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Assessment of Ambient Air Pollution Pattern in Ikpeshi Community Edo State Nigeria Using Geostatistical Analysis

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ABSTRACT

Understanding the Spatial distribution of ambient air quality in an active mining and solid mineral processing community is important in order to determine pollution hot spots and cold spots, as well as the trend. This will help Air Quality Managers to evaluate areas that are highly exposed to air pollution for mitigation purposes. In this study, dust particles in the form of ambient PM2.5, and PM10 were measured on weekly basis for a period of one year at 73 sampling points located in Ikpeshi, a mining and mineral processing community in Edo State, Nigeria using Double Parameter HoldPeak HP-5800D model Laser PM2.5 Meter. Geospatial data was also collected by means of Garmin GPSmap 78s model. The PM2.5 and PM10 data were preprocessed in MS Excel 2010 computer software to obtain the mean pollutant concentrations for the two parameters. The mean PM concentrations were analyzed and mapped using ArcGIS 10.0 software to generate various geostatistical surfaces to describe the ambient air pollution pattern and spatial distribution of pollutants in the community. The predicted mean concentrations ranged from 5.25 to 88.75µg/m3 for PM2.5 and 8.15 to 552.85µg/m3 for PM10. Mann-Kendall's test showed that the observed pattern in ambient air quality exhibits a linear trend at 5% significant level with pollution hot spots found in the South-Eastern part of the community where the mills and quarries are domiciled while the cold spots appeared in the residential areas found in the North-Western part of the community. It was therefore concluded that the ambient air pollution pattern in the study area exhibits a linear south-east to north-west trend which is statistically significant at 5% level.
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Keywords: Ambient air quality, Mining, Mann-Kendall, Geostatistical Analysis, Spatial distribution.

1.0. Introduction

Air pollution has wreaked havoc on humanity due to its deleterious effects on man and the environment (Nishida and Yatera, 2022). Studies have shown that increasing anthropogenic activities such as industrialization, and urbanization have intensified the emissions of various pollutants that cause air pollution (Iqbal et al., 2022). According to WHO (2014), air pollution is the contamination of the atmosphere by any agent that modifies its natural characteristics. These agents emanate from both anthropogenic and natural sources, and include particulate matter, gases, and biological species. Mining and solid mineral beneficiation have the potential to contaminate the ambient air through the emission of particulate dust into the atmosphere. Losacco and Perillo (2018) noted that particulate matter (PM) concentrations have been linked with several clinical manifestations of pulmonary and cardiovascular diseases and are associated with morbidity and mortality induced by respiratory diseases both in humans and animals. These primary pollutants also travel far from its source and can react with other atmospheric constituents under certain conditions to form secondary pollutants that are more deleterious. Thus, adequate knowledge of the spatial distribution pattern is important as this will help to determine areas that are at high risk of pollution for mitigation purposes. It is important to occasionally monitor the ambient air quality of mining communities to ascertain the level of air pollutants discharged into the atmosphere, the spatial distribution of the pollutants in the atmosphere, and her vulnerability to adverse environmental impacts in order to recommend mitigation measures. This is the reason why Ikpeshi community was selected considering the high level of mining and/mineral processing activities taking place in the locality. Such magnitude/scale of work raised the suspicion that mining and mineral processing activities in the area could result to severe air quality deterioration and potential exposure of the community to risk. Geostatistical methods have become a useful analytical tools available to researchers for spatial data analysis (Zanini and D'Oria, 2021). Kriging interpolation is a geostatistical method that predicts values at unsampled locations. It is described as an unbiased linear interpolator (ESRI, 2001). Krause and Krivoruchko (2014) noted that the worst kriging interpolation is still better than any other interpolation method because while other traditional methods tends to produce a smoothed predicted surface, kriging achieves a better prediction because it considers the statistical properties such as autocorrelation existing in the data, and also gives a measure of uncertainty associated with the prediction. Omoseebi and Tanko (2021) have successfully utilized kriging interpolation technique in the determination of the distribution of geochemical properties of dolomite deposit in Ikpeshi. However, Utilization of this method in air pollution studies for the mining sector in Nigeria has not gained prominence despite the numerous limitations of the traditional interpolation methods often employed.

