

# Estimation of Relationship Between Aerosol Optical Depth, $PM_{10}$ and Visibility in Separation of Synoptic Codes, As Important Parameters in Researches Connected to Aerosols; Using Genetic Algorithm in Yazd



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## Abstract

Aerosol Optical Depth (AOD) is closely related to  $PM_{10}$  (mass concentration of particulate matter with aerodynamic diameter less than 10  $\mu m$ ) and visibility; and all of these three parameters are so important and useful to studies connected to aerosols, troposphere dust, air pollution and atmospheric radiation budget. This study analyzed the mathematic relations between AOD,  $PM_{10}$  and visibility whit separation of 05, 06 and 07 synoptic conditions; whit using evolutionary Genetic Algorithm. The area's case study has been Yazd city as representative of central of Iran for 5 years (2011-2015). The aim of this analysis has been to reach relations that can estimate lack quantities of mentions data parameters from another existence data whit the least error. To attain these mathematic relations, liner regression equation and several kind of famous function has been comparison; which the Polynomial function selected as the best fitness function. The conclusion of this study was four function based on polynomial liner model with 95% confidence bounds that presented. These presented equations are for estimate AOD from  $PM_{10}$  and visibility quantities in general condition; and in 05, 06 and 07 synoptic codes separations.

**Keywords:** Aerosol optical depth;  $PM_{10}$ ; Visibility; Genetic Algorithm; Polynomial Function; Yazd

**Abbreviations:** PM: Particulate Matter; AOD: Aerosol Optical Depth; MODIS: Moderate Resolution Imaging Spectro Radiometer; RMSE: Root-Mean-Square Error; UTC: Coordinated Universal Time

## Introduction

Troposphere aerosols which are well known as particulate matter (PM) consist one of the regulatory parameters in the atmosphere by changing the Earth's radiation budget and thus aerosols have an extensive impact on our climate and our environment. The PM concentration has become an important index of air pollution, and gained more and more attention from the organizations and administrations of environmental protection, public health and science all over the world. Short and long term exposure to PM causes ascending mortality rates, and morbidities such as variety of cardiovascular diseases [1-4]. PMs with aerodynamic diameters less than 10 microns ( $\mu m$ ) known as  $PM_{10}$ ; that is a major component of air pollution that threatens both our health and our environment.

Visibility is defined as the greatest distance in a given direction at which an object can be visually identified whit unaided eyesight [5]. Horizontal visibility is an indicator of air quality, and PM adversely associated with visibility impairment. Also, 05 (Haze), 06 (widespread dust in suspension not raised by wind) and 07

(dust or sand raised by wind) are some of the most important synoptic condition effective to horizontal visibility. As reported by previous studies, aerosol concentration variability can change particle extinction properties and thus affect visibility [6,7]. On the other hand, Aerosol Optical Depth (AOD) is defined for the entire column of atmosphere and is a measure of the extinction of light from the surface to the top of the atmosphere. AOD is an aerosol optical property which is now well retrieved from numerous sensors such as Moderate Resolution Imaging Spectro radiometer (MODIS) [8,9]. It can be measured by MODIS as well as by ground based instruments (sun photometers) at multiple wavelengths [10]. Therefore, it seems that we can establish some equations to estimate these parameters to define some lack data from other existence.

Previous researches have examined the correlation between visibility and the aerosol characteristic, and have made it clear that the heterogeneous concentration of aerosols in the atmosphere, changes atmospheric optical conditions and consequently,

visibility. Various studies have been carried out using the AOD to estimate the troposphere particle matters concentration in the world. The earlier studies suggested simple linear regression as the simplest type of statistical models resulting in a wide range of performance for PM predictions (correlation coefficients of 0.2 ~ 0.6) [11,12]. Some researchers have used linear models and some have also used non-linear models. Some researchers like also estimate the concentration of suspended particles using AOD based on empirical physical relationships [13-18]. In 1986, a two-year study on a turbidity network covering 11 stations on the coastline of southern Sahara in Africa, using a regression model, which uses the following equation to estimate the horizontal visibility of the aerosol mass concentration [19,20].

$$C = 914.06 VV^{-0.73} + 19.03 \quad (1)$$

This equation permits the horizontal visibility  $VV$  in km to be expressed in terms of aerosol mass concentration  $C$  in  $\mu\text{g m}^{-3}$  and vice versa. Even in some cases, the greatest change in horizontal visibility is attributed to the  $PM_{10}$  range [21]. In Shao et al. [22] in a study on North East Asian dust storms, found two equations for estimating dust concentration from visibility with following separation.

