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Air Quality in Terms of Airborne Particulate Matters $PM_{2.5}$ and PM_{10} at Analakely in Antananarivo City-Madagascar

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Abstract: There are many pollutants that are major factors in disease in humans. Among them, Airborne Particulate Matter, particles of variable but very small diameter, penetrate the respiratory system via inhalation, causing respiratory and cardiovascular diseases and cancer. Air quality index (AQI) is a quantitative tool through which air pollution data can be reported, providing information on how clean or polluted the air is. This AQI focuses on health effects people may experience within a few hours or days after breathing polluted air. The present study was carried out to determine the concentrations of ambient air quality in terms of airborne particulate matter of aerodynamic diameter lower than 10 µm (PM_{10}) in the aerosol collected at Analakely along the busy roads of Antananarivo city (Madagascar). Evaluation of the concentrations of ambient PM_{10} were determined on the basis of PM_{10} size fractions at the selected site. The air quality is measured with the Air Quality Index. The result shows that Air Quality Indices in the study area vary from 22.28 to 138.39 for $PM_{2.5}$ and from 22.53 to 105.69 for PM_{10}. For $PM_{2.5}$, 27% of the collected samples are categorized as good quality, 67% as moderate quality and 6% as unhealthy quality for sensitive people. For the PM_{10} parameter, 44% are of good quality, 54% of moderate quality and only 2% of unhealthy quality for sensitive people. For the particulate matters, all results are compared to the World Health Organization and United States Environmental Protection Agency air quality guidelines. Almost their concentrations are exceeding these guidelines. Therefore, it is important to constantly monitor the air quality in this site. Moreover, such a report allows the authorities to project how reducing particulate air pollution could benefit the health of the population.

Keywords: Air Quality Index, Ambient Air, Airborne Particulate Matter, Antananarivo City

1. Introduction

Air pollution is a serious problem throughout the world and threatens the human health and the environment. Since 1996, the "Institut National des Sciences et Techniques Nucléaires (INSTN-Madagascar)" has studied the air pollution, in particular the pollution by the particulate matters in the city of Antananarivo. PM stands for particulate matter (also called particle pollution): the term for a mixture of solid particles and liquid droplets found in the air. Particle pollution includes PM_{10} (inhalable particles, with diameters that are generally 10 micrometers and smaller) and $PM_{2.5}$ (fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller) [1]. Fine particles $PM_{2.5}$ and PM_{10} are airborne elements that have adverse effects on the human health. According to the World Health Organization (WHO), nine out of ten people breathe polluted air in the world and about seven million people die each year due to the exposure to fine particles contained in polluted air [2]. The strong body of scientific evidence shows that long- and short-term exposures to fine particles ($PM_{2.5}$) can harm people's health, leading to heart attacks, asthma attacks, and premature death. Large segments of the U.S. population, including children, people with heart or lung conditions, and people of color, are at risk of health effects from $PM_{2.5}$ [3]. From the study of the air quality carried out by INSTN-Madagascar in Antananarivo in 2003, the concentrations of $PM_{2.5}$ / PM_{10} vary respectively between 41 $\mu g.m^{-3}$ / 128 $\mu g.m^{-3}$ and 53 $\mu g.m^{-3}$ / 157 $\mu g.m^{-3}$ on the Ambohidahy, Soarano, Avaradoha, Ampasamadinika and Route Digue axes. This study shows that the air quality in these areas is categorised as "poor" and "bad". Chemical compositions of particulate matter (PM) from traffic emissions vary by region and with time [4]. In the present work, INSTN-Madagascar studied the air quality in Analakely, from November 21, 2019 to January 13, 2020. This area was chosen because of its relatively high attendance rate, the traffic is heavy and there is a market. Traffic has been targeted as important contributor to ambient air pollution in cities. In this paper, a methodology for developing an Air Quality Index (AQI) for Analakely is also presented.

2. Material and Methods

2.1. Air Quality Index Category and Health Effects Statements

The purpose of the Air Quality Index is to help for understanding what local air quality means to the human health and the environment. Concentrations of particulate matter were used to calculate the results in terms of AQI.