2.0. Methodology

2.1 *Description of the Study Area*

Ikpeshi is located along Auchi – Igarra road in Akoko-Edo LGA, Edo State, Nigeria and it is a home to industrial minerals such as limestone, marble, dolomite, calcite, kaolin, feldspar, etc. It lies in latitudes 7^0 06’ 00”N to 7^0 20’ 00”N and longitudes 6^0 08’ 30”E to 6^0 20’ 64”E within the Precambrian Basement Complex of Southwest Nigeria (Omoseebi and Tanko, 2021). Interaction with the locales revealed that active quarrying as well as mineral processing has been going on in the community since 1989. From the researcher’s field work, the land area involved measures about 2.75km^2 and it is shown in Figure 1. The general topography is characterized by conspicuous rocky formations while the climate is sub-humid tropical with an average annual rainfall of about 150cm. It has average temperature of 25^{o}C in the wet season and 28^{o}C in the dry season (Rilwani and Ikhuoria, 2011). The wet season is April – October, while the dry season is November – March. Predominant occupation of the people includes agriculture, trading, tourism, artisanal mining, etc.

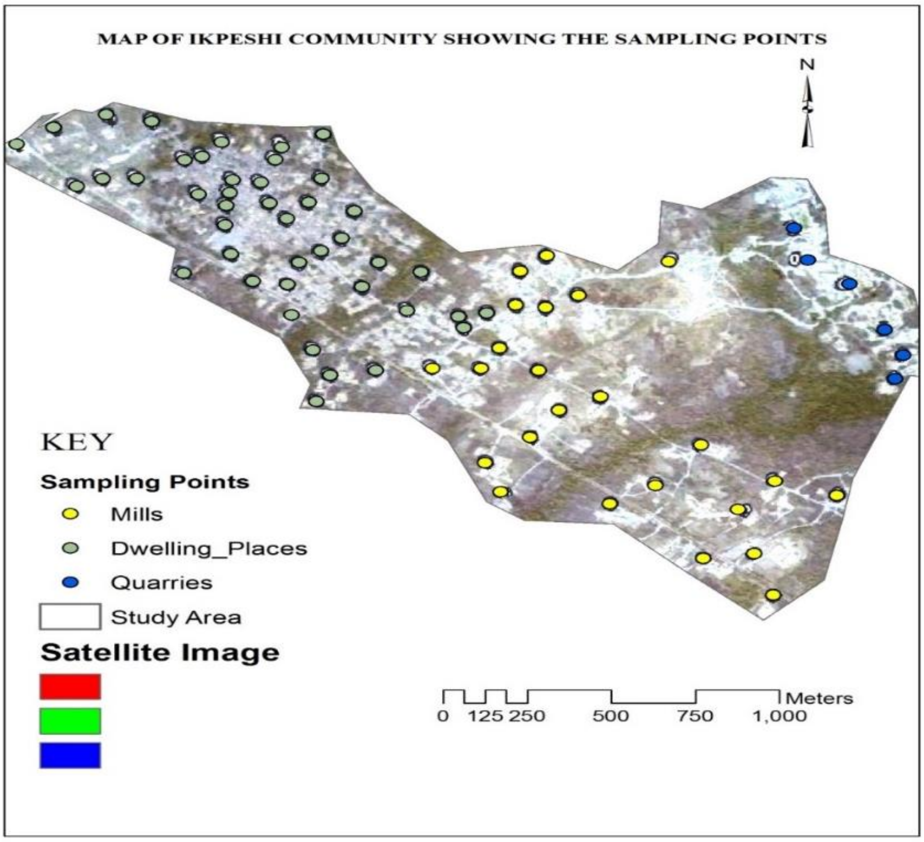

Figure 1: Image Map of the Study Area Showing the Sampling Points.