$$C = 3802.29V^{-0.84} \quad V \leq 3.5 \quad (2)$$

$$C = \exp(-0.11V + 7.62) \quad V \geq 3.5 \quad (3)$$

In these equations,  $V$  is the horizontal visibility in km, and  $C$  is the dust concentration in  $\mu\text{g m}^{-3}$ . In 2006, during a study in the Athens metropolitan area, hourly  $PM_{10}$  concentration was predicted by using the genetic algorithm on meteorological parameters [23,24]. In this research, the efficiency of neural network models was evaluated more than linear regression models ( $r^2$  in the multiple liner regression models was between 0.29 and 0.35, but in the neural network models it was estimated between 0.50 and 0.70). In 2008, a study that sought to find the relation between  $PM_{10}$  concentrations and visibility in Israel used the Ln function [25]. That function is as follows:

$$Y = -505 \ln(X) + 2264 \quad (4)$$

where  $y$  is the  $PM_{10}$  concentration, in  $\mu\text{g m}^{-3}$ , and  $x$  is the visibility, in 100 m units. Studied the relationship between AOD from Tera and Aqua sensors from the MODIS, and the  $PM_{10}$  surveyed the ground at 12 Croatian air quality control stations over a five-year period [26]. In this study, AOD and  $PM_{10}$  have been considered as independent and dependent sequences; and the linear multivariate model and artificial neural network have been diagnosed for estimating the relationship between these two parameters. Some Chinese researchers also presented an experimental non-linear model for estimating  $PM_{10}$  concentration in 2015 using AOD from MODIS [27]. This study was based on three years daily  $PM_{10}$  concentration from 13 air quality control stations and ground meteorological measurements in northwestern China the results of this study shown that there is almost a threefold improvement from 0.28 to 0.78 in the correlation coefficient when using the nonlinear model compared to using a linear regression

model of AOD and  $PM_{10}$ . The root-mean-square error (RMSE) is reduced from 34.42 to 21.33  $\mu\text{g}/\text{m}^3$  using the nonlinear model over the linear model. In 2017, several Malaysian and Greek researchers, using the artificial neural network and multiple linear regressions, tried to estimate  $PM_{10}$  from the 550 nm AOD data from the MODIS and some meteorological parameters [28]. Their relationship is as follows:

$$PM10 = 268.51 + (56.19 \times AOD550) + (1.30 \times \text{surface temperature}) + (-0.86 \times k \text{ index}) + (-0.26 \times RH) \quad (5)$$

Where  $RH$  is relative humidity in percent; and  $k$  index is atmospheric stability index. The aim of our research is analyzing and finding the mathematic relationship between AOD obtained from Aqua and Terra,  $PM_{10}$  obtained from ground air quality stations, and visibility in separation of 05, 06 and 07 synoptic conditions; using Genetic Algorithm in Yazd in representation of Central Iran.

## Data Collection and Reprocessing

The present study was focused on Yazd province located in unique arid area in center of Iran. The reason for choosing a city in the central part of Iran is that this part of Iran is affected by dust and aerosols both from the outside (atmospheric conditions recorded with 06 code at synoptic stations) and from the local origin (atmospheric conditions recorded with 07 code); and in a urban area, the occurrence of the Haze or the air darkness caused by air pollution (05 synoptic code) will be more noticeable than an ineffective area of human occupation. A number of data sets from various sources were collected for this research; including five years (2011– 2015) of hourly  $PM_{10}$  mass concentration from 2 ground air quality monitoring stations in Yazd, Terra and Aqua-MODIS AOD at 0.55  $\mu\text{m}$ , and local ground-based meteorological station in Yazd. Table 1 provides main information on different data sets and below Sections describes each data set in more detail.

## Ground-Based $PM_{10}$ Concentration Data

Five years hourly  $PM_{10}$  mass concentration were collected from two air quality control stations affiliated to the environmental protection organization of Yazd province ( $31^\circ 51' 31'' \text{ N}$  &  $E 54^\circ 21' 40''$ ;  $31^\circ 53' 6'' \text{ N}$  &  $54^\circ 18' 52'' \text{ E}$ ) in  $\mu\text{g}/\text{m}^3$ . These stations monitor the mass concentration of particulate air pollutants on the ground.  $PM_{10}$  concentration values are measured at a height of approximately 4m in a relatively open area, away from high buildings.

## MODIS Satellite Data

Over the past few years, the algorithm for data retrieval has continued to evolve to achieve better accuracy, and various studies have shown that the MODIS AOD products are quite accurate when compared to ground-based AOD such as the Aerosol Robotic Network AOD. MODIS-derived AOD represents the extinction of incoming solar radiation by aerosols over the whole atmospheric column [29-31]. Two MODIS instruments were put onboard the EOS-Terra satellite in December 1999 and the EOS-Aqua satellite in May 2002, respectively. Both instruments collect AOD data.

AOD represents columnar aerosol loading of the atmosphere, and is retrieved as a level-2 product (5 minute swath granules) at a spatial resolution of 10 km at nadir. The ambient AOD is obtained through the MODIS aerosol algorithm over the oceans and over dark land surfaces. In this study, we use the values of both MOD04 and MYD04 AOD, which were extracted at 550 nm (MODIS parameter name: Optical\_Depth\_Land\_And\_Ocean). The data acquired during the daytime passes of both MODIS instruments are used.

