Using MODIS data for nonlinear hazard analysis of the Middle East aerosols

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Abstract

Aerosols are among the most important of atmospheric pollutants observed like the microscopic particulate matter in the lower parts of the troposphere. The main purpose of this study is introducing a new method based on satellite images processing results and nonlinear analysis (fractal based) to investigate the origin and dynamical mechanism of aerosols distribution in North Africa and the Middle East. As a rule, the Middle East aerosols subject to non-linear distributions because a chaos reign of atmosphere. We used NASA based MODIS images to measure the atmospheric content of aerosols optical thickness (AOT), nitrogen dioxide (NO2) and carbon monoxide (CO). Spatial analysis of data and seasonal - annual compare of them with together, is representing the exponential relative relationship in aerosols dispersion pattern. By using an innovative variance-distance equation, besides representing relationships between atmospheric pollutants of Iran, Iraq and Arabia with climate changes in the North Africa, two tropospheric regimes of hot and cold weathers were compared according to the energy content and chemical composition of different seasons. In practice, both natural aerosols and industrial pollutants are function of their chaotic behaviors in the cold seasons that are logically greater than the summer months of the years. Therefore, the environmental hazards of winter regimes are more than of the summer. Also, changes of fractal dimension (especially at the Brownian surface of AOT), the possibility of study the remote sensing criteria has provided on the basis of the fractal geometry principles, whereby, a new approach has been introduced to prediction the cumulative behavior and movement pattern of aerosols in Middle East.

Keywords: Aerosol; Fractal Analysis; Nonlinear Distribution; Middle East.

1- Introduction

According to the results of advanced device measurements (aero-database), scientists have shown that atmospheric phenomena such as accumulation of clouds, gases and microscopic particulate matter (aerosols) have a climate effects and environmental interaction with land surface and ocean phenomena (Tegen and Schepanski, 2009). In the meantime, particulate matters in the lower atmosphere (with natural and artificial origin), are among the most important of main pollutants in the Middle East region and cause the incidence of climatic disturbances. Abundance of aerosols depend on factors such as wind speed, air moisture, soil moisture, vegetation, climate changes (in local and regional scales), amount and length of atmospheric precipitations, intensity and volume of the deforestation phenomenon, ascendancy the drought periods of short term and long term, user changes of land and human activities (Rezaei and Iranmanesh, 2013) (Kermani *et al*., 2016). Actually, aerosols refer to solid and liquid particles that suspended in air and average diameter of them is lesser than 500 microns. Most of these particles are scattered at a height of several meters above ground level (lower troposphere) (Nadafi, 2013). Volcanic ashes, sea salts, smoke of fires and pollution from factories and other particles that produced in the industry (such as fossil fuels) are among the most important sources of aerosols. In practice, natural aerosols have larger dimensions than industrial pollutants. Particles in size of silt and clay due to lightweight are get up to greater heights from ground level by wind forces and remain suspended for a long time. Then by increasing in air pressure and drop in temperature in the lower atmosphere, will be provided the collapse conditions of them (such as rain drops) (Maleki and Maveddat, 2013). Aerosols and atmospheric pollutants are among the most important of environmental hazards in troposphere of country and cause the incidence of lung diseases such as asthma, chronic bronchitis and cancer. Also aerosols emission give rise to economic losses such as decreased vision of passages, severe erosion of buildings and industrial equipment, disordering in land and air travels and reduction in harvest surfaces of agricultures. Social consequences of such hazards, will be lead to increasing urban migrations and irregularities of the land uses (Gheyaseddin, 2006). According to importance of aerosols hazards, current research has been introduced a method of fractal geometry that is used from MODIS photomaps for modeling the non-linear distribution of the Middle East aerosols prior to realizing the mechanism of aerosols dynamics by apply exponential equation into images. Moreover, achieving statistical algorithms is an important procedure for prognosis of the dynamical behaviors of the aerosols in association with spatial distribution and recursive appearances of the pollutants due to declination processes. In confront with the excessive aggregation of Iran aerosols, our solution is about making a belt of evergreen plants in western provinces of Iran with focus on vegetation index variations for sustainable regions.

