# INVESTIGATING COMPLEXITY OF İZMİR REGION BY FRACTAL ANALYSIS

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# ABSTRACT

## INVESTIGATING COMPLEXITY OF İZMİR REGION BY FRACTAL ANALYSIS

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Application of fractal analysis under complexity sciences to cities and regions have become a research area. This study aims to analyze the relationship between complexity patterns of regional road network with growth dynamics with respect to borders as exogenous context and then to represent the endogenous complexity of İzmir with respect to time by using fractal analysis. The analyses cover a time span from mid-20$^{th}$ to present time. Due to inaccessibility of older image and photos of the region, standardized maps published by public institutions are used to produce road network. In the first part of the study aiming to identify the exogenous complexity, two scales are determined as the extended and the İzmir region. Extended region is defined with respect to road system thresholds covering an area extending the administrative borders of İzmir. The frame of İzmir region is determined as the administrative provincial border and the present district borders to identify the relationship between fractal dimension values with population change with respect to time. Since complex urban and regional systems are emergent open systems, in the second part of the study endogenous complexity of the İzmir region is analyzed by sub-fractal analysis. In the second part as endogenous complexity analyses, the outcomes of the analyses are compared with respect to real-world changes. According to the results, complexity of the extended region presents stable periods observed in the chaos theory. For İzmir region, non-urban network presents complexity apart from settlement presence. Higher fractal dimensions could be observed in both central districts and non-urban settlements by hard and soft cluster analysis. Parallel to regional growth dynamics, change in complexity of the parts is not directly relational to complexity of the whole system. The other outcome is that relationship between population and fractal dimension is not positively correlated in each period. This outcome is observed both for extended region and for *İzmir* that further growth is observed with decline in fractal dimensions. Finally, the endogenous complexity could be represented by sub-fractal analysis since the analyses results fits to the real-world dynamics through time.

Keywords: Complex regions, fractal analysis, sub-fractal analysis

## ÖZ

**FRAKTAL ANALİZ YÖNTEMİ İLE İZMİR BÖLGESİNİN KARMAŞIKLIĞININ İRDELENMESİ**

Özdemir, Sıla
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Karmaşıklık Biliminin kentler ve bölgelere uygulanması bir araştırma alanı haline gelmiştir. Bu çalışmanın amacı fraktal analiz yöntemi ile bölgesel ulaşım ağının karmaşıklığı ile büyüme dinamikleri arasında sınırlar çerçevesinde eksojen olarak zamana bağlı ilişkisinin bulunup bulunmadığının ortaya koyulması ve devamında İzmir'in endojen karmaşıklığının yetmiş yıllık bir süreçte temsil edilmesidir. Analizler 20. Yüzyıl ortası ile günümüz arasını kapsamaktadır. Bölgeye ait eski tarihli fotoğraflara erişim imkânı olmaması nedeniyle yol ağının üretimi için kamu kurumlarınca basılan standart haritalar kullanılmıştır. Çalışmanın ilk bölümünde eksojen karmaşıklığın saptanması amacıyla geniş bölge ve İzmir olmak üzere iki ölçek belirlenmiştir. Geniş bölge yol eşikleri ile belirlenirken İzmir'in idari il sınırı dışındaki alanı kapsamaktadır. İzmir bölgesi ise fraktal boyut ve nüfus arasındaki zamansal ilişkinin saptanabilmesi amacıyla mevcut İl ve ilçe sınırları ile belirlenmiştir. Karmaşık kentsel ve bölgesel sistemler kendiliğinden ortaya çıkışı içeren açık sistemler olduğundan çalışmanın ikinci aşamasında İzmir bölgesinin endojen karmaşıklığı alt fraktal analizi ile incelenmiştir. Çalışmanın ikinci aşamasında üretilen endojen karmaşıklık analizleri gerçekleşen değişimler ile karşılaştırılmıştır. Sonuçlara göre kaos teorisinde de görüldüğü gibi geniş bölge

ölçeğinde durağan dönemler olduğu tespit edilmiştir. İzmir bölgesinde ise kentsel olmayan ağın yerleşimlerden bağımsız bir karmaşıklığa sahip olduğu görülmüştür. Yüksek fraktal boyut değerlerinin hem merkezi ilçeler hem de kentsel olmayan yerleşimler için söz konusu olduğu hiyerarşik ve bulanık kümeleme analizleri ile görülmüştür. Bölgesel büyüme dinamiklerine paralel olarak parçaların karmaşıklığının değişiminin doğrudan bütünün karmaşıklığı ile ilişkili olmadığı tespit edilmiştir. Bir diğer sonuç nüfus ile fraktal boyut arasında her dönem için pozitif yönlü bir ilişki bulunmadığıdır. Hem geniş bölge hem de İzmir Bölgesinde süreğen büyüme fraktal boyutun düşmesi ile birlikte gözlenmiştir. Son olarak alt fraktal analiz ile temsil edilen endojen karmaşıklığın gerçek dünya dinamiklerinin zamana bağlı değişimi ile uyumlu olduğu tespit edilmiştir.

Anahtar kelimeler: karmaşık bölgeler, fraktal analiz, alt fraktal analiz

*To my family*

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# CHAPTER 1

# INTRODUCTION

Epistemology of urban and regional planning has been challenging with paradigm shifts in natural and social sciences. Since urban and regional models and planning approaches built their epistemological base with respect to different disciplines, in addition to the changes of global settlement system, change in those conceptualizations lead to investigation of new approaches of settlement system. Complexity approaches have been developing for representing and modelling the urban and regional systems.

The classical approaches take their roots from the mechanics of Newton and the geometry of Euclid. Likewise, neo-Kantist geography shape representative approaches and abstractions of the global structure. The individuals were conceptualized with respect to neo-classical economic models while relations of them are based on the assumptions of neo-classical economy theories, Darwin's theory of evolution and class based theories. Urban and rural involve a division as the core and periphery. The models having those conceptualizations about settlement systems are constructed with positivist and deterministic calculations based on perfect fit and equilibrium.

The altered conceptions about time, space and individuals presents changes in economic, social and ecological conceptions of urban, rural or urban-region. Accordingly, the main models defining, representing and conceptualizing urban areas is mainly derived from them. The approaches regarding cities as open and complex systems criticized the classical urban models with respect to those conceptualizations. The views representing urban and urbanization process as a self-organizing systems are not completely isolated and provide explicit link to the view of the cities regarding central places, ecological systems or socio-cultural structures.

Classical physics challenged from absolute terms to relative terms. Space and time conceptualization altered with respect to Einstein's Intuition. Development of quantum physics starting from the theory of Planck of quanta leaded to a shift from determinism. In addition to shift to complexity, the other sole change in science is the shift from reductionism to holism that classical science has become ineffective for explaining the time and space relations (Berthon & Robinson, 1991). As Merrifield (2013) states moving away from the notion of a *city* / *nature* toward *the urban* is linked to the paradigm shift on a par with Einstein as a shift from the absolute to the relative. The anti-calculus based fractal objects (space) and dynamic systems (time) has altered space and time conception in natural sciences. Complexity and chaos based approaches evolved in the perception of settlement systems including urban, rural and region.

The individual tendencies, preferences and relations are subjected to conceptualization change the main ontological assumptions of neo-classical paradigm was partially replaced with a new approach based on network sharing and corporation (Yeung, 1984). It has been discussed that complexity science can be applied to economic, technologic and human-interacted networks (Batty, 2005).

The duality of urban and rural is also discussed by the first emphasis of (Lefebvre, 1970) as "*the complete urbanization of society"*. Meanwhile, United Nations declared in 2009 that the world has become more urban than rural (United Nations, 2009). The old duality of traditional rural and rural as contradiction of each other was altered. In early twenty-first century, urban became a floating signifier: devoid of any clear definitional parameters, morphological coherence, or cartographic fixity, it is used to reference a seemingly boundless range of contemporary socio-spatial conditions, processes, transformations, trajectories, and potentials. The blurriness of urban and rural supported by planetary urbanization arguments (Brenner, 2013), (Brenner & Schmid, 2012).

Affected by those paradigm shifts, urban and regional settlement systems have been conceptualized as complex systems as they are self-organizing, emergent, non-linear and open (Batty & Longley, 1994), (Portguali, 2000), (Batty, 2012). Their morphology is produced by top-down (global) and bottom-up (local) processes (Batty, 2010). The tools of urban modeling are augmented with the incorporation of non-conventional mathematics/modeling techniques and theory including chaos theory, cellular automata, agent based modeling, artificial intelligence, neural networks, spatial metrics and fractal analysis.

Depending on this context, this study's main aim is to analyze the relationship between complexity of the region involving urban and non-urban areas as fractal analysis with regional development trends. This aim is organized by the following objectives (secondary aims):

- Determining the relationship between population and network growth with fractal dimension in regional scale
- Comparing scaling factor of the regional complexity analysis
- Developing a methodology to intrinsic, endogenous complexity representation of regional studies
- Providing an evaluation scheme for applicability of fractal analysis to regional scale

Moreover, the aim and the related objectives are formulated by the following research questions:

RQ1) Which complexity approaches could be used for analysis of road network in regional scale?

RQ2) Are the relationships between regional growth with fractal dimension in regional scale consisted with the expected results with respect to literature review with urban scale studies?

RQ3) Do the fractal dimensions of the parts involve relations with the whole and the other parts?

RQ4) Are there any similarities or differences among parts of the system?

RQ5) Do fractal dimension of a part with respect to given (exogenous) borders are consistent with the intrinsic (endogenous) complexity pattern?

RQ6) Could the development dynamics of a region with respect to time could be represented by fractal dimension analysis?

The analyses are conceptualized with respect to scale and direction. Appropriate to the findings of regional conceptualization two scale / framework of analysis are defined as; (i) Extended region, (ii) İzmir region. The extended settlements around İzmir's network are conceptualized as extended region with a map scale of 1/85000. İzmir region is then defined as the provincial borders of İzmir. The analyses are produced by 1/25000 scaled maps. In order to construct a comparable relationship between fractal dimension and population with respect to time, firstly fractal dimension analyses are conducted with respect to administrative borders exogenously involving relational aspects of complexity, population and network growth. Secondly, as a bottom-up and intrinsic approach, complexity of the region is analyzed by sub-fractal analysis for İzmir region. The organization of the analyses are represented in Figure 1-1.

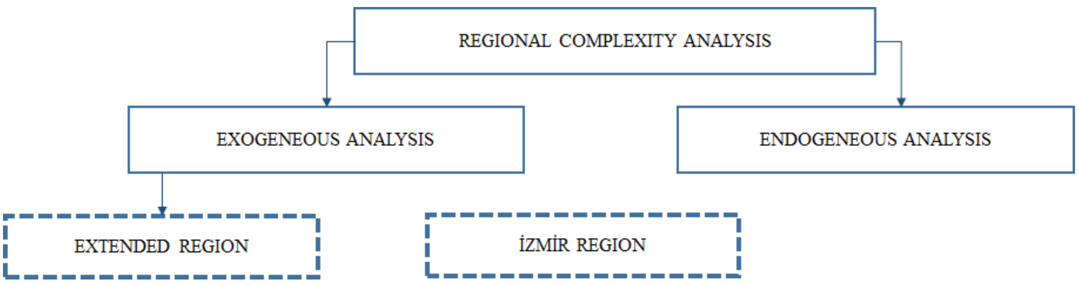



Figure 1-1 Organization of the Analyses

Accordingly, the study is organized into chapters as follows:

Chapter 2 provides the general background of the study in terms of complexity approaches. The roots of paradigm shift from classical urban conceptualizations to complex urban system approaches are introduced. The conceptualizations of classical theories are briefly discussed. Then main complexity approaches are summarized by evaluating the existing discussions of the classical models.

Chapter 3 involves a narrowed literature about fractal analysis as one of the approaches of complex urban system. The definition of fractal, theoretical concepts and measuring methods are presented. Then, the main literature findings about fractal analysis of cities are discussed. Moreover, fractal dimension analyses studies of Turkish cities are summarized. As a specialized application of fractal studies, fractal analysis of road network and city-systems are introduced. At the end of the second background chapter, further analysis of fractal analysis as lacunarity and sub-fractal analysis are identified.

Chapter 4 presents the case study area and methodological framework. In this framework, the regional background of İzmir is presented including major historical development trends, regional plans, legal framework and conceptualizations of the region. After a general summary of the regional background, sub-regions are defined and each district of İzmir is briefly introduced in terms of main development trends. Definition of the case study area is followed by definition of the method. Data preparation processes for the analysis are defined. Then, selected fractal dimension analysis and sub-fractal dimension analysis method is presented. Furthermore, statistical methods are introduced which are used to define relationship between given and measured complexity parameters.

Chapter 5 presents the analyses results of extended and İzmir region's fractal dimensions from early 1950s to 2018. Then, statistical relationships between extended region's fractal dimension values with population of İzmir are expressed. İzmir region analyses cover a time span from 1950s to present time. For İzmir region, firstly the whole network's fractal dimension and the relationship of it with demographic and network based variables are introduced. Then, each district is evaluated by the same method.

Chapter 6 introduces the evaluatıon of the analysis presented in Chapter 5. Population change of İzmir region is summarized for each period from 1950s to present time. Then detailed relationship analyses of fractal dimension with respect to parts and the whole of the region are discussed.

Chapter 7 presents endogenous complexity of İzmir region by sub-fractal analysis. Firstly, the intrinsic complexity is represented with respect to optimized mesh size. Then, for comparable analysis with respect to time, least mesh size analyses are obtained for each time period. The results are discussed with respect to real-world changes.

Chapter 8 concludes the study with a summary of the research. Then, sole findings of the study are presented. According to the analyses results and literature background a brief discussion is proffered about possible contribution of the fractal analysis to planning. At last, the limitations of the study and future research possibilities are discussed. The research map is presented in Figure 1-2.

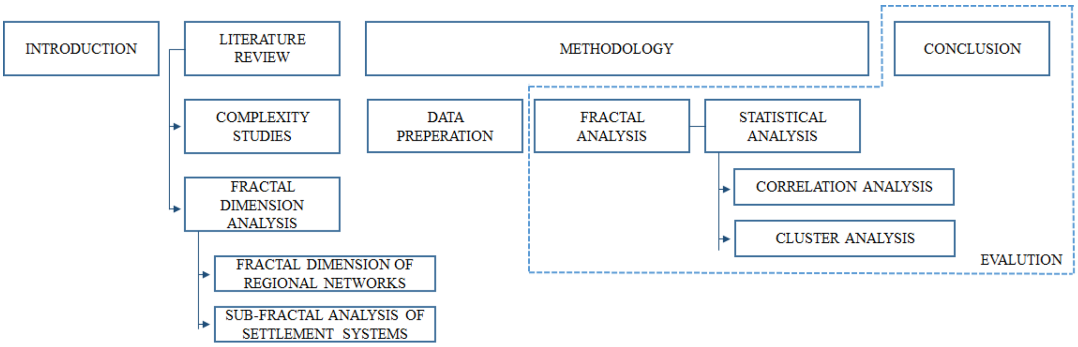



Figure 1-2 Research Map

# CHAPTER 2

# BACKGROUND: COMPLEX URBAN AND REGIONAL SYSTEMS

This chapter presents a background review about the transition from classical urban concepts and theories to complexity approaches. The focus is to understand how complex and self-organizing city and city systems is evolved. Consequently, as presenting the paradigm shifts from classical to complexity of approaches an extensive review is presented about how city systems could be modeled and conceptualized with respect to complexity science.

## 2.1 Roots of Paradigm Shift from Classical to Complexity Science

The transformation process in conceptualization of settlements and settlement systems is derived from the paradigm shifts in natural and social sciences. Since urban and regional models and planning approaches built its epistemological base with respect to different disciplines, alterations in settlement related conceptions caused in a transformation of urban and regional conceptualization. Firstly, transformation in space and time conception is evaluated. Then, changes in theory and assumptions of economic geography and regional growth theories are presented in order to identify the new lens observing cities and city systems as open, emergent complex systems.

### 2.1.1 Roots of Paradigm Shift from Classical to Complexity Science

The main the dimensions of a physical entity or an object are space and time (Baranger, 2000). During 19$^{th}$ century, the mechanics of Newton and the geometry of Euclid became the cornerstone of modern science. Then, Darwin's theory of evolution proposing survival of the fittest prepared epistemological base for understanding social systems. The representation of space in perfect geometry is rooted in the perfect spherical model of the earth including (i) the point, (ii) the line, (iii) the circle and (iv) the sphere. Newton's science is rooted in the notion of a perfect geometry in terms of his and Leibnitz's mathematical views. Furthermore, Newtonian mechanics depended upon the principle of continuity, all which resulted in a continuous and linear space and time conception. As a result, social sciences began the quest to develop a science akin to physics based on reducing every phenomenon to continuously varying structures of simple casual relations, pure geometry, equilibrium and convergence.

As the interpretation of the settlements, towns and cities are classified into those, which grow 'naturally', or 'organically' and those, which are 'artificial' or 'planned'. The first conception of the earth was the Greeks conceived the earth as a sphere. The favor of both conception and creation of space in perfect geometry emerged by Greek scientists and provided the foundation of the modern age dominating the architecture and planning until present day (Berthon & Robinson, 1991).

Beginning from the late 19$^{th}$ century, classical physics is challenged from absolute terms to relative terms. Firstly, physical observations of phenomena involving the speed of light like planetary orbits no longer fit to Newtonian theory. Einstein's Intuition was reconciled the space-time continuum. It is observed by the Relativity Theory that the absolute within the universe exists if observers see the same thing at different positions in time and space. Secondly, reductionism in physics took a major step forward in the late 19$^{th}$ century when the idea of the atom and its constituent parts became the intense focus of concern. Development of quantum physics starting from the theory of Planck of quanta leaded to a shift from determinism.

Perception of time and space by scientific tools also rooted in mathematics related to physics. Approximately three centuries ago, Newton and Leibniz invented calculus. As Baranger (2000) states, invention of calculus eased to handle and analyzed complicated objects. The simplicity of calculus provided a deterministic approximation conception of space. The mathematicians suggested concepts like continuity and analyticity to describe smoothness more precisely. Moreover, it is accepted that everything can be reduced to little pieces of straight lines, therefore everything can be known and understood, if we analyze it on a fine enough scale. The anti-calculus based fractal objects (space) and dynamic systems (time) has altered space and time conception in natural sciences. Complexity and chaos-based approaches evolved in the perception of urban space as well as time are still growing in epistemological and practical studies.

### 2.1.2 Changes in Space and Time Conception

Social sciences adopted the concept of space and time from the epistemology of natural sciences by defining new concepts for the missing aspects. Multi-dimensional aspects of the space and time create a different way of understanding. A materialist interpretation of spatiality is the recognition that it is socially produced like society. Space exists in substantial concrete forms as a set of relations between individuals and groups. Socially reproduced space which is presented by Lefebvre differs from physical space (material nature) and mental space (cognition and representation). Soja (1989) argues that in a certain extent, physical and mental spaces can be theorized independently however; physical, mental and social spaces should not be theorized rigidly separated since there are interconnections among them. Defining the interconnections is a challenge of contemporary social theory especially since the historical debate is monopolized by the physical-mental dualism. This interpretation is created by the effect of Cartesian abstractions, post-Newtonian social physics or a post-Darwinist socio-biology. In other words, reduction of spatiality to mental cognition of space in which the "image" of reality takes epistemological precedence over the tangible substance has been defined as a hypertrophic illusion by Soja (1989) which resembles the argument of Christopher Alexander as "*City is not a tree*".

In terms of representation of space, modernism and nation state dominancy represented settlements by neo-Kantian paradigm, which is mainly based on a territorial (area-based) representation. After World War II, new geographical representations and abstractions were constructed by the impact of neo-positivist approaches. Tekeli (2006) identifies those representative techniques as the point and network based representations of space added to old territorial based differentiation. The spatial parameters of urbanization are generally represented and conceptualized with reference to two major vectors—inter-city relations (expressed, for instance, in exchange or communications networks); and city-suburban-hinterland relations (expressed, for instance, in flows of labor, food, energy and materials) (Brenner, 2014). During 1960s, following the population-centric definition of urbanization developed earlier by Kingsley Davis, settlements are conceptualized as two dimensional territories for smaller scales and dots weighted according to population sizes in larger scales.

After World War II, an era dominated by instrumental rationality, space was evaluated by the ontological assumptions of the neo-classical economic view by mainstream models. The models identify the city as a mono-centric point controlling a territory having its own integrity. During 1970s by surpassing quantitative revolution, new representation proposals were developed. Tekeli (2006) expresses that meaning of space was associated with individual by phenomenology.  Other spatial conceptualization is produced by Marxian theory defining the role of capitalist production in geography. The western philosophical tradition rigidly separates time from space by regarding space as fixed, undialectical and immobile while regarding time as rich and dialectic is criticized. As Harvey (1973) states investigating the only absolute, relative or relational aspects of space could not be valid that *"... it can become one or all simultaneously depending on the circumstances.*" Although Marxist models put little contribution to space conception, the continuous and equally divided time conception has been transformed by the term "uneven development". The spatial unevenness is also described in regional science and economic geography which involve the deterministic space and time conception of classical physics.

In order to answer the question what stimulates geographic development, the properties of spatial agglomerations have been analyzed by economic geographers. In the second half of 1980s, a new paradigm approach was developed proposing the integration of local to global. In this respect, representation of space was varied with respect to international trade theories as well as macro-economic paradigms. New economic geography identified that concentrations does not depend on the uneven distribution of natural resources, climate or proximity to coasts and rivers which is called as “endogenous core-periphery model”. However, the main challenge of new economic geography models are the application them to real cities and city-regions. Since city-regions are formed through agglomeration and decentralization processes, urban economists also focus in different types and driving forces of de-concentration. In order to achieve lower trade costs and higher levels in economies of scale, industries decentralized to peripheral regions and new agglomerations were arise in peripheries (Storper, 2013). However, where agglomerations and decentralizations occur still lacked a sufficient precision and they mainly based on neoclassical economics ontological assumptions.

As it can be observed by Schelling (1978), non-racist individuals can exhibit a preference form having a small minority of people “like them” living close by. Due to those individual tendencies, dramatic levels of segregation can occur in a settlement. In other words, incremental slight preferences can lead to high levels of change that unintended consequences can emerge in space. From agent level there exist second-order preferences, blocked future preferences, irrational decisions or collective rationalities. As a geographical scale of economic system, cities and city-systems have complex economic development processes shaped by infinite range of forces. One of the main ontological assumptions of neo-classical paradigm was partially replaced with a new approach based on network sharing and corporation (Yeung, 1984). After all those alterations in the real-world and it’s conceptions, it has been discussed that complexity science can be applied to economic, technologic and human-interacted networks (Batty, 2005).

## 2.2 Change in Conceptualizations of Settlements

Discussions on globalization minified distinction between core and periphery in economic geography. Dual driving forces of agglomeration and decentralization could be integrated to discussion about the terms what and where urban, rural and region is. Lefebvre (1970) firstly emphasizes hints of planetary urbanization by referring it as "*the complete urbanization of society"*. Moreover, it is identifies rural and urban structures are no longer a definitive split between strict opposites. Rather separation, it is *immanent* within the accumulation of capital itself, *immanent* within its secondary circuit of capital that 'the frontier line doesn't pass between the city and the country, *but is within the interior of the phenomenon of the urban*, between a dominated periphery and a dominating center.It is also argued by Angelo (2016) that the argument in the first decade of the 21st century as we live in an urban age has also become a foundational ideology of our time like the urban-rural dichotomy rooted in post-colonial urban literature. Brenner & Schmid (2014) claim 50% global urban population threshold that is claimed to have recently been crossed has become a convenient metanarrative.

Urban categories could also be observed in terms of definitions and categorication of settlements. Gans (2009) referred to categorization problem urban-suburban-town-rural by inventing adjectives to deal with at least some of the variations in blurry 'rurban' spaces. Brenner (2013) points out in the early twenty-first century, urban became a floating signifier: devoid of any clear definitional parameters, morphological coherence, or cartographic fixity, it is used to reference a seemingly boundless range of contemporary socio-spatial conditions, processes, transformations, trajectories, and potentials. Likewise, Brenner & Schmid (2014) states the ideological dimension of urbanization requires sustained analysis and deconstruction by critical urban theorists that socio-spatial organization are radially reorganized to produce new landscapes of urbanization whose contours remain blurry, volatile and confusing and are therefore particularly subject to fetishized forms of narration, representation and visualization. As an answer to those arguments, planet scale urbanization discussions revises Schumpeter's creative destruction as "implosion-explosion". It is not confined to any specific place, territory, or scale and is connected to the uneven generalization of urbanization on a planetary scale. The problem of an area-based representation of urban space is discussed by Amin & Thrift (2002, p. 1) as;

*"The city is everywhere and in everything. If the urbanized world now is a chain of metropolitan areas connected by places/corridors of communication (airports and airways, stations and railways, parking lots and motorways, teleports and information highways), then what is not the urban? Is it the town, the village, the countryside? Maybe, but only to a limited degree. The footprints of the city are all over these places, in the form of city commuters, tourists, teleworking, the media, and the urbanization of lifestyles. The traditional divide between the city and the countryside has been perforated."*

In addition, there occurred a tendency from abstaining of the use of the terms 'urban'. Usage of 'settlement' or aggregation' may be seen as substitutes (Gans, 2009), (Tekeli, 2016). Another response is to construct new fundamental urban categories for urban studies and urban social analysis due to altering physical and economic geographies and the ontological nature of the urban like the Brenner's "Planetary urbanization" (Angelo, 2016). The term 'planetary' is evaluated by Merrifield (2013) as alive, growing and more vivid term. A similar new terminology is suggested as "extended regional urbanization" by Soja and Kanai (Soja & Kanai, 2006, p. 58) as;

*Urbanism as a way of life, once confined to the historical central city, has been spreading outwards, creating urban densities and new "outer" and "edge" cities in what were formerly suburban fringes and green field or rural sites…urbanization has expanded on even larger regional scales, creating giant* *urban galaxies with population sizes and degrees of polycentricity far beyond anything imagined only a few decades ago. . . . In some cases city regions are coalescing into even larger agglomerations in a process that can be called "extended regional urbanization."*

Those arguments are also integrated with the conception and representation of space and how it is altered. Portugali (2000) claims problems in defining the city derives from the fact that they have been put cities into classical categories. (Angelo, 2016) states urban political ecology, American urban sociology and postcolonial urban studies have made 'nature', the 'rural' and the 'not yet' city the objects of urban analyses. The lens, named as city lens, has ground in the context of the 19th century industrial metropolis, interprets the world on the basic assumption that the city is defined against a non-urban outside. The socio-spatial dimensions of urbanization are described as polymorphic and dynamic in twentieth-century urban studies possess a methodologically territorial cartography. The territorial and settlement-based understanding of "cityness" is condemned to take its basis in the morphologies of industrial and metropolitan urbanization during the nineteenth and twentieth centuries (Brenner & Schmid, 2012).

Merrifield (2013) explains that urbanization of the world is a kind of exteriorization of the inside as well as interiorization of the outside. This can be interpreted as both urban unfolds into the countryside just as the countryside folds back into the urban. Furthermore it is also stated that the fault-lines between these two worlds aren't defined by any simple urban-rural divide instead, centers and peripheries are immanent within the accumulation of capital itself. Furthermore, it is added that the dissolution of binary as urbanization shed its skin and corroded its shell. Likewise to neo-Marxist approaches, the explosion of urban growth has consequently been a process of uneven development, homogeneity and fragmentation so rural places have said to become integral moments of neo-industrial production and financial speculation.

Definition of a diffusing “urban” creates a new understanding of rural. Brenner & Schmid (2014) argue the non-urban realm cannot be interpreted simply as an empty field, as an indeterminate outside that serves to demarcate the urban condition. This terrain has been neither empty nor disconnected from the process of agglomeration; it has actually evolved dynamically through a complex, constantly thickening web of economic, social and ecological connections to the heartlands of urban concentration across every zone of the world. The zones determined as non-urban have been materialized in densely tangled circuits of labor, commodities, cultural forms, energy, raw materials and nutrients simultaneously radiate outwards from the immediate zone of agglomeration.

The views about new epistemological seek do not only involve the metropolitan cores, urban or rural, but they also articulate vast grids of accumulation and spatial regulation that cascade intercontinental transportation corridors; large-scale infrastructural, telecommunications and energy networks: free trade zones; transnational growth triangles and international borders. In other words a re-description is regarded as necessary for reposition the vision (Brenner & Schmid, 2014), (Merrifield, 2013), (Angelo, 2016). In terms of urban rural dichotomy Angelo (2016, p. 4) states that *“..the urban can no longer be represented as the familiar ‘grey’ of the city in contrast to a presumably ‘green’ outside’.* An integrated argument with planetary/extended urbanization is grounding urban metabolism. İbanez & Katsikis (2014) suggests a territorial approach with specific functional sites of metabolic activity, such as landfills, mines, agricultural fields, and ports. This is the view that cities are open, complex and dynamics systems that that settlements and infrastructure systems, buildings and cities, ports and highways, dams and pipelines, mines and oil rigs, agricultural lands and irrigation networks, landfills and waste treatment plants are all are parts of a dynamic metabolism of people, energy, water, nutrients.

## 2.3 Change in the Models of Settlement Systems

19th century social scientists fascinated by industrial cities' human density, diversity, vibrancy, isolation, poverty and anomie described in city/not city terms. Those binaries could be observed as; Gemeinschaft/Gesellschaft, agrarian/industrial and traditional/modern. Gans (2009) explains the study of Wirth defining cities as large, dense, and heterogeneous provided a definition of the rural areas as lacking this trio of characteristics.

Starting from 1920s, the early models are based on the effects of rapid urban growth after industrial revolution. After World War II, as a result of the increased car ownership and welfare economic policies, zoning based growth model could be observed. Growing suburbs and metropolitan areas created a focus on incoherence of the city as a spatial or economic unit in 1960s. Then, the most widespread use of models in urban geography was developed in 1960s which is described as *quantitative revolution*. Furthermore, neo-Marxists put growth in agenda by considering urban economy first. Changing geographies of production and consumption, as well as new cultural forms including postmodernism were the focus of theoretical debates in 1970s and 1980s (Angelo, 2016).

To sum up, the altered conceptions about time, space and individuals are relevant with the changes in economic, social and ecological conceptions of urban, rural or urban-region. Accordingly, the main models defining, representing and conceptualizing urban areas is mainly derived from them. The approaches regarding cities as open and complex systems criticized the classical urban models with respect to those conceptualizations. Nonetheless, complexity approach conceptualize urban and urbanization process as a self-organizing system is not completely isolated and provides explicit link to the view of the cities as central places, ecological views or socio-cultural concept. Therefore, both the classical and complexity based approaches defining and representing urban systems are discussed.

### 2.3.1 Classical Approaches

The history of the many attempts to define “a city”, its borders and extent is rather confusing (Allen, 1996), (Portugali, 2009). Classical models can be categorized into three types with respect to their degree of simplification and abstraction as; (i) scale models, (ii) conceptual models and (iii) mathematical models. The miniature copies of reality can be referred as scale models. The increased level of abstraction by focusing on the relationships between different components of reality can be referred as conceptual models. Lands use models like Von Thunen’s is an example of conceptual, diagrammatic model of urban areas. The highest level of abstraction can be observed in mathematical models (Liu, 2009). The main classical approaches conceptualized city or city region could be summarized as;

#### 2.3.1.1 The Economic Model

Rise of capitalism and the eclipse of the mercantile provoked the conceptions of Marx, Weber, and Durkheim’s first urban observations of the industrial city in the 19$^{th}$ century. However, classical Marxist observations do not execute any spatial representation or abstraction. Those models based on economic theories. In terms of constructing models, von Thunen’s classical model of agricultural location, *Der Isolierte Staat (1826),* could be regarded as the first urban model. The model identifies an “isolated state, with only one central city as the sole market. A uniform plain surrounds the city that a concentric land-use pattern is generated with the least intensive land use located the farthest ring from the city centre (Liu, 2009). Three factors is determined in the model as; *(i) the distance of the farmers (ii) the prices of the goods* and *(iii) land rent.* Then revised models based on land rent were studied by different scholars. Weber’s (1909) *Industrial location* emphasized urban growth by triangles of the location of industries and Christaller’s (1933) *Central Place Theory* focused on regional growth.

#### 2.3.1.2 The Ecologic Model

This approach is based on the belief that human behavior is determined by ecological principles, such as competition, selection, succession, and dominance. The conceptualization of the city represented as concentrated rings in ecological concept. Rather than land rent, the city's concentrated rings emerge out of a competition between socio-economic groups resembling to the competition of the species in the nature. Chicago School's urban ecology model of Burgess is revised by Hoyt's sector model representing the city as a radial structure. Ecological models can be traced back to the work of the Chicago School of Human Ecology in the 1920s which explains urban development trends as invasion / succession process referenced in natural sciences. In other words, Chicago School approach focused in urban growth through competition for space. In ecological models the sole argument is that the most powerful human group would obtain the most advantageous spatial position. There exist three main ecologic models which are; Burgess's (1925) concentric zone model, Hoyt's (1939) sector model, and Harris and Ullman's (1945) multiple nuclei model. The first model which is concentric zone model based on the notion that a heterogeneous and economically complex urban society actively compete for central locations within the city. As Yin (2009) states model involves an oversimplification of reality and encouraged the postulation of growth since it does not consider various urban environmental factors such as topography or transportation networks. Hoyt (1939) revised the concentrated rings by a sector model in which homogeneous areas of residence tended to grow outward from the center toward the periphery in wedge-shaped sectors. Differing from Burgess model, it involves transportation system as an indicator. Furthermore, the effects of topographic variations and natural features are considered in advanced versions. The latest main urban macroform and growth model is Harris and Ullman's multiple nuclei model which still follows the general ecological principles as it proposes zoning. The land uses select location with respect to affordability of rent which maximizes around multiple centers, *nuclei,* rather than single center and activities always tend to be located in the vicinity of each other. As the city grew and changed, some new districts became more attractive than others.

#### 2.3.1.3 The Social Physical Models

As epistemological base of urban research is mainly derived from natural sciences, social physical models were developed as a direct analogy to physics. Newton's *Law of Gravitation* was based as an analogy for human interaction in space. The constraint is determined as distance or time. In addition to constraint of distance, by referring gravity model, human activities such as changes in residence and employment are modelled proportional to the mass of the activity at the origin and destination (Liu, 2009). The model was widely used in migration studies as well as urban networks involving allocation functions based on spatial accessibility analysis. As taking its roots from deterministic physics, making predictions is the sole part of the model. The typical gravity models revised in 1970s by adding the second law of thermodynamics, the maximum entropy law. In this model, the movements of people and goods in cities were treated as particles in gases considering origin and destination. The main principles of gravity based urban models have influences in complexity approaches while the pure quantitative calculations and equilibriums are eliminated.

#### 2.3.1.4 The Neoclassical Models

Urban economic models were built on the assumption that the process of urban development is essentially an economic phenomenon. They are driven by market mechanisms and the natural forces of competition among economic activities and social groups (Liu, 2009). They are based on equilibriums with respect to a deterministic resolution of supply-and-demand relationships obeying the general rule of least cost or maximum benefit in other words; utility maximization. Similar to socio-physical and economic models, two main constraints are transport costs and land rent. Furthermore, the ontological assumptions of the model are concentric, homogeneous city with one single center resembling to ecological models. Housing demand is simply determined by one indicator which is the plot size that public sector policies are ignored. The main known models are Wingo's (1961), Alanso's (1964) and Lowry's (1964) models. The first model developed by Wingo as a transport demand based model considering the spatial relationship between home and work. The accessibility is also taken into consideration like economic, ecologic and social economic models as the time cost of transportation. The model involves maximization rule of utility and aims to achieve a locational equilibrium. Alonso's model has similar attributes A bid-rent curve is constructed as a set of combinations of rent and transport costs including the assumption of the same satisfaction level for an individual. Lowry's model is the most widely practiced economic equilibrium approach. There are two basic assumptions of the model as; (i) residential densities located around the centers of employment, (ii) location of employment are influenced by the accessibility of customers. In 1970s, Lowry model was revised by comprehension of multiple urban centers, different transport modes and externalities such as pollution and public goods. Residential location models also incorporated income variations, differences in household preferences, variations in environmental quality, and racial discrimination in housing markets.

#### 2.3.1.5 The Behavioral Model

As a reaction to neoclassical models, behavioral approaches focus on cognitive behavior in urban modelling. Since positivist approaches explored human behavior by ontological assumptions of neoclassical economics as utility maximization, behavioral approach focuses attention to individual behavior. Rather than atomistic utility maximizer individual of positivist models, behavioral approach draws an individual who learn, experience and adopt in urban environment. Urban development was viewed as a final product of human actions. In other words, the main aim is to seek explanations of urban development in terms of human behavior. Therefore, urban development was regarded as the consequence of certain strategic decisions of actors including households, business and government. Despite learnability and adaptation capacity of individual decision-makers, collective rationality does not taken into consideration in the behavioral model.

#### 2.3.1.6 The System Model

Following by positivist and quantitative approaches in 1960s, the system model takes its roots from the General Systems Theory. All existing elements in a system are regarded to be linked and interrelated to the system's environment. The application of systems theory to urban environment as a comprehensive system consists of elements or subsystems like population, land, employment, transportation or other services. The city is mainly perceived as a node without considering the central functions it provides. Meanwhile, system indicators do not only exist with their own attributes but also with their relations to the other elements. Thus, system evolves with respect to connections and processes that link all the elements (Liu, 2009). General systems theory is also applied to urban environment by the rank size rule. German geographer Auerbach found regularity in the size distribution of cities in several countries. The basic finding is that the size distribution of cities is hierarchical in the sense that there is one/few big city/cities, more medium-size cities and so on, and finally a relatively large number of very small cities (Portguali, 2000), (Portugali, 2011). Auerbach's proposition is defined by Zipf (1949) based on the idea that the size distribution of cities in a country can be approximated by a Pareto distribution and obeys the power law. There exist different mathematical models based on systems theory including factor analysis, principal component analysis, multi-criteria analysis, linear and nonlinear programming as well as simulations. There exist some rules of system model in complexity approach without taking it as a static structure.

#### 2.3.1.7 The Central Place Model

The model is developed by Christaller which perceives the city as a central place of a hierarchical network in regional level. Different from territorial representations, a network based spatial approach could be observed by regarding the city as a central place of tertiary activities such as; market place, transportation node and administrative center. In addition to Christaller's conceptualization, Losh reformulated Christaller's model in a more complicated way. Large number of K values in a hierarchical hexagonal pattern replaced Christaller's three locational principles. The agglomerations create the city-poor and city-rich sectors by taking the city as the central place of all production, consumption and political activities. In addition, maximization of agglomeration relative to production locations and local purchases, while minimization of the total distance between productions points are proposed. The network based hierarchical systems provide insights to complexity studies like rank size rule. However, the central place model does not consider non-optimal human decisions, involve the assumptions of homogeneous spaces and ignore remote relations (Liu, 2009). Furthermore, both the system model and central place model evaluated as static since they are not open to dynamic changes occurring in different time lapses (Allen, 1996).

#### 2.3.1.8 Class based and Socio-cultural Model

With the impact of paradigm shift in 1970s, Marxist theories added to liberal social and economic ones. The city is handled as a representation of the society. However, there is hardly exists the spatial representation of the city. The structuralist theory conceptualizes that city as the representation of the structure of the society (Castells, 1977). The other Marxist configuration of the city involve urbanization of capital focusing on the spatial agglomeration and dispersal forces by considering the city's landscape as a consequence of the capitalist mode of production (Harvey, 1973). By the impact of Wirth and Park's studies that the city has been regarded as a force shaping the life of the people living in it (Portguali, 2000). Although it has a Marxist point of view, Lefebvre puts forward the role of urbanism as a global phenomenon that society is reaching a stage of being completely urban since the major force, industrialism, will be replaced by urbanism (Lefebvre, 1970).

#### 2.3.1.9 Post-modern Models

The postmodern city is described by Portugali (2000) as untamed, shrew, capricious and ever-changing. Urbanism of 21st century is resembled to a kaleidoscope of shapes, forms, high-tech science fiction of structures, cultures and sub-cultures. As a result, it is claimed that neither Marxist theories nor any other grand theories can explain urban categories. Merrifield (2013) identified many concepts have been brandished by post-modern models including endless city, shrinking city, 100-mile city, global city, mega-city and arrival city. Postmodern theories involve the wisdom of variety and complexity; however, they do not suggest an epistemological or theoretical base or explanation for understanding urban systems.

### 2.3.2 Complexity Sciences and Approaches

Portugali (2000) states the theories of self-organization have been evolved into complexity theories that they are derived from the paradigm change in natural sciences mainly physics. Complexity science may describe as the science of emergence dealing with self-organizing in open systems. Self-organization could be defined as a property of open and complex systems that achieve their order spontaneously. It is a central property of open and complex systems. Although they have orders, rules and organization, no one fully plan and control such systems since they emerge out of many synergetic interactions among individuals. It is condemned to be a sole property of open and complex systems which are described by Haken (1983) as systems being far from equilibrium condition including chaos and fractal structure.

System theory has been evolved for understanding the macro-systems. Constructing the whole from the parts in a static focus could be described as the general systems theory. The theory has been evolved in the last decades of 20th century concerning system dynamics and behavioral aspects. Berthon & Robinson (1991) indicates that the very small and the very large can involve different aspects of the same underlying system phenomena. The system theory approach affected the region based understanding of settlement typologies inter-linking the micro and macro structures. Batty (2010) states morphology is the result of top-down (global) and bottom-up (local) processes driven by individual actions, and institutional and governmental control at different levels which vary from the microscale to the macroscale.

The emergence and discontinuities as reflecting a new underlying order and system provide a perspective to social and economic processes. Systems involve catastrophes, bifurcations sudden changes and chaos. The behavioral paths are unique and never repeat themselves qualitative studies of complex system behavior. Portugali (2000) described information compression, inflation and adaptation as a view accepting Shannon’s notion of information as a property of closed system while semantic information are taken into consideration in complex, self-organizing systems. In terms of space conception, smooth geometrical abstraction, conception and control tendency gave way to geometry of irregular. The geometry still has an order but the order repeats itself across many scales through many times.

The notion of self-organization, which evolved in complexity theories in common use, originated in the science, mainly in physics. Complex system approaches treat the urban areas as dynamic, nonlinear, dissipative, open structures. McAdams (2007) argues the areas of complexity and chaos theory in urban geography and spatial analysis is regarded as a challenge of traditional approaches involving applications of regression analysis, econometric models etc., which are grounded in logic-positivism.

Batty (1995) identifies much urban theory developed during the past 50 years has been unable to link the underlying economic and ecological theory of cities to the actual spatial patterns which are observed. Changes in mainstream literature in terms of epistemological base of scientific methods, time and space conception and human capability in calculation altered the conceptualizations and analyses of the settlement systems. Furthermore, settlements which were conceptualized as urban, rural or transitory areas have been re-conceptualizing. As Batty (2011) states; cities were firstly formulated as systems of interacting entities reaching equilibrium by interaction. Those conceptions regard settlement system as organized from the top to down, distinct from the wider environment with their functioning. Complexity approach argue cities could not be closed from the wider world and they are far from equilibrium, open to change, not centrally ordered and involve solely from the bottom-up since they are produced by many individual or collective decisions.

