THE RELATIONSHIP BETWEEN PARTICULATE MATTER (PM_{10}) AND METEOROLOGICAL PARAMETERS IN IPOH, PERAK (2020 - 2021)

Hubungan antara Partikel Terampai (PM_{10}) dan Parameter Meteorologi di Bandaraya Ipoh, Perak (2020 - 2021)

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Received: 20 March 2023 ; **Revised:** 24 April 2023 ; **Accepted:** 25 May 2023 ; **Published:** 16 June 2023

To cite this article: Hashim, M. H., & Ibrahim, M. H. (2023). The Relationship between Particulate Matter (PM10) and Meteorological Parameters in Ipoh, Perak (2020 - 2021). *GEOGRAFI*, *11*(1), 27–43. https://doi.org/10.37134/geografi.vol11.1.2.2023

ABSTRACT *Air pollution is often associated with the level of suspended particles, especially PM_{10} and is classified as one of the air pollutants. High levels of PM_{10} concentration will have a negative impact on the environment and human health. The objective of this study is to determine the level of PM_{10} concentration and the relationship of meteorological parameters which is, temperature, relative humidity and wind speed on particulate matter (PM_{10}) in Ipoh, Perak. PM_{10} and meteorological parameters data collection were recorded directly at 10 sampling stations located around Ipoh. All data were taken for one week during the Southwest Monsoon (SWM), Northeast Monsoon (NEM) and inter-monsoon seasons. A non-parametric test (Spearman rank correlation) was used because the data were non-normal. The analysis showed that S6 had the highest average PM_{10} concentration within a week, with a value of 175.78 µg/m3. Temperature showed no correlation on PM_{10} concentration during SWM (ρ = 0.096), while NEM (ρ = 0.480) and inter-monsoon (ρ = 0.280) showed a positive correlation. The results also showed that PM_{10} and relative humidity had no relationship during SWM (ρ = 0.024), while NEM and inter-monsoon showed a negative correlation. Wind speed negatively correlated in all seasons (ρ = - 0448 to -0.126). Overall, the level of PM_{10} concentration level is influenced by an area's meteorological parameters.*

Keywords: *PM_{10}* relationship, meteorological parameters, concentration, correlation, particulate matter

Geografi Vol.11 (1),27-43
ISSN 2289-4470 /eISSN 2462-2400

ABSTRAK *Pencemaran udara sering dikaitkan dengan tahap partikel terampai terutamanya PM_{10} dan diklasifikasikan sebagai salah satu bahan pencemar udara. Tahap konsentrasi PM_{10} yang tinggi akan memberi kesan negatif kepada alam sekitar dan kesihatan manusia. Objektif kajian ini adalah untuk menentukan tahap kepekatan PM_{10} dan hubungan parameter meteorologi iaitu, suhu, kelembapan bandingan dan kelajuan angin terhadap partikel terampai (PM_{10}) di Ipoh, Perak. Pengumpulan data PM_{10} dan parameter meteorologi direkodkan secara langsung di 10 stesen pensampelan yang terletak di sekitar Bandar Ipoh. Semua data diambil selama seminggu semasa Monsun Barat Daya (MBD), Monsun Timur Laut (MTL) dan peralihan monsun. Ujian bukan parametrik (korelasi Spearman) digunakan kerana data tidak normal. Hasil analisis menunjukkan S6 mempunyai purata kepekatan PM_{10} tertinggi dalam tempoh seminggu dengan nilai 175.78 $\mu g/m^3$. Suhu menunjukkan tiada korelasi pada kepekatan PM_{10} semasa MBD ($\rho = 0.096$) manakala MTL ($\rho = 0.480$) dan antara monsun ($\rho = 0.280$) menunjukkan korelasi positif. Keputusan juga menunjukkan bahawa PM_{10} dan kelembapan relatif tidak mempunyai hubungan semasa MBD ($\rho = 0.024$) manakala MTL dan antara monsun menunjukkan korelasi negatif. Kelajuan angin menunjukkan korelasi negatif dalam semua musim (ρ = - 0448 hingga -0.126). Secara keseluruhannya, tahap kepekatan PM_{10} dipengaruhi oleh parameter meteorologi sesuatu kawasan.*

