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Modelling of Pollutants Dispersion from Open Burning of Solid Waste Using AERMOD

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Abstract

This study evaluates the air quality impact of open burning of solid waste activities in Ilorin, Nigeria. An emission inventory was carried out to quantify the emitted CO, NO_x and SO_x from 2016- 2020 in the study area. Their ground level concentrations were computed with the Industrial Source Complex – American Meteorological Society (AMS) and United State Environmental Protection Agency (EPA) Regulatory Model (AERMOD) dispersion model and compared with standards to determine their impacts on ambient air quality. The average hourly, daily and annual concentrations were 25,267 $\mu g/m^3$, 4,609 $\mu g/m^3$, 447 $\mu g/m^3$ for carbon monoxide (CO); 4,700 $\mu g/m^3$, 730 $\mu g/m^3$, 130 $\mu g/m^3$ for oxides of nitrogen (NO_x) and 954 $\mu g/m^3$, 144 $\mu g/m^3$, 24 $\mu g/m^3$ for oxides of sulphur (SO_x) respectively. The hourly air quality for CO were within the World Bank standard for all the receptor communities except at Abe-Emi with 2.17 folds, while the daily air quality was within the Federal Ministry of Environment (FMEnV) limit. However, the 1-h, 24-h and annual air quality for NO_x exceeded the FMEnV and World Bank standard for all the receptor communities. Similarly, the hourly and daily air quality for SO_x exceeded the FMEnV and World Bank standard for all the receptor communities.

Keywords: *Air quality, Open burning, Solid waste, AERMOD, Dispersion modelling, Pollutants*

1. Introduction

Anthropogenic activities such as open burning of dump sites are extremely harmful to surrounding communities due to their closeness to the ground rather than up high via stacks where pollutants can be dispersed accordingly to reduce their impacts on health. It normally entails burning large quantities of unselective waste, with an intense impact on human health and the environment, due to the release of hazardous emissions into the atmosphere and onto land, posing risks to populations, workers and the environment [1].

Dump site fires are accompanied by large, visible clouds of black smoke and the fires generally burn gradually, lasting over a long period of time, causing the quantity and concentration of pollutants to build up. The waste often covers large areas rather than at point sources, a factor that influences an even greater threat to public health [2]. Air pollutants are usually defined as substances in the atmosphere arising from anthropogenic activities or from natural processes, to the detriment of humans, plants, or animal lives. A lot of studies have shown a significant relationship between the degeneration of the environment and human health and the presence of pollutants in the atmosphere [3]. The main air pollutants in the atmosphere are: carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM), oxides of sulphur (SOx) and volatile organic compounds (VOCs) [4].

To examine the dispersion of air pollutants emissions from open burning of solid waste, air dispersion modelling can be employed to help evaluate air quality, health and environmental impacts on their receptor communities [5]. Air dispersion modelling is utilized to predict ambient impacts of one or more sources of air pollution. They are used to estimate or predict the downwind concentration of air pollutants or toxins emitted from sources such as emissions from concentrated animal feeding operations (CAFOs) [6], open burning of wastes, vehicular traffic or accidental chemical releases

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[7]. Hence the impacts of criteria air pollutant emissions from open burning of solid waste needs to be assessed to ascertain health and environmental quality.

Several studies have been done using AERMOD to predict concentration at selected downwind receptor locations based on emissions and meteorological inputs, to assess the air quality and their impact on human health and the environment [8]. AERMOD and CALPUFF model were used to evaluate the concentration of NO_X, SO_x and PM emitted in Ghana. The result showed that the daily concentrations were greater during the rainy season than the dry season [3]. The ground level concentration of PM, SO_2 and NO_x in an industrial area were determined using AERMOD model in Bangalore (India). NO_x had the highest concentration of 24 μg/m^3, SO_2 with 1.2 μg/m^3 and PM with 0.0028 μg/m^3 [3]. The objective of air quality dispersion models is to relate mathematically the effects of source on ground level concentrations, and to establish that permissible levels are, or are not, being exceeded [9]. The standards used in this study to assess the anticipated air pollutants associated with open burning of solid waste are summarized in Table 1.

Table 1. Standards of ambient air quality.

