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Fractal and geography: Fractal scanning in three different urban areas of Elazığ

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Abstract

The study of systems' ability to self-organize, internal structural balance, and space partitioning is the focus of a larger body of theories produced by mathematicians in the second half of the twenty-first century, which includes fractal theory and analysis. These theories focus on how the distribution of forms and urban functions within an urban agglomeration, the sequencing of the settlement system, the choice of a specific style of localization, or the evolution of urban sprawl is influenced by a region with inhomogeneous characteristics. The study's objective is to quantify how urban macro-forms reflect urban space. It is aimed to use fractal analysis, one of the methods that examine the structure of urban areas, as a measurement technique and to increase the recognition of this method in the community. When performing fractal analysis, the study area is generally evaluated holistically. Determining the place of the parts that make up this whole within the analysis is another aim of the study. The most basic method used in the study is the Fractal Analysis method. In order to make a relevant evaluation, Fractalyse 3.0 program was used. Two bases were created for the urban spots to be used in the program. While one of these bases is the parcels of Elazığ city center, the other one is buildings. In order to measure the parts of the whole mentioned as one of the aims of the study, three different regions of the city were identified, and fractal analyzes were carried out separately for those regions. The study field covers all the central 42 neighborhoods where Elazığ city develops. According to the results obtained from the analysis, the Fractal dimension value of the city was 1.62. This value is a very interesting result as it is considered a transition criterion for cities to be fringed and compact. Accordingly, Elazığ city is a fringed city in the process of becoming compact. In the analysis of three different sections containing the parts that make up the whole, the fractal value of Doğukent neighborhood, located in the easternmost part of Elazığ city, was calculated as 1.70. This area, which has a compact structure, presents a positive response against the urban sprawl. The sample taken from the central part of the city, called the Center, showed a high value of 1.89 in fractal dimension. The fractal dimension value of the sample selected from the south of the city showed a high fringed result of 1.32.

Keywords: Elazığ, fractal, fractal dimension, fractal geography

1. Introduction

First, in 1975, Mandelbrot coined the word “fractal” by transforming the word "fractus", derived from the verb "frangere" meaning to break (Köprülü & Topçu 2023, p. 952), to describe the shapes, sizes and geometry he produced, which is also compatible with the sound of the English words fracture and fraction and is used as noun and adjective in English and French today (Trippet 1994; Gleick 1997; Kaya 2003, p. 41). Many studies have been done on generating fractal geometry. In this regard, the works of mathematicians Julia, Fatou, Hubbad, Barnsley and Mandelbrot are of paramount importance (Kaya 2003, p. 48).

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A rough, jagged universe model that is neither spherical nor flat can be seen in the geometric structure of many natural elements, including the shapes of clouds, mountains, and river basins. This is the geometry of objects with indentations, protrusions, breaks, bends, tangles, and knots (Figure 1). In Richardson's 1961 article, Mandelbort attempted to use geographic objects to illustrate this geometry. In actuality, Mandelbort (1967) used the length of the British shoreline as his initial illustration. In his subsequent work "Fractal Geometry of Nature" (Mandelbort, 1977), he expanded on this topic.

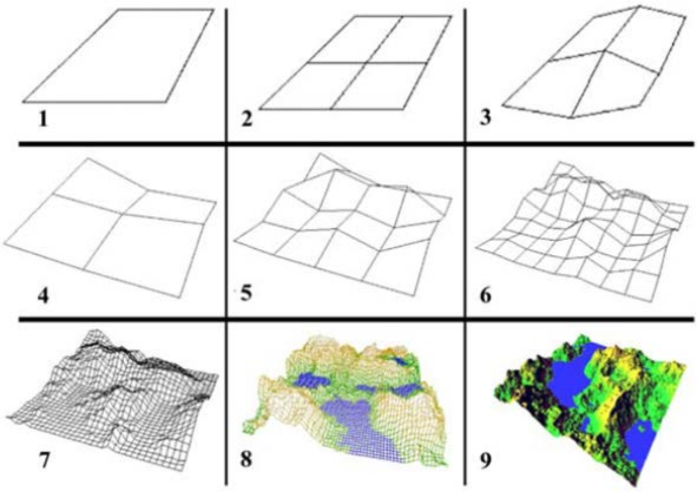

Figure 1 An example of a fractal structure created in a virtual environment (Bourke, P.)

Lovejoy (1982) has made studies indicating that cloud formation areas and their environments are fractal in almost all of his works. Based on these early examples, other meteorologists also used multifractal methods to understand the organization of temperature and pressure fields (Dauphiné 2012, p. 3).