Kata kunci: *$PM_{10,}$ hubungan, parameter meteorologi, konsentrasi, korelasi, partikel terampai*

1. Introduction

Air pollution issue is one of the problems that is often associated with rapid development, especially in developed and developing countries. Particulate matter or suspended particles is one of the air pollutants classified as PM_{10} (Sham Sani, 1979; Siti et al., 2014). The release of particulate matter (PM_{10}) into the atmosphere will cause air pollution in an area (Punsompong & Chantara, 2018). According to Feng et al. (2019), excessive PM_{10} emissions will significantly increase the Air Pollution Index (API). The release of suspended particles also negatively impacts human health, especially in the human respiratory system (Mohd Latif et al., 2018; Nadhira et al., 2020). High particulate matter emissions will cause various negative impacts on the physical environment and human health (Chen et al., 2020; Mohd Hashiq et al., 2020). Generally, the high suspended particle is often associated with anthropological factors in an area. Industrial areas significantly contribute to suspended particle emissions, mainly limestone and ceramic-based industries (Mohd Hairy et al., 2011). In addition, traffic congestion due to the increase in the number of vehicles in an area is also the cause of the increase in suspended particles PM_{10} (Mohd Talib et al., 2006; Song et al., 2016). Quarrying also led to an increase in PM_{10} emissions in the form of dust (Sayara et al., 2016). Several natural causes can increase the PM_{10} concentration, such as forest fires and volcanic eruptions (Lim et al., 2008; Zailina et al., 1997). As such, anthropological and natural factors can cause an increase in suspended particles in an area.

However, the meteorological characteristics in an area will affect the concentration of PM_{10} in the atmosphere. According to Norfazillah et al. (2016), weather and climatic elements such as temperature, relative humidity and wind speed play an essential role in determining the concentration of PM_{10} in an area. Kinney (2008) also argues that wind affects the transport of pollutants in the atmosphere, especially PM_{10}. Such a situation is also discussed by Muhammad Arieff et al. (2017), who stated that meteorological parameters consisting of temperature, relative humidity and wind influence the concentration and distribution pattern of PM_{10}. Whalley and Zandi (2016) emphasize that the hilly terrain also has an impact on PM_{10} concentrations. Such a situation can be seen as a research gap because the relationship between PM_{10} and meteorological parameters is dynamic based on the characteristics of an area. The main objective of this study is to determine the relationship between particulate matter (PM_{10}) and meteorological parameters consisting of temperature, relative humidity and wind speed in Ipoh, Perak.

2. Literature Review

2.1 Particulate Matter (PM_{10}) in Ipoh City

Rapid urbanization without concern for the environment will cause air pollution problems, especially in the emission of ash and dust from construction sites and the burning of fossil fuels (Li et al., 2018). The issue of air pollution in Ipoh is common as it is classified as the third-largest city in Malaysia and has various limestone-based industrial sectors. According to Selamat (2009), Ipoh has more than 20 limestone resources and three quarries with a volume of 726,600 metric tons. Small limestone hills have a height of about 160 meters in the southern area of Ipoh (Mohd Hairy et al., 2011). This limestone-based industry contributes to the release of suspended particles, especially PM_{10} around Ipoh.

Quarrying activity is one of the causes that increase the number of suspended particles in the atmosphere. According to Lim (2008), the increase in suspended particles also increases the Air Pollution Index (API). An industrial area in the centre of Ipoh has a ceramic factory and a limestone quarry located in Tasek industrial area. The situation caused air pollution that recorded an API of 117, classified as unhealthy (BERNAMA, 2019). The increase in API is due to the release of particulate matter consisting of ash and dust from limestone-based industrial areas (Mohd Hairy et al., 2021). This condition harms the environment and threatens human health, especially the respiratory system (Norlen et al., 2016; Xiaoyan et al., 2015).