Air Pollutants	Averaging Period	Maximum Concentration (μg/m^3)	
		FMENV[a]	World Bank[b]
CO	1 – h	-	30,000
	8 – h	22,800	10,000
	24 – h	11,400	-
NO_X	1- h	-	200
	24 – h	75 – 113	-
	Annual	-	40
SO_2	1- h	260	-
	24 - h	26	20

[a]Source: [10]; [b]Source: [11]

With the magnitude of waste being burned daily on a 600 plot (390,000 m^2) government-approved ultimate disposal site in Ilorin, Nigeria, there is a need for forward trajectory modelling with the AERMOD dispersion model to assess and evaluate the impact on air quality in the receptor communities surrounding the pollutant source (Sokoto Aiyekale). This study aims at evaluating the ground level concentrations of CO, NO_x and SO_x emitted from the open burning of solid waste in Ilorin, Nigeria using the AERMOD dispersion model.

2. Research Methodology

2.1. Study Area

The study area is a 600-plot (390.000 m^2), government approved disposal site with 130 burning points (Figure 1), located at Aiyekale, along Jebba-Bode Saadu Road, Ilorin, Nigeria (Figure 2).

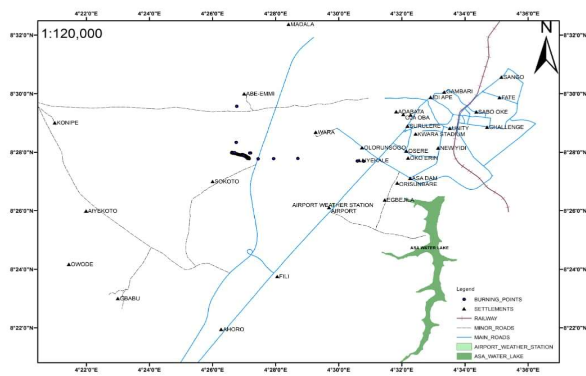

Figure 1. Sokoto Aiyekale Dump Site in Ilorin.

Figure 2. Map of Nigeria showing Bode-Saadu.

The ancient city of Ilorin, the capital of Kwara State in Central Nigeria, is located on latitude 8°30'N and longitude 4°35'E. It is about 500 km from Abuja, the Federal Capital of Nigeria and strategically located at the geographical and cultural confluence of the Northern and Southern part of Nigeria [12]. In 2015, the government of Kwara State legislated that all the former dump sites within the metropolis should be scrapped for more development and urbanization in the state, because it's an eyesore for a state capital to be having heaps of open refuse dumps on every available space on the road and street.

2.2. Model Description – AERMOD

The AMS/EPA Regulatory Model (AERMOD) is a collaborative between the U.S. Environmental Protection Agency (EPA) and the American Meteorological Society (AMS). AERMOD is an improved version of the Industrial Source Complex 3 (ISC-3). ISC-AERMOD is used to estimate the ground level concentration of each of the identified pollutants at specific locations of interest and to predict the change in ground-level air quality associated with the study area at communities within a defined radius of the location to the source of the pollutants. Its uses include a wide range of option for modelling air quality impact of pollution sources. It uses pathway that compose the run stream file as the basis for its functional organization. These pathways include Control Pathway (CO), Source Pathway (SO), Receptor Pathway (RE), Meteorological Pathway (ME), Terrain Grid Pathway (TG), Output Pathway (OU) [13]. This model has two preprocessors, a meteorological data pre-processor called AERMET, which calculates the boundary-layer meteorological parameters (such as wind speed, wind direction, temperature, and cloud cover), and prepares these data in a format readable by AERMOD. A terrain data pre-processor called AERMAP, which designates the elevation of the receptor grid and generates gridded terrain data [14].

Table 2. Total average emissions (g/s).

Year	CO	NO_x	SO_x
2016	366.3	26.2	3.8
2017	377.5	27.0	4.0
2018	389.0	27.8	4.1
2019	400.8	28.6	4.2
2020	413.0	29.5	4.3
Average	389.3	27.8	4.1

Air quality modelling is a basic tool to evaluate the spatial distribution of the overall pollutant concentration. AERMOD was used to estimate the ground level concentrations of each of the identified CAPs, and to predict the change in ground level air quality within 15 km radius from the location to the source of the pollutant. The emission rates (Table 2) and the meteorological conditions were used as model inputs. These emission rates are totaled for all the burning points. Meteorological data, such as air temperature, wind speed, wind direction, cloud cover, pressure, relative humidity, and precipitation were obtained from the Ilorin meteorological station, Kwara State.

