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RESEARCH ARTICLE

Atmospheric Air Pollution in Niamey, Niger: Assessment of Particulate Matter From Road Traffic (PM2.5 and PM10)

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ABSTRACT

The aim of this study was to characterise the air based on atmospheric particles in the city of Niamey. To do this, a mass concentration detector type PCE-RCM 11 and station type Davis Pro were used as collection equipment. Particulate matter with diameters of less than 2.5 µm and 10 µm, PM2.5 and PM10, respectively, as well as meteorological parameters, temperature and humidity were determined. The study was carried out over 15 days in 5 districts of Niamey between 7.30 am and 10.10 pm at the main roundabouts in each district. According to the results obtained, the average concentrations of PM2.5 in the air measured ranged from 75.34 µg/m^3 to 162.34 µg/m^3, whereas the WHO recommends 15 µg/m^3 for PM2.5 for daily exposure, which would cause cardiovascular or pulmonary disease in those exposed. The PM10 values recorded ranged from 100.43 µg/m^3 to 221.90 µg/m^3, well in excess of the WHO standards published in 2021, which recommend 45 µg/m^3 for PM10, indicating a probable risk of throat and respiratory disorders. Average temperature values ranged from 23.051 °C ± 0.1 °C to 34.186 °C ± 0.1 °C. The average relative humidity measured ranged from 17.164% ± 1% to 26.910% ± 1%. The results of the correlation analysis showed a strong correlation between PM2.5 and PM10. The latter has a strong positive correlation with temperature. PM2.5 is strongly negatively correlated with relative humidity, while PM10 is moderately negatively correlated with relative humidity. Temperature and humidity show a weak negative correlation with each other. Each of the particles studied is present in the communes of Niamey at the 5 roundabouts representing the study area. It should be confirmed that these particles emitted into the air could have come from urban transport. The correlation circle obtained from the PCA explains the relationship between the variables measured (PM and meteorological parameters). The first two dimensions explain 97.55% of the total information, with 81.62% for dimension 1% and 15.93% for dimension 2.

Keywords: Atmospheric air pollution, Niamey, PM and temperature, road traffic.

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1. Introduction

The consideration of poor atmospheric air quality has been the subject of several scientific studies [1]–[3]. Many of these studies have closely linked atmospheric air pollution in large cities to human activities, more specifically transport [4]–[6]. This pollution is amplified by natural climatic conditions, especially in sub-Saharan countries such as Niger, through the significant release of dust-containing suspended matter into the air [7]–[9]. In addition, in the context of demographic growth, the illusion of finding a better life in the big cities leads to migration to the big cities [10]. On the other hand, the centralisation of administrative and economic activities in the capitals of African countries contributes significantly to the movement of people towards urban centres [11], [12]. Proportional to this demographic growth, we are witnessing an increase in the number of people living in urban areas. As for the environmental aspect, this air pollution is seen through the increase in temperature, soil degradation, water pollution and the reduction in vegetation cover, thus contributing to the phenomenon known as climate change [13]–[15]. The direct interaction between environmental components, such as water, land, air and vegetation, facilitates the transfer of polluting substances from one medium to another [16]. As a result, air pollution causes water pollution and the disappearance of plants and vice versa [17]–[19]. According to the national statistics institute, the area of degradable land in Niamey will increase from 80 ha in 2019 to 332.5 ha in 2021. Despite these potential health and environmental impacts, very few studies have focused on air pollution caused by particulate matter in Niamey. In order to make up for this shortcoming, and to carry out this study successfully, the emphasis was placed on the concentration of particulate matter, specifically particles with diameters of less than 10 µm (PM10) and those with diameters of less than 2.5 µm (PM2.5). Certain meteorological parameters were also determined, such as temperature and relative humidity, and the concentration of these pollutants from road traffic was determined.

