Introduction to Coherent Component Nonlinear Analysis (CCNA) for Revealing Seismogenic Decomposed Lineaments in Northern Regions of Tehran

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ABSTRACT

In this research, a nonlinear analysis of geophysical databases has been performed with spectrum-area applications for revealing seismogenic decomposed lineaments in northern regions of Tehran. According to geophysical concepts, a fabricated pattern that is generated by multiplicative processes usually represented to power-law relationships under different statements. Therefore, a multifractal solution is proposed by this research for obtaining iterative peculiarities of seismogenic resources as an imagery location of triggering movements before destructive earthquakes. Several casual studies on North Tehran Faulted regions have performed since 1965, but it is theoretically updated in current research by considering a coherent concept to geospatial evidences. In practice, available databases including vectors and instrumental acquisitions have been processed by GIS facilities due to applying a multicriteria decision-making algorithm into gridded values. The results showed that nonlinear analysis of decomposed lineaments around North Tehran Fault can provide a new seismogenic pattern for updating Hazard Analysis Programs based on reducing in structural complexities.

Keywords:
Coherency; Lineaments; Multifractal; Nonlinear; Seismogenic; Tehran

1. Introduction

Most of the earthquakes have a severe long term processes in a continuum solid states assumption before responding to triggering movements near hypocenters. From Euclidean, Granular and Fractal points of views, there are three major competent frameworks in association with geometrical, mechanical, and mathematical (*GMM*) nature of faulted regions [1]. In the ordinary first view, faults are known as regular planar Euclid zones in a continuum solid. In this continuum framework, the macroscopic structures are fundamentally smooth with continuous optimum values at the borders and therefore could be analyzed in terms of fractures [2]. The second view focuses on granular aspects of faulted structures with emphasizing on different deformation processes. In this framework, faulted zones are discrete and strongly behave heterogeneously. In this model, strain hardening processes create a negative feedback mechanism opposite to that associated with strain weakening [3]. The third view is that faults are fractal objects with rough surfaces and branching geometry. In the fractal framework as it is shown in Figure (1), the fundamental structures are irregular with significant discrete features which have strongly heterogeneous characteristics in various scales [4].

The fractal structures follow a power law frequency-size distribution which is reported to characterize important brittle deformation in the crust over several bands of length scales. This research subject to third view that is focused on nonlinear processes for gathering an optimized geophysical dataset and making a new model from structural evidences in northern regions of Tehran based on multifractal peculiarities of geophysical signatures in a frequency domain. Processes involve two types of power law relationships for realizing decomposed lineaments respect to Tehran seismic activities. Greater Tehran as the capital of Iran with a rapidly growing population is located in an active region near central Alborz. Large faulted systems are extended in northern part of the city. Northern faulted system is also documented as Quaternary rupture and moved repeatedly at the recent geological time [5-6]. According to catalogue, at least two destructive records have been recorded in northern regions of the city with *Ms* = 7.1 and *Ms* = 7.2 in 855-856*AD* and 1177*AD* [7-10]. Table (1) shows the major events (after 743*AD*) and related seismological attributes for Greater Tehran regions.

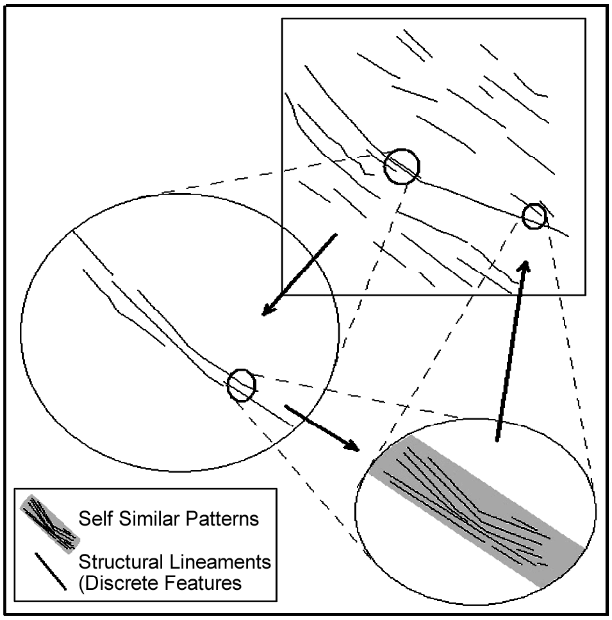

Figure 1. Scale invariant structures in active faulted regions [3].