According to Batty and Longley (1994) Euclidean geometry is not powerful enough to explain highly complex spatial organization. On the other hand, complexity proposes analysis tools offering a different perspective on the urban landscapes by taking into account urban spatial complexity. Moreover, cities are regarded as complex self-organizing systems. The reasons behind defining cities as self-organizing systems are their fractal dimensionality, self-similarity, self-organization and emergence. The association with those terms with the city has two aspects firstly as a metaphor to convey the notion of self-organization and secondly as a genuine of the city in its own sake. In terms of geographical civil systems cities have features with respect to complexity science as (Samet, 2013);

1. Complexity, complex adaptive system, co-evolution, disequilibrium, specialization.

2. Open systems, transacting entities, spatial structure, civil eco-structures, system growth parameter, diffusion of investment capital, endogenous change, territorial colonization, far-from-equilibrium, urban hierarchy, power law distribution (Zipf's rule).

3. Path dependence, technological evolution, network dynamics, connectivity, bifurcations, extreme events, chaos, anti-chaotic institutions, guided self-transformation, designed intervention, diversity, resilience, cellular automata, agent based models, urban morphology, simulation models.

4. Transactional microstructure, transactional complexity, informational growth, uncertainty, civil and societal phase transitions, contextual macrostructure.

5. Property investment returns, gradients, attractors (static, cyclic, vibrant or chaotic).

6. Macro-laws, eco-dynamics, gradient reduction, universal attractor, law of atrophy, heterogeneity.

7. Emergence, social norms, planning standards, scaling factors.

8. Allometric growth, fractal networks, shape, density.

9. Equipollence, evolutionary trajectory.

According to Batty (1995) self-organization implies complex systems include an internal organization while the local interactions can result in different global structure. The tools of urban modeling are augmented with the incorporation of non-conventional mathematics/modeling techniques and theory including chaos theory, cellular automata, agent based modeling, artificial intelligence, neural networks, spatial metrics and fractal analysis. They are facilitated with spatial technologies, which do not only depend on rich data sources but also new platforms and techniques for data management, (i.e., Geographic Information Systems and Remote Sensing) (McAdams, 2007), (Liu, 2009).

The nonlinear process of interaction between different elements of the system can generate possibilities of bifurcation that may upset the global state of the system and lead to "order from fluctuations" (Liu, 2009). In chaotic systems, some nonlinear processes destruct the order and generate a new order beyond another bifurcation. They obey deterministic laws and involve unpredictable uncertainty. Recent studies on nonlinear systems reinforced the effects of bifurcation and chaos, but they also suggest that orders exist within chaos (Batty & Longley, 1994). Chaotic relations could be observed in its own systems as well as with other cities and its hinterland (Batty, 1995), (Liu, 2009), (Portugali, 2009). The main theories regarding cities as complex and open system could be referred as; dissipative approach, synergetic approach, chaos based approach, fractal structures, cellular automata approach, agent based approach, sandpile-small world approaches and space syntax approach

#### 2.3.2.1 Dissipative Approach

A metaphoric approach to associate self-organization and urban settlements, particularly, the city is adopted by Nicolis & Prigogine (1977). The Bernard cell phenomenon is associated with self-organization. Prigogine created a model involving the conception of "far-from equilibrium". These types of structures are termed as dissipative as an ordered structure that forms according to the second law of thermodynamics. The roots of the theory based on chemistry approach of Bernard cells or atomic-molecular structures. Then as a theoretical approach cities as self-organizing systems are modeled by reformulating central place theory with respect to Prigogine's theory (Portugali, 2015). The models preserved the hexagonal landscape of central place theory by reformulating it by hexagonal Benard cells. The reformulation involves integration of self-organization phenomenon by ejection of equilibrium based approach from static models. The model firstly identifies the infrastructural pattern of a region including residents and jobs both having their intrinsic mobility. The mobility resulted in the creation of a carrying capacity of each locality through nonlinear growth, decline and uneven distribution of population (Figure 2-1).

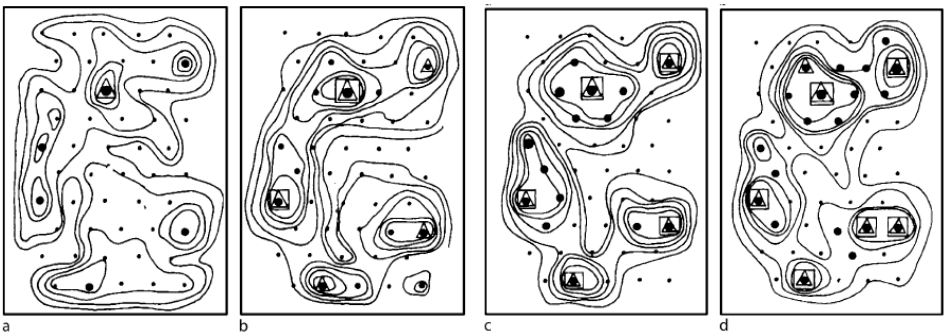



Figure 2-1 Dissipative Urban Model (Portugali, 2009, p. 7960)

#### 2.3.2.2 Synergetic Approach

Synergetics has been based on the "neuron theory" emerged in the late nineteenth century. Neuroscientists and theorists interested in models to explain brain functioning as a complex system including its effects on cognition and behavior (Portugali, 2015). SIRN (synergetic inter-representation network) is a an approach of cognitive mapping suggesting that cities emerge, maintain their order and change as a result of an ongoing interaction between internal and external representations of the city. Internal representation could be referred as the cognitive maps constructed in the human mind and the external one could be described as the city. Two main synergetic approaches have been applied to the study of cities as the first one is Weidlich's and co-workers studies in sociology, economics and urban dynamics. The second one is the pattern recognition approach developed by Haken and co-workers. The theory is mainly based on brain activities, cognition and pattern recognition. Pattern recognition which has been derived by an analogy of pattern formation determines mainly two patterns. The first one is the material pattern of the city, and the second is the cognitive pattern named as; cognitive maps. The dynamics of cities have been analyzed with respect to Haken's synergetics by examining the fast and slow processes. The micro-level changes have been regarded as fast ones such as; building sites, streets, subways while macro-level changes are the slow ones containing the whole region by describing the system of cities (Portguali, 2000). In this perspective regional macrostructure evolves by the global resultant of many local structures. The model mainly involves stochastic or quasi-deterministic evolution equations by considering the utility differences of each configuration.

#### 2.3.2.3 Chaos Based Approach

Chaotic behavior could be observed in cities in the long term. Looking at the longue *duree of cities*, evolution of cities exhibits a very distinct and routinized path as; a long period of steady state, a short period of strong fluctuations and chaos. Furthermore, via bifurcations chaotic state to a steady state and its iterations could be detected. In fact, stability is a macro-concern for cities since there always exist a few local unstable chaotic areas in the creation process of stability states which is termed as captivity principle (Portguali, 2000).

#### 2.3.2.4 Fractal Structure

The idea of fractal cities is mainly based on the notion of self-similarity. Fractal dimension of complex morphological shapes could be calculated by iterative processes. The term, fractal, is described by the originator Mandelbrot (1983) as; objects of any kind whose spatial form is nowhere smooth, irregular, whose irregularity repeats itself geometrically across many scales. Both on intra-urban and inter urban-regional scales a few and simple rules could produce complex urban form and its growth. Batty & Longley (1994) states different orders of transport net and the ordering of cities in the central place hierarchy are fractal structures which form the cornerstones of urban geography and spatial economics. Difference is mainly not seeking an equilibrium or stability observed in the central place theory. However, complex evolution has been investigated according to an ordering principle.

#### 2.3.2.5 Cellular Automata Approach

Similar to the discrete elements of cities including houses, lots and city-blocks, cellular automata models construct cells as discrete spatial units. The discrete units are determined with respect to differentiation of one or more variable in relation to their immediate neighbor. The dynamics of cities with respect to determined differentiating variables could be simulated by mathematical tools. There can be defined two sole models as implicit and explicit self-organized cellular automata approaches. The implicit models aim to explain an existing or historical pattern, or alternatively predict the future behavior. The explicit group mainly seeks the self-organization properties inherent in cities and urbanism based on heuristics. The impact of micro-decisions has been investigated with respect to the global behavior namely as individuals/firms as local and the city as the global structure (Batty, 2005). Cellular-automata models could also generate tools for fractal morphological analysis since they include iterative steps generating complex structures of cities.

#### 2.3.2.6 Agent-based Approach

Different from Cellular-automate models, agent base models include the agency into city simulation models. Portugali (2000) states unlike urban infrastructure, agents can learn and move in the city with a vision beyond the nearest neighbor. The main inspiration of the model is theory of Schelling's residential segregation. Schelling model proposes an agent-based model that might help explain why segregation is so difficult to combat that even when agents didn't mind being surrounded or living by agents of a different race, they would still choose to segregate themselves from other agents over time. The model tells simple micro behaviors can lead to complex and large extent of differentiation (Schelling, 1978) (Hatna & Benenson, 2012). Free agents on a cellular space (FACS) models integrate cellular-automata models with agent based models by superposition of those two layers as a population layer of human agents describing migratory and interaction activities of individuals and as urban landscape. The model firstly offers the agent-based layer construction that it proposes a new agent(s)with a certain intention in mind according to its set of preferences aiming to pick the best one. Once the agent located itself in a certain cell, the cellular-automata dynamics starts as the properties of each cell are determined by reference to the properties of its neighbors (Portugali, 2009).

#### 2.3.2.7 Sandpile and Small World Approaches

The main arguments of the sandpile approach are the unstable status of the system in local state whereas there is an absolute robustness in the global state (Batty, 2005). It is argued that like sandpile approach, cities appear volatile and fast moving at their local scales while at their global scale they are robust Compared to the synergetic and dissipative cities, the sandpile city is a kind of a zooming in to the internal dynamics of self-organized cities in their steady state periods so as Portugali (2000) identifies Sandpile cities show how complex and rich is the internal dynamics of a city in steady state. The approach of small-world cities has the notion of complex networks following the power law. Barabasi & Albert (1999) tells this as a mark of self-organization while Portugali (2000) refers to the Alexander's classic "city is not a tree" quote demonstrates that cities are typified not by a simple tree network, but by a complex semi-lattice network (Figure 2-3).

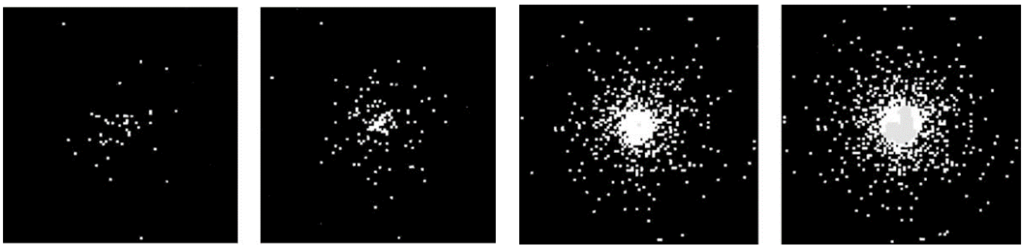


Figure 2-2 Simulation of Sandpile cities hypothetical urban growth pattern in its critical level (Batty, 1995)

#### 2.3.2.8 Space Syntax Approach

The other re-formulated network based approach is the space syntax approach which mainly analyzes urban morphology in terms of networks. The approach is the entry of mathematical tools into urban morphology increased with the graph theory and set theory focusing on graph representations of urban form. Furthermore space syntax evaluates graph representation of cities as considering them the systems of open spaces (Hiller & Hanson, 1984).

In addition to physical attributes and growth pattern, social space is also evaluated with respect to complexity science. Samet (2013) argues complex civil ecostructures emerge through the diffusion of investment capital challenging the notion of economic equilibrium. Although economic development is a process of guided self-transformation rather than self-organization, it is the spontaneous emergence of macrostructure. Batty (2005) states complexity science could be applied to networks. The complex capital accumulation process emerges at the scale of the world as stated by Samet (2013) within a long-range or macro-time dimension. Those arguments are parallel with the arguments about planetary urbanization.

## 2.4 Chapter Discussion

In this part of the study the questions are answered as;

(i) How and why conceptualizations of settlement systems have been changed?

(ii) What are the classic and new conceptualizations? Which aspects of the classic models sustained in complexity models?

In this respect firstly, how space and time concepts have been altered is firstly discussed. Then changes in conceptualization of settlements and settlement systems are investigated by considering the changes in flows and interactions. Under the light of those paradigm changes how complexity science evaluates cities and city systems are introduced. In this part of the study, classic urban models and complexity approaches are both briefly explained since some aspects of classical models sustain in new understanding of cities.

Different complexity approaches regarding cities as complex systems are presented to identify appropriate methods with respect to data availability and context of the background. As observed from literature review about conceptualizing urban geography, firstly where the city begins and ends could not be represented by territorial differentiation since relations emerge through networks and nodes. Secondly, urbanism has been conceptualized as a metabolism. Traditional understanding of urban is altered and evolved through non-urban areas that involve intrinsic and exterior relations. The other finding from complexity approaches can be explained that cities present chaotic behavior in the long run that steady states or slow processes is followed by fast processes and turbulences in the short run. In order to catch the chaotic motion, in this study it is aimed to examine the change of a region as much time as possible with respect to data availability. For long-run regional analyses, available data is determined as road maps and population for Turkish cities.

Then complexity approaches presented in this chapter are re-evaluated in order to determine which approaches could be applied with respect to available regional scale and long-run data. Since maps of public institutions do not involve building plots, fractal dimension analysis method is selected to investigate the complexity of İzmir region from 1950s to present time. As a result, in the fallowing chapter, definition and methods for fractal analysis of settlements and settlement systems are presented.

# CHAPTER 3

# FRACTAL ANALYSIS OF URBAN AND REGIONAL SYSTEMS

This section presents the definition and measurement methods of fractals and how fractal dimension is applied to cities and regions. Fractal dimension analysis of road system and sub-fractal analysis is explained in this part of the study.

## 3.1 Definition and Concept of Fractals

The main parameters defining an object, space or mass in physics have two main dimensions as time and space. Baranger (2000) defines fractal as an object which is chaotic in space. Aiming to discover fundamental laws of physics and universe, “elementary particles” is firstly investigated. Although, at the beginning they were atoms, they are made of nuclei and electrons by looking on a finer scale. After refining the scale again, protons and neutrons were observed and regarded as elementary particles by replacing atoms. A few decades later it is founded that they are also actually made of quarks of various flavors and of gluons which presented as a process go on ad infinitum. That makes particle physics a big fractal in terms of space. In addition to chaos in space, chaos in time has been observed since configuration of chaotic systems is capable of changing in time as a dynamical system. The signature of time-chaos is something called “sensitivity to initial conditions”. Edward Lorenz, the discoverer of sensitivity to initial conditions, also called it “the butterfly effect”. Those systems could not be handled by reductionism since any small uncertainty may exist in the initial condition. It may grow exponentially with time, and eventually become large. The connection between time-chaos and space-chaos is very close that fractal can be seen as the possible result of the prolonged action of time-chaos. Complex systems are different from chaotic systems although they share some shared properties. For example, both two systems contain nonlinearity. However, complex systems involve further properties as;

(i) *Complex systems are interdependent*, the whole is not just the sum of the parts,

(ii) *Complex systems possesses a structure spanning in several scales*, at every scale a structure can be found,

(iii) *Complex system is emergent and self-organized,* emerging behavior is related to scale and resulted from global interactions. It leads to self-organization by changing the structure and creation of a new structure. The *complex adaptive systems* have ability to adapt to a changing environment. Complexity could be observed only during the presence of chaos. The simple fractals are chaotic although they are not complex. A complex system always has several scales and involves interplay between chaos and non-chaos (Baranger, 2000).

Euclidean dimension which rooted in Newtonian physics of deterministic natural sciences could not be correspond complex objects in the real World. Fractal analysis is a new approach developed to measure level of complexity via analyzing the change of measurement result of length, area or volume with the change of measurement unit or scaling factor rather than simple Euclidean dimensions (Kaya & Bölen, 2017).

Fractal, as a mathematical term, was defined by Mandelbrot (1983) to refer to objects whose forms are essentially irregular, scale invariant, and self-similar. Fractal geometry is the spatial expression of chaos theory. Baranger (2000) defines fractals as chaotic objects that it does not become simpler when you analyze it into smaller and smaller parts. Batty & Longley (1994) gives the classic example of fractal as coastline since they are never straight and they enclose space by twists and turns. The theory has been developed through the coastline by Mandelbrot’s article (1967) entitled “How Long is the Coast of Britain” as a response to Richardson (1961) who wrote about the calculation of the length of coastlines and national boundaries. They are more than a straight line but less than a plane which have a Euclidian dimension between 1 and 2. By a similar perspective mountains as the other example of natural fractals have fractal dimension between 2 and 3 as more than a plane and less than a volume (Figure 3-1). In other words, the notion of fractal dimension is somewhat counter-intuitive – it says that fractals do not have the conventional dimension of 0 (point), 1 (line), 2 (plane), 3 (cube) but rather broken dimensions such as 0.35 (an object that is more than a point but less than a line), or 1.6 (more than a line but less than a plane) (Portugali, 2011).

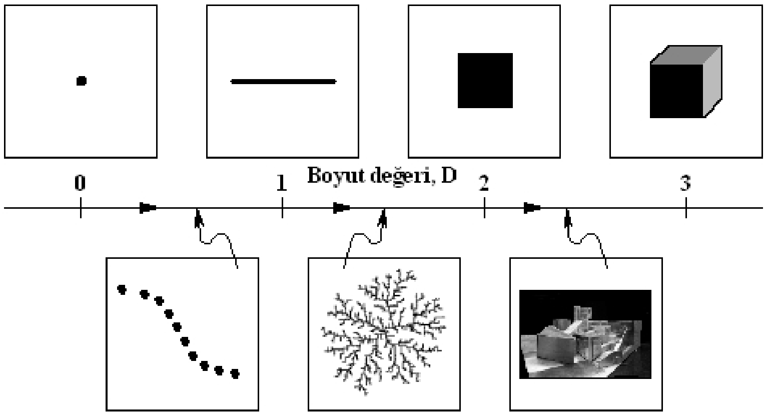



Figure 3-1. Euclidian and fractal dimensions (Kaya, 2003, p. 46)

The third main principles of fractals are described can be observed as;

(i) Fractals are always self-similar, free from scale they involve the same shape or the same degree of irregularity

(ii) Fractals are described in terms of a hierarchy of self-similar components like the trees, road network and settlements

(iii) Fractals are irregular and non-differentiable in terms of calculus (Batty & Longley, 1994).

Fractals could be observed in the nature. Mountain range, trees, human body, a fern of a leaf, pattern of earthquake faults, the sky on a partial cloudy day, section of the coast and the waves on the surface of ocean are examples of natural fractals (Batty, 1995), (Baranger, 2000). As observed in Figure 3-2, they involve a high degree of self-similarity and they do not become simpler when they are examined by increasingly powerful lens.

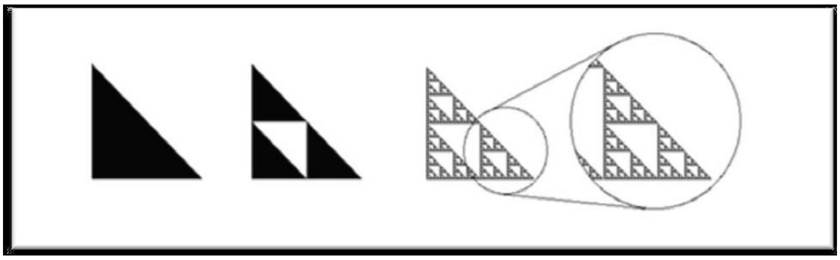


Figure 3-2 Self-similarity and iteration processes of fractals (Yale, 2014; Erdoğan, 2015, p. 2)

In addition to natural fractals, fractal objects could be artificially designed. The basic elements related to fractal creation/generation and analyses are:

(i) an object
(ii) a generator (initiator) and
(iii) the emerged form (Mandelbrot, 1983), (Batty & Longley, 1994), (McAdams, 2007)

The simple fractals like the Koch Curve are constructed by applying the generator to the initator by a hierarchy or scale down. By re-application of the generator the process continued indefinitely towards the limit. The well-known theoretical fractal of the Koch Curve is developed in 1904 by Helge von Koch involving a straight line of initiator and four copies of one third of the length of it as the generator (Figure 3-3).

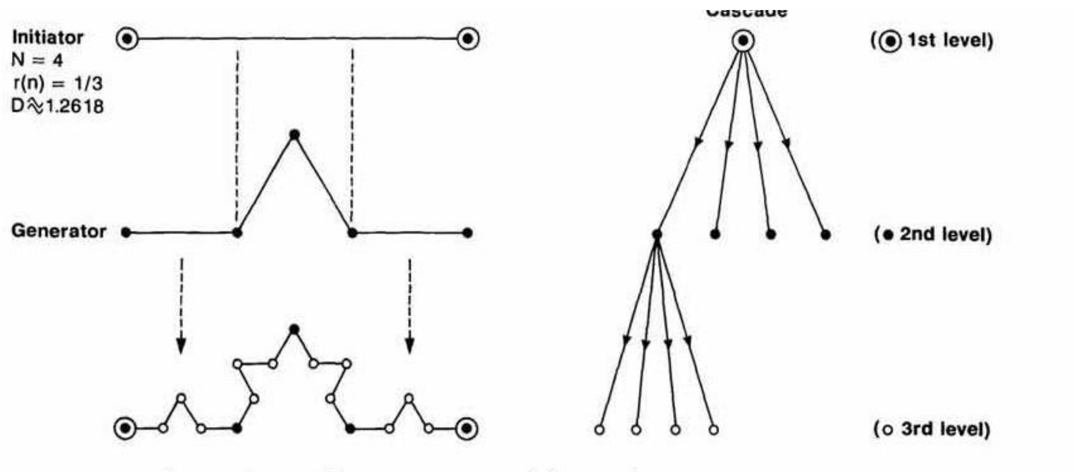



Figure 3-3 The construction of the Koch Curve (Batty & Longley, 1994, p. 62)

The regular Koch curve's fractal dimension is "1.262". The other examples of theoretical fractals are the 'C' curve, Dragon Curve, the Sierpinski's gasket. The fractal dimension of Sierpinski gasket is "1.585". There are many fractals which are artificially designed especially related to the development of computers easing the possibility of iterative processes (Figure 3-4).

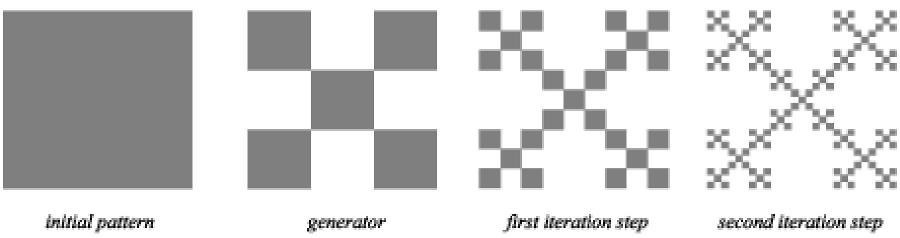



Figure 3-4 An example of theoretical fractal pattern- The Sierpinski Carpet (Myint & Liam, 2005)

## 3.2 Fractal Analysis of Cities

Studying the settlements or cities has been one of the major themes in urban geography and urban morphology. Non-conventional mathematics and modeling techniques has been augmented in urban morphology. One of them is fractal analysis. Fractal Dimension is used to measure the spatial complexity as a departure from Euclidian geometry (Batty & Longley, Fractal Cities: A Geometry of Form and Function, 1994), (Portguali, 2000), (Alberti, 2008). The evolution process of the urban pattern results in higher level of complexity and this also increases the fractal dimension values (Kaya & Bölen, 2017).

The seminal book of Fractal Cities (Batty & Longley, 1994) is the first comprehensive examination of the use of fractal analysis to analyze urban systems. It has been realized that attributes of abstract fractals were similar to those of the form of urban areas. Fractal patterns can be interpreted to describe the complex nature of urban structure, exceeding or complimenting previous spatial analysis techniques such as density, cluster analysis, regression (McAdams, 2007). Different orders of transport net and the ordering of cities in the central place hierarchy are fractal structures which form the cornerstones of urban geography and spatial economics. Cities have distinct fractal features (Batty & Longley, 1994).

The idea of fractal cities is mainly based on the idea by the notion of self-similarity. The term, fractal, is described by the originator Mandelbrot (1983) as; objects of any kind whose spatial form is nowhere smooth, irregular, whose irregularity repeats itself geometrically across many scales. Both on intra-urban and inter urban regional scales a few and simple rules could produce complex urban form and its growth. There does not seek an equilibrium and stability as in the central place theories, but a rich and complex evolution has been investigated according to an ordering principle.

Towns and cities introduce major discontinuities in statistical landscapes of spatial population distributions that heterogeneous patterns of density embodied in the structure of city-regions. Like a city, or like a city-region system, the distribution of their mass in space is never uniform, neither dense nor diluted. Nonetheless, this fragmented distribution is not clearly random, since fractal objects are structured following a central organization principle, self-similarity throughout the scales. Myint & Lam (2005) asserts that it is a property especially useful for studies in urban geography. A result of the self-similarity property of fractals, regular hierarchical spatial distribution of elements through the scales including self-similarity and heterogeneity lead to center-periphery patterns. All fractal geographical entities exhibit the following dimensional relationship as Batty & Longley, (1994) states;

$$L^{1/1} \propto S^{1/2} \propto V^{1/3} \propto M^{1/D} \qquad (1)$$

where *L* is the length of a geographical entity, *S* is the area, *V* is the volume, *M* is any mass measurement, and *D* is the fractal geometry of $M$.

Since fractal structures are characterized by the repetition of the same distribution principle of elements at a multitude of scales, theoretical fractal forms are built from the iteration of a pattern at infinity of scales. For theoretical patterns, like Sierpinski carpet, the same form is produced by generative iterations (Myint & Liam, 2005). However, the same spatial distribution mode does not always produce the same form. Furthermore, 'real' urban fractals are also subject to the influence of physical topography which limits and shapes its direction and form. In addition to physical barriers, there are entropy factors based on economic functioning of the city (McAdams, 2007).

Fractal analysis of cities includes hierarchies. The gradient was valid in terms of density which is decreasing by distance. It is usually summarized by a measure which is called the fractal dimension. Like Pareto model or Zipf's law the geometry of central places is a subset of fractal geometry and that an iterative fractal process could generate all possible systems of central places (François era lii, 1995; cited in Myint & Lam, 2005). Although, fractal analysis do not fully segregated from gravity-based or pareto models fractal patterns can be interpreted to describe the complex nature of urban structure, exceeding or complimenting previous spatial analysis techniques such as density, cluster analysis, regression and more (McAdams, 2007). The distance factor is one of the entropy factors affecting the growth pattern of the city.

While there are multiple types of fractals, a few of them can be used as models for the city (i.e., Seripenski, diffusion). Abstract fractal objects which could be seen as the basis for examining cities are (McAdams, 2007);
(i) the Dendrictic Pattern: similar to the growth of urban development along transportation lines(dimension as 1,60)
(ii), Sierpenski Carpet: is similar to a regular gridded city with a highly regular pattern and containing a large amount of gaps (fractal dimension as 1,77)
(iii) Sierpenski Triangle Variation: is similar to dentric pattern with small bays (Figure 3-5)

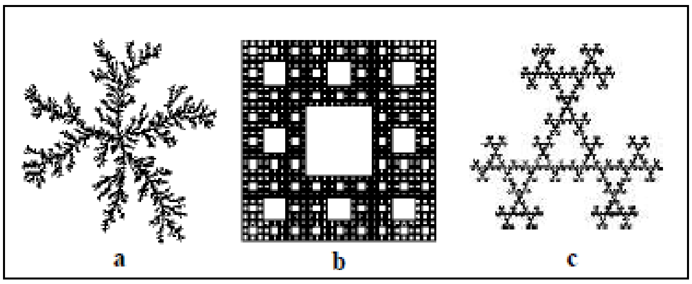



Figure 3-5 Abstract Fractals: **a-** Sierpenski Carpet, **b-** Dendritic Pattern, and **c-** Sierpenski Triangle Variation (McAdams, 2007, p. 156)

Fractal dimension can be calculated via different methods such as 'self-similarity dimension', 'topological dimension', or 'Hausdorff dimension', 'box counting dimension' etc. (Frankhauser, 1998),(Peitgen, Jürgens, & Saupe, 2004). Box counting dimension is a specific case of Mandelbrot's fractal dimension and regarded as a most preferred method among different methods (Peitgen, Jürgens, & Saupe, 2004), (Kaya & Bölen, 2017). The scaling relationship in calculating box counting dimension is defined as the relationship among number of boxes, box size and fractal dimension can be expressed as;

$$K = A \,.\, \varepsilon^{-D_f} \tag{2}$$

Where "K" represents the 'number of boxes', "ε" is 'grid size, "A" is a 'constant coefficient' and "Df" is the fractal dimension.

One of the sole properties of complex systems is scale invariance that the scale-free systems cannot be described with the conventional mathematical methods. As a tool for complex systems, urban form can be characterized by fractal dimension, and urban growth can be reflected by fractal dimension change (Chen & Zhou, 2003). There have been many studies which examined the fractal dimension of urbanized areas that some shared findings are proposed. Firstly, Batty & Longley (1994) state that cities have fractal dimensions between 1 and 2. The global analysis shows that fractal dimension is mostly greater than 1.4 and in between 1.6 and 1.8. On the other hand, different parts of the cities may have different fractal dimensions. Frankhauser (2004) asserts fractal dimensions of city centers in European cities (from 1.8 to 1.95) are higher than new towns (about 1.6 to 1.77) and less than in controlled growth areas (about 1.64 to 1.85). On the other hand, the collection of geographical objects (sub-systems) can be differentiated by their size. Myint & Lam (2005) claim that the scaling effect can be expressed by a statistical distribution following a Pareto law, or measured by a single fractal dimension which can characterize the whole system. The scaling relationship suits with other mathematical approaches as rank-size rule and power law. Furthermore, fractal objects, settlements or settlement system, may be defined as multi-scaled structures so that their altered relations can be observed at different scales. It can be indicated that an urban system can be conceptualized at different scales as (Lu & Tang, 2004), (Myint & Liam, 2005).

(i) *individual scale:* “town” or a “city” generated by actors or agents (as residents, firms, political bodies, pressure groups) through their interactions. The city is regarded as a fractal property and the main focus of the researchers are mainly urban growth or space-filling processes

(ii) *urban network:* interacting towns and cities which is characterised by new emerging properties (as the hierarchical structure according to Zipf’s law. Fractal analyses goes to a larger spatial scale and investigates the fractal nature of the patterns of urban systems

(iii) *landuse patterns:* Fractal analyses focus on the creating sub-systems of the city such as land-use patterns, population distributions or transportation system.

There exist studies involving the relationship of fractal dimension with other parameters and it is claimed the relationship between fractal dimension with population and city size is positive (Batty & Xie, 1996), (Shen, 2002), (Chen & Jiang, 2016), (Lan, Li, & Zhang, 2019). However, a meaningful relationship could not be identified with population density.

## 3.3 Literature Review of Fractal Analysis of Turkish Cities

With respect to western cities, fractal analysis of cities in developing countries is limited except Chinese cities. Fractal analyses of Turkish cities evaluating urban growth, sprawl or space quality have been conducted since 2001. The studies provide significant information in terms of fractal dimension of Turkish cities including the core and fringe areas. The main method is observed as box-counting that in the latest studies, multi-fractal analysis and optimized mesh structure could be identified.

The whole city of İzmir or İzmir region was not studied in terms of fractal dimension in published works. However, a GIS based fractal analysis study about the space-filling efficiency of urban form in İzmir has been studied by Çubukcu & Erdoğan (2011). Aerial photographs and Satellite images of Metropolitan Area have been used in the study from 1951, 1963, 1987, 1996 and 2000. The study focused on the fractal dimension of urban boundaries by using the box-counting method. It is asserted that the findings are parallel to the claims in the literature that İzmir moved from a less efficient spatial organization and space-filling to a more efficient one between 1960 and 2000. Furthermore, in research findings, decreased fractal dimension in 1963 is explained by the first urban spill over during 1950s the first rural immigration era. The calculated fractal dimensions of the study are presented in Figure 3-6.

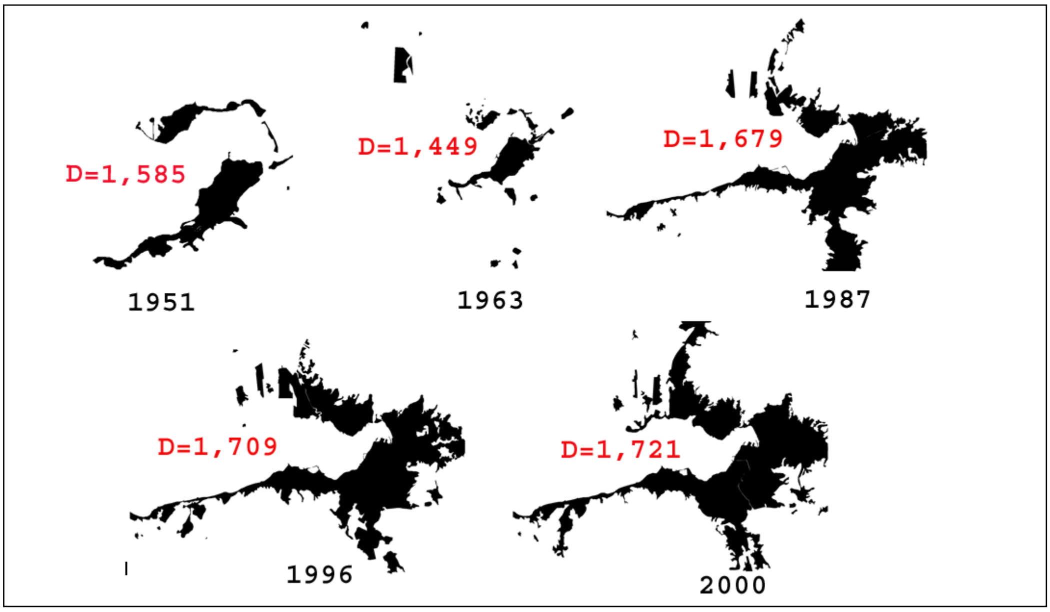



Figure 3-6 Fractal dimension of İzmir Metropolitan Area from 1951 to 2000 (Çubukçu & Erdoğan, 2011)

There are several studies analyzing fractal dimension of different Turkish cities. The studies involve urban parts or urban macroform (Table 3-1). Kaya (2003) investigates two districts of İstanbul one of which is a historical core and the other is the grid-iron formed apartment blocks zone. It is asserted that the district in the historical peninsula involve higher fractal dimension. The other contribution of the study is priori fractal dimension analysis of several Turkish cities (Çorum-Erzurum-Giresun-İzmir-K.Maraş- Mardin- Siirt- Sivas-Trabzon). The average fractal dimension of those cities by analyzing urban boundary is determined as 1,7. A more comprehensive study of Kaya and Bölen (2006) has been conducted for the same districts of İstanbul. Urban road system has been used for input data that urban design and structural scales are covered. The main arguments of the study can be summarized as; (i) open-spaces remains as left-over and death spaces due to modernist planning approach. Ordered geometries negatively affected the continuity of complex systems by creating closed surfaces and (ii) lack of hierarchy in transportation network and high geometric order lead to decrease in the interaction. Fractal analysis of İstanbul is also studied by Mc Adams (2007) and Terzi & Bölen (2009). In both studies, fractal dimension is analyzed by combining lacunarity analysis. The results of those studies asserts that central area have higher fractal dimension (more than “1.8”) whereas it is low in outskirts (the lowest value as; “1.3”).

In addition to determination of fractal dimension analysis of cities in terms of urban growth, spatial quality or urban sprawl, investigation of fractal dimension with other parameters has been conducted in Atabeyoğlu & Bulut (2013) and Erdoğan (2015). Atabeyoğlu and Bulut (2013) investigated land-uses and fractal dimension in adjacent municipal area with respect to neighborhood character analysis. Erdoğan (2015) does not cover Turkish cities in the analysis that the fractal dimension of randomly selected 29 cities from the world are analyzed by considering fractal dimension of urban boundaries. However, in the research multiple linear regression analysis joined to estimate relationships between fractal dimension and some parameters such as; *the altitude of cities, per capita income* *and total surface area of countries, age of cities, car ownership and per m$^2$price of land.*

Kaya & Bölen (2017) observes multi-fractal dimension of İstanbul by considering scaling relationship. Furthermore, the study synthesizes all topological, cognitive and complexity measures of urban morphology based on urban blocks. The aim of the study is constructing a DNA of the urban character of the city that fractal analysis, as a complexity measure, is an integrated part of it. In addition to single time analysis, change of fractal dimension in time has been investigated by Aydın (2016) for Isparta case. Urban sprawl from 2003 to 2015 is investigated by fractal analysis of urban boundary. Change in urban borders of Bursa from 1939 to 2019 has been analyzed and fractal dimension calculated by İlhan & Ediz (2019). Furthermore, fractal dimensions of urban road system of districts were analyzed from 2006 to 2019. The results are discussed with respect to land-use pattern and sub-centers. Öztürk (2020) analyzed the fractal dimension change of urban boundary of Samsun, interaction, spatial efficiency and connectivity of some districts of different cities also have been analyzed in different researches for the cities of Denizli and Bodrum by Erdoğan & Çubukçu (Erdoğan & Çubukçu, Kentsel Morfolojide Yeni Bir Yöntem: Fraktal Boyut Metodu, Bodrum Örneği, 2015) and Erdoğan (2018) and  and the city of Safranbolu by Çubukçu & Çubukçu (2008).

The most comprehensive study including all 81 Turkish Province centers are analyzed with respect to fractal dimension and lacunarity values. Then the results are analyzed by hierarchical cluster analysis. It is asserted that small-size cities are more alike. The other contribution of the study is that there exists a positive correlation between fractal dimension and population and gross domestic product per capita by provinces ($p<0.01$). Central İzmir around the Bay is also analyzed and the fractal dimension of the network is calculated as; “1.5857”. İzmir is observed under the cluster with the other cities as; *Adıyaman, Aydın, Çorum, Isparta, Kütahya, Nevşehir, Şanlıurfa, Uşak* and *Batman* with respect to fractal dimension and lacunarity values (İlhan & Gürsakal , 2021).

Table 3-1 Literature Review of Fractal Dimension Analysis of Turkish Cities

| **Author /Date** | **City** | **Method** |
|---|---|---|
| Yüzer (2001) | Bursa | - |
| Kaya (2003) | İstanbul | Revised box-counting |
| Kaya ve Bölen (2006) | Çorum / Erzurum / Giresun / İzmit /Kahramanmaraş / Mardin / Siirt /Sivas /Trabzon / Some parts of İstanbul | Box-counting |
| Mcadams (2007) | İstanbul | Box-counting |
| Terzi ve Kaya (2008) | İstanbul | Box-counting |
| Çubukcu ve Çubukcu (2009) | Safranbolu | Box-counting |
| Terzi ve Bölen (2009) | İstanbul | Box-counting |
| Erdoğan & Çubukçu (2011) | İzmir | Box-counting |
| Çubukçu & Erdoğan (2012) | Bursa | Box-counting |
| Atabeyoğlu et al. (2013) | Erzurum | Box-counting |
| Atabeyoğlu ve Bulut (2013) | Ordu | Box-counting |
| Erdoğan (2015) | Selected world cities | Dilation Box-counting, linear |
| Aydın (2016) | Isparta | Box-counting |
| Kaya & Bölen (2017) | İstanbul | Box-counting (multi-fractal) |
| Öztürk (2017) | Samsun | Box-counting |
| Erdoğan (2018) | Bodrum | Box-counting |
| Erdoğan (2019) | Denizli | Box-counting |
| İlhan & Ediz (2019) | Bursa | Box-counting |
| İlhan & Gürsakal (2021) | All Turkish cities | Box-counting |

As Chen (2016) identifies that fractal analysis of cities have been studied for more than 30 years. However, rural systems or urban-rural regional systems are handled in fewer works. This argument is also valid for Turkish cities. Some of studies of Turkish cases focus on urban boundaries or edges observed from maps or satellite images. The others focus on fractal dimension analysis of road system for some districts of the urban area. In other words, regional based fractal analysis is not handled regarding the city-system as a network of metabolism.

### 3.4 Fractal Analysis of Road network and Regions

Urban transportation system is a typical fractal system regarded as effective to evaluate complexity and growth. In other words urban transportation network is a typical fractal system and studies applying fractal geometry to describing an urban road system have proved to be effective (Batty & Longley, 1994), (Shen G. , 1997), (Chen & Luo, 1998), (Shen G. Q., 2002), (Lu & Tang, 2004), (Avineri, 2010), (Thomas, Frankhauser, & Badariotti, 2011), (Thomas & Frankhauser, 2013), (Wang, Luo, & Luo, 2016), (Sreelekha, Krishnamurthy, & Anjaneyulu, 2015), (Lu, Zhang, & Southworth, 2016), (Lan, Li, & Zhang, 2019) The equation analyzing complexity of the road systems are;

$$D_{L_s} = - \ln \frac{\ln\left(\frac{N_i}{N_{i-1}}\right)}{\ln\left(\frac{L_i}{L_{i-1}}\right)} \tag{3}$$

where Ni represents the number of cells which have streets in them for the ith level of the grid, and Li is the cell size.

The D values for the four graphs from left to right show how the fractal dimension can reflect the space filling by different linear feature on a continuous scale (Lu & Tang, 2004). As Mc Adams (2007) states urban land-uses are complex and remote-sensed data may not cover the detailed or multi-layered pattern of geographies. In addition to the total length of transportation system, the spatial pattern of the roads and their complexity measures correlate with urban growth (Lu & Tang, 2004). It is observed by the findings that fractal dimension of urban networks obey when it is in a self-organized critical states power-law (Chen, 2008), (Thomas & Frankhauser, 2013) and otherwise exponential law (Chen & Jiang, 2016). The application example of fractal analysis to urban transportation system is presented in Figure 3-7 involving analysis of Tel-Aviv's metropolitan area.

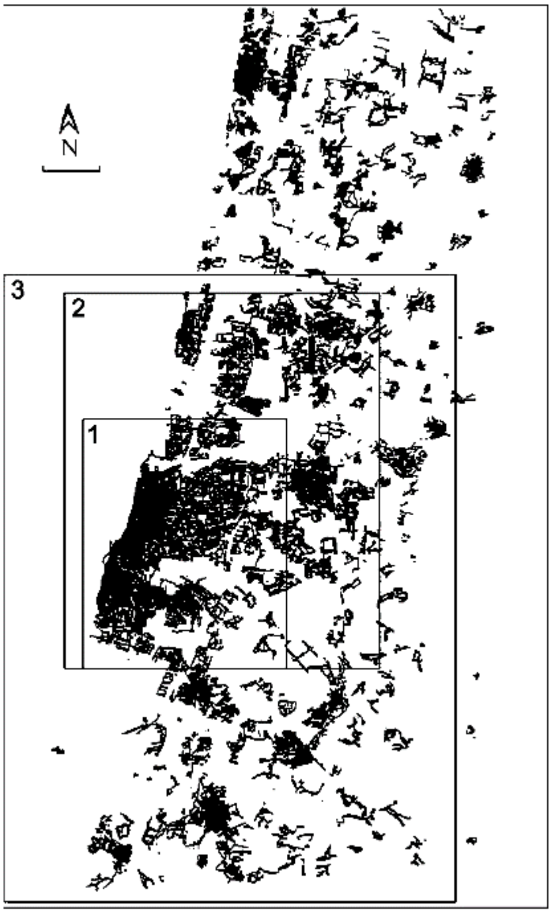



Figure 3-7 The evolving fractal structure of the Tel-Aviv metropolitan area in 1935, 1985 and 1991 (Benguigui, 1995; Portugali, 2009, p. 7966)

An urban road network is a typical linear feature. There are generally three groups of methods for fractal analysis of line features as;

(i) The line-walk method: For each step a base line is defined by keeping the geometrical shape of a line feature while measuring the length (Figure 3-8). There are different methods differing from each other according to the starting point of the base line (Batty & Longley, 1994), (Lu & Tang, 2004).

