

# **Review Article:** Evaluating the Computational Values of Suspended Particles Below 10 µm With Their Actual Concentration

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## ABSTRACT

**Background & Aims of the Study:** Dust as a phenomenon is among the significant problems in numerous regions of Iran and other countries. Empirical equations can be used to estimate the concentration of particulate matter. This study evaluated computational values of suspended particles less than 10 µm with their actual concentration in Ahvaz city based on a linear regression model.

**Materials and Methods:** This descriptive cross-sectional study was conducted from April 2016 to March 2018. The dust images were obtained from the MODIS sensor of the Aqua satellite. The meteorological data included 3-hour horizontal visibility data recorded in m.  $PM_{10}$  concentration data were obtained from the Environment Organization. Accordingly, 5 empirical equations between horizontal visibility and  $PM_{10}$  have been used in this case. The calculated values of particulate matter less than 10  $\mu$ m in Ahvaz City, Iran, were evaluated with actual values of  $PM_{10}$  based on the linear regression model.

**Results:** The study results suggested that the computational R index for empirical equations had higher accuracy in 2017 data. The coefficients of determination using D'Almeida (1986), Dayan (1986), Chung (2003), Jugder et al. (2014), and Camino et al. (2015) indicators were calculated as 0.87, 0.806, 0.745, 0.873, and 0.866, respectively.

**Conclusion:** Jugder et al. (2014) index with  $R^2$  equal to 0.548667 was the best index for estimating  $PM_{10}$  in this region. The study results showed that empirical equations could estimate particulate matter and dust in southwestern Iran.

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### **1. Introduction**

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ineral dust strongly interacts with the climate system through direct and indirect impacts [1]. Mineral dust emissions into the atmosphere negatively impact human health, causing or aggravating allergies, respiratory

diseases, and eyes infections [2]. Mineral dust is discussed concerning dust storms and serious environmental problems in arid and semi-arid regions [3]. What is known as the dust today is due to the movement of air ambient forming soils suspended in the air affected by storms and air currents [4]. The speeds over 7 m/s at an altitude of 10 m play an essential role in storm conditions and dust formation. A dust storm develops when a low-pressure system moves toward a desert area [5]. Particle size and concentration, atmospheric persistence, and altitude in different dust storms of various sources are not the same [6]. The horizontal visibility reduces by increasing dust [7]. Horizontal visibility is among the events recorded by observers at meteorological stations [8]. Various atmospheric factors, including dust, reduce horizontal visibility and atmospheric turbidity [9]. The reported horizontal visibility varies according to the intensity of the dust. However, this report depends on the observer's personal experience and does not indicate the amount of dust [10]. Knowing the concentration and intensity of dust will effectively understand its nature and control strategies [11].

Furthermore, it is a criterion for comparing the results of air pollution models. Shao presents a valid classification for dust types based on horizontal visibility, 2015 [12], based on wind dust, blowing dust, dust storm, and severe dust storms. Multiple studies investigated the relationship between horizontal visibility and particulate matter and its importance. The results of various studies, such as Shao et al. [13], Camino et al. [14], and Baddock et al. [6], indicated the importance of the particulate matter in atmospheric parameters significantly influence climate and habitats. Camino et al. (2015) found an empirical equation between horizontal visibility and particulate matter concentrations in North Africa and compared them with other empirical equations in the same region. Bertahina et al. [11] simulated the scattering of dust particles by comparing observational dust data with a gray model with a coefficient of determination greater than 0.8. Dayan [15], in his synoptic analysis and classification of the prevailing air for dust patterns in Palestine, stated that a significant difference was between the seasonal routes of these patterns. He outlined the main routes for Israeli dust from 5 routes

in northwestern Europe, Eastern Europe, Jordan, Saudi Arabia, and the coasts of North Africa. D'Almeida [16] outlined a well-described relationship between horizontal visibility and particulate matter based on data from a solar pyranometer. He hypothesized that horizontal visibility and turbidity parameters are often related. Zoljoodi et al. [17] found a relationship between increasing drought and dust storms in west of Iran from 1996 to 2011, highlighting the significance of studying dust in Iran's western and southwestern regions. Ahvaz City has extended boundaries with Iraq from the west. Due to its proximity to the deserts of Iraq, Kuwait, and Saudi Arabia. Besides, this city is affected by the deserts of those areas and experiences several dust events annually [18]. In this article, focusing on particulate matter pollution concentration in Ahvaz City in southwestern Iran, the best empirical equation between horizontal visibility and the extent of particulate matter is determined.