2.2 *Reconnaissance Survey*

Reconnaissance survey was done with the aid of a GPS receiver and remotely sensed imagery of the project site in order to familiarize with the study area. This involved limited field work and data collection from points of interest and/landmarks using Garmin GPSmap 78s model GPS receiver. The collected data were pre-processed in Google Earth Pro and ArcGIS 10.0 softwares. The study area was delineated from Google Earth Pro and saved in jpeg file format and utilized as a complementary navigational aid with the Garmin GPSmap 78s model GPS receiver to traverse the community in order to establish sampling points for ambient air quality monitoring.

2.3 *Location of Sampling Points*

Sampling points were established throughout the community using Google Earth Pro satellite imagery and Garmin GPSmap 78s model GPS receiver as complementary navigational aid and data collection tools. The procedure and method for the choice of sampling points followed the guidelines suggested in Durand (2012) and USEPA (2014). These methods suggested that sampling points should be placed at established exposure locations that will give optimal coverage to the exposed population. Such places include markets, playgrounds, schools, religious places/worship centers, residential and industrial areas, etc.

2.4 *Ambient Air Quality Monitoring*

Ambient air quality monitoring of the community was done to obtain datasets needed to evaluate the ambient air. The ambient air quality data were monitored in-situ throughout the established sampling points on weekly basis for one year. The collection of ambient air quality datasets involved the use of Double parameter HoldPeak HP-5800D model Laser PM2.5 Meter. The outputs from the air quality monitoring are attribute datasets needed to compute mean ambient air pollutant concentrations of the study area.

2.5 *Pre-Processing of the Air Quality Datasets*

The air quality data together with their geographic coordinates were pre-processed in M S Excel 2010 to obtain mean pollutant concentrations for $PM_{2.5}$ and PM_{10} to serve as input data to ArcGIS 10.0 software. The mean pollutant concentrations data were imported into ArcGIS' ArcCatalog where a geodatabase was created to hold the files. With ArcGIS' Arctoolbox conversion toolset, the sampling locations were converted from geographic coordinates to UTM coordinates (X, Y data) corresponding to easting and northing respectively. The X, Y data were joined with their corresponding mean pollutant concentrations through a geo-processing routine to produce attribute tables that served as input datasets to the ArcGIS 10.0 Geostatistical Analyst tool extension.

2.6 *Trend Analysis*

Ambient air pollution pattern existing in the community was evaluated by exploring the Geostatistical Analyst Trend analysis tool in ArcGIS 10.0 Software. This was followed by a Mann-Kendall's hypothesis test which was done at 95% confidence level using excel's real statistics *add in* tool extension. According to Nguyen et al (2022), it is a non-parametric test and mathematically, it is stated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\,(Xj - X_i) \tag{1}$$

Where X_i and X_j are random variables (divided the given data X into two variable sets, as $X_1, X_2, \ldots X_i$, and $X_{i+1}, X_{i+2}, \ldots, X_j$).

$$Sign\,(Xj - X_i) = \begin{cases} 1 \; if \; Xj - X_i > 0 \\ 0 \; if \; Xj - X_i = 0 \\ -1 \; if \; Xj - X_i < 0 \end{cases} \tag{2}$$

The null hypothesis, H_0, is that there is no trend in the data while the alternate hypothesis, H_1, states that there is trend in the data. The test helped to determine whether the observed trend/pattern is statistically significant at the chosen level.

2.7 *Kriging and Mapping of Mean Ambient Air Quality*

This was accomplished by using geostatistical analysis routines in ArcGIS 10.0 program in line with ESRI (2001). First, the mean pollutant concentrations were subjected to exploratory spatial data analysis (ESDA) in order to verify the geostatistical assumptions of normality. This is because geostatistical mapping is optimal when data is normally distributed (Krause and Krivoruchko, 2014). The data was further subjected to variography so as to explore its spatial autocorrelation properties for kriging. Continuous geostatistical surfaces showing the spatial distribution of ambient air pollutant concentrations in the study area were finally generated through kriging and mapping.