In the discipline of hydrogeology, French geographers provided additional fractal instances. Delahaye provided the first and Martin provided the second examples in 2002 and 2004, respectively. The research on river system mapping by RE Horton and AN Strahler, both published in 1945 and promoting the use of the Fractal system, serve as the foundation for these efforts, though. By employing this technique, Delahaye and Martin were able to create a power law between river length and basin area.

Fractal later began to be used in the field of Geomorphology. In fact, Canada quickly became interested in the fractal paradigm in this regard. Especially in the first quarter of the 90s, some works, albeit rare, were produced. Although the Fractal method was used in a study on corals in the field of biogeography in the 1980s, geographers did not continue this subject.

In the field of geography, the area where the Fractal method is most applied is urban studies. Fractal analysis, a mathematical method, was developed completely independent of urban morphology. Scientists studying urban geography are interested in interdisciplinary studies due to the nature of their work. During their interest, they discovered that this method, which explains mathematical methods, is actually similar to the shapes of urban areas (Mcadams, 2007, p. 153).

In geographical research that aims to comprehend the structural uniqueness of the city, fractal theory has a significant impact on urban management and planning. Numerous urban geographers have been working on this topic ever since fractal theory was established in the early 1970s (Mendelbrot, 1967). The spatial and temporal dynamics of the process of urban growth and land use change are also successfully revealed by it (Erdoğan, 2015, p. 33).

Urban areas generally grow with a non-homogeneous distribution. It undergoes various evolutions as it grows. Built-up areas and empty areas intertwine and thus cities have different density areas. For all these reasons, fractal analysis of urban texture finds a much closer correspondence with spatial realities (Cirnu, 2014, p. 67). France was also the pioneer of using fractal in urban areas. This movement was started by Frankhauser in France in 1994 and continued by his students. These trained geographers contributed to the creation of many algorithms that were later integrated into the Fractalyse program, one of the system's software. A number of urban geographers outside France have created a list of population densities and other variables using digital terrain modelling. The fractal dimension allowed them to describe the spatial irregularity of cartographic phenomena. For example, Wong and colleagues analyzed social segregation in American cities in 1999 using a Fractal approach. But unfortunately, geographers did not pay much attention to the issue in the following periods. Fractal method has also been used in studies on urban transportation networks. Chapelon (1996), Françosis (1997) and Genre-Gradpierre (1999) have conducted many studies on this theme. These studies were greatly appreciated by British researchers (Dauphiné 2012). Apart from the subjects mentioned above, the Fractal method has also been used on issues such as population, traffic flow, internet traffic and migration flow.

Studies on the fractal dimension in our country started in the 1990s. The first applications of this method, which is generally used frequently by engineering faculties, were given mostly by Computer and Electrical and Electronics Engineering. In the 2000s, works on the subject were published by the Architecture, Urban and Regional Planning departments. The first representatives of studies on urbanization were Yüzer (2001) and Kaya (2003) with their City and Regional Planning studies. No study on the Fractal method has been done by geographers until this study.

2. Fractal Dimension Calculation Methods

Although the fractal dimension is widely adopted today, it is still seen as an abstract concept to make this less of an abstract concept, the fractal dimension is generally considered to be the degree to which it fills spatial gaps. A curve with D very close to 1.0 (such as 1.1) behaves much like an ordinary one-dimensional line, but a curve with D very close to 2.0 (such as 1.9) has a very convoluted shape, much like a two-dimensional surface. Unfortunately, this space-filling perspective often creates the incorrect impression that fractal dimension is another measure for density. Essentially, density is a Euclidean concept, while fractal dimension is fractal-based (Jiang & Yin, 2013, p. 532).

Fractal dimension is defined as a ratio of the change in detail to the change in scale (Mandelbrot 1982). This is not a simple ratio, but the ratio of logarithms, such as $D = \log(N)/\log(r)$, where r is the measuring scale (or simply change in scale) and N is the number of the scale needed to cover the whole fractal pattern or set (or equivalently change in detail). The slope of the distribution line in the Richardson plot (logarithm) is equal to the fractal dimension D. The simple ratio is not used because the change in scale r and the change in detail N are disproportional (Jiang & Yin, 2013, p. 533).

The meaning and properties of the dimension have been a matter of curiosity since ancient times, especially in mathematics. After Mandelbort developed the fractal dimension, many concepts describing the dimension have been developed in connection with it. Some of these are as follows:

i. Hausdorff dimension
ii. Self-similarity dimension
iii. Box-Counting dimension
iv. Topological dimension
v. Fractal dimension
vi. Euclidean dimension
vii. Compass dimension (Divider or Ruler dimension; compass dimension)
viii. Single-way Dimension
ix. Lyapunov Dimension
x. Information Dimension

All of the above dimension types are special forms of the "Fractal Dimension" (Kaya, 2003, p. 52).