### 2. Materials and Methods

This study was conducted in Ahvaz City in southwestern Iran (Ahvaz). Figure 1 shows an image taken from the MODIS sensor of the Aqua satellite. It demonstrates dust routes that cover areas in Iraq, the Persian Gulf, and southwestern Iran on January 21, 2018; periods of dust occurrence in the present study.

This was a descriptive cross-sectional study. The obtained data were analyzed in 3 groups from the beginning of April to the end of March of the following year (2016, 2017, & 2018). This study requires meteorological and environmental data (particulate matter). The meteorological data included 3-hour horizontal visibility data recorded in m.  $PM_{10}$  concentration data were obtained from the Environment Organization. All data were filtered for less than 10 km (only dust data were extracted). After preparing the given data, using the following empirical equations,  $PM_{10}$  level was determined by horizontal visibility:

After calculating  $PM_{10}$  using Table 1 relationships, the values were compared with observational  $PM_{10}$ . A linear regression test was used to investigate the correlation between the two. In this study, regression analysis was used to determine the relationship between empirical equations and the relationship between horizontal visibility and  $PM_{10}$  concentration in Ahvaz aimed to find the best connection to estimate the amount of particulate matter. The lowest, highest, and mean values were also compared. Finally, particulate matter was classified on the World Wide Web report [12].





Figure 1. Geographic location of Ahvaz City and Khuzestan Province (Aqua satellite image)



### **3. Results**

The data relating to the main variables, including wind speed and dust concentration based on satellite and field of visibility data, have been used at 3 time periods of 2016, 2017, and 2018. The data relating to horizontal visibility in the city Ahvaz at these three intervals are shown in Figures 2, 3, and 4. Given that the data are recorded hourly, there are 8760 records each year.

Climatic data (wind speed and direction) and environmental data ( $PM_{10}$  concentration and horizontal visibility) were calculated using D'Almeida, Dayan, Chung, Jugder, et al., and Camino et al. indicators. The method of calculating each of the empirical equations is presented in Table 1. The calculations were made only for days when the horizontal visibility was less than 10,000 m. Horizontal visibility time series, observational and computational  $PM_{10}$  in Ahvaz in 2016 is shown in Figure 5. The obtained results indicated that the lowest horizontal visibility of 500 m was recorded on March 3, 2016. The value of  $PM_{10}$  on this day is 1103.3 mg/m<sup>3</sup>. The highest D'Almeida, Dayan, Chung, Jugder, et al., and Camino et al. indicators were measured as 3798.9, 1535.1, 1451.2, 831.6, and 976.9, respectively (Figure 6). The correlation coefficient results suggested that the highest level of correlation was between the Camino et al. index and particulate matter (r=0.72). D'Almeida and Jugder et al.'s indicators present a high correlation with the particulate matter with correlation coefficients of 0.7 and 0.71. The correlation estimation and calculation of empirical dust indicators are shown in Table 2.

Region	Visibility	PM <sub>10</sub> Conditions	Empirical Equation	References
West Africa	200 m to 10 km	30 to 700	PM <sub>10</sub> =914.06×V-0.72+19.03	D'Almeida [16]
West Asia	Only dust and vis <5 km Vis (100m) Time 06 to 15 UTC	-	PM <sub>10</sub> = 505In(V×10)+2264	Dayan [15]
East Asia	-	-	PM <sub>10</sub> = 1120×EXP(-0.2733V)	Chung [19]
Asia	-	50 µg	PM <sub>10</sub> = 485.67×7V-0.72	Jugder [20]
-	-	-	PM <sub>10</sub> = 1772.24×7V-1.1	Camino [14]
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Table 1. Empirical equations between horizontal visibility and PM<sub>10</sub>\*

\*V: Represents the horizontal visibility in m, and PM<sub>10</sub> represents surface dust concentration in micrograms per cubic meter.