2. Materials and Methods

2.1. *Study Area*

Niamey, the capital of Niger, is located between latitudes 13° 28′ and 13° 35′ North and longitudes 2° 03′ and 2° 10′ East. It is built on a plateau overlooking the left bank of the River Niger and on an alluvial plain on its right bank, between 180 and 250 m above sea level. The surface area of the city of Niamey is estimated at 552.27 km^2 in 2022 [20]. The city of Niamey is characterised by intense administrative, economic and subsistence activities. The population, which was 707,951 in 2000 and 1,033.295 in 2008, is estimated to be 1,407.635 in 2024. This is reflected in exponential urbanisation, estimated at 95.2% in 2024 [20]. As a result, transport plays a key role in daily activities. There are personal vehicles, taxis, public transport commonly known as "Faba-Faba", motor tricycles and two-wheeled motorbikes of all categories. This concentration of motorbikes and vehicles is directly proportional to the fluidity of traffic, making it very difficult to get around [21]. The main phenomenon can be observed at roundabouts, where vehicles and motorbikes idle for an average of 5 minutes. The Niamey region has a climate that corresponds to that of the Sahelian tropical belt [22]. In this region, more than a third of precipitation falls with an intensity greater than 50 mm.h^{-1}, and more than half of total annual precipitation falls in less than 5 hours [6]. The maximum temperature recorded during the day can reach 45 °C in the shade at the end of the dry season [7]. This leads to the production of dust and the release of exhaust fumes, combined with the degraded air that is a source of airborne matter [23], [24]. Fig. 1 illustrates the five districts where the measurement campaign was carried out.

2.2. *Choice of Study Sites*

Measurements were taken in the five districts of the city of Niamey. In each one, the largest crossroads with significant road traffic was selected. These were the Gadafawa roundabout (CUN 1), Francophonie roundabout (CUN 2), Sixième roundabout (CUN 3), Telwa roundabout (CUN 4), and Haro-banda roundabout (CUN 5).

2.3. *Measuring Equipment*

The series of measurements was carried out over a fifteen-day period from Monday, 23 January 2023, to Sunday, 6 February 2023, at the major roundabouts in Niamey's 5 municipal districts. Every day, the period of darkness extended from 7 am–7.30 am to 10 pm–10.30 pm, i.e., 15 hours out of the 24 hours of the day, depending on the roundabout. The insecurity in Niamey imposed this time interval on us. At the same time, we recorded PM2.5, PM10, temperature and relative humidity. The Davis-type meteorological station was used in this study. The Davis station records meteorological data from the site and consists of an iconic anemometer, a passive radiation shield connected to a solar panel and a spectrum radio. The Vantage Pro2 high-frequency spread-spectrum wireless radio offers a long transmission distance with improved reception (transmission up to 300 m). With this kit from Davis, you can simultaneously record temperature, humidity, barometric pressure, and wind speed and direction. The screen displays over 100 graphs for the last 24 hours, days, months, or years. A PCE-RCM 11 mass concentration detector was used to determine particle concentrations inductively. The PCE-RCM 11 particle analyzer can simultaneously measure environmental parameters such as PM10 (in µg/m^3) and PM2.5 (in µg/m^3) in real-time. To carry out a series of continuous measurements, we connected the particle analyzer to a 'power bank' as a source of electrical power. The measuring device is equipped with a colour bar to make it easier to interpret the concentration.

2.4. *Statistical Analysis*

The data matrices were subjected to various statistical analyses using R software version 4.2.2. Descriptive statistical parameters were recorded (mean, standard deviation, standard error, lower bound, upper bound). The Shapiro-Wilk test [25] and the Bartlett test [26] were used to check the normality of the data and the homogeneity of the variance, respectively. The data were subjected to an analysis of variance (ANOVA) at the 5% threshold, followed by Duncan's contrast for comparison of means. To check the adequacy of the data collected, principal component analysis was adopted, the Kaiser-Mayer-Olkin (KMO) coefficient was determined, and the Bartlett test was performed. The KMO coefficient is an index used to test the suitability of samples for factor analysis by comparing the observed correlation coefficient with the significance of the partial correlation coefficients. A KMO value of less than 0.50 indicates that the data are not acceptable for principal component analysis. The Bartlett homogeneity test is used to check whether the variances of all the samples are equal. It is, therefore, used to check whether the hypothesis of equality of variances is true before carrying out the statistical test. For the data to be compatible with principal component analysis, the significance level (P value) of the Bartlett test must be less than 0.05.