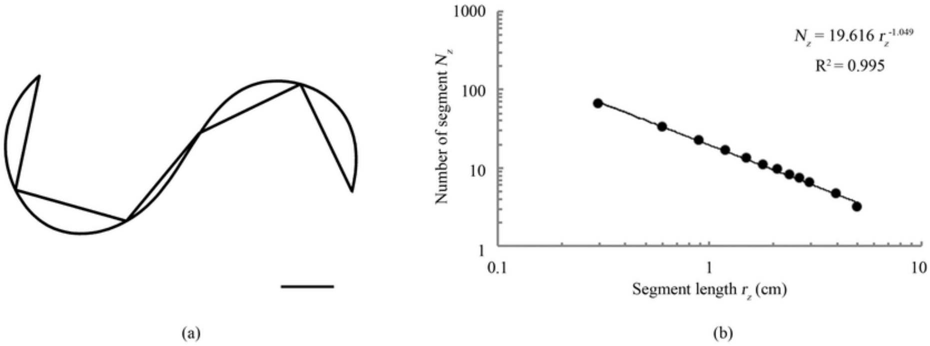



Figure 3-8 The line walk method for analyzing fractal dimension (Losa, Ristanovic, Ristanovis D, & Zaletel, 2016)

(ii) The length-area relation method: The method is mainly analyzes the relationship between the lengths of line features and the areas they cover (Figure 3-9). This is designed to reveal the relationship between the lengths of line features and the areas they cover or serve. The main weakness is the assumption there is a simple central point which can be measured as the service area of the lines. Furthermore, attaining a service area with respect to the size of roads may lead to insufficiencies (Lu & Tang, 2004).

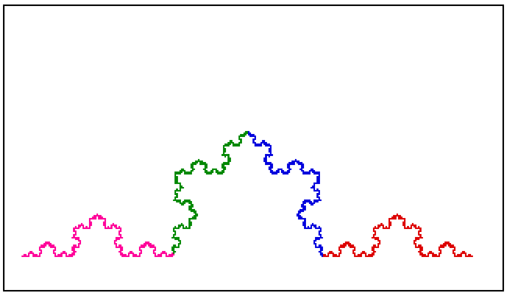


Figure 3-9 The length area measure method of a Koch Curve (Yale, 2014)

(iii) The box-counting (or cell-counting) method: It is designed to cover the study area a uniform square mesh whose size is defined by a finite set of values. The size of cell and number of cells with the line feature is identified through a regression function. Determination and modification of the cell-sizes are important in this method. The box-counting method for analyzing the fractal dimension of transportation system can be explained as;

$$\ln\ N_s = A + D \ln\left(\frac{1}{s}\right) + E_s \tag{4}$$

A is the intercept, "E" is the error term, and "D" is the fractal dimension of the line feature under investigation. The procedure is repeated for squares of increasing size until the empirical curve is then fitted to a theoretical curve corresponding to a fractal law (Figure 3-10). The goodness of fit is given by a pseudo-$R^2$ (Lu & Tang, 2004).

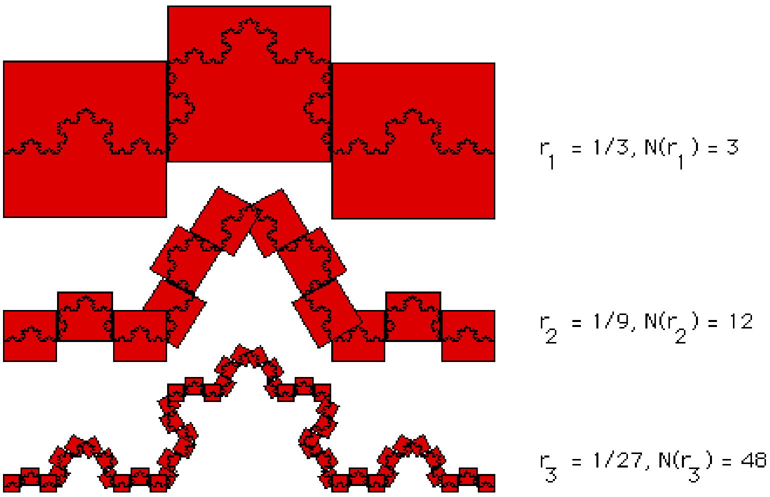



Figure 3-10 The box-counting method for measuring fractal dimension (Yale, 2014)

Similar to urban macroform based studies, smaller fractal dimension of the road network correlates with the density of the network and obtained in central areas. Conversely, fractal dimension increases in suburban areas by getting closer to central places (Lu, Zhang, & Southworth, 2016), (Sun, Jia, Kato, & Yoshitsugu, 2007), (Thomas & Frankhauser, 2013). Shen (1997) claims that larger cities have higher fractal dimension. The studies exhibits that densely populated areas have higher network fractal dimensions (Rodin & Rodina, 2000), (Shen G. Q., 2002), (Sun, Jia, Kato, & Yoshitsugu, 2007), (Thomas & Frankhauser, 2013). Like urban boundary or solid-void based studies, the findings can be interpreted as there is a positive correlation with the network's fractal dimension with population. The other finding can be interpreted as the more developed and larger cities having a maturity in transportation system reveal higher fractal dimension values (Lu & Tang, 2004), (Lu, Zhang, & Southworth, 2016). Although density of the network has a correlation with fractal dimension in positive manner (Thomas & Frankhauser, 2013), (Lu, Zhang, & Southworth, 2016), (Wang, Luo, & Luo, 2016). An increase in the total length of a road system has a relationship with the complexity of the network system is still open to research (Lu & Tang, 2004).

Since networks are topologically different from built-up environments their fractal dimensions can differ. Thomas & Frankhauser (2013) asserts networks tend to be 'hypertrophic' than built-up space since;

-Buildings do not always continuously distributed along the road/street network,

-Streets not only connect buildings at the intra-urban scale, but they also ensure the connection with the 'rest of the World (including transit flows)

-Streets also have to provide access to non-urbanized areas (greenspaces, farmlands and forests)

The study conducted by Thomas & Frankhauser (2013) shows for the city of Antwrep that fractal dimension of street network is higher than fractal dimension of built-up environment as; mean 1.525 and 1.690 respectively. However, for Greater Montreal fractal dimension of the road network (1.732) is calculated below the fractal dimension of urban boundary (1.858). In terms of regional studies, it is asserted that at the city level, the values will be in the range of 1 and 2. Lu & Tang

(2004) studied Dallas city-region including eleven counties based on the transportation system. It is remarked that about half of the settlements have a fractal dimension between 1.2 and 1.4 and 81% of them are in the range between 1.1 and 1.5. The fractal dimension of the same settlement's macroform or the road system may differ in lower and upper directions. However, it is also argued that fractal dimension could be calculated in the range of 0 and 1 for systems of cities (Myint & Liam, 2005), (Lu & Tang, 2004), (Thomas & Frankhauser, 2013). In other words, in an intra-urban spatial organization, the combination of different types of fractal behaviors at different scales could be observed.

### 3.5 Further Analysis of Complexity as Lacunarity and sub-fractals

Fractal dimension shows the complexity of urban pattern but different spatial organizations can have same fractal dimensions (McAdams, 2007), (Kaya & Bölen, 2017). In addition to fractal dimension, lacunarity can be regarded as a complementary part of fractal analysis. The concept of lacunarity was originally developed by Mandelbrot (1983) to describe a property of fractals as a parameter analyzing patterns added to the fractal dimension. Lacunarity has been extended to describe real data sets that may or may not have fractal and multi-fractal distributions (Plotnick, Gardner, Hargrove, Prestegaard, & Perlmutter, 1996; cited in Myint & Lam, 2005). It has been introduced in urban fractal analysis to characterize different texture appearances, which may share the same fractal dimension value. It measures the distribution of gap sizes that low lacunarity geometric objects are homogeneous because all gap sizes are the same, whereas high lacunarity objects are heterogeneous. Since lacunarity measures the heterogeneity, a higher index value of lacunarity means a more heterogeneous feature or a more complex spatial arrangement, and vice versa (Myint & Liam, 2005). Lacunarity analysis focuses on the spatial size and distribution of open spaces. A fractal with more gaps, bays or tears has a higher lacunarity. In box-counting method, lacunarity can be calculated as one plus the ratio of the variance and the mean square of the box mass is presented in equation 5 (Wu & Sui, 2001; Kaya & Bölen, 2017).

$$\Lambda(r)= [\ var(S)/E2(S)]+1, [\ 1, \infty) \quad (5)$$

where "E(S)" is the mean and "var(S)" is the variance of the number of occupied pixels per box"

Lacunarity analysis is observed in fractal analysis of city sub-systems in higher scales when the image is described from plots and blocks. The solid and void relationship is needed to estimate size and variety of the open systems. As mentioned by Thomas & Frankhauser (2013) fractal dimension analysis of built-up environment and road network can differ both in terms of methods and results due to different topological features. Thus, the other approach in order to understand the further complexity of a region by analyzing road network is to analyze sub-fractals of the system. In other words, alteration of the complexity levels can be obtained through measuring the complexity of the parts since parts can contain different levels of complexity with respect to the whole. Allometry can be defined as the scaling relationship between the size of a body part and the size of the whole body when an organism grows (Lan, Li, & Zhang, 2019). Fractal analysis can be operated on the whole image of an object for different box-sizes. Since urban networks are not perfectly scale free and do not contain perfect similarity like theoretical fractals, fractal dimension of the parts differ from the fractal dimension of the whole system.

The fractal dimension of an object is calculated by overlaying a grid of squares as boxes of size "S" on the object to be measured and then counting the number of boxes that contain part of the object. As Mandelbrot states (1982); reducing the value of s step by step, a series of the number of boxes (Nb) can be obtained.

$$Nb \propto S^{-D} \tag{6}$$

as Db can be interpreted as the fractal dimension of the object by box-counting. In addition to fractal dimension analysis of the whole object, fractal dimension of the parts can be measured by a mesh providing the least number of non-overlapping boxes “Ns” with the size of “S”.

While calculating the fractal dimension of an object by box-counting method a mesh is firstly created to cover the study area and the boxes overlapping with objects are counted. While changing the mesh size, the count re-processed in a finite number of turns. Plotting the number of boxes (Ns) and the mesh size (S) in a log-log graph, fractal dimension (D) is calculated by regression method by using the pairs of Ns” and “S” as;

$$\ln N_s = A + D \ln\left(\frac{1}{s}\right) + E_s \tag{7}$$

$$D = \lim_{\Delta s \to 0}\left(-\frac{\ln N_s}{\ln s}\right)^n \tag{8}$$

where A is the intercept, Es is the error term.

The mesh size and position is the crucial point of sub-fractal analysis. The conventional methods of box counting is also criticized by Sun et all (2007) that they treat the city as a whole while a single value cannot represent the parts. As a proposed method for the city of Dalian, the fractal dimension of a selected part of the city is calculated then the frame moved by a small step until the whole map covered in order to understand in which areas the transportation network is well developed or not by $R^2$ values. Then the distributive continuous fractal analysis is produced as a gradient map. The location and texture of the selected parts still affects the mesh size by this method. It is also argued that the curve of scaling behavior is used to understand the empirical relationship. For theoretical fractals the slope of the linear log is remains constant. However, in real-world urban structures the slope may vary with distance (Thomas & Frankhauser, 2013). The scaling behavior and different complexity measures can be obtained through space-syntax analysis which is another tool of complexity sciences conducted by road network data.

### 3.6 Chapter Discussion

In this chapter, definition and methods for fractal analysis is introduced. Then as the being fractals,  fractal analyses of settlements and settlement systems are presented. With respect to literature survey, firstly content of the study is determined. Fractal objects for regions as systems of cities involve transportation network, settlement macroforms and building plots. The spatial data for Turkish cities involve information of settlement stain macroforms and different hierarchies of road system among them. For seeking the complexity of the whole system without a lens of urban-rural dichotomy, road system is selected to be analyzed as the fractal object. With respect to this aim fractal analyses of large city systems and road systems are presented. Furthermore for further complexity analyses in terms of fractal dimension, sub-fractal and lacunarity analyses are briefly discussed. In addition to main literature findings acquired from word-wide analyses, fractal analyses of Turkish cities are also introduced in this chapter in order to evaluate the findings of this study with respect to those. The main arguments which are tested in fallowing chapters could be summarized in Table 3.2.

Table 3-2 Summary of the Literature Findings

| |
|---|
| *Fractal analysis fits to power law and central place theories in theoretical manner*<br>(Batty & Longley, 1994), (François, 1995), (Lu & Tang, 2004), (Chen, 2008), (Myint & Lam, 2005), (Thomas &Frankhauser, 2013). |
| *Box-counting method is suitable to analyze spatial distribution of urbanized areas and rass-madius method is appropriate to analyze urban growth patterns of mono-centric radial cities*<br>(Batty & Longley, 1994), (Frankhauser, 1998), (Petigen et al, 2004), (Kaya & Bölen, 2007) |
| *Fractal dimension close to "1" points out sprawl while "2" to compactness as well as spatial efficiency. Lack of transportation hierarchy and high geometric order is related to low fractal dimension*<br>(Chen & Zhou, 2003), (Frankhauser, 2004) |
| *Fractal dimension values of cities are generally greater than 1.4 with a mean of 1.6. Fractal dimension in the city centers could be higher and calculated close to 1.85 -1.95 range. New towns could have a dimension value between 1.60 and 1.77. For irregular and less controlled growth values could be in the range of 1.64 and 1.85.*<br>(Batty & Longley, 1994), (Frankhauser, 2004) |
| *Fractal dimension does not appear to be related to density. The relationship between fractal dimension and city size is positive.*<br>(Batty & Xie, 1996), (Shen, 1997), (Shen, 2002), (Chen & Jiang, 2016), (Lan et al, 2019) |
| *Central road system has higher fractal dimension values with respect to suburban areas.*<br>(Lu, Zhang, & Southworth, 2016), (Sun, Jia, Kato, & Yoshitsugu, 2007), (Thomas & Frankhauser, 2013) |
| *Populated areas and the areas have dense network have higher network fractal dimensions.*<br>(Rodin & Rodina, 2000), (Shen G. Q., 2002), (Sun, Jia, Kato, & Yoshitsugu, 2007), (Thomas & Frankhauser, 2013) (Lu, Zhang, & Southworth, 2016), (Wang, Luo, & Luo, 2016). |
| *Fractal Dimensions of road networks and built-up environments can differ in lower and upper directions. Fractal dimension could be calculated in the range of 0 and 1 for systems of cities.*<br>(Myint & Liam, 2005), (Lu & Tang, 2004), (Thomas & Frankhauser, 2013). |
| *For Turkish cities, fractal dimension and population is positively correlated to each other.*<br>(İlhan &Ediz,2019), (Erdoğan, 2015) |
| *Average fractal dimension of Turkish cities are 1.6 and 1.7.*<br>(Kaya & Bölen, 2006), (İlhan &Ediz) |

# CHAPTER 4

# METHODOLOGY

This chapter presents the methodology applied in the study in detail. Firstly the aim and resarch objectives are introduced. Then case study area is presented. Then the methodological frame is explained.

## 4.1 Aim of the Study and Research Questions

In the previous chapters how cities and regions are evaluated. According to complexity science, the motives leading to paradigm change are explained. Then, fractal dimension analysis as an approach to investigate complexity is presented. In order to narrow down the research background, application of fractal analysis to road systems and regions including systems of cities is presented.

Depending on the context, the first objective of the study is to analyze the relationship between complexity of the region involving urban and non-urban areas as fractal analysis with regional development trends. The second objective is to investigate the relationship between population and network growth with fractal dimension in regional scale, Thirdly, as observed from the literature review, evaluate the effect of scaling factor. In addition to analyses of complexity with respect to given borders the fourth objective is to develop a method for representing endogenous complexity of regions. The final objective is to provide an evaluation scheme for applicability of fractal analysis to regional scale.

Depending on the presented objectives, the following research questions are formulated to reach a conclusive frame:

RQ1) Which complexity approaches could be used for analysis of road network in regional scale?

RQ2) Are the relationships between regional growth with fractal dimension in regional scale consisted with the expected results with respect to literature review with urban scale studies?

RQ3) Do the fractal dimensions of the parts involve relations with the whole and the other parts?

RQ4) Are there any similarities or differences among varying study areas?

RQ5) Do fractal dimension of a part with respect to given (exogenous) borders are consistent with the intrinsic (endogenous) complexity pattern?

RQ6) Could the development dynamics of a region with respect to time can be represented by fractal dimension analysis?

### 4.2 Justification of the Case Study Area

In order to investigate the relationship between complexity approaches with regional change, in previous chapters a gradual literature review is presented. Firstly, approaches sustained or altered from classical urban theories are explored. Then different complexity approaches regarding cities as complex systems are presented to identify appropriate methods with respect to data availability and context of the background. As observed from literature review about conceptualizing urban geography by complexity issues, division of rural and urban areas have become blurred. As a result, it can be said that determination of urban boundary is firstly deterministic and uncertain. In other words, where the city begins and ends could not be represented by territorial differentiation since relations emerge through networks and nodes. Secondly, urbanism has been conceptualized as a metabolism. Traditional understanding of urban is altered and evolved through non-urban areas that involve intrinsic and exterior relations. Throughout those findings, a larger or regional context is aimed to be investigated comprehending urban, non-urban or partly urban areas. The other finding from complexity approaches can be explained that cities present chaotic behavior in the long run that steady states or slow processes is followed by fast processes and turbulences in the short run. In order to catch the chaotic motion, in this study it is aimed to examine the change of a region as much time as possible with respect to data availability.

Advances in technologies including satellite images and remote sensed data provide spatial information for complexity studies in the short run. For the decades before 2000s, aerial photographs could not be obtained for larger territories. Thus, maps are needed to be used to analyze larger time spans for complexity analysis. Since the main aim of this study involves comparative changes of the same spatial context with respect to time; detail level, symbols, signs as the language of maps are needed to be set as stable. Due to those reasons, for regional analysis of a long time span, standardized maps produced by public institutions are used. Two institutions produce regular and standardized maps for different purposes in the Republic of Turkey. First institution is General Directorate of Highways that produces highway maps for decades involving road network information. Secondly, General Directorate of Mapping produces military maps since early 20th century. Those maps are produced in different scales involving different detail. The most detailed maps are scaled to 1/25.000 having information about borders, transportation system, stain shaped macroform of major settlements, groves, wetlands and landmark notations. They have standardized legend which does not change with respect to location or time period the map is produced.

After investigation of the approaches and the source of data, selection criteria of the case study area are constructed with respect to classical urban models. The case study area is aimed to present hierarchy of central places which is accepted by both classical and complex approaches. Thus, rather than a mono-centric city, city-regions of Turkey which comprises network of settlements are evaluated that

Muğla, Antalya, İstanbul and İzmir fit to that criteria. The second filter is observed as the variety of sectors the city region presents. İstanbul as a giant metropole is regarded as an extreme case of regional complexity analyses that does not involve traditional rural tissue. Likewise, Antalya and Muğla have poly-centric structure whereas settlement hierarchy is mainly organized with respect to coastal tourism. İzmir, as the third largest city of Turkey, have a metropolitan core while at the same time have a rich regional network of settlements specialized in different sectors. All non-urban wildlands, industrial quarters, farm-based classical rural zones, touristic settlements and large public investments could be observed for the region of İzmir.

### 4.3 Background of İzmir Region

As the third most populous metropolitan city of Turkish Republic, the metropolitan region is located in the western extremity of Turkey. In geographical manner, a plain terrain is observed along with north-south axis and around the Bay. The modern name İzmir is derived from original Greek name "*Smyrna"*. The city and the region have been subjected to human inhabitance since Neolithic period due to its advantageous location (Figure 4-1). The Bay, the *Gediz* and the *Meles* Rivers as well as the topographical features affected the morphology of settlement patterns. It is proved by excavations that Smyrna emerged on the north eastern part of the Bay. Then, first settlement area was moved to its second location from *Tepekule* near *Bayraklı* to down slopes of *Pagus* Mountain around *Kadifekale* (Oral, 2010). Around 7$^{th}$ century settlements such as; *Buca, Bornova, Işıklar, Çiğli, Pınarbaşı, Narlıköy and Naldöken* existed in that period (CADOUX, C.J., 1938, pp.67-94; cited in (Belge, 2005) After re-foundation of Smyrna as a free-statute of *polis*, the city and its vicinity are ruled by the Roman Republic. In addition to ancient settlements in central İzmir, the whole city-region is subjected to inhabitance.

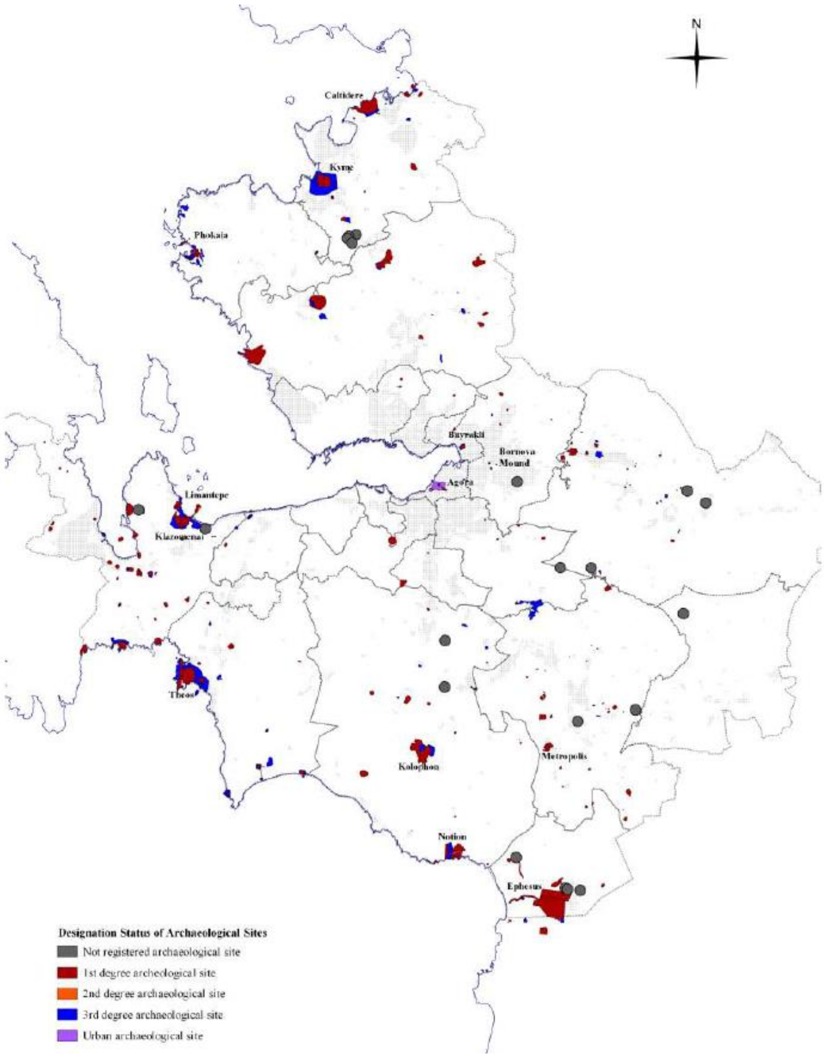



Figure 4-1 Archeological sites in İzmir Region (Esen, 2014; pp.209)

The emergence of the current central İzmir dates back to 17th century as a port city in order to distribute goods from its vicinity like *Manisa* and *Aydın*. The city enriched by its commercial capacity and the population reached 100.000 at the end of 18th century (Kuban, 2001). In 19th century, the focal importance of the city increased by the construction of ports as well as the railway system. Growth of İzmir has been historically integrated to regional network. Oral (2010, p.108) states the fertile agricultural potentials of the *Gediz* and *Bakırçay* Rivers help to the emergence of a regional hierarchy of settlements. The old caravan roads collecting and distributing the surplus to İzmir created an integrated regional system. Furthermore, the tram development and the railroads through *İzmir, Aydın* and *Turgutlu* empowered suburban development in the region. The macroform of the city enlarged mainly towards north between railway stations (Figure 4-2).

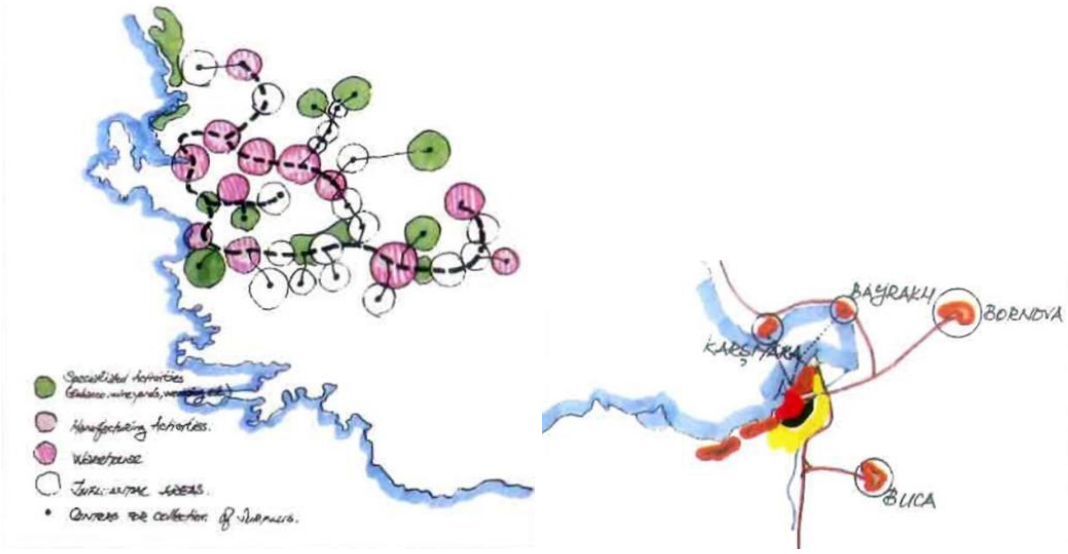



Figure 4-2 Regional Layout of Late Ottoman Layout and Suburban Developments of 19th century (Oral, 2010)

Being a part of the Province (*Sancak*) of *Sığla* established in the 15th century, İzmir became the center of the province in 1850. In addition, parallel to the development of the core and the backbone region, the municipality of İzmir is firstly established in 1867 by slitting from *Aydın.* In the republican period, by the Law *"Teşkilat-ı Esasiye"* aiming to construct a hierarchical provincial system İzmir became a distinct province by the year 1924. Gedikler (2012) states there exists 17 districts and 682 villages in 1950. Furthermore, 6 sub-districts (*bucak*) are administrated under the Central District involving *Center, Bornova, Buca, Cumaovası, Değirmendere* and *Karşıyaka.* By the years 1954, 1957 and 1958 *Karşıyaka, Selçuk, Bornova* become separated districts. The district of *Kuşadası* located in the south of *Selçuk* is separated from *İzmir* and tied to the province of *Aydın* in mid-1950s. In late 1950s, new sub-districts are established close to the central core like *Eşrefpaşa, Narlıdere, Güzelbahçe* and *Gaziemir.* Alterations of district borders, joins and secretions of the settlements from districts or provinces can also be identified by population data. Not only the political reasons, but also the development trends taking place in the region have connections with those rearrangements.

As a result of the advantages due to its geographical location, historical background and spatial characteristics; İzmir has been continuously changing in the face of rapid urbanization within the complex dynamics of economic, social and political forces. After 1945 the city experienced rapid population increase (TÜİK, 2009). The district of *Konak* was known as "İzmir Municipality" until 1984. In 1984 the Law no. 3030 concerning "*The Administration of Metropolitan Municipalities*" is enacted. By this law, eight more central district municipalities constituted the Central İzmir as urban districts namely as; *Balçova, Bornova, Buca, Çiğli, Gaziemir, Güzelbahçe, Karşıyaka* and *Narlıdere*. By a law enacted in 1987, all neighborhoods located in the Central İzmir District are tied to *Konak Municipality* except *Buca.* The borders and central İzmir is presented in Figure 4-3 observed from Environmental Plan prepared in 1973.

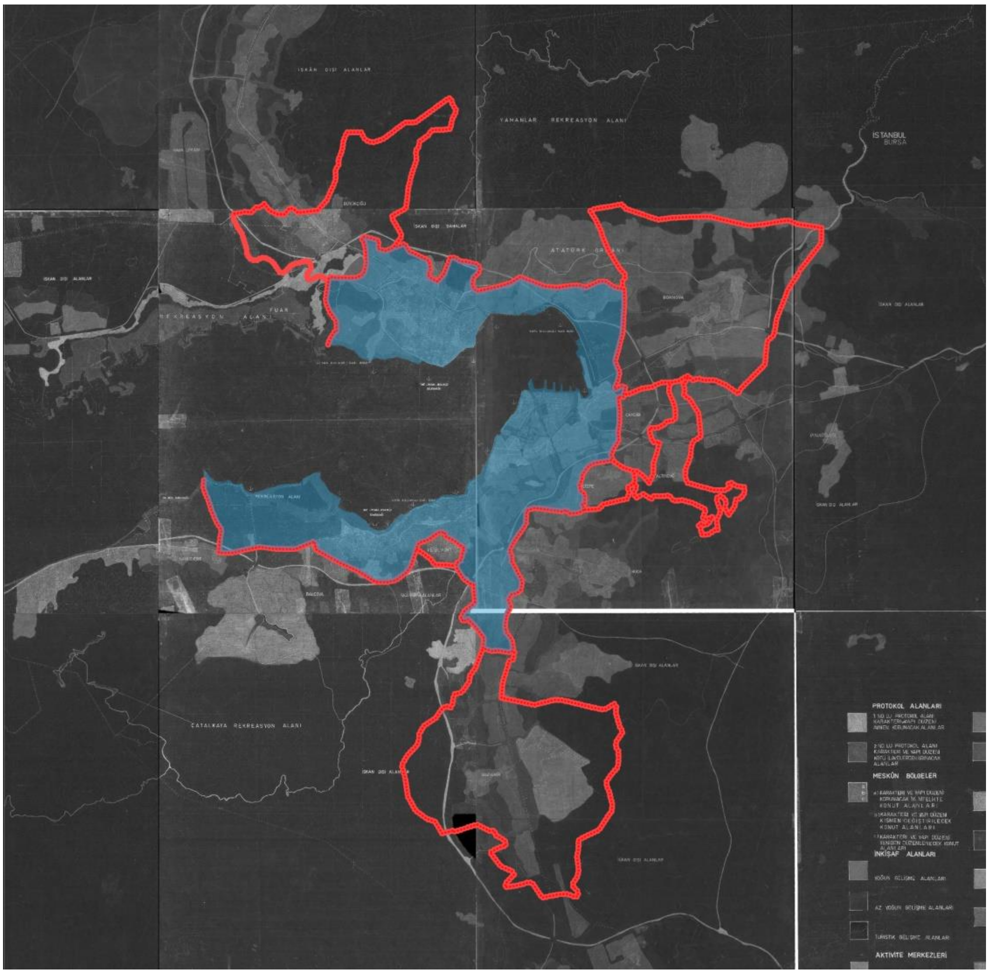



Figure 4-3 Borders and central İzmir defined in 1973 Environmental Plan

The Law about Metropolitan Municipality numbered as 5216 was accepted in 2004. Then definition of “central district” changed. With respect to the new Law, the governorate is considered as center and a circle with a radius of twenty kilometers with a population up to one million, a circle with a radius of thirty kilometers from one million to two. Then, a radius of fifty kilometers with a population more than two millions is accepted to be the metropolitan area. For İzmir, the districts involved in 50 kilometers radius are; *Aliağa, Foça, Menemen, Kemalpaşa, Bayındır, Torbalı, Menderes, Seferihisar* and *Urla*. As a result, they are also added into central districts (Figure 4-4).

In 2008 with the Law no. 5747 which is "*The Establishment of Districts within the Borders of Metropolitan Municipality and the Amendments of Certain Laws*", first-tier municipalities in eight metropolitan cities are converted into district municipalities. As the final arrangement in 2012, the Law no. 6360, about "*Unicities*", all regulations with respect to radius limits were annulled and metropolitan governance are adopted to provincial borders for İzmir. As a result of the last legal status, administrative distinctions of settlements and population with respect to urban and rural have diminished.

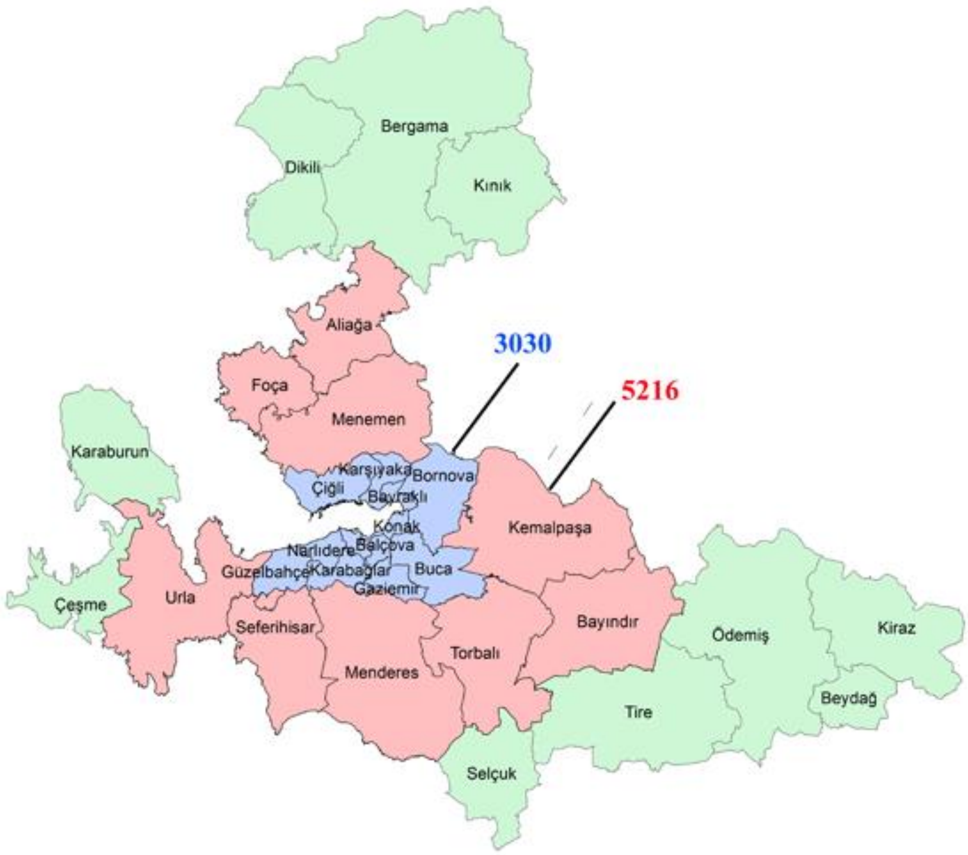



Figure 4-4 Borders of İzmir Metropolitan Area by the Laws no 3030 and 5216 (İzmir Büyükşehir Belediyesi, Retrieved from; https://www.izmir.bel.tr/tr/IzmirUlasimPlani2009/431/77)

The province of İzmir has 30 districts and 1295 neighborhoods at present. The districts of the İzmir are; *Aliağa, Balçova, Bayındır, Bayraklı, Bergama, Beydağ, Bornova, Buca, Çeşme, Çiğli, Dikili, Foça, Gaziemir, Güzelbahçe, Karabağlar, Karaburun, Karşıyaka, Kemalpaşa, Kınık, Kiraz, Konak, Menderes, Menemen, Narlıdere, Ödemiş, Seferihisar, Selçuk, Tire, Torbalı* and *Urla*.

### 4.3.1 Conceptualization of İzmir Region

İzmir region is mainly conceptualized by Eraydın & Güldem (2012) after 1990 as three conceptualized rings. The first ring is described as "the core of the core" around the Bay. This ring is characterized as the zone which loses its growth dynamic, recessed in terms of population and employment and even declined. The second ring is described as the rapid growth zone surrounding the main core around the Bay. Lastly, the third ring is the exterior ring which does not subject to significant growth. However, it is asserted that by stabilization of the second ring and the effect of public investments, focal growth nodes could be emerged in some zones located in the exterior ring. The radius of the three rings is approximately defined as 50 to 60 kilometers. Furthermore, it is also argued that the concavity of the region of İzmir is not limited by the provincial borders besides *Manisa* and *Aydın* which are significant part of the regional system.

By referring this triad conceptualization, the city-region is described by Tekeli (2017) by four zones including three rings and the other peripheral settlements. The first ring is described by the border of the district of *Konak*, the second ring is consisting of *Karşıyaka, Bornova, Güzelbahçe, Narlıdere, Güzelbahçe, Narlıdere, Balçova, Çiğli, Buca, Bayraklı, Karabağlar, Gaziemir.* The other districts of İzmir is described as the third ring including *Menemen, Aliağa, Kınık, Bergama, Dikili, Kemalpaşa, Menderes, Seferihisar, Urla, Karaburun, Torbalı, Selçuk, Tire, Bayındır, Ödemiş, Kiraz, Beydağ, Foça.* The other peripheral settlements is also added into conceptualization including *Saruhanlı, Gölmarmara, Akhisar, Manisa, Kuşadası, Söke, Germencik, İncirliova, Köşk, Yenipazar, Sultanhisar, Turgutlu,* *Ahmetli, Salihli, Ayvalık, Gömeç, Çeşme, Aydın* that all are neighboring settlements of *İzmir.*

In addition to rapid urbanization movement in and around the central core in 1950s and fallowing decades, Tekeli (2017) states public supported investments affected the growth of the second ring including university campuses, industrial and free zones. University campus in *Buca,* airport of *Adnan Menderes,* 17 industrial zones, 2 free zones in *Menemen* and *Gaziemir* are presented as examples of those investments. In addition to them investments in the transportation system affected the city-system including; *İzmir-Çeşme Highway, İzmir-Aydın Highway, Aliağa-Torbalı Highway* and *İZBAN* commuter train system. It is said that finance, insurance and real-estate sectors are still located in the first ring while new specialized nodes appear. *Aliağa* is identified as industrial node, *Menemen, Kemalpaşa, Turgutlu, Torbalı, Menderes* as agricultural industrial nodes while *Çeşme* and *Seferihisar* as touristic or secondary-housing based specialized districts.

The regional organization is also identified by firm's location choice. It is declared that more than 60% of the newly established firms choose location as *Konak* until 1980s. In 1990s, approximately 75% of them choose *Bornova* (17.6%)*, Karabağlar* (6.8%) and *Çiğli* (5.7%). The choice rate of *Konak* declined to 38.2%. The location choice mainly altered after 2000 as preference of *Konak* further declined and decreased to 21.1% by 2011. After 2000, the other popular locations in terms of new firm's choice are listed as; *Kemalpaşa* (7.1%), *Torbalı,* (5.9%), *Menderes* (4.7%), *Çiğli* (10.9%) and *Gaziemir* (7.0%). Like *Konak*, shares of *Bornova* (21.0%) and *Karabağlar* (4.4%) declined in this period as well. In addition to choice of firms, decline is also visible in terms of inhabitant population in central core after 2000 (Eraydın & Öztağan, 2013).

In addition to declined profile of the central core, İzmir development Agency declared *Karaburun* and *Beydağ* as the districts losing both rural and urban population (İzmir Development Agency, 2015). The other districts subjected to rural population loss are declared as; *Bergama* and *Kınık* in the north, *Torbalı,* *Bayındır, Selçuk* and *Tire* in the south and *Ödemiş* and *Kiraz* in the east. Rural population loss is declared also by Oğuz (2013). By examining the population change of *İzmir* in three periods as (i) 1930-1950, (ii) 1950-1980 and (iii) 1980-2010, it is declared that the highest population loss is observed in the third period. Decline is recorded as 22 times in total population which is 8 times in urban and 27 times in rural (Oğuz, 2013). Due to alterations in administrative legal system, definition of urban and blurriness of the urban rural transition, recognizing the population dynamics in terms of urban rural dichotomy is hard. However, they provide clues about the dissolution of the rural based forms of organization around the river basins since the rural-called districts are located around the plains of the *Bakırçay, Gediz* and *Küçük Menderes Rivers* (Figure 4-5).

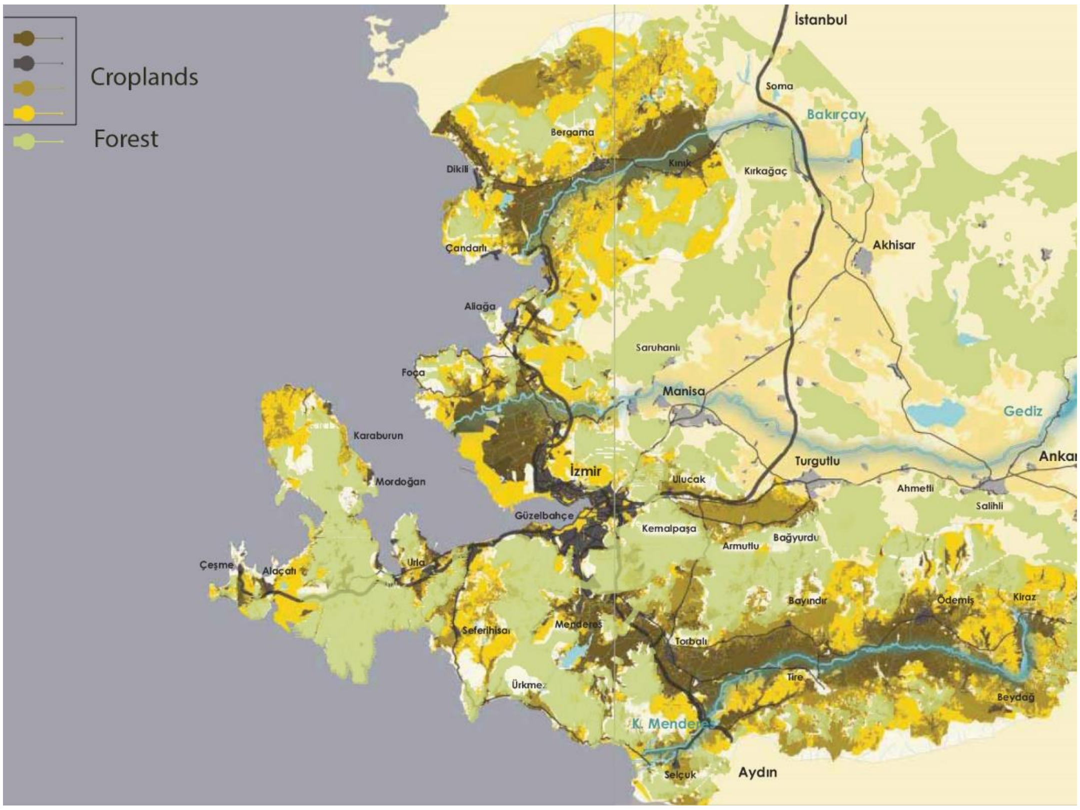



Figure 4-5 Forest, Croplands and River Basins of *İzmir* (Reproduced from; İDA, 2013; p.83 and 119)

Although literature related to the regional growth of *İzmir* is quite limited Oğuz (2013) presents a similar conceptualization. Four main dynamics are identified as ;

-*Growth of the centre:* As an aged CBD except *Konak,* continuous population growth in central districts including *Balçova, Bayraklı, Bornova, Buca, Çiğli, Gaziemir, Güzelbahçe, Karabağlar, Karşıyaka, Konak* and *Narlıdere.*

-*Decline in agricultural economies:* After 1990s severe rural population loss in the districts having agriculture dominant economies. However, it is stated that the aging and disintegrated rural gained strength in *Bayındır, Bergama, Beydağ, Karaburun, Kınık, Kiraz, Ödemiş, Selçuk* and *Tire*. Population decline in *Kınık* and *Karaburun* is recorded for three decades from 1930 to 2010.