Except to the youngest structures, most of the seismic patterns have been decomposed and therefore require to be revealed by geophysical interpretations. Because of chaotic natures that are revealed in historical earthquakes [11], study of decomposed lineaments with emphasize on triggering responsibilities has not been detailed for Tehran regions [6]. Therefore, a multifractal solution seems to be applicable for reconstructing the seismogenic patterns after realizing the coherent fabrics along northern faulted regions of the city.

2. Conceptual Statements

In most of the earthquakes, active regions contain a set of seismogenic lineaments that is properly produced by scale invariant processes. Although frequency-magnitude relationship [12] is an applicable statement for describing the nonlinearity of magnitude variations [13], many of earthquake-related parameters, including structural patterns and its related fabrics, may be affected by geological

Table 1. Historical earthquakes in Tehran, 734AD- 2004AD; Ms ≥ 6.0; r ≤ 200 km [10].

Row	Longitude	Latitude	Ms	Year (AD)	Month	Day	r (km)	Ref.
1	52.2	35.5	7.2	743			74.08	AMB
2	51.5	35.6	7.1	855	5	22	13.25	AMB
3	51.1	36	7.7	958	2	23	44.08	AMB
4	50	36.38	6.5	1119	12	10	148.55	AMB
5	50.7	35.7	7.2	1177	5		65.16	AMB
6	53.2	36.1	6.7	1301			166.7	AMB
7	50.5	36.7	7.2	1458	8	15	138.41	AMB
8	50.5	36.4	7.6	1603	4	20	113.59	AMB
9	52.1	35.7	6.5	1665	6	25	61.54	AMB
10	52.6	36.3	6.5	1687			125.5	AMB
11	51.3	34	6.2	1778	12	15	188.91	AMB
12	52.5	36.3	6.5	1809			117.95	AMB
13	52.6	36.1	6.7	1825			115.4	AMB
14	52.5	35.7	7.1	1830	3	27	97.74	AMB
15	52.5	34.9	6.4	1868	8	1	132.38	AMB
16	53.32	36.36	6.8	1935	4	11	186.24	AMB
17	52.47	36.07	7	1957	7	2	103.31	AMB
18	49.81	35.71	7.2	1962	9	1	145.7	AMB
19	50.65	34.47	6.2	1980	12	19	153.46	IGUT
20	52.97	35.9	6	1990	1	20	141.85	IGUT
21	51.65	36.37	6.4	2004	5	28	76.94	IGUT

Ref.: AMB: Ambraseys and Melville [7]
Ref.: IGUT: Institute Geophysics, University of Tehran, 1983

gouging processes which usually decrease in seismic resources efficiencies for quantitative interpretations. In such cases, using power law relationships for producing a logarithmic recursive function is a legal decision making procedure for reducing the probable ambiguities of the seismicities. Turcotte et al [17] showed that the length of faulting breaks and related areas of faulting activities introduce an applicable power law relationship as Eq. (1) [14]:

$$N_{CE} = B.r^{-2b} \qquad (1)$$

where N_{CE} is the cumulative number of earthquakes with a magnitude greater than or equal to M; B is a constant number and b-value is the slope of the log-linear relationship that is known as fractal dimension (FD) [15]. $r = \sqrt{A}$ is the length of the fault break and A is the area of the fault break. Then $2b = FD$ is the dimension of seismic activity for regions from which the data were collected.