3. Results and Discussion

The environment within the designated nearby locations as indicated in Figure 1 was considered as receptors to the air pollutants resulting from the open burning of solid waste. The identified communities are Sokoto, Abe Emi, Ayekale, Wara, Airport, Olorunsogo, Osere, Oko-Erin, Asa Dam, Orisumibare and Egbejila. The wind rose plot (Figure 3) was obtained by using meteorological pre-processed data, which shows the strongest wind direction. As observed, the wind rose revealed a primary wind direction of south west with an annual probability of up to 65% and average wind speed of 3 m/s and maximum value of 3.6 m/s.

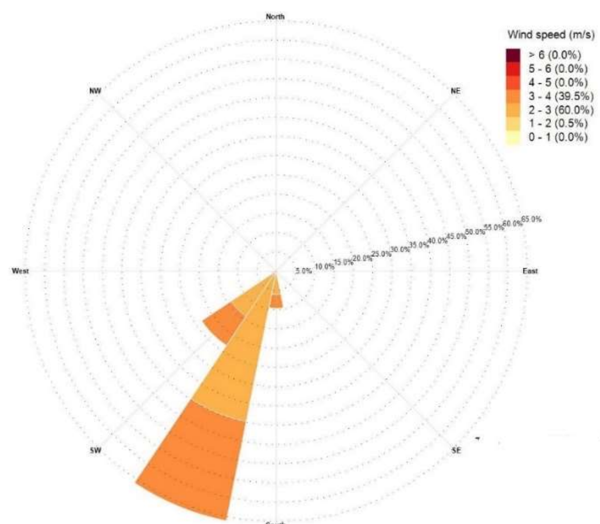

Figure 3: Wind rose.

3.1. CO emissions around the receptor locations

The 1-h, 24-h and annual predicted concentrations of CO have values in the range 10652 – 1065162 µg/m^3 (Figure 4), 2126 – 212633 µg/m^3 (Figure 5) and 293 – 29333 µg/m^3 (Figure 6) respectively. The maximum concentration of CO in the 1-hr, 24-hr and annual averaging periods are 1065162 µg/m^3, 212633 µg/m^3, and 29333 µg/m^3 respectively.

3.2. NO_x emissions around the receptor locations

The 1-h, 24-h and annual predicted concentrations of NO_x have values in the range 2130 – 213033 µg/m^3 (Figure 7), 425 – 42527 µg/m^3 (Figure 8) and 59 – 5867 µg/m^3 (Figure 9) respectively.

3.3. SO_x emissions around the receptor locations

The 1-h, 24-h and annual predicted concentrations of SO_x have values in the range 426 – 42606 µg/m^3 (Figure

10), 85 – 8505 μg/m^3 (Figure 11) and 12 – 1173 μg/m^3 (Figure 12) respectively.

The impacts of the ground level emissions of CO on ambient air quality of the host environment were carried out using the most stringent limits of Federal Ministry of Environment (FMEnV) and World Bank. For FMEnV standard, the predicted ground level concentration on three receptors (Sokoto, Abe-Emi and Wara) were all within the limits (Table 3) with 27.3%, 66.7% and 27.3% of the 11,400 μg/m^3 24-h limit. However, using the World Bank standard, 30,000 μg/m^3 (1-h averaging period), the predicted ground level concentrations were within the limits for all identified receptors except at Abe-Emi where 2.17 folds was predicted. Open burning of waste gives an estimated 37 million t/year of CO gas, or 7% of CO emissions worldwide, and is responsible for the release of a significant amount of CO into the atmosphere [15]. Residents of Abe-Emi community may have slight symptoms of CO poisoning which include headache, exhaustion, dizziness, nausea, shortness of breath and more. Those that openly burn waste or are in areas where open burning of waste occurs may be at risk for any of these symptoms due to release of CO gas [2].