-*Rapid growth of coastal zone:* After 1980s a rapid growth is observed as secondary housing in holiday settlements. This dynamic is stated to be observed in *Çeşme, Dikili, Foça, Seferihisar* and *Urla*. It is also stated by Tekeli (2017) that measuring growth in those locations are problematic due to seasonality of the demographic and economic mobility.

*-Consistent growth of peripheral industrial locations:* Except *Aliağa* those districts are close city center providing job opportunities and affordable housing. This dynamic is defined for *Aliağa, Kemalpaşa, Menderes, Torbalı* and *Menemen.*

Another but similar conceptualization is described by Karataş (2006) by focusing industrial zones. It is stated that industrialization accelerated after 1965 in the region. In 1970s, industrial firms are scattered around the city while they are mainly concentrated around the central core until 1950s. Affected by the plan of Aru, the eastern side of the core grew like *Pınarbaşı, Bornova, Gaziemir, Çamdibi, Kemalpaşa* and *Çiğli.* By the plan of Bodmer in mid 1960s, heavy industry is shifted to the *Pınarbaşı* zone. However, increased land prices lead to growth in *Kemalpaşa* in 1970s. After 1984 some large scale mass housing projects affected the direction of the growth that *Buca, Cumaovası, Kemalpaşa* and *Bornova* specialized in manufacturing industry. The sole mass housing projects are located in the districts of *Gaziemir, Karşıyaka (Denizbostanlısı-Mavişehir), Karabağlar (Esentepe-Üçkuyular), Buca, Çiğli, Bornova* and *Menemen* (Türkçü, ve diğerleri, 1996). Similar to statement of Tekeli (2017), Karataş (2006) asserts campus development in *Buca* and free zone in *Gaziemir* give important direction to settlement growth.

### 4.3.2 Background of the Regional Plans

Various planning studies have been carried out for Izmir since the early days of the Republic. However, preparation of a regional plan has a quite limited time span. The first urban plan of İzmir was produced shortly after the establishment of Republic. After the great fire in 1922 preparation for a plan İzmir become a prior issue for Ankara government. As a result "*Control of Re-planning and re-development of İzmir Company (İzmir'in Yeniden İmar ve İnşaasını Tetkik Şirketi*)" was established. The company made contact with Henri Prost. Afterwards a contract was signed with Prost and Dangers. The expected results of the plan were rehabilitation of destructed areas as well as functional organization of the city to enhance the economic activity (Bilsel, 2009).

The plan which is presented in Figure 4-6 was prepared in 1925. The main decisions of the plan includes (i) combining two railway stations by a central station, (ii) relocating the port to the north of *Alsancak*, (iii) proposing an industrial quarter and commuters zone near the new port which was segregated from the rest of the city by green corridors, (iv) developing new residential areas in order to decrease the population density and (v) redeveloping destroyed areas (Bilsel, 1996), (Bilsel, 2009). Until the Great Depression some further implementations including the construction of main arteries were succeeded.

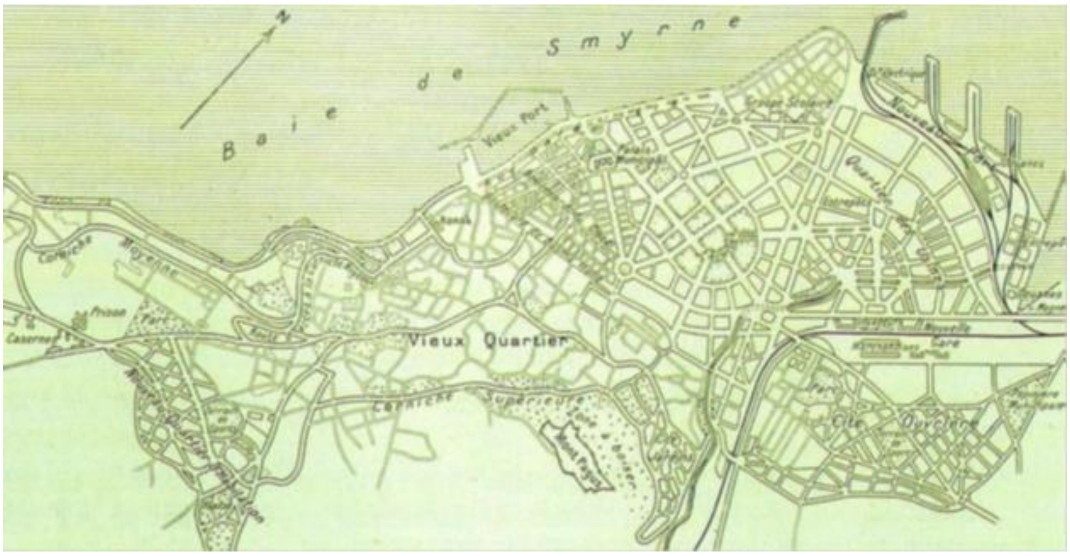



Figure 4-6 The plan of Danger and Prost - 1925 (İzmir Metropolitan Municipality Archives)

In 1930 the Municipality Law was enacted. Thus, urban planning became compulsory for municipalities. In advice of Hermann Jansen (the planner of Ankara) was taken in 1932 that he criticized the large boulevards. The first plan was revised in 1933 by the Municipality that a large open space in Alsancak was designed in the revised version. Boulevards were narrowed. Furthermore, relocation of the port suggested and new residential areas were removed. Urban morphological character of central area is mainly shaped by the decisions of the Proust Plan. The other important planning action was the plan of *İzmir Kültür Park*. A circular design was proposed for the central green area proposed in Proust Plan. Due to financial obstacles the project was combined with İzmir Fair Project. Then the Park was opened in 1936 and completed in 1939 (Bilsel, 2009). The revised Danger and Prost Plan is presented in Figure 4-7.

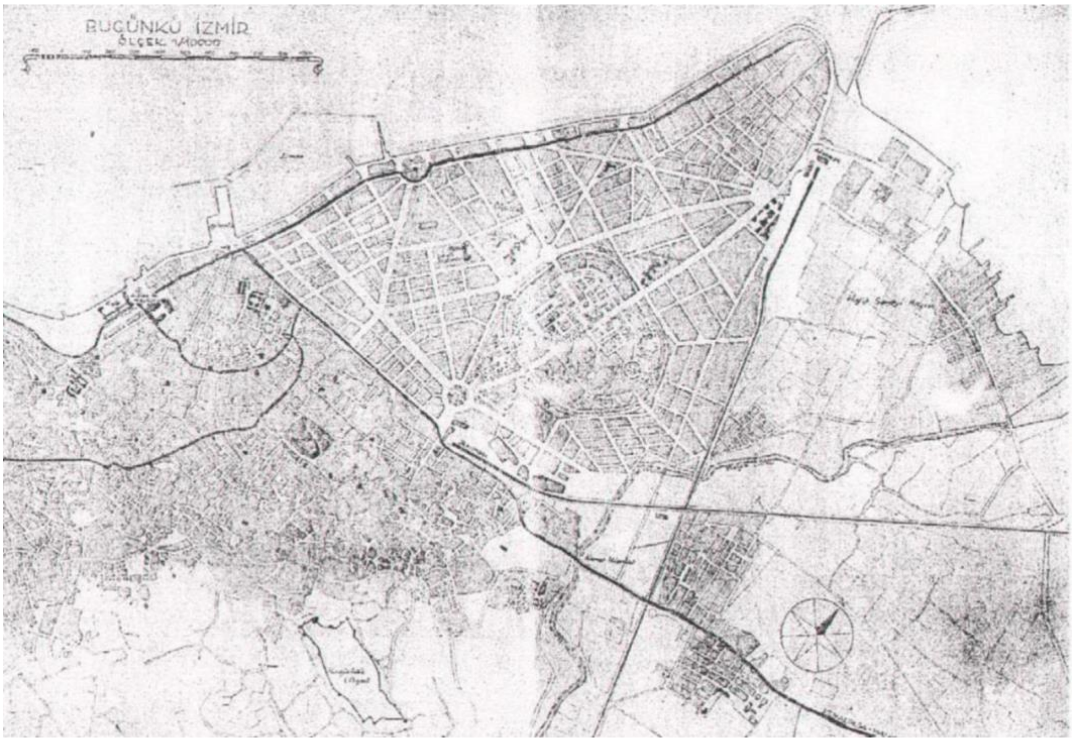



Figure 4-7 The revision of the Danger and Prost Plan in 1933 (İzmir Metropolitan Municipality Archives)

The plan proposes renewal of the destroyed historical quarter by preserving its tissue. However, the authority aimed to redevelop the historical quarter with respect to contemporary planning principles. Then the municipality of İzmir created a contact with Le Corbusier in 1938 (Bilsel, 1999). In addition to new development areas, the existing pattern was suggested to be refunctioned with respect to functionalist planning principles. It also includes green industry suburban sites connected to radial settlements in a linear form along motorways and waterways (Figure 4-8).

Due to WWII, the proposal could be prepared in 1949. The scheme was not regarded as applicable due to two reasons. Firstly, the scheme handles the historical quarter as tabula rasa and secondly it ignores the land ownership pattern in new development areas (Bilsel, 1999). However, some decisions were indirectly implemented such as; (i) new housing development along Hatay Road and connecting them to Konak by a variant, (ii) development of central area around Konak Square (Bilsel, 2009).

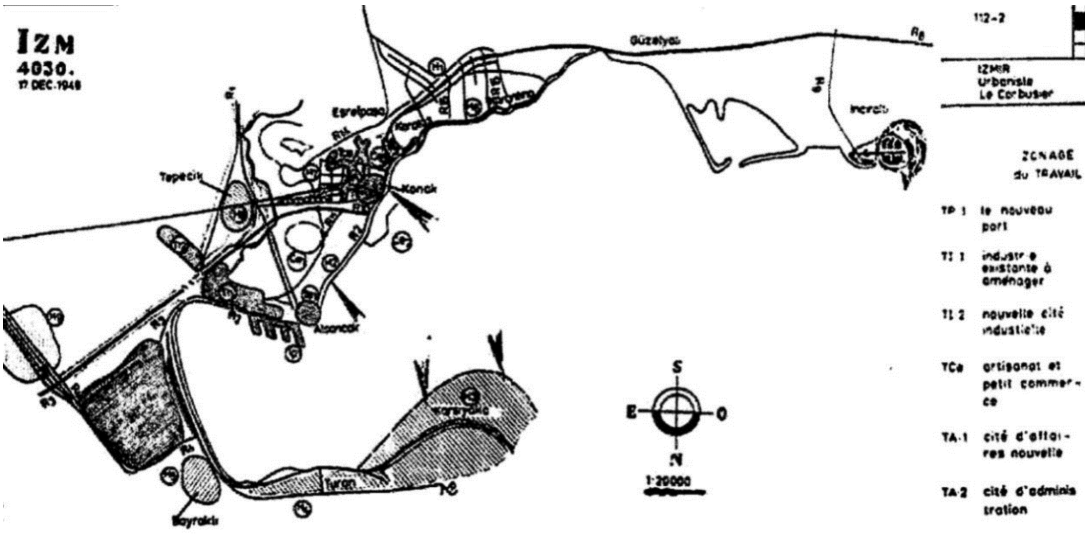



Figure 4-8 The plan scheme of Le Corbusier- 1949 (İzmir Metropolitan Municipality Archives)

Since Le Corbusier's plan could not be implemented the city still needed a comprehensive plan. Government chose a different method and announced a competition for the plan of İzmir. K.Ahmet Aru, Emin Canpolat and Gündüz Özdeş won the competition. The main selection criterion was the applicability of the proposal scheme. Population in 1950 was 230.000 that plan proposes 400.000 in fifty years (Bilsel, 2009). The functionalist planning decisions were mainly;

-Improving *Alsancak Port* as a freight and trade port

-Creating a new industrial zone

-Creating new residential areas from *Karataş* to *Üç Kuyular Districts* as well as *Hatay Road* and western *Karşıyaka*

-Proposing commuters zone in southern *Tepecik* and *Bayraklı*

-Connecting railways and motorways

-Linear macroform development

-Removal of *Sarıkışla* and renewal of the area by culture-art based functions

The Plan of Aru, Özdeş and Canpolat ise presented in Figure 4-9.


Figure 4-9 The Plan of Aru, Özdeş and Canpolat (prepared as a competition project in 1952, improved by the planning office of the Municipality of İzmir with the collaboration of Aru and approved in 1955) (İzmir Metropolitan Municipality Archives)

During and after 1950s greater cities are subjected to urban sprawl, illegal housing and uncontrollable building activities. During 1960s, interaction of the central city with its surrounding was studied in the context of Aegean Region and İzmir Metropolitan Region. Oral (2010) explains the main idea under defining several metropolitan sub-regions as; sustaining a planned scheme of activities in a interrelated hierarchical order. An urban belt as development corridors are proposed in regional scale including regional centers with city size distributions (Figure 4-10).

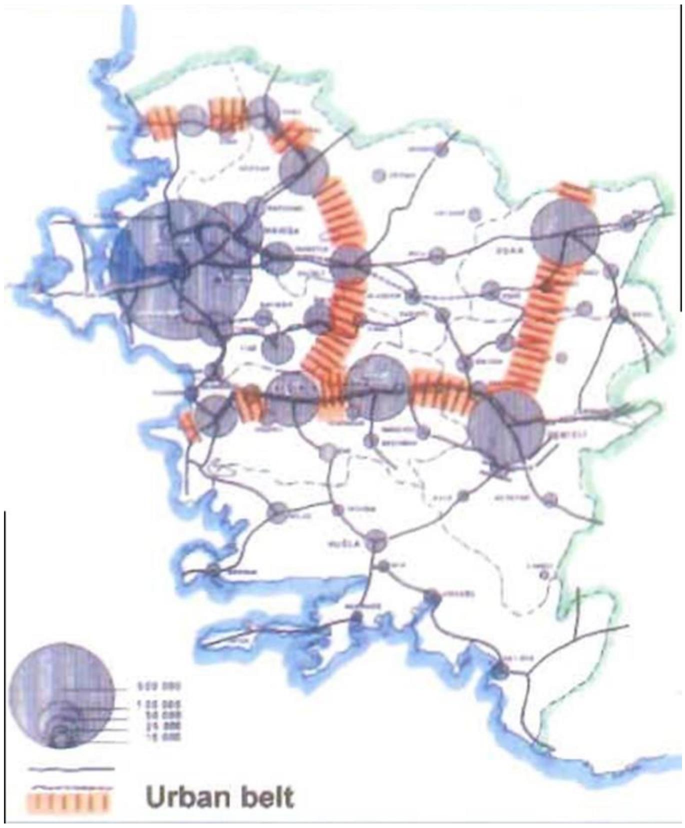



Figure 4-10 Regional Development of urban centers and strategy for city size distributions (Oral, 2010)

Due to rapid population growth a new plan was prepared by the İzmir Metropolitan Planning Office. Main macroform of the city was planned to be linear again. The plan is completed in 1972 and revised in 1978 (Figure 4-11). The plan was produced to solve the problems as; (i) congestion, (ii) weak infrastructure, (iii) expansion of squatters and (iv) pollution of the Bay. Main decisions of the plan are;

-Creation of tourism centers

-Planning of sub-centers

-Protection of satellite centers

-Development of heavy industry

-Construction of suburban rail system (İzmir Metropolitan Planlama Bürosu, 1972). Furthermore, the plan suggested a linear development along the north-south axis to provide effectiveness of transportation system (Oral, 2010).

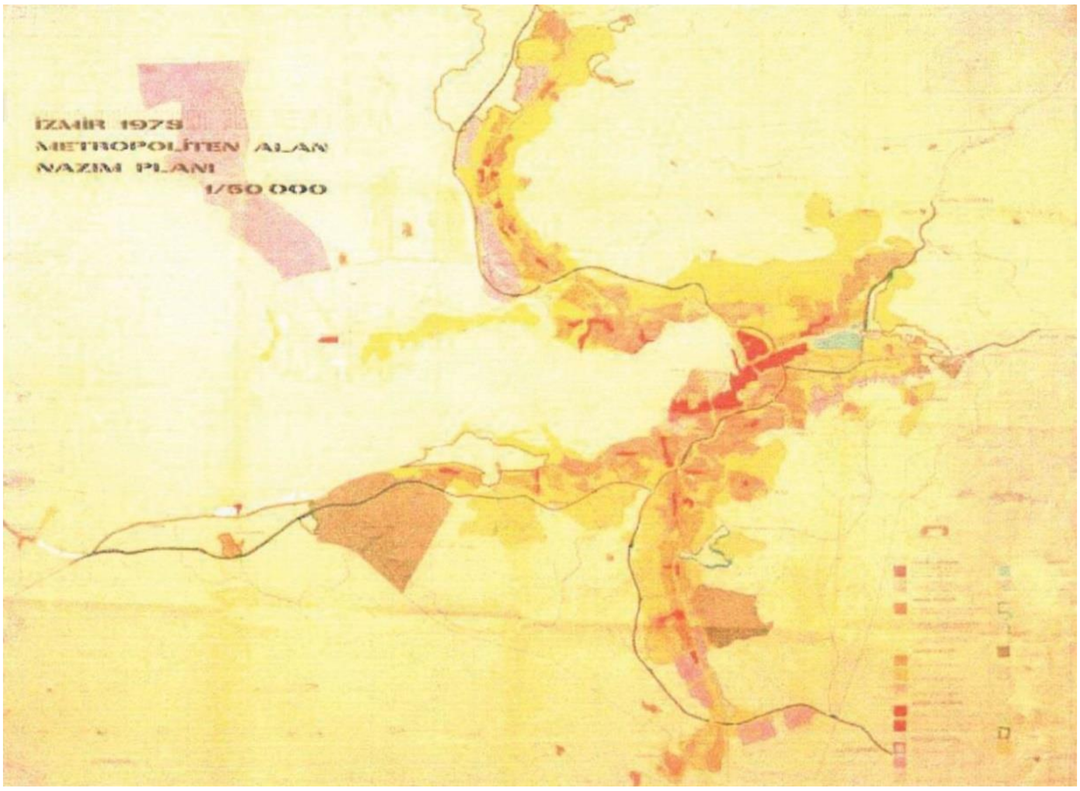



Figure 4-11 The Plan of Metropolitan Planning Office, 1978 (İzmir Metropolitan Municipality Archives)

The master plan was partially implemented and altered related to project based decisions. In 1980s control on growth dispersed. The centripetal force and speculative developments resulted in the invasion of the territory (Oral, 2010). The sixth plan of İzmir was a revision plan that it mainly aimed to balance the development pressure in the southern districts. In this plan unauthorized building sites were accepted while green areas were preserved. Moreover, a free-trade zone connected to the airport is suggested in *Gaziemir.* The Master Plan of Metropolitan Municipality is presented in Figure 4-12.

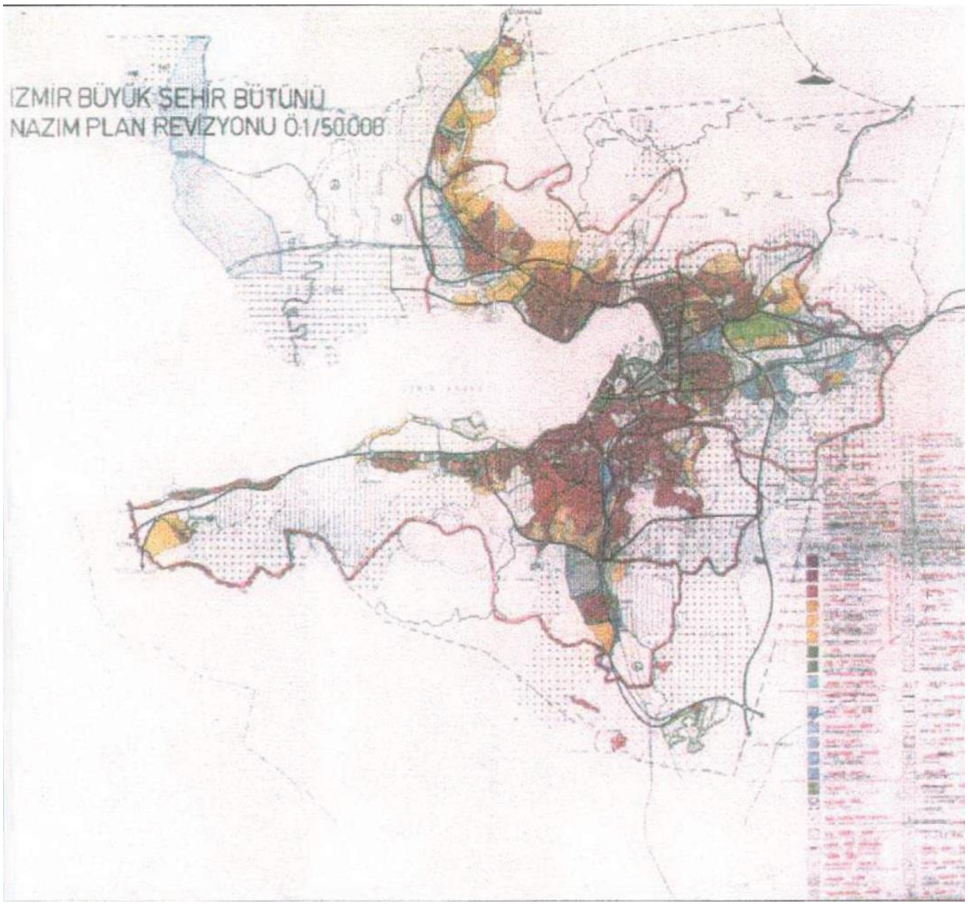



Figure 4-12 The Master Plan of Metropolitan Municipality, 1989 (İzmir Metropolitan Municipality Archives)

1/25.000 Scale İzmir Metropolitan City Land Use Plan Revision in 1989 was cancelled in 2002 since the Great Municipalities had no longer authorized to make 1/25.000 scaled plans. Afterwards four more environmental plans were approved. In terms of regional scale, in 2014 1/100.000 scaled Environment Plan was approved by Ministry of Environment and Urbanization, Spatial Planning General Management). Some revisions were approved in 2012, 2015 and 2017. In 2018 an expanded revision was approved (Figure 4-13). Moreover, environmental plans of some districts like *İzmir-Çeşme-Altınkum Tourism Center* 1/25.000 Environment Plan Revision was approved as well. In 2018 Revision Environmental Plan Report "Central City (Merkez Kent)" was defined including thirteen settlements as; *Balçova, Bayraklı, Bornova, Buca, Çiğli, Gaziemir, Güzelbahçe, Karabağlar, Karşıyaka, Konak, Narlıdere, Menderes* and *Menemen*. It is stated that the reason of this definition is the spatial integration of those settlements (Mınıstry of Envıronment and Urbanısm , 2018).

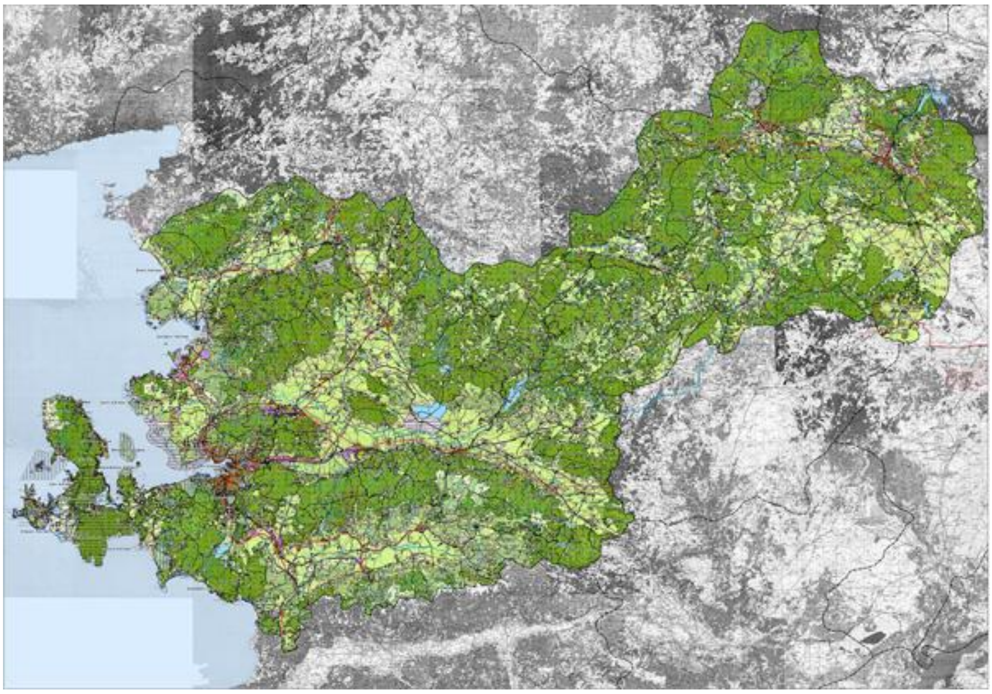


Figure 4-13 İzmir-Manisa Plan (Revised in 2018) (Ministry of Environment and Urbanism Archives)

Furthermore, in 2012 1/25.000 scaled Environment Plan (Figure 4-14) is approved by İzmir Metropolitan Municipality. The sole aim of the plan is to enhance existing settlements in a more sustainable and livable manner. The main development axis was determined as the north that sub-centers were also proposed in order to make existing settlements more self-sustainable. In order to decrease the pressure on CBD, a polycentric and linear urban macroform was defined. The agricultural land was aimed to be protected by segregating the urban development by a green belt in the south. Furthermore, low-density residential development was planned on an eastern corridor in order to orient the pressure from the south. The development areas in the plan are defined as; *Konak, Karabağlar, Karşıyaka, Çiğli, Bayraklı,Bornova, Buca, Gaziemir, Balçova* and *Narlıdere*. Furthermore, *Seferihisar*, *Menderes* and *Selçık* in the west axis, *Menemen, Foça* and *Aliağa* are in the north axis, *Torbalı* and *Bayındır* in the south axis and *Kemalpaşa* in the east axis were defined as development areas (İzmir Büyükşehir Belediyesi, 2012).

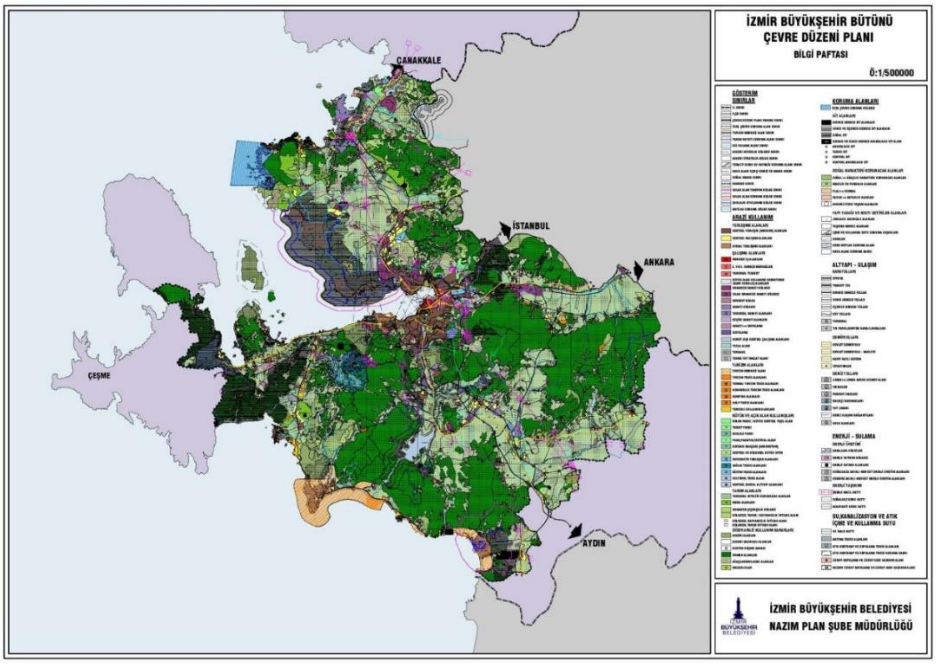



Figure 4-14 2012 İzmir Greater Municipality Plan (İzmir Greater Municipality Plan Report)

### 4.3.3 Development of sub-regions of İzmir

In order to evaluate the development trends and major alterations in city-region morphology, regional development of İzmir is evaluated by sub-parts. Five main sub-regions (Figure 4-15) are determined with respect to geographical and functional integration of districts. They are;

(i) The Bay: Çiğli, Karşıyaka, Bayraklı, Bornova, Buca, Gaziemir, Konak, Balçova, Narlıdere and Güzelbahçe

(ii) The Southern: Torbalı, Selçuk, Menderes, Seferihisar

(iii) The Western: Urla, Çeşme, Karaburun

(iv) The Northern: Menemen, Foça, Aliağa, Dikili, Bergama and Kınık

(v) The Eastern: Kemalpaşa, Bayındır, Tire, Ödemiş, Kiraz and Beydağ

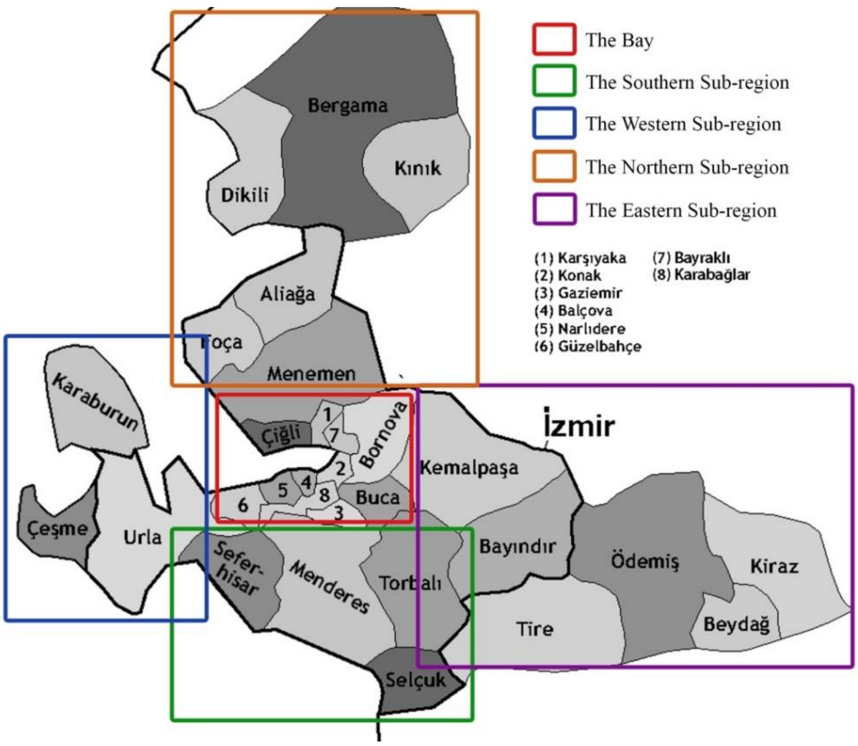



Figure 4-15 Sub-regions and districts of İzmir Region

**The Bay**

Rather than a sub-region, the region consisting of the districts around the İzmir Bay are central core of İzmir city-region in terms of heterogeneity, population and density. As a result this part is accustomated to population and development density.

*Konak*, is the economic, administrative historical and present central core of İzmir. The local municipality was known as İzmir Municipality" until 1984. In addition to central land-uses the southwestern part includes a rural character covered by forest and mountains. As a hub, the district is connected to other parts by a network of roads, ferry and a subway system. Many landmarks of İzmir such as; *Konak Square, Kemeraltı Bazaar, Kadifekale, Alsancak District, Asansör (The Elevator)* and *Kordon (the shoreline)* can be regarded as the sole well-known symbols of İzmir.

*Balçova*, as the smallest district of İzmir, became a separate district in 1992 by the Law No. 3806 (Oğuz, 2013). In addition to central activities, the district can be described as middle to upper middle income residential district involving shopping malls, hospital, İzmir Economy University and new housing projects.

*Narlıdere* is a fully urban district. The district was separated from the center in 1992 by the Law No.3806 as *Narlıbahçe*. In 1993, *Narlıbahçe* is separated into two districts as *Güzelbahçe* and *Narlıdere* (Oğuz, 2013). Since late Ottoman period and early Republican times, the settlement was called as *Tahtacı, Aşağınarlıdere, Yukarınarlıdere and Yeniköy*. The district gained investments in terms of new housing projects. Moreover, one of the important use is the Turkish Army School. *Güzelbahçe* district is the smallest one among the central districts in terms of population. Although majority of the district is highly urbanized, isolated villages and vineyards are located in the southern mountainous parts. In addition to middle-income housing, villa-type housing projects are emerged during last two decades.

*Karabağlar* is separated from *Konak* District in 2008, by the Law no.5747. In old sub-district *Uzundere*, public housing projects (TOKİ)is located. There exist mountain villages of *Kavacık* and *Tırazlı* in the western part of *Karabağlar.* The main axis as *Halil Rıfat Paşa Road* and *Mısırlı (current İnönü Street)* shaped during late 19th century. In addition to high-rise regular development along main axes, *Karabağlar* was subjected to illegal housing after 1950s.

*Gaziemir* is characterized by İzmir International Airport. Furthermore, the industrial park of Aegean Free Zone is located in the district. The settlement of Gaziemir dates back to 14th century that previous nameas are *Umur Beg* and as *Seydiköy* laterly. The district become a separate district by the Law no 3806 in 1992. As being a hub of industry and transportation, it has been continuously developed by outlet centers, furniture industry and sales centers surrounded by new residential development areas.

*Buca* is developed in 17th century and developed during 19th century as a Levantine suburb by the help of railway connection. The historical identity has been partially preserved in central part despite high rise apartment blocks constructed after mid-20th century as housing cooperatives. Between 1980 and 1990 *Buca* is recorded by TUİK (2009) as having the highest population growth rate in Turkey among all metropolitan districts. The district became a separate district in 1987 according to Law no. 3392. The significant uses in *Buca* are *Dokuz Eylül University, hospital, Hippodrome* as well as major public parks.

*Bornova* which can be defined as a transition zone from urban central area to rural areas became a district in 1957. However, *Bornova* municipality was established during 19th century. The area was characterized as a European and Levantine settlement by the help of railway connection of *İzmir-Manisa* lane. Housing and university functions are the most important sectors in the district. Furthermore, there is considerable volume of small scale industry. The district was subjected to rapid growth between 1960 and 1980 (Oğuz, 2013). In addition to urbanized lands, there exist forested uplands around Mount Yamanlar. The district involve shopping malls, cultural and recreational facilities.

*Çiğli* is located in the northeastern edge of the Gulf of İzmir. After registering as a village during Republican period, the district became a municipality in 1956. *Çiğli* became a separate district of central İzmir in 1992 according to Law no 3806. The area has a significant natural importance due to bird inhabitance in the *Gediz Delta.* The Organized Industrial Zone is also located in *Çiğli* operates as a sole economic hub since late 1970s. Furthermore, there exists a major air force base in the district. It experienced growth since its establishment.

The other two districts of *"The Bay"* are *Bayraklı and Karşıyaka. Bayraklı* was established in 2008 by the Law no. 5747 seperated from the districts of *Karşıyaka* and *Bornova.* In addition to historical quarters, *Bayraklı* is planned to be grow as a new CBD of the city (Oğuz, 2013). In addition to middle-income residential areas and higher income new housing projects, considerable amount of illegal housing activity exist in *Bayraklı* district.

*Karşıyaka* is located in the northern coastline of the gulf of İzmir as the opposite coast of *Konak.* Al commercial, cultural, educational and touristic activities can be observed in the district. The district was established in 1954 according to the Law no 6325. Like *Konak* and *Balçova, Karşıyaka* is characterized as an urban metropolitan district of *"The Bay".* Population growth of the district was accelerated during 1980s and 1990s (TÜİK, 2009).

**The Western Sub-region**

The sub-region includes *Urla, Çeşme* and *Karaburun* located in the western peninsula. The main characteristics of the sub-region are natural and rural areas, tourism activities as well as secondary housing not only for inhabitants of İzmir but also for other metropolitan areas of Turkey mainly İstanbul and Ankara. Similar to *Dikili* and *Seferihisar* as districts of the northern and the southern sub-regions, *Urla, Çeşme* and *Karaburun* are attractive destinations for aged and retired population for permanent and semi-permanent accommodation.

*Urla* has been labelled as a separated district since the establishment of the Republic. In addition to retired population, younger working households also reside and commute to the city from *Urla*. Population growth rate of *Urla* continuously increased and accelerated between 1980s and 2000s. Secondary residences play a key role in the development of the district. Socio-cultural activities flourished in last decades.

*Karaburun* has a similar feature with *Urla* respect to the attraction of retired population as well as secondary housing. Due to accessibility obstacles growth of Karaburun remained slower than *Çeşme* and *Urla*. In recent years transportation motorways investment projects increased the attraction of the district. Furhermore, Karaburun was announced as Special Protection Area in 2019 due to distinct flora and fauna elements.

The most attracted district of the western sub-region is *Çeşme*. It is under the development pressure with respect to *Urla* and *Karaburun*. Although *Çeşme* is an important destination of retired population and secondary housing, tourism sector is much more expanded and specialized. Like *Urla, Çeşme* has been always a separated district. Beginning from 1970s, the growth tendency goes on and highly accelerated due to the increasing transportation facilities mainly as the construction of İzmir-Çeşme Highway. From 1980 to 1990 *Çeşme* took the leadership with the growth rate of population exceeding 100%. After 2007, a reasonable decline in resident's population can be observed. In addition to historical town center, villages and countryside of *Çeşme* are well-known tourism destinations such as; *Boyalık, Ilıca* and *Alaçatı*. Hotels, marinas, clubs, restaurants, family accommodation possibilities and beaches have national and international importance (Oğuz, 2013).

### The Northern Sub-region

Districts in the northern sub-region of İzmir have quite different characteristics with respect to other sub-regions. The districts in the northern sub-region are; *Menemen, Foça, Aliağa, Dikili, Bergama* and *Kınık. Menemen* and *Aliağa* has some shared characteristics with *Kemalpaşa, Menderes* and *Torbalı* in the eastern and southern sub-regions since they have on integration with *the Bay* as a peripheral industrial-agricultural location. Due to their spatial proximity to the center there exist considerable residential areas. On the other hand, there exist interregional networks with their surrounding districts as well as neighbor cities which is the case for *Kınık*. Moreover, some basic features of *Foça* and *Dikili* resembles with *Seferihisar, Urla* and *Karaburun* as attraction locations for retired population and secondary housing.

*Menemen* as an outer metropolitan area has been subjected to continuous population growth. The district is always a separated district during Ottoman and early Republican periods. The district is mainly covered by a fertile land fed by *Gediz River*. In addition to two organized industrial zones, agricultural and husbandry activities still persist in the district. Furthermore, a free zone based on leather-works is established in the district. The district is integrated with İzmir by railway and roadway which ease to transfer products.

*Aliağa* is the other district involves industrial activity although it has not proximity of central İzmir. The continuous population growth of *Aliağa* accelerated after 2000s. Oğuz (2013) states *Aliağa* was aparted from *Menemen* in 1982 and became a separate district. The distinct feature of *Aliağa* is that the district's intrinsic industrial activity. In the northern part of, Turkey's biggest petroleum and chemistry industry is located in the district. As a result of the industrial profile, rural population has declined and urban population increased in time especially after 2000s.

*Bergama* is a separate district since the establishment of the Republic. After *Ödemiş*, *Bergama* involves the largest rural population share due to continuous predomination of agricultural activity (Oğuz, 2013). On the other hand rural population declined after 2000 until the Law 6360. Furthermore, it is observed that similar to *Ödemiş,* wider agricultural land divisions with respect to other districts can be observed in *Bergama*. Apart from that, the largest number of villages is belonged to this district in İzmir. In addition to agricultural sector, the archeological sites having international significance makes *Bergama* a tourism destination. Until 2000s, a steady population growth took place in *Bergama,* and then with respect to rural loss, total population declined.

*Kınık* is separated from *Bergama* in 1948. It is one of the smallest districts of İzmir after *Karaburun, Beydağ* and *Kiraz* in terms of population. The economic activity and settlement pattern is mainly based on agriculture. Despite the rural character, rural population loss can be observed after 2000. Some villages are integrated to İzmir in last few decades that *Kınık* operates as a rural node of Soma-Manisa region.

Like *Karaburun, Foça* is a special natural protection sites due to flora and fauna elements the district comprises. In addition, the old town has remarkable historical values. The areas under the development pressure is *Yenifoça (New Foça).* Like *Karaburun, Seferihisar* and *Urla, Foça* is an attractive settlement area for retired population as a calm coastal zone. In addition to protected sites, there exist important Turkish Navy in *Foça* which resulted in sprawl of secondary housing among the district. Despite its relatively low population, high population forecasts could be observed in environmental plans (Mınıstry of Envıronment and Urbanısm , 2018).

The other district located in the northern sub-region of İzmir region is *Dikili,* which has similar trend in attracting the retired population as well as seasonal / secondary housing. After *Karaburun,* the district is the highest median age with respect to other districts. On the other hand, like *Foça,* considerable population growth can be observed in *Dikili* after 2000 while *Karaburun* loose population. Appropriate to the district's is long existence, *Dikili* is a separated district since the establishment of the Republic. Despite the steady growth throughout the Republican history, rural population declined after mid-2000s.

### The Eastern sub-region

*Kemalpaşa, Bayındır, Tire, Ödemiş, Kiraz* and *Beydağ* are consisting of the sub-eastern region of İzmir. This sub-region involves shared characteristics of districts. Different from the coastal zones, this sub-region is interrelated with the backbone of İzmir as Anatolia. Although, *Kemalpaşa* has resembling features with the outer periphery districts of İzmir like *Menemen* and *Menderes*, the sub-region has an agricultural based rural presence. The rural network is fed by many villages, sub-districts and districts involving an integrated agricultural based pattern in plains. The mountainous parts of the sub-region have a similar pattern in terms of small and isolated villages.

*Kemalpaşa* as an outer peripheral metropolitan district is integrated with İzmir from the west. Since İzmir-Ankara highway crosses the district, there exist high levels of development in terms of industry and services. The district has a large organized industrial zone (*KOSBİ).* On the other hand, the southern and eastern parts of the district prevails a rural character. The northeastern villages also integrated with Manisa-Turgutlu. With its transitionary, character, *Kemalpaşa* has been a separate district since the establishment of Republic. Like *Menemen* and *Torbalı*, *Kemalpaşa* have the lowest median age and a steady population growth rate for decades as a growing district of outer metropolitan area. In spite of the fact that the district remains its agricultural character, *Kemalpaşa* has also been subjected to rural population loss after 2000 (Oğuz, 2013).