3.0. Results and Discussion

The data collected at seventy-three (73) sample locations for the period of one year at the study area showing information on the sampling points, the coordinates, average $PM_{2.5}$, PM_{10}, and land use form the attribute table used for data analysis in ArcGIS 10.0.0 software and it is presented in Table 1.

Table 1: Average Ambient Air Quality Data for Ikpeshi Community, Akoko-Edo LGA, Edo State

Sampling Points	UTM Zone 32N /Coordinates X & Y (m)	Average $PM_{2.5}$ (μg/m^3)	Average PM_{10} (μg/m^3)	LANDUSE
1	190326, 0789226	78.65	460.7	Industrial
2	190118, 0789384	48.1	264.7	Industrial
3	190269, 0789405	13.65	51.15	Industrial
4	190221, 0789596	7.65	13.9	Industrial
5	189840, 0789620	10.7	30.3	Industrial
6	190516, 0789656	6.65	11.15	Industrial
7	189515, 0789671	47.3	260.05	Industrial
8	189976, 0789699	10.1	30	Industrial
9	190332, 0789718	82.05	293.1	Industrial
10	189470, 0789797	31.4	151.4	Industrial
11	190112, 0789873	9.15	22.9	Industrial
12	189603, 0789907	14.55	58.6	Industrial
13	189689, 0790023	42.95	73.55	Industrial
14	188968, 0790062	9.7	23.4	Residential
15	189812, 0790081	39.55	267.45	Industrial
16	190688, 0790159	14.1	49.5	Quarrying
17	189008, 0790175	10.2	21.25	Residential
18	189144, 0790196	15.45	45.9	Worship Centre
19	189629, 0790196	88.75	552.85	Industrial
20	189313, 0790204	6.3	12.55	Industrial
21	189457, 0790203	7.65	13.9	Industrial
22	190713, 0790260	16.8	52.6	Quarrying
23	188957, 0790283	21.4	29.95	Residential
24	189513, 0790292	13.5	28.35	Industrial
25	189406, 0790379	12.8	31.75	Residential
26	190659, 0790371	16.2	52.9	Quarrying
27	189391, 0790428	6.8	20	School
28	188893, 0790434	6.65	9.55	Residential
29	189474, 0790443	6.45	11.2	Residential
30	189237, 0790454	6.5	12.5	School

Table 1 Continues

31	189649, 0790466	14.2	54.2	Industrial
32	189560, 0790476	10.55	36.2	Industrial
33	189747, 0790518	26.15	111.6	Industrial
34	189103, 0790556	6.2	9.95	Residential
35	188882, 0790566	7.4	12.95	Residential
36	188777, 0790579	9.35	14.4	Tipper Garage
37	190552, 0790569	15.3	51.1	Quarrying
38	188572, 0790614	7.8	11.35	School
39	189278, 0790619	5.25	9.5	Worship Centre
40	189573, 0790624	19.5	67.3	Industrial
41	188916, 0790662	6.25	8.8	Residential
42	189153, 0790660	7.45	13.05	School
43	190016, 0790664	16.2	79.2	Industrial
44	190430, 0790671	16.1	48.6	Quarrying
45	188714, 0790697	8.6	13.8	Market Place
46	189653, 0790691	7.05	11.1	Industrial
47	188981, 0790710	5.8	8.3	Residential
48	189043, 0790765	5.9	10.05	Residential
49	190388, 0790809	17.4	53.7	Industrial
50	188696, 0790823	5.75	10.35	Residential
51	188880, 0790849	8.95	16.25	Residential
52	189080, 0790882	8.1	29.1	Residential
53	188700, 0790906	8.55	11.95	Residential
54	188829, 0790917	8.85	13.8	Residential
55	188945, 0790920	7.25	11.1	Residential
56	188617, 0790955	15.7	20.85	Residential
57	188709, 0790961	17.15	24.65	Residential
58	188255, 0790988	7.8	10.7	Residential
59	188802, 0791007	7.55	11.5	Residential
60	188719, 0791016	8.95	17.45	Residential
61	188332, 0791022	8.8	14.1	Worship Centre
62	188433, 0791024	7.95	13.2	Residential
63	188983, 0791024	6.55	9.4	Residential
64	188575, 0791103	9.7	16.45	Residential
65	188845, 0791105	7.45	12.8	Residential
66	188627, 0791118	8.95	15.55	Residential
67	188864, 0791157	7.8	11.4	Residential
68	188075, 0791171	7.2	12.95	Filing Station
69	188686, 0791179	6.25	8.6	Residential
70	188987, 0791215	5.95	8.15	Residential
71	188186, 0791244	7.95	11.75	Residential
72	188478, 0791270	6.7	10.55	Worship Centre