### Ground-Based Synoptic Meteorological Data

Visibility is an important factor of air masses movement as well as mixing and thus affects  $PM_{10}$  concentration. Between all of meteorological data related to Visibility that recorded from Yazd meteorological organization (31° 54' 18" N, 54° 16' 35" E), we use 3-hourly horizontal visibility observations by separation 05, 06 and 07 synoptic codes.

### Data Preprocessing and Integration

Since the data from the three sources have different temporal and spatial resolution, all the data sets were re-processed to be consistent in space and time to form a complete data set that can be used as the basis for the following analyses. For the retrieved AOD data from both Terra and Aqua satellites, we have tested the impacts of three different window sizes (1×1, 3×3 and 5×5 pixels) of AOD values on  $PM_{10}$ . We found that the nearest of AOD pixel over a window size of 1×1 pixels (~110 km) centered at a given  $PM_{10}$  station is appropriate for our analysis. We used a combination of the AOD data retrieved using dark-target and deep blue algorithms. To avoid possible cloud contamination, we eliminated all the AOD- $PM_{10}$  pairs where the number of pixels is less than two. As the Terra and Aqua satellites cross Yazd near 07:30 and 10:00 Coordinated Universal Time (UTC) respectively, we use Terra's AOD data at 07:30 and Aqua's data at 10:00 UTC. The data acquired during the daytime passes of both MODIS instruments are used.

The surface synoptically data from the closest distance between the meteorological station and the monitoring station were used to represent the meteorological condition for each  $PM_{10}$  monitoring station. The tow per day (11:00 and 13:30 LST, corresponding to the satellite overpass times)  $PM_{10}$  for each air-quality monitoring station, AOD, and ground-based meteorological values are matches together. In this manner that, at the first, the days that happens 05, 06 and 07 synoptic code observations around the 11:00 until 13:30 LST selected. Then, AOD and  $PM_{10}$  values at the same time from Aqua, Terra and air-quality monitoring stations respectively matches together.

### Modeling Techniques

**Artificial neural networks:** Artificial neural network (ANN) is a modeling technique which can determine non-linear relationships between variables in input datasets and variables in output datasets. ANNs modeling is based on a learning (training; calibration) process, after which the ANN network can estimate values of output variables for input datasets. ANNs

need a considerable amount of historical data to be trained; upon satisfactory training, an ANN should be able to provide output for previously "unseen" inputs. Often, there can be some uncertainty about precisely which input variables to use. The selection of input variables for an ANN forecasting model is a key issue, since irrelevant or noisy variables may have negative effects on the training process, resulting unnecessarily complex model structure and poor generalization power [32,33].

**Genetic Algorithm:** The Genetic Algorithm (GA) is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution. You can apply the genetic algorithm to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective function is discontinuous, non differentiable, stochastic, or highly nonlinear (GA and Direct Search Toolbox). GA is one of the advanced problem solving tools and the best selection of fitness functionality in MATLAB software.

### Results and Discussions

**Table 1:** Information on various surface and satellite data sets used for estimating equations.

Parameters	Frequency	Source
PM10	Hourly	Air quality monitoring stations in Yazd
AOD	Hourly	MODIS Terra and Aqua satellite
Visibility by separation 05, 06 and 07 synoptic codes	3-hourly	Yazd Meteorological Administration

Information on various surface and satellite data sets used for estimating equations are given in (Table 1). Also, statistical analysis of AODs,  $PM_{10}$ s and visibilities; whit their normal frequency distribution graphs are shown in sections of (Figure 1). Pierson correlation between  $PM_{10}$  - AOD,  $PM_{10}$  - visibility, and visibility - AOD data in 95% confidence level was 0.741, -0.58 and -0.773 respectively. The most connection and relation had seen between  $PM_{10}$ , AOD and visibility data whit 05 and 07 synoptic codes; whit 0.87 and 0.76 correlation respectively. Also, Comparison of the trend of  $PM_{10}$  variations and horizontal visibility compared with the AOD values (Figure 2), shown a very high connection especially in less than 500  $\mu\text{m}^3$   $PM_{10}$  quantities and from 4000 - 9000 m visibility quantities. Additionally, in comparison of frequency and distribution quality of synoptic codes and visibility quantities, great frequency of 05 synoptic code especially in 5, 6, 6.5, 7 and 8 km visibility quantities, proportional equality to happen of 06 and 07 synoptic conditions; and low frequency of less than 2.5 km visibility quantities are seeable.