Additionally, there are many methods used to measure the fractal dimension, and these methods have advantages and disadvantages against each other. We can list the calculation methods as follows:

Fractal dimension can be calculated in 7 different ways:
1. Grid
2. Radius mass
3. Dilation
4. Correlation
5. Gaussian convolution
6. Box-counting
7. Network (Erdoğan, 2015, p. 43)

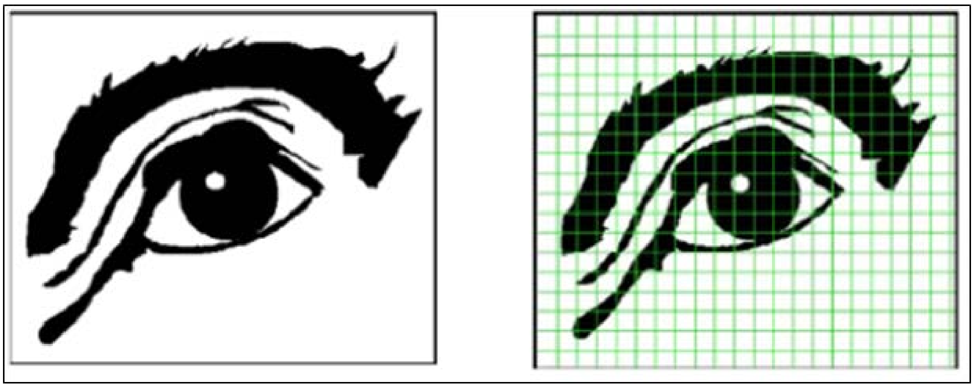

Figure 2 Situation of an Image Used for Analysis in Boxes (Kaya 2003, p. 83)

The most frequently used calculation method is the box counting method. The box counting method is conceptually related to the self-similarity dimension. Although this method often gives the same numbers as the self-similarity dimension, this is not always the case. Generally, examples that can be studied with different compass length settings, such as coastlines, or structures that have very special properties that can be characterized, such as self-similarity, are shown as examples. Box counting dimension offers a systematic measurement method that can be applied to every structure on the plane and easily adapted to every structure in the space, without looking for self-similarity (Kaya 2003, p. 58).

This technique, meaning box counting or Cobblestone (here cobblestone is used because it resembles a three-dimensional square box), is the most used method for fractal measurement. The basis of this dominance lies in the fact that it can be easily calculated automatically by machine. The program can be implemented regardless of the presence or absence of self-similarity. Objects can also be placed within higher dimensional space. For example, if objects are considered in three-dimensional space, the boxes are not in the plane but are three-dimensional cubes with height, width and depth (Kaya 2003, p. 60). The box counting method's closest accuracy depends on the resolution of the measured area. The data used in this method is first divided into the required number of boxes and the areas remaining in the box are evaluated with the result obtained as a result of a series of calculations (Figure 2).

3. Objectives and Methodology

The aim of the study is based on measuring the reflection of urban macroforms on urban space. More clearly, it is to measure the development form of cities, which constitute one of the elements of urban morphology, with a different method. It is aimed to use Fractal analysis, one of the methods that examine the structure of urban areas, as a measurement technique and to increase the recognition of this method in the geography community. In addition, while fractal analysis analyzes an area as a whole, determining the place of the parts that make up this whole within the analysis constitutes the other purpose of the study.

The most basic method in the study is the Fractal Analysis method. Fractalyse 3.0 program was used in order to make an evaluation. Fractal analysis is used today by some scientific fields, especially to calculate the morphological features of cities. The Fractalyse program was developed to analyze urban textures more easily. This program has the capacity to count entire cities at different scales and produce different types of analysis based on the distribution of the city. This program has been developed in 2001, within the ThèMa laboratory of the Franche Compté University, being constantly improved up to its current 3.0 version.

In each of the counting stages, the number of pixels belonging to urban spots contained in the structured environment is taken into account. Each time, the size of the defined perimeter is also modified. In this sense, the two main elements are the elements number (black pixels marked by the print of the built area) – N – and the size of the defined perimeter or of the referential element (ε). A series of points are obtained with the absciss ε and the ordinate N, doubled by the relation N = εD or N = ε-D, with D being the fractal dimension. D falls between the values 2 and 0. The value of this dimension characterizes the level of concentration of the constructed mass in a certain area of the urban fabric. A value close to 2 corresponds to a homogeneous structure, without a pronounced hierarchy, while a value close to 0 corresponds to a strong hierarchy in terms of elements, with mass concentrations on particular points and isolated concentrations from the other elements made possible through void spaces (Cirnu, 2014, pp. 67-8).

Two basic bases were created for the urban spots produced to be used in the program. While one of these bases is the parcels of Elazığ city center, the other one is buildings. The main purpose of including both parameters in the system is to better observe the change of the fractal dimension. In other words, these selections are intended to show the difference between the fractal dimension in the area where the parcels are located and the fractal dimension in the measurements of the buildings.