From Table 1, ambient air quality data were collected from 73 sampling locations established at the study area. The table shows that the average sampled values range from 5.25 to 88.75µg/m^3 for $PM_{2.5}$ and 8.15 to 552.85µg/m^3 for PM_{10}. The various activities found in the study area were categorized into eight land uses namely industrial, residential, quarrying, worship centre, school, market place, filling station, and tipper garage. High pollutant concentrations were observed mostly at sampling points located within the land use areas designated as Industrial where solid minerals are processed. The observation is expected because of the cluster of mineral processing mills located in this part of the community. It implies that mining and solid mineral processing were the major sources of dust generation in the area which agrees with Ruhela et al (2022) who noted that mining contributes adversely to ambient air quality. Thus, the rising dust concentrations in the community occasioned by industrial activities call for concern because of the high exposure potentials to public and environmental health it poses.

Conversely, low values were observed from most sampling points located within the residential areas, schools, and worship centres. This is because these areas being more of dwelling places are characterized by less industrial/economic activities that generate significant dust particles except from fugitive emissions coming from the industrial areas. The trend Analyses of mean $PM_{2.5}$ and PM_{10} in the study area are presented in Figures 2 and 3 respectively.

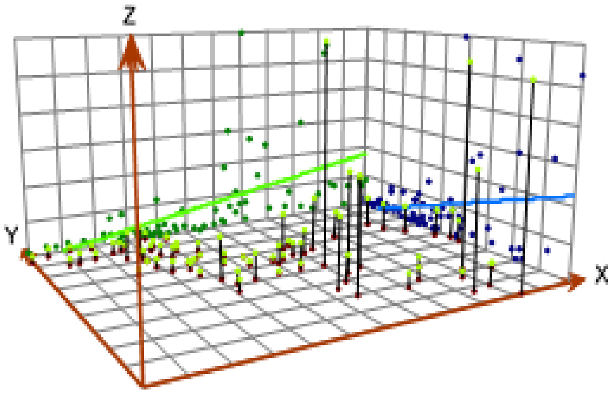

Figure 2: Trend Analysis of Mean PM2.5 Concentrations in Ikpeshi

$PM_{2.5}$ refers to particulate matter with aerodynamic diameter of less than 2.5µm (Thangavel et al., 2022). These are fine dust particles that can penetrate deep into the lung alveoli of humans and reach the blood stream. It can be seen from Figure 2 that the ambient $PM_{2.5}$ exhibits a linear upwards trend along X and Y axes respectively. This suggests that the high values (pollutant hot spots) are concentrated in the eastern part of the community as one moves in the east-west direction and in the southern part when moving along south-north direction. This observation is expected considering the fact that the solid mineral processing mills from where most of the pollutants emanated from are located in the south-eastern part of the study area. Conversely, the cold spots are mostly found in the western and northern directions because the residential areas are located in the north-western part of the community thus less pollution is expected from this part of the community except the fugitive emissions from the industrial areas in the south-west. The PM_{10} mean pollutant concentrations followed similar trend as shown in Figure 3.