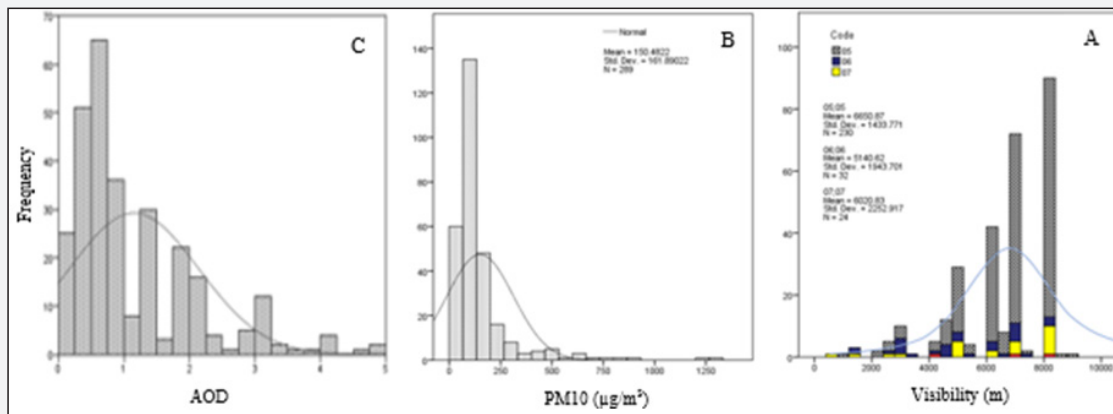


Figure 1: Statistical analysis of visibilities (A), PM10s (B) and AODs (C), with their normal frequency distribution graphs.

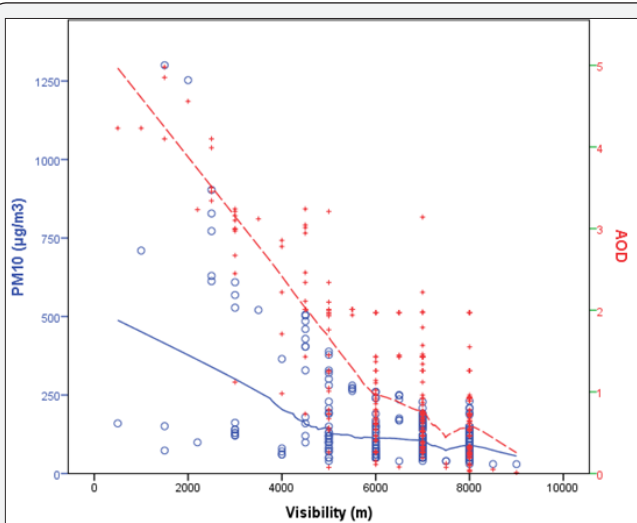


Figure 2 : Comparison of the trend of PM10 variations and horizontal visibility compared with the AOD values.

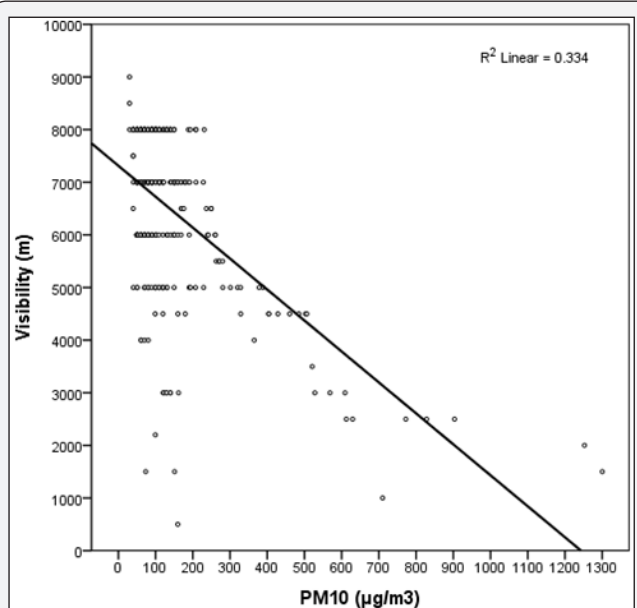


Figure 4 : Simple two-parameter regression between visibility and PM10 parameters.

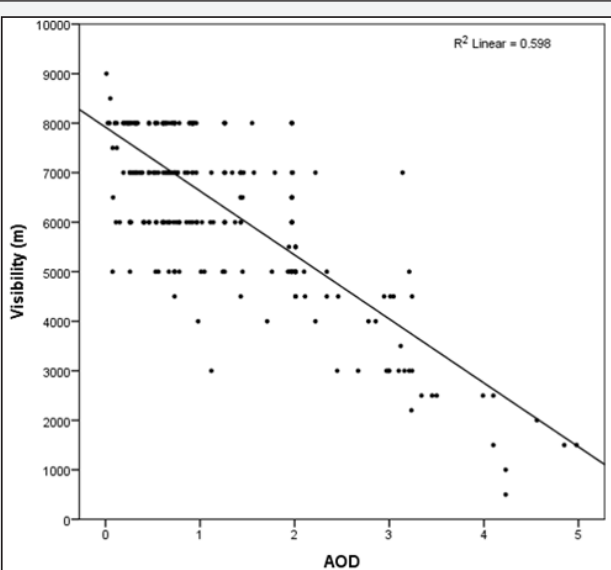


Figure 3 : Simple two-parameter regression between visibility and AOD parameters.