After the comparative fractal dimension analysis in parcel and building measurements, measurements were continued with only the building spread areas of the city. In order to measure the parts of the whole mentioned as one of the aims of the study, three different regions of the city were identified and fractal analyzes were carried out separately for those regions. A common dimension was chosen for these analyses, and sections from three different areas of the city were obtained with this dimension. Sections were taken from the planned area in the east of the city, from the densely populated area in the central part of the city, and finally from the sparse and scattered textured area in the south of the city (Figure 3).

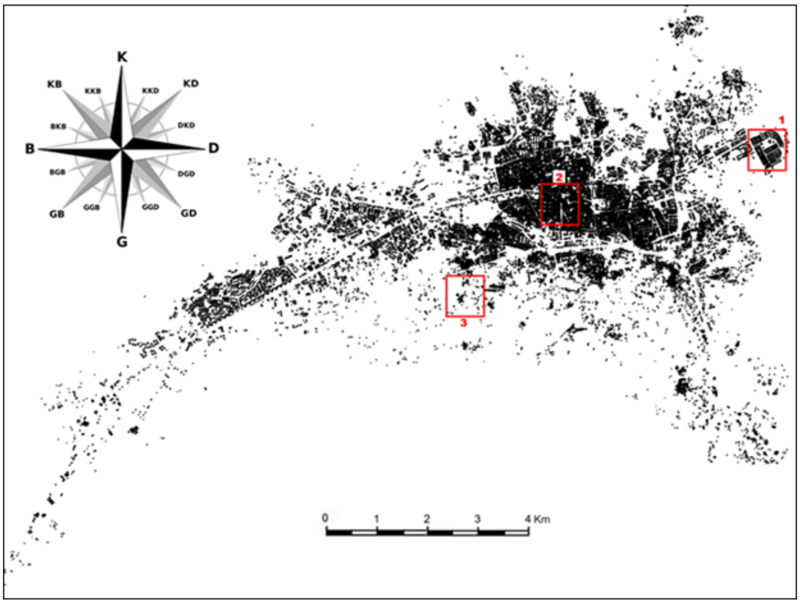

Figure 3 Sampling Areas Selected for Fractal Dimension Analysis

Measuring the fractal dimension is used in many independent scientific fields, from health to architecture, geography and mathematics. Accordingly, software such as Fractalyse, İmagej, HarFA have been developed just to measure the fractal dimension, as well as tools have been developed to measure the fractal dimension for well-known GIS programs such as ArcGIS. Of the programs mentioned above, Fractalyse 3.0 was preferred in the study as it can analyze both raster and vector data. To prepare the bases for the program, islands and buildings were first recorded in separate layers. Then, for raster analysis, the work area was saved in .tif format using MapInfo Pro, and for vector analysis, it was saved as files with .shp extension. The created files were measured using the Fractalyse 3.0 program to measure the fractal dimension of the working area.

4. Study Area

Elazığ is located in the Upper Euphrates section of the Eastern Anatolia Region. The city is neighbors with Kovancılar and Palu in the east, Maden Sivrice in the south, and Baskil and Keban districts in the west. On a provincial basis, it neighbors Tunceli in the north, Bingöl in the east, Diyarbakır in the southeast, and Malatya in the west and southwest. Elazığ is also surrounded by Keban Dam Lake from the North and Karakaya Dam Lake from the West and South (Figure 4).

This region, which is entirely located within the Southeastern Taurus Mountains fold belt, has mountains extending in the southwest-northeast direction and occasionally forming regular rows, and co-oriented plains located between these mountains. In the north of this mountainous mass, Uluova, one of the important plains of Eastern Anatolia, with an altitude varying between 900-1000 meters, and 1020 m, where today's Elazığ city is located. Elazığ Plain is located at a high altitude. To the north of Uluova, there is the Harput mountainous mass extending in the southwest - northeast direction (Ünal, 1989, pp. 31-32; Tonbul & Karadoğan, 1999). The study area is limited to the city center that spreads over the Elazığ plain.

The historical development of the city of Elazığ dates back to the migration from Harput to Elazığ between 1800 and 1900. The first settlements of the city are Çarşı District and Sarayatik District. İcadiye, Mustafapaşa, Akpınar Neighborhoods were added to these between 1833-1876, and Rızaiye and İzzetpaşa Neighborhoods were added between 1876-1923. With the establishment of the Republic, the post-war problems in the country negatively affected urbanization and the city of Elazığ was limited to 7 neighborhoods. Between 1927 and 1935, Rüstempaşa and Nailbey Neighborhoods were added to the city.