2.2. Air Quality Index Calculation Method by the US EPA

The U.S. AQI is EPA's index for reporting air quality [5]. The objective of the Air Quality Index (AQI) is to simplify the concentrations of pollutants to communicate the results to the public. According to the AQI category adopted by the United States Environmental Protection Agency (US EPA) on the concentrations of $PM_{2,5}$ and PM_{10}, the level of pollution can be referenced according to the value of the AQI. This AQI is calculated in relation to the standards set by US EPA Equation (1) is used to convert the concentration of a pollutant into an air quality index [6, 7].

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} \left(C_p - BP_{Lo}\right) + I_{Lo} \quad (1)$$

where I_p is the index of the pollutant p; C_p is the truncated concentration of pollutant p ($\mu g.m^{-3}$); BP_{Hi} is the concentration breakpoint that is greater or equal to C_p; BP_{Lo} is the concentration breakpoint less than or equal to C_p; I_{Hi} is the AQI value corresponding to $BP_{Hi;}$ BP_{Lo} is the AQI corresponding to BP_{Lo}.

The AQI is divided into six categories. Table 1 shows the zoning of the air quality index and the health indication Air Quality Index category and Health effects statements [5, 8].

In the table 1. the "sensitive groups" are the elderly, children and people prone to heart and lung infections. The analytical results are interpreted according to these criteria.

Table 1. *Air Quality Index category and Health effects statements.*

Air Quality Index Values	**$PM_{2,5}$ ($\mu g.m^{-3}$)**	**PM_{10} ($\mu g.m^{-3}$)**	**Levels of Health Concern**	**Colors**
$I_{min} – I_{max}$	**$C_{min} – C_{max}$ (average)**	**$C_{min} – C_{max}$ (average)**		
0 to 50	0.0-12.0 (24 h)	0-54 (24 h)	Good	Green
51 to 100	12.1-35.4 (24h)	55-154 (24 h)	Moderate	Yellow
101 to 150	35.5-55.4 (24h)	155-254 (24 h)	Unhealthy for Sensitive Groups	Orange
151 to 200	55.5-150.4 (24h)	255-354 (24 h)	Unhealthy	Red
201 to 300	150.5-250.4 (24h)	355-424 (24 h)	Very Unhealthy	Purple
301 to 400	250.5-350.4 (24h)	425-504 (24 h)	Hazardous	Maroon
401 to 500	350.5- 500.4 (24h)	505-604 (24 h)		

Figure 1. *The caption of the fi Sampling point in Analakely (Google Maps).*

2.3. Methodologie

2.3.1. Study Area

The sampling is carried out in the site of Analakely where is located in downtown of Antananarivo (capital of Madagascar). This site is the busiest area. Most buses pass in this site and there is one of the largest markets in the city of Antananarivo. It is therefore interesting to study the air quality in this part of the city. The $PM_{2.5}$ and PM_{10} samples were collected in Military Region number 1 (RM1) which is near the Analakely market and a four-lane junction. The Laborde geographic coordinates of the sampling point are 18.910048 South and 47.527505 East. Figure 1 shows the location of this sampling point.

2.3.2. Sampling Protocol

The collection of airborne particulate matter (APM) in urban area of Antananarivo - Madagascar were carried out using the samples collector which complies with the GENT PM_{10} stacked Filter Unit (SFU) [9] provided by International

Atomic Energy Agency (IAEA). This air sampler was able to separate fine particles or respirable particles with an aerodynamic dimension of less than 2.5 µm ($PM_{2.5}$) and coarse particles or inhalable particles with a diameter between 2.5 µm and 10 µm ($PM_{2.5-10}$). Two types of Nuclepore polycarbonate filters of diameter 47 mm collect respectively the coarse fraction $PM_{2.5-10}$ (of porosity 8 µm) and the fine fraction $PM_{2.5}$ (of porosity 0.4 µm). The SFU samplers were set up with its PM_{10} inlet at about 160 cm above the ground surface and operated at an air flow rate of 16 liters per minute in order to optimize the separation. Sampling APM were done during 24 hours in site. The works took place during the period from November 21, 2019 to January 07, 2020. It should be noted that the samples were taken during the rainy period. 48 samples were taken, including 96 samples of $PM_{2.5}$ and $PM_{2.5-10}$. Figure 2 illustrates the sampling site and the GENT air sampler.