We use the least square graph for simple two parameter regression between visibility and AOD parameters (Figure 3) and between visibility and PM<sub>10</sub> parameters (Figures 4). These graphs are appearance of correlation and regression line equation between mentioned parameters. This is right that by estimate of regression line equation coefficients (X and Y coefficients) you can assessment the action of each parameter on other (in liner connections), but in here, whit due attention to the number of parameters used in this research and prospected accuracy from mathematic connections between parameters, has been used from genetic algorithm After the PM<sub>10</sub> data, visibility and AOD data were identified in the three-matrix formulation with the names X, Y and Z in the genetic algorithm respectively, 70% of these data were considered for the training transaction and 30% for the test transaction. Because the most accurate collection of dust and aerosol data is done with air quality control devices in the environmental organization (due to their presence in the

context of this air pollution - contrary to satellite sensors - and their remoteness from errors caused by The involvement of humans in the data acquisition - contrary to the visibility data at the Yazd synoptic station -) It was decided to introduce Z and Y values which are AOD and visibility respectively, as dependent variables and PM<sub>10</sub> as an independent variable to the genetic algorithm. Additionally, synoptic codes should also be presented as conditions for the algorithm, which was done by programming. In optimization problems that are implemented in the context of the genetic algorithm, the goal is to minimize the error or minimize the cost function. In most optimization problems, the cost function is defined as the Sum Square Errors (SSE), and Relative Sum Square Error (RSSE). These functions are represented in relations (Function 6,7):

$$SSE = \sum_{i=1}^n (F_{actual_i} - F_{estimated_i})^2 \quad (6)$$

$$\%RSSE = \frac{SSE}{\sum_{i=1}^n F_{actual_i}^2} \times 100 \quad (7)$$

$F_{actual}$  is the function of the estimated values based on the optimization parameters displayed by the genetic algorithm. When the SSE is less than 0.0001 or the RSSE is less than 0.01, this defined as the convergence criterion. After testing various functions such as the Wei bull, Gaussian, Power, Binomial, Exponential, Linear, Furrier and Gaussian functions, according to SSE, RMSE and r<sup>2</sup>, the best function and model for optimization The math transitions between PM<sub>10</sub>, AOD and visibility were evaluated based on the 05, 06 and 07 synoptic codes, the linear model of the binomial function was evaluated. In Table 2, the statistical characteristics of the paired parameters are presented in this paper. In Figure 5, the binomial fitness graph between PM<sub>10</sub>, AOD and visibility in general and without regard to the synoptic codes depicted by MATLAB software, has been shown. The color range shows the best response border of the mathematical relations presented in this study based on the coefficients derived from the application of the genetic algorithm. The binomial fitness graph between PM<sub>10</sub>, AOD and visibility during the occurrence of synoptic codes 05, 06 and 07 are also given in (Figures 6-8).

Table 2: The statistical characteristics of the paired parameters.

RMSE	SSE	R <sup>2</sup>	Z	Std		Z	Mode		Z	Mean		Z	Max		Z	Min		
				Y k m	X µg/ m <sup>3</sup>		Y k m	X µg/ m <sup>3</sup>		Y k m	X µg/ m <sup>3</sup>		Y k m	X µg/ m <sup>3</sup>				
0.52	76.42	0.73	0.99	1.648	161.9	1.97	8	50	1.15	6.428	150.5	4.98	9	1300	0.01	0.5	29.68	PM10, AOD & Visibility
0.424	40.81	0.733	0.817	1.434	132.4	0.73	8	50	1.01	6.651	137.7	4.56	9	1235	0.01	1	29.68	PM10, AOD & Visibility (05code)
0.62	11.15	0.82	1.406	1.944	282.9	2.01	7	50	1.79	5.141	265.9	4.98	8	1300	0.04	1.5	39.61	PM10, AOD & Visibility (06code)
0.58	7.07	0.81	1.283	2.253	156.2	0.1	8	80	1.565	6.021	126.7	4.23	8	2/828	0.1	0.5	30.32	PM10, AOD & Visibility (07code)

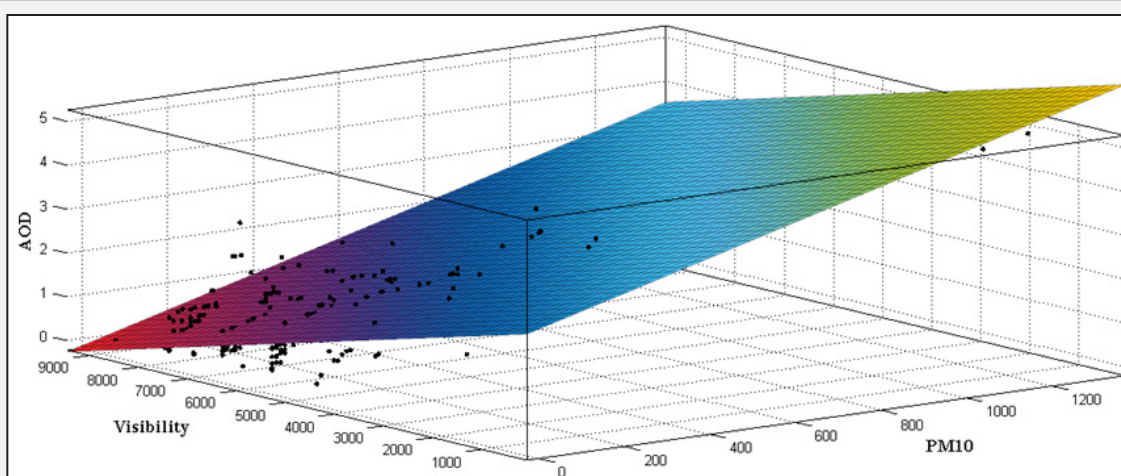


Figure 5: The binomial fitness graph between PM10, AOD and visibility in general and without regard to the synoptic codes.

