Spatio-Temporal Distribution and Health Risk Levels of TSP and PM_{10} in the Mining Town of Tarkwa, Ghana*

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Krampah, F., S. A., Amegbey, and Ndur, S. (2021), "Spatio-Temporal Distribution and Risk Levels of TSP and PM_{10} in the Mining Town of Tarkwa, Ghana", *Ghana Mining Journal*, Vol. 21, No. 1, pp. 53-67.

Abstract

Particulate matter (PM) varies significantly in space and time. Effective PM risk analysis requires adequate knowledge of the spatial and temporal distribution of PM. In order to understand TSP/PM_{10} variability within the microclimate of Tarkwa and their potential impact. The Spatio-temporal distribution of Total Suspended Particulates (TSP) and PM_{10} in Tarkwa was studied. Five years TSP and PM_{10} monthly concentration data from fifteen (15) monitoring stations were collected and analysed for Spatio-temporal characteristics within the suburbs around three mining companies in Tarkwa. Autocorrelation between neighbouring suburbs, attainment rate, particle size distribution and risk levels were evaluated. The results revealed that all the monitoring stations except two (stations NV and TN) recorded TSP and PM_{10} concentrations below the national guideline for all years of study. Geo-spatially, highest TSP and PM_{10} risk level were recorded East of Tarkwa. Inhalable particles constitute about 44.09-72.90% of TSP. Attainment values between 44.09%-100% and 30%-100% were recorded for TSP and PM_{10}, respectively. Estimated AQI values ranged between good and unhealthy for sensitive groups. Future studies directed at the chemical composition of PM was recommended to enhance further understanding of the risk levels.

Keywords: Particulate Matter, Attainment Rate, Air Pollution, Trends, Particle Size Distribution

1 Introduction

Atmospheric particulate matter (PM) is a complex heterogeneous mixture of solid or liquid particles whose individual physical size distribution changes in time and space (Abdeen *et al.,* 2014). PM is currently considered a major environmental hazard due to their effects (cardiovascular disease, respiratory disease, cancer, allergic effects, poor visibility), on human and ecological health. PM is noted to affect more people than any other pollutant and is thus considered a major indicator of air quality in a given area (Javed *et al.,* 2015; Gurjar *et al.,* 2010).

Several epidemiological and toxicological studies (Lipsett et al. 2006; Monn and Becker 1999; Pekkanen et al. 1997; Villeneuve et al. 2003; Xia et al. 2004; Yeatts et al. 2007; Pakbin *et al.,* 2010) have identified association between these adverse effects and mass concentration of various size fractions. Generally, PM can be classified into inhalable and non-inhalable fractions according to their ability to enter the human respiratory system. Inhalable fractions, according to Brown *et al.,* 2013, represent the mass fraction of airborne particles which is inhaled through the nose. They are less than 10 µm and can further be divided into thoracic and repirable fractions. Non-inhalable particles are however, greater than 10 µm and are too large to be inhaled. These particles present different risks and are thus essential to distinguish between them during Particulate matter pollution studies.

Other than mass concentration and particle size distribution, spatio-temporal variation of PM is essential when assessing the potential health risk. Hasenfratz *et al.,* (2014) and Xu *et al.,* (2017) noted that PM varies significantly in space and time, hence inadequate knowledge in its spatial and temporal distribution hinders effective risk analysis. Paciorek *et al.,* (2009) and Abdeen *et al.,* (2014) divulged that many epidemiological studies have had to rely on either central monitoring station data or data set that are sparse in space and time. This traditional approach falls short of true population exposure leading to exposure misclassification. It is thus essential that during PM studies a dense network of sites in multiple locations are employed to better understand the relationship between mass concentration, sources and their spatio-temporal distribution. This study employs 15 monitoring sites scattered across Tarkwa for spatial distribution analysis.

The essence of a well-studied spatial and temporal variation in PM include; resolving spatial and temporal heterogeneity, identification of hotpots, identification of time trends, identification of true health risk, adoption of effective mitigation methods, measurement of effectiveness of emission control plans etc. Despite these merits, (Abdeen *et al.,* 2014) noted that data on coarse PM is limited and hence significantly less is quantitatively known about their spatial and temporal distribution.

Whilst PM pollution might be a general issue, the situation is worse in mining areas especially where open cast mining is practiced. Amegbey et al, (2016) divulge that mining activities including overburden removal, drilling and blasting, haulage, ore crushing and the use of heavy duty vehicles continuous release PM into the atmosphere. However, limited

*Manuscript received February 24, 2021
Revised version accepted June 22, 2021
https://doi.org/10.4314/gm.v21i1.6

number of PM pollution studies (Bansah and Amegbey, 2012; Amegbey et al, 2016) have been conducted in Tarkwa, which is the hub of mining activities in Ghana. These studies only used dispersion models to try and predict the concentration of PM in a location away from one mine or the other. In this present study, the spatio-temporal distribution, Particle size distribution and attainment rate of PM in Tarkwa are analyze using 15 different monitoring site data while using PM-AQI to ascertain the potential health risk due to PM exposure.

1.2 Study Area

1.2.1 Location and Accessibility

Tarkwa and its surrounding villages located in the Tarkwa –Nsuaem municipality in the western region of Ghana constitute the study area (Fig. 1). It is the hub of the extractive industry in Ghana and lies between latitude 4^0 50' 00" N and $5^0$40'0" N; and longitude $1^0$45'0" W and $2^0$10' W with a total land area of approximately 2,354 km^2 (Seidu and Ewusi, 2018; Ewusi *et al.,* 2017). It is linked by road to major cities including Takoradi (85 km), Kumasi (233 km) and the national capital, Accra (316 km). It is also accessible by rail transport from Takoradi and Kumasi (Seidu and Ewusi, 2018).

1.2.2 Climate and Vegetation

The study area lies within the South-Western Equatorial Climate Zone in the tropical rainforest belt of Ghana. It is marked by the wet and dry climatic seasons resulting from the moist South-West monsoon winds from the South Atlantic Ocean and the dry dust-laden north-east trade winds (Seidu and Ewusi, 2018; Ewusi *et al.,* 2017). It has a bimodal rainfall regime due to the passage of the inter Tropical Convergence Zone over the town twice every year. The Tarkwa-Nsuaem municipality records the highest rainfall in Ghana with an annual mean of 1874 mm impacting the concentration of suspended particles due to scavenging effect (Seidu and Ewusi, 2018; Kuma & Younger, 2001).

Generally, the study area is warm and humid with an average 7hr sunshine a day. Daily temperatures range between 28-30 ^{0}c in the wet season and 31-33 ^{0}c during the dry season. The town has high relative humidity throughout the year ranging between 70-80% and 75-78% in the dry and wet seasons respectively (Bhattacharya *et al.,* 2012).

Tarkwa has a rich tropical rainfall vegetation with high fauna and flora diversity. The trees reach heights of 15-45 m and are mostly dispersed along the apex of hilly areas with underneath growth of shrubs, climbers and lianas (Ewusi & Ahenkorah, 2017). Vegetation cover of the area has decline over the years because of anthropogenic activities such as mining, logging, population growth and construction.

2 Resources and Method Used

2.1 Data Source and Description

Large-scale mining companies in Ghana are mandated by law to report on host communities' air quality status to the EPA, Ghana. The data from the report formed the source of data for this study. Real-time monthly air quality data (TSP and PM10) in Tarkwa between 2015 and 2019 from fifteen active monitoring stations (Fig. 1) were obtained from the three large scale mining companies in Tarkwa namely Goldfields Tarkwa Mines (GFGL), AngloGold Ashanti Iduapriem Mines (AAIL) and Ghana Manganese Company (GMC). Monitoring stations code and the GPS locations are provided in Table 1. All the three mining companies employed MiniVol Tactical Air Sampler which they set up for 24 hours for both TSP and PM10 monitoring. Monthly data on wind speed and direction from 2015 to 2019 were obtained from the Tarkwa District Synoptic Meteorological station located at the University of Mines and Technology (UMaT), Tarkwa. These data were used to develop wind roses, which show the study area's prevailing wind conditions (Fig. 2).