Figure 2. *GENT air sampler (INSTN-Madagascar).*

2.3.3. Measurement of Aerosol Samples

The filters were weighed with a Sartorius Quintix65-1S microbalance (Figure 3) before and after sampling to determine the mass of microparticles deposited on the filters.

The dust contents are obtained by the gravimetric method [10] and the obtained values are converted into the Air Quality Index.

Figure 3. *Sartorius Quintix 65-1S Balance (INSTN-Madagascar.*

3. Results and Discussion

3.1. Daily Mean Concentration of $PM_{2.5}$ and PM_{10}

The daily mean concentrations of microparticles $PM_{2.5}$ and the particulate matter smaller than 10 µm (PM_{10}) taken in the study site are given in Table 2. For $PM_{2.5}$, they vary between 5.35 and 50.68 µg. m^{-3}. As for PM_{10}, their daily mean concentrations vary from 24.33 to 164.48 µg. m^{-3}.

The concentrations of $PM_{2.5}$ and PM_{10} at Analakely are compared to WHO air quality guidelines in 2005 [11] and US EPA guidelines in 2006 [12].

Table 2. *Daily mean concentrations of $PM_{2.5}$ and PM_{10} at Analakely.*

Sampling date	**Daily average concentrations of airborne dust in the air (µg.m^{-3})**		**Limited value adopted by WHO and U.S. EPA in daily average (µg.m^{-3})**			
	$PM_{2.5}$	**PM_{10}**	**$PM_{2.5}$**		**PM_{10}**	
			WHO	**US EPA**	**WHO**	**US EPA**
Thursday, 21/11/2019	25.32	95.36				
Friday, 22/11/2019	16.54	83.71				
Saturday, 23/11/2019	20.85	87.56				
Sunday, 24/11/2019	23.07	66.44				
Monday, 25/11/2019	18.71	97.33				
Tuesday, 26/11/2019	50.68	91.79				
Wednesday, 27/11/2019	47.76	136.86				
Thursday, 28/11/2019	41.10	164.48	25	35	50	150
Sunday, 01/12/2019	15.47	109.65				
Monday, 02/12/2019	18.50	99.11				
Tuesday, 03/12/2019	11.50	87.00				
Wednesday, 04/12/2019	17.62	116.00				
Thursday, 05/12/2019	27.15	107.70				
Saturday, 07/12/2019	11.32	51.36				
Sunday, 08/12/2019	20.13	60.17				
Sampling date	**Daily average concentrations of airborne dust in the air (µg.m^{-3})**		**Limited value adopted by WHO and U.S. EPA in daily average (µg.m^{-3})**			
	$PM_{2.5}$	**PM_{10}**	**$PM_{2.5}$**		**PM_{10}**	
			WHO	**US EPA**	**WHO**	**US EPA**
Monday, 09/12/2019	24.29	73.76				
Tuesday, 10/12/2019	19.61	74.67	25	35	50	150
Wednesday, 11/12/2019	7.04	30.54				
Thursday, 12/12/2019	11.79	56.83				