Comminution is the main process for detailed explanation of fractal distributions in faulted regions [17]. It is initializing to the processes in which the solid materials are reduced in size, by crushing or other natural phenomena. Studies on fragmentation processes yield a power law relation of frequency-size distribution with $D = 2.5$ [18].

Figure (2), indicate to a discrete model of fractal distributions in faulted regions. According to comminution theory, each block is represented to single but self-similar segmentation of a huge fault system. With this assumption, there is a fractal growing algorithm in each faulting territory due to $D = ln3 / ln2 = 1.585$. Therefore, multifractal distribution of faulted regions easily implies to multifractal distribution of related earthquakes [19].

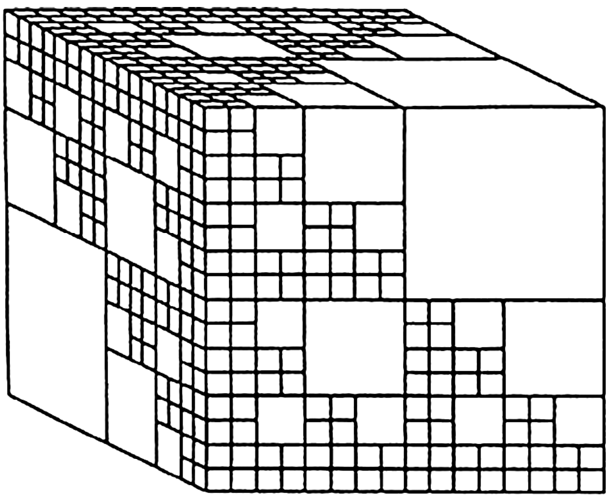

Figure 2. Discrete model for active fault regions, blocks satisfy a fractal relationship with D = ln6 / ln2 = 2.585 [13].

This research uses the comminution hypothesis as the conceptual theory for seismomatics expressions before establishing of a revealed seismogenic model in northern faulted regions of Tehran. The basic discussion usually introduces nonlinear analysis and surfacing of airborne geophysical responses. Also seismogenic fabrics and related lineaments should be extracted due to integrating of geophysical datasets according to earthquake catalogues.

With due regard seismicities and seismotectonic evidences, northern regions of Tehran have enough potential for striking with destructive earthquakes in near future. However, with a linear interpretation of the exposed structures (observed and remotely sensed), there are different ambiguities for locating the real focal entities in association with the real position of pre-existing epicenters. Therefore, a nonlinear analysis is necessary for extracting the real entities of seismic resources based on analysis of seismic coherencies using of multifractal equations.

3. Databases

A minimal set of geophysical ingredients, including seismic, aeromagnetic and airborne gravimetric databases are needed for reducing decomposition traces of the seismogenic lineaments [20]. It is widely accepted that spatial disordering of geophysical gradients may be affected by rupturing processes near faulted zones [21]. Like a case in northern regions of Tehran, both magnetic and gravimetric gradients can be used to interpret several nonlinear features related to end members of seismogenic lineaments. Meanwhile, locations of the large asperities could be recognized by nonlinear geophysical studies and easily implemented into rupturing models [22]. The following subdivisions are discussed to inquiries of databases before processing and analytical attempts.

3.1. Airborne Geophysics

Magnetic and gravimetric field values have been collected by airborne measurements due to several systematic flights over the city [23]. Important geometrical parameters represented in Table (2) and updated spatial information also standardized by updated Worldwide Geodetic System ($WGS84$) based on decimal degrees (dg) coordinates [23].

Table 2. Geometrical -statistical parameters of geophysical datasets for Tehran region.