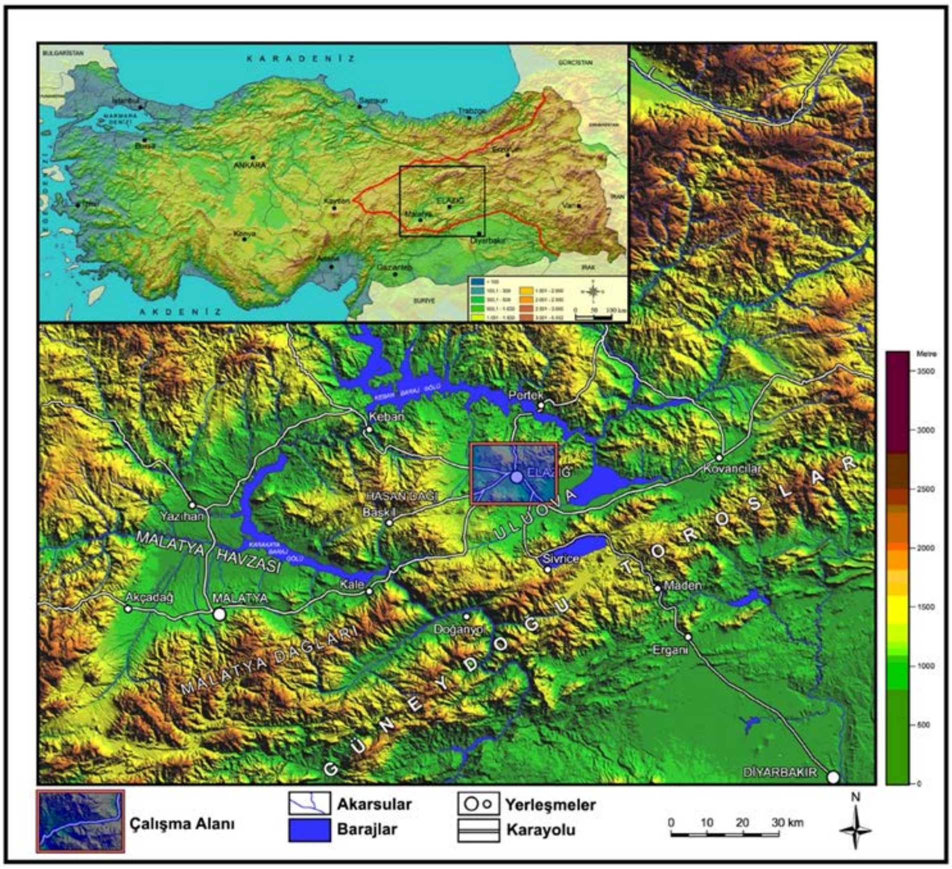

Figure 4 Location of the Working Area

Gazi Street was added in 1940, roughly dividing the city into two in east-west direction. Again, after the 1940s, developments in the western parts of Rızaiye, İzzetpaşa, Nailbey and Akpınar Neighborhoods located in the north of the city accelerated (Karakaş, 2001). Development progressed slowly until 1950, compared to later periods that started to gain momentum with the help of transportation and public investments, and the acceleration of internal migration after 1990 with the completion of the Keban Dam in 1974 helped the development to continue rapidly (Karakaş, 1999). Its development until 1950 was towards the railway located to the south of the current Gazi street. The railway prevented the city from advancing southwards, and Sürsürü and Kesrik, Yenimahalle and Kültür Mahallesi were added later. In 1968, Elazığ was included among the priority provinces in development and the opening of the Academy in 1967, with the creation of a slum prevention zone in Zafran and areas such as Abdullahpaşa on the "Malatya road (1800 Evler)" (in case the city could not handle the population that came and will come before the dam and the possibility of slums (Atay, 1991; Çotur, 1990), the city started to develop towards the west. For these reasons, Fevzi Çakmak and Yıldızbağları developed in the north of Yenimahalle and İzzetpaşa District in the northern part of the city, and the development of the city was directed towards the west with the 1800 Houses created for the future residents of Keban and the University District formed due to the academy. As a result, Aksaray, Üniversitesi, Fevzi Çakmak neighborhoods were developed in 1967 and Yıldızbağları neighborhoods were developed in 1968. After the 1970s, the establishment of a small industrial site caused the nearby villages of Çatalçeşme (Morning), Gümüşkavak (Hırhırik), Ulukent (Hüseynik) to grow and become populated, as well as the fact that Salıbaba Neighborhood, which is connected to Çatalçeşme village located to the east of the industry, was preferred by those working in the industry and those coming from outside. This led to it being turned into a neighborhood since 1974. Since 1991, Doğukent District has emerged in the area between Ulukent and Çatalçeşme Districts (Karakaş, 1999). After the 2000s, four different neighborhoods were added to the city: Ataşehir, Hicret, Hilalkent and Çaydaçıra District. After the 2020 Elazığ earthquake, with the transformation of the areas where TOKİs were established in various areas of the city into neighborhoods, Elazığ became a city consisting of 42 neighborhoods with a population of 387,072 (TUIK 2022). The study area border covers all the central 42 neighborhoods where the city is developing.