Figure 2. Horizontal visibility in Ahvaz (2016)





Figure 3. Horizontal visibility in Ahvaz, 2017



Figure 4. Horizontal visibility in Ahvaz (2018)







Figure 5. Horizontal visibility time series, observational and computational PM<sub>10</sub> in Ahvaz, 2016



**Figure 6.** A: Relationship between horizontal visibility and  $PM_{10}$  observational and computational; and B: Distribution of  $PM_{10}$  observational and computational in Ahvaz in 2016

Investigating the 2017 data revealed that the lowest horizontal visibility of 300 m was recorded on October

15, 2017 (Figure 7). The extent of  $PM_{10}$  on this day is 1119. 4 mg/m<sup>3</sup>. The highest D'Almeida, Dayan, Chung,

Table 2. Calculation of statistical indicators of horizontal visibility and PM<sub>10</sub> observational and computational in Ahvaz, 2016

Index	No.	Mean±SD	Min	Max	PM <sub>10</sub> Correlation
Visibility	108	-	0.5	8	-0.52
PM <sub>10</sub> Ob	108	377.7±169.3	20.2	1103.3	
Camino et al	108	633.4±695.7	179.9	3798.9	0.72
D'Almeida	108	440.7±279.1	219.3	1535.1	0.70
Dayan-	108	456.4±366.5	51.1	1451.2	0.63
Jugder et al	108	215.9±153.9	96.7	831.6	0.71
Chung	108	410.0±255.4	125.8	976.9	0.60
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Figure 7. Horizontal visibility time series and PM<sub>10</sub> observational and computational in Ahvaz, 2017





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**Figure 8.** A: Relationship between horizontal visibility and PM<sub>10</sub> observational and computational; and B: Distribution of PM<sub>10</sub> observational and computational in Ahvaz, 2017

Table 3. Calculating the statistical indicators of h	horizontal visibility and PM.	observational and compu	tational in Ahvaz, 2017
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Index	No.	Mean±SD	Min	Max	R
Visibility	87	-	0.3	8	-0.62
PM <sub>10</sub> _Ob	87	354.1±161.9	42.4	1119.4	-
Camino et al	87	632.0±1097.7	179.9	6663.3	0.86
D'Almeida	87	419.1±362.7	219.3	2220.3	0.87
Dayan	87	394.4±372.3	51.1	1709.2	0.80
Jugder et al	87	205.3±204.5	96.7	1236.2	0.87
Chung	87	359.4±241.3	125.8	1031.8	0.74
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Figure 9. Horizontal visibility time series and PM<sub>10</sub> observational and computational in Ahvaz, 2018



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Figure 10. A: relationship between horizontal visibility and  $PM_{10}$  observational and computational; and B: distribution of  $PM_{10}$  observational and computational in Ahvaz, 2018

Jugder, et al., and Camino et al. indicators were 2220.3, 1709.2, 1031.8, 1236.2, and 6663.3, respectively (Figure 8). D'Almeida and Jugder et al. empirical indicators with correlation coefficients of 0.87 provided the strongest correlation with  $PM_{10}$ . Also, Camino et al.'s empirical index with a correlation coefficient of 0.86 addresses a high correlation with particulate matter above ten microns. Dayan and Chung's indicators also correlated with the particulate matter with correlation coefficients 0.8 and 0.74. The initial data in 2017 had the lowest level of missing data, compared to 2016 and 2018 data (Tables 3 & 4).

In 2018, the lowest horizontal visibility of 100 m was recorded on March 16, 2018, and February 19, 2018 (Figure 9). The highest D'Almeida, Dayan, Chung, Jugder, et al., and Camino et al. indicators are 4927.8, 2264, 1089.8, 2899.6, and 22311.1, respectively (Figure 10). The concentration of  $PM_{10}$  on this day has been reported to be 3267 mg/m<sup>3</sup>. The highest correlation coefficient was for Dayan empirical index (r=0.625).

The results of the Shao classification for dust events in Ahvaz in 2016, 2017, and 2018 revealed that the most severe dust storm in 2018 had 2 events. The total number of dust events in Ahvaz in 2018 was equal to 2627 events (Table 5). The classification of Shao results for the highest and lowest indicators calculated in each category is presented in Table 5.