In addition, rapid development will lead to population growth. The population growth will increase the development of residential and commercial areas. According to Yang et al. (2018), construction sites are one of the contributors to the increase in PM_{10}, especially in the form of dust. Noor Ainon (2019) stated that residents of Seri Palma, Bandar Seri Botani, in Ipoh, have complained that housing projects around the area contributed to a high dust count. The high dust concentration is mainly caused by heavy machinery regularly passing through the roadhouse construction sites. Heavy machinery that frequently commutes to the house construction site causes the surrounding area to be dusty.

Besides, quarrying activities are one of the critical issues that occur around Ipoh. According to the local newspaper Berita Harian, Mount Lanno, located in Simpang Pulai, which has a height of more than 370 meters and is 330 years old, is about to disappear from the map of the state of Perak as a result of the quarrying activities carried out (Balqis, 2021). Non-governmental environmental organizations such as Sahabat Alam Malaysia (SAM) and the Pertubuhan Alam Sekitar Sejahtera Malaysia (GRASS Malaysia) reported that Mount Kanthan, which is located in Ipoh and is one of the geological heritage sites, is being destroyed by quarrying activities carried out to obtain limestone source (Meor, 2021). The continuous quarrying of limestone resources will cause the release of PM_{10} in ash and dust (Bouet et al., 2019; Mohd Hairy et al., 2016).

3. Data and Methodology

3.1 Sampling Locations

This study was conducted in the Hulu Kinta sub-district (Ipoh, Lahat, Chemor, Tanjung Rambutan) and Sungai Raya sub-district (Simpang Pulai). The selection of this sampling station is based on the land use zone to show the PM_{10} concentration distribution in more detail. This station was also chosen based on the gaps found in previous studies focusing only on polluted areas. There are sampling stations located in industrial zones that are used as pollution hotspots and nonpoint source pollution areas, as suggested by Corwin and Wagenet (1996), Li et al. (2017), Querol et al. (2001) as well as Siti Haslina et al. (2022). The primary location of this sampling station is around the city of Ipoh, which focuses on industrial areas. A total of 10 sampling stations were selected based on land use around the city of Ipoh to measure the concentration of PM_{10}. The selected sampling stations consisted of industrial, infrastructure and utility, commercial, residential, and recreational areas to compare particulate matter particularly, as shown in Figure 1 and listed in Table 1.

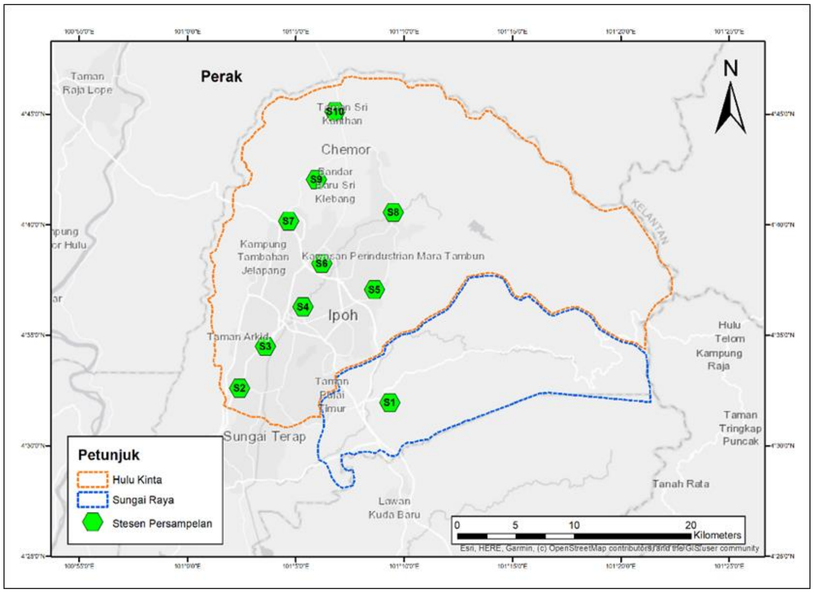

Figure 1. *Sampling Stations.*

Table 1

Type of landuse in sampling stations.