2.2 Statistical Analysis

The five-year monthly TSP and PM_{10} data obtained were statistically analysed using Microsoft Excel 2019. Annual averages for the various monitoring stations were also computed.

Pearson Correlation Analysis was employed to investigate the TSP and PM_{10} relationship between the fifteen monitoring stations at $p < 0.005$ using SPSS 19.0.0. The correlation coefficient was estimated using Equation (1).

$$r_{xy} = \frac{\sum x_i y_i - n\bar{x}\bar{y}}{(n-1)s_x s_y} \quad (1)$$

where:

n $= sample\ size;\ x_i y_i\ are\ the\ individual\ sample\ points\ indexed\ with\ i$

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \quad (sample\ mean);\ and\ anologous\ for\ \bar{y}$$

$$s_X = \sqrt{\frac{1}{n-1} + \sum_{i-1}^{n}(X_i - \bar{X})^2}$$

(Sample standard deviation); and analogous for s_y

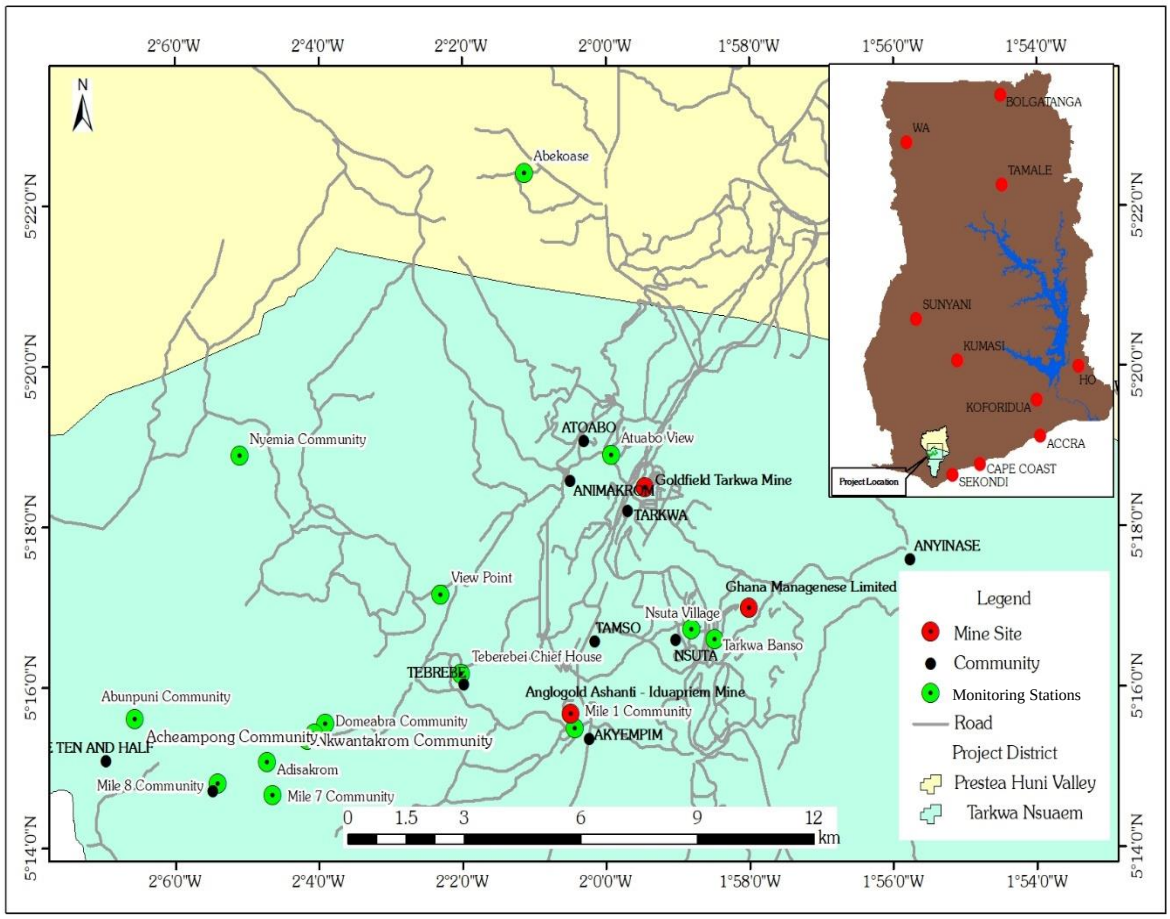

Fig. 1 Study Area and Monitoring Stations

Table 1 Monitoring Stations and Locations

MONITORING Stations	CODE	GPS COORDINATES	
		EAST	NORTH
Atuabo View	AT	610943.49	587559.30
Nsuta	NV	613002.39	583541.92
Tarkwa Banso	TN	613612.28	583325.49
Abekoase	AK	608700.00	594031.00
Mile 7	M7	602235.48	579734.05
Mile 1	M1	6100112.91	581279.28
Teberebei	TB	607086.01	582531.96
ViewPoint	VP	606559.26	584347.32
Mile 8	M8	600810.66	580004.36
Domebra	DO	603589.43	581371.34
Acheampong	AC	603129.00	581009.00
Adisakrom	AD	602084.74	580499.41
Nkwantakrom	NK	603309.37	581149.81
Nkyemia	NY	601386.04	587535.87
Abunpuni	AB	598686.00	581491.00

2.3 Spatial and Temporal Distribution

To explore the spatial patterns of TSP/PM_{10}, the monthly average TSP/PM_{10} data were used to estimate the annual average. The monitoring sites and their annual averages were mapped using ArcGIS. Inverse distance weighting (IDW) interpolation method was then employed to interpolate TSP and PM_{10} concentrations of unknown points in the study area. According to Gorai *et al.*, (2018), IDW operates on the principle that each point has a local influence that diminishes with distance and hence cells closer to the processing cell have greater weighting than those afar. The IDW method estimates the values of unknown points based on Equation 2.

$$z_j = \frac{\sum_i \frac{Z_i}{d_{ij}^n}}{\sum_i \frac{1}{d_{ij}^n}} \quad (2)$$

Where z_j = value to be estimated; Z_i= ith data value; d_{ij}= distance between point i and i; and n= the weight power that determines the mode of weight of drop.

Temporal distribution of pollutants concentrations was explored by plotting a linear graph of the calculated annual averages of pollutant concentrations using Microsoft excel.

2.4 Air Quality Index (AQI)

AQI is an indicator for reporting air quality and is a popular method of air quality knowledge translation. It tells how clean or unhealthy the air is and provides recommendations for sensitive populations (Gorai *et al.*, 2018). This study uses the USEPA (1999) AQI estimating method in Equation 3.

$$AQI_{ap} = \frac{AQI_{uc} - AQI_{lc}}{BP_{uc} - BP_{lc}}\left(C_{ap} - BP_{lc}\right) + AQI_{lc} \quad (3)$$

where AQI_{ap} is the index for a given pollutant (ap); C_{ap} is the concentration of the pollutant; AQI_{uc} and AQI_{lc} is the index value corresponding to the upper and lower of each breakpoint category (BP) respectively; BP_{uc} and BP_{lc} are the upper and lower concentration at each breakpoint category, respectively. This index is divided into six subcategories with specified colours as shown in Table 2. AQI for both TSP and PM_{10} were computed for each monitoring location. The highest AQI among the two pollutants was considered as the AQI for the location.The estimated AQI values were then used to develop a spatial map for the study area.