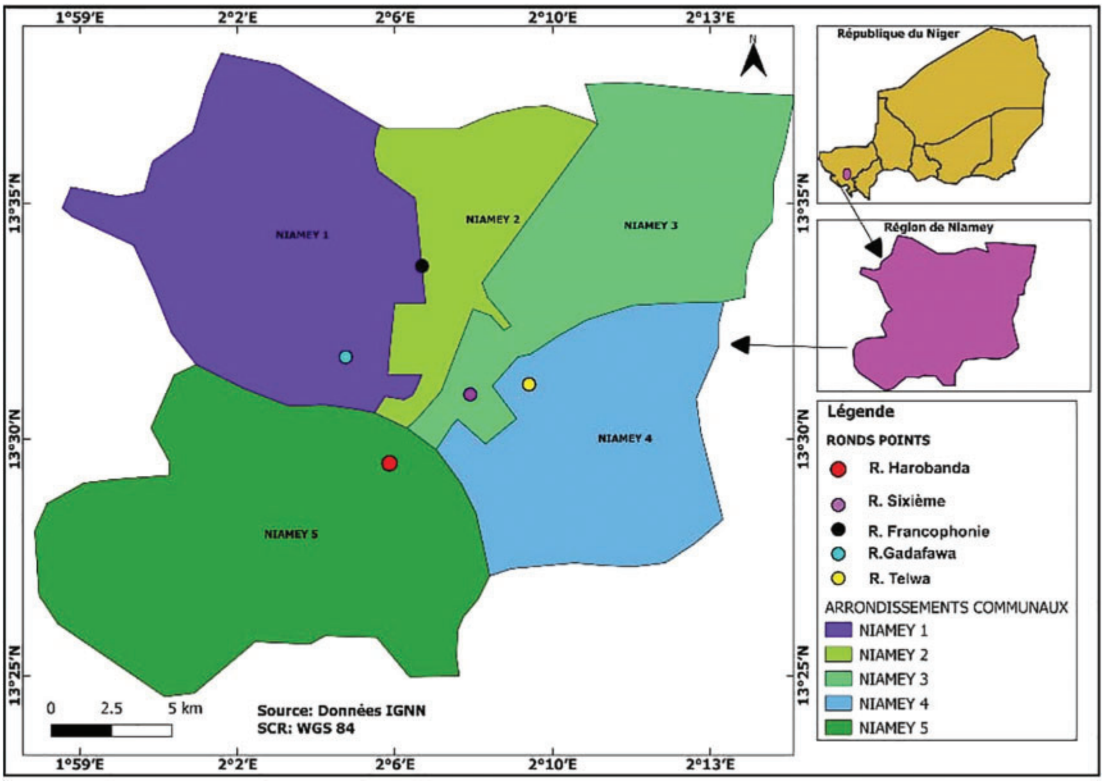

Fig. 1. Sites selected for sampling in the five districts of Niamey (ArQGIS).

3. Results

3.1. Descriptive Analysis

Table I shows the results for environmental parameters, i.e., particulate matter and meteorological parameters recorded at roundabouts in five Niamey communes during the course of this study. Mean PM2.5 values ranged from 75.34 μg/m^3 ± 1 μg/m^3 to 162.35 μg/m^3 ± 1 μg/m^3. Mean PM10 values ranged from 100.43 μg/m^3 ± 1 μg/m^3 to 232.92 μg/m^3 ± 1 μg/m^3. All the mean values for PM2.5 and PM10 measured during the course of the study greatly exceeded the admissible daily limit values prescribed by the WHO as air quality standards, which are 15 μg/m^3 and 45 μg/m^3, respectively [27]. With regard to the meteorological parameters recorded, the average mean temperature values ranged from 23.0 °C (in CUN1) to 34.3 °C (CUN2) and relative humidity from 17.16% (CUN4) to 26.91% (CUN3).

3.2. Meteorological Parameters

3.2.1. Humidity Level in the City of Niamey

Humidity levels varied significantly (P. value < 0.001) (Fig. 2) between the different communes of the city of Niamey. The highest humidity levels were obtained in CUN1, CUN2 and CUN3 with 26.2% ± 4.1%, 26.2% ± 5.7% and 26.9% ± 7.3%, respectively, while CUN4 recorded the lowest humidity level (17.2% ± 7.9%).

3.2.2. Community Temperatures in Niamey

The temperature between the different communes varied significantly (P value < 0.001). CUN2, CUN4 and CUN5 recorded the highest mean temperatures with 34.3 °C ± 6.0 °C, 33.5 °C ± 5.2 °C, 34.2 °C ± 2.418 °C, respectively. The lowest temperature was obtained in CUN1, at 23.0 °C ± 1.5 °C).

3.3. Environmental Parameters: Particulate Matter

3.3.1. Average PM2.5 Concentration in Niamey Communes in μg/m^3

Particulate matter (PM2.5) determined in the various communes of the city of Niamey varied significantly between them (P value < 0.001). Municipality 4 recorded the highest PM2.5 concentrations, with a value of 162.34 μg/m^3 ± 100.010, while the lowest concentrations were obtained in municipality 1, with a value of 75.34 μg/m^3 ± 60.832.