Station	Landuse Type	Location	Latitude	Longitude
Station 1 (S1)	Quarry and cement based industrial	Simpang Pulai	4.53379 N	101.15391 E
Station 2 (S2)	Industrial	Lahat	4.54404 N	101.04048 E
Station 3 (S3)	Industrial	Menglembu	4.57481 N	101.05918 E
Station 4 (S4)	Infrastructure and utility	Bandar Ipoh	4.60377 N	101.08935 E
Station 5 (S5)	Recreational	Tambun	4.61826 N	101.14305 E
Station 6 (S6)	Quarry, cement and ceramic based industrial	Tasek	4.63636 N	101.10323 E
Station 7 (S7)	Commercial	Meru	4.67075 N	101.07728 E
Station 8 (S8)	Residential	Tanjung Rambutan	4.67678 N	101.15934 E
Station 9 (S9)	Ceramic based industrial	Chemor	4.70092 N	101.09900 E
Station 10 (S10)	Quarry and cement based industrial	Kanthan	4.75160 N	101.11529 E

3.2 *Sampling Technique*

The PM_{10}, temperature, relative humidity and wind speed data collection was conducted in a weekly cycle adapted from Hernandez et al. 2017, Wui et al. 2018 and Valencia et al. (2020) during Southwest Monsoon (July 2020), inter-monsoon (April 2021) and Northeast Monsoon (December 2021). This study adapted The Air Pollution Model (TAPM) designed by Hurley (2005) to study and understand the phenomenon of air pollution influenced by meteorological parameters. Land use is also one of the factors in the selection of sampling stations for this study which is adapted from the study of Muhammad Azahar et al. (2016) and Ha et al. (2016). PM_{10} data were observed at peak time (8.00 am), which has high traffic flow, as Srimuruganandam and Shiva (2010) suggested. The starting point of data collection started from the southern part to the northern part of Ipoh. Data collection was also conducted approximately 50 meters from the road with a height of three meters from the ground surface suggested by Ramirez et al. (2018) as well as Mokhtar and Sham Sani (1991). PM_{10} concentration levels were also determined based on MAAQS (Table 2). PM_{10} suspended particles were observed using Portable Laser Aerosol Spectrometer and Dust Monitor Model 1.108. This device measures the PM_{10} concentration directly by using an optical particle counter (OPC), while the meteorological data were recorded directly using a WM-350 multi-function weather meter.

Table 2.
Malaysian Ambient Air Quality Standard.

Air Pollutant	Average Time	Ambiet Air Quality Standard Standard (2020) μg/m³
PM₁₀	1 year	40
	24 hour	100

Source: Department of Environment 2015

3.3 *Data Analysis*

The PM_{10} and meteorological parameters data (temperature, relative humidity and wind speed) were analysed descriptively and inferentially. The relationship between the independent and dependent variables was determined using Spearman rank correlation analysis. Spearman rank correlation analyses were used because of the non-normal data distribution. The strength of the relationship is shown using the value of the correlation coefficient (ϱ) suggested by Chua (2014). Table 3 shows the values of the correlation coefficient (ϱ) used in this study.

Table 3.
Correlation coefficient (ρ)

Range	Correlation strength
0.91 - 1.00	Very strong
0.71 - 0.90	Strong
0.51 - 0.70	Moderate
0.31 - 0.50	Weak
0.01 - 0.30	Very weak
0.00	No correlation

Source: Chua (2014)

