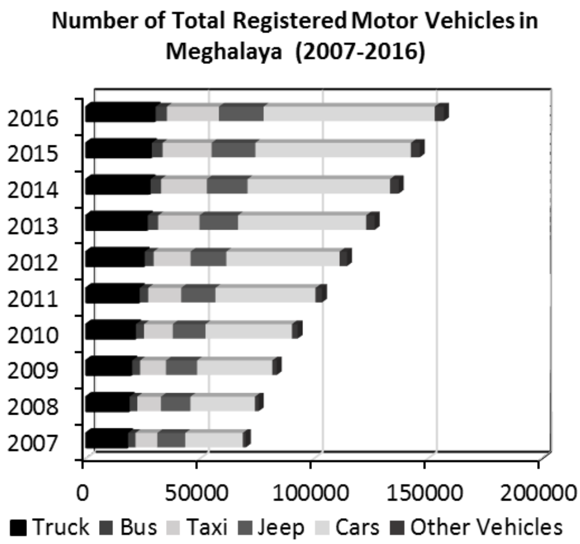

Fig 5. Total number of Registered Vehicles in Meghalaya
(Source: Ministry of Shipping, Road Transport & Highways, Govt. of India. (ON285), (ON1633))

CONCLUSION

With the advent of industrialization and urbanization, there is a serious threat to air quality all over the globe. It possesses even a bigger risk for human health (Kampa & Castanas, 2008) and plant growth (Honour, Bell, Ashenden, Cape, & Power, 2009). Particulate matters are one of the major air pollutants (Pope & Dockery, 2006). The present work focused at presenting spatial and temporal attributes of $PM_{2.5}$ distributions over the state Meghalaya using satellite data. The results showed that $PM_{2.5}$ concentrations are more in western part of Meghalaya, which is encircled with major coal areas of the state and Bangladesh, and shares border with one of the most urbanized division of Bangladesh. Moreover, due to increase in vehicles and advancement in societal life, $PM_{2.5}$ concentrations increased temporally in all the districts with two namely Ri bhoi and Jaintia Hills showing significant increments. Our results and observations suggest that with internal factors within Meghalaya, there is a significant influence of external factors (outside the state) in agglomeration of $PM_{2.5}$ concentrations over Meghalaya. This appeals for a comprehensive study on particulate transport over this region of India that may put more light on impacts of exterior sources of particulate matters.

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