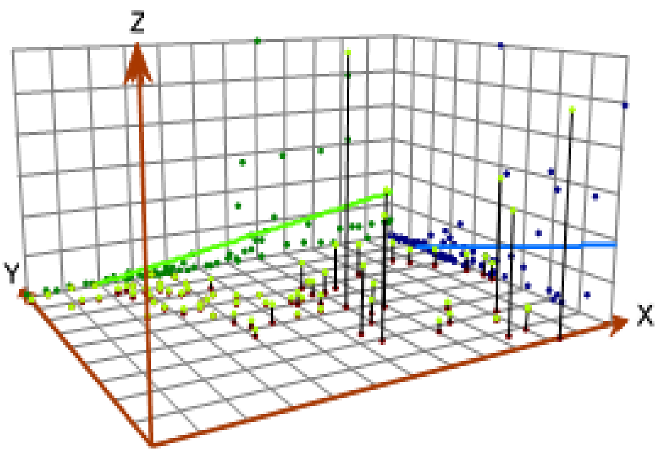

Figure 3: Trend Analysis of Mean PM10 Concentrations in Ikpesh

The PM_{10} are the particulates with aerodynamic diameter of less than 10µm. These are so important measure of air quality because of its negative effect on the environment (Jandacka and Durcanska, 2019). It can be seen that the PM_{10} exhibits the same trend as the $PM_{2.5}$ and due to similar reasons.
Mann-Kendall’s tests on the datasets showed statistically significant evidence of linear upwards trend at 5% level suggesting a pattern in the ambient air quality of the study area. This is shown in Table 2.

Table 2: Mann-Kendall’s Hypothesis Test for Trend in the Ambient Air Quality of Ikpeshi.

DISCRIPTIVES	$PM_{2.5}$	PM_{10}
alpha	0.05	0.05
Mann-Kendall statistics	-844	-1082
Standard error	209.9444	209.9714
z-stat	-4.01535	-5.14832
p-value	5.94E-05	2.63E-07
trend	yes	yes

The ambient air quality maps showing the spatial distribution of predicted $PM_{2.5}$ and PM_{10} concentrations are presented in Figures 4 and 5 respectively.

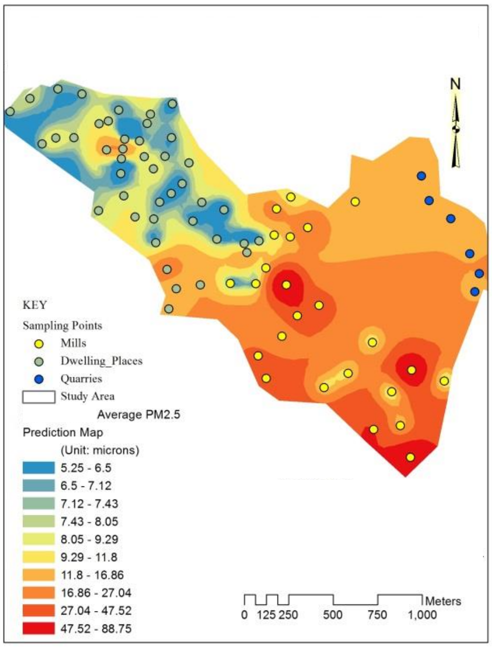

Figure 4: Prediction Map of Mean $PM_{2.5}$ in Ikpeshi.