4. Results and Discussions

4.1 Descriptive Analysis of PM_{10} Concentrations

Table 4 to Table 6 summarize the descriptive analysis of daily PM_{10} concentrations at each station based on the season. Based on Table 5, S1, S6 and S10 show a maximum value higher than the guidelines set in the MAAQS (100 μg/m^3). S6 showed the highest concentration of PM_{10} with a value of 273.60 μg/m^3, followed by S1 of 160.67 μg/m^3 and then S10 of 143.57 μg/m^3. In contrast, the inter-monsoon season shows four stations with maximum values that exceed the MAAQS guidelines (S1, S6, S9 and S10). This condition occurs because S1, S6, S9 and S10 are ceramic-based industrial areas and limestone. However, during the NEM season, only two stations showed maximum values of PM_{10} concentration above MAAQS, which are S1 (103.10 μg/m^3) and S6 (109.30 μg/m^3). These conditions occur due to meteorological factors during the NEM season, which generally has a high rainfall rate (Mohmadisa et al., 2012). These suspended particles are classified as coarse particles having a diameter between 2.5 to 10 micrometres (Alastuey et al., 2004; Shamzani et al., 2015). The World Health Organization (WHO) stated that coarse particles contain dust blown away from roads, quarrying and mining activities, and industrial areas. The high PM_{10} concentrations on S1, S6 and S10 indicate that the area releases excessive dust from cement factories and quarries.

Table 4.

Summary of descriptive analysis of PM_{10} concentrations during SWM

Station	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Mean	95.51	26.33	24.78	8.94	6.89	175.78	7.80	5.80	32.55	103.79
Median	112.70	29.50	31.80	8.30	6.87	218.10	5.60	6.83	34.23	111.17
Std. Deviation	60.13	9.23	14.62	3.97	1.08	94.33	5.03	2.23	19.22	33.46
Skewness	-.268	-1.899	-1.192	.653	-.764	-1.090	.560	-1.087	.687	-.703
Kurtosis	-2.168	3.636	-.819	.227	.592	.195	-1.417	.512	.285	-.897
Minimum	20.90	7.13	2.37	3.70	4.97	9.33	2.57	1.73	9.23	54.47
Maximum	160.67	33.73	35.90	15.67	8.10	273.60	15.60	7.87	66.03	143.57

Table 5.

Summary of descriptive analysis of PM_{10} concentrations during inter-monsoon

Station	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Mean	113.14	25.05	10.87	5.77	7.55	153.66	17.48	9.03	85.86	84.31
Median	114.07	26.67	10.65	5.43	7.42	155.23	14.77	8.34	90.47	74.70
Std. Deviation	11.00	7.12	2.21	2.02	3.81	17.07	5.86	2.45	29.49	30.12
Skewness	-.01	.41	-.30	.72	-.01	-.92	1.19	1.72	-1.00	1.67
Kurtosis	.35	-.04	.49	-1.14	-2.09	1.62	.83	3.11	1.58	4.05
Minimum	96.20	15.70	7.20	3.73	2.70	121.87	11.83	6.93	30.67	49.20
Maximum	130.43	36.93	14.10	8.73	12.30	174.80	28.33	14.03	122.60	146.67

Table 6.
Summary of descriptive analysis of PM_{10} concentrations during NEM

Station	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Mean	63.36	15.66	13.95	18.10	13.67	52.87	11.93	14.72	23.20	24.94
Median	63.33	17.07	15.40	20.93	14.67	46.57	12.97	13.63	26.57	25.27
Std. Deviation	36.42	2.71	4.23	4.32	5.01	30.81	3.07	4.90	9.99	11.61
Skewness	-.11	-.23	-.02	-.39	.10	1.02	-.21	1.23	-.90	-.44
Kurtosis	-2.18	-2.40	-2.12	-2.50	-1.30	.74	-1.53	2.59	-.87	-.31
Minimum	19.83	12.47	9.17	12.63	7.57	23.40	7.60	8.53	7.23	6.37

4.2 Seasonal Comparison of PM_{10} Concentration in Ipoh

Figure 2 compares the average concentration of PM_{10} in Ipoh for one week. Referring to the figure, S6 recorded the highest average PM_{10} concentration during the SWM (175.78 μg/m^3) and the inter-monsoon (153.66 μg/m^3). In contrast, the highest average PM_{10} concentration during NEM showed in S1 (63.36 μg/m^3). Several stations recorded average PM_{10} concentrations above the limit during SWM and inter-monsoon periods in S1, S6 and S10. This situation is influenced by land use characteristics and anthropological factors around the sampling station focusing on industrial activities. Different from the NEM period, which shows an average PM_{10} concentration below the set limit for a week. This situation indicates that the meteorological characteristics during the NEM season influence the PM_{10} concentration, even though some areas carry out limestone and quarry-based industrial activities. This situation is supported by Dung et al. (2019) and Giri et al. (2008), who stated that rain would cause airborne particulate matter to be washed away.