5. Findings

When the urban stain of the residential area of Elazığ city divided into parcels is analyzed, a possible fractal dimension of 1.86 appears as high as 1.86. In other words, it tells us that the city is highly compact. However, this value leads us to a misleading conclusion. Because choosing islands in the city stain in the analysis is contrary to the logic of measuring urban structure in Fractal theory. Because in this system, a result is obtained as if the entire residential area of the city is used (Figure 5).

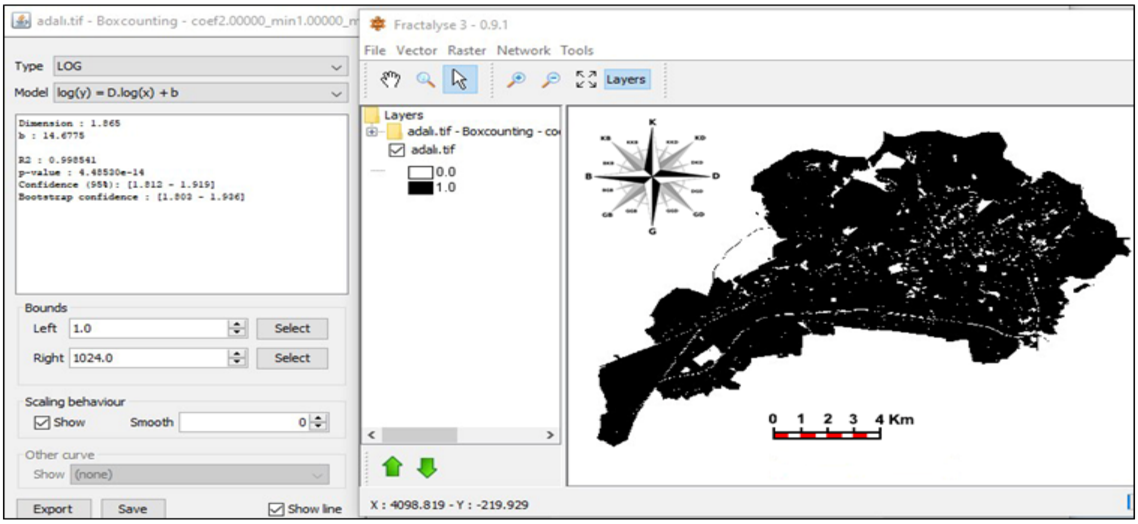

Figure 5 Urban Spot and Fractal Analysis (Raster) of Elazığ Residential Area at

When we apply the same measurement to the urban spot, where only the buildings of the city are spread, the result is quite different compared to the previous analysis. According to the new result obtained, the Fractal dimension value of the city is 1.62. This value is a very interesting result as the value of 1.60 is considered a criterion for cities being fringed and compact. Accordingly, Elazığ city is a fringed city in the process of becoming compact. In other words, a tendency for buildings within the city to come closer to each other has been observed (Figure 6).