For FMEnV standard, 75-113 μg/m^3 (24-h averaging period), the predicted NO_x ground level concentration were higher than the limits (Table 4) with 8 folds predicted for each of the identified receptors (Sokoto, Aiyekale, Wara and Olorunsogo), and 16.66 folds for Abe-Emi. Similarly, using the World Bank standard, 200 μg/m^3 (1-h averaging period), the predicted ground level concentrations were above the limits for all the eleven identified receptors (Sokoto, Aiyekale, Abe-Emi, Wara, Airport, Olorunsogo, Osere, Oko-Erin, Asa-Dam, Egbejila and Orisumibare), with the predicted folds ranging from 15.8 to 73, with the highest impact at Abe-Emi and the lowest at Airport, Osere, Oko-Erin, Asa-Dam, Egbejila and Orisumibare. Also for 40 μg/m^3 (annual averaging period), the predicted ground level concentrations were likewise higher than the limits for three receptors (Sokoto, Abe-Emi and Wara) having 2, 6.25 and 1.48 folds respectively. The oxides of nitrogen (NO_x) can be formed by the oxygenation of nitrogen in the waste or by fixation of atmospheric nitrogen in a high-temperature flame [16]. Smaller quantities of these particles can penetrate deeply into sensitive lung tissues, leading to damages, and premature death in severe cases [17]. All the residents of the receptor communities are at high risk of NO_x pollution. For FMEnV standard, for 260 μg/m^3 (1-h averaging period), the predicted SO_x ground level concentrations for all the eleven identified receptors (Sokoto, Aiyekale, Abe-Emi, Wara, Airport, Olorunsogo, Osere, Oko-Erin, Asa-Dam, Egbejila and Orisumibare) were above the limits, with ranges between 1.64 and 14.42 folds, with the highest impact at Abe-Emi and the lowest at Egbejila. Also for 26 μg/m^3 (24-h averaging period), the predicted ground level concentration of five receptors (Sokoto, Aiyekale, Abe-Emi, Wara and Olorunsogo) were above the limits (Table 5) ranging from 3.27 to 13.46 folds with the highest impact at Abe-Emi and the lowest at Aiyekale and Olorunsogo. Similarly, using the World Bank standards, 20 μg/m^3 (24-h averaging period), the predicted ground level concentrations were also above the limits for five receptors (Sokoto, Aiyekale, Abe-Emi, Wara and Olorunsogo) ranging from 4.25 to 17.5 folds with the highest impact at Abe-Emi and the lowest at Aiyekale and Olorunsogo. Oxides of sulphur are major air pollutants, and have a great effect on human health. The United States Environmental Protection Agency reported that inhalation of sulphur dioxide is related with increase respiratory symptoms, difficulty in breathing and premature death, which all the residents of all the receptor communities are susceptible to.

4. Conclusion

This study reported on the dispersion and concentration of different pollutants such as CO, NO_x and SO_x emitted from the open burning of solid waste in Ilorin. Nigeria, using AERMOD with site-specific meteorological data. The results of these three pollutants showed that the hourly average concentration of CO was 25,267 μg/m^3, 4,700 μg/m^3 for NO_x and 954 μg/m^3 for SO_x. Daily average concentrations were 4,609 μg/m^3 for CO, 730 μg/m^3 for NO_x and 144 μg/m^3 for SO_x. Results for annual concentrations were 447 μg/m^3 for CO, 130 μg/m^3 for NO_x and 24 for SO_x. The 1-h 30,000 μg/m^3 limit by World Bank was exceeded at Abe-Emi by 2.17 folds while the air quality remains in compliance with the CO standards ranging from 67.8 % to 100 % of the recommended limit in the other receptor communities. The percentage recommended limit by World Bank and FMEnV were exceeded with ranges between 15.58 – 73 folds for NO_x and 1.64 – 14.42 folds for SO_x, respectively. The daily air quality was within the recommended limit of FMEnV for CO ranging from 27.3 % to 66.7 %. However, the air quality was higher than the limit of FMEnV for NO_x with folds ranging from 8 – 16.66, and also higher than the limit of FMEnV and World Bank for SO_x ranging from 3.27- 17.5 folds. The annual air quality for NO_x was above the World Bank limit, it ranges from 1.40 – 6.25 folds. This study should prompt the government to make swift action on open burning of solid waste emissions to protect the environment and human life. Also, this study could serve as a template for other cities and states showing the real effects of open burning of solid waste on human health and environment.

Table 3. Predicted cumulative impacts of CO around Sokoto-Aiyekale dump site.

Receptor	Predicted Concentration (µg/m³)			Folds of FMEnV limit	Folds of World Bank limit
	1 - h	24 - h	Annual	24 - h (11,400µg/m³)	1 - h (30,000µg/m³)
Sokoto	20,326	3,113	397	0.273	0.678
Aiyekale	20,326	-	-	-	0.678
Abe-Emi	65,000	7,600	650	0.667	2.167
Wara	30,000	3,113	293	0.273	1
Airport	20,326	-	-	-	0.678
Olorunsogo	20,326	-	-	-	0.678
Osere	20,326	-	-	-	0.678
Oko Erin	20,326	-	-	-	0.678
Asa-Dam	20,326	-	-	-	0.678
Egbejila	20,326	-	-	-	0.678
Orisumibare	20,326	-	-	-	0.678

Table 4. Predicted cumulative impacts of NO_X around Sokoto-Aiyekale dump site.