Sampling date	Daily average concentrations of airborne dust in the air ($\mu g.m^{-3}$)		Limited value adopted by WHO and U.S. EPA in daily average ($\mu g.m^{-3}$)			
			$PM_{2.5}$		PM_{10}	
	$PM_{2.5}$	PM_{10}	WHO	US EPA	WHO	US EPA
Monday, 16/12/2019	20.12	39.33				
Tuesday, 17/12/2019	19.71	51.42				
Wednesday, 18/12/2019	31.50	89.73				
Thursday, 19/12/2019	12.41	70.64				
Friday, 20/12/2019	14.61	62.44				
Saturday, 21/12/2019	24.23	81.55				
Sunday, 22/12/2019	13.46	24.33				
Monday, 23/12/2019	7.62	52.67				
Tuesday, 24/12/2019	17.41	68.82				
Wednesday, 25/12/2019	21.57	60.67				
Thursday, 26/12/2019	11.18	76.93				
Friday, 27/12/2019	13.19	40.54				
Saturday, 28/12/2019	10.57	28.87				
Sunday, 29/12/2019	11.27	43.23				
Monday, 30/12/2019	10.14	58.36				
Tuesday, 31/12/2019	14.56	45.70				
Wednesday, 01/01/2020	13.61	42.35				
Thursday, 02/01/2020	13.04	36.42				
Friday, 03/01/2020	11.96	32.00				
Saturday, 04/01/2020	5.35	28.87				
Sunday, 05/01/2020	13.96	48.23				
Monday, 06/01/2020	27.42	55.54				
Tuesday, 07/01/2020	12.81	44.00				
Wednesday, 08/01/2020	17.32	49.76				
Thursday, 09/01/2020	13.88	133.08				
Friday, 10/01/2020	11.32	42.56				
Saturday, 11/01/2020	13.87	47.67				
Sunday, 12/01/2020	10.85	27.56				
Monday, 13/01/2020	12.21	46.42				

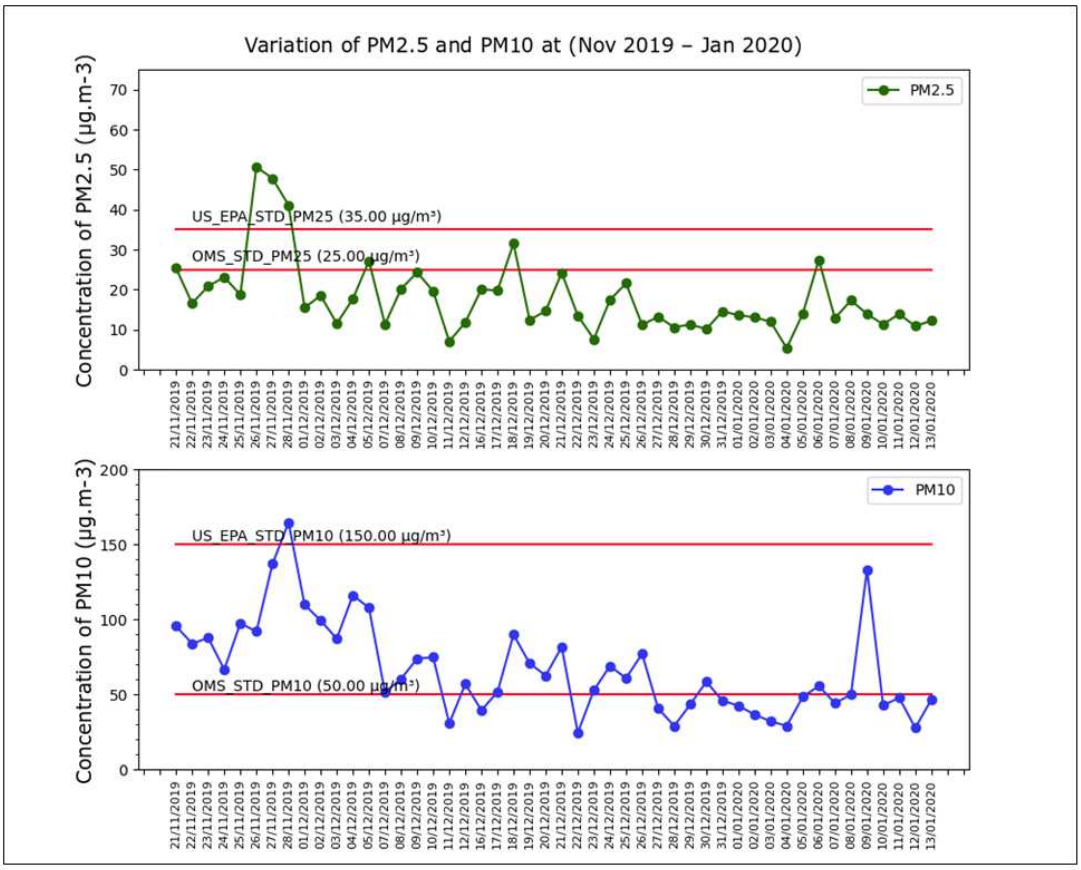

Figure 4. *Variation of $PM_{2.5}$ and PM_{10} at Analakely (source INSTN-Madagascar).*