Airborne Gravimetric Dataset								
Entity Unit: dg, Sys: WGS84, Zone: 39N				Z Value Unit: mgal		Z Value Statistics		
Longitude		Latitude						
Xmin	Xmax	Ymin	Ymax	Zmin	Zmax	Mean	SD	Skewness
50.8557	51.7037	35.1873	36.0603	39358.95	39648.05	39503.51	69.47	2.73

Airborne Magentic Dataset								
Entity Unit: dg, Sys: WGS84, Zone: 39N				Z Value Unit: n.t		Z Value Statistics		
Longitude		Latitude						
Xmin	Xmax	Ymin	Ymax	Zmin	Zmax	Mean	SD	Skewness
50.8557	51.7037	35.1873	36.0603	-156.62	-103.99	-125.62	11.62	-0.35

3.2. Earthquakes Catalogue

Berberian and Yeats [9] reported 21 destructive earthquakes according to seismic recorded since 743 *AD* [9]. In this catalogue, see Table (1), two seismic records have been located in northern regions of the city with an approximation for epicenter entities and the lack of geometrical associations with instrumental measurements.

3.3. Structural Evidences

For comparing seismogenic lineaments with the observed structural evidences, the research plans have been focused on updated seismotectonics map that is issued by Berberian et al [14]. In the revised map, the North Tehran Fault (*NTF*) is a main active structure with several branches of decomposed lineaments which have been effectively covered by Quaternary formations without significant traces of fabrications.

4. Nonlinear Analyses

An ordinary power law equation has been used for analyzing the structural responsibilities based on scale invariant properties of self-similar spectrums. In spatio-temporal scaling, distribution of geophysical values and subsequent variations of related fabrics indicate to a time dependent relationship [24]. However, in spectral domain, geometrical properties of above-mentioned values are mainly represented by distribution of a power spectra statement [25-26].

4.1. Geophysical Interpolations

Inverse Distance Weighting (*IDW*) and Polynomial regression (*PR*) are two geostatistical methods used for interpolating the magnetic and gravimetric airborne values the same as Figure (3) [27-28]. This illustration is a *GIS*-based plot with setting up of analysis properties according to 0.001 *dg* of cell