Receptor	Predicted Concentration (µg/m³)			Folds of FMEnV limit	Folds of World Bank limit	
	1 - h	24 - h	Annual	24 - h (75 - 113µg/m³)	1 - h (200µg/m³)	Annual (40µg/m³)
Sokoto	4,100	600	80	8	20.50	2
Aiyekale	5,100	600	-	8	25.50	-
Abe-Emi	14,600	1,250	250	16.66	73	6.25
Wara	5,100	600	59	8	25.50	1.48
Airport	3,115	-	-	-	15.58	-
Olorunsogo	4,100	600		8	20.50	-
Osere	3,115	-	-	-	15.58	-
Oko Erin	3,115	-	-	-	15.58	-
Asa-Dam	3,115	-	-	-	15.58	-
Egbejila	3,115	-	-	-	15.58	-
Orisumibare	3,115	-	-	-	15.58	-

Table 5. Predicted cumulative impacts of SO_X around Sokoto-Aiyekale dump site.

Receptor	Predicted Concentration (µg/m³)			Folds of FMEnV limit		Folds of World Bank limit
	1 - h	24 - h	Annual	1 – h (260 µg/m³)	24 – h (26 µg/m³)	24 - h (20 µg/m³)
Sokoto	700	100	21	2.69	3.85	5.00
Aiyekale	1000	85	-	3.85	3.27	4.25
Abe-Emi	3750	350	40	14.42	13.46	17.50
Wara	1250	100	12	4.81	3.85	5.00
Airport	700	-	-	2.69	-	-
Olorunsogo	700	85	-	2.69	3.27	4.25
Osere	500	-	-	1.92	-	-
Oko Erin	500	-	-	1.92	-	-
Asa-Dam	463	-	-	1.78	-	-
Egbejila	426	-	-	1.64	-	-
Orisumibare	500	-	-	1.92	-	-

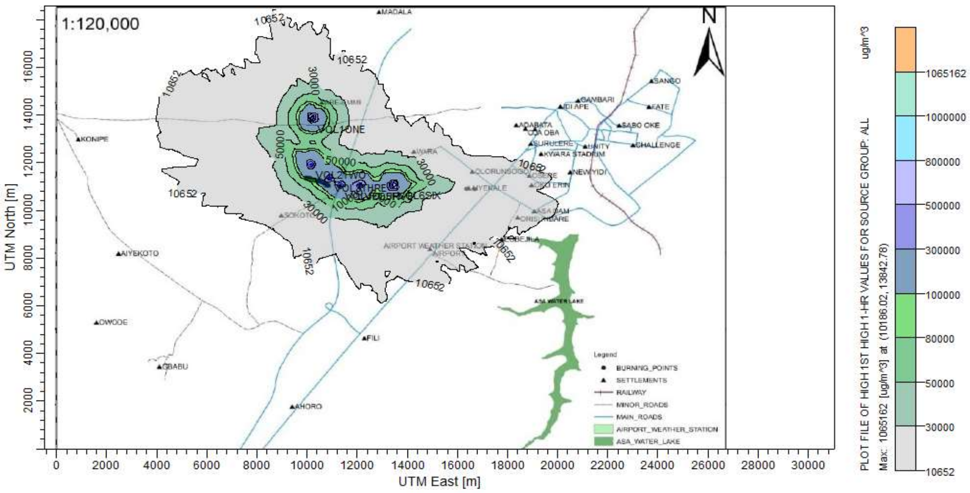

Figure 4. Isopleth of 1-h ground level CO from Sokoto-Aiyekale dump site.