According to table 2 and figure 4, the maximum concentration of 50.68 $\mu g.m^{-3}$ of $PM_{2.5}$ is observed on Tuesday, November 26, 2019. The minimum value of 5.35 $\mu g.m^{-3}$ is noted on Saturday, January 04, 2020. As for PM_{10}, the maximum concentration of 164.48 $\mu g.m^{-3}$ is seen on Thursday, November 28, 2019 and the minimum value on Sunday, December 22, 2019. The highest value could be due to the abundance of atmospheric turbulence of dust particles produced by the daytime running cars at the nearby Mahamasina market. In many developing cities, for instance, particles stirred up by road dust and produced by solid fuel combustion, are important sources of particulate pollution [13].

However, on Saturday and Sunday (weekends), the air at Analakely is moderately clean because of the traffic flow.

Compared to the World Health Organization guidelines, 15% of $PM_{2.5}$ in collected samples have concentrations exceeding the limit value, set at 25 $\mu g.m^{-3}$, with a peak of twice this limit value on November 26, 27 and 28, 2019. According to European Environment Agency, 77 % of the EU-28 urban population is exposed to $PM_{2.5}$ concentrations above the WHO Air Quality Guidelines value. Air pollution affects all areas of the world, with the population in urban areas particularly exposed to high concentrations of small particulate matter ($PM_{2.5}$). Exposure to these concentrations can lead to major health problems [14]. For PM_{10}, 62% of the collected samples have also concentrations which exceed the limit value, set at 50 $\mu g.m^{-3}$ by two to three times. Diesel-fueled vehicles are major sources of harmful pollutants, such as ground-level ozone and particulate matter [15].

In comparison with the United States Environmental Protection Agency (US EPA) standards, in terms of concentration, 6% of the collected samples are higher than the limit value, set at 35 $\mu g.m^{-3}$ for $PM_{2.5}$, and 2% of the samples exceed the limit value, set at 150 $\mu g.m^{-3}$ for PM_{10}. Figures 5 and 6 show the comparison of $PM_{2,5}$ et PM_{10} to WHO and US EPA guidelines.

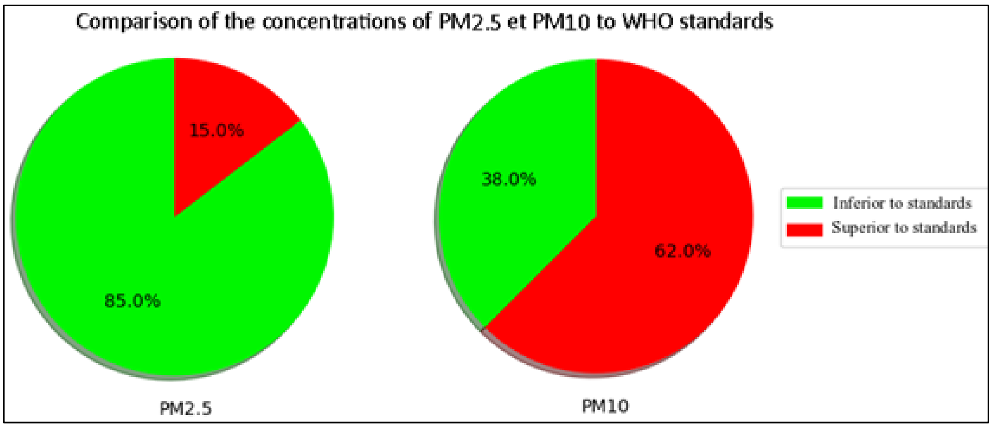

Figure 5. *Comparison of $PM_{2,5}$ et PM_{10} to WHO standards (source INSTN-Madagascar).*