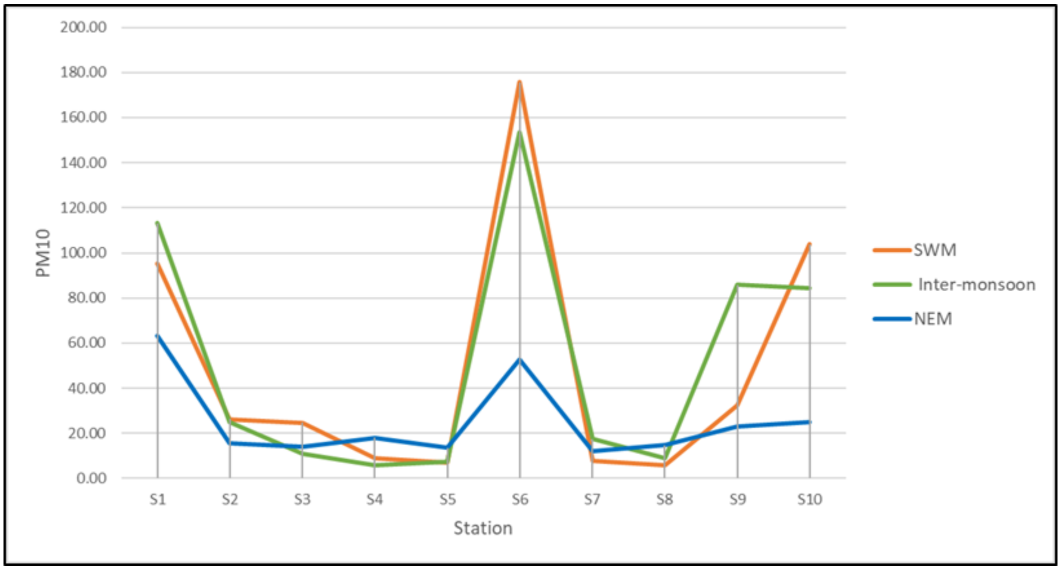

Figure 2. *PM_{10} comparison in each station.*

4.3 Relationship between PM_{10} and Meteorological Parameters

Table 7 shows the results of Spearman rank correlation analysis to show the relationship between PM_{10} and meteorological parameters (temperature, relative humidity and wind speed). The results of the correlation analysis show that the relationship between the two variables is dynamic according to the season. During SWM, the temperature and relative humidity had a weak relationship to PM_{10}, while wind speed showed a weak negative correlation (ϱ = 0.234). During the inter-monsoon period, the temperature had a weak relationship with PM_{10} (ϱ = 0.254), while relative humidity showed a negative relationship with a weak strength rate (ϱ = 0.262), and wind speed had a negative relationship with moderate strength (ϱ = 0.448). During the NEM season, temperature showed a positive relationship with a moderate strength with PM_{10} (ϱ = 0.480), while relative humidity and wind speed showed a negative relationship with PM_{10}. The temperature has no relationship to PM_{10} concentration during the SWM season (ϱ = 0.096). In contrast, during the NEM (ϱ = 0.480) and the inter-monsoon periods (ϱ = 0.254), temperature is related to PM_{10} concentration. Generally, the SWM period in Malaysia is a dry and hot season. However, Li et al. (2017) stated that the temperature positively correlates with PM_{10} during summer. A study by Doreena et al. (2012) stated that temperature positively correlated with PM_{10} concentrations in Malaysia for three years (2007-2009). A different situation can be seen in Dung et al.'s (2019) study, which stated that temperature negatively correlates to PM_{10} concentrations throughout 2018 in Thailand. However, this opinion is general and does not look from the perspective of monsoon winds.