3.3.2. Average PM10 Concentration in Niamey Communes in μg/m^3

The particulate matter (PM10) recorded (Fig. 4) in the 5 communes varied significantly (P value < 0.001). Communes 2 and 4 recorded the highest concentrations of particulate matter (PM10), with 221.900 μg/m^3 ± 121.891 and 232.920 μg/m^3 ± 88.036, respectively. Municipality 1 recorded the lowest concentration of particulate matter (PM10) with a value of 100.430 μg/m^3 ± 71.140.

3.4. Correlation Analysis

Table II shows the Pearson correlation matrix between particulate matter (PM2.5 and PM10) and meteorological conditions (temperature and relative humidity). PM2.5 and PM10, which have the same source and similar physicochemical characteristics, show strong positive correlations with each other. The latter have a strong positive correlation with temperature. PM2.5 is strongly negatively correlated with relative humidity, while PM10 is

TABLE I: Values Measured for PM2.5 and PM10 (μg/m³) Temperature (°C) and Humidity (%) in the Selected Sampling Sites

Parameter	Commune	N	Average	Standard deviation	Standard error	Minimum value	Maximum value
PM2.5	CUN1	3	75.34	60.83	3.58	68.30	82.39
	CUN2	3	128.94	65.07	3.83	121.41	136.48
	CUN3	3	106.38	55.36	3.26	99.97	112.79
	CUN4	3	162.35	100.01	5.88	150.77	173.93
	CUN5	3	134.88	101.97	5.99	123.07	146.68
PM10	CUN1	3	100.43	71.14	4.18	92.19	108.67
	CUN2	3	221.90	121.89	7.17	207.78	236.01
	CUN3	3	189.95	103.54	6.09	177.96	201.94
	CUN4	3	232.92	88.03	5.18	222.73	243.11
	CUN5	3	192.87	132.37	7.79	177.54	208.19
Temperature	CUN1	3	23.0	1.5	0.1	22.9	23.3
	CUN2	3	34.3	6.0	0.4	33.6	35
	CUN3	3	28.2	5.2	0.3	27.5	28.8
	CUN4	3	33.5	5.2	0.3	32.9	34.1
	CUN5	3	34.2	2.4	0.1	33.9	34.5
Humidity	CUN1	3	26.2	4.1	0.2	25.7	26.7
	CUN2	3	26.2	5.7	0.3	25.5	26.9
	CUN3	3	26.9	7.3	0.4	26	27.8
	CUN4	3	17.2	7.9	0.5	16.2	18
	CUN5	3	23.5	5	0.3	22.9	24

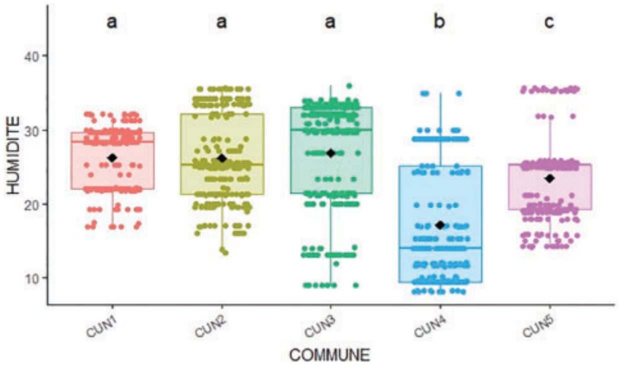

Fig. 2. Average humidity of communes in Niamey. P value < 0.001. The letters a, b and c are from the Duncan comparison at threshold a = 0.05.

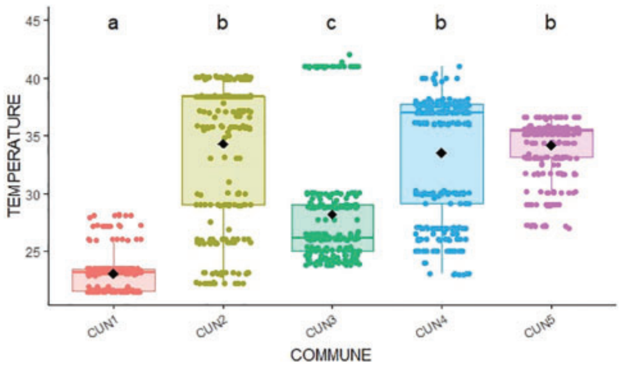

Fig. 3. Average temperatures in the 5 communes of Niamey. P value < 0.001. The letters a, b and c are from the Duncan comparison at threshold a = 0.05.