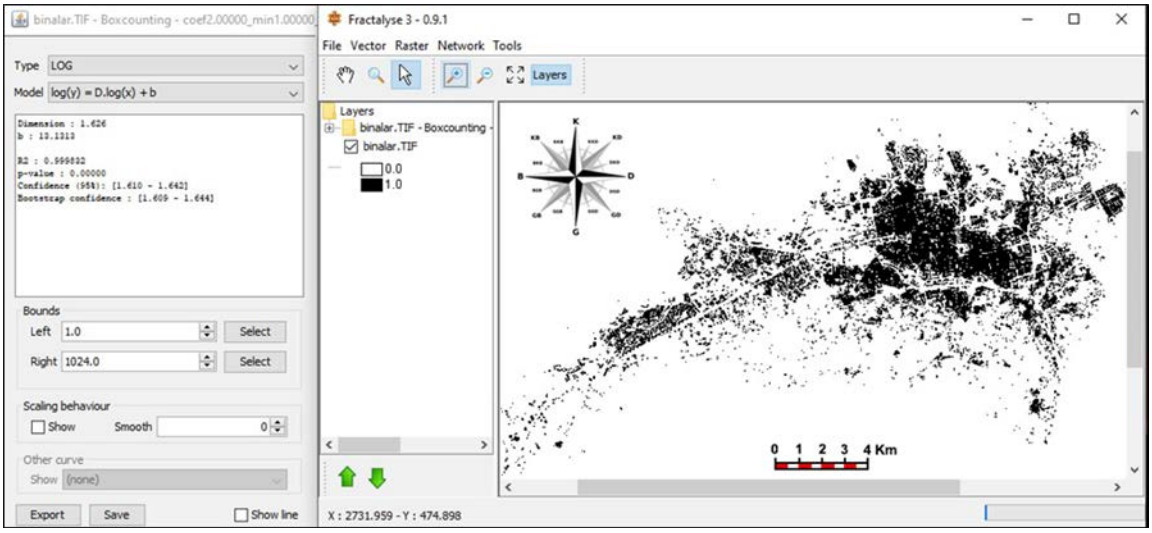

Figure 6 Urban Spot and Fractal Analysis (Raster) of Elazığ Residential Area at

A different result was obtained when the study area was analyzed vectorially. The result of fractal dimension analysis in vector data was 1.59. This value is very close to 1.60. However, what is understood from this analysis is that Elazığ is a city that still maintains its fringed structure on the way to compactness (Figure 7).

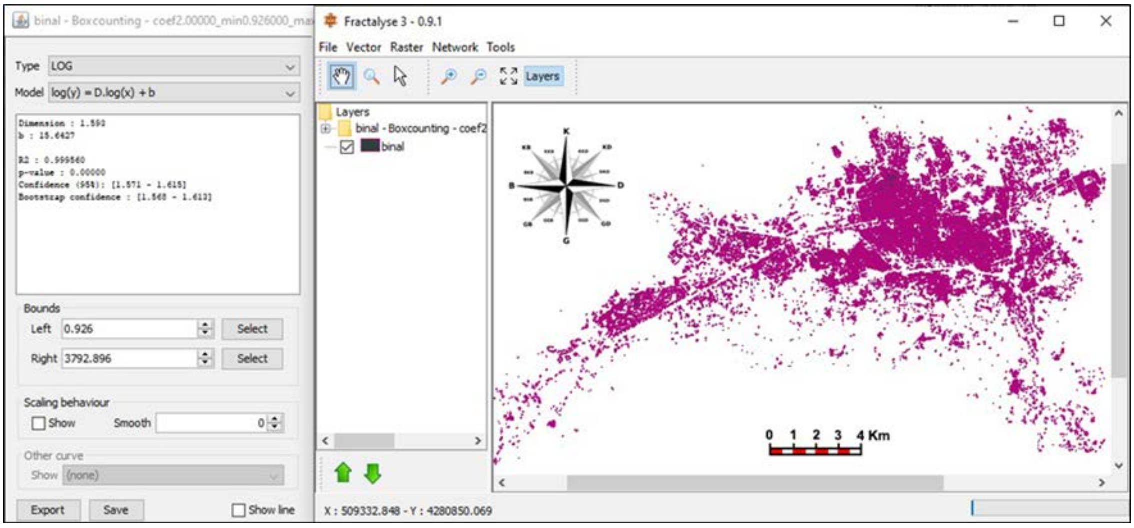

Figure 7 Urban Spot and Fractal Analysis of Elazığ Residential Area at Building

Urban morphology: Chapters are a section that provides understanding of the formation and transformation processes of settlements, their spatial characters, advanced developments and various comprehensive analyzes involving settlements (Kubat & Topçu, 2009, p. 336). One of the methods used when analyzing urban morphology is Space Sequence Analysis. In this method, both global and local analyzes can be performed. Thus, it is possible to explain both holistic and partial analysis. In this context, one of the questions that comes to mind is what is the Fractal dimension behavior of the parts that make up the whole? In order to answer this, it is necessary to resort to the analysis of three different selected spaces (Figure 3).