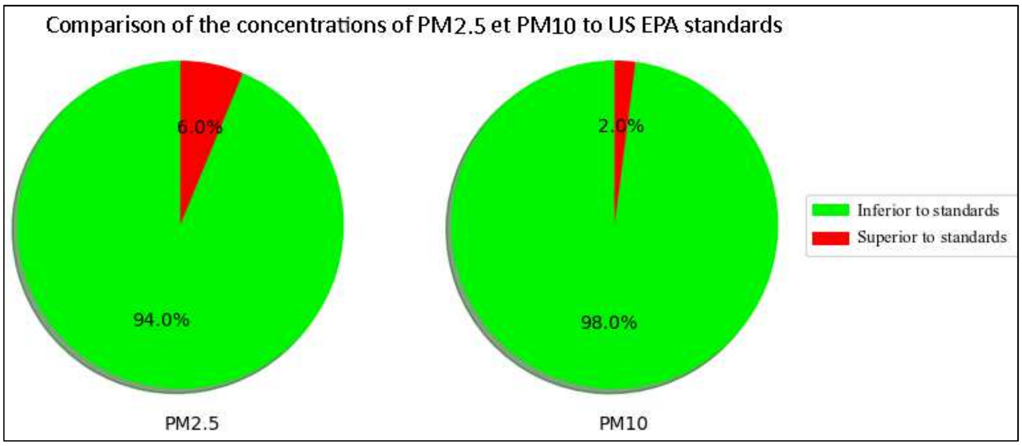

Figure 6. *Comparison of $PM_{2.5}$ and PM_{10} to the US EPA standards (source: INSTN-Madagascar).*

3.2. Air Quality Index and Zoning of $PM_{2.5}$ and PM_{10}

Air quality indices in the study area are presented in Table 3. These indices vary from 22.28 to 138.39 for $PM_{2.5}$ and from 22.53 to 105.69 for PM_{10}.

Referring to the standards adopted by US EPA and the zoning in Table 3, for $PM_{2.5}$ particles, 13 out of 48 samples are considered as good quality, 32 as moderate quality and as unhealthy quality for sensitive people. For the PM_{10} parameter, 21 out of 48 collected samples are of good quality, 26 of moderate quality and one sample of unhealthy quality for sensitive people.

Table 3. *Results of AQI category and Health Effects Statements.*

Date	IQA $PM_{2,5}$	IQA PM_{10}	Zoning $PM_{2,5}$	Zoning PM_{10}
2019/11/21	78.80	70.98	Moderate	Moderate
2019/11/22	60.33	65.21	Moderate	Moderate
2019/11/23	69.41	67.11	Moderate	Moderate
2019/11/24	74.08	56.66	Moderate	Moderate
2019/11/25	64.91	71.95	Moderate	Moderate
2019/11/26	138.39	69.21	Unhealthy for Sensitive Groups	Moderate
2019/11/27	131.19	91.52	Unhealthy for Sensitive Groups	Moderate
2019/11/28	114.78	105.69	Unhealthy for Sensitive Groups	Unhealthy for Sensitive Groups
2019/12/01	58.09	78.05	Moderate	Moderate
2019/12/02	64.46	72.83	Moderate	Moderate
2019/12/03	47.92	66.84	Good	Moderate
2019/12/04	62.62	81.19	Moderate	Moderate
2019/12/05	82.65	77.08	Moderate	Moderate
2019/12/07	47.17	47.56	Good	Good
2019/12/08	67.89	53.56	Moderate	Moderate
2019/12/09	76.64	60.29	Moderate	Moderate
2019/12/10	66.80	60.73	Moderate	Moderate
2019/12/11	29.33	28.28	Good	Good
2019/12/12	49.13	51.91	Good	Moderate
2019/12/16	67.88	36.42	Moderate	Good
2019/12/17	67.00	47.61	Moderate	Good
2019/12/18	91.80	68.19	Moderate	Moderate
2019/12/19	51.65	58.74	Moderate	Moderate
2019/12/20	56.28	54.68	Moderate	Moderate
2019/12/21	76.50	64.14	Moderate	Moderate
2019/12/22	53.86	22.53	Moderate	Good
2019/12/23	31.77	48.77	Good	Good
2019/12/24	62.17	57.84	Moderate	Moderate
2019/12/25	70.92	53.80	Moderate	Moderate
2019/12/26	46.58	61.85	Good	Moderate
2019/12/27	53.30	37.54	Moderate	Good
2019/12/28	44.02	26.73	Good	Good
2019/12/29	46.96	40.03	Good	Good
2019/12/30	42.23	52.66	Good	Moderate
2019/12/31	56.16	42.32	Moderate	Good
2020/01/01	54.17	39.21	Moderate	Good
2020/01/02	52.98	33.72	Moderate	Good
2020/01/03	49.85	29.63	Good	Good
2020/01/04	22.28	26.73	Good	Good
2020/01/05	54.91	44.66	Moderate	Good
2020/01/06	83.22	51.27	Moderate	Moderate
2020/01/07	52.49	40.74	Moderate	Good
2020/01/08	61.98	46.07	Moderate	Good
2020/01/09	54.73	89.65	Moderate	Moderate
2020/01/10	47.17	39.41	Bon	Good
2020/01/11	54.73	44.14	Moderate	Good
2020/01/12	45.22	25.51	Good	Good
2020/01/13	51.23	42.98	Moderate	Good