*Kemalpaşa, Bayındır, Tire, Ödemiş, Kiraz* and *Beydağ* have some similarities in terms of their agricultural based network, disintegration after 1990s and resulted in declining and aging population due to immigration of the youth. *Bayındır* is an old district registered while establishment of the administrative system. Sole economic activities are agriculture and flower planting and the district experienced a constant growth until 1990s. *Bayındır* has sub-districts as local nodes having agricultural dominance as *Çanlı* and *Çırpı*. Likewise, *Ödemiş* has been a separate district since the establishment of the Republican administrative system. *Kiraz* and *Beydağ* were sub-districts of *Ödemiş*. Since there exists railway service, the town operates as an agricultural exchange center. After 2000s, despite a small increase in urban population, a considerable rural population loss is observed. Nevertheless, Ödemiş has the highest rural population since 2014 recorded for İzmir. Some villages like *Bıçakçı* and *Pirinççi* could keep young inhabitants. Furthermore, the district accommodates industry based on agriculture and animal husbandry.

The other agricultural district in the southern sub-region fed by the *Küçük Menderes River* is *Tire*. Likewise *Tire* is located on İzmir's regional railway and has always been a separate district. On the other hand, there exists an organized industrial zone. The district has a growing local husbandry products industry. After *Ödemiş, Bergama* and *Kiraz,* the district had the highest rural population until the last records. *Tire* has a steady growth for decades and similar to other districts having agricultural predominance, *Tire* lost rural population after 2000.

*Kiraz* is the district having to longest distance to central İzmir among all districts. According to the State Planning Organization (2004), *Kiraz* has the lowest ranking in terms of socioeconomic development among all districts. The district was a part of *Ödemiş* and aparted in 1948. After *Ödemiş* and *Bergama* it has the highest rural population despite the loss after 2000s. The economy is based on agriculture and industrial production does not take place. The aged population can be observed in *Kiraz* except *Karaburç* village which is close to district center and ease commuting (Oğuz, 2013).

*Beydağ* has a closer distance to Aydın than İzmir that it is one of the furthest districts to central İzmir. The district was a part of Ödemiş until 1987. After *Karaburun* and *Seferihisar* it has the lowest population and it has the most dramatic rural population loss in 2000s. The declining district's economy is based on agriculture. After *Karaburun* and *Dikili,* which are attractive for retired population, *Beydağ* is the third district having the highest median age. Since the aged population of *Karaburun* and *Dikili* is the result of immigration of retired inhabitants, it can be argued that *Beydağ* is the most declined district by out-migration. Some villages of *Beydağ* are attached to İzmir after 1980s from Aydın.

**The southern sub-region**

The southern region comprises districts involve heterogeneous characteristics. The sub region is comprised of *Torbalı, Selçuk, Menderes* and *Seferihisar* districts.

*Torbalı* has always been a separate district and operated as a peripheral metropolitan region with a relatively low median age. In addition to agricultural production, industry provides an important economic contribution since global firms preferred the location. The district is connected to İzmir by railway and İzmir-Aydın highway. During 2000s, the decline of agricultural sector also led to decrease in rural population of *Torbalı* like *Bergama* and *Ödemiş. Resembling to median age feature, Torbalı* gained residents commuting to İzmir due to increased accessibility by railway and motorway like *Menemen*.  The rural population loss after 2000 until the last rural population records can be observed in *Torbalı* as well. However, total population is increased since the district gained urban population by industrial activities and cheap housing stock for commuters.

*Selçuk* was a town of *Kuşadası-Aydın* until 1957. The district is an important tourism destination due to religious, historical and archeological sites such as; *Ephesus, House of the Virgin Mary* and *Şirince*. The town center itself is also embedded in archeological sites. Although *Selçuk* is connected to Aydın due to spatial proximity and tourism activities, connection to the north has increased by railway connection. After *Beydağ, Selçuk* is the second district subjected to highest rural population loss after 2000. However, total population has a steady rate of growth for decades. The growth rate increased between 1980s and 2000s.

*Menderes* was an old district named as *Cumaovası* in the Ottoman and early Republican periods. *Menemen* has been registered since the beginning of the republic as a separate district. As a peripheral metropolitan district the median age is low like *Kemalpaşa* and *Torbalı*, the district indicated rapid growth mainly between 1990s and 2000s. The district have many sub-distrits which are closed and became a part of *Menderes* as; *Asarlık, Emiralem, Maletepe, Türkelli, Koyundere, Maltepe, Seyrek* and *Ulukent.* Rural population declined after 2008 because of the administrative alterations rather than a functional change. The district has been subjected to immigration from eastern provinces of Turkey.

*Seferihisar* has been subjected to increased tourism activity in district scale including the town center itself and the outlier areas. Several housing projects concentrated along the coastline that the district is subjected to immigration of retired population and secondary housing like *Dikili, Urla, Foça* and *Karaburun.* The town center is the first *citta-slow* city of Turkey which empowered this process. *Seferihisar* have two sub-districts as; *Doğanbey* and *Ürkmez. Seferihisar* has always been a separate district then two bub-districts became the neighborhoods of it by administrative organization alterations. After *Güzelbahçe* and *Dikili, Seferihisar* is the third district gained urban population after 2000.

## 4.4 Data Collection and Methods

In this part of the study the data acquisition process is presented. Then the methods and approaches used in the study for complexity and relational analysis are introduced.

### 4.4.1 Data Collection

İzmir as a settlement system or urban region is the third largest city of the country. Sole sectoral cores and their network can be observed both interregional and intraregional scales. As an agglomeration; some districts, neighborhoods or villages of İzmir are part of the network of neighbor cities. In terms of agriculture dominated areas in the eastern part, some settlements are part of the network of *Manisa* region. In addition to in-situ observations, it has been understood from the population data that some villages are previously connected from *Manisa* to *İzmir* or *vice versa.* The southern part such as *Selçuk* has interconnections with the districts of *Aydın.* The number of daily bus and minibus services is higher between *Selçuk* and *Aydın* with respect to *İzmir*. However, with development of railway network named as *İZBAN (İzmir Banliyö Sistemi)* after 2010, the network of urban region has been altered and integration has been increased. Through observations and development trends, it can be argued that development of railway system in the city-region will have an impact on the integration.

As it can be observed from the literature, city systems have heterogeneous structures and have different level of detail in different scales. Furthermore, complexity levels of the parts do not reflect the whole system. Likewise, each agglomeration is differently embedded to a larger context. The other significant argument can be observed is that a degree of blurriness exist in terms of firstly (i) where urban areas starts and ends and (ii) what is the extent, hinterland or the network of an agglomeration. The study area covers the city-systems of İzmir region including rural territories, sub-centers and metropolitan city. Since determination of the boundaries of urban, rural or region could not be precisely handled, two scales are determined as the the extended region and İzmir region.

The time span of the study covers approximately seven decades from 1950s to present time. Different maps for diversified purposes are acquired including insurance, municipal services, taxation or cadastral surveys. For *Konak,* insurance maps dates back to 19$^{th}$ century. Examples of mentioned old maps of İzmir in 1817 and 1905 are presented in Figure 4-17. Furthermore, starting from 1952, air photographs exist for the city of metropolitan İzmir. However, a complete map or image could not be obtained for the entire province before 2000. 1/20000 (data of

1911)  and 1/25000 (data of 1922) scaled military maps produced by the Command of Ottoman State Press (*Erkan-ı Harbiye Umumi Matbaası*) which are archived by the *General Directorate of State Archives*. The 1/20000 scaled map involve limited information about road network. 1/25000 scaled maps have the standard legend with later versions produced by of General Directorate of Maps of Turkish Republic. However, all maps covering İzmir Province are not available which would results in discontinuities in transportation network and accordingly in the analyses. In order to sustain a comparable standardized dataset, study time period has been started from 1950s for both extended and İzmir region analyses when standardized and complete maps are available.

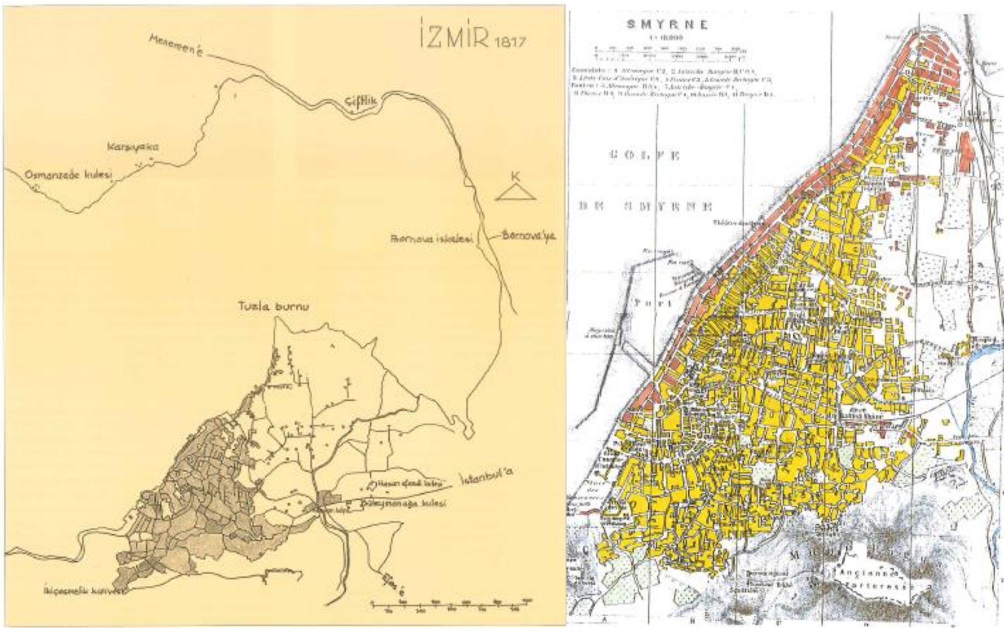



Figure 4-16 Old maps of İzmir in 1817 and 1905 (Beyru, 2011, p.43 and p.86)

**Extent and Data Gathering of Extended Region Analyses**

Chaotic systems and complexity analysis possesses non-linearity both in time and space. Thus, observations of fractal dimension change are evaluated in long-time span. For regional analysis, spatial information is gathered from maps since old photographs covers only the metropolitan borders and satellite images cannot be acquired for previous decades. Furthermore, each map involves different information due to map scale and institutional standards as Brenner and Schmid (2014) executed as a limitation. In order to avoid from altered detail and information involving in different types of maps, standardized maps of General Directorate of Highways of Turkish Republic have been used for extended region analyses. For the analyses of İzmir Region which is determined as the provincial borders of İzmir, 1/25.000 scaled maps of General Directorate of Maps are used.

By Tekeli (2017) the exterior peripheral zone of the region of *İzmir* is described including the settlements of *Saruhanlı, Gölmarmara, Akhisar, Manisa , Kuşadası, Söke, Germencik, İncirliova, Köşk, Yenipazar, Sultanhisar, Turgutlu, Ahmetli, Salihli, Ayvalık, Gömeç, Çeşme, Aydın*. Firstly, those settlements are aimed to be covered in the extended region analysis. Since fractal dimension of road system is analyzed, a spatial extent is determined as the extended-region of İzmir by taking the road system as an edge which can be observed in the city-scale or regional studies. To illustrate, studies of London mainly take the London orbital Motorway (M25) as an edge for the network based studies (Hillier, 1996), (Vaughan, 2007), (Hillier & Stonor, 2010), (Yamu & van Nes, 2017). The spatial extent of the study is determined as; *Ayvalık, Sındırgı, Simav, Denizli, Yatağan, Milas* and *Didim*. In addition to İzmir, *Aydın* and *Manisa* are condemned to be a part of extended region since those settlements involve structural and economic relations. *İzmir* does not have a precise network edge like a ring-road or a geographical barrier except the *Aegean Sea*. As a result determination of such an edge for the extended region studies can be altered and studied with respect to mobility or commuting patterns or natural zoned as well as economic activity. For previous decades except the last two, the only variable can be gathered from public institutions in provincial level is population. As a result, the frame of the study is determined with respect to road network. Since this study focus on the change of complexity level of the region with respect to time, an acceptable comparison can be sustained in the selected frame represented in Figure 4-18.


Figure 4-17 Spatial Extent of Extended-region analysis

From 1955 to 2018 highway maps which are prepared by General Directorate of Highways are gathered for available years. Adobe Photoshop software used to super-position of different maps and all maps are scaled to 1/85000. In order to sustain standardized information from all maps, four degrees of roads are drawn by assigning thicknesses for each of them. Thus, hierarchy can be obtained in the analysis regardless from change of time and representational standards of maps. The thicknesses of the roads are determined by the superposition of the Highway Map of 2018 and Google Satellite Image. The four degrees of regional roads are categorized as;

(i) Highway and multi-lane roads (10 pixels)

(ii) Two lane paved roads (7 pixels)

(iii) One lane macadam roads (4 pixels)

(iv) Dirt roads (2 pixels)

Population data gathered from Turkish Statistical Institute (TUİK) which is announced for 5 year periods between the years 1950 to 2007. With respect to population increase rate, five-year period population data is converted to annual data by Microsoft Excel in order to encounter the years of highway maps.

**Extent and Data Gathering of İzmir Region Analyses**

For İzmir Region Analyses administrative borders are taken as the edge of the study area due to two main reasons. Firstly in settlement level, population data has been gathered with respect to administrative borders. In order to make a statistical configuration between fractal dimension and population, both variables are taken in administrative borders. Since this study focus on the comparison of the parts of the city-region with respect to time, by considering population data administrative boundaries are taken as the extent of each district.

In order to construct comparable relations of population and fractal dimension, some rearrangements on data are needed. During seven decades district borders have changed, some villages or towns turned in to districts, some districts are separated from the other or co-joined. The municipal borders of İzmir is altered, new municipalities are established with respect Laws. In 2008, the final and present spatial divisions of the districts have completed. As a result, for earlier periods there exist inconsistencies in district’s population since they gathered with respect to different spatial borders. To overcome this problem present district divisions supplied by General Directorate of Land Registry and Cadastre is admitted. For every time period from 1950s to contemporary network, the road system is cropped with respect to contemporary borders in order to make comparison analysis in the same context. A similar preparation is operated for population data. Population data is acquired in village/township/neighborhood level for each time period. Then, the contemporary neighborhoods of the present time districts are listed. The population data is matched and assigned to the contemporary district. The migrated, abandoned and renamed settlements are determined by literature research and listed under the current district to which they are connected. By summing village / neighborhood population, populations of the districts of each time period are re-calculated.

For İzmir Region analysis 1/25.000 scaled maps of General Directorate of Maps are used. The maps have a standard legend which does not change with respect to time. Thus, they are appropriate to be used for comparison analysis. Those raster maps include detailed information including topography, vegetation, railroads, infrastructure elements as well as hierarchy of roads from pathways to highways. All maps are coordinated by the help of NetCAD software. The province of İzmir is consisted of 1/25000 scaled 123 sheets that each sheet is not produced in the same year. However four time periods can be obtained as;

(i) Period I: 1958-1964

(ii) Period II: 1974-1980

(iii) Period III: 1996-2000

(iv) Period IV: 2012-2018

Then six degrees of roads from pathway to highway are drawn for four periods. By repositioning the drawn road map with satellite image and open source road map, the thickness of the degrees of roads attained for the fourth period in order to sustain the hierarchy (Figure 4-19). Since the earlier period of maps have the same standard legend, the same thicknesses of the same road types are attained for the first three periods.

Figure 4-18 Repositioning the 1/25000 scaled road system with satellite image

The completed map is exported as a .pdf file and imported to Photoshop software. After acquiring threshold images, the maps are imported to the software "*Fractalyse". The* counting models allows to pick *free box* algorithm and automated number of iterations. The correlation coefficient is determined as 0.999 for unifractal analysis. For the analysis of districts, each district is cropped with respect to present borders and fractal dimensions for four periods are calculated.

As mentioned in the background history of the region, the core area of İzmir around the Bay was administratively one district until the Greater Municipality Law. Accordingly, population data for this area did not separated with respect to neighborhoods or present districts. In order to protect the same scale rule, the central area is regarded as a whole district involving the present districts of *Balçova, Bornova, Buca, Karabağlar, Konak* and *Narlıdere.* A similar feature is observed in the northern part of the bay as populations of *Karşıyaka* and *Bayraklı* are not segregated in the first three periods. Likewise, the road network of

*Karşıyaka* and *Bayraklı* are analyzed as a whole. Although for population based analysis some districts are unified, fractal dimensions of each district for four time periods are calculated in order to identify the structure of fractal dimension values with respect to administrative borders.

### 4.4.2 Methods used for Analysis

The road network of the region is analyzed by fractal dimension analysis by using box-counting method. The relationships of the parameters are analyzed by different statistical methods including correlation analysis, hierarchical cluster analysis and fuzzy cluster analysis.

**Fractal Dimension Analysis**

In this study, box-counting method is preferred to calculate fractal dimension. In the box counting method, more than one mesh with different grid sizes are overlapped with urban pattern. The relationship among the grid, box size and fractal dimension can be expressed as;

$$K = A.\varepsilon^{-D_f} \quad (9)$$

"K" represents the 'number of boxes', "ε" is 'grid size, "A" is a 'constant coefficient' and "Df" is the fractal dimension.

The fragility of box-counting method is the location of grid as well as size and the number of boxes. Since urban structure is not homogeneous, all above mentioned parameters can affect the result. To solve this problem, the software called as 'Fractalyse' used to calculate fractal dimension for several grid sizes and grid locations. Among iterated calculations, the highest frequency has been accepted as fractal dimension. In this method, the logarithmic ratio between changing grid sizes and number of grid cells overlapped with objects are determined as the fractal dimension (Mandelbrot, 1983), (Peitgen, Jürgens, & Saupe, 2004), (Kaya & Bölen, 2017). The equation can be described as;

$$D_B=(log\ K_{S1}-\ log\ K_{S2}\ )\ /\ (log(\ 1/S_2)-\ (log\ 1/S_1)) \quad (10)$$

Where "DB", is box counting dimension, "K" number of boxes (cells) and, "S"; side length of boxes.

**Sub-Fractal Analysis**

One of the main aims of the study is to identify the intrinsic complexity of the city-region and how it can be represented. In addition to calculation of the fractal dimension of the whole system, fractal dimension of the parts can be measured by a mesh providing the least number of non-overlapping boxes "Ns" with the size of "S". Plotting the number of boxes (Ns) and the mesh size (S) in a log-log graph, Fractal Dimension (D) is calculated by regression method by using the pairs of Ns" and "S" as;

$$\ln N_s = A + Dln\left(\frac{1}{s}\right) + E_s \quad (12)$$

$$D=\lim_{\Delta_s \to 0}(-\frac{\ln N_s}{\ln s}) \quad (13)$$

where A is the intercept, Es is the error term. By the help of the software calculating fractal dimension, this process can be automated that fractal dimension of an object can be calculated by obtaining the highest $R^2$ value when $R^2$ exceeds 0.999 as Thomas et al (2011) and Thomas & Frankhauser (2013) indicates. Furthermore, fractal dimension of each box can be calculated for a pre-determined mesh size.

For each period the available lowest mesh size is attained by 1%pixcel ratio of the İzmir Region's network image. Since the orientation of the grid automation can differ in each period, the perpendicular grid orientation is preserved to sustain comparable results for different periods. The sub-fractal analyses are operated by “Fraclac” plugin of“Image_J” software.

## Statistical Methods

Relationships among the parts of the system with respect to fractal dimension and population correlation analysis are used. Furthermore, similarities/dissimilarities of the parts of the system are defined by cluster analysis.

### *Correlation Analysis*

From literature review, it is observed that correlation analysis is used to construct a relationship between or among fractal dimension analysis with other parameters like economic data, land-use differentiations or natural elements. However, data of those indicators can be partially acquired in district /settlement level only after 1990s. The only available and continuous data for the years from 1950 till present time is population. Thus, correlation analysis is used to investigate the relationship between fractal dimension and population.

Correlation analysis aims to find the relationship and dependence between two variables by referring to the correlation coefficient r. The value of “r” represents the ratio of the variation of the variable “x” by the variable “y” as;

$$r=\frac{\sum(x_i-\mathrm{E(x)})(\mathrm{y_i}-\mathrm{E(y)})}{\sqrt{\sum(x_i-E(x))^2}\sum(y_i-E(y))^2} \quad (14)$$

There exist three main correlation estimation methods as; *Spearmen, Pearson* and *Kendall’s* correlation coefficients. Spearmen correlation is applicable for continuous and discrete variables while Pearson correlation is used for continuous data analysis (Lehman, 2005). Pearson correlation coefficient is a measure the strength and direction of the linear relationship between two variables, describing the direction and degree to which one variable is linearly related to another. The assumptions are expressed that both variable are interval or ratio variables and are well approximated by a normal distribution, and their joint distribution is bivariate normal.

$$r_{XY} = \frac{\sum\left(X - \overline{X}\right)\left(Y - \overline{Y}\right)}{\sqrt{\sum\left(X - \overline{X}\right)^2 \sum\left(Y - \overline{Y}\right)^2}} \qquad (15)$$

For fractal dimension and other demographic and network based variables Spearmen correlation analysis is used. On the other hand, for determining grid-sizes by syntactic variables Pearson correlation analysis is run. The Pearson correlation coefficient takes values from -1 to +1. A value of +1 expresses a perfect positive linear relationship while a value of -1 shows that two variables are perfectly linear related by an decreasing relationship. The values close to 0 shows that the variables are not linearly related by each other. Correlation is evaluated as strong if the correlation coefficient is greater than 0.8 and when it is less than 0.5.

Spearmen's correlation coefficient is a non-parametric measure of correlation depending on how well an arbitrary monotonic function could describe the relationship between two variables. Any assumptions are not needed to be verified about the linearity and frequency distribution of the variables. Spearman rank correlation coefficient is calculated by converting two variables into ranks. The common significance level is taken as 0.01 and 0.05 for correlation analysis.

$$R = 1 - \frac{6\sum d^2}{n\left(n^2 - 1\right)} \qquad (16)$$

where $R =$ Rank correlation coefficient. $d =$ the difference between the pairs of ranks of the same individual in the two variables $n =$the number of pairs. Correlation analysis is conducted by SPSS software.

### *Cluster Analysis*

Cluster analysis can be defined as a set of techniques which ask whether data can be grouped into *categories* on the basis of their similarities or differences (Andrew, Sharpe, & Lawrie, 2010). It can be conducted by various algorithms based on the data set and intensions about the output. Main clustering approaches can be defined as *hard clustering* and *soft clustering.* By hard clustering methods each object is located into a cluster in a deterministic manner. On the other hand, by soft clustering algorithm, which is also described as fuzzy clustering, each object is located in each cluster to a certain degree. Hard clustering methods are also called as traditional clustering based on connectivity, centroid, distribution and density based algorithms. For small data set hierarchical (connectivity-based) clustering is suitable to be used. When the number of clusters of the data is not known hierarchical clustering is useful since the number of clusters is not pre-defined. The procedure of the hierarchical clustering involves the construction of a hierarchy of a treelike structure by agglomerative or divisive procedures. In order to visualize the form of clusters, a *dendrogram* is produced. Including integrated districts like *Central Core* and *Karşıyaka-Bayraklı,* 24 districts are analyzed in order to identify which districts constitute clusters with respect to fractal dimension values.

For hierarchical cluster analysis different similarity measures are used with respect to the expected similarity or difference pattern of the outcome as the aim of the clustering. Some of them are average linkage, centroid linkage, nearest neighbor (single linkage), farthest neighbor (complete linkage) and Ward's linkage that all have advantages and disadvantages while grouping data. The nearest neighbor measure can distinctly interpreted the extreme values of the data so firstly, this measure is used to identify the districts which can be defined as outliers or extreme cases. Then, within groups-linkage method is used to identify similar districts with respect to distance of each district with the other all. The formula is expressed as fallows for *r* and *s* clusters as;

$$L(r,s) = \frac{1}{n_r\, n_s} \sum_{i=1}^{n_r} \sum_{j=1}^{n_s} D(x_{ri}, x_{sj}) \tag{17}$$

For clustering analysis, different distance types are also used for measuring the distance between cases like the squared Euclidian distance, the Pearson coefficient, Manhattan and Minkowski distance. Distance can also be defined manually. For hierarchical cluster analysis the squared Euclidian distance is preferred by standardized values between 0 and 1 as fallows;

$$d=\sqrt{(\alpha_{11}-\alpha_{21})^2} + (\alpha_{12}-\alpha_{22})^2 + \cdots + (\alpha_{1m}-\alpha_{2m})^2 \tag{18}$$

Hard cluster analysis are performed by SPSS Software that verification of the number of clusters is operated by two-step cluster analysis which firstly run pre-clustering and then hierarchical methods. Two-step cluster analysis include silhouette measure which measures how similar an object is to its own cluster (cohesion) compared to other clusters (separation). Cluster quality above fair is condemned to be sufficient.

Although, hierarchical clustering provides important insights about describing similar districts in statistical manner, as observed from literature search, complexity sciences applied to city systems aims to explore the blueness and fuzziness in the complex city-regions. Therefore, fuzzy (soft) cluster analysis also operated to identify the transactions of the groupings among clusters.

Fuzzy clustering allows individuals to have multiple cluster memberships which also indicate information about the relative membership of each individual in each cluster like a partial membership.  The algorithm is based on minimizing the objective function described by Kauffman & Rousseeuw (2005) as;

$$F = \sum_{k\_1}^{K} \frac{\sum_i \sum_j u_{ik}^2 u_{jk}^2 d_{ij}}{2 \sum_l u_{lk}^2} \tag{19}$$

where $u_{ik}$ is the membership coefficient showing the membership share observation $i$ in cluster $k$ as all $u_{ik} \geq 0$ and $d$ is the distance measure. Although it produces similar clusters to hard cluster methods it provides the strength of membership for each cluster.

Since fuzzy clustering is an extension of the traditional K-means algorithm based on fuzzy set theory (Everitt et al., 2011; cited in Bolin et al., 2014) it provides a pre-determination of the number of cluster. One of the sole aims of the study is to identify the intrinsic pattern of the structure of İzmir's city region that how many clusters are optimum to construct for districts arise as an issue. In order to identify the number of clusters for fuzzy clustering of the data, internal validity indices are assigned. The validity indices measure compactness and separation of clusters for each clustering session. By running Fuzzy C-Means Clustering (FCM), Possibilistic C-Means (PCM) and Unsupervised Probabilistic Clustering (UPFC) cluster validity indices optimal number of clusters in datasets can be obtained (Cebeci, 2020). The optimum number of fuzzy clusters is determined via selecting the number showing better performance via validity index. All fuzzy cluster analysis and validity procedures are operated by R-studio software since soft-clustering methods could not be applied by SPSS or EViews Statistics.

### 4.5 Chapter Discussion

Since main aim of the study is to examine relationship between complexity pattern of the region with regional development trend in this Chapter regional development background, conceptualizations of the region in the literature, regional plans and legal instruments are investigated. In addition to the development of the whole region, each district is briefly analyzed in terms of development trends as the parts of the region with respect to main aim of the study. A conceptual scheme of the districts with respect to main functions of them observed from background literature of İzmir region is presented in Figure 4-16.

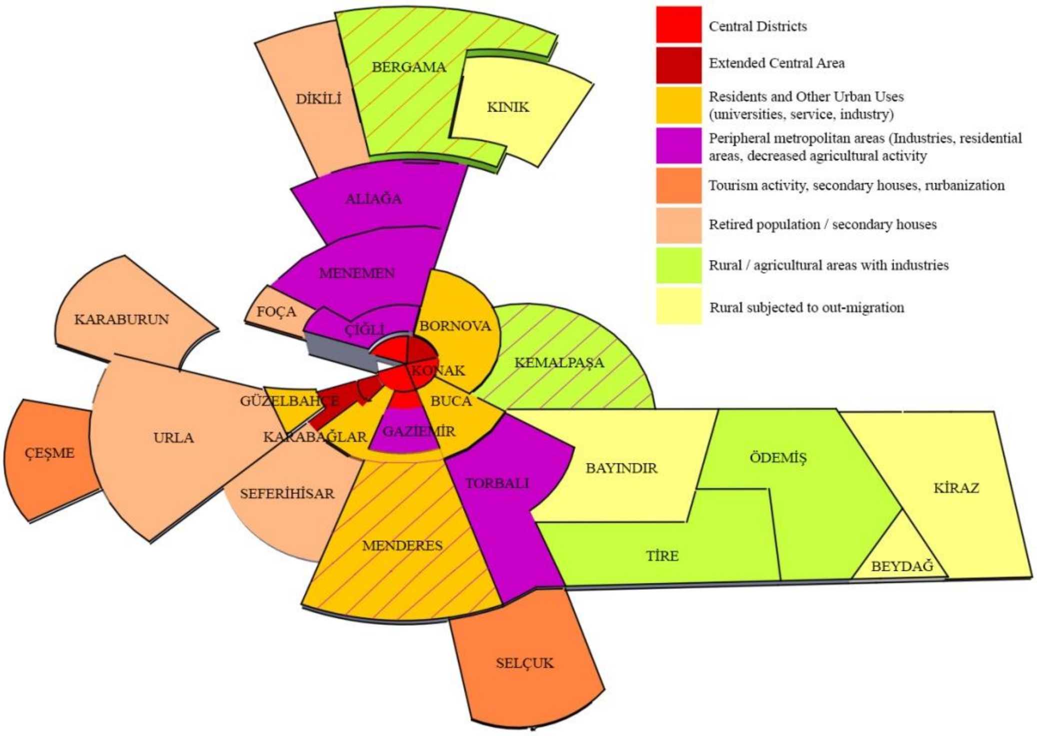



Figure 4-19 Conceptualization of Districts

In this chapter the context of the study area, it's historical background and the methods used in the thesis are presented. It is observed from regional background of İzmir presented in Chapter 4 that system of the region exceeds the provincial borders. Therefore, two contexts for regional analysis are determined which are (i) extended region and (ii) İzmir region. Extended Region is determined by taking roads as frame of the analysis covering an area described as outer periphery of İzmir in regional literature. The spatial frame of the study take Ayvalık, Sındırgı, Simav, Denizli, Yatağan, Milas and Didim as edges involving İzmir, Aydın and Manisa. For extended region analysis, highway maps are used which are obtained from General Directorate of Highways.

From literature review, it is observed that fractal dimension of cities and city systems have correlative relations with demographic, physical and economic parameters. For the time context of the study the only available data for İzmir is population which is recorded with respect to municipal borders for urban settlements and villages or townships for rural areas. Thus, the second context is determined as the administrative border of İzmir including province’s and districts’ borders in order to investigate relationships between population and complexity analysis.  For İzmir region analysis, 1/25.000 scaled military maps are used obtained from General Directorate of Maps.

The methods used for analyses are also presented. According to the literature survey conducted in Chapter 3, box-counting method is selected for fractal analysis in order to identify the complexity of the regional system. Furthermore, correlation analysis is used to identify the relationship between fractal dimension and other variables including population, population density, acreage, road-length and road density. The resemblances and clustering trends are identified by hard and soft cluster analysis with respect to fractal dimensions of all periods.  Results of the analysis for both contexts are presented in Chapter 5 while interpretations of the results and relational aspects of complexity are investigated in Chapter 6. The methods used for analysis is presented in Figure  4.20.

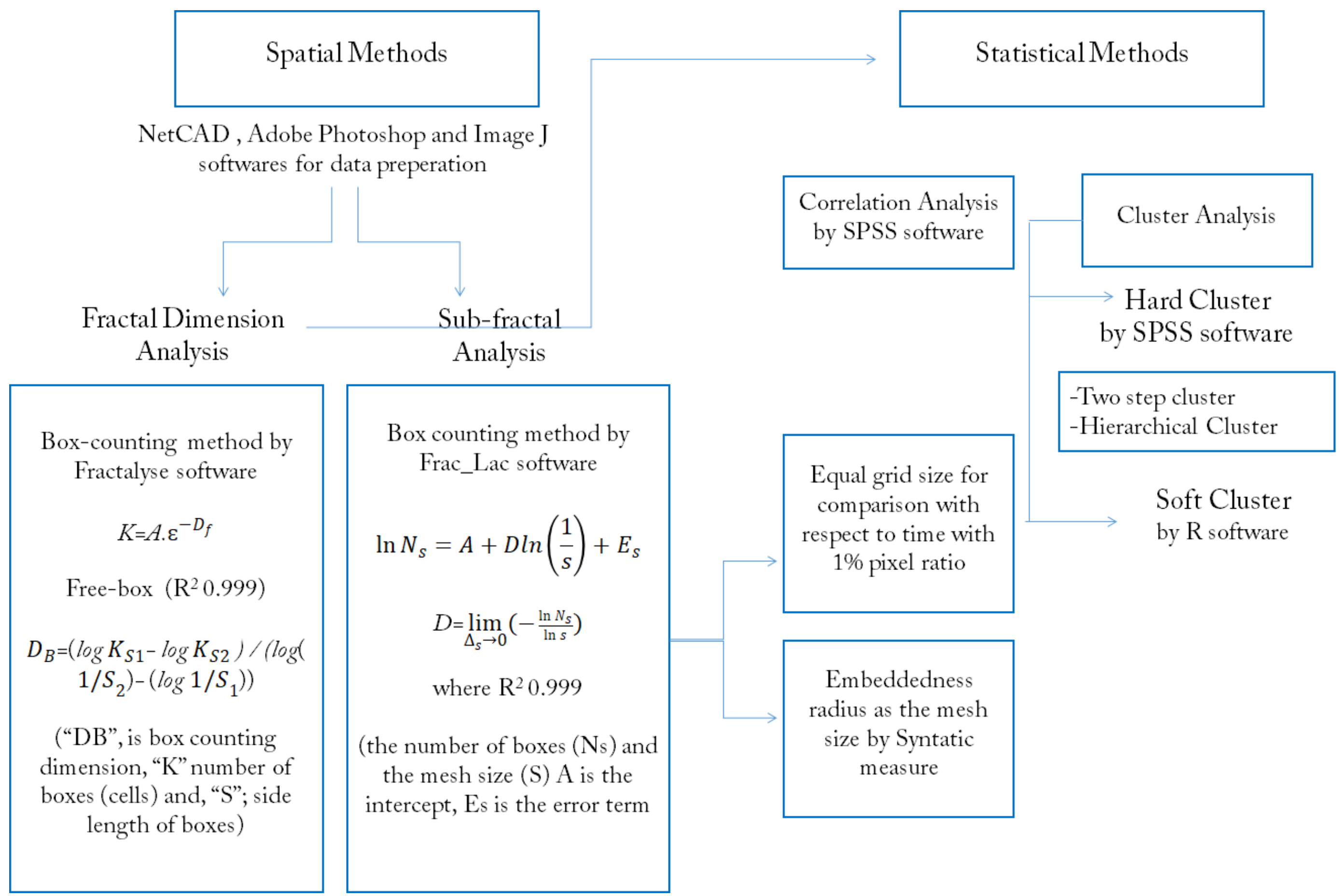



Figure 4-20 Repositioning the 1/25000 scaled road system with satellite image

# CHAPTER 5

# COMPLEXITY ANALYSIS OF EXTENDED AND IZMIR REGION

In this part of the study, the results of the analysis are presented for the extended and İzmir region (city-region). For the extended region, fractal dimension analysis and their relationship with population change is discussed. For the İzmir Region analysis firstly the system is analyzed as a whole. Secondly, parts of the system with respect to district borders are examined. For the İzmir Region, fractal dimensions, total population, gross population density, network length and network density is presented for each district.

## 5.1 Fractal Dimension and Population Analysis of Extended Region

The earliest map was produced by Republic of Turkey General Directorate of Highways in 1953. The map covers the whole country that extended region is extracted from the map. Fractal dimension of the road network is calculated by "*Fraclac"* as 1,237 ($R^2$ over 0.99) as "1,41" which is the initial value of the study. The population of İzmir in 1953 is re-calculated by population data as; "849.318".

For the year 1958, extended region was cropped and repositioned. It can be observed that the road system was developed. Furthermore, the roads reaching to *Manisa* and *Aydın* became dominant in the hierarchy. Fractal dimension of the network is calculated as; "1.49" by the highest $R^2$ over 0,99. The population of İzmir for the year 1958 is "998.009". Both population of İzmir and fractal dimension of extended region have increased.

For 1960s a highway map could not be obtained. The fallowing map is belonged to the year 1972. After repositioning it can be visually observed that road network hierarch is enriched and a linear connection is sustained along İzmir to *Salihli.* Furthermore, the connection is extended to the city of *Uşak.* Fractal dimension calculation of the system increased to “1,53” by the highest $R^2$ over 0,99 in 14 years. Population increased took place as well from “998.009” to “1.600.632”.

The highway map of 1977 presents slight differences in terms of road development when compared to the map of 1972. Fractal dimension of the road network is calculated as “1.52” as the best fit over $R^2$ is 0,99. Fractal dimension is close but below the value calculated for the road map of 1972. Despite a slight decrease in the complexity level, it is observed that population of İzmir is increased to “1.675.083”.

By the year 1983, new branches can be observed in the road system which mainly operates as short-cuts around districts of neighboring cities as *Manisa, Uşak* and *Denizli.* Fractal dimension of the network is calculated as; “1.53” by the highest $R^2$ over 0,99 which is close to previous two periods. The population of İzmir exceeded 2 million as; “2.024.036”. Despite of the population growth, it can be argued that complexity of the extended region does not increase.

From the road map of 1990, the highway development from İzmir to *Çeşme* and *Aliağa* districts can be observed in addition to minor developments on the network. A highway connection is constructed from İzmir to *Uşak* as well. Fractal dimension of the extended region’s network is calculated as “1.53” again while population is increased to “2.694.770”.

By the year 1998, compared to map of 1990, it can be seen that *Çeşme* highway is completed. Moreover, road system gained more hierarchy as well as new branches emerged mainly around *Uşak* region. The fractal dimension is increased to 1.56 determined by the highest $R^2$ value over 0,99 after a steady period over 25 years.

Re-calculated population of İzmir increased from 1990 to 1998 as well and exceeded 3 million as; “3.184.898”.

Very slight changes can be visually observed in the road network of the year 2002 when compared to 1998 after repositioning and rescaling of the maps. Except the widening of highway between *Uşak-Denizli*, road network did not significantly developed in 4 years. Likewse, fractal remained stable as “1,56” by the highest $R^2$ over 0,99. Despite the stability of the complexity level of the extended region, population increased from “3.184.898” to “3.516.032”.

When the road map of İzmir’s extended region in 2018 is compared to the map of 2002, many alterations can be observed. It can be seen that new road developments took place in both north to south and east to west axis. A strong connection from *İzmir* to *Balıkesir* is succeeded. Furthermore the highway along *İzmir-Aydın-Denizli* is constructed. Despite the increased capacity of the network, fractal dimension remained the same as “1.56”. On the other hand, population exceeded 4 million and increased to “4.320.519”. Thus, it can be interpreted that despite the increased population and road construction, extended region of İzmir do not become more complex in 2018 with respect to 2002.

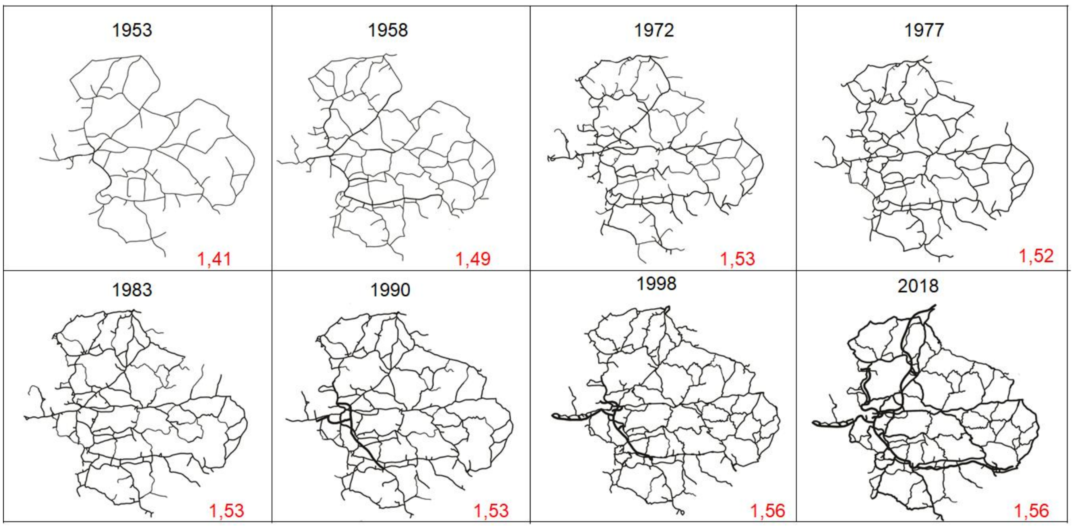



Figure 5-1 Fractal Analysis of Extended Region of İzmir between 1953 to 2018

The results of the fractal dimension analysis from 1953 to 2018 are presented in Figure 5-18. It is observed from related literature that there exist a positive relationship between fractal dimension and population. As observed from Figure 5-2, continuous population increase do not always resulted in increased complexity. In fact, stable periods can be observed for more than one decade as chaos theory proposes. The correlation analysis between fractal dimension of extended region and population analysis show that there exist a positive correlation ($p<0.01$). The correlation coefficient is calculated as “0.932”.

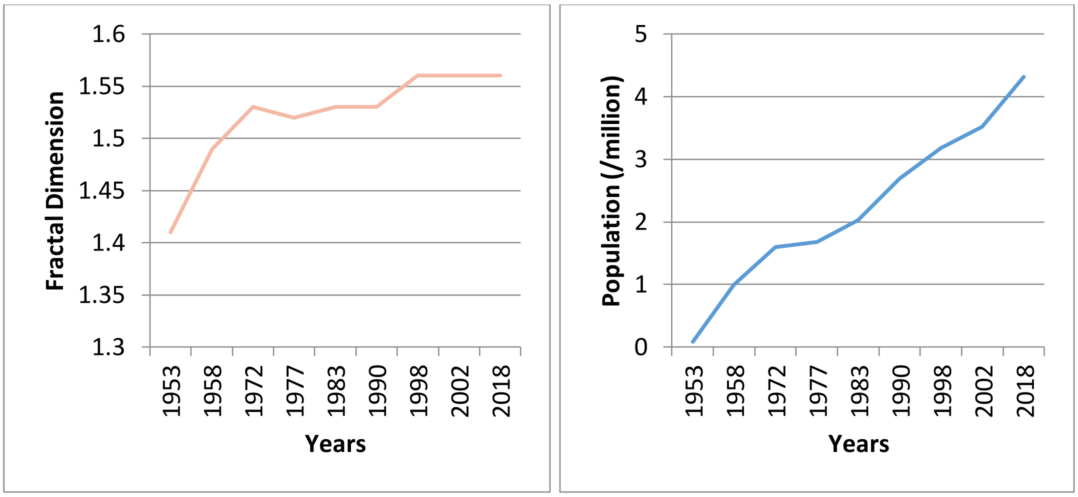



Figure 5-2 Graphical representation of the fractal dimensions of extended region and population of İzmir

## 5.2 Fractal Dimension Analysis of İzmir Region

For analysis of İzmir Region firstly the whole road network has been analyzed for each four period. The first period covering the time span from 1958 to 1964 is assumed as initial condition. The visual investigation of the road map shows that around the Bay, the core-sub region, the present central quarters of *İzmir* as *Konak* and *Balçova* interprets density. *Karşıyaka* also represents a dense structure as well. From the Bay to south an axis having semi-rural character including linear axis and cropland sub-divisions to *Menderes* can be observed. In the eastern sub-region an agricultural division based network organization is visible around *Ödemiş* and *Tire.* This network approaches to *Selçuk* to the southern part of the city-region. From the Bay to *Kemalpaşa,* another rural linear development can be observed which is not directly connected to the organization of *Ödemiş* and *Tire.* The northern-sub-regions present a different entity which is not directly connected to the core. *Bergama* is observed like a rural node supported by cropland sub-divisions in its own internal entity. The spatial layout of the road network of İzmir Region is presented in Figure 5-3.