2.5 Particle Size Distribution and Attainment Rate

The study also assessed the percentage of inhalable dust and non-inhalable dust in total suspended matter using Equations 4 and 5.

$$\%\ \text{inhalable} = \frac{PM10\ concentration}{TSP\ concentration} * 100\% \quad (4)$$

$$\%\ noninhalable = 100 - \%inhalable \quad (5)$$

The compliance or attainment rate gives the number of times the measured pollutant concentration was within the guideline value or standard and is calculated using Equation 6.

$$Attainment\ rate = \frac{measured\ concentrations\ within\ standard}{total\ number\ of\ measured\ \ concentrations} * 100\%$$

Table 2 AQI Categories and Related Health Risk

AQI Level	AQI Category	Category Colour	Action to Protect Health
0 – 50	Good	Green	Air quality is satisfactory and poses little or no risk
51 – 100	Moderate	Yellow	Air quality is acceptable. However, poses health risk to unusually sensitive group
101 -150	Unhealthy for sensitive group	Orange	Sensitive groups likely to be affect. General public unlikely to be affected.
151 -200	Unhealthy	Red	General public may begin to experience health effects. Sensitive groups at increased risk.
201 – 300	Very Unhealthy	Purple	Higher health risk to general public.
301 - 500	Hazardous	Maroon	General public may experience severe health effect

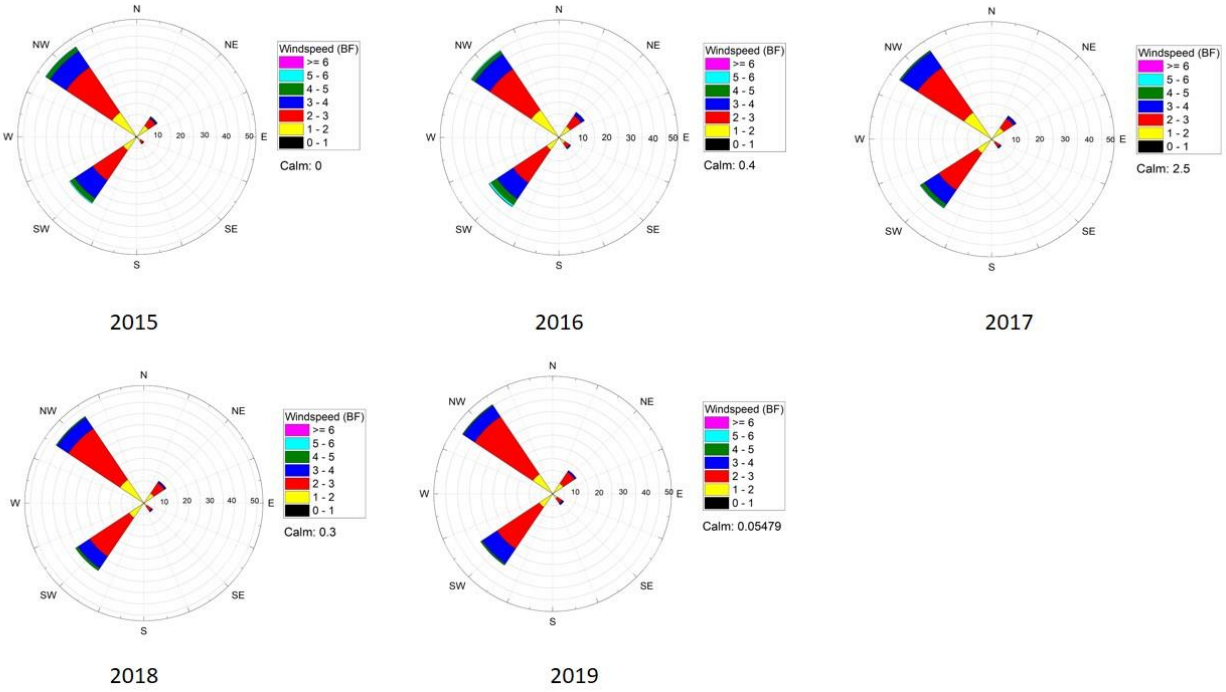

Fig. 2 Prevailing Wind Condition of the Study Area

3 Results and Discussion

3.1 Results

3.1.1 Spatial Distribution

The mean annual TSP/PM_{10} concentrations from the fifteen monitoring sites within Tarkwa from 2015 to 2019 were interpolated to show the spatial and temporal characteristics as in Figs. 3 and 4. The annual mean TSP concentration for 2015 ranged from 30.14 µg/m^3 at station AB located in the western part of Tarkwa to 135.1 µg/m^3 at station TN in the eastern Tarkwa. It was observed that the monitoring stations in eastern Tarkwa recorded higher TSP concentrations than those in western Tarkwa. Similar trends were observed in the years 2016 to 2019 with monitoring station TN always recording the highest TSP concentration. The average TSP concentration in Tarkwa was generally lower than the standard of 150 µg/m^3 for most stations (except TN and NV). The maximum annual averages were clustered in eastern Tarkwa. Similar spatial distribution characteristics were observed for PM_{10}.

3.1.2 Temporal Distribution

Figs. 5 and 6 show the temporal pattern for TSP and PM_{10} along the 5-year study expressed as yearly running means, respectively. It was observed that the TSP concentrations of eleven monitoring stations (AB, AC, M8, M1, TB, VP, M7, AD, DO, NK, NY) increased from 2015 to 2019, whilst trend towards reduction was observed for AT and AK from 2015 to 2019. TSP concentration for station TN increased from 2015 to 2017 and then decreased from 2018 to 2019. Monitoring station NV showed an alternating increasing and decreasing trend from 2015 to 2019. An analysis of variance ($p<0.05$, 4 df) showed significant difference between the yearly average TSP concentrations. All the estimated annual averages were below the EPA standard of 150 µg/m^3 except for station TN and NV (Fig. 5).
Varied PM_{10} temporal trends were identified. It was observed that the PM_{10} concentrations at six (6) of the monitoring stations (AB, AC, M8, M7, DO, NV) increased from 2015 to 2017 and then decreased gradually to 2019. Four other monitoring stations (TB, AD, NY, and TN) recorded concentrations rise from 2015 to 2018 and decreased in 2019. PM_{10} concentrations in stations M1 and VP decreased from 2015 to 2016 and then increased through 2019. Monitoring stations AT and AK observed a regular annual decreasing trend in concentration from 2015 to 2019 (Fig. 6). Monitoring station NK other the other hand recorded alternate increasing and decreasing trends from 2015 to 2019. However, an analysis of variance ($p<0.05$, 4 df) showed non-significant difference between the yearly average PM_{10} concentrations Here again, all the monitoring stations recorded annual averages within the limits of the standard (70 µg/m^3) except for TN which recorded exceedance for the years 2016 to 2019 and NV which also exceeded the limit for the years 2016 to 2018.

3.1.3 TSP/PM_{10} Relationship Between Monitoring Stations

The relationship between the different monitoring stations expressed as Pearson correlation coefficient are shown in Table 3. A weak to strong correlation was observed between the stations. Closer station-pairs (with shorter distances) showed a higher correlation. Most of the station pairs showed a positive correlation. Station AK, located at the North-Eastern part of the study area, showed an inverse relationship with all the stations except AT, NV and TN. Stations located in Western Tarkwa showed a strong correlation with each other, whereas their correlation with eastern stations was relatively lower. The correlation coefficients of TSP for stations were generally higher than those for PM_{10}.

3.1.4 AQI and Health Risk Levels.

The annual average TSP and PM10 concentrations from the various monitoring stations were used to compute the AQI and then interpolated to show health risk levels across Tarkwa as in Fig. 7. In 2015 the AQI values ranged from 14.4 at station NY in western Tarkwa to 59.4 at station AT in north-eastern Tarkwa. The AQI values in 2016, 2017, 2018 and 2019 also ranged from 18.6 to 69.8; 23.1 to 103.0; 20.4 to 73.3 and 10.1 to 61.9 respectively. Furthermore, the highest yearly AQI (103.0) was recorded in 2017 for station NV, whilst the lowest AQI was recorded in 2019 for station AK. There was a general increase in health risk from the north-west to the south-west of Tarkwa.

3.1.5 Compliance Rate

Figs. 8 and 9 show the compliance rate for TSP and PM10, respectively, for the various monitoring stations from 2015 to 2019. Twelve (12) monitoring stations (AB, AC, M8, M1, M7, VP, TB, AD, DO, NY, NK, and AK) recorded 100% TSP compliance rate for all the years under review. Stations NV and TN recorded 100% compliance rate for 2015 only whilst AT had 100% compliance rate for 2019 only.