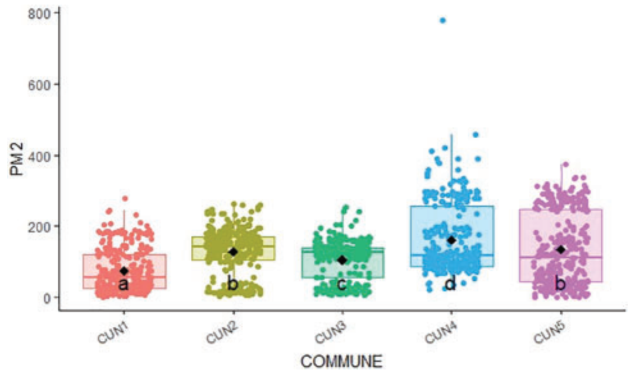

Fig. 4. Average PM2.5 concentration in Niamey communes. P value < 0.001. The letters a, b, c and d are from the Duncan comparison at threshold a = 0.05.

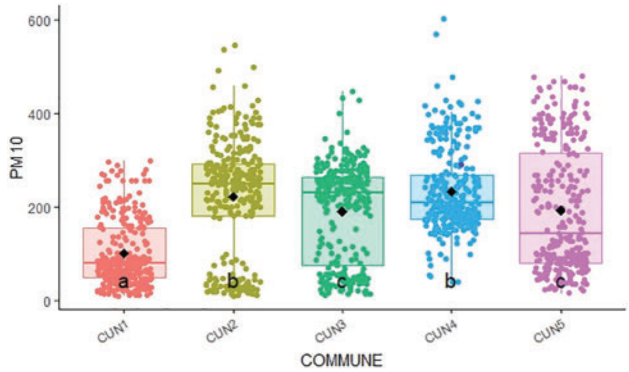

Fig. 5. Average PM10 concentration in Niamey communes. P value < 0.001. The letters a, b and c are from the Duncan comparison at threshold a = 0.05.

moderately negatively correlated with relative humidity. Temperature and humidity show a weak negative correlation with each other.

3.5. *Principal Component Analysis*

Principal component analysis was used to visualise the relationships between the various PM and meteorological parameters. The results of the KMO and Bartlett tests applied to the different parameters are presented in Table III. This table shows that the KMO value of the data used for the principal component analysis is 0.635 (a value of to be KMO superior to 0.5) and that the significant value of the Bartlett test is close to zero, implying that the data are suitable for principal component analysis.

The correlation circle obtained from the PCA (Fig. 6) on the basis of the first two axes explains the relationship

TABLE II: Pearson Correlation Analysis of PM2.5, PM10 and Meteorological Parameters

Parameters	PM2.5	PM10	T	H
PM2.5	1.0000000	0.9060830	0.8975240	−0.7895722
PM10	0.9060830	1.0000000	0.9018853	−0.5033771
T	0.8975240	0.9018853	1.0000000	−0.4694180
H	−0.7895722	−0.5033771	−0.4694180	1.0000000

TABLE III: Kaiser-Meyer-Olkin (KMO) Index and Bartlett test

KMO index and Bartlett test		
KMO index for measurement of sampling adequacy		0.635
Test of sphericity of Bartlett	Approx. Chi-square	16.089
	df	6
	Signification	0.013

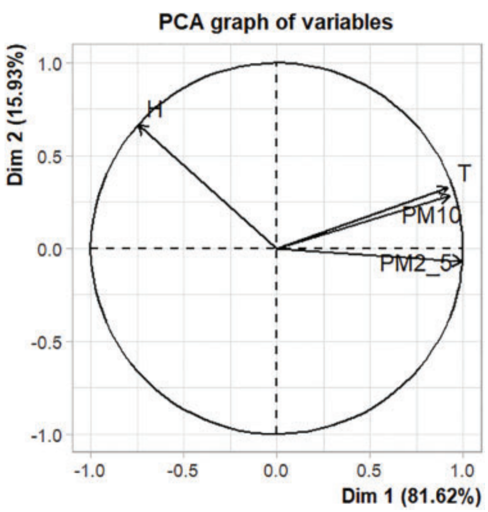

Fig. 6. Correlation circle between PM and meteorological parameters.

between the variables measured (PM and meteorological parameters). The first two dimensions explain 97.55% of the total information, with 81.62% for dimension 1% and 15.93% for dimension 2. The parameters PM2.5, PM10 and T are positively correlated with dimension 1 and therefore positively correlated with each other, while humidity (H) is negatively correlated with dimension 1 and other parameters.