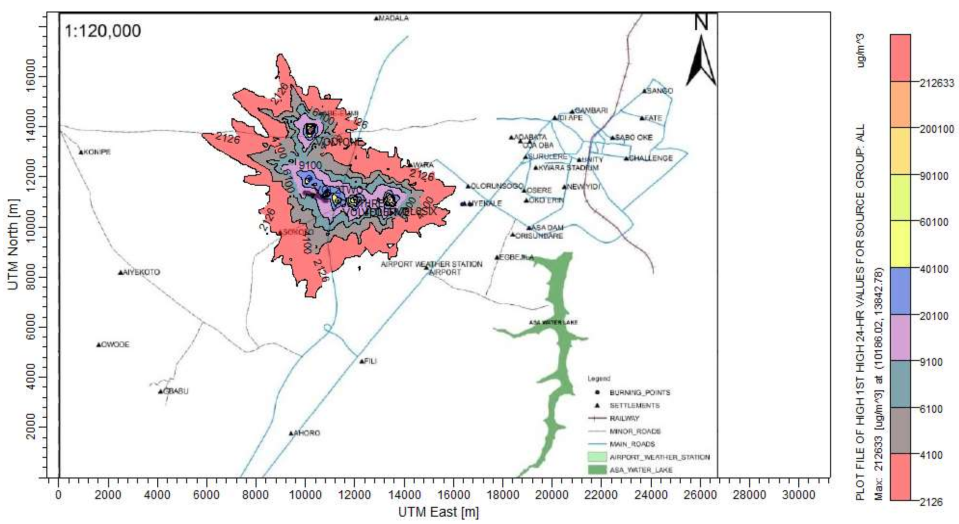

Figure 5. Isopleth of 24-h ground level CO from Sokoto-Aiyekale dump site.

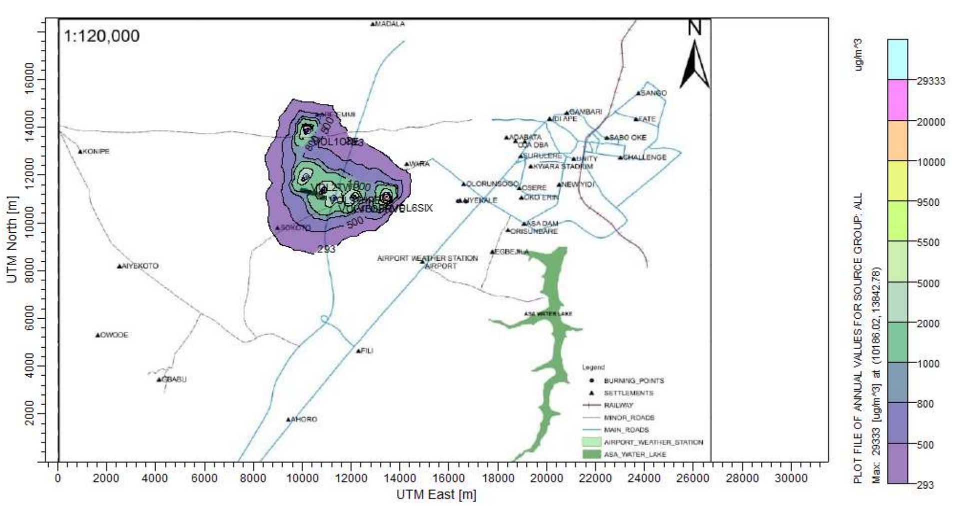

Figure 6. Isopleth of annual ground level CO from Sokoto-Aiyekale dump site.

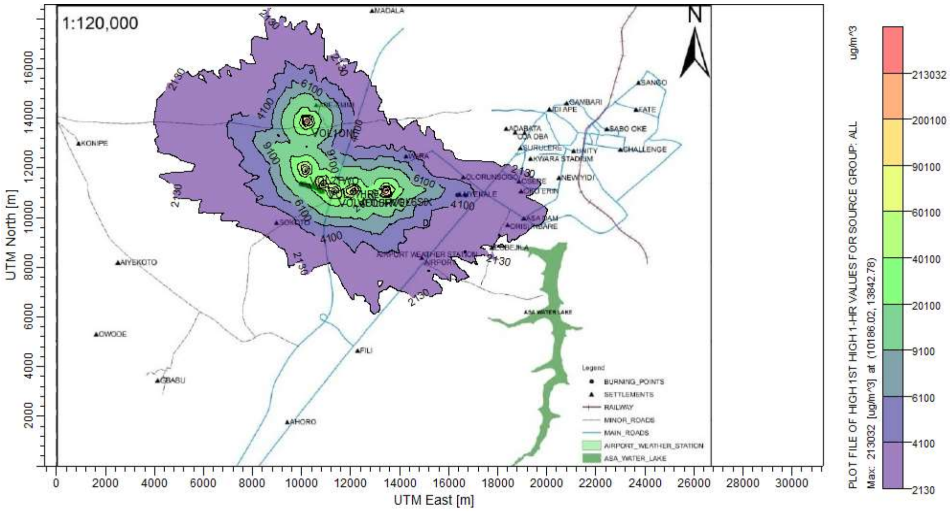

Figure 7. Isopleth of 1-h ground level NO_x from Sokoto-Aiyekale dump site.