2- Study area

Our study area is a part of the geographic scope of the Middle East that is located between 50-70 degrees of longitudes and 20-40 degrees of latitudes in East and North trends respectively. Based on MODIS databases (NASA, 2004-2015), large amounts of the lower atmosphere in Saudi Arabia, Iraq and Iran are under the influence of particulate matters (PM) and gases of resulting from fossil fuels combustion (such as carbon monoxide and nitrogen dioxide) which because of the climatic conditions in the mentioned areas (lack of vegetation and meteoric precipitations) have a long relatively sustainability. At the recent years, we have observed an excessive accumulation of the atmospheric pollutants within the combination process of the aerosols with the gases resulting from industrial activities up to their seasonal stability, have been caused the extreme climate changes in the Middle East.

Figure 1, shows the lack of vegetation index (VI) in the large parts of the North Africa and the Middle East which indicate a severe dry weather with minimal of atmospheric precipitation in the past half century that because instability of aerosols particles, is entered into the air flow attributed to sub-tropical climates, and as huge mass of microscopic pollutants have been migrated toward Saudi Arabia, Iraq and Iran. Also, Kutiel and Furman studies (2003) on the Middle East aerosols showed Iran, Sudan, Iraq, Saudi Arabia and countries of Persian Gulf are in the first category which represent the highest abundance of the aerosols formation in above mentioned areas (Kutiel and Furman, 2003).

Nowadays using of remote sensing technology in order to studying the aerosols phenomenon is in priorities of climatology researches. Also, study on aerosols distributions for measuring their thickness and aggregation, provide the ability of the pollutant resources identification. In other word, MODIS images are one of the most important remotely sensed databases for analyzing and prediction the mechanisms of the aerosols distribution. These images have more spatial coverage and lesser BIAS than geo-databases (Soleimani *et al*., 2016).