Varied PM compliance rate was observed for the monitoring stations under different study years (Fig. 9). Only five (5) monitoring stations (NY, NK, DO, AD, M1) recorded 100% compliance rate for all the years under review. Another five (5) of the monitoring stations (AB, AC, TB, VP, AK) recorded 100% compliance rate for four of the five years under review. 2017 was identified as the year with more monitoring stations, (9) recording some degree of percentage non-compliance. Monitoring stations NV and TN always competed for the highest TSP and PM_{10} non-compliance rate spot for all the years except for 2015 when station AT recorded the highest non-compliance rate.

Table 3 Pearson Correlation Coefficient Between Monitoring Station. TSP (Cell below diagonal) and PM10 (above diagonal)

	AB	AC	M 8	M 1	TB	VP	M 7	AD	DO	NK	NY	NV	TN	AT	AK
AB	1	**.682**	**.678**	**.477**	**.694**	**.541**	**.490**	**.614**	**.532**	**.625**	**.611**	.149	.200	.058	-.251
AC	**.787**	1	**.589**	**.526**	**.647**	**.508**	**.699**	**.699**	**.674**	**.792**	**.505**	**.342**	**.294**	.164	-.101
M 8	**.789**	**.753**	1	**.582**	**.753**	**.568**	**.579**	**.644**	**.496**	**.616**	**.604**	.088	.116	.088	-.148
M 1	**.490**	**.539**	**.550**	1	**.614**	**.625**	**.603**	**.705**	**.450**	**.526**	**.563**	.046	.135	.070	-.060
TB	**.682**	**.662**	**.749**	**.473**	1	**.583**	**.599**	**.708**	**.464**	**.631**	**.562**	.092	.112	.047	**-.265**
VP	**.656**	**.694**	**.561**	**.613**	**.606**	1	**.572**	**.642**	**.405**	**.503**	**.637**	.015	.187	.071	-.044
M 7	**.653**	**.794**	**.700**	**.460**	**.532**	**.566**	1	**.653**	**.508**	**.645**	**.457**	**.277**	**.268**	.123	-.011
AD	**.625**	**.697**	**.698**	**.619**	**.734**	**.626**	**.610**	1	**.593**	**.654**	**.734**	.162	.217	.245	-.048
DO	**.682**	**.844**	**.654**	**.459**	**.645**	**.704**	**.803**	**.635**	1	**.774**	**.578**	.221	.247	**.293**	-.057
NK	**.670**	**.871**	**.714**	**.534**	**.609**	**.675**	**.703**	**.666**	**.797**	1	**.672**	**.268**	**.268**	.019	-.225
NY	**.536**	**.605**	**.530**	**.520**	**.606**	**.742**	**.578**	**.778**	**.594**	**.651**	1	.054	.159	.091	-.181
NV	**.307**	**.333**	**.291**	.170	.167	.184	.249	.248	**.297**	**.275**	.108	1	**.731**	**.566**	**.351**
TN	.237	**.340**	.168	-.013	.086	.011	.178	.086	**.283**	**.264**	-.026	**.747**	1	**.396**	.202
AT	.131	.165	.142	.101	.100	.104	.187	**.315**	.249	.079	.215	**.308**	**.381**	1	**.618**
AK	**-.290**	-.076	-.184	-.059	-.121	-.175	.030	.052	.025	-.048	-.092	.198	.202	**.511**	1