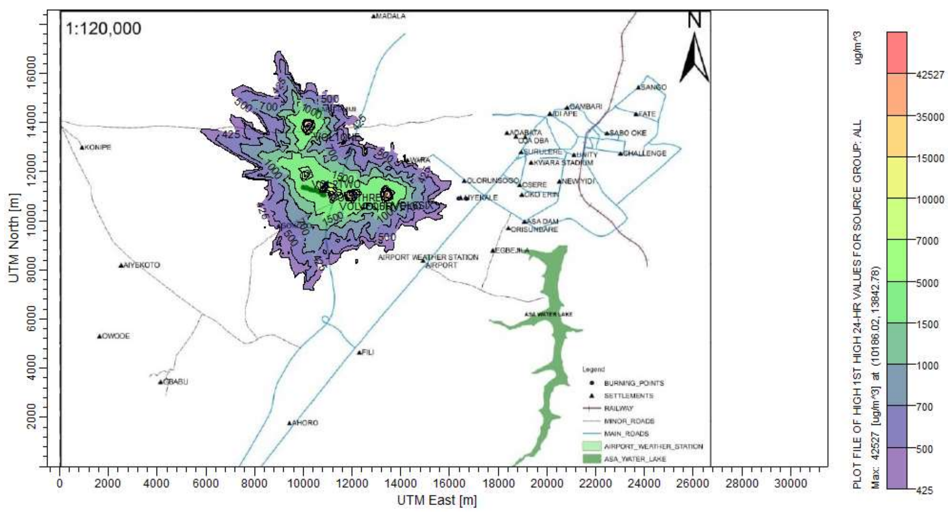

Figure 8. Isopleth of 24-h ground level NO_x from Sokoto-Aiyekale dump site.

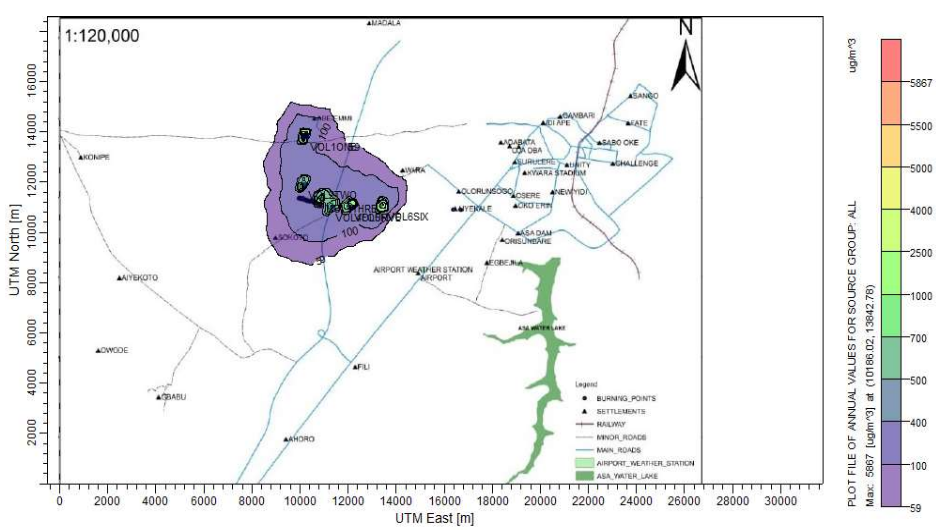

Figure 9. Isopleth of annual ground level NO_x from Sokoto-Aiyekale dump site.