Table 7.
Spearman Rank Correlation between PM_{10} and Meteorological Parameters

Season	Parameters		PM_{10}
Southwest Monsoon (SWM)	Temperature	Correlation coefficient (ϱ)	0.096
		P-value	0.429
	Relative Humidity	Correlation coefficient (ϱ)	0.024
		P-value	0.842
	Wind Speed	Correlation coefficient (ϱ)	-0.234
		P-value	0.051
Inter-monsoon	Temperature	Correlation coefficient (ϱ)	0.254*
		P-value	0.034
	Relative Humidity	Correlation coefficient (ϱ)	-0.262
		P-value	0.029
	Wind Speed	Correlation coefficient (ϱ)	-0.448**
		P-value	0.000
Northeast Monsoon (NEM)	Temperature	Correlation coefficient (ϱ)	0.480**
		P-value	0.000
	Relative Humidity	Correlation coefficient (ϱ)	-0.404*
		P-value	0.001
	Wind Speed	Correlation coefficient (ϱ)	-0.126**
		P-value	0.300

** Significant level $\alpha = 0.01$, * Significant level $\alpha = 0.05$

There was no significant relationship between relative humidity to PM_{10} concentration during the SWM period (ϱ = 0.024). Different conditions can be observed during the NEM (ϱ = -4.04) and inter-monsoon periods (ϱ = -0.262), indicating a relationship between the relative humidity and the PM_{10}. However, the NEM and the inter-monsoon seasons show a negative correlation which explains that as the relative humidity increases, the PM_{10} concentration will decrease. This situation proves that humid weather will decrease PM_{10} concentration readings, as discussed by Arnis et al. (2018), Dung et al. (2019), Kliengchuay et al. (2021) and Siti et al. (2014). However, a study by Kayes (2019) showed a negative correlation between relative humidity and PM_{10} concentration during summer in Dhaka, Bangladesh.

Wind speed did not affect the PM_{10} concentrations during SWM (ϱ = -0.234) and NEM (ϱ = -0.126) by showing a negative correlation. This condition was caused by another meteorological factor affected by the dry and wet seasons during the two periods. During the inter-monsoon period, wind speed has a relationship with PM_{10} concentration with a negative correlation (ϱ = -0.448). This condition suggests that as the wind speed increases, the PM_{10} concentration will decrease. Higher wind speeds will decrease the number of suspended particles associated with dust dispersion (Clements et al., 2016; Dung et al., 2019).

However, a different situation was reported by Li et al. (2017), who stated a positive correlation between wind speed and PM_{10} concentration during spring in China in 2015. Nevertheless, past studies state that high wind speed will reduce the number of PM_{10} due to the dispersion factor (Crawford, 1969; Ganguly et al., 2019; Kumar et al., 2019).

5. Conclusion

In conclusion, this article discusses the relationship between PM_{10} and meteorological parameters, emphasizing temperature, relative humidity and wind speed in Ipoh City. The results showed that several stations showed PM_{10} concentrations exceeding the guidelines set in the MAAQS. A high concentration of PM_{10} will negatively affect the environment and human health if not properly supervised. The results of Spearman correlation analysis also show that the relationship between PM_{10} and meteorological parameters is dynamic according to the seasons. Seasonal diversity in Malaysia is one of the factors in determining the level of PM_{10} concentration. This study considers meteorological factors during the SWM, NEM and inter-monsoon periods to examine PM_{10} concentration levels more specifically. For example, the source of PM_{10} emissions should be identified in addition to considering physical conditions such as temperature, relative humidity and wind speed to determine accuracy in measuring PM_{10} concentration levels. Based on the WHO statement (2006), PM_{10} is one of the major factors in air pollution because it is often associated with the level of health of the respiratory and cardiovascular systems. To ensure accuracy, the measurement of PM_{10} concentration levels should consider the current conditions, especially meteorological factors in an area.

6. Acknowledgement

The authors sincerely thank every party that contributed to this study, both directly and indirectly

Author Contribution Statement: Mohd Hashiq Hashim & Mohd Hairy Ibrahim: Conceptualisation, Methodology, Analysis, Data Curation, and Editing.

Conflicts of Interest: The authors declare no conflict of interest.

Data Availability Statement: The authors confirm that the data supporting the findings of this study are available within the article.

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