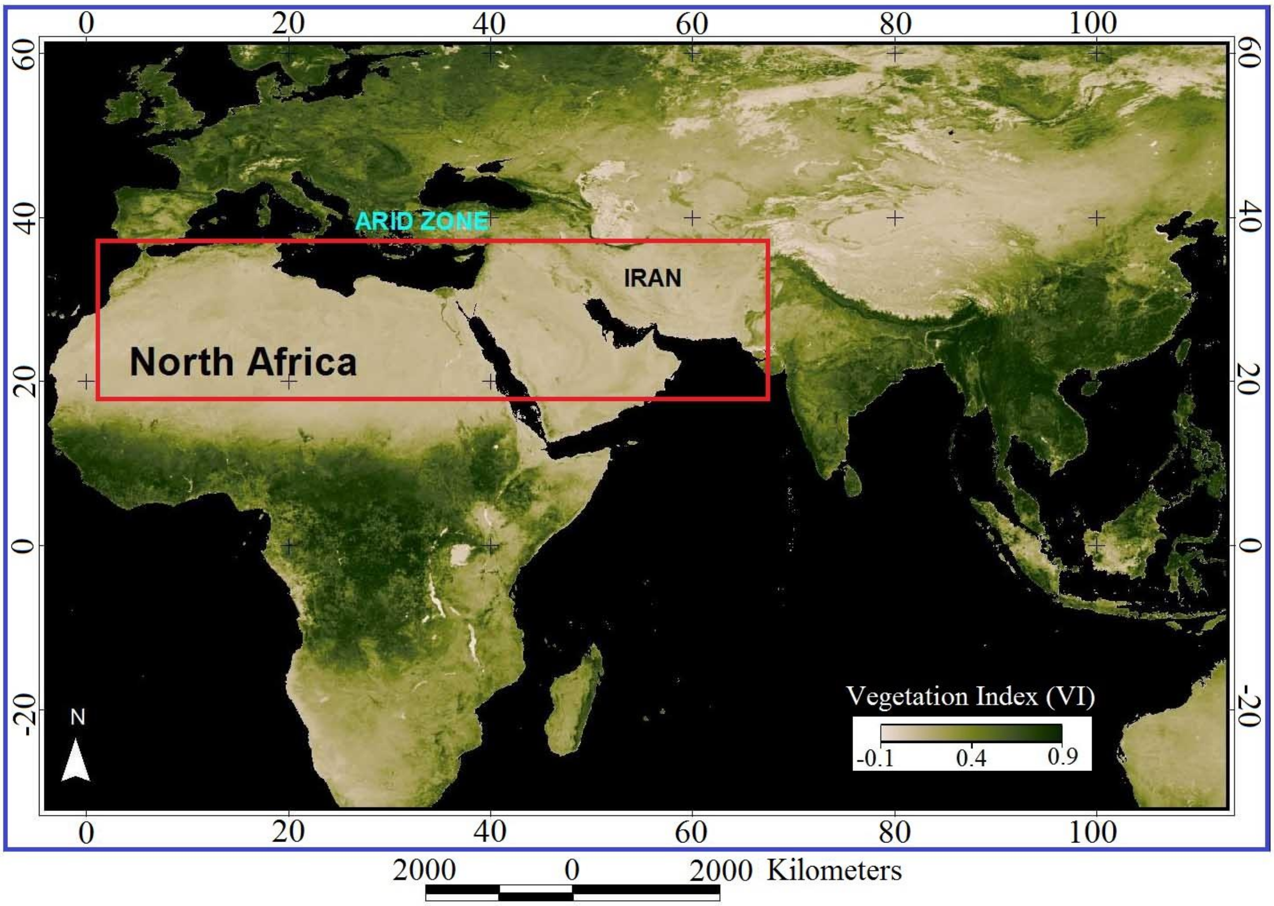

Figure 1) The MODIS image from vegetation index in parts of the Middle East and North Africa that is proportional with the drought process and aerosols formation in these areas. Areas with dense vegetation have a higher index and are shown to color of dark green. In contrast, areas where vegetation is very poor, have a fewer index and are shown in brown close to yellow color. (Vegetation index is obtained based on taken measurements in October 2015 by MODIS/Terra, American Space Agency).

Investigation of aerosols optical thickness [AOT] that has been done by America's space agency (NASA, 2004-2015), was provided the possibility of achieving statistical parameters such as mean, standard deviation and variances. Meanwhile, the correlation index of aerosols thickness (Regression variable) can be obtained by the climate changes of the Middle East (2013 and 2014) as it is shown in Figure 2. It should be noted that the aerosols optical thickness is a dimensionless parameter shows the amount of permeability of light beam (visible and infrared) in the atmosphere. Also, this quantity is representing the rate of absorption and dispersion for those aerosols have been located in the path of transmitted light (Wang and Sunder, 2003). In fact, an impressive rate of aerosols on the light beams depends on size, number and particle types. Above mentioned parameter is very important to understanding the relationship of atmospheric aerosols with climate changes and biogeochemical cycles (Soleimani *et al*., 2016).

The variation of AOT is an unbiased estimator for optical thickness of the aerosols in December 2013. For this study area, AOT has direct relation with the aerosols thickness in

October 2013, November 2013, January 2014 and February 2014.