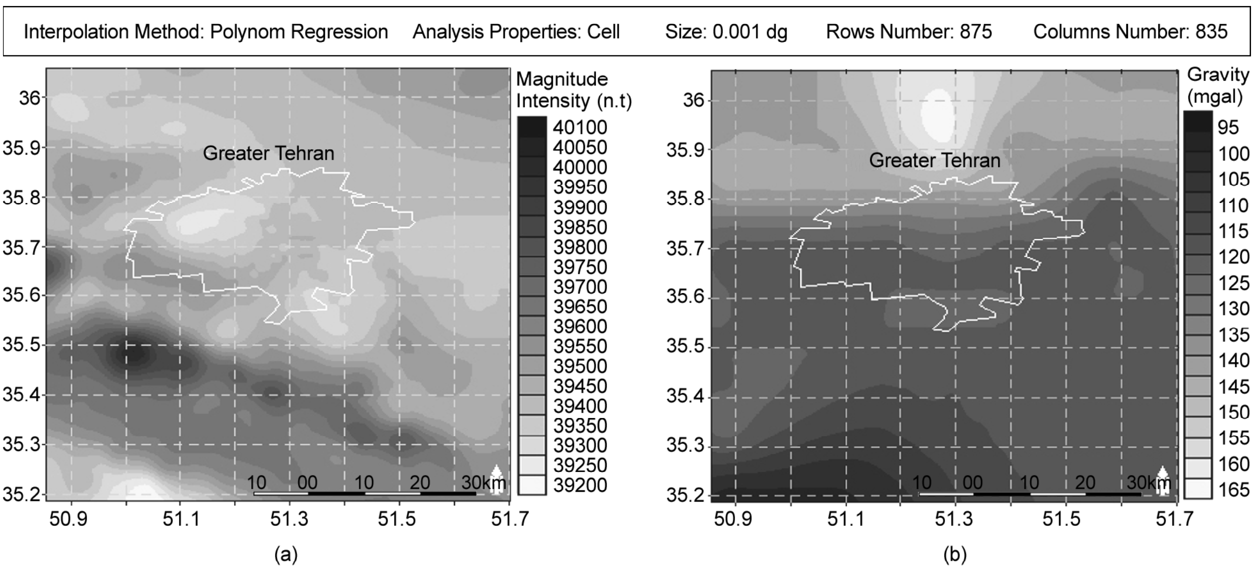

Figure 3. IDW results for Magnetic (a) & Gravity (b) Residual values of Tehran.

values with No. of columns = 853 and No. of rows = 875.

Interpolation results showed that the northern faulted regions have significant potentials of fabrications along *EW* trends. In this region, both magnetic and gravimetric values indicate to a dense but complicated isogrades on the basis of contoured maps. Correlative interpretations have been done for recognizing the seismogenic lineaments by using of logistic algorithms. South of Tehran is also affected by *NW-SE* structures; however, a lack of isotropic gradients in addition to lesser gravimetric abnormalities (4b) give rise to lesser opportunities for meaningful interpretations than northern regions.

4.2. Spectrum - Area (S-A) Equation

Izawa [29] and Turcotte et al [30] showed that a power-law relationship holds true at least for both magnetic and gravimetric field values while anisotropies are insensible within invariant scaling properties. Anisotropy is an ordinary specification of gridded intensities, which produce different types of non-momentum orientations between surfaces [29, 31]. From seismological points of view, a bigger anisotropy causes bigger noises in earthquake lineaments and grows up the rate of Biases due to interpretations [32-33]. For *S-A* model, the relationship between encircled area $A(\geq E)$ and spectral values (E), is represented by Eq. (2):

$$A(\geq E) = E^{-\beta} \quad (2)$$

where (β) is the values of slope variations and calculated by plotting the $log\, A(\beta E)$ versus $log\,(E)$ [34-35].

In practice, a set of airborne geophysical values including magnetic and gravimetric intensities have been functioned in *S-A* log-log plots for obtaining fractal density function of the frequency signatures in northern regions of Tehran, see Figure (4). According to comminution hypothesis, most of the seismogenic resources have been covered by decomposing processes and subsequently introduced to meaningful interferes between coherent and incoherent lineaments in faulted regions [26, 28].

For magnetic density function, see Figure (4a), the filter value = -0.45 indicates to moderate discriminations between backgrounds (*Log* Area < -0.45) and anomalous regions (*Log* Area > -0.45), while in gravimetric function, see Figure (4b), the filter value = -0.10 indicates to meaningful discrimination between background (*Log* Area < -0.10) and anomalous region (*Log* Area > -0.10).

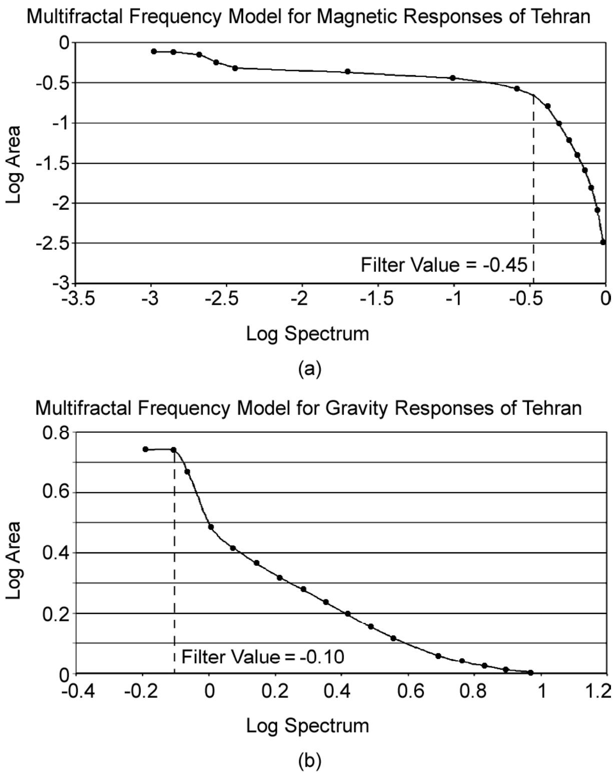

Figure 4. SA model for assigning spectral distributions in Magnetic (a) and Gravity (b) Dataset.