4. Discussion

The relative humidity measurements (Fig. 2) carried out in the 5 communes showed a relatively uniform humidity in the city of Niamey, with the exception of commune 3 (26.7%). This difference is justified by the fact that the Sixième roundabout in commune 3 is surrounded by military camps and public and private services where greenery is regularly maintained, thus keeping humidity constant. The temperature recorded in the 5 communes (Fig. 3), having shown that Rondpoint Francophonie has the highest value, may be due to the fact that the households dominating its surroundings contribute to it through the effect of congestion coupled with human concentration. The results of particulate matter measurements obtained (Figs. 4 and 5) at 5 roundabouts in the boroughs show a high concentration of these particles. Strictly speaking, commune 4 recorded much higher values for PM2.5 (162.34 μg/m^3) and PM10 (232.92 μg/m^3), which could be explained by the proximity of the Telwa roundabout (CUN4) to the Niamey bus station, a crossroads used directly by interurban transport vehicles, which are often ageing and poorly maintained, thus emitting large quantities of exhaust fumes, and the amplification of emissions by uncontrolled dumping in Niamey's green belt. Our results are in line with those of [28], who specifies that at Niamey-Aéroport the average annual concentration of PM10 is 67 μg.m^{-3} and is in agreement with those of the World Health Organization [29] which stipulates, in its report that the average concentration in African countries (32 μg/m^3) is higher than the global level and that Niger has the highest concentrations of fine particles (PM2.5) in the African Region (50.1 μg/m^3). Reference [29] and [6] who point out that PM2.5 concentrations measured in the air in the city of Niamey (Commune 5) have an average value of 11.65 μg/L, the average temperature value is 25.3 °C and the average air humidity value measured is 13.3%. The World Health Organisation's 2018 guidelines recommend a daily exposure limit of 15 μg/m^3 for PM2.5 and 45 μg/m^3 for PM10, while the lowest average concentrations recorded were 73.34 μg/m^3 in PM2.5 and 100.430 μg/m^3, which is not without consequences for human health. These PM10 concentrations indicate a probable risk of throat diseases and respiratory disorders, while PM2.5 concentrations are thought to cause cardiovascular or pulmonary diseases in those exposed. According to a report by the World Health Organisation (WHO), 9 out of 10 of the world's population breathe polluted air [29], [30]. The Organisation for Economic Co-operation and Development (OECD) [30] points out that the world as a whole has seen a steady increase in premature deaths attributed to exposure to PM2.5. The Czech Republic, Greece, Hungary, Latvia, Poland, and the Slovak Republic have the highest number of deaths attributed to exposure to PM2.5 relative to population, with more than 500 deaths per million inhabitants each year. A correlation has also been found between PM concentrations and temperature. This situation could contribute to the dispersion of pollutants in the atmosphere, as reported by Naima and Manal [31]. Consequently, there will be a risk of environmental degradation in the chain of three environmental components.

5. Conclusion

This study focused on the qualitative and quantitative assessment of atmospheric particles in the Niamey region. The pollutants concerned by this study are mainly fine suspended particles (PM2.5 and PM10) and meteorological parameters (T and H). The concentrations of PM2.5 and PM10 measured in the air ranged from 2 μg/m^3 to 777 μg/m^3, with an average value of 121.58 μg/m^3, and from 10 to 601 μg/m^3, with an average value of 187.61 μg/m^3. Temperature values ranged from 21.5 °C to 42 °C, with an average value of 30.64 °C. The air humidity measured ranged from 8.2% to 36%, with an average value of 23.99%. Compared with World Health Organisation guidelines, the PM2.5 and PM10 concentrations measured during this study exceeded the recommended limit values. The results of the correlation analysis showed a strong correlation between PM2.5-PM10, PM2.5-T and PM10-T. According to the eigenvalues, the dimensions DIM.1 and DIM.2 explained 97.54% of the total variance. We can deduce from this that air pollution is a major contributor to the increase in respiratory and cardiovascular diseases, which affect life expectancy and the well-being of the population, and to environmental degradation. It would be important for a country like Niger to have a policy, a strategy or an action aimed at a real transition in the field of transport and urbanisation. Promoting inter-urban and intra-urban public and rail transport and raising awareness of the need to use bicycles, especially at weekends, could be an alternative way of minimising the emission of these pollutants into the air. Controlled urbanisation, i.e., the promotion of green towns and the widening of road infrastructures, is also a technology for a less polluted environment.

Conflict of Interest

The authors declare that they do not have any conflict of interest.

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