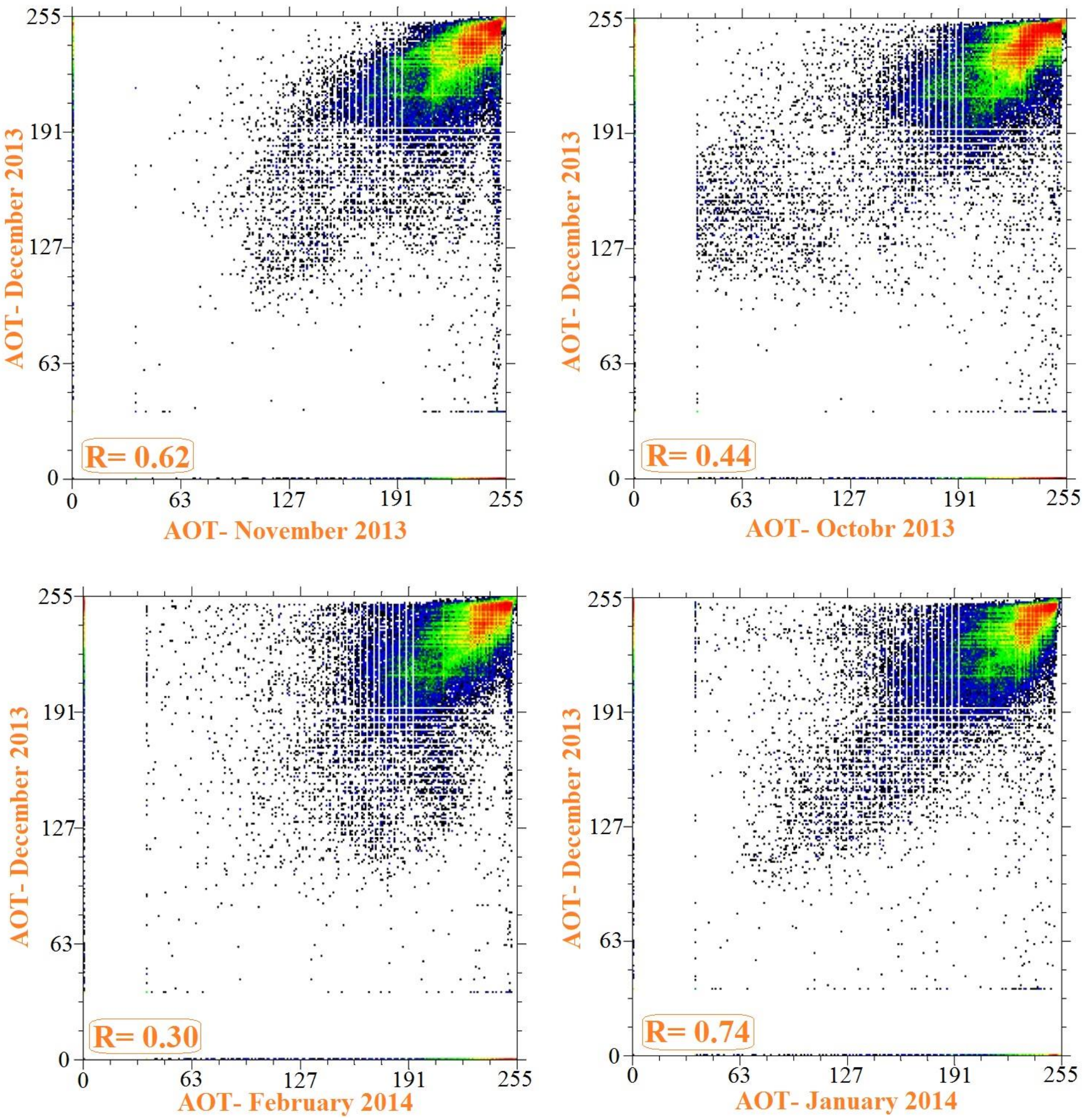

Figure 2) Calculation of correlation index the aerosols thickness in the Middle East based on Winter changes of AOT (2013 and 2014) (basic data is derived from America's space agency,(http://neo.sci.gsfc.nasa.gov)

3- Discussion and research methodology

MODIS [Moderate Resolution Imaging Spectroradiometer] is a detector system that was launched by NASA in 1999 on board of Terra satellite, and in 2002 on board of Aqua satellite respectively (Soleimani *et al*., 2016) (Kaufman *et al*., 1997).