Table 3 and Figure 7 also show that for the $PM_{2.5}$ and PM_{10}, the quality of the air collected during the day of Thursday, November 28, 2019 is of unhealthy quality for people sensitive. However, none of the samples collected on the other days are of unhealthy, very of unhealthy or dangerous quality.

Figure 8 shows in terms of the proportion for $PM_{2.5}$, that 27% of the collected samples are categorized as good quality, 67% as moderate quality and 6% as unhealthy quality for sensitive people. For the PM_{10} parameter, 44% are of good quality, 54% of moderate quality and only 2% of unhealthy quality for sensitive people.

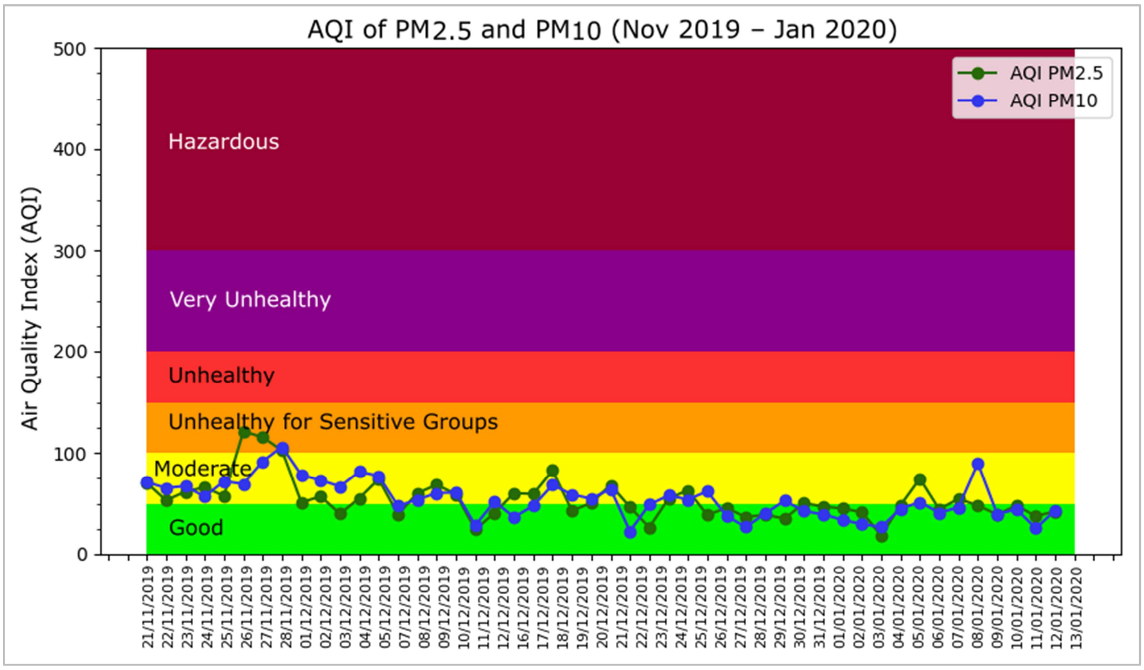

Figure 7. *Air Quality Index of $PM_{2,5}$ et PM_{10} at Analakely (source: INSTN-Madagascar).*