When fractal dimension of the region of İzmir province is calculated by non-linear observation with a $R^2$>0.999 it is observed as “1.502”.  As mentioned by Thomas & Franhauser (2013) fractal dimension of street network can be calculated higher than fractal dimension of built-up environment. Furthermore, it is stated that the fractal dimensions at the city level which ranged between 1 and 2 can be calculated the range of 0 and 1 for systems of cities (Myint & Liam, 2005), (Lu & Tang, 2004), (Thomas & Frankhauser, 2013). Due to above mentioned reasons rather than comparing the fractal dimension of İzmir, with different world or Turkish cities, the fractal dimension value of the first period (1958-1964) is condemned to be the initial value.

The population of the province is taken for the year 1964 as; “1.063.490” while the population density is 89.43 per $km^2$. Total length of the roads is calculated as 7469,513 km. The highest road densities are observed for *Gaziemir, Karşıyaka-Bayraklı* and central district while the lowest road network densities are calculated for *Karaburun, Beydağ* and *Menderes.* Appropriate to the observations from network organization, apart from the Central İzmir (Central core) which is recorded as a whole, the most populous district is *Ödemiş,* followed by *Karşıyaka-Bayraklı* and then *Tire.*

Figure 5-3 Spatial layout of İzmir Region in the first period (1959-1964)

The second period extends between the time span from 1976 to 1980. As observed from Figure 5-2, the first visible change is the densification of the network structure around the Bay. Linear coastal developments are visible through the west for the central area as; *Balçova* and *Narlıdere.* Similarly, *Karşıyaka-Bayraklı* district is connected to the central core. In addition it developed through the coastal area of *Çiğli.* The southern axis from the core to the south becomes more visible by a considerable agglomeration around *Gaziemir.* Although a significant alteration could not be seen in the western sub-region, the connection to *Karabağlar* became visible. The segregated internal rural organization in the southern region developed and interlinked to linear axis which can be visible in the first period from the core to *Kemalpaşa* and to *Menderes.* The rural peripheral network observed in the first period presents a backbone to the core area around the Bay. The dominance of the rural *Bergama* is still visible for the second period with stronger connections with the coastal area.

The fractal dimension value of the second period is increased from “1.502” to “1.581” by a non-linear estimation with a $R^2>0,999$. The complexity level of İzmir region is increased in two decades. The increased complexity is not only related to the development of core area, but also can be visualized in the network of the countryside which will be discussed for each district separately. The population level is increased from “1.063.490” to “1.976.763” that population density is increased to 166,23 for per $km^2$. In terms of districts, it can be observed that the highest population can be observed in central İzmir and *Karşıyaka-Bayraklı* district. Although, *Ödemiş* became the third most populous district from the second rank, it is followed by *Bergama* and *Tire* which shows the dominance of the agricultural organizational centers in the city-region. The population gain is highest in the northern Bay as; *Karşıyaka-Bayraklı* and *Çiğli.* The lowest population gains are observed in the contemporary vacation destinations as *Karaburun* and *Dikili.* Furthermore, total length of roads is calculated as; 11206.228 km which is approximately 50% higher than total road length of the period I. The first three districts having the highest road network density remained the same while *Karşıyaka-Bayraklı* exceeded the density of *Gaziemir.* Due to its geographical thresholds, the lowest network density is observed in *Karaburun.*

Figure 5-4 Spatial layout of İzmir Region in the second period (1976-1980)

The third period involve the years from 1996 to 2000. For all road scales, development of the network can be visually observed. The densification and ramification of the rural areas around the core-sub-region can be observed. As a result the linear corridors in the east and south became less significant by the increased homogeneity. The northern region mainly around *Bergama* does not reveal a further development. On the other hand, agglomerations along the coastal line can be easily observed in the north including *Dikili, Foça* and *Aliağa.* An altered densified pattern is also observable for *Çiğli* and *Menemen* which is not limited to coastal focal points but as an integrated network pattern to northern Bay. The linear coastal development can also be seen from the central core to the west that a continuity of urban network of the central İzmir reaches to *Urla*.

Development of *Çeşme* peninsula is another significant visual change in the road network. Although, it is not densely populated, *Karaburun* gained new connections as well. A new development pattern is visible in the southern sub, region different from agricultural subdivisions of previous two periods that a coastal development along the coastline of *Seferihisar* and *Menderes* can be defined while comparing the previous road maps (Figure 5-4).

Those developments differ in character that they involve different development patterns involve industry, secondary housing and suburban commercial and residential uses. The visual observations of the increased integrity and complexity can be proven by the change in fractal dimension value. The fractal dimension of the third period for the years from 1996 to 2000 is calculated as; "1.819" by the highest $R^2$ over 0,999.

The population of the province of İzmir is increased to "3.370.866" in 2000 announced by TUİK. The highest population is observed around the Bay *Ödemiş* protects the leadership in terms of population among the other districts apart from central core. However, fallowing districts changed profile from agricultural prominence to industrial quarters as; *Menemen* and *Bergama.* The most significant population increase between period 2 and period 3 are observed in the peripheral districts of the core to north and the south namely as; *Gaziemir* and *Çiğli.* Between those periods, firstly population loss of a district is observed for *Beydağ* which gained population between first two periods.

Total network length in the third period increased by %128 which was %50 between the first and second periods. The total length of the roads reached to 25660.595 km. The most densified road network remained the same as; *Karşıyaka-Bayraklı, Gaziemir* and central district respectively. The district having the lowest road network density remained the same as well which are; *Karaburun* , *Menderes* and *Beydağ.*

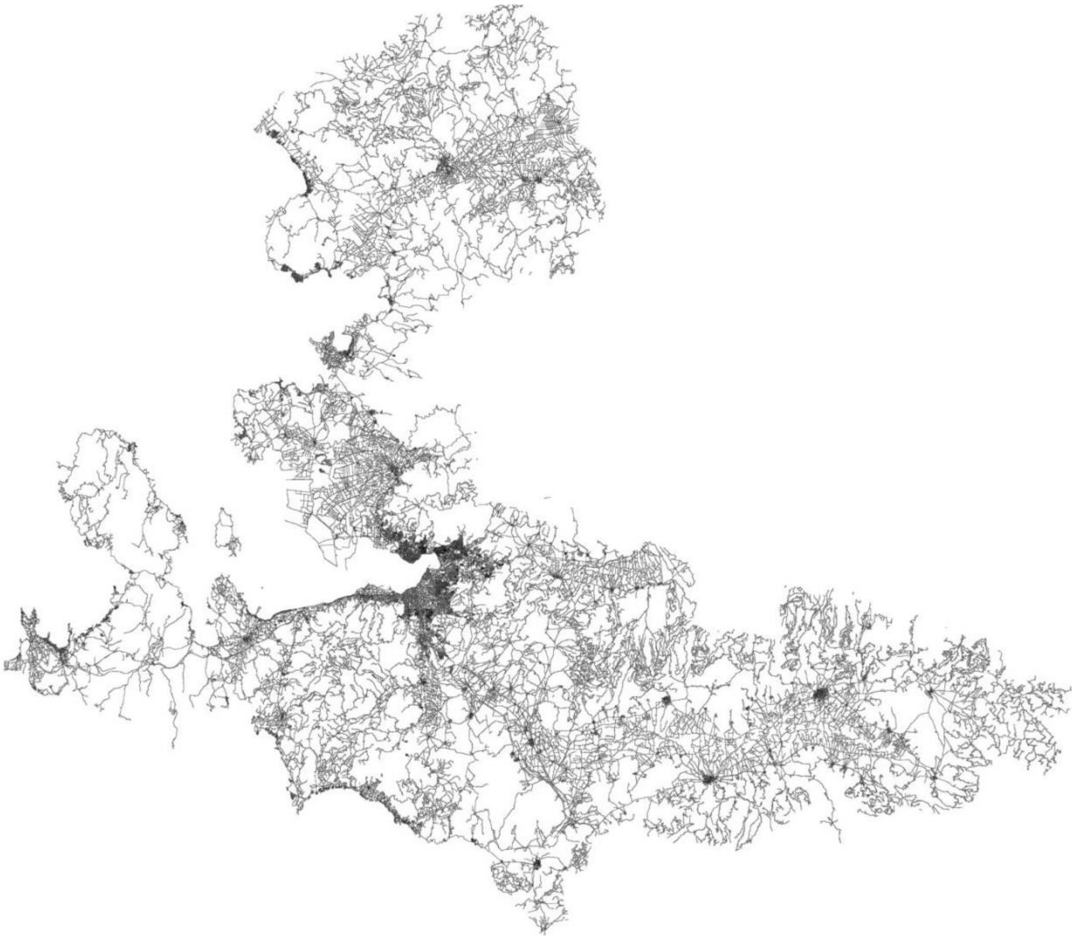


Figure 5-5 Spatial layout of İzmir Region in the third period (1996-2000)

The last period covers a time span from 2012 to 2018. Rather than alterations in main spatial organizations, further agglomerations can be observed. The agricultural subdivisions in the eastern sub-region are organized mainly around *Tire* and *Ödemiş.* A less significant connection from *Urla* to *Seferihisar* became more visible and ended with a further coastal development. The focal densifications can be observed in the coastal parts of *Çeşme, Foça* and *Seferihisar.* lthough a further significant sprawl can be visually observed, the linear corridor developments of central İzmir empowered. The northern Bay is connected to *Çiğli* and *Menemen.* Likewise, the linear continuous pattern from the central core to the west (*Urla)* presents a scattered pattern along the axis. Despite densifications the overall structure of the İzmir Region is not significantly improved (Figure 5-5).

The fractal dimension is calculated as “1,724” with the highest $R^2 > 0,999$. It has been noted that firstly fractal dimension decreased despite of increase in population and network length. In other words, it can be argued that complexity level of the city-region decreased between the period 3 and period 4. In terms of population change, population of *İzmir* increased to “4.279.677” and the density exceeded 350 persons for per $km^2$ for the whole province. As *Çiğli* became a part of the metropolitan core, the most populous districts after the Bay are recorded as; *Torbalı* and *Menemen* which are main commuter zones. The highest population gain between the period 3 and period 4 are observed in *Torbalı* and *Güzelbahçe.* In spite of appearance of densified zones, many districts loose population. From highest negative population change to the lowest are determined as; *Karaburun, Bayındır, Foça, Beydağ, Kınık, Kiraz* and *Bergama*. Those results can be interpreted as; the rural settlements are subjected to population loss despite some gained secondary housing residents. *Bergama* as a sole agricultural center firstly loses net population.

The total network length is reached to 32671,121 km long. When the road network density is examined, it is observed that the most densified three districts unchanged which are *Karşıyaka-Bayraklı, Gaziemir* and central district. However, the lowest three of them changed. *Kınık* is calculated as the less densified district among the others. *Karaburun* which is determined as the lowest for the previous periods is observed as the third lowest while *Menderes* is the second.

Figure 5-6 Spatial layout of İzmir Region in the fourth period (2012-2017)

It is shown in the Figure 5-7 that except the last period, population and fractal dimension value of the whole system increased. In terms of Pearson Correlation Analysis, it is shown that When the correlations between fractal dimensions of four periods are analyzed, it is observed that there exist a strong relationship among the fractal dimensions of first three periods with a p value below 0,01. Only the first and last periods' correlation is significant at the 0,05 level.

The statistical relationship between total road length and population shows that there exist a positive statistically significant relationship with a p value below 0,01 for the second, third and the fourth periods. When correlation between population and road network density is examined, the same relationship pattern can be observed as well with a p value below 0.05 for the second period and p values below 0.01 for the third and the fourth periods.

The other correlation analyses aim to examine the statistical relationship between the fractal dimension and road length and road network density. It is observed that there exist a positive correlation between the total road length and fractal dimension only for the third period with a p value below 0,05. For the road network density there could not be determined any relationship between fractal dimension and road network density.

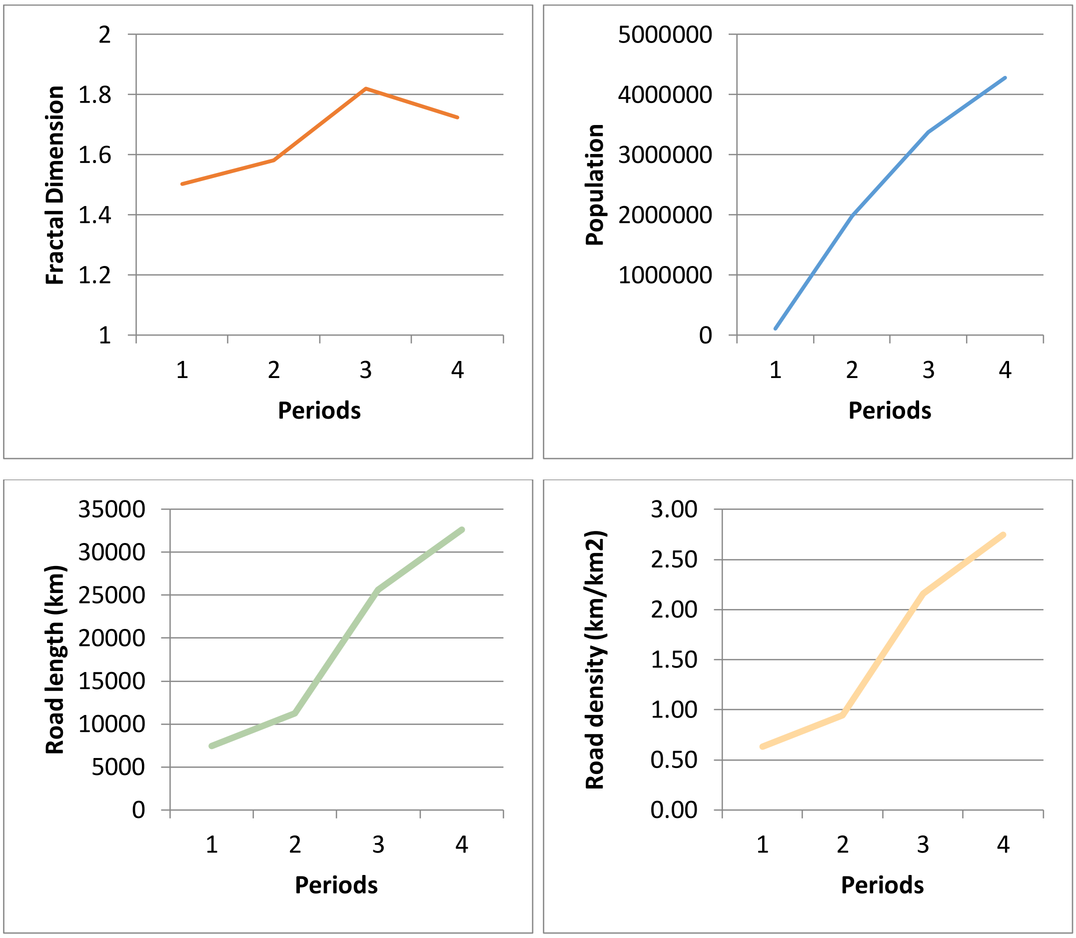



Figure 5-7 Graphical relationship of fractal dimension, road length and population of İzmir Region

## 5.3 Fractal Dimension, Population and Network Analysis of Districts

The heterogeneity of settlement systems represents the fact that the whole does not present the properties of the parts. Since population data is gathered in terms of administrative borders, each district will be analyzed in order to understand the internal structural change of the road network of the İzmir Region with respect to time. Parallel to the literature review, districts are specified as;

(i) The Bay: Çiğli, Karşıyaka, Karabağlar, Bayraklı, Bornova, Buca, Gaziemir, Konak, Balçova, Narlıdere and Güzelbahçe

(ii) The Western: Urla, Çeşme, Karaburun

(iii) The Northern: Menemen, Foça, Aliağa, Dikili, Bergama and Kınık

(iv) The Eastern: Kemalpaşa, Bayındır, Tire, Ödemiş, Kiraz and Beydağ

(v) The Southern: Torbalı, Selçuk, Menderes, Seferihisar

### 5.3.1 The Bay

As the central core of İzmir city-region, districts of the Bay are subjected to continuous population density and spatial growth. The Bay-sub region involves 10 districts. Since population data is gathered as a whole and named as “center”, population based analysis of *Konak, Balçova, Narlıdere, Karabağlar, Bornova and Buca* are taken as the “center”. However, fractal dimension analyses for the four periods are examined for each district separately since those central districts involve different development and complexity measures.

The first and one of the most central districts is *Konak*. The fractal dimension of the district was “1,333” in the first period which is higher than mean fractal dimension of the districts of İzmir province. On the other hand the value is lower than the fractal dimension of the total İzmir Region which is calculated as; “1,502”. The value increased to “1,395” during the second period which is still higher than the mean fractal dimension of districts and lower than total value of the İzmir Region which are “1,343” and “1,581” respectively. Unlike the total İzmir Region which decreased between the third and the fourth periods, fractal dimension value of *Konak* decreased in the third period from “1,395” to “1,362”. In the third period covering the years from 1996 to 2000, fractal dimension of *Konak* district became lower than the mean value of districts which is “1,521” and the whole İzmir Region which is “1,819”. In the last period it can be seen that fractal dimension of the district increased to “1,449”. Despite of the increase, fractal dimension of *Konak* remained lower than mean value of the fractal dimension of districts, “1,492”, and also fractal dimension of the total İzmir Region’s network, “1,724”. The results show that after the first period, comparative complexity of *Konak* has decreased approximately for 50 years although fractal dimension of the district has continuously increased in all periods (Figure 5-8).

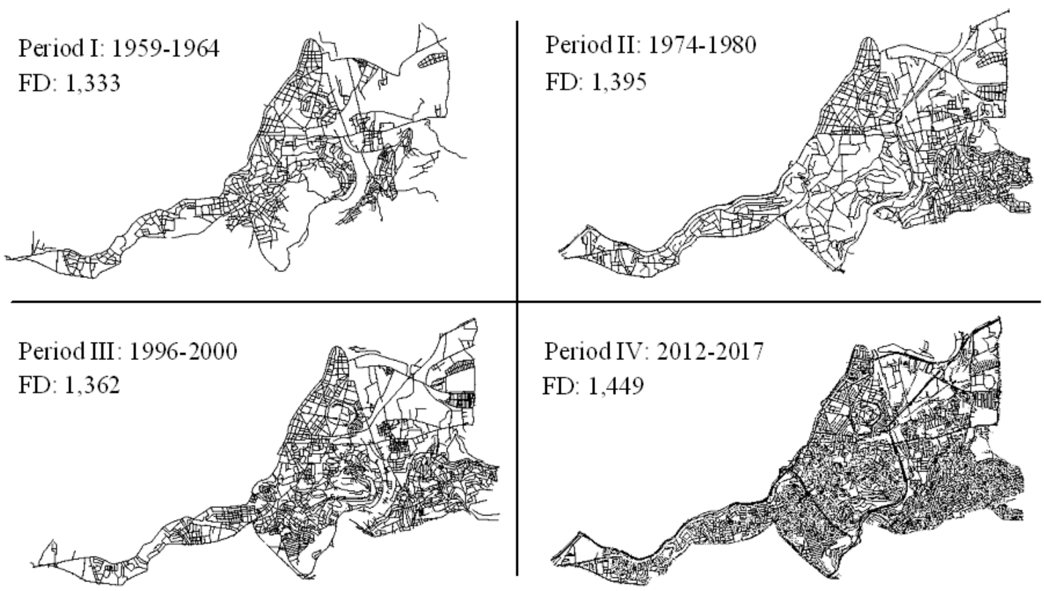



Figure 5-8 Fractal dimension change of *Konak* District

The other central and coastal district of the "Bay sub-region" is *Balçova* is located on the west of *Konak.* Development of the network for this district can be observed by the observation of the road network maps. For the initial period involving years from 1959 to 1964, fractal dimension of the district is pretty low as; "1.058". The value is lower than the mean value of the fractal dimension of all districts, "1.313", as well as the value of the whole İzmir Region of İzmir, "1,502". During the second period fractal dimension is increased to "1.145" which is still lower than the fractal mean dimension of districts, "1.343", and the whole İzmir Region, "1.581". Increase in the fractal dimension had continued in the third period covering the years from 1996 to 2000 and calculated as "1.542" which is higher than the mean of the districts' fractal dimension in the third period, "1.521". Although complexity of *Balçova* exceeded the average in terms of fractal measures of districts, it is below the fractal dimension of the whole network of the İzmir Region which is "1.819". In the last period road network developed and further intensified. However, like the total İzmir Region, fractal dimension of *Balçova* decreased to "1.432". This value is again lower than the both mean value of the districts, "1.492" and the İzmir Region "1.724". The results can be summarized as complexity of *Balçova* remained lower than the complexity level of the İzmir Region as a part of it. Parallel to the development of İzmir Economy University, shopping malls, residents and other amenities, complexity of the district has started to increase after 1990 (Figure 5-9).

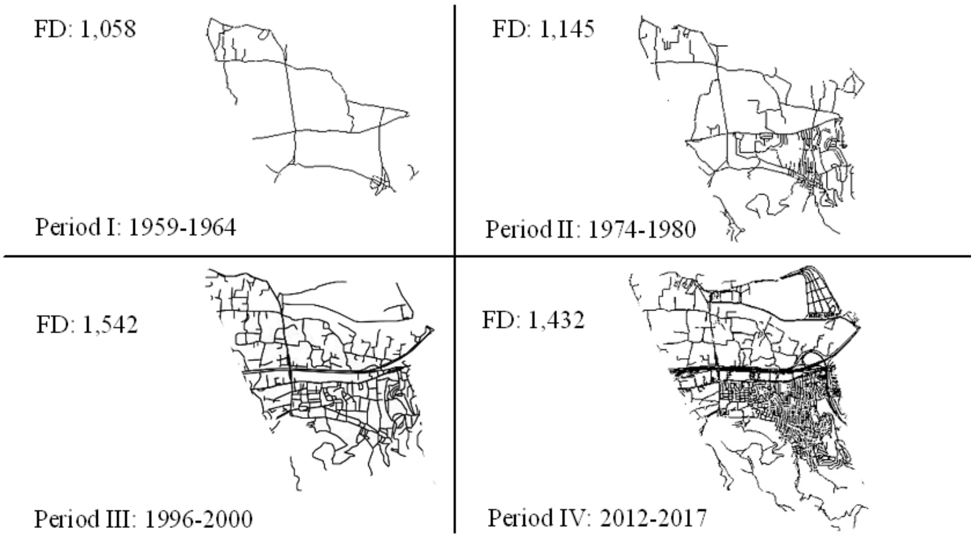



Figure 5-9 Fractal dimension change of *Balçova* District

*Narlıdere* which is located on the west of *Balçova* along the Bay has a similar trend with *Balçova* as a neighbor district. In the first period (1959-1964) fractal dimension value of *Narlıdere* is pretty low as "1,055". In the second period as the second half of 1970s, the value is increased to "1,145" and in the third period to "1,571" respectively. As located in the west, a little far from the core of the city and on the coastal development axis, the values are found a slower than *Balçova.* For the first two periods which can be accepted as early development periods of *Narlıdere,* fractal dimension of the district is lower than both the mean of the fractal dimension of all districts, "1,313" and the İzmir Region "1,502". In the third period, with increased road investments and residential development and facilities, *Narlıdere* subjected to further development. The connection of the district with the rest of the city reflected of the fractal values as for the third period it is higher than the mean fractal dimension of the districts, "1,521". However, as a part of the system complexity of the district remained lower than the total since fractal dimension of the İzmir Region's network is "1,819". Despite densification on the coastal part, fractal dimension of the road network between 2012 and 2017 decreased to "1,363" which is not only below the mean of the all districts, "1,492" but also the İzmir Region's fractal dimension; "1,724". This trend is found to be similar to the İzmir Region in addition to the neighbor district *Balçova* (Figure 5-10).

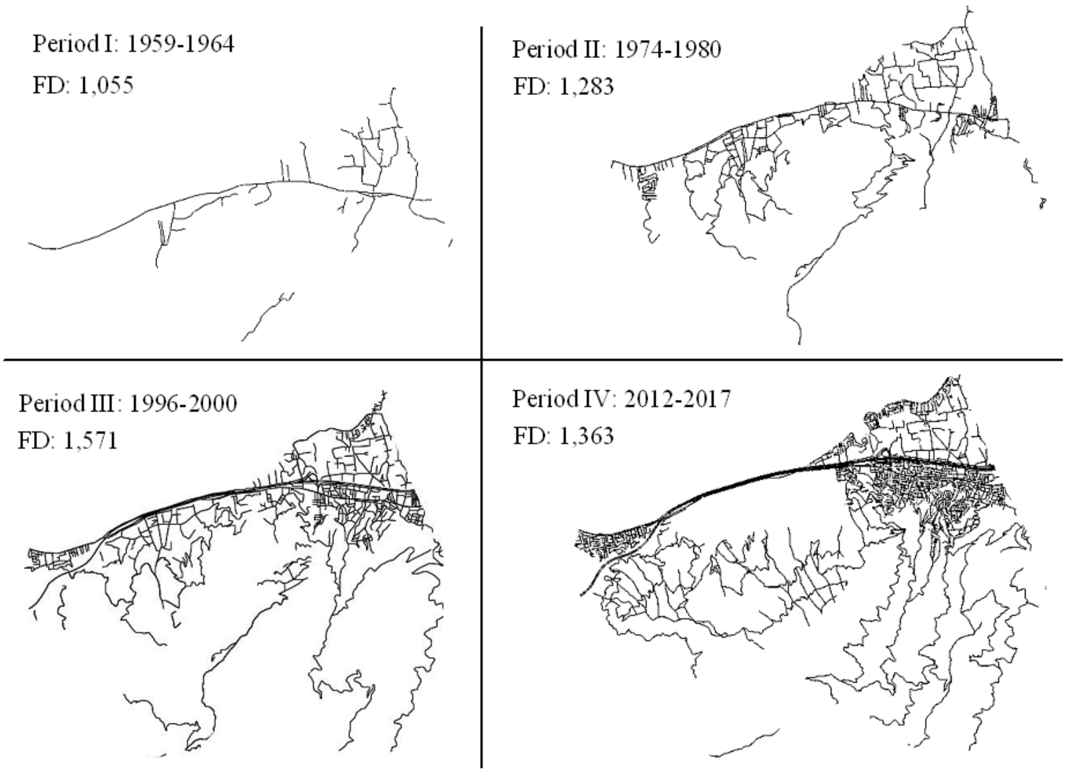



Figure 5-10 Fractal dimension change of *Narlıdere* District

The southern neighbor of *Narlıdere* and *Balçova is Karabağlar.* Although *Karabağlar* is not a coastal district, as a western core district, it follows a similar complexity development pattern with *Narlıdere* and Balçova. However, fractal dimension values for this district are high in all four periods that the north-eastern part of the district is connected to the central core. For the time span containing years from 1959 to 1964 which is named as initial period, fractal dimension of *Karabağlar* is calculated "1,198". The value is below the average fractal dimension value of all districts, "1,313" and the total İzmir Region which is "1,502". For the second period, the value is increased to "1,315" although it is still below the mean fractal dimension of districts, “1,343” and the İzmir Region’s value as a whole which is “1,581”. After the mid of 1990s the district became more densified and fractal dimension value exceeded the mean value of the districts. Although, as a part of the system *Karabağlar* exceeded the average in terms of complexity fractal measure, the value is still lower than the İzmir Region’s fractal dimension. It can be observed that fractal dimension is decreased to “1,563” from”1,579” within a similar trend with the total network as well as neighbor districts. However, the values is still higher than the mean of districts, “1,492” and lower than the whole İzmir Region’s network, “1,724” for the years between 2012 and 2017 (Figure 5-11).

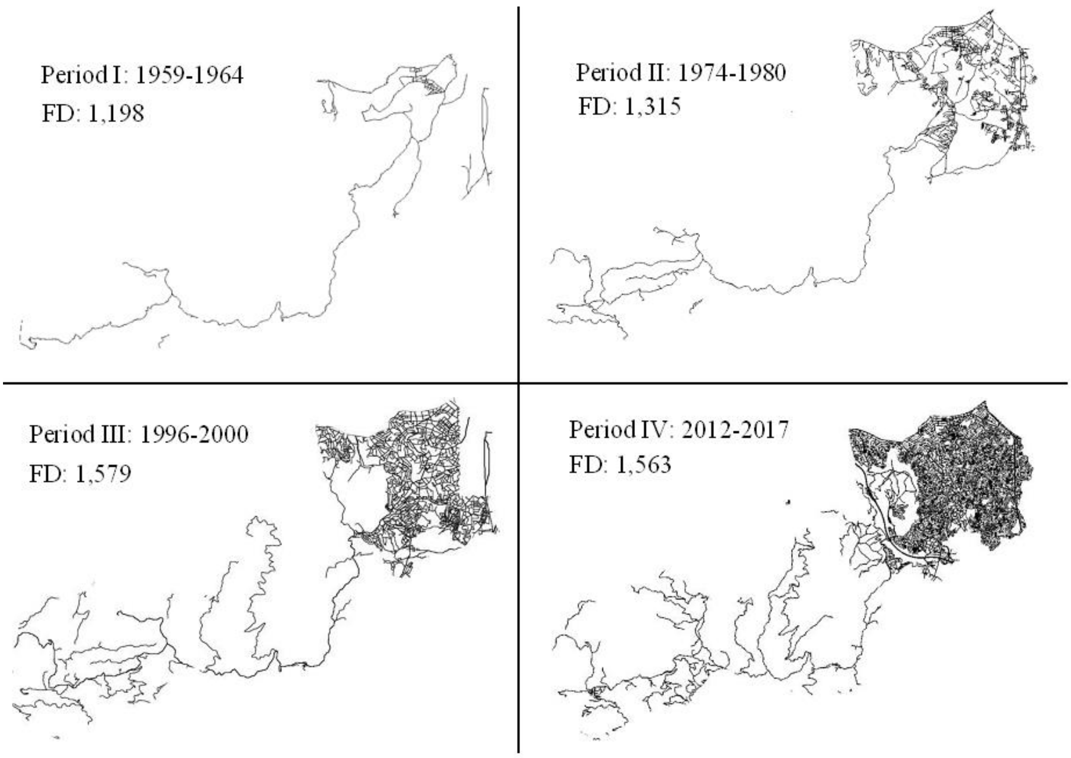



Figure 5-11 Fractal dimension change of *Karabağlar* District

The other district of the central area of the Bay is *Bornova* which is a transitory district from the center to eastern regions like *Kemalpaşa.* The other core districts as *Bayraklı, Konak* and *Buca* are neighbors of the district around the Bay. As the initial period covering the years from 1959 to 1964, fractal dimension of *Bornova* is calculated “1,233” which is both lower than the mean fractal dimension of all districts “1,313” and the whole network of the İzmir Region, “1,502”. For the second and third periods, *Bornova* further developed in terms of road network and fractal dimension values that it is calculated “1,288” and “1,334” respectively. The values are still lower than the mean fractal dimension value of the second and the third periods which are; “1,313” and “1,343”. However, in the fourth period fractal dimension of *Bornova* exceeded the mean fractal value of the districts, “1,492”, that it is calculated “1,581 for Bornova. Similar to first two periods, the third and the fourth periods are both lower than the fractal dimension value of the whole system for *Bornova* which are “1,819” and “1,724” (Figure 5-12). Although in the fourth period, fractal dimension of the whole system decreased, *Bornova* has been preserved the continuous increase. It can be argued that as a part, complexity of *Bornova* is lower than the İzmir Region in terms of fractal measures. However, district became more complex unlike the whole İzmir Region except *Konak.*

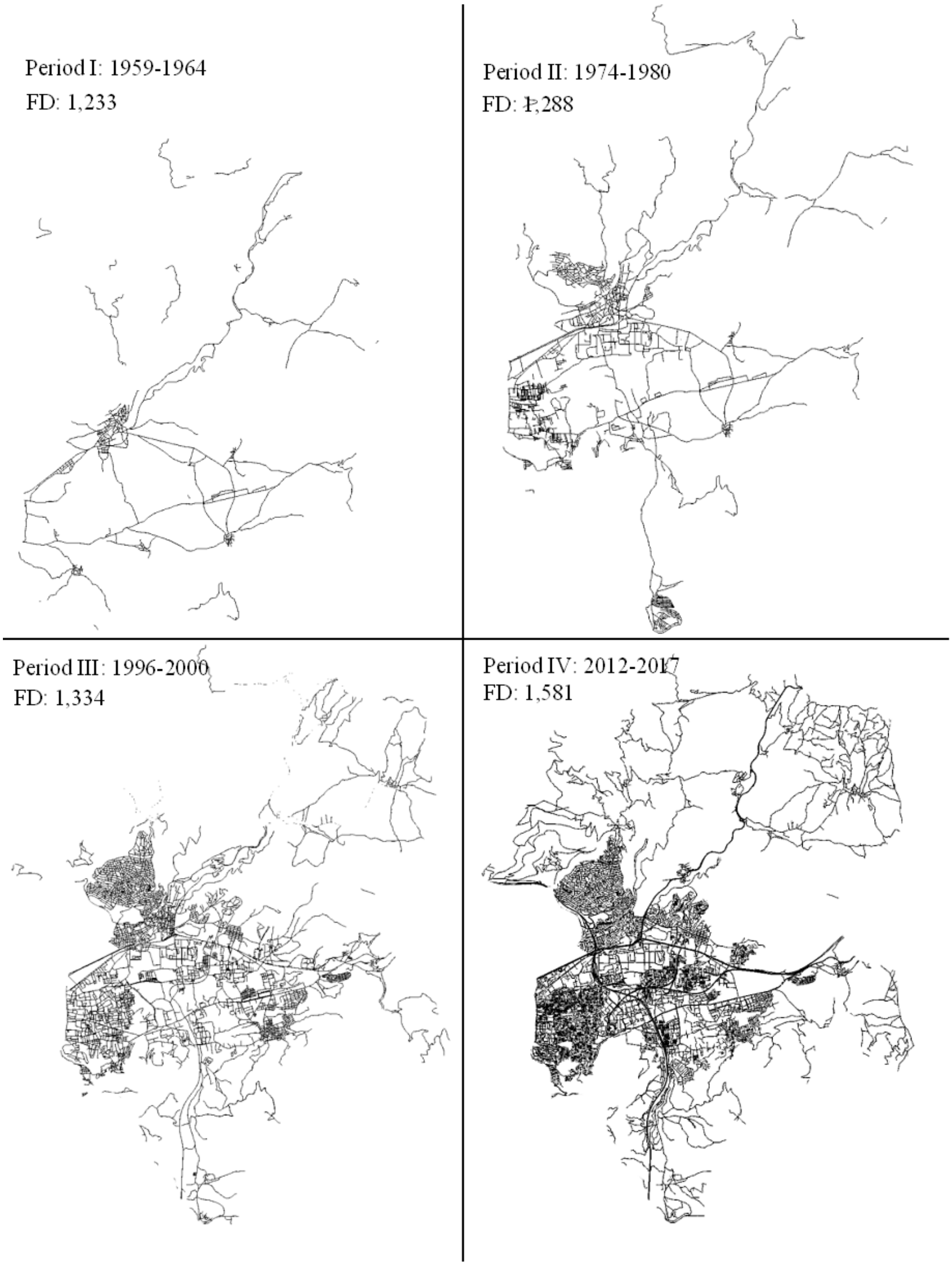



Figure 5-12 Fractal dimension change of *Bornova* District

The last central district is *Buca* which is the southern neighbor of *Bornova.* Like *Bornova*, *Buca* is a surrounding peripheral district of the Bay connecting *Torbalı* and *Kemalpaşa* to the center. The district experienced an increasing dense and complex pattern through the four periods. For the initial period, fractal dimension of *Buca* is calculated as; "1,222" which is both below the mean fractal dimension of the districts and the whole İzmir Region. The value is increased to "1,274" for the time period from 1974 to 1980 which is still below the mean fractal dimension value, "1,374" and the total network, "1,581". This trend has continued in the third and the fourth period as well. During late 1990s which is determined as the third period, fractal dimension of *Buca* increased to "1,300" remained below the mean district fractal value, "1,521" and the value of the whole İzmir Region's network; "1,724". Likewise in the fourth period fractal dimension value is calculated as; "1,333" which is below the district's average, "1,492" and the whole İzmir Region's values which is "1,724" (Figure 5-13). Despite of continuous increase in fractal dimension of *Buca*, complexity of the district remained below the mean of the parts of the system as well as the whole of it.

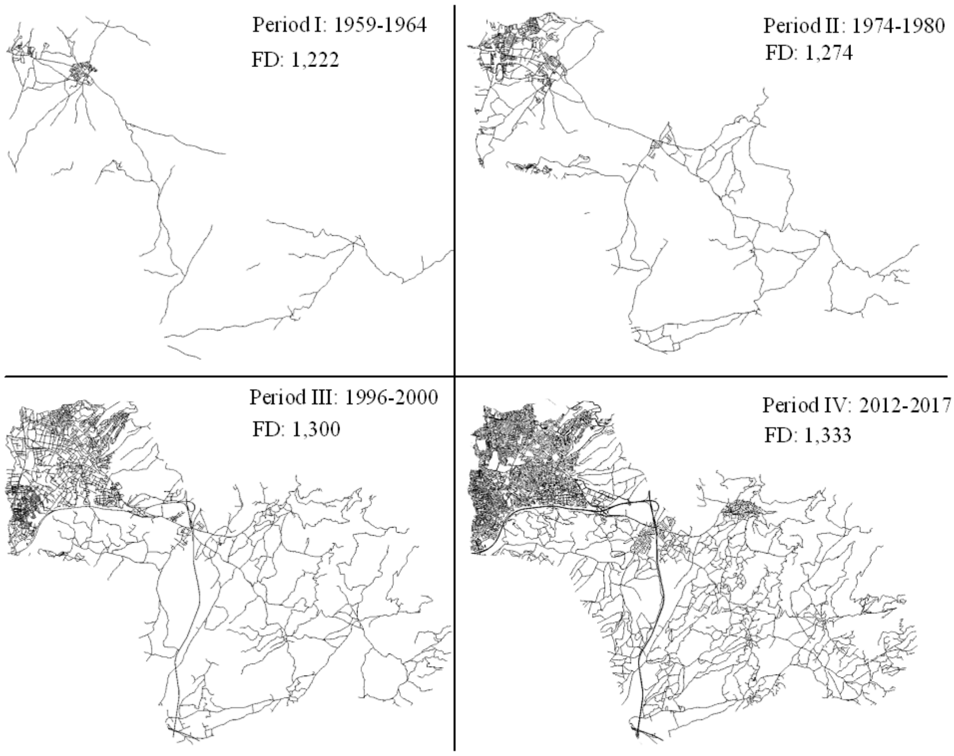
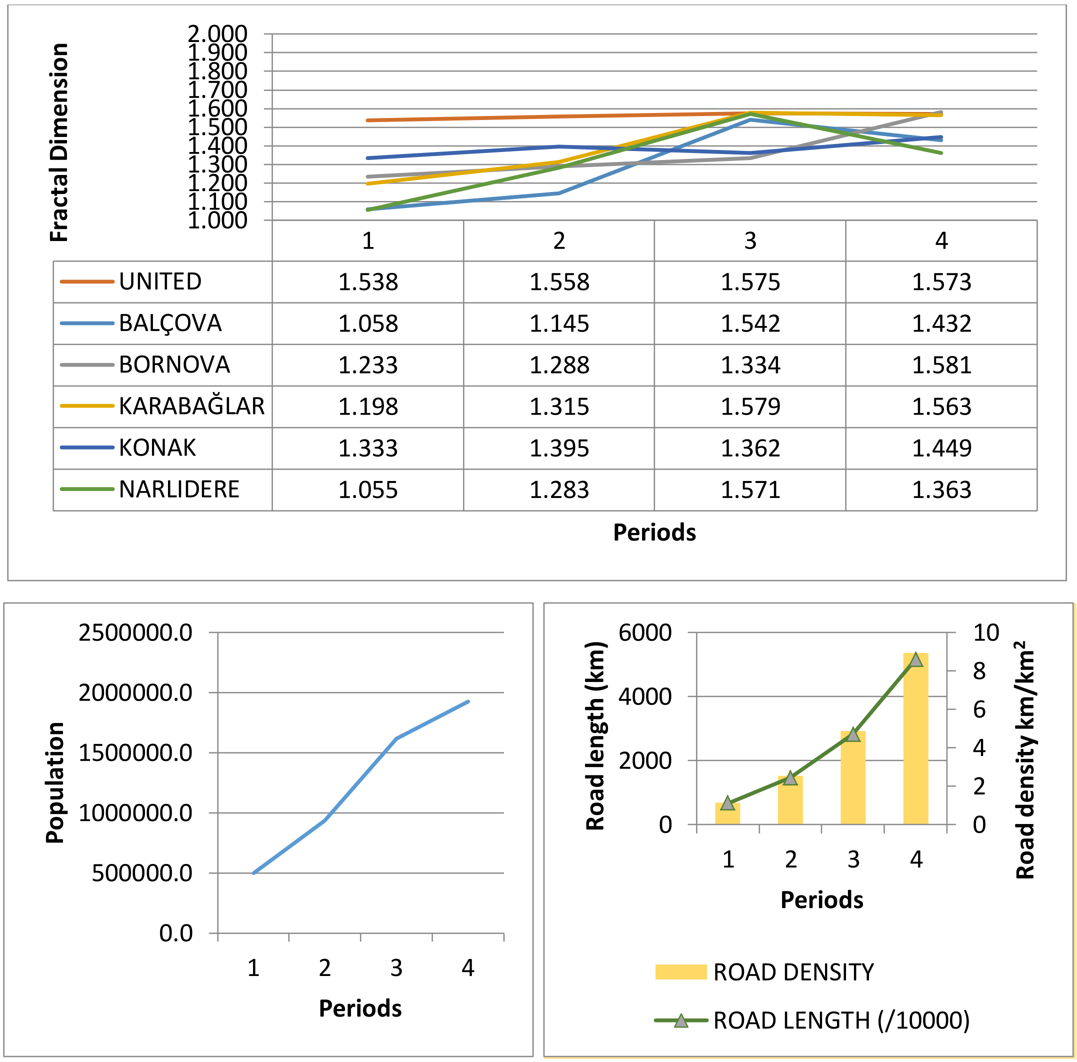



Figure 5-13 Fractal dimension change of *Buca* District

The relationship between the fractal dimension of the central districts and population of related districts are examined for central districts as a whole since population data has been gathered as a whole. Fractal dimension of central districts including *Konak, Balçova, Narlıdere, Karabağlar, Bornova* and *Buca* is calculated for the first period as “1,54”. This value increased to “1,56” for the period between 1974 to 1980. With a slight increase it reached to “1,58” in the second half of 1990s. The value is decreased to “1,57” in the last period. It can be argued that central districts preserve the complexity in all four periods covering a time span more than 50 years.  When the population is examined it is observed that the most dramatic population increase took place between the first and second periods with more than annually 8%. The rate decreased in following periods and calculated below 3% for last two periods. When the statistical relationship between fractal dimension and population for center districts are examined, it can be observed that complexity level of the center districts remain stable despite of the population change. In addition to population and fractal dimension values, it can be observed that total road length increased in all periods and accelerated for the the last period. The other observation can be pointed as the similar trend of population change and road network density of the central districts. Among the others, central district has the second or third the most densified road network. Eventhough both the road length and road network density increased, fractal dimension decreased during the fourth period (Figure 5-14).




| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| UNITED | 1.538 | 1.558 | 1.575 | 1.573 |
| BALÇOVA | 1.058 | 1.145 | 1.542 | 1.432 |
| BORNOVA | 1.233 | 1.288 | 1.334 | 1.581 |
| KARABAĞLAR | 1.198 | 1.315 | 1.579 | 1.563 |
| KONAK | 1.333 | 1.395 | 1.362 | 1.449 |
| NARLIDERE | 1.055 | 1.283 | 1.571 | 1.363 |

Figure 5-14 Population, road length, road density and fractal dimension change for center districts

The other district located in the Bay as the southern district neighboring to *Karabağlar* and *Buca* is *Gaziemir*. The district involves the airport and railway connection in addition to other uses. As observed from Figure 5-15, fractal dimension of *Gaziemir* is calculated “1,235” in the first period including years between 1959 and 1964. The value is both below the mean of the fractal dimension of districts, “1,313”, and the İzmir Region as “1,502”. In the second period this remained that fractal dimension is calculated as; “1,265”which is still below the average of districts which is “1,343” and İzmir Region’s value as “1,581”. Although there exist some discontinuities in the network maps of the third and the fourth periods, road system is regarded valid. With this respect, in the late 1990s fractal dimension of *Gaziemir* considerably increased and is calculated as“1,585”. Although the value is below the complexity level of the whole system in terms of fractal measure, it increased above the mean of all districts. In the last period fractal dimension decreased like the İzmir Region as well as some other core-sub region districts such as; *Balçova, Narlıdere* and *Karabağlar.* The value is calculated as “1,354” which is again below the average fractal dimension of all districts “1,492” as well as the fractal dimension of the whole network of the İzmir Region, “1,724”.