This instrument has been designed for imaging the visible and thermal infrared spectrums within the wavelength ranges of 0.415 to 14.235 mm. MODIS data can be used to measuring number of physical variables such as temperature and humidity of the atmosphere, clouds thicknesses, aerosols properties, land and sea surface temperatures, fire resources, distribution and depth of snow and ice, ocean color, vegetation indices, etc. (Kaufman *et al*.,

1997) (Wang *et al*., 2010). However, MODIS is an advanced space system with the ability to recording and measuring of troposphere pollutants (important feature of MODIS). In fact, the basis of retrieve the spatial data is based on the difference in surface reflectivity and the received reflections by the satellite (Kaufman *et al*., 1997). This difference initializes a basic calculation for the aerosols optical thicknesses (Kaufman *et al*., 1997). In other words, this system used EM reflections to measuring the aerosols optical thickness as well as concentration of gases pollutants (NO2 and CO).

Moreover, some evidences for the quantitative measurements are based on NASA remotely sensed data between 2013 and 2014 which analyzed to obtain the extremum values of atmospheric variables. As it is shown in Figure 2, in the northern hemisphere, AOT changes have depend on to climatic conditions of different seasons and we have seen the increasing in data correlation in cold months (October, November, December, January, February). The common technique to achieving the correlation coefficient of AOT is the using of R value that is calculated according to Equation 1.

$$R_{(AOT)} = \frac{Covariance\ (AOT_1 . AOT_2)}{Stdev\ (AOT_1)\ .\ Stdev\ (AOT_1)} \qquad (1)$$

In this regard, $R_{(AOT)}$ is the correlation coefficient of aerosols thickness at different time intervals and Covariance (AOT_1, AOT_2) is represent the variance of different thicknesses that have a directly relationship with multiplied of standard deviations [Stdev (AOT_1) and Stdev (AOT_2)].

In most cases, comparing the aerosols thickness for winter versus other seasons is proportional with threshold changes in R-coefficient. It means that, dynamical pattern of AOT is not the same for different seasons and meaningful changes can be seen within the aerosols distribution. Scatter plot of the aerosols represents Poisson distribution statistically. For normal Poisson function, the mechanism of aerosols suspension is expressed on the basis of the distribution algorithm of the components. In such a distribution, the aerosols aggregation is negligible in comparison with other ingredients of the troposphere. Therefore, our ability to achieving unbiased statistical evidences usually increase with using non-linear functions such as Fractals. We believed that, the mechanism of formation and migration of the Middle East aerosols subject to non-linear algorithms that is controlled by chaotic climatic systems. In such circumstances, a successful prediction for assessing dynamical behaviors of the aerosols is difficult or even impossible according to Euclidean linear algorithms. It is because that, for accessing to the basic pattern of the aerosols migrations, we should recognize number of inherent components and their associations with initial conditions of the dynamics in complex systems (Mark and Aronson, 1984). Recursive functions are the best choice for study of aerosols complexity based on a fractal equation such as variance-distance power law relationship (Mehrnia, 2016).

Equation 2, represents the exponential function of variance - distance according to Mark and Aronson (1984) for achieving Brownian surfaces of the self-organized distributions (Mark and Aronson, 1984). This surface represents the self-similarities of any nonlinear distributions within a recursive function to illustrate an edge dependent regular variability of the chaotic environments (Turcotte, 1997). In mathematics, a non-linear distribution of an anomalous pattern can be obtained after a power law reduction to the line trends with logarithmic functions (fractal dimension). Fractal functions are logarithmic relations derived from power law equations which are known as scale-invariant functions for geological – geographical applications.