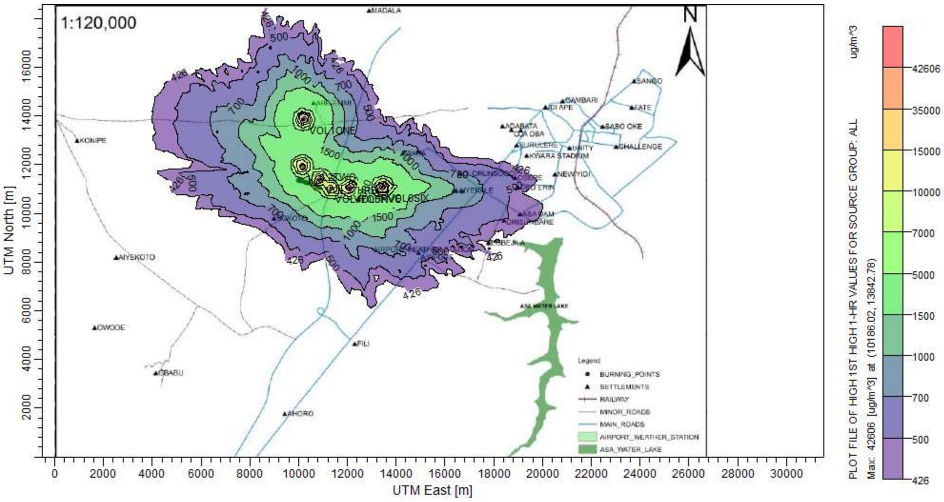

Figure 10. Isopleth of 1-h ground level SO_x from Sokoto-Aiyekale dump site.

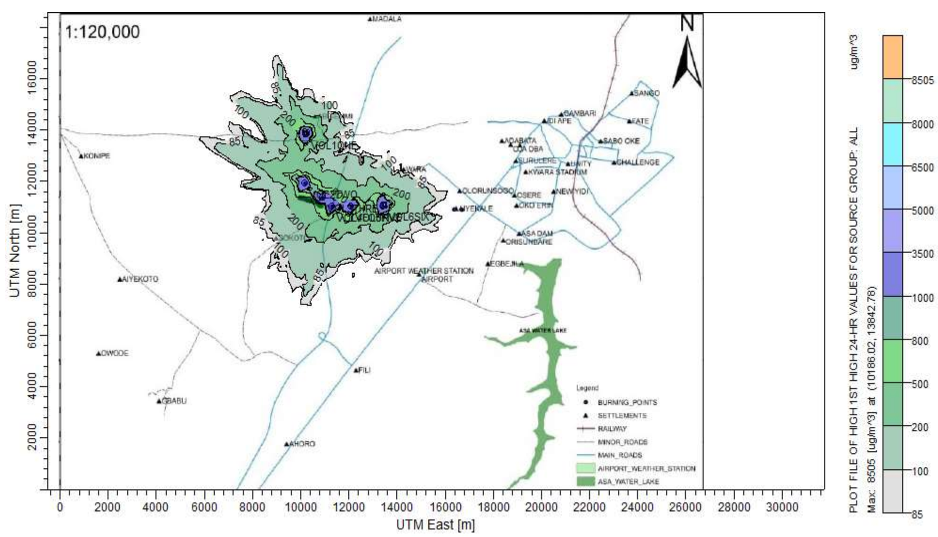

Figure 11. Isopleth of 24-h ground level SO_x from Sokoto-Aiyekale dump site.

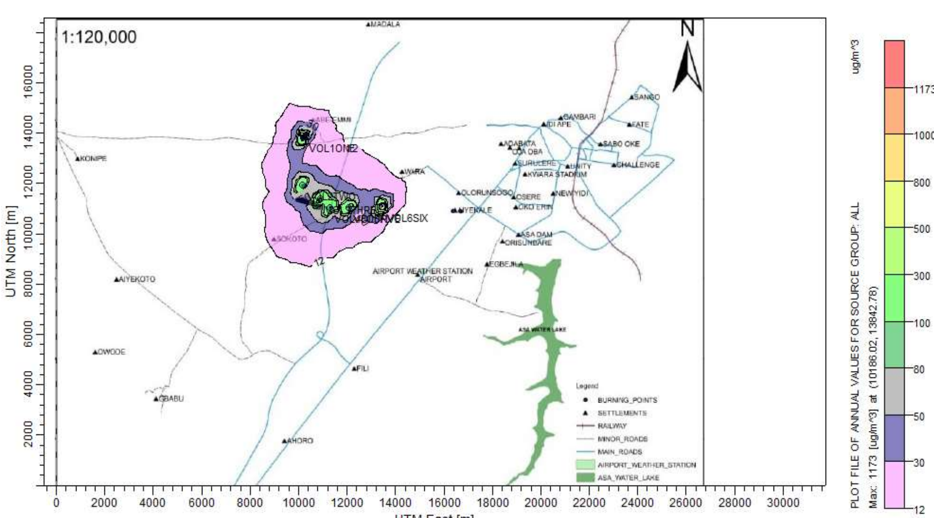

Figure 12. Isopleth of annual ground level SO_x from Sokoto-Aiyekale dump site.

Competing Interest Statement

The authors declare no known competing interests or personal relationships that could have influenced the work reported in this paper.

Data and Materials Accessibility

Supplementary materials and data used in this research are accessible upon request. For access, please contact the corresponding author.

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