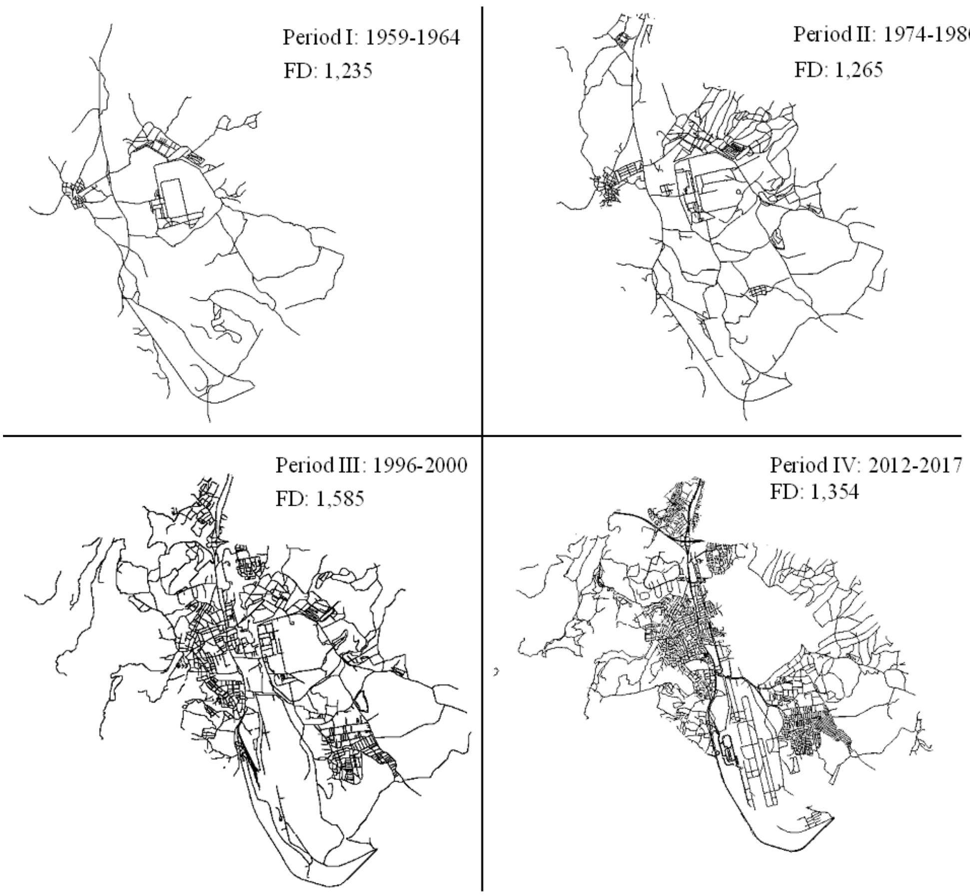



Figure 5-15 Fractal dimension change of *Gaziemir* District

When population values are examined, it is observed that *Gaziemir* is subjected to a continuous population increase. Between the second and third periods, the highest population increase among all districts is took place in *Gaziemir*. During this period, fractal dimension also significantly. Population increase decelerated after 2000 that fractal dimension of the district decreased. Likewise, increase rate of total road length of *Gaziemir* decelerated with respect to other phases between the third and the fourth periods. In the first period *Gaziemir* is determined as the first district having the highest road network density. This districts' road network density rank placed in the second and the third periods and became the third in the last period. Except the fourth period, fractal dimension of *Gaziemir* is calculated below the mean of other districts except the fourth period even it has a densed road structure (Figure 5-16).

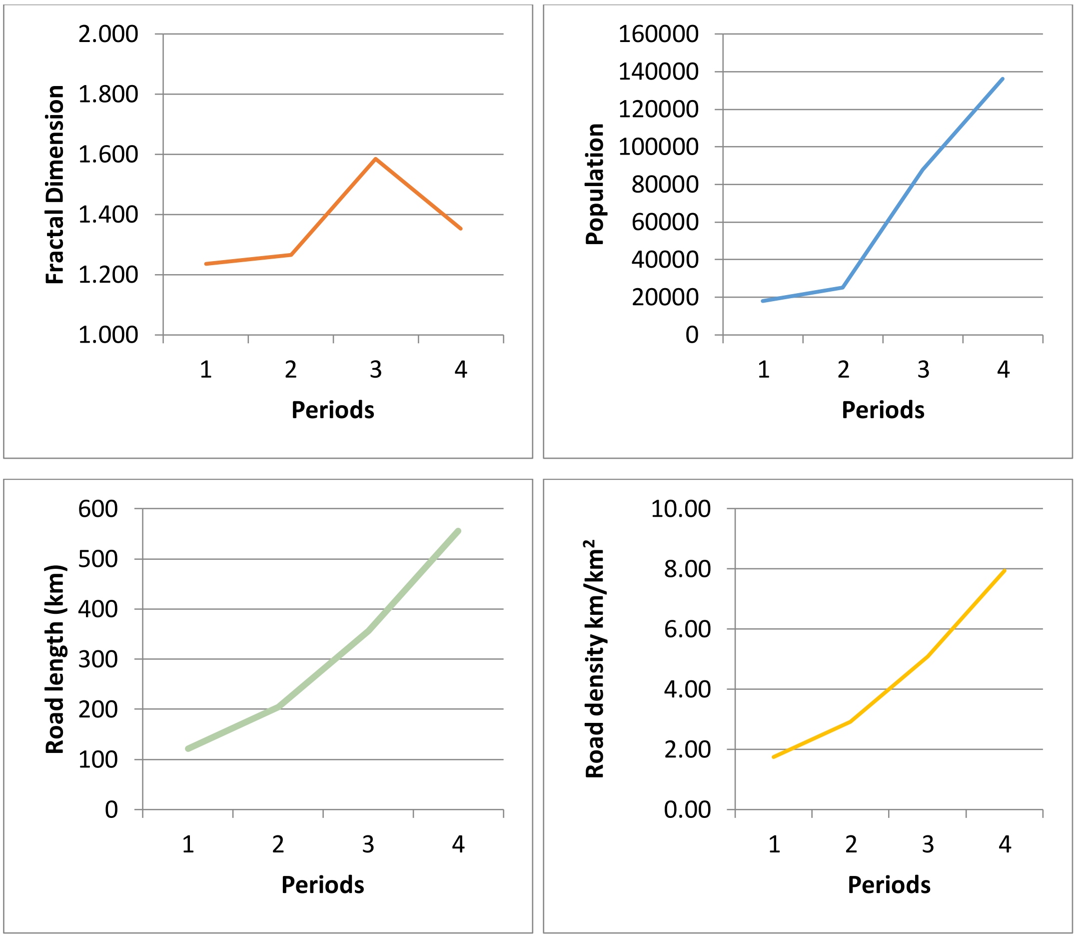



Figure 5-16 Population, road length/density and fractal dimension change for *Gaziemir*

The other district of the Bay-sub-region is *Güzelbahçe* which is a coastal district along the western coastal line of the Bay. The district is between *Urla* and *Narlıdere* which can be defined as the development corridor for the last two decades. This trend can be observed by the development of road network of the district as well. In the initial period covering the time span from 1959 to 1964, fractal dimension of the district is calculated 1,211 which is below the mean of fractal dimensions of İzmir Region's districts "1,313". This value is also below the fractal dimension of the whole network of the İzmir Region in the first period, "1,502". During the second period, coastal parts of the district developed and calculated "1,236" which is again below the average fractal dimension of all districts, “1,343” and the whole İzmir Region’s fractal dimension value as “1,581”. In late 1990s *Güzelbahçe* considerably developed which resulted in the increased complexity of the district by a fractal dimension value of “1,544”. This is above the mean value of the fractal dimension of all districts, “1,521” whereas below the İzmir Region’s value which is “1,819”. In the last period, like *Bornova* and *Buca* fractal dimension increased to “1,572” which is above the mean of districts, “1,492”, and below the İzmir Region’s fractal dimension, “1,724” (Figure 5-17).

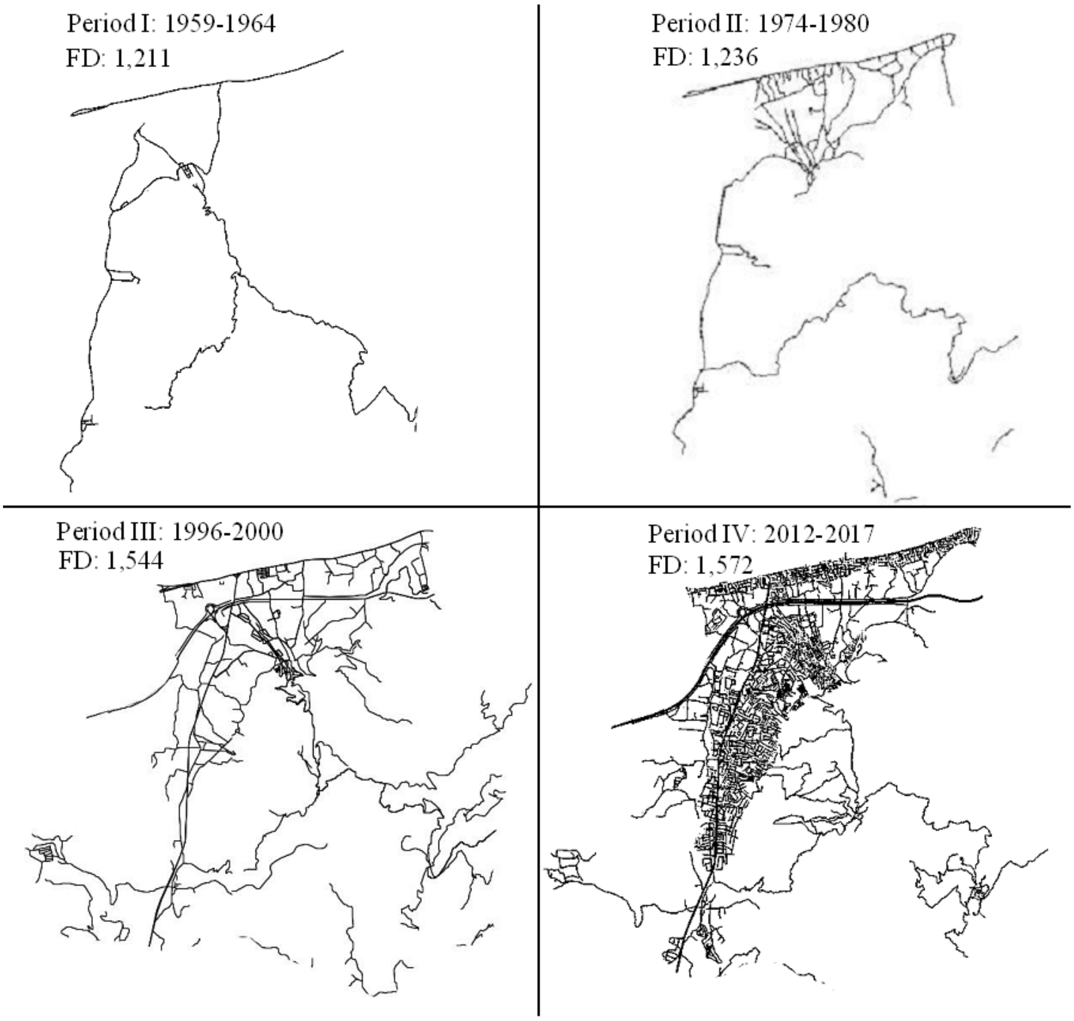



Figure 5-17 Fractal dimension change of *Güzelbahçe* District

When population data of the district is examined, it is observed that *Güzelbahçe* gained a continuous population increase like fractal dimension. The annual highest population increase rate occurred between the second and the third periods which can be also observed in the road length increase rate as well as fractal dimension. As being a part of the Bay's settlement structure, network density is above the mean of all districts. However, fractal dimension as a part of the system reached above the average in the third period (Figure 5-18).

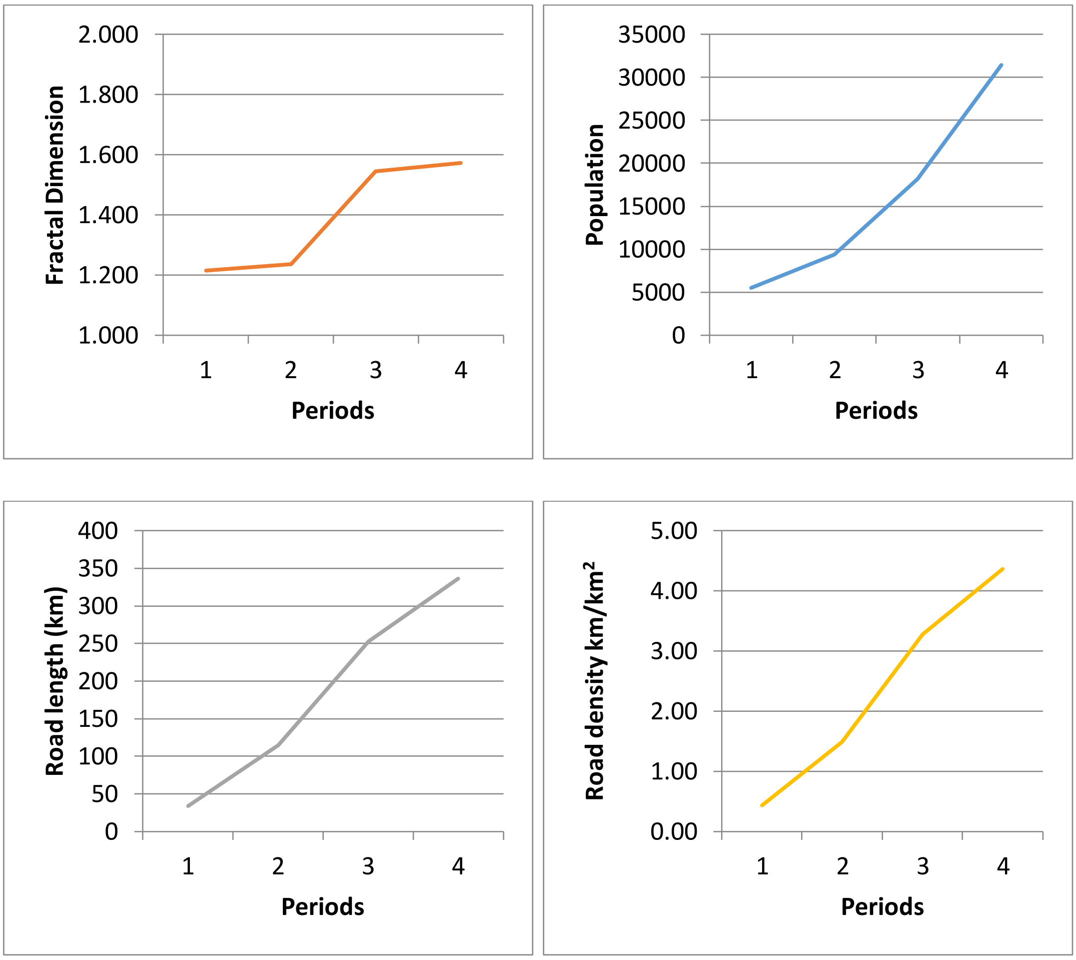



Figure 5-18 Population, road length/density and fractal dimension change for *Güzelbahçe*

The other three districts located in the Bay sub-region are *Çiğli, Bayraklı* and *Karşıyaka* which are coastal districts around the northern part of the Bay. Like center districts, population data of *Bayraklı* and *Karşıyaka* gathered as a whole and unit district except the last period. *Karşıyaka* is one of the oldest urban quarters around the İzmir Bay. The initial fractal dimension value of *Karşıyaka* is calculated as "1,174" below the mean fractal dimension of districts and the İzmir Region's fractal dimension which is "1,502". This district has a continuous increasing complexity. For the second period, fractal dimension is calculated "1,323". This value is increases to "1,362" in the third and "1,424" for the fourth period (Figure 5-19).

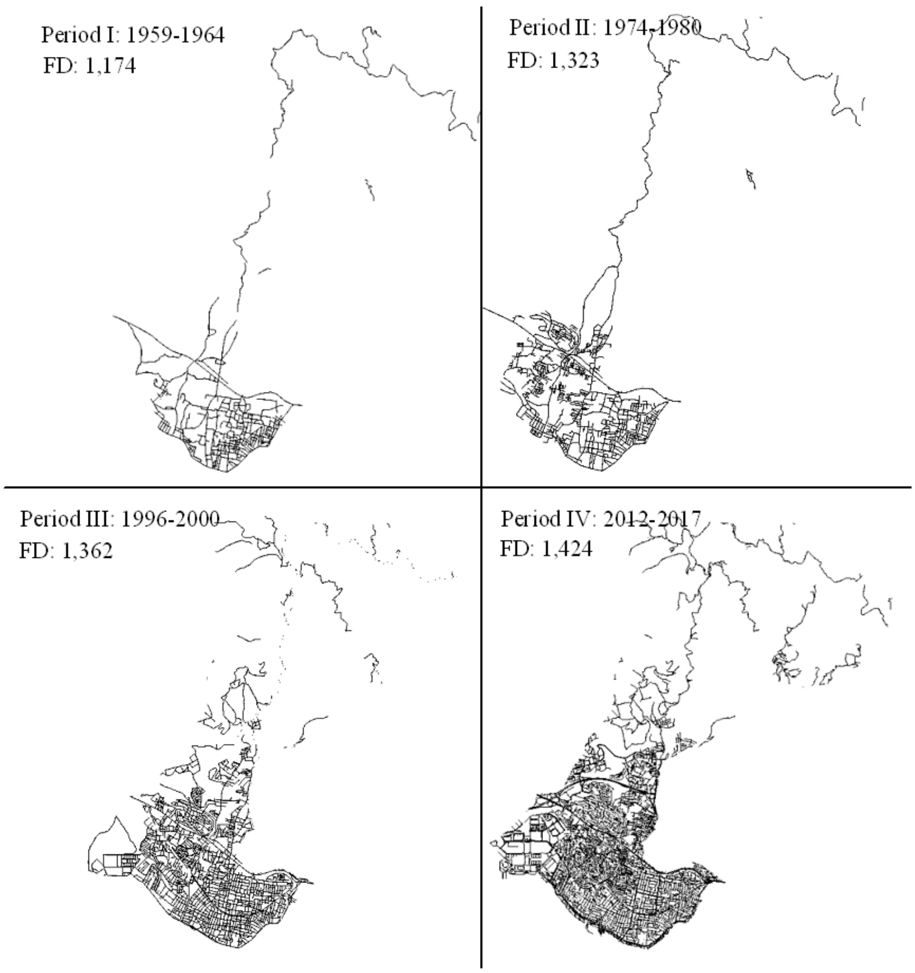



Figure 5-19 Fractal dimension change of *Karşıyaka* District

For *Bayraklı* complexity has been increased except the last period. In the initial period covering the years between 1959 and 1964, fractal dimension of *Bayraklı* is considerably low as “1,055”. This value is the second lowest value after *Beydağ.* Then fractal dimension increased to “1,187” and then to “1,433” in the second and the third periods respectively. For the last period fractal dimension slightly decreased to “1,431” (Figure 5-20).

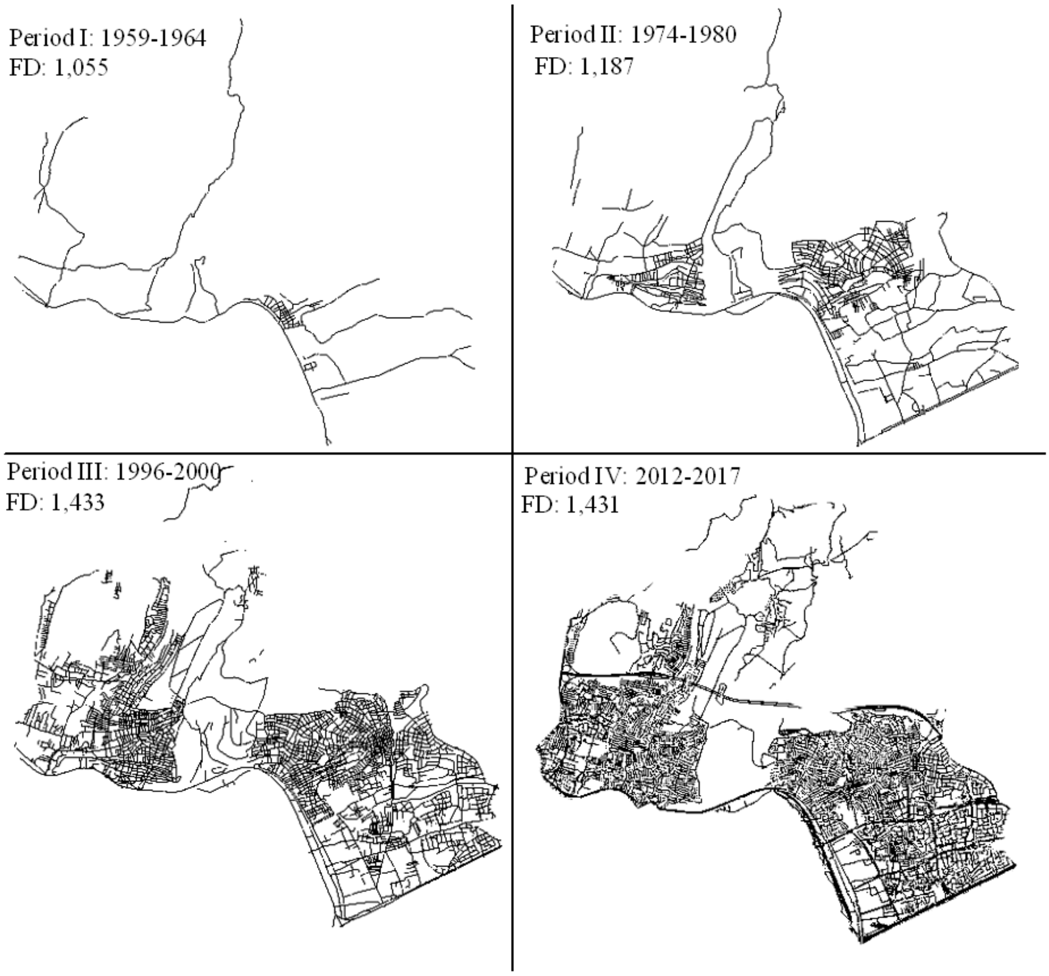
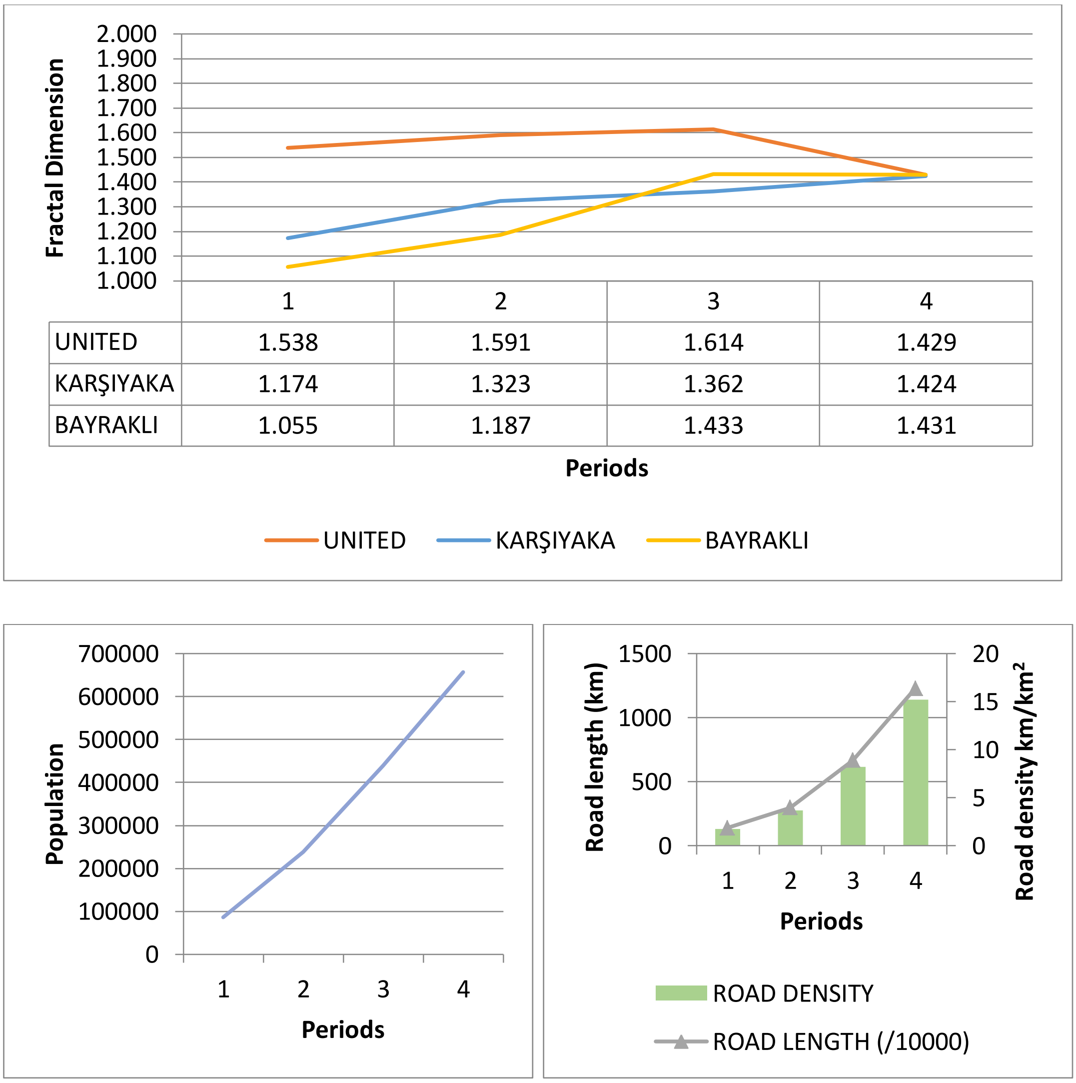



Figure 5-20 Fractal dimension change of *Bayraklı* District

Although *Karşıyaka* experienced a continuous increase in fractal dimension and *Bayraklı* as well within the last period, fractal dimension of *Karşıyaka* and *Bayraklı* as a whole presents a different trend. During the years between 1959 and 1964 as the intimal period, fractal dimension of *Karşıyaka* and *Bayraklı* is calculated "1,538" which is the second highest value after *Menderes* and the same with the central core. In other words, central *İzmir* around the Bay involve the same complexity level. For the second period including the years from 1974 to 1980, the value increased to "1,591". Then it increased to 1,614 in the second half of 1990s. For the last period containing years between 2012 and 2017, fractal dimension of *Bayraklı* and *Karşıyaka* decreased to "1,429". When population of *Bayrakli* and *Karşıyaka* district is examined, a continuously increasing trend is observed. *Karşıyaka* preserve the central and residential activities during all four periods while *Bayraklı* is subjected to illegal housing development during 1980s and 1990s. In the last decade, the area experienced partial re-development projects as well as relocation of administrative activities. In all time spans from 1959 to 2017, the integrated district of *Karşıyaka* and *Çiğli* always remained as the most densely populated district among the all districts. Furthermore, between the first and the second period, the highest population increase rate occurred for this part of *İzmir.* In spite of the stable population increase rate between the third and the last period, complexity level of the integrated district does not increase. In all four periods covering a time span more than a half decade, fractal dimension values of *Karşıyaka* and *Bayraklı* remained below the fractal dimension of the mean of all regions as well as the below the values calculated for the whole *İzmir* region. Due to increased central activity, length of the road network increase rate accelerated between the last two periods. A considerable network density can be observed in *Karşıyaka-Bayraklı* which is in the second rank in the first period and reached to first in following years. After the second period, the highest network density observed in *Karşıyaka* and *Bayraklı* while fractal dimension decreased which means construction of new roads have not effect on the complexity level of the system (Figure 5-21).




| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| UNITED | 1.538 | 1.591 | 1.614 | 1.429 |
| KARŞIYAKA | 1.174 | 1.323 | 1.362 | 1.424 |
| BAYRAKLI | 1.055 | 1.187 | 1.433 | 1.431 |

Figure 5-21 Population, road length/density and fractal dimension change for *Karşıyaka* and *Bayraklı*

The last district located in the core sub-region is *Çiğli* which is located in the northern part of the Bay in the west of *Karşıyaka.* Although being the part of the *Gediz ecosystem*, rather than an agricultural activity, it has been transformed into an economic hub including industrial activities during the related time period. For the early 1960s which is determined as initial stage, fractal dimension of *Çiğli* is calculated “1,195” is lower than the mean value of districts. In the second period, this value increased to “1,235”. A rapid increase is observed in the complexity level during the second half of 1990s since the fractal dimension increased to "1,611" which is one of the highest values among all districts. Fractal dimension value of *Çiğli* exceeded the mean of the all districts during this period. However, in the fourth period covering the years between 2012 and 2017, fractal dimension decreased to "1,379" which is below the mean value of districts again (Figure 5-22).

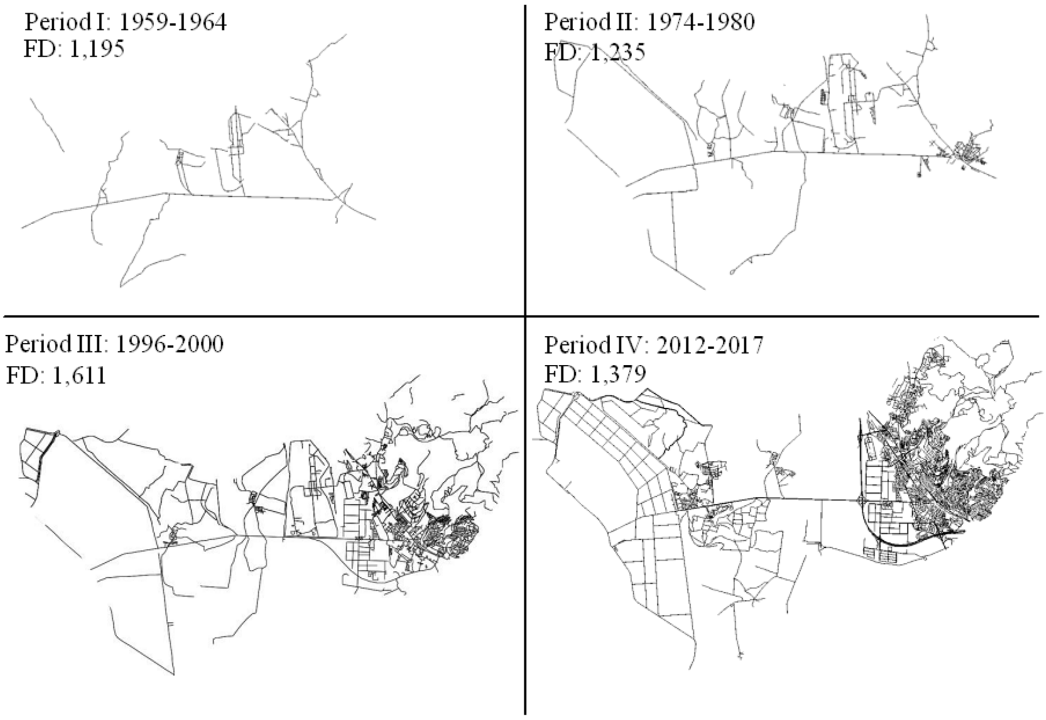



Figure 5-22 Fractal dimension change of Çiğli District

When population of *Çiğli* is examined, it is observed population increase rate accelerated after the first period and preserve this increasing trend for the following periods. When the length and the density of the network of *Çiğli* is examined, it is observed that the slope of the road length and density gradually increased and reached to the highest value between the third and the fourth periods covering a time span from mid-1990s to late 2010s. Although population and network density is high in the last period with respect to other districts, increased regular divisions in the network system may be resulted in a decrease in fractal dimension for *Çiğli* (Figure 5-23).

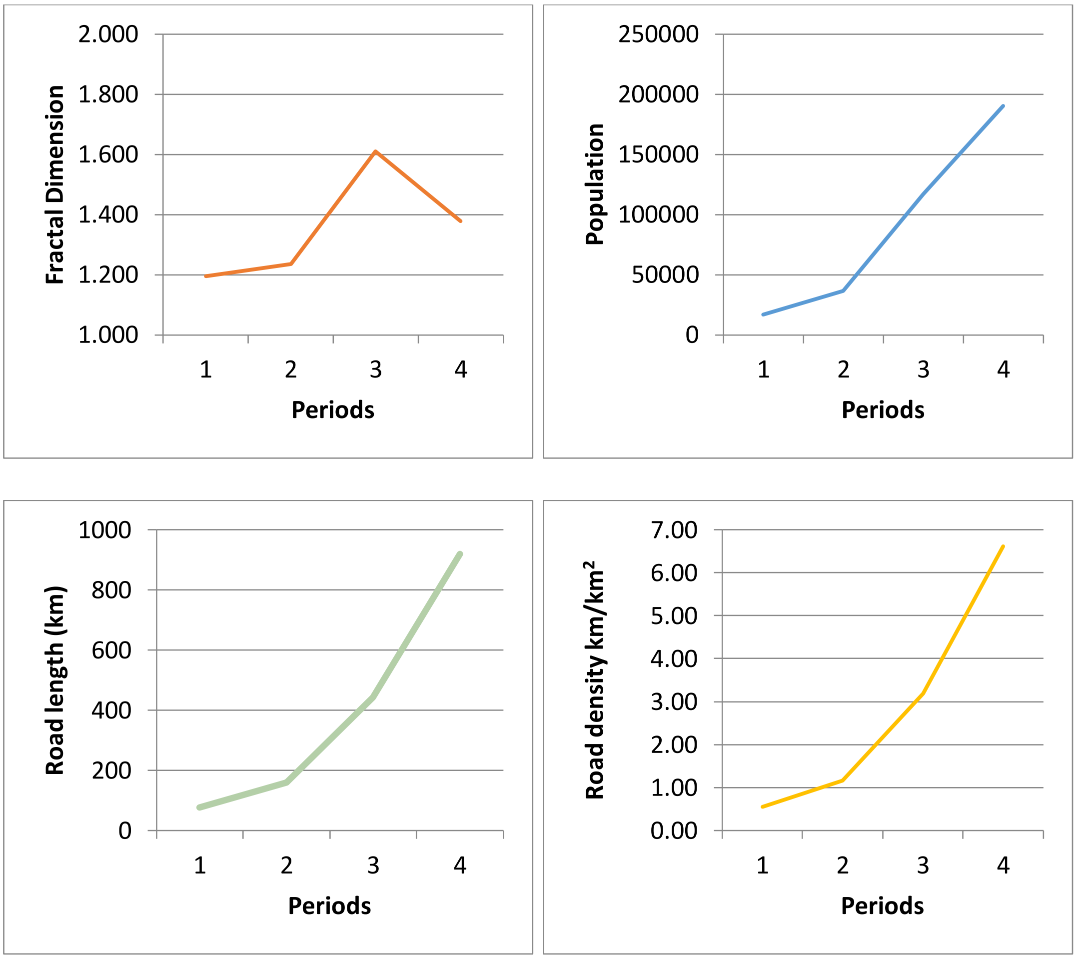



Figure 5-23 Population, road length/density and fractal dimension change for *Çiğli*

### 5.3.2 The Western sub-region

The sub-region includes *Urla, Çeşme* and *Karaburun* located in the western peninsula which includes rural areas, tourism nodes and secondary housing. The first district which was developed along the coastline of the Bay is *Urla* (Figure 5-24). When fractal dimensions of *Urla* are examined, the fractal dimension is calculated 1,510 for the first period which is both above the mean of the fractal dimensions of all districts as well as fractal dimension of the whole *İzmir* (1,502). For the second period covering the time span 1974 to 1980, fractal dimension of *Urla* increased to “1,530”. The road system is observed to be developed and the value remained above the mean of the fractal dimensions of all districts. In the third period, depending on the connection with the coastline from the east with *İzmir*, remarkable development in the road network can be observed. However, fractal dimension of the second half of 1990s is calculated as “1,525” which is still slightly above the mean fractal value of the districts. In the last period, fractal dimension again increased to “1,540” with further developments and densification and the gap between the fractal dimension of *Urla* and the mean fractal value of districts increased.

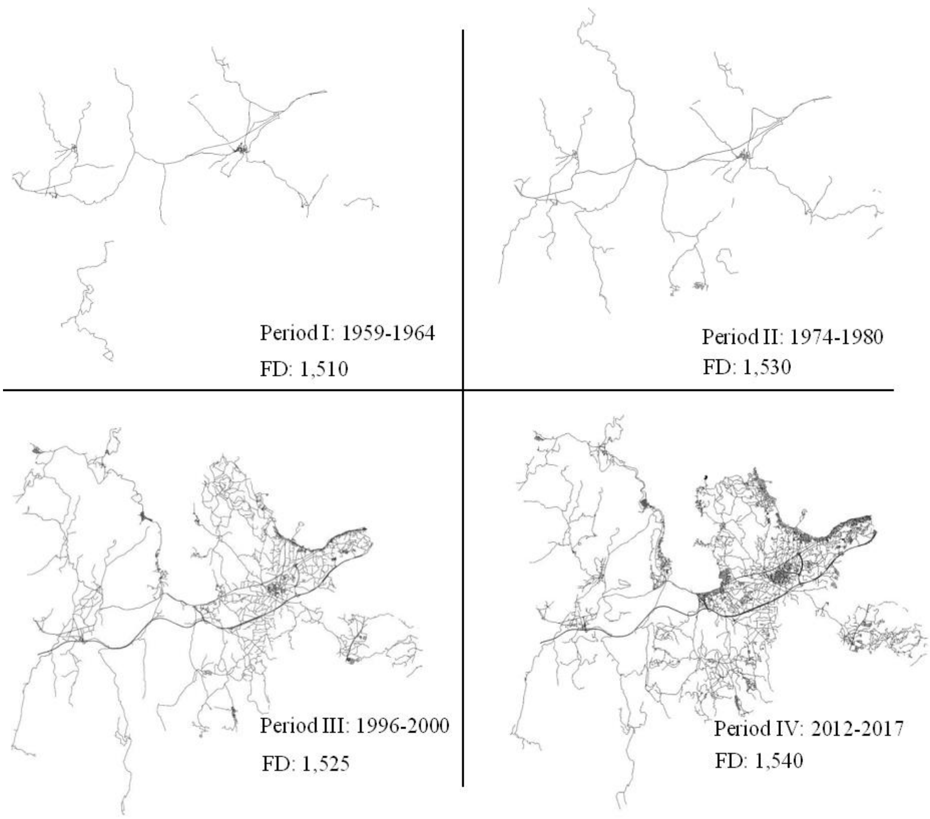



Figure 5-24 Fractal dimension change of Urla District

The highest rate of population increase occurred between the second and third periods. In last two decades population increase slightly deccelerated while densification along the coastline can still be observed. This can be interpreted as the result of increased attraction of the district for retired immigrants from İzmir as well as other metropolitan cities. Densifications in certain points resulted in a slight increase in the complexity of the network system similar to neighboring districts of *Urla*. When the length and the density of the road network is examined it is observed that both of the increasing trend of the both values are accelerated after the second period mainly due to the charming effects of the districts as a leisure/calming zone attributes. The network density tripled from second to third period and nearly doubled from third to fourth period which resulted in a slight increase in the complexity level of the network (Figure 5-25).

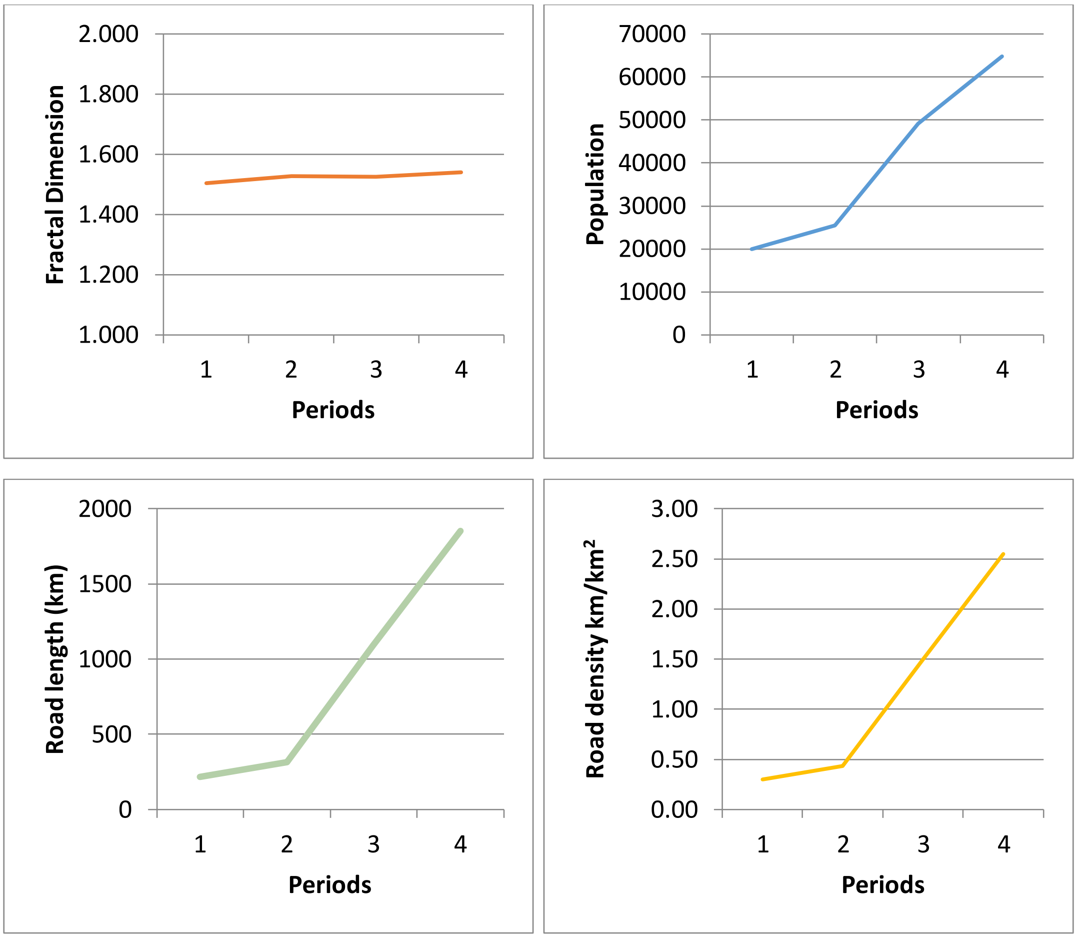



Figure 5-25 Population, road length/density and fractal dimension change for *Urla*

As being connecting to the same spine, development of *Çeşme* is connected to *Urla* which is the most popular tourism destinations of the country. When fractal dimension of the first period is examined covering a time span from 1959 to 1964, it can be observed the value is calculated as "1,218" which is both below the mean fractal dimension of all districts as well as the total system. The value is increased to "1,236" again below the average and the whole systems' fractal dimension. After the highway construction and nation-wide tourism investments, district gained attention as becoming a tourism center in 1990s. This resulted in an increased level of complexity of the road system that the fractal dimension value increased to "1,533" in the third period. The increasing complexity continued in the fourth period as fractal dimension is calculated "1,566" for the last period.(Figure

5-26). Fractal dimension of *Çeşme* district is determined above the mean value of the districts and below the fractal dimension of the whole system for the third and the fourth periods.