Equation (2), indicates a relation of variances (x) with the co-distances alternations (Dist. x) as below:

$$Var.\ x = (Dist.\ x)^{FD} \quad (2)$$

which Var. x and Dist. x are the variances and distances respectively and FD is fractal dimension as the power of this equation. Applying logarithmic scale convert this power law relationship to linear as Equation (3).

$$Log\ (Var.\ x) = FD\ Log\ (Dist.\ x) \quad (3)$$

which, Log (Var. X) is the logarithm variance of (x) and Log (Dist. X) is logarithm distance for the same variable that is converted by FD to linear. The self-similar components are mostly continuous points among limited yield points as self-affinities. The yield points give rise to separation of fractals into background, threshold and anomalies populations (Teymoorian *et al*., 2012). Any changes of the similarities, cause changing in fractal dimension. Therefore, an exponential function such as variance - distance equation should be converted to logarithmic scales for measuring FD as the main variable in relevant to variation of similarities on log-log plots.

For this purpose, available spatial databases including lines and contour features have been analyzed with GIS facilities and reproduced statistical quantities on the grids. we used a V-D model for obtaining FDs. In this model, any changes in slopes represents the fractal dimensions (Mohammadizadeh *et al*., 2012). This model is new application of fractal techniques for evaluation of non-linear distributions in our databases. Comparing linear procedures, the appropriate nonlinear algorithms are better than linear for studying the natural behaviors of the atmospheric pollutants (Mandelbrot, 2002).

For a case: FD< 2, the Brownian surface not made up and pollutants will be followed from linear distributions. Specifically, in case of FD≤ 1, the possibility of the similarities formation is lesser than the first case and indicates a dominant linear distribution.

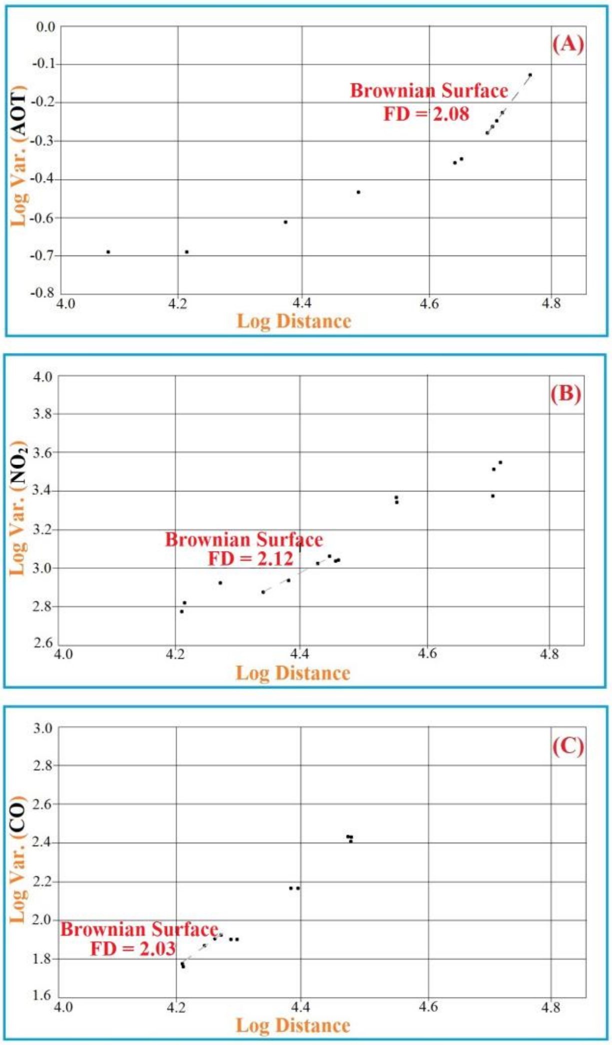

Figure 3) Variance-distance function for a changes A) AOT, B) NO_2, C) CO in winter regime of Middle East, December 2014.