Several components of the frequency signatures may be concerned with coherent properties of the seismogenic resources. A self-similar feature is rare but generated at the edge of chaos [43] while the highest fractality rates of the features have direct relations with critical points of structural triggers. Most of the hidden fabrications may be revealed and considered as earthquake lineaments after applying *SA* model into geophysical datasets. Above-mentioned process is the most important reason for using spectral and nonlinear solutions for realizing earthquake potentials in northern regions of Tehran.

5. Modeling and Discussion

Applying binary filters to frequency images can provide a relatively high and low power-spectrum without regularly bounds on Figure (5). In a binary map, coherent appointments are known as continuum values of extended frequencies which not only their attributes imply to linear distribution of geophysical responses, but cumulative appearances (such as aggregated contours) can be referred to topological associations with deep seismic resources [33].

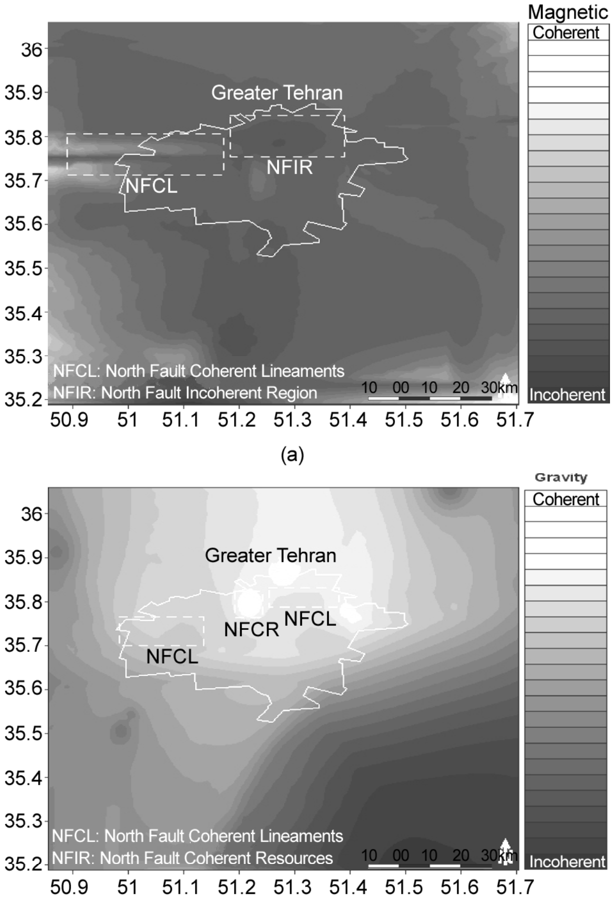

Figure 5. IDW results for Magnetic (a) and Gravity (b) spectrums. Coherent (NFCL and NFCR) Vs. incoherent subsets (NFIR) have been recognized by power spectra relationship.

Carter [31] has been introduced to Inverse Fourier Transformations (*IFT*) for converting frequencies back to temporal. A same technique is well done by this research for geophysical residuals after *IFT* applied. Figure (5) consists of two plots, which are gridded by *IDW* techniques due to polynomial regression techniques. Figure (5a) shows magnetic wavelet variables that are converted to spatial signatures with applying filter area > -0.45. Figure (5b) is a gravity wavelet response that is converted to spatial signatures with a same method and filter area > -0.10 applications.