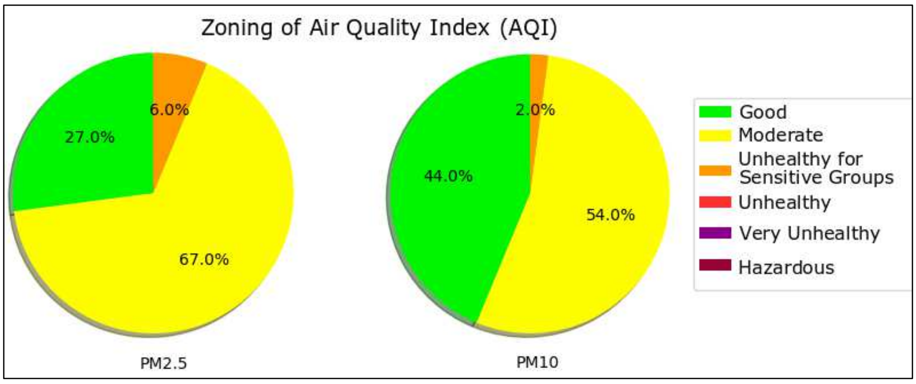

Figure 8. *Zoning of Air Quality Index (source: INSTN-Madagascar).*

For the future work, the main objective of this work was to evaluate the new AQI performances in terms of the capacity of distinguishing different air pollution situations. This index is a national air quality rating system based on the national ambient air quality standards [16].

4. Conclusion

During the period from November 21, 2019 to January 13, 2020, preceding the period of confinement, the air quality in Analakely improved slightly compared to the previous periods of air sampling carried out by INSTN-Madagascar in the Ambohidahy, Soarano, Avaradoha, Ampasamadinika and Route Digue axes. This slight improvement is probably due to the rainy season.

Compared to the World Health Organization air quality guidelines, 15% of the collected samples have concentrations of $PM_{2.5}$ which exceed the limit value, set at 25 $\mu g.m^{-3}$ with a peak of twice this limit value on 26, 27 and 28 November, 2019. For PM_{10}, 62% of the samples have concentrations exceeding the WHO limit value, set at 50 $\mu g.m^{-3}$ by two to three times. Peaks usually occur on market days in Mahamasina, every Thursday, especially when there is no rain. The rains have the property of reducing air pollution.

Compared to the United States Environmental Protection Agency air quality guidelines more than 94% of the samples comply with the guidelines for $PM_{2.5}$, set at 35$\mu g.m^{-3}$. For PM_{10}, 98% comply with the standards and 2% exceed the limit values, set at 150 $\mu g.m^{-3}$. In terms of quality zoning, 27% of the $PM_{2.5}$ collected samples are qualified as of good quality, 67% of moderate quality and 6% of unhealthy quality for sensitive people. For the PM_{10} parameter, 44% are of good quality, 54% of moderate quality and only 2% of unhealthy quality for sensitive people. Despite a slight improvement compared to previous periods, the air quality was not yet 100% acceptable before the period of confinement in the city of Antananarivo. It continued to further weaken a significant part of the population of 'Antananarivo susceptible to respiratory diseases, asthma, diabetes, cancer, thus increasing the future risks of complication of COVID-19 symptoms. Indeed, it is proven that the cities with a high pollution rate generally experience a higher mortality rate during such pandemics.

5. Recommendations

The number of vehicles in town should be reduced, by adopting the system of rotation of vehicles with even and odd numbers.

It should be necessary to increase unannounced checks on the exhaust pipes of combustion engine vehicles and to promote the import of environmentally friendly vehicles.

To minimize the exposure by avoiding exposure to outdoor air in more polluted places, such as high-traffic, industrial areas would be recommended.

Acronyms

APM: Airborne Particulate Matter
AQI: Air Quality Index
IAEA: International Atomic Energy Agency
INSTN: Institut National des Sciences et Techniques Nucléaires
RM1: Military Region number 1
SFU: Stacked Filter Unit
US EPA: United States Environmental Protection Agency
WHO: World Health Organization

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