Also in case of $1 \leq FD \leq 2$, a transitional status will be occurred and convert quantities from linear to non-linear distributions, so that some values have a features of similar components but due to constrain the spatial distribution of initial components, the maximum variations have been observed in the ground section and initialized to decreasing next to threshold population (Turcotte, 1997). In thresholds, the emergence of quasi fractal characteristics is common. That, in its turn, increases the probable achievement to self-similar pattern (Mandelbrot, 2002). Quasi fractal characteristics are for communities that are located in the threshold of chaotic environment but they have not a plurality of similar components for the emergence of fractal properties (recursive phenomenon). For cases of $2 \leq FD \leq 2.5$, pollutants will be faced with nonlinear distribution along Brownian surfaces. Initializing these surfaces are usually coincided with the emergence of several affinities and dominant bifurcation of self-similarities in the anomalous region (Thorarinsson and Magnusson, 1990).

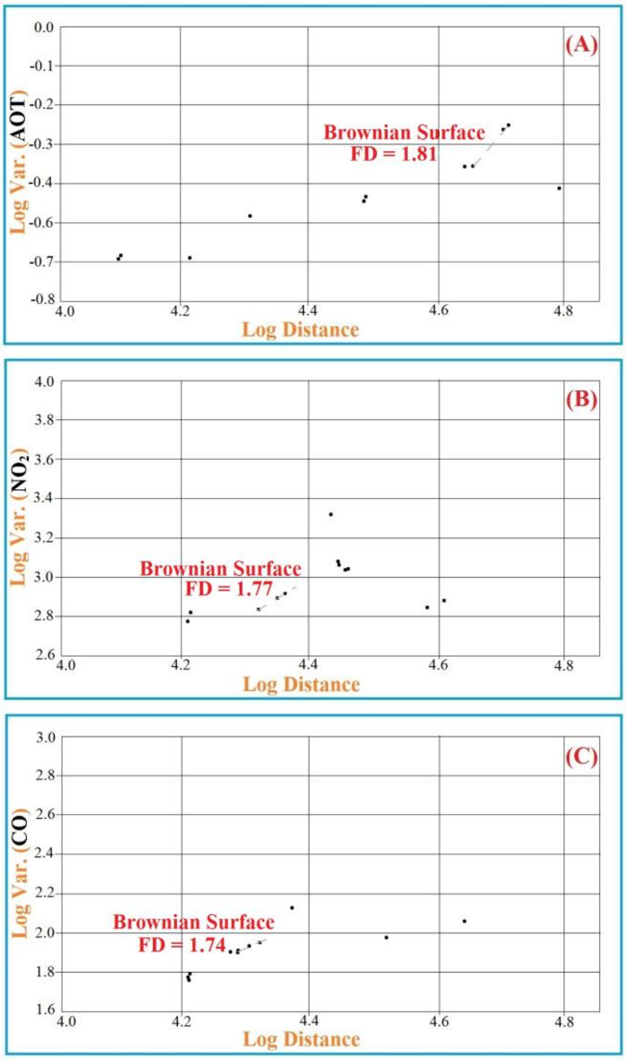

Figure 4) Variance-distance function for a changes A) AOT, B) NO_2, C) CO in summer regime of Middle East, July 2014.

Figure 3, illustrates a multifractal dimension for non-linear distributions of AOT, NO2 and CO in winter regime of Middle East (December 2014). Also a same representation can be seen in Figure 4 for atmospheric pollutants of the Middle East in summer months' regimes (July 2014).

According to layers of AOT (A), nitrogen dioxide (B) and carbon monoxide (C), Figure 3 shows that FD is greater than 2 for the winter regime. It means that aerosols and other pollutants are located in Brownian surface more self-similarities of distributions in the anomalous regions. It means that, the winter dynamics of the aerosols and pollutants has a more consistent with non-linear distribution than summer. As a result, we will see more accumulation of aerosols and atmospheric pollutants in cold seasons. From fractal point of view, aerosols and other air pollutants are sensitive to the sequences of self-similar components as well as their changing in the linear coefficients according to variance - distance equation (V-D model). The relative abundance of similar components is a symptom of aerosols atmospheric stability and subsequently with the emergence of heterogeneous quantities (changing in the line slopes along with ruptures in the yield points), the possibility of incidence the unexpected changes increase in mechanism of atmospheric distribution in the Middle East (Mehrnia, 2016).