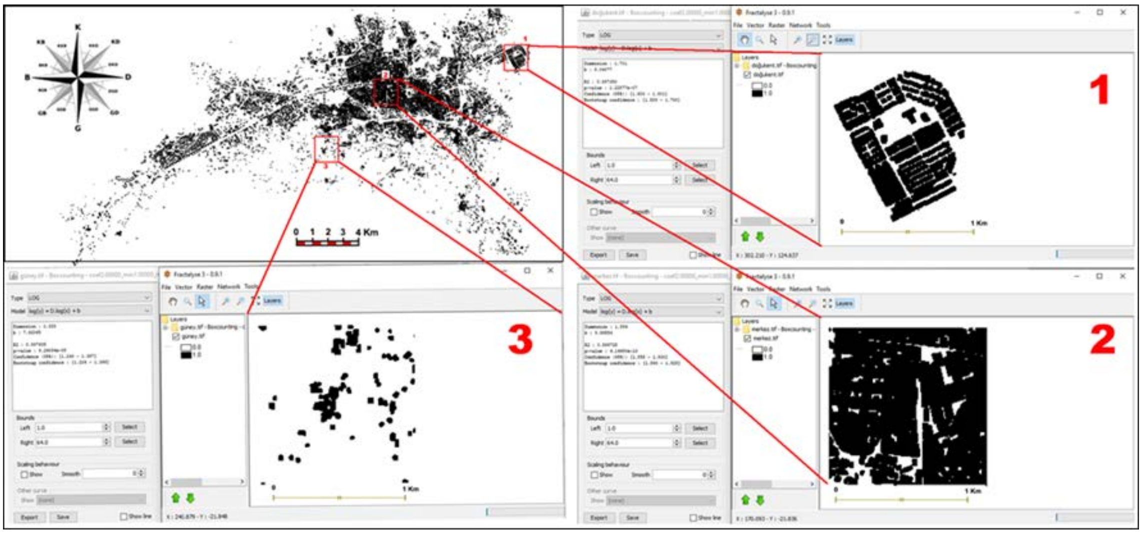

Figure 8 Fractal Analysis Results of Sample Selected Places. 1 Doğukent Sampling Area, 2. Central Sampling Area, 3. South Sampling Area Sampling Area, 2. Central Sampling Area, 3. South Sampling Area Scale (Vector)Building Scale Island Scale

In the easternmost part of Elazıg city, there is Doğukent District, which was built in a planned manner in the 1990s. In this place, which was developed in a "D" shaped pattern, residences and green areas were planned and built in advance. As a result of the fractal dimension analysis, the fractal value of the area was calculated as 1.70. This area, which has a compact structure, presents a positive situation against the urban sprawl. The sample taken from the central part of the city, called the Center, showed a high value of 1.89 in fractal dimension. The fact that the lands in the urban area are very valuable in terms of area has led to the construction of almost every part of this region. Dense construction, on the other hand, of course exhibits a compact structure with a high value. The newly developing northern, western and especially southern parts of the city display a sparse texture compared to an urban space. This sparse and scattered texture has of course created the areas where the fringing is most intense. As a matter of fact, the fractal dimension value of the sample selected from the south of the city showed a high fringed result of 1.32 (Figure 8).

6. Conclusion

Urban morphology consists of holistic subjects that examine the process of the physical texture of cities coming together, the qualities of the patterns within the texture, and the observation of temporal changes. One of the important methods that makes sense of the morphological features of cities and produces products on a scientific scale is the fractal dimension. There are many ways to calculate fractal dimension. The most common of these is the box counting method. Many software have been developed in this context. While some of these software are developed only for fractals, some are in the form of tools within programs. The preferred program for this study was Fractalyse 3.0, which can analyze both vector and raster data.

While raster data counts only point urban spots, vector data also includes points, lines and polygons. Vector and raster data have advantages and disadvantages against each other. For example, vector data allows network analysis because it can analyze polygons and lines, while raster data allows correlation analysis. Higher resolution of vector data can provide more accurate results in fractal measurements. Based on the information obtained from the study, it was concluded that the measurement difference was not very high. Raster and vector data can preferably be used in analyses.

In fractal analysis, city spots should be created not on islands-parcels but on buildings that show the real expansion area of the city and the way it uses the space. In this context, it is possible to say that the city of Elazığ is at a point between being fringed and compact, based on both vector and raster analyzes performed on city spots obtained from buildings. While the old neighborhoods of the city contribute positively to its compactness, the newly developed neighborhoods around the city increase the city's sprawl coefficient. The evolution of the city over time will determine its own destiny.

Of course, the data obtained from holistic analyzes are meaningful on their own. However, analyzing the parts that make up the whole gives information about how the city should actually grow as it grows. For example, in the fragment analysis, the center and Doğukent emerged as compact spaces. But is the city formally like Doğukent? Or is it like in the center? We need to consider that it should be compact. So, does having a very high fractal dimension always have a positive outcome for cities? The answer to the question must be sought. In fact, further studies can be carried out to reveal the optimum numerical value of compactness. For example, when viewed morphologically, Doğukent District in the study area presents a harmonious structure for the urban form, both with its green area and its alignment. Since the fractal dimension value of this area is 1.70, it can be said that this value is the optimum fractal dimension value for the study area.

While measuring the fractal dimension in the future, it is thought that performing part analyzes as well as holistic analyzes will make a positive contribution to the system in order to get a more detailed idea about the study areas.

In line with the information obtained from previously produced publications during the study, it was concluded that fractal analyzes are not just simple fractal measurements. Multi-fractal analyzes can also be performed in which the physical, human and economic characteristics of cities are overlapped with their fractal dimensions. In line with this information, we can say that geographers in our country should show interest in studies using both fractal and multi-fractal methods.

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Resume

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