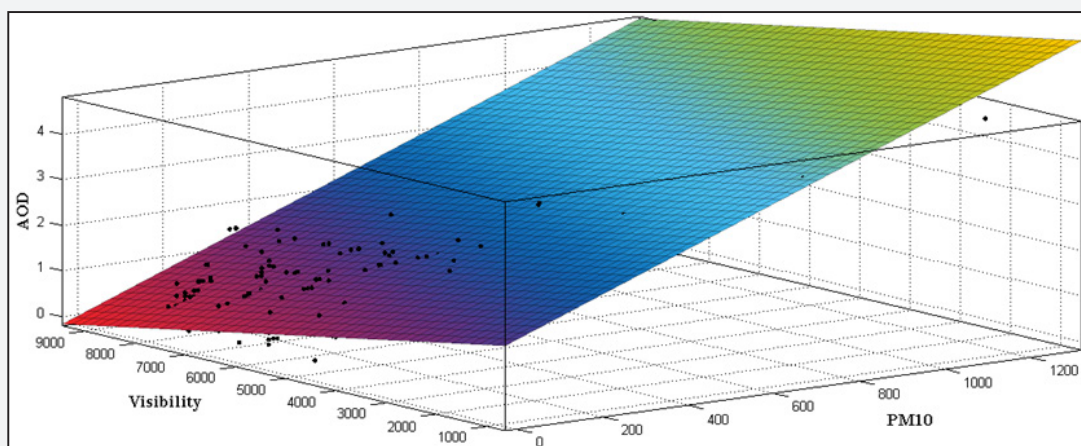


Figure 6: The binomial fitness graph between PM10, AOD and visibility in general and without regard to the synoptic codes.

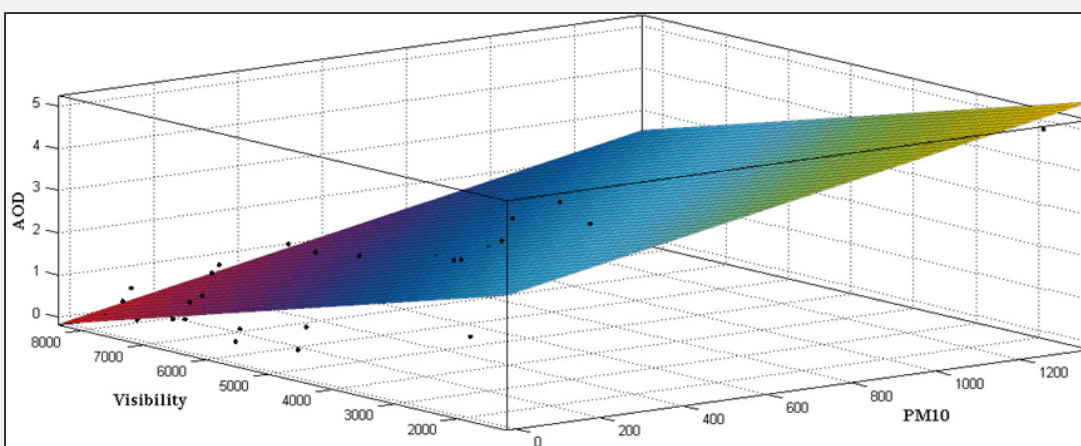


Figure 7: The binomial fitness graph between PM10, AOD and visibility during the occurrence of 06 synoptic codes

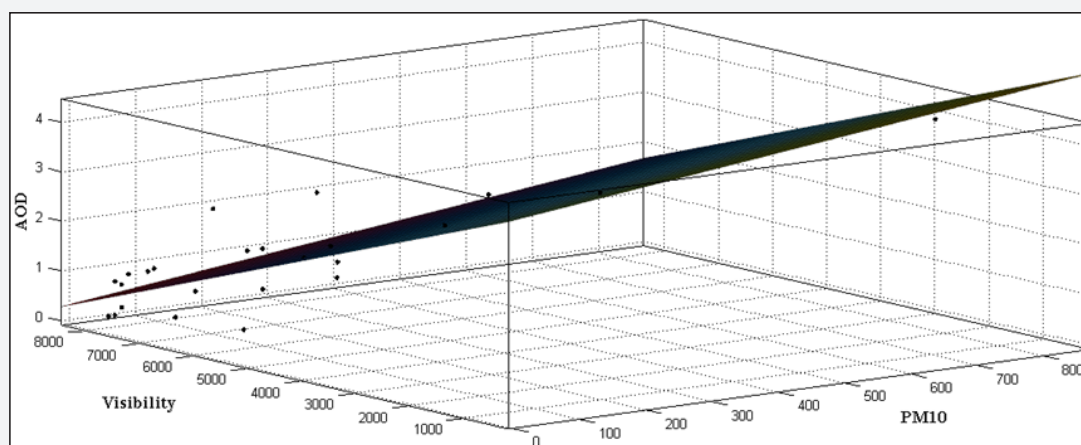


Figure 8: The binomial fitness graph between PM10, AOD and visibility during the occurrence of 07 synoptic codes.