*Bolded values are significant at $p < 0.005$

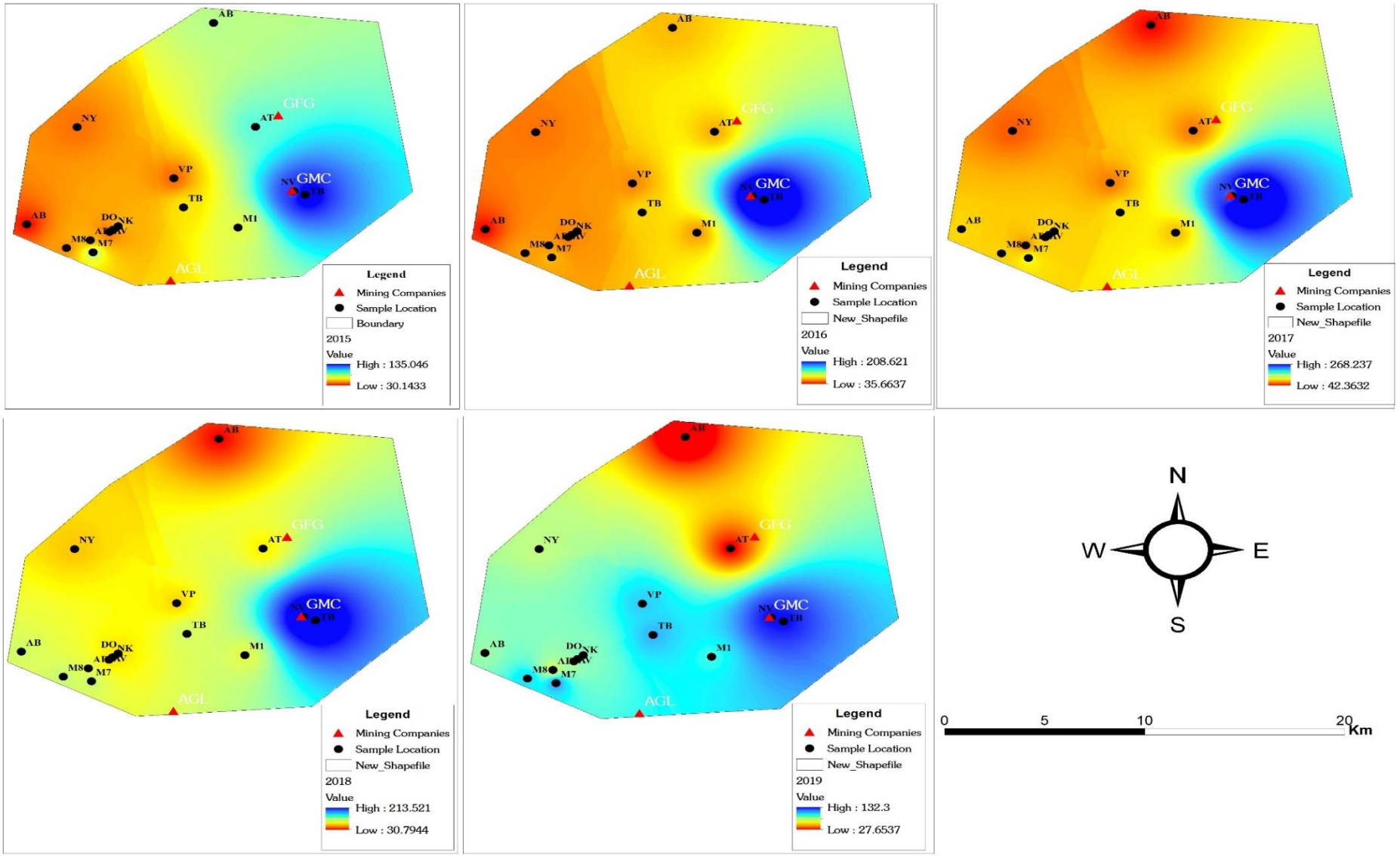

Fig. 3 Annual Average TSP Spatial Distribution Characteristics 2015-2019

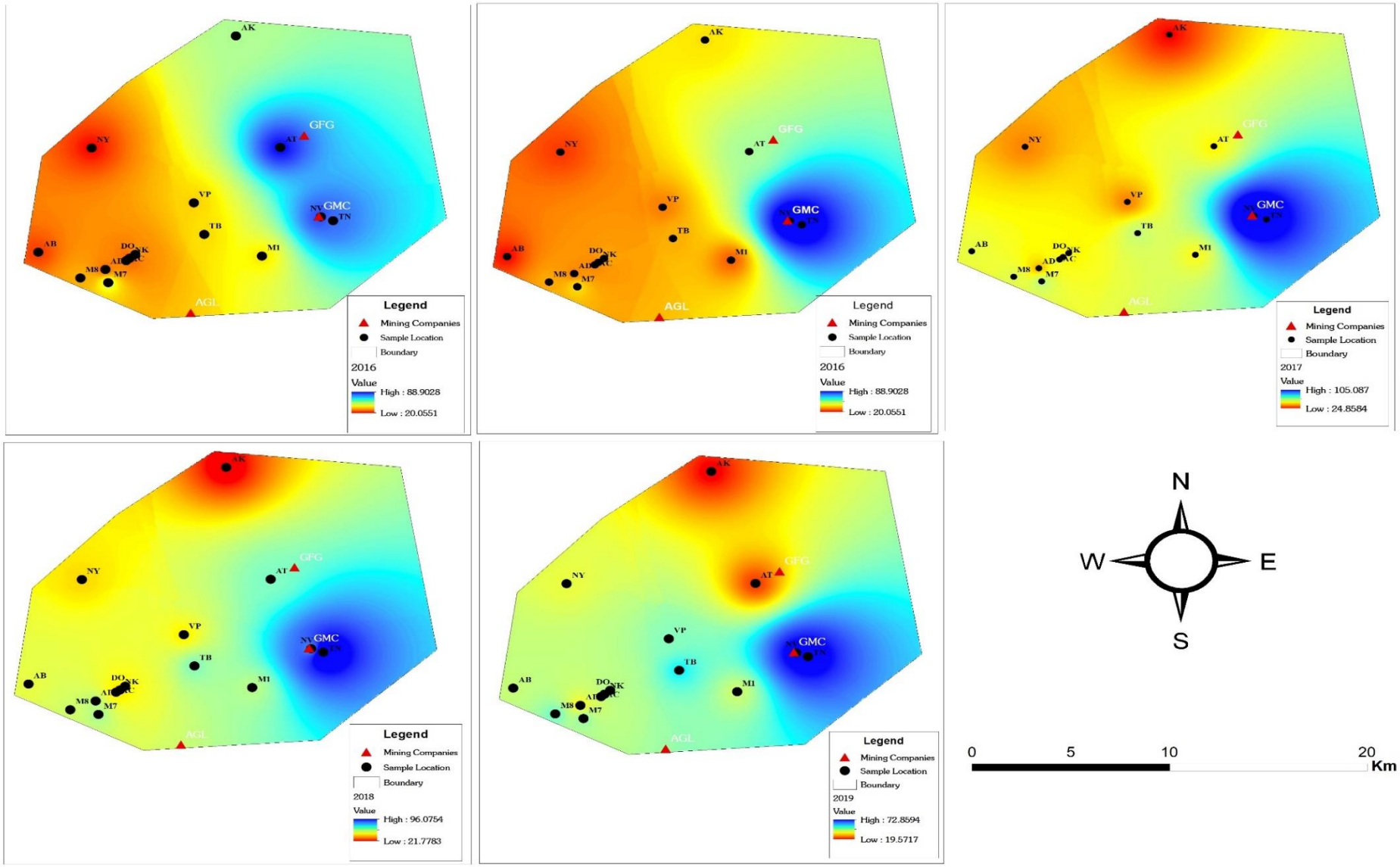

Fig. 4 Annual Average PM10 Spatial Distribution Characteristics

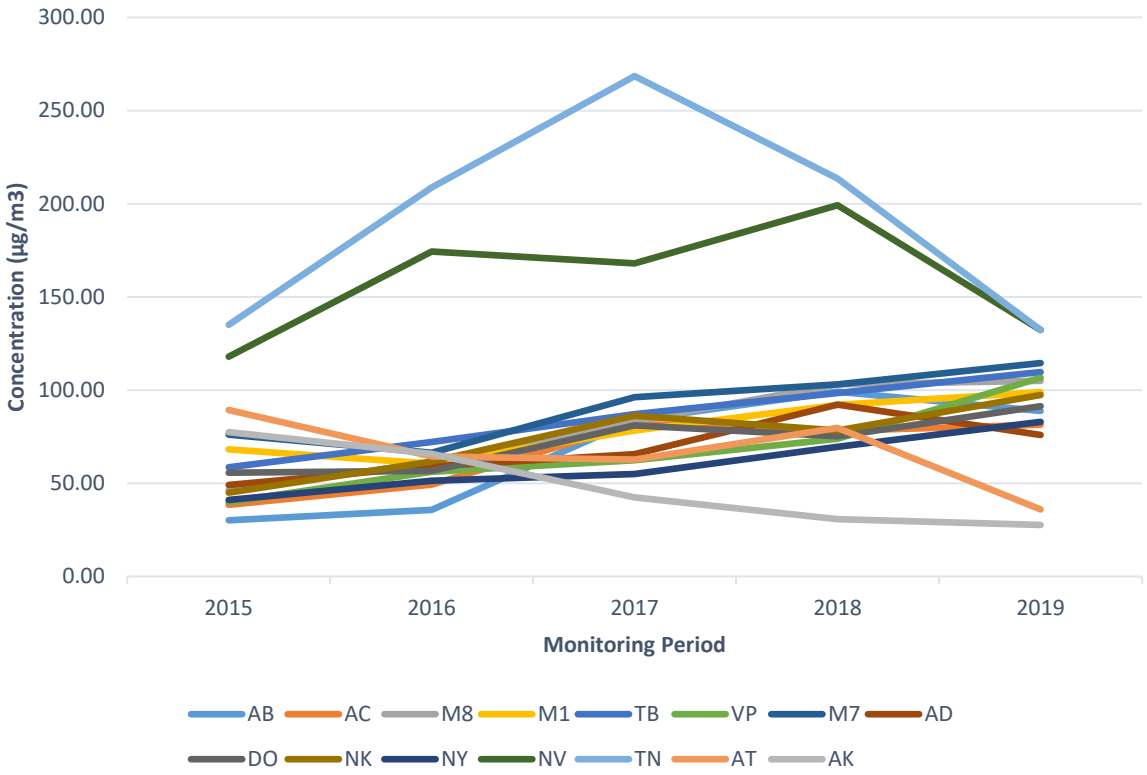

Fig. 5 Annual Average TSP Temporal Distribution 2015-2019

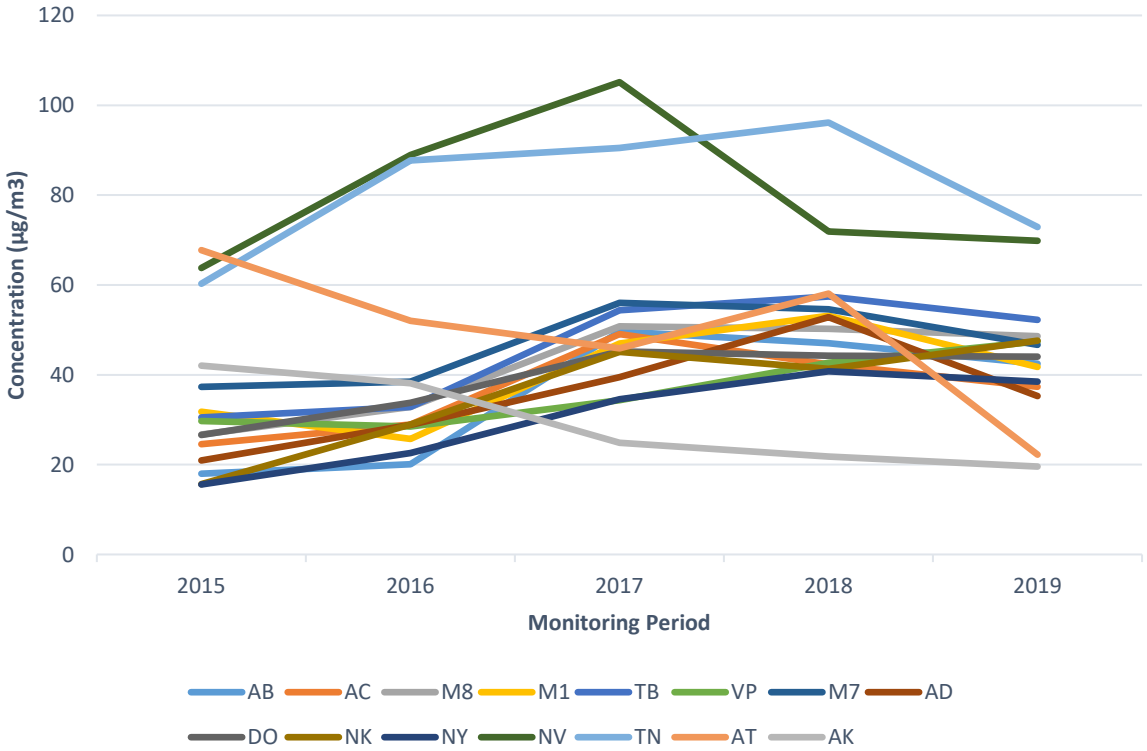

Fig. 6 Annual Average PM10 Temporal Distribution

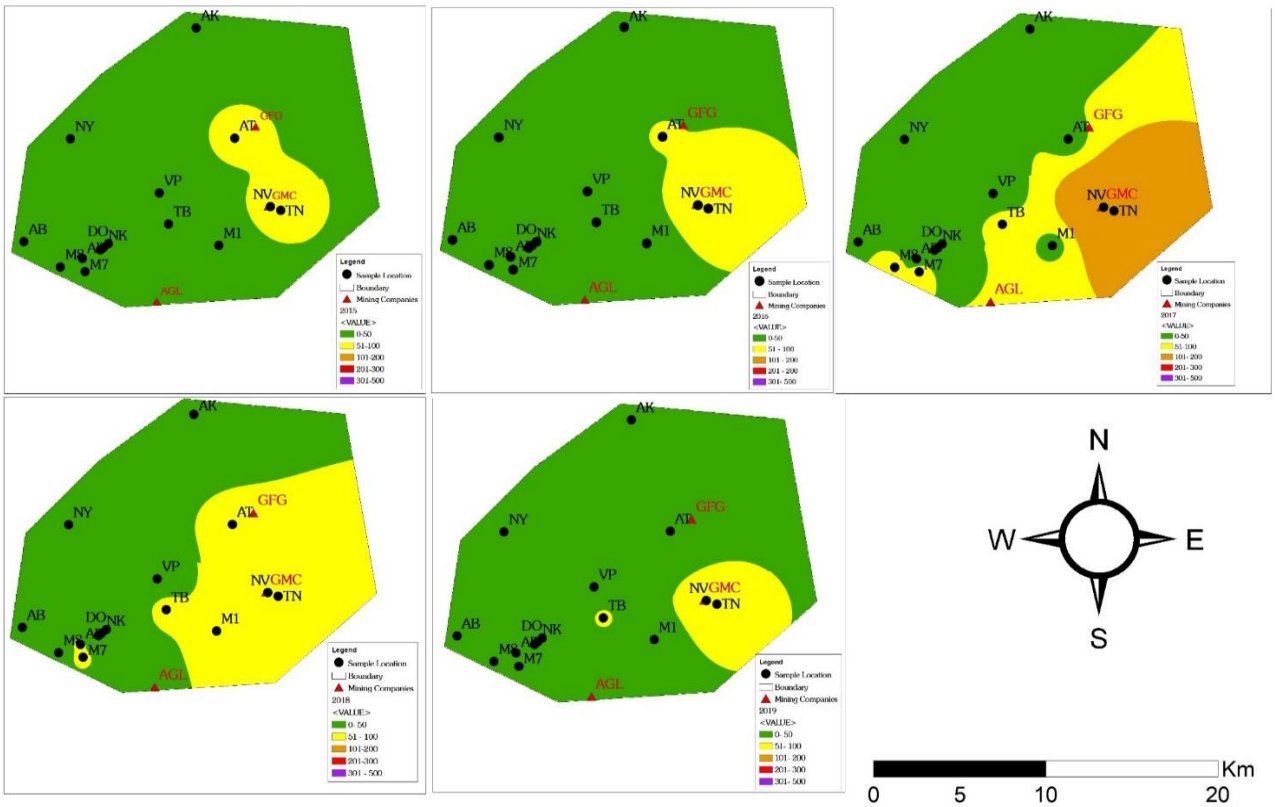

Fig. 7 AQI Distribution Maps 2015 - 2019

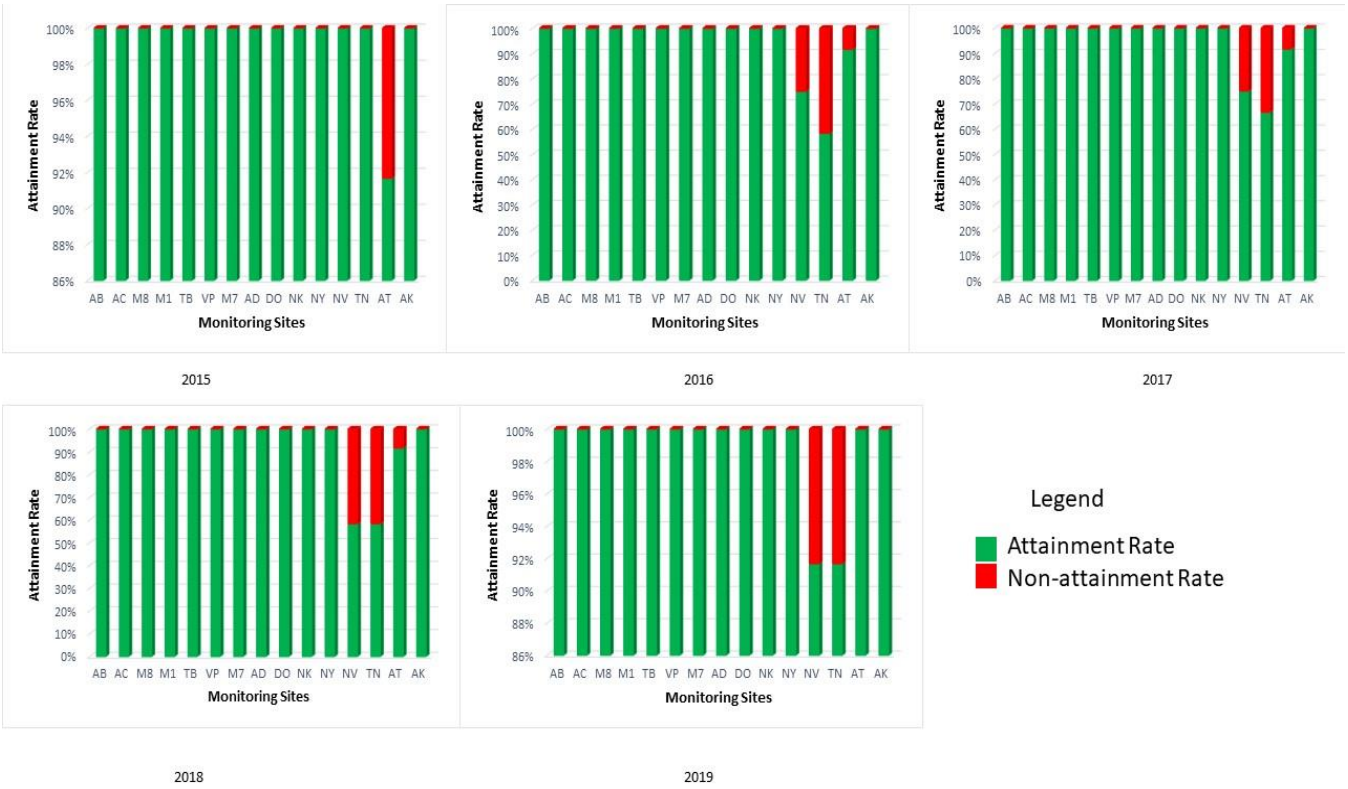

Fig. 8 TSP Compliance vs. Non-compliance Rate 2015-2019

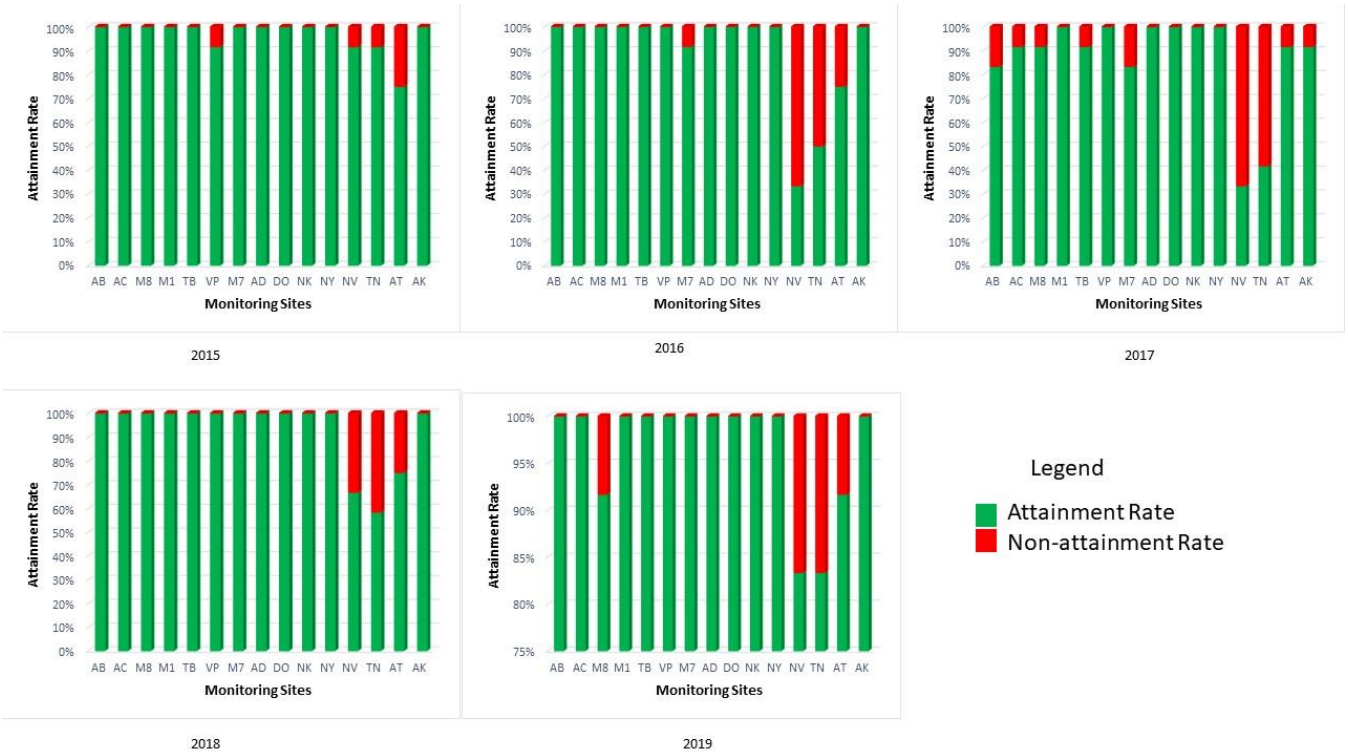

Fig. 9 Compliance vs. Non-compliance Rate 2015-2019

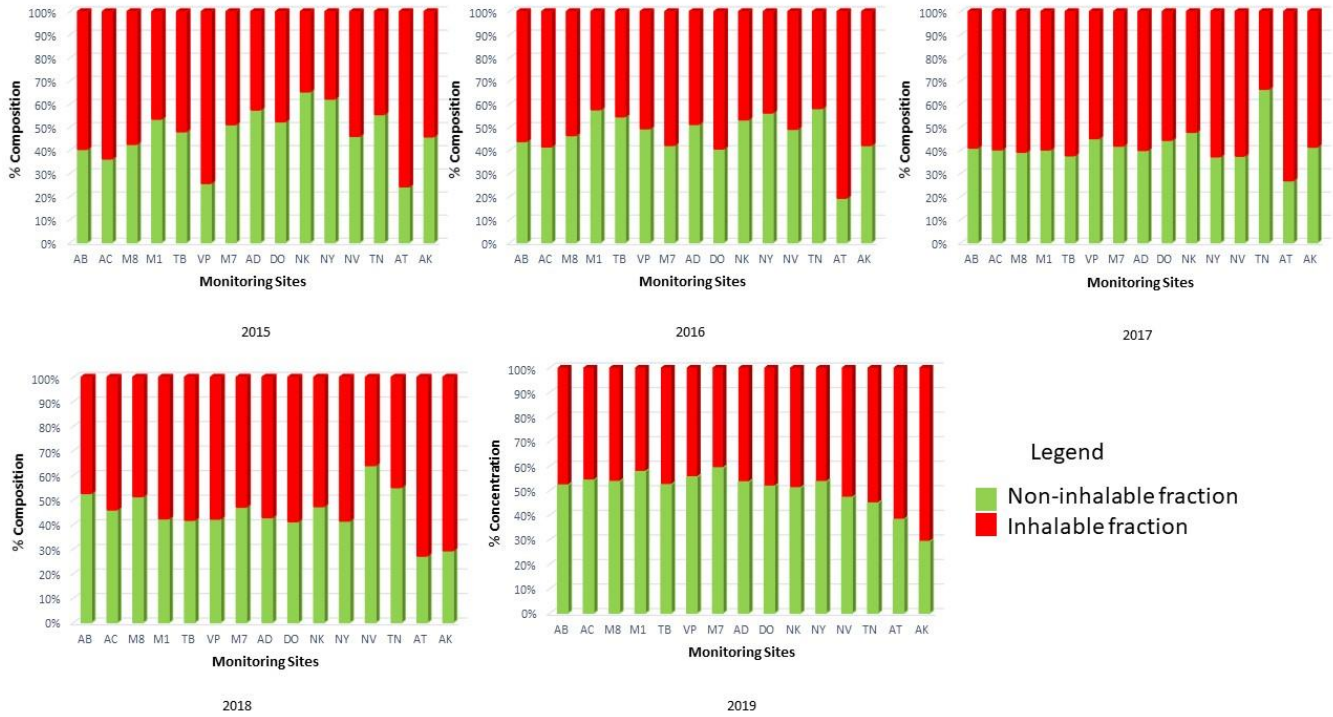

Fig. 10 Inhalable vs. Non-Inhalable Fractions of TSP 2015-2019

3.1.6 Particle Size Distribution