As it is shown in Figures 4, the value of summerly dimension is smaller than the winter. When FD values is between 1 and 2, the pollutants represent a transitional status that is known as quasi fractal. This is an intermittent case of threshold communities with chaotic distributions while never representing the multiplicity of similar components for the emergence of fractal properties (the lack of self-similarities in the pollutants).

As a result, the Brownian surface of summer regime is lesser developed than the winter and the possibility of combined aerosols and pollutants is reduced in summer regime. Other words, summerly patterns of the Middle East have lesser self-organized components because a lesser correlation of homogeneous components than cold season patterns according to fractals.

4- Conclusion

This research used a fractal equation according to variance - distance logarithmic relation as a new approach for investigating dynamical behaviors and distribution of the aerosols as the main pollutant of the lower troposphere. In this method, achieving FD≥2, indicates the presence of similar components in the Brownian distribution surface which in turn, associated with the emergence of recursive patterns in the anomalous surfaces and represents the aerosols stability in threshold of chaotic environments.

Results showed that the pattern of the Middle East aerosols have not a uniform trend and based on primary researches, two regimes of winter and summer have been considered for it. In winter pattern, due to the inversion of lower troposphere temperature, the concentration of gaseous compounds has been increased in the sky of big cities and industrial centers in the Middle East and we can see an accumulated halo of AOT with NO_2 and CO content. The phenomenon of air pollutants resonance from one side has led to the cold climate stability and on the other hand led to the emergence of unusual patterns (chaotic) in during the concentration and distribution of pollutants (increasing of environmental hazards). Because in the Brownian surface of summer regimes, there are lesser similarities than winters, the possibility of co-existing the industrial pollutants with natural aerosols is significantly reduced. According to Figs 3 and 4, the fractal dimension of summer pollutants is smaller than the winter pollutants and therefore has a lesser environmental hazard.

Considering the relationship of vegetation index (VI), with the content of troposphere pollutants (minimum fractal dimension in spring regime, $FD_{(AOT)} < 1.5$), developing a belt of evergreen plants is recommended in the western regions of Iranian plateau, southern of Turkey, west of Iraq and Saudi Arabia. Indeed, an accustomed planting of the evergreen cultivations in the west of Iran cause decreasing in FD values of the pollutants as well as decreasing in jeopardized interactions between the North Africa and the Middle East AOTs. For winter regimes, the possibilities of stabilization of aero-masses are greater than summers. Also, the chance of aerosols combination with industrial pollutants is greater for cold seasons which caused an incidence of serious environmental hazards in Iranian metropolises.

Investigation of changing in FD values and its role on pattern recognition of the Middle East aerosols is the most important achievement of this research. By using spatial database (remote sensing, geophysics and aero-chemical data) and explaining the quantitative targets in the local scales (from Iranian plateau toward the margin of Persian Gulf in Makran), we have provided a prognostic dynamical map of the aerosols for answering the questions of how the accumulation of pollutants is occurred? and how their migration to the Middle East are channelized? Remember that one of the main thoroughfares of atmospheric aerosols is from path of the western provinces in country. So by creating Bakhtaran green belt and its developing to the southwest of Iran, a meaningful increasing in VI will be occurred and caused decreasing in FDs of AOT (reduction in environmental hazards).

In a confidence distance (95%), fractal dimension of AOT is an unbiased estimator for the case of atmospheric pollutants of the Middle East. Hence, by gathering geospatial database and studying the nonlinear variation of optical thickness, a valid method has been introduced for evaluating the atmospheric pollutants of the Middle East based on MODIS image processing and statistical algorithms applied in AOTs by V-D fractal model.

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http://neo.sci.gsfc.nasa.gov (2014, aqua / modis, no2 and co concentration maps).