### Conclusion

After mentioned calculations, four functions and mathematical formulas based on binomial linear model with a 95% confidence level are presented as follows for the first time to dear researchers in the field of dust and aerosols:

$$AOD = 2.748 + 0.002687 \times PM10 - 0.0003107 \times V \quad (8)$$

Function 8 shows the relationship between  $PM_{10}$ , AOD and horizontal visibility in general. In this function and other forward mathematical functions,  $PM_{10}$  is expressed in grams per cubic meter ( $\mu\text{g}/\text{m}^3$ ), the visibility ( $V$ ) in meters, and the AOD,

as previously mentioned, is a dimensionless quantity. Function 9 shows the relationship between  $PM_{10}$ , AOD and horizontal visibility in the event of 05 synoptic code:

$$AOD = 1.879 + 0.003654 \times PM_{10} - 0.0002064 \times V \quad (9)$$

Function 10 shows the relationship between the  $PM_{10}$ , AOD and horizontal visibility when 06 synoptic conditions occurs:

$$AOD = 3.551 + 0.001928 \times PM_{10} - 0.0004422 \times V \quad (10)$$

And finally, the Function 11, which correlates the relationship between the  $PM_{10}$ , AOD and horizontal visibility when 06 synoptic conditions occurs:

$$AOD = 4.126 + 0.001574 \times PM_{10} - 0.0004585 \times V \quad (11)$$

According to the similarity of climate and topography between the natural and urban parts of central Iran, eastern and southeastern Iran, it seems that the presented relations in this study have the generalized efficiency in all of these regions and can be used in these areas. And in the end, now that the geographical phenomena such as dust and aerosol are so important and widespread in a vast section of Iran, and are among the most harmful natural hazards in the country, it is hoped that the relationships offered in this collection could be useful to researchers interested in researching these breathtaking geographic features.