Magnetic responses of power-spectra relations indicate to limited anomalous regions with significant slope variations in a recurrence system [19]. Relatively unified threshold plus background regions indicate to continuity of the self-similar populations with filter area < -0.45 applied. For magnetic filters, unique coherencies have been found along the North Tehran Fault (*NTF*) system. The main magnetic coherent segmentation belongs to western part of *NTF*. This coherency is located in tuffaceous formations between Tehran-Karaj cities. Most of the above-mentioned coherencies have been seen along a new fabricated lineament that is introduced to North Fault Coherent Lineament (*NFCL*) by this research. Another accumulation of coherencies has been found in the central region of the city. This region has a tempered coherent aggregation without any declination to *NTF*. Except to *NFCL*, more than 3/4 *NTF* shows incoherent properties in a weakened or non-fabricated subset. The new subset is also introduced to North Fault Incoherent Region (*NFIR*) by research. As it is shown in Figure (6a), both *NFCL* and *NFIR* are two possible spectral subsets according to magnetic spectral differentiations in northern regions of Tehran.

Contrary to magnetic limitations, the gravity power-spectra relations represent to extended anomalous gradients with one significant slope variation at the beginning of density function. Therefore, the gravity responses are extended toward end-members of coherencies by a tempered slope variations of thresholds, see Figure (5b). Same as magnetic responses, several gravimetric coherencies have been recognized in *NFCL* region and in adjacent to North Fault Coherent Resources (*NFCR*) region that is introduced by this research.

In Figure (5b), *NFCL* can be divided into unequal subsets in which segmentations; there is a moderate increasing of threshold values nearby fabrics. The above-mentioned area also can be divided into left and right subdivisions which are dominantly located at the southwest and east part of *NTF* respectively. Both left and right parts contain linear fabrics due to transitional gravitation responses. Another subset is called as *NFCR* that is represented to aggregation of coherent gradients around probable dense resources in depth. This anomalous subset may be potentiated to some stress accumulations throughout central regions of *NTF*. However, it is just an evidence for existing of probable stresses and needs more investigations before any claims.

5.1. Integrative Model

According to *SA* plots, Figure (5), geophysical self-similarities have been grouped under varieties of fractal dimensions as a main criterion for assessing the coherencies values of geophysical residues. An integrative plot is shown in Figure (6) for prognosis

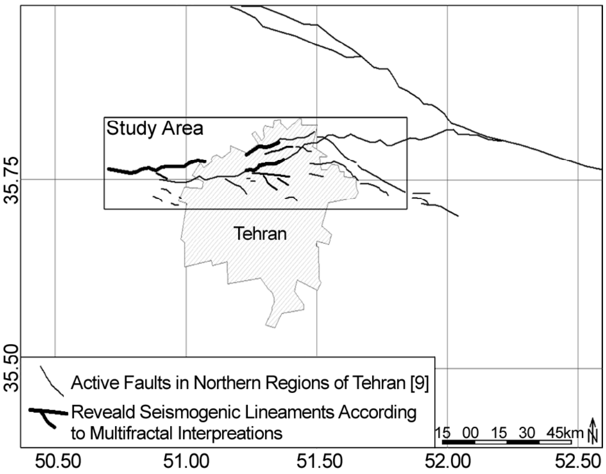

Figure 6. Integrative results for revealing seismogenic lineaments in northern regions of Tehran.

of those fault locations which are usually absented and frequently decomposed by dynamical processes, although their seismic traces have been recorded in catalogues. In this figure, the results of geophysical integrations in order to define coherent component priorities of the *NTF* lineaments have been shown by using of magnetic and gravimetric data fusion techniques. Active faults in Figure (6) referred to Active Faults Map of Tehran (*AFMT*) which issued by Berberian et al [14]. *NTF* and adjacent branches are selected for studying target areas in northern regions of the city. Arc view Spatial Data Modeler (*SDM*) and Spatial Analyst (*SA*) packages are involved software for data fusion and data integration purposes. In addition, a Multi Criteria Decision-Making legitimate (*MCDM*) which supported by geophysical datasets, buffered lineaments and seismic catalogues, see Table (1), have been used to generate the fusion model. In this plot, two subsets of NTF are selected by logical processes, which take into account for weighting of coherencies, see Figure (6), and obtaining evidences in order to prioritization of the seismogenic lineaments.