The relative contributions of inhalable and non-inhalable particles to total suspended matter for the various monitoring sites from 2015 to 2019 are shown in Fig. 10. The non-inhalable suspended matter constitutes TSP-PM_{10} fraction whilst the inhalable fraction constitutes PM_{10}. Varied size percentage contributions were observed for the different monitoring stations and for different years. The percentage contribution of the inhalable fractions ranged between 34.81-75.85, 42.04-80.78, 33.69-73.23, 36.07-72.89, and 40.77-70.77 for the years 2015 to 2019 respectively. Out of the 15 monitoring stations 8, 9, 14, 10 and 4 recorded higher inhalable fraction contributions to non-inhalable particles from 2015 to 2019. Monitoring station AT recorded the highest inhalable fraction composition for all the years under review except for 2019. In general, the average percentage inhalable fraction for the monitoring stations was ranged from 44.09% to 72.90%.

3.2 Discussion

3.2.1 Spatio-Temporal Distribution

Assessing spatio-temporal variability of pollutants is an essential task as it reveals variations in local risk levels and trends for effective pollution control strategies. The study reveals that (Figs. 3and 4) the annual average of TSP and PM10 concentrations of monitoring stations located around the same mine were similar and showed similar temporal and spatial patterns. Thus, NV and TN stations located close to GMC showed similar pattern whilst AT and AK close to GFGL showed a similar pattern. Stations AB, AC, M1, M7, M8, TB, DO, VP, AD, NK, and NY close to AGL also gave a similar pattern and trend. This indicates that the concentration of TSP/PM_{10} in the study area is influenced by local conditions (sources and meteorology).