Table 5. Classification of Ahvaz dust events based on Shao index

Year Shao Classification	2016	2017	2018
Severe dust storm	0	0	2
Dust storm	31	25	35
Blowing dust	345	639	1248
Dust haze	1455	1441	1337
Total	1831	2105	2622
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### 4. Discussion

Numerous empirical equations have been estimated with horizontal visibility and the concentration of particulate matter less than 10  $\mu$ m in diameter (PM<sub>10</sub>) [19-21]. The study results indicated that in the data of 2016, a total of 1834 events, 2017 with 2111 events, and 2018, a total of 2627 3-hour data with a field of visibility of fewer than 10000 m had been recorded. D'Almeida Dayan, Chung, Jugder, et al., and Camino et al. indicators were calculated based on the established relationships. R<sup>2</sup> suggested that empirical equation calculations for the 2017 data were more accurate. The coefficients of determination for D'Almeida, Dayan, Chung, Jugder, et al., and Camino et al. indicators were calculated to be 0.87, 0.806, 0.745, 0.873, and 0.866, respectively. The mean R<sup>2</sup> for D'Almeida, Dayan, Chung, Jugder, et al., and Camino et al. indicators were measured as 0.548667, 0.431333, 0.479667, 0.58333, and 0.539, respectively.

These results indicated that Jugder et al.'s [20] index with  $R^2$  equal to 0.87 is the best index for estimating  $PM_{10}$  in Ahvaz. It should be noted that these results do not signify su-

periority of this relationship over other empirical equations but provide the best output for the climate of the city Ahvaz city based on environmental and meteorological criteria. Such a relationship makes it possible to estimate empirical equations to determine the amount of particulate matter and dust in the atmosphere. Pahlavan et al. (2015) provided the following equation (y=4049e-6E-04x) for Ilam Province. The correlation coefficient between computational and observational values in this study was estimated to be 0.75. The Jugder et al. index with R<sup>2</sup> of 0.548667 had the best estimate in the present study. Dehghan et al. [23] introduced Gaussian function as the most appropriate function of the fit index. In this study, the linear regression method was used. Camino et al. found an empirical equation between horizontal visibility and particulate matter concentrations in North Africa and compared them with other empirical equations in the same region [14]. Bertahina et al. (2012) simulated dust scattering by comparing fine-grained observational data with a gray model with a coefficient of determination greater than 0.8. The results of a study done by Ebrahimi et al. [24] showed that approximately 45 percent of Iran's area has suffered from the increase of dust level in the atmosphere from 1998 to 2018.

Table 4. Calculating the statistical indi	cators of horizontal visibility ar	id PM <sub>10</sub> observational and	d computational in Ahvaz, 2018
0	5	10	

Indexes	No.	Mea	n±SD	Min.	Max.	R
Visibility	118	-	-	0.5	8	-0.53
PM <sub>10</sub> _Ob	118	518.5	616.0	57.1	3267.0	-
Camino et al.	118	524.3	564.5	179.9	22311.1	0.587
D'Almeida	118	397.2	228.8	219.3	4927.8	0.622
Dayan et al.	118	411.5	300.9	51.1	2264	0.625
Jugder et al.	118	191.8	126.1	96.7	2899.6	0.619
Chung	118	377.9	209.9	125.8	1089.8	0.620

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### **5.** Conclusion

The results of the study show that according to Shao classification, dust events in Ahvaz during 2016 to 2018 had an upward trend. Considering that Iran's western and southwestern provinces have had numerous problems with dust storms in recent years, we can use empirical relationships to understand the dust storms better. As we know, different variables effectively affect the occurrence of dust storms. The best indicator should be identified in any region, such as Ahvaz. It is suggested to hold studies like the present case in other areas involved with dust storms to determine the best indicator for estimating the relationship between horizontal visibility and PM. Using empirical equations can lead to faster estimating the concentration of particulate matter and dust.

### **Ethical Considerations**

### Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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#### Authors' contributions

Conceptualization, acquisition, resources, and supervision: All authors; Methodology: Elham Mobarak Hassan; Investigation: Manoush Asadi; Writing - original draft: Ali Shafie and Maedeh Rouzkhosh; Writing - review and editing: Reza Ziaie Rad and Reza Sakipour; Data collection: All authors; Data analysis: Ali Shafie, Elham Mobarak Hassan and Manoush Asadi.

### Conflict of interest

The authors declare t no conflict of interest.

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