The first segmentation is located in longitude: 50.75-51.25 and Latitude: 35.75-35.78, approximately. Moreover, a second parallel segmentation is located in longitude: 51.25 - 51.35 and latitude: 35.71 - 35.79. Above-mentioned segmentations (the bold black lines on Figure (6)) have been called as Seismogenic Decomposed Lineaments (*SDL*) by this research. Some geological processes, including long time brecciation over sedimentary formations are responsible to change *SDL* into weakened seismic traces with lesser efficiencies of seismicities than ordinary fault systems.

According to these multifractal investigations, *SDL* traces have been originated from self-affined properties, which appear after ordinary distribution of autogenic similarities in northern seismic regions. For *NTF* cases, while the self-similar signatures are the most common iterations along faulted structures, the seismogenic singularities have been taken place and suddenly accumulated in *NFCL* and *NFCR* to produce intense fabrics or focal stresses as nonlinear responses to northern seismic behaviors of the city.

6. Conclusions

Multifractal analysis of the coherent geophysical signatures is a nonlinear with newly developed techniques for revealing *SDL* traces in northern regions of Tehran. According to the results obtained from this research, the rates of *NTF* activities can be specified by considering a fractal dimension to geophysical alternations. A finer analysis also performed by calculating the multifractal dimensions after achieving to Fourier Transformation. Obtaining a logical statistical correlation between geophysical coherencies and related seismogenic appearances is one of the most important results of the paper. Other conclusions are thoroughly explained in main contents, and here the author just points out to the main topics of the research as below:

- A long-axes and thrusted structure in northern regions of Tehran [9, 45] can be divided into coherent and incoherent seismogenic segmentations by applying a multifractal technique to frequency values of the geophysical responses, see Figure (5).
- Multifractality of earthquakes is an applied concept for interpreting the geophysical intensities in order to produce a number of scale invariant quantities in an act or transactions with frequency-dependent values of the seismicities.
- According to coherent component nonlinear analysis (*CCNA*) technique, the final results indicate to research abilities to realizing most of the decomposed lineaments in *NTF* territories of which seismic structures (especially in central and western subdivisions) are significantly affected by external processes.
- Two types of spectral components, including

coherent lineaments and coherent resources are new terminologies proposed by this research after spectrum-area (*SA*) applied to *NTF* seismicities.

- Except for ordinary distribution of the *NTF* branches [8], two seismic subsets have been recognized as *NFCL* and *NFCR* by author. These seismogenic subsets contain a number of real fabrics (at *NFCL*) or focal gradients (at *NFCR*) according to their geophysical appearance in frequency domains, see Figure (5).
- A new set of seismogenic lineaments have been recognized and separated from *NTF* regions by *GIS* facilities, see Figure (6). According to *MCDM* model, a large and fabricated segment has been revealed in *NW* of the city while another segment was appeared in smaller proportions and is mostly located in the center of the studied area, see Figure (6).
- A severe dynamical process is significant in *NTF* regions, but it is structurally limited to western subdivisions. Although the western fabrications are responsible for destructive earthquakes [10], a correct locating of the historical epicenters is necessary for their meaningful displacements due to slowly deformation of the surficial components.
- For Probabilistic Seismic Hazard Analysis (*PSHA*) and Earthquake Hazard Reduction Program (*EHRP*), a fractal-based integrative model can be suggested with newer structural contents better than earthquake prediction programs for land-use planning of greater Tehran.

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