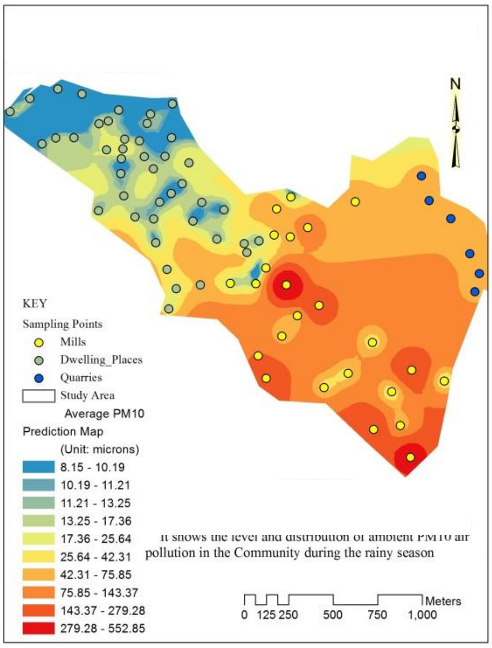

Figure 5: Prediction Map of Mean PM_{10} in Ikpeshi.

It can be seen from figures 4 and 5 that the predicted values range from 5.25µg/m^3 – 88.75µg/m^3 for $PM_{2.5}$, and 8.15µg/m^3 – 552.85µg/m^3 for PM_{10}. Extreme high values showing pollution hotspots were observed to dominate the South-Eastern part of the study area because of large presence of pollution sources, the quarries and solid Mineral processing mills. The areas are shown with different shades of red colors on both maps whereas, extreme low values showing pollution cold spots were observed in the North-Western part of the community because of relatively less pollution sources and composed mainly of residential areas such as dwelling places, schools, worship centres, etc. These areas are represented with various shades of blue to yellow colors on both maps. The community dwellers residing in the North-Western side of the community may likely become major receptors of fugitive emissions emanating from the mills and quarries from the South-Eastern part. Mayer (1999) opines that atmospheric processes such as wind, temperature and rainfall are the major transport and dispersal mechanisms of air pollution. However, the dilution process may become weakened due to sustained discharge of dust particles from the sources. This calls for concern due to the numerous health effects it portends to the exposed population namely the community dwellers, mine and mill workers as well as their customers.

4.0 Conclusion

The ambient air pollution pattern in Ikpeshi Community, Edo State, Nigeria has been assessed by geostatistical kriging method using mean $PM_{2.5}$ and PM_{10} data from the community. Additionally, Mann-Kendall's hypothesis test was conducted at 95% confidence level to verify the statistical significance of the observed pattern. The results showed that the ambient air pollution pattern in the study area exhibits a linear south-east to north-west trend which is statistically significant at 5% level. The mean ambient concentrations varied from 5.25µg/m^3 – 88.75µg/m^3 for $PM_{2.5}$, and 8.15µg/m^3 – 552.85µg/m^3 for PM_{10}. It must be noted that while extreme high values (pollution hotspots) were observed to dominate the South-Eastern part of the study area, the reverse was the case in the North-Western part. The observed pattern was due to the large presence of pollution generating sources; the quarries, and the mills in the South-Eastern part. Conversely, the residential areas; dwelling places, schools, worship centres, etc with less pollution generating potentials were the reason for the low concentrations observed in the North-Western part. The result has led to the deduction that mining and solid mineral processing are the primary sources of ambient air pollution in the study area. These findings will be helpful to air pollution managers; the Regulators, Mineral Title Holders, and Solid Mineral Processors in the optimization and implementation of pollution abatement programs for the community; they may wish to deploy more resources for pollution mitigation to the south eastern part of the community where most of the pollutant sources are domiciled. Additionally, regulators may wish to vigorously pursue strict enforcement of pollution abatement laws and practices in the work place and in mine fields around the study area. For the Stakeholders in the mining sector, an additional impetus has been supplied for them to frequently enlighten and sensitize Mineral Title Holders and Solid Mineral Processors on modern pollution abatement practices in the work place. Finally, these findings may push the Government at all level to adequately equip and timely fund her field offices for efficient enforcement and monitoring inspections.

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