Among all the stations studied, only TN and NV (located close to GMC in Eastern Trakwa) were observed to have recorded TSP and PM_{10} concentrations above the national standards of 150 and 70 µg/m^3. This could be attributed to the fact the ore mined by GMC is transported through these two towns by heavy-duty vehicles for export. Hence, the heavy vehicular traffic could be responsible for high particle resuspension (Pakbin *et al.,* 2010). According to Charron and Harrison (2005), high particle resuspension is associated with heavy-duty vehicles compared to light vehicles. Garg *et al.*, (2000) also noted that heavy-duty vehicles have high brake wear emissions due to strong abrasion processes, thus impacting coarse particles' concentration. Wind-blown ore particles also from these heavy-duty trucks could contribute to the high TSP/PM_{10} concentrations.

Another factor contributing to the high TSP/PM_{10} concentration in TN and NV, located in Eastern Tarkwa, is wind transport. Fig. 2 shows that wind direction in the study area is predominately from NW and SW towards the East where these two monitoring stations are located with a wind speed range of 1-5 on the Beaufort scale. The 1-5 wind speed range represents light air to moderate waves, taking a more pronounce and longer form (Fresh breeze), hence carrying suspended particles generated at the West to the East.

TN and NV are also noted for high agricultural activities, contributing to the high TSP/PM_{10} concentrations. Several authors (Madden *et al*., 2008; Bogman et al., 2007**;** Arslan and Aybek, 2012**)** have implicated agriculture as a significant contributor to coarse particles. According to Pattey *et al.*, (2015) in 2011 agriculture accounted for 3066 kt of TSP, 1190 kt of PM10 and 276 kt of PM2.5 in Canada. PM from agricultural sources may be emitted directly (Primary) from farm transport equipment, wind erosion, land tillage, biomass burning, livestock activities or may originate from reaction of gaseous emissions such as NH_3 (secondary) in the atmosphere **(**Garcia *et al.,* 2013**).** The decreasing order of pollution of monitoring sites ranked by average yearly concentrations is TN>NV>M7>TB>M8>M1>NK>DO>AD>VP>A B>AT>AC>NY>AK. This order also corresponds to the risk levels.

Pollutants (TSP and PM10) concentrations of stations AB, AC, M1, M7, M8, TB, DO, VP, AD, NK and NY although were all less than the national standard were seen to have followed increasing trend. This could be attributed to the increasing production of AGL over the years as well as increasing population and agricultural activities in these areas. Population growth is associated with increased fuel consumption, construction activities, and transport activities, which invariably increase TSP/PM_{10}.

3.2.2 TSP/PM_{10} Correlation Analysis Between Monitoring Sites

Correlation analysis of pollutant concentrations between monitoring stations reveals typically two types of information; the nature of pollutant sources and variability in pollutant distribution. The study revealed that the correlation between stations closer to each other was stronger. Same was also revealed because stations located in the West recorded a stronger correlation with each other than eastern stations and vice versa. This is indicative that stations close to each other are subjected to similar

sources. However, the difference in source strength and intensity can limit predictability (Table 2) (Pakbin *et al.,* 2010). The statistically significant correlation ($p<0.005$) reflect two main drivers in the variability of the pollutants: common sources and meteorological condition variability (Cattani *et al.,* 2010). The high correlation among station located in the same locations (east, West) indicates that the monthly pattern of variability is superimposable on each other (Cattani *et al.,* 2010). The weak correlation between western and eastern stations suggests different sources and source strength as PM is typically associated with site-specific activities such as type and abundance of industrial activities and the nature of emissions. (Abdeen *et al.,* 2014). These stations were thus mostly exposed to a local source. The results also revealed that PM_{10} shows more spatial variability than TSP, which is consistent with the many sources of PM_{10} (Burning, agriculture, blasting, excavation, construction) compared to TSP.

3.2.3 AQI and Health Risk Levels

The essence of AQI is to inform the general public regarding air quality status and its associated health risk. The dimensionless figure is indicative of how safe or unhealthy the air is and provide recommendations (Saraswat *et al.,* 2013). The AQI maps (Fig. 7) indicate that the AQI values ranged from good to moderate for all the stations except NV, which recorded AQI values in unhealthy for sensitive groups category in 2017. This could be interpreted that the air quality in most of the areas in Tarkwa is satisfactory to acceptable with no risk or little risk to unusually sensitive groups. The air quality status of station NV as estimated for 2017 is likely to pose a health risk to sensitive groups; however, the general public is less likely to be affected. Averagely, the risk levels posed by PM pollution for the various monitoring areas was found to be in the order of TN>NV>AT>M7>TB>M8>M1>DO>NK>VP>AC >AB>AD>NY>AK

3.2.4 Compliance Rate

Air pollution control's objective is to prevent adverse responses by all receptor categories especially human to pollutants. To avoid these responses, pollutant concentration must be below level at which these responses occur. Air quality guideline recommends concentration levels (targets) at which these responses are significantly reduced. In this study, TSP and PM10 concentrations were compared with Ghana EPA guidelines of 150 $\mu g/m^3$ and 70 $\mu g/m^3$ respectively to determine attainment levels (Figs. 8 and 9). It was observed that 12 out of the 15 monitoring stations recorded 100% TSP attainment for all the years under study. This is indicative of low risk. The likelihood of TSP/PM-related effects such as respiratory illness, cardiovascular diseases, and cancer is minimal. The other three monitoring stations recorded varied attainment rate between 55 and 100, indicating moderate risk. Nevertheless, for stations TN, NV and AT all the stations achieved PM_{10} attainment rate between 80 to 100% indicating a low risk. AT, TN, and NV's attainment rate was within 30% to 92%, indicating high to low risk.

3.2.5 Particle Size Distribution

Particle size distribution is an essential characteristic of suspended particulate matter for three critical reasons. Firstly, it helps identify the contribution of various size fractions to particulate matter; secondly, it indicates the sources of particulate matter. Lastly, it indicates the health risk level. The particulate matter sizes in the atmosphere range between 0.005 to 100 µm which is generally referred to as total suspended particles. However, not all size ranges can enter into the human body. Particles with aerodynamic diameter $\leq$ 10 µm (PM10) are the inhalable fraction and are further distinguished into four distinct fractions; coarse, fine, ultrafine and nanoparticles (Cheremisinoff, 2002; Gurjar *et al.,* 2010). In this study, the contribution of the inhalable and non-inhalable fraction to total suspended particles was assessed. In general, the percentage inhalable fraction for the monitoring stations ranged from 44.09% to 72.90%, consistent with the US EPA 40% to 70% inhalable particles composition in Total Suspended Matter (Cheremisinoff, 2002). Majority of the monitoring stations recorded a higher percentage of inhalable than non-inhalable particles for all the years under study except 2019. This indicates a higher inhalation risk. The higher PM10 contribution is also indicative that mechanical processes such as stone crushing, construction activities, blasting, excavation, and dust resuspension are the most likely sources (Javed *et al.,* 2015). The risk levels in terms of inhalable fraction composition is in order of AT>AK>VP>AC>DO>AB>M8>TB>M7>NV>A D>M1>NY>NK>TN.

4 Conclusion

The study presented an overview of a 5-year measurement of TSP and PM_{10} at fifteen different monitoring stations within Tarkwa where three different mining companies are located in Ghana. The characteristics of TSP and PM10 pollution including spatio-temporal variation, Air Quality Index (AQI), particle size distribution and attainment rate were comprehensively discussed by investigating average monthly and annual pollutants mass concentrations.

Thirteen (13) of monitoring stations investigated recorded TSP and PM10 concentrations below the national standard of 150 and 70 µg/m^3 respectively. However, trend analysis revealed increased pollutant concentration from 2015 to 2019 for eleven (11) of these stations. Only two stations (TN and NV) recorded TSP and PM10 values above the national guideline. Spatially interpolated maps of TSP and PM_{10} indicates Eastern Tarkwa is exposed to harmful levels of pollutants concentrations.

Local sources, source strength and prevailing wind direction, were identified as the main drivers of atmospheric PM concentration. AQI values between good and unhealthy were recorded for the study area with eastern Tarkwa recording mostly unhealthy values whilst the West obtained good to moderate values. Attainment values between 44.09%-100% and 30%-100% were recorded for TSP and PM10, respectively. In general, 44.09-72.9% of total suspended particles in the study area were made up of inhalable fractions. It is recommended that future research should investigate the chemical composition of these particles as it contributes to toxicity.

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