## References

- Cao JJ, Wang QY, Chow JC, Watson JG, Tie XX, et al. (2012) Impacts of aerosol compositions on visibility impairment in Xi an, China. *Atmos Environ* 59: 559-566.
- Christopher J (2008) Spatiotemporal associations between GOES Aerosol Optical Depth Retrievals and Ground-Level  $PM_{2.5}$ . *Environ Sci Technol* 42(15): 5800-5806.
- Chu DA, Kaufman YJ, Ichoku C, Remer LA, Tanré D, et al. (2002) Validation of MODIS aerosol optical depth retrieval over land. *Geophysical Research Letters* 29(12).
- Dayan U, Ziv B, Shoob T, Enzel Y (2008) Suspended dust over southeastern Mediterranean and its relation to atmospheric circulations. *International Journal of Climatology* 28(7): 915-924.
- Dominici F, Peng RD, Bell ML, Pham L, McDermott A, et al. (2006) Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. *JAMA* 295(10): 1127-1134.
- Engel Cox JA, Holloman CH, Coutant BW, Hoff RM (2004) Qualitative and quantitative evaluation of MODIS satellite sensor data for regional and urban scale air quality. *Atmospheric environment* 38(16): 2495-2509.
- Ganjehkaviri A, Mohd MN, Hosseinim SE, Barzegaravval H (2017) Genetic algorithm for optimization of energy systems: Solution uniqueness, accuracy, Pareto convergence and dimension reduction. *Energy* 119(15): 167-177.
- Gauderman WJ, Avol E, Gilliland F, Vora H, Thomas D, et al. (2004) The effect of air pollution on lung development from 10 to 18 years of age. *N Engl J of Med* 351(11): 1057-1067.
- Grivas G, Chaloulakou A (2006) Artificial neural network models for prediction of  $PM_{10}$  hourly concentrations, in the Greater Area of Athens, Greece. *Atmospheric Environment* 40(7): 1216-1229.
- Grzegorz M, Wioletta R, Piotr O, Artur B, Andrzej B (2015) The Impact of Selected Parameters on Visibility: First Results from a Long-Term Campaign in Warsaw, Poland. *Atmosphere* 6(8): 1154-1174.
- Guillaume A, Almeida D (1986) A model for Saharan dust transport. *American Meteorological Society* 25(7): 903-916.
- Gupta P, Christopher S (2008) Seven year particulate matter air quality assessment from surface and satellite measurements. *Atmospheric Chemistry and Physics Discussions* 8(12): 327-365.
- Holben BN, Eck TF, Slutsker I, Tame D, Buis JP, et al. (1998) AERONET-A federated instrument network and data archive for aerosol characterization. *Rem Sens Environ*, 66(1): 1-16.
- Hujia Z, Huizheng C, Xiaoye Z, Yanjun M, Yangfeng W, Hong W, Yaqiang W (2013) Characteristics of visibility and particulate matter (PM) in an urban area of Northeast China. *Atmospheric Pollution Research* 4(4): 427-434.
- Levy RC, Remer LA, Dubovik O (2007) Global aerosol optical properties and application to Moderate Resolution Imaging Spectroradiometer aerosol retrieval over land. *Journal of Geophysical Research* 112: (D13).
- Levy RC, Remer LA, Kleidman RG, Mattoo S, Ichoku C, et al. (2010) Global evaluation of the Collection 5 MODIS dark-target aerosol products over land. *Atmospheric Chemistry and Physics* 10: 10399-10420.
- Levy RC, Remer L, Mattoo S, Vermote EF, Kaufma YJ (2007) Second-generation operational algorithm: Retrieval of aerosol properties over land from inversion of Moderate Resolution Imaging Spectro radiometer spectral reflectance. *Journal of Geophysical Research* 112(D13).
- Lin S, Munsie JP, Hwang SA, Fitzgerald E, Cayo MR (2002) Childhood asthma hospitalization and residential exposure to state route traffic. *Environmental research* 88(2): 73-81.
- Liu Y, Franklin M, Kahn R (2007) Using aerosol optical thickness to predict ground level  $PM_{2.5}$  concentrations in the St. Louis area: A comparison between MISR and MODIS. *Remote Sensing of Environment* 107(1-2): 33-44.
- Nurul Amalin Fatimah KZ, Kasturi DK, Dimitris GK (2017) Estimating Particulate Matter using satellite based aerosol optical depth and meteorological variables in Malaysia. *Atmospheric Research Accepted Manuscript* pp. 141-162.
- Palani S, Liang SY, Tkalic P (2008) An ANN application for water quality forecasting. *Mar Pollut Bull*, 56(9): 1586-97.
- Ramanathan V, Crutzen PJ, Kiehl JT, Rosenfeld D (2001) Aerosols, climate, and the hydrological cycle. *Science* 294(5549): 2119-2124.
- Remer LA, Kleidman RG, Levy RC, Kaufman YJ, Tanré D, et al. (2008) Global aerosol climatology from the MODIS satellite sensors. *Journal of Geophysical Research* 113(D14).
- Sanja G, Josip K, Goran G, Oleg A, Zdravko Š, et al. (2014) Relationship between MODIS based Aerosol Optical Depth and  $PM_{10}$  over Croatia. *Central European Journal of Geosciences* 6(1): 10-25.
- Shao Y, Yang Y, Wang J, Song Z, Leslie LM, et al. (2003) Northeast Asian dust storms: Real-time numerical prediction and validation. *Journal of Geophysical Research* 108(22): 1-18.
- Tian j, Chen D (2010) A semi-empirical model for predicting hourly round-level fine particulate matter  $PM_{2.5}$  concentration in southern Ontario from satellite remote sensing and ground-based meteorological measurements. *Remote Sensing of Environment* 114: 221-229.
- Van Dankelaar A, Martin R (2008) Estimating ground-level  $PM_{2.5}$  with aerosol optical depth determined from satellite remote sensing. *JOURNAL OF GEOPHYSICAL RESEARCH* 111(21): 69-77.
- Voukantsis D, Karatzas K, Kukkonen J, Räsänen T, Karppinen A, et al. (2011) Intercomparison of air quality data using principal component analysis, and forecasting of  $PM_{10}$  and  $PM_{2.5}$  concentrations using

- artificial neural networks, in Thessaloniki and Helsinki. *Sci Total Environ* 409(7): 1266-1276.
29. Wang J, Christopher SA (2003) Intercomparison between satellite-derived aerosol optical thickness and  $PM_{2.5}$  mass: implications for air quality studies. *Geophysical research letters* 30(21).
30. Wang Z, Chen L, Tao J, Zhang Y, Su L (2010) Satellite-based estimation of regional particulate matter (PM) in Beijing using vertical-and-RH correcting method. *Remote Sensing of Environment* 114(1): 50-63.
31. Wei Y, Zengliang Z, Lifeng Z, Mei Z, Xiaobin P, et al. (2015) A nonlinear model for estimating ground level  $PM_{10}$  concentration in Xi'an using MODIS aerosol optical depth retrieval. *Atmospheric Research* 168: 169-179.
32. Wei Y, Zengliang Z, Lifeng Z, Mei Z, Zhijin L, et al. (2015) Estimating ground-level  $PM_{10}$  concentration in northwestern China using geographically weighted regression based on satellite AOD combined with CALIPSO and MODIS fire count. *Remote Sensing of Environment* 168: 276-285.
33. Zhu CS, Cao JJ, Ho KF, Chen LWA, Huang RJ, et al. (2015) The optical properties of urban aerosol in northern China: A case study at Xi'an. *Atmospheric Research* 160(15): 59-67.



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