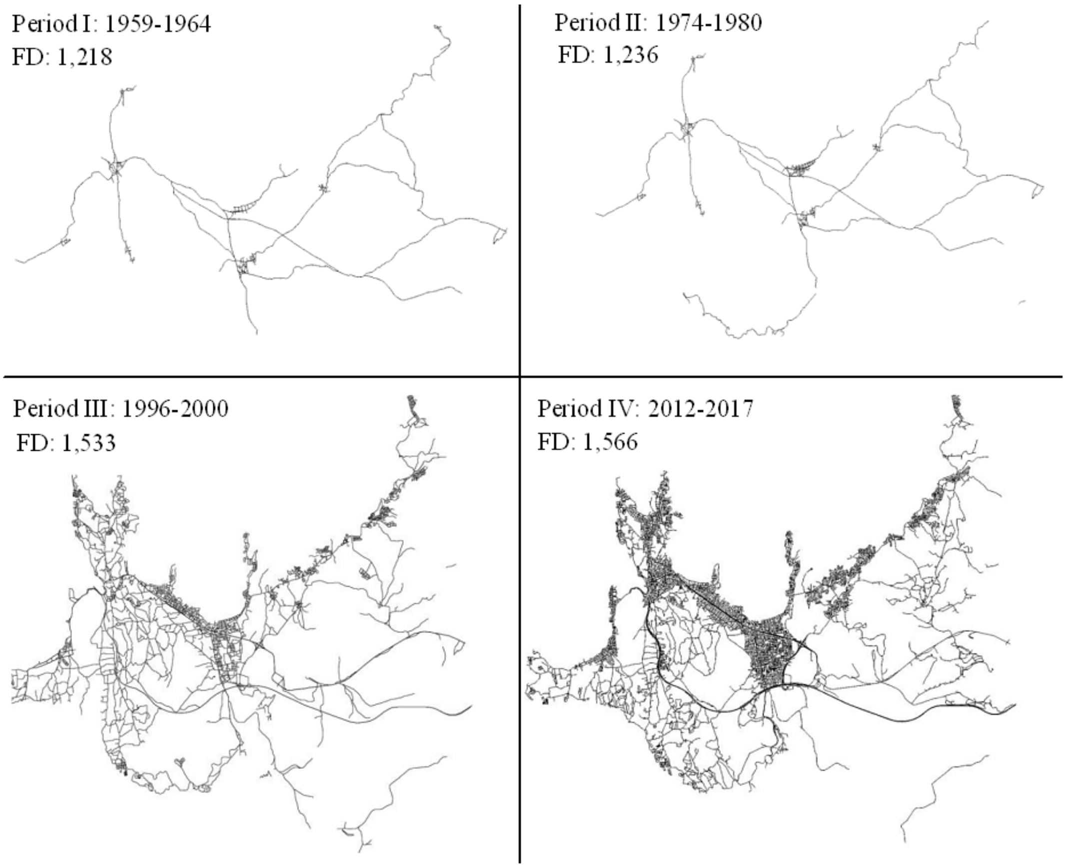



Figure 5-26 Fractal dimension change of Çeşme District

Densification of the network can be easily observed by the third period along the northern coastline. Between the second and the third periods network density increased more than five times and nearly doubled between the third and the fourth periods. A similar trend of fractal dimension can also be observed for rate of population change. Although road network and density have a sustainable increasing trend, pattern of population and fractal dimension fluctuating and then relatively decreased for the last period. In other words, further development of the built-up area and the road network did not reflected in the complexity level and population (Figure 5-27). *Çeşme* is the only district which is not located around the Bay that all the fractal dimension, road length and population values increased in all periods.

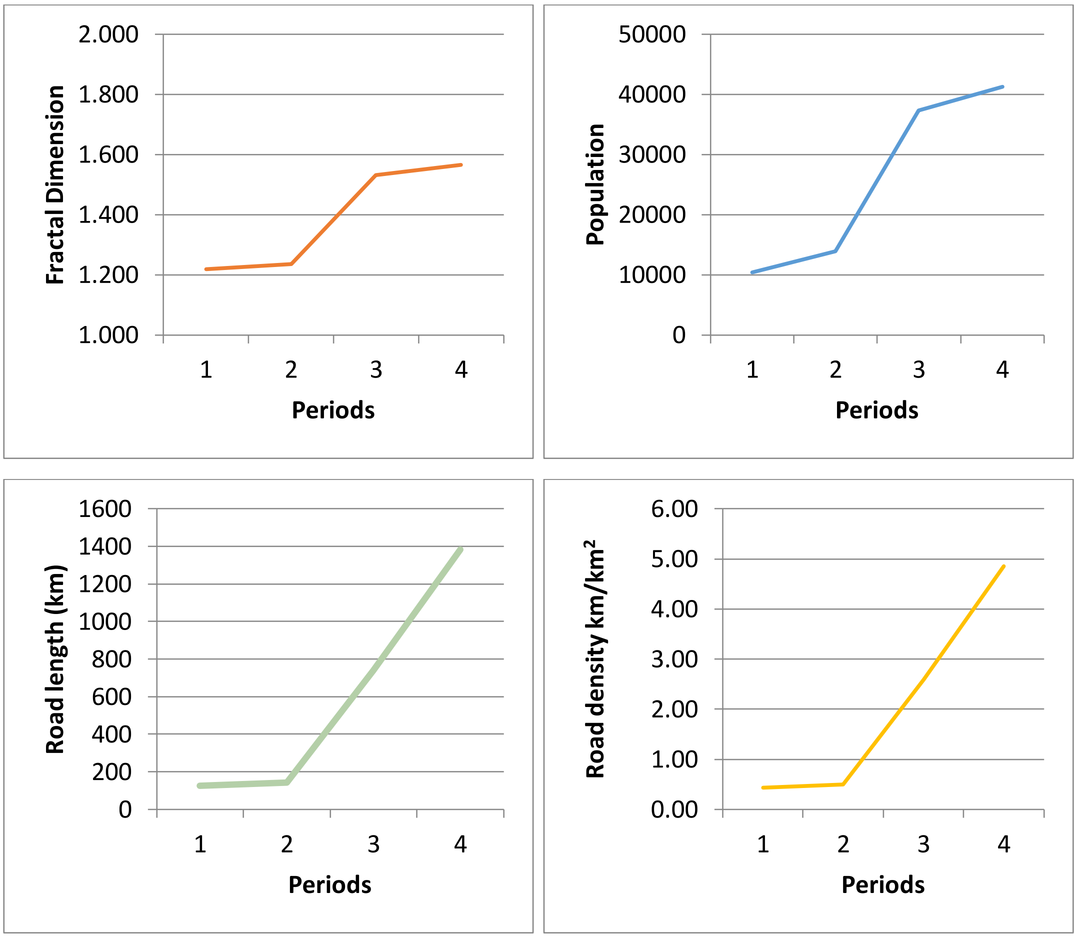



Figure 5-27 Population, road length/density and fractal dimension change for *Çeşme*

The last district of the western sub-region is *Karaburun* which is another attractive location for metropolitan permanent and semi-permanent immigrants due to its natural and rural attributes as a calm coastal town. The unique situation of *Karaburun* among the districts is that road system was not drawn on the 1/25000 scaled maps for the first period covering the time span 1959-1964. For this reason, analysis of the road network started from the second period covering the years from

1974 to 1980. The district had been considerably isolated due to geographical features while an ongoing highway construction project resulted in further built-up area and population increase which took place in 1990s for *Çeşme.* Similar to *Urla* and *Seferihisar*, *Karaburun* was took advantage of secondary housing and small-scale tourism by Its virgin nature and small coastal Aegean town features.

For the second period, when the road system of *Karaburun* can be firstly interpreted from the maps, fractal dimension is calculated “1,473” which is above the mean fractal value of all districts and below the fractal dimension of the whole network of İzmir. In the third period covering the time span of 1996 to 2000 an era characterized by the start of the attraction of the district by İzmir’s residents and the remote retired population, fractal dimension increased to “1,553”. Similar to the previous period the value is above the mean fractal value of all districts “1,521“ while below the value of the whole system “1,819“. For the last period covering the time span from 2012 to 2017 it is observed that fractal dimension of *Karaburun* decreased to “1,523” which is again above the mean of districts (1,492) and below the fractal dimension of İzmir “1,724“.

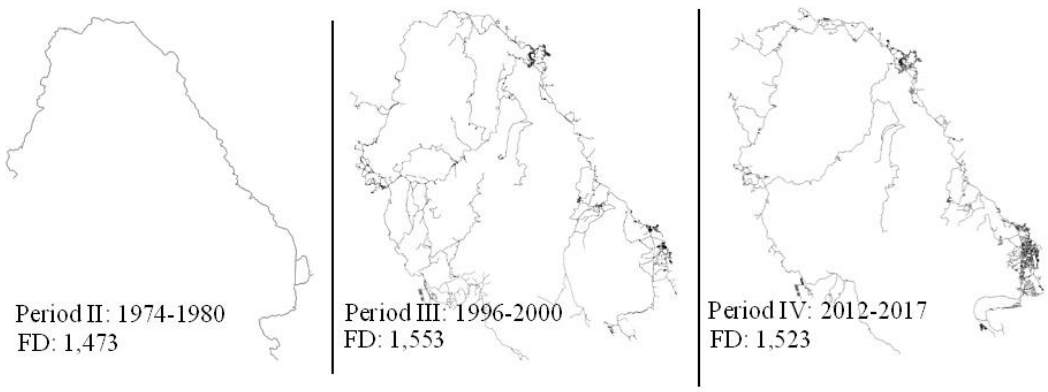



Figure 5-28 Fractal dimension change of Karaburun District

When population change is examined it is observed that population increase rate decreased from second to third period to third to fourth period similar to fractal dimension. The highest population loss is experienced in *Karaburu*n more than between the third and the last periods approximately 1,5% annually.  Increase in the road length and the road density shows a similar trend which shows that development of *Karaburun* decelerated after 2000 with respect to late 1990s (Figure 5-29).

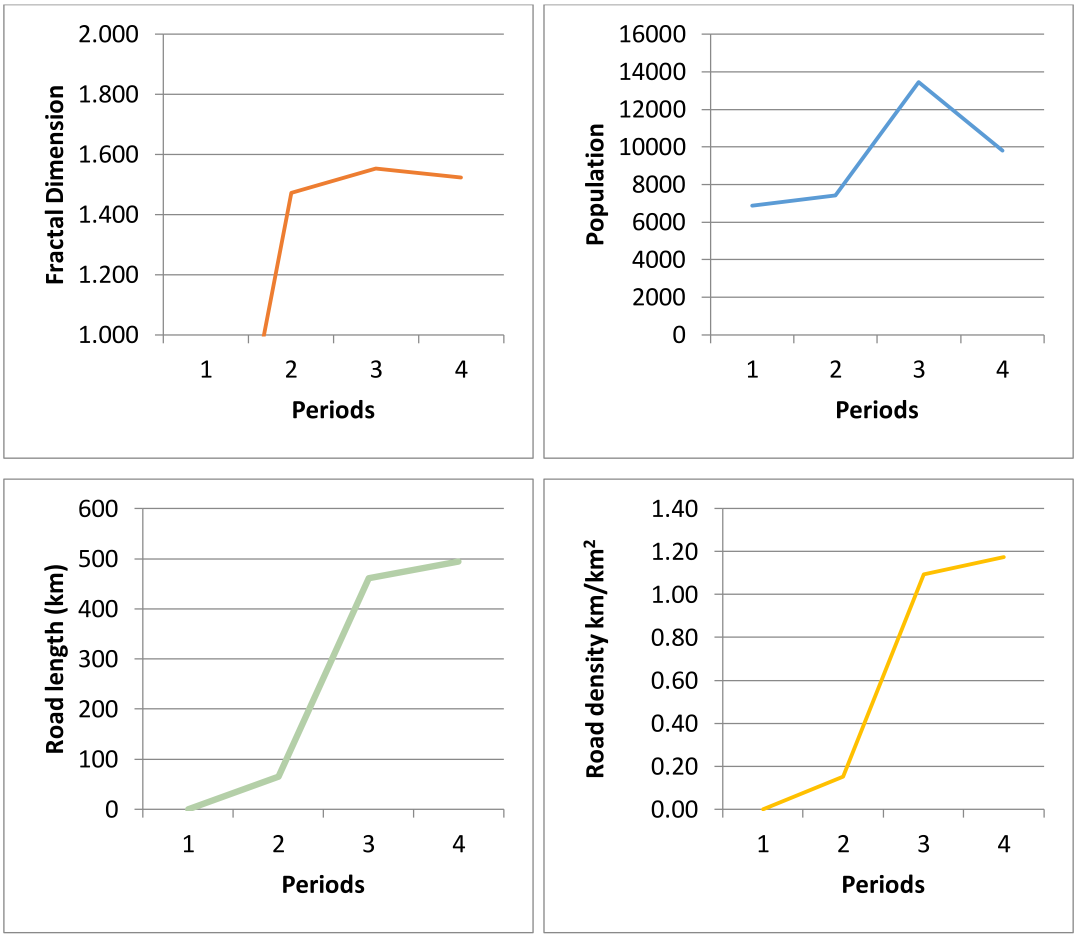



Figure 5-29 Population, road length/density and fractal dimension change for *Karaburun*

### 5.3.3 The Northern sub-region

The northern sub-region is observed as the strongest sub-region in all periods involving districts have quite different characteristics with respect to other sub-regions. The districts in the northern sub-region can be listed as, *Menemen, Foça, Aliağa, Dikili, Bergama* and *Kınık.*

*Menemen* is characterized by urban development as well as agricultural and industrial production. The agricultural prominence is due to rich plain fed by the *Gediz* river. Development of the district by 1990s can be visually observed via network system. For the initial period covering the time span from 1959 to 1964, fractal dimension of this district is calculated “1,514” which are above the mean of fractal dimensions of İzmir Region’s districts which is “1,313”. The value is also above the fractal dimension of the whole network of which is “1,502”. During the second period, peripheral growth of the district observed while fractal dimension is calculated “1,508” which is still above the average fractal dimension of all districts However, the value is determined below the dimension of the total network system of İzmir which is “1,581”. In late 1990s, *Menemen* considerably developed which leads to increased complexity of the district by a fractal dimension value of “1,544”. This is above the mean value of the fractal dimension of all districts “1,521” but below the İzmir Region’s value which is “1,819”. Eventhough, further growth fractal dimension decreased to “1,545” which is still above the mean of districts, “1,492”, and below the İzmir Region’s fractal dimension, “1,724” (Figure 5-30).

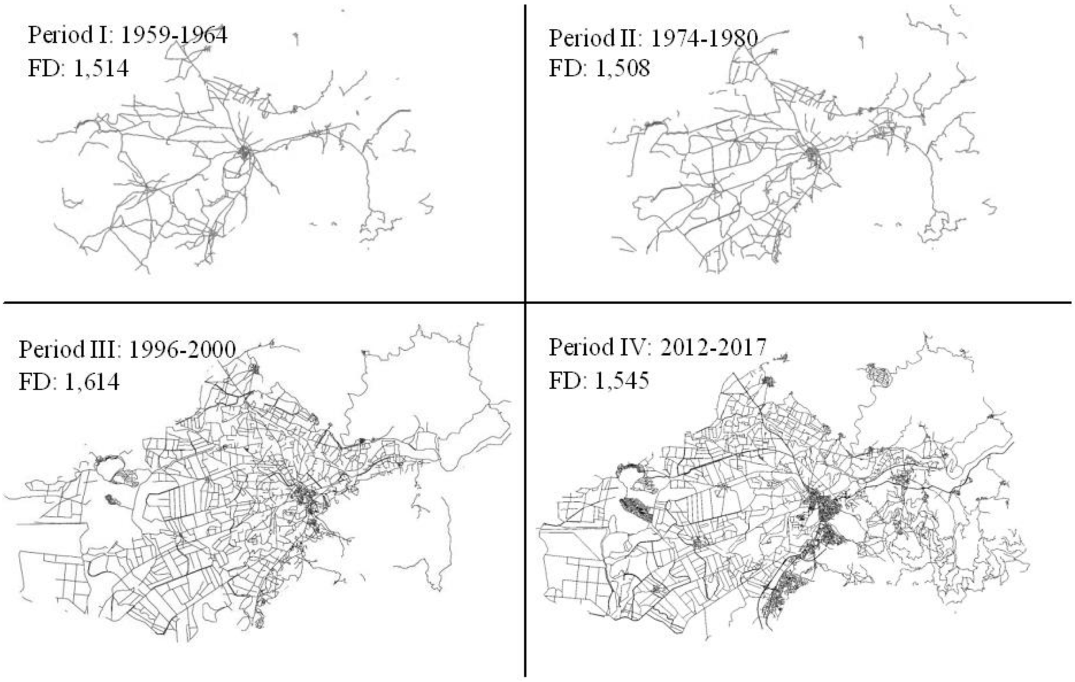



Figure 5-30 Fractal dimension change of Menemen District

As being connecting to northern spine, a continuous increase in population and network length can be observed in *Menemen* like *Aliağa.* As observed from Figure 5-31, the highest population increase rate is calculated between the second and the third periods. Likewise, increase in the total road length of the district is observed between those periods as well. In terms of population change, with respect to changes in road length and road density rank of this district is above the average among the other districts.

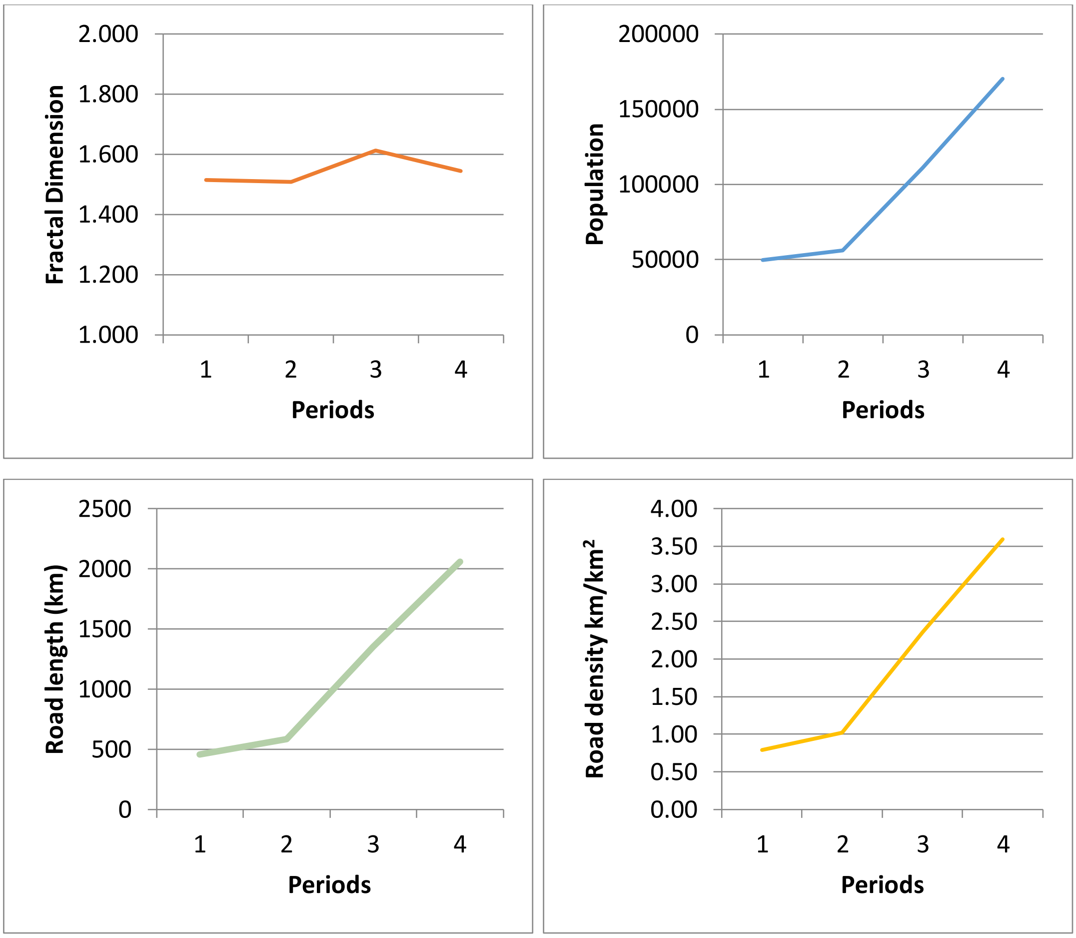



Figure 5-31 Population, road length/density and fractal dimension change for *Menemen*

The other district located in the northern sub-region of İzmir is *Foça.* Different from *Menemen* and *Aliağa, Foça* is characterized as a coastal town of small-scale tourism activity, secondary housing as well as seasonal or temporary retired population's destination. The most visible growth can be observed during the third period covering the time span of late 1990s while densification in coastal parts can be visualized during the last period.

For the first period (1959-1964) fractal dimension value of *Foça* is below the average fractal dimension of all districts and the whole İzmir region as it is calculated "1,206". For the second period as the second half of 1970s, fractal dimension value is determined quite similar and calculated “1,209.” Since district has developed in terms of touristic and secondary housing activities, fractal dimension increased to”1,591”. For the third period it is higher than the mean fractal dimension of the districts “1,521”. However, as a part of the system complexity of the district remained lower than the whole since fractal dimension of the İzmir Region’s network is “1,819”. Despite of the densification on the coastal parts, fractal dimension of the road network between 2012 and 2017 is decreased to “1,535” which is still above the mean of the all districts, “1,492” but below the İzmir Region’s fractal dimension; “1,724”. The fractal dimension change of *Foça* is observed in Figure 5-32.

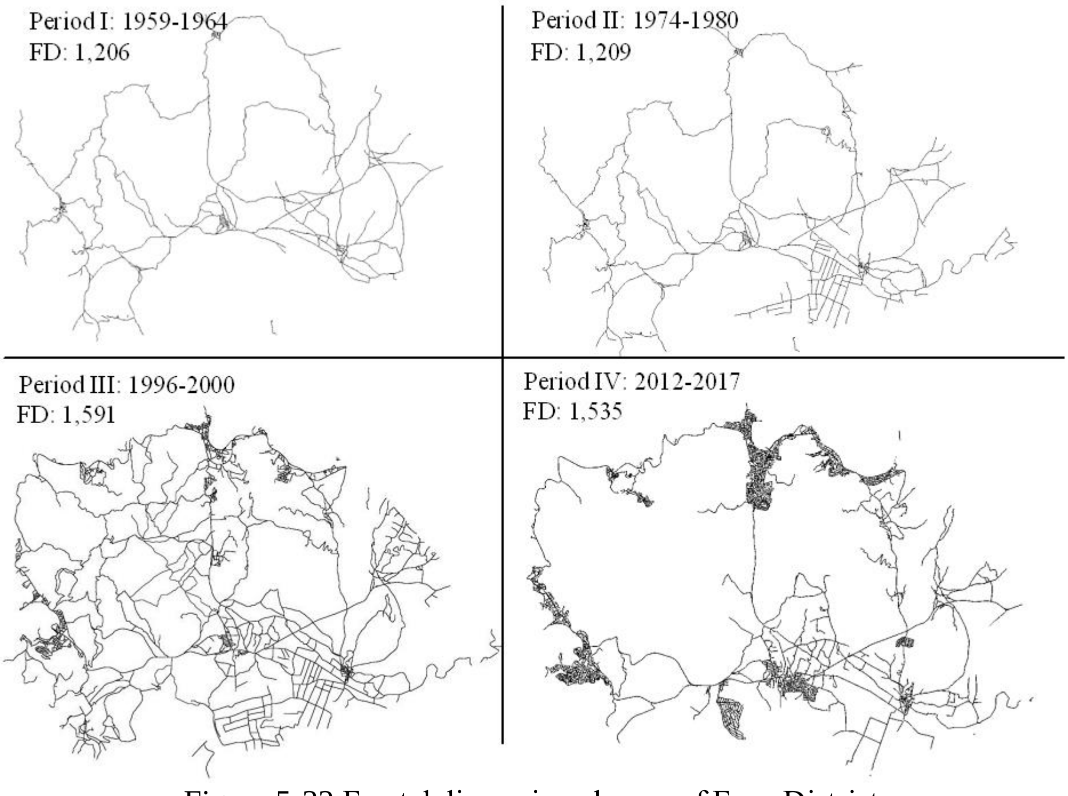



Figure 5-32 Fractal dimension change of Foça District

When the road length is examined it is observed that *Foça's* network mainly developed by the third period and growth trend preserved during the fourth period as well. This trend also resulted in population increase which is accelerated between the second and fourth periods. Similar to the other districts attracted by touristic activity and retired population, *Foça* had been took advantage of network development and population growth during 1990s even those trends did not reflected on the complexity level of the district (Figure 5-33). The visual observations also show that main densified areas can be identified along coastal zones mainly around *Foça, Yenifoça, Çanak* and *Sazlıca.*

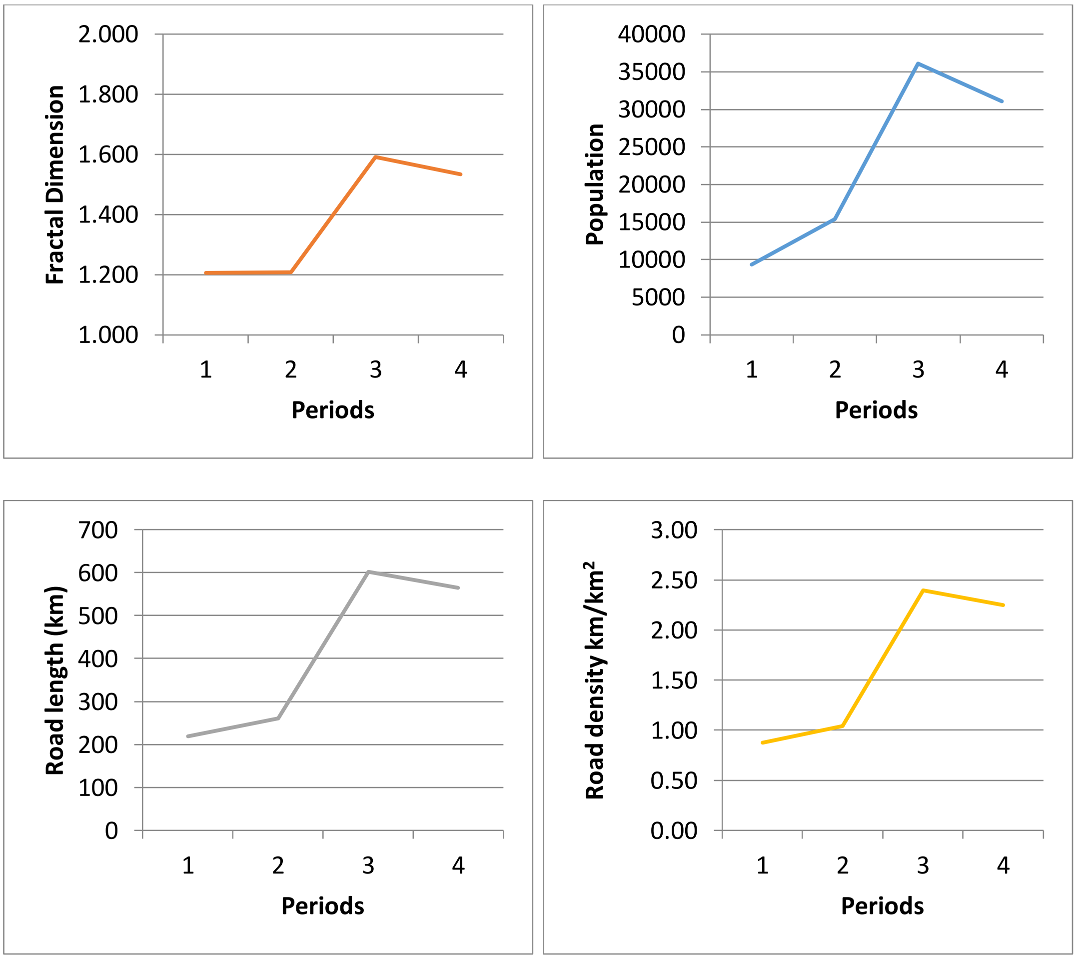



Figure 5-33 Population, road length/density and fractal dimension change for *Foça*

The other district of the northern sub-region is *Aliağa* which resembles to *Menemen* and *Menderes* as a closer peripheral district of the Bay sub-region. The distinctive feature of *Aliağa* can be specified that it involves the largest petroleum and chemistry based industrial activity. When the petroleum refinery completed in late 1980s as well as other industrial activities, *Aliaga* considerably has developed after the second period. For the initial period covering the time span from 1959 to 1964, fractal dimension of the district is calculated "1,201". During the second period, peripheral growth of the district observed while fractal dimension is calculated; "1,506" which is still above the average fractal dimension of all districts. However, the value is determined below the dimension of the total network system of İzmir which is "1,581". In late 1990s a slight increase observed by a fractal dimension value of "1,616". This is above the mean value of the fractal dimension of all districts, "1,521" whereas below the total İzmir Region's value which is "1,819". Despite of the further growth opportunities of the district, fractal dimension remained the same in the fourth period which is still above the mean of districts, "1,492", and below the İzmir Region's fractal dimension, "1,724" (Figure 5-34). It can be argued that complexity of *Aliağa* as a part of the system remained below the complexity level of the whole system during all four periods.

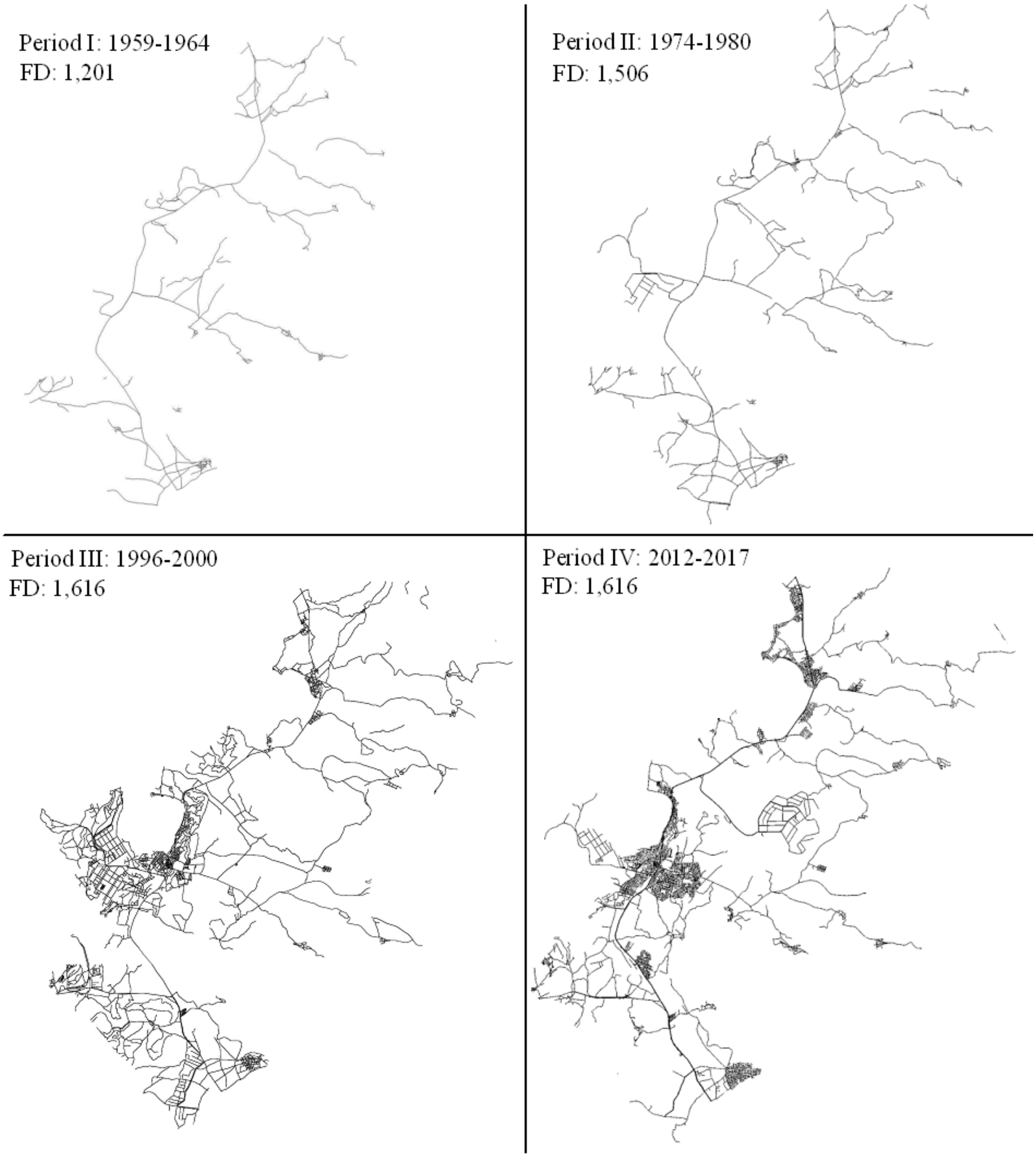



Figure 5-34 Fractal dimension change of Aliağa District

When rate of population change for *Aliağa* is examined, it is observed population increase rate accelerated after the first period. A parallel trend can be observed in population with fractal dimension, road density and total road length of *Aliağa* accelerated between the second and third periods. The rate of increase decreased after 2000. When the road system is visually investigated, high density of road network can be observed in certain focal points in addition to presence of organized industrial zone in the last period (Figure 5-35).

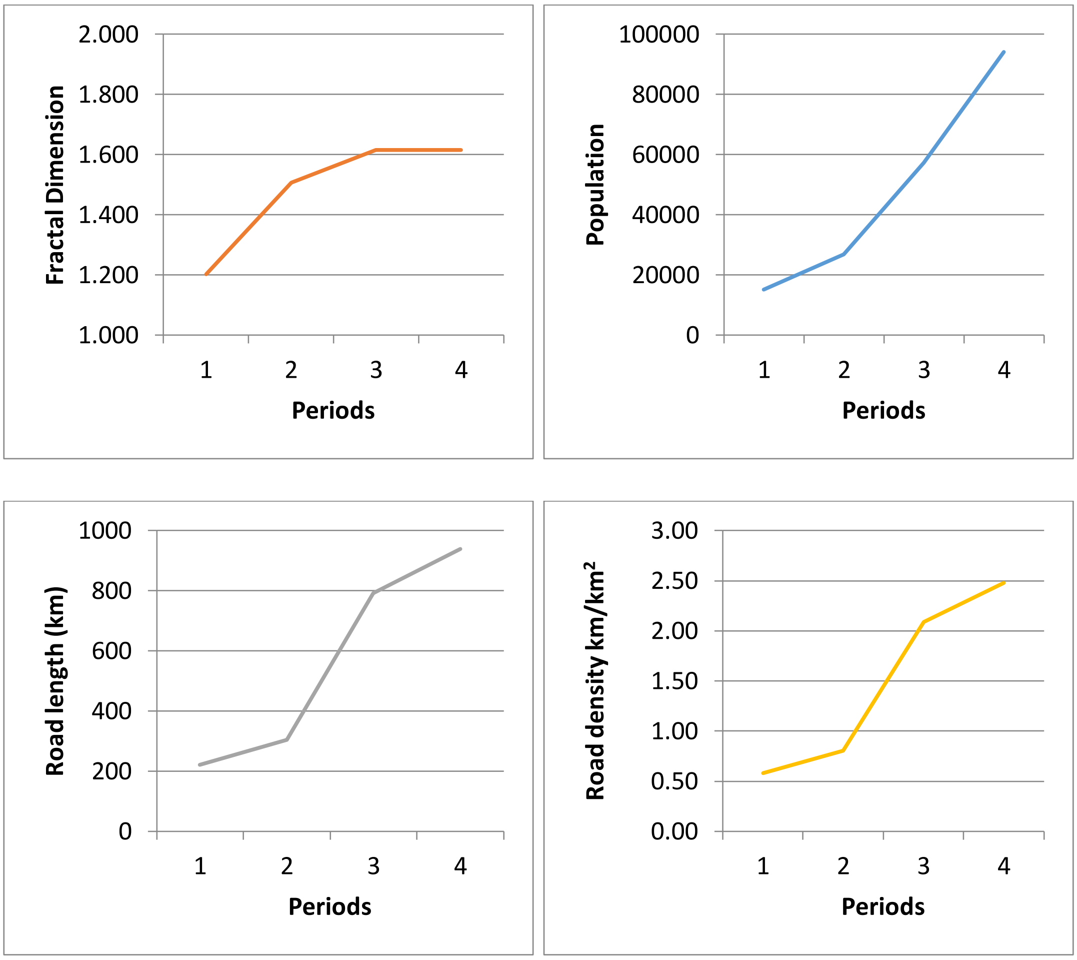



Figure 5-35 Population, road length/density and fractal dimension change for *Aliağa*

Similar to *Foça, Dikili* is a coastal town of small-scale tourism activity, secondary housing as well as seasonal or temporary retired population's destination. The most visible growth can be observed after the second period covering the time span of late 1990s. Densification of the network system continued during the last period with a moderate decrease mainly along the coast. The northern coastal line of *Dikili* also connects with *Ayvalık* which is a similar calm tourism destination of *Balıkesir* neighbor city.

The initial fractal dimension of *Dikili* is calculated “1,498” for the first period which is above the average fractal dimension of all districts and the whole İzmir region as; “1,206” despite the rural coastal character of the sparse network pattern. In the second period containing the time span as the second half of 1970s, value is slightly increased and calculated as “1,500.” Since the district developed in terms of touristic and secondary housing activities, fractal dimension increased to ”1,557” during the third period which is also higher than the mean fractal dimension of the districts, “1,521”. However, as a part of the system complexity of the district remained lower than the total since fractal dimension of the İzmir Region’s network is “1,819”. Similar to *Foça,* despite densification on the coastal parts, fractal dimension of the road network between 2012 and 2017 is decreased to “1,529” which is still above the mean of the all districts, “1,492” while below the İzmir Region’s fractal dimension; “1,724” (Figure 5-36).

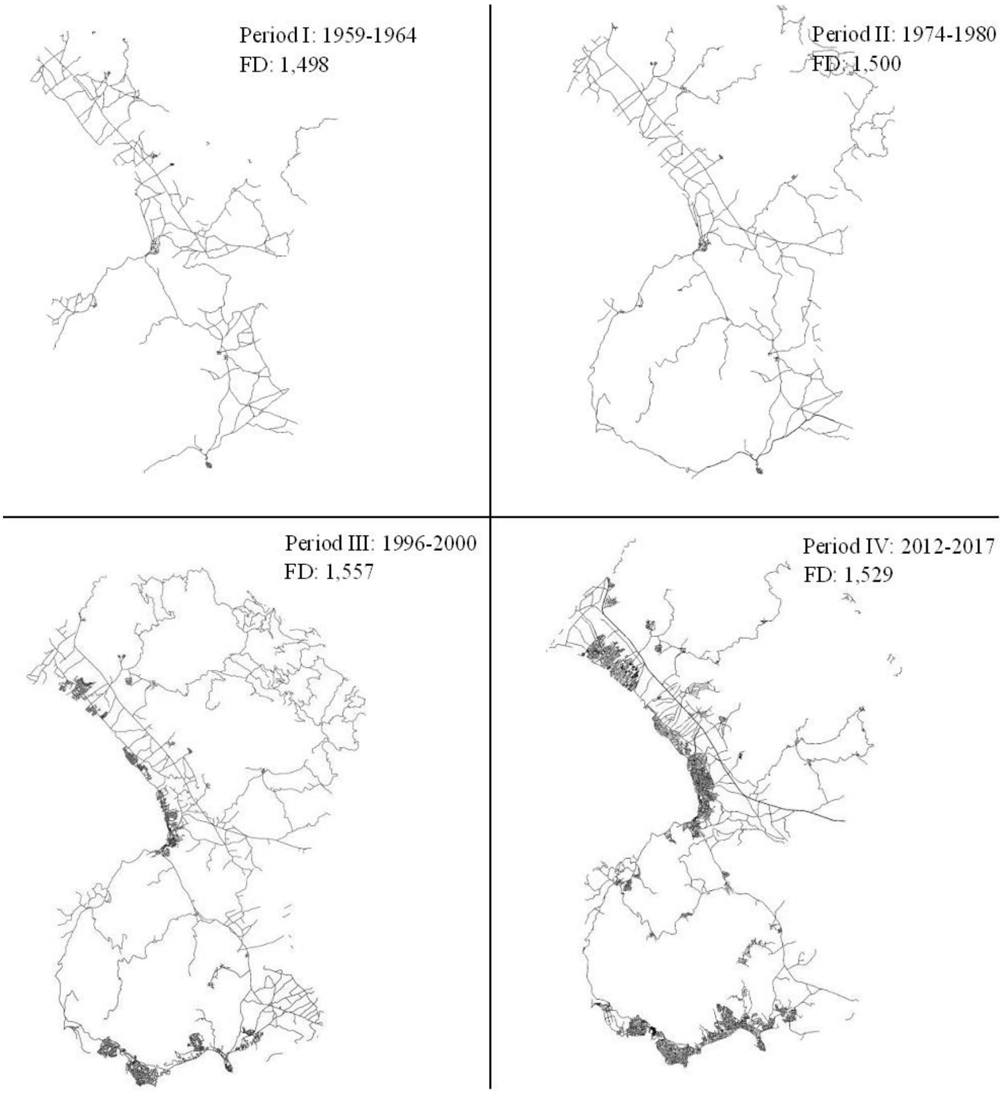



Figure 5-36 Fractal dimension change of Dikili District

Related to increased popularity of the district during 1990s, similar to other zones of *İzmir* like *Seferihisar, Selçuk, Foça* and *Karaburun,* the district gained population and population increase rate maintained its trend during following periods. The lowest population increase rate appeared in *Dikili* was determined between the first to second periods from 1960s to 1980. Similar to population increase trend, road length and density increased after the second period and moderated during the last period covering the time span between 2012 and 2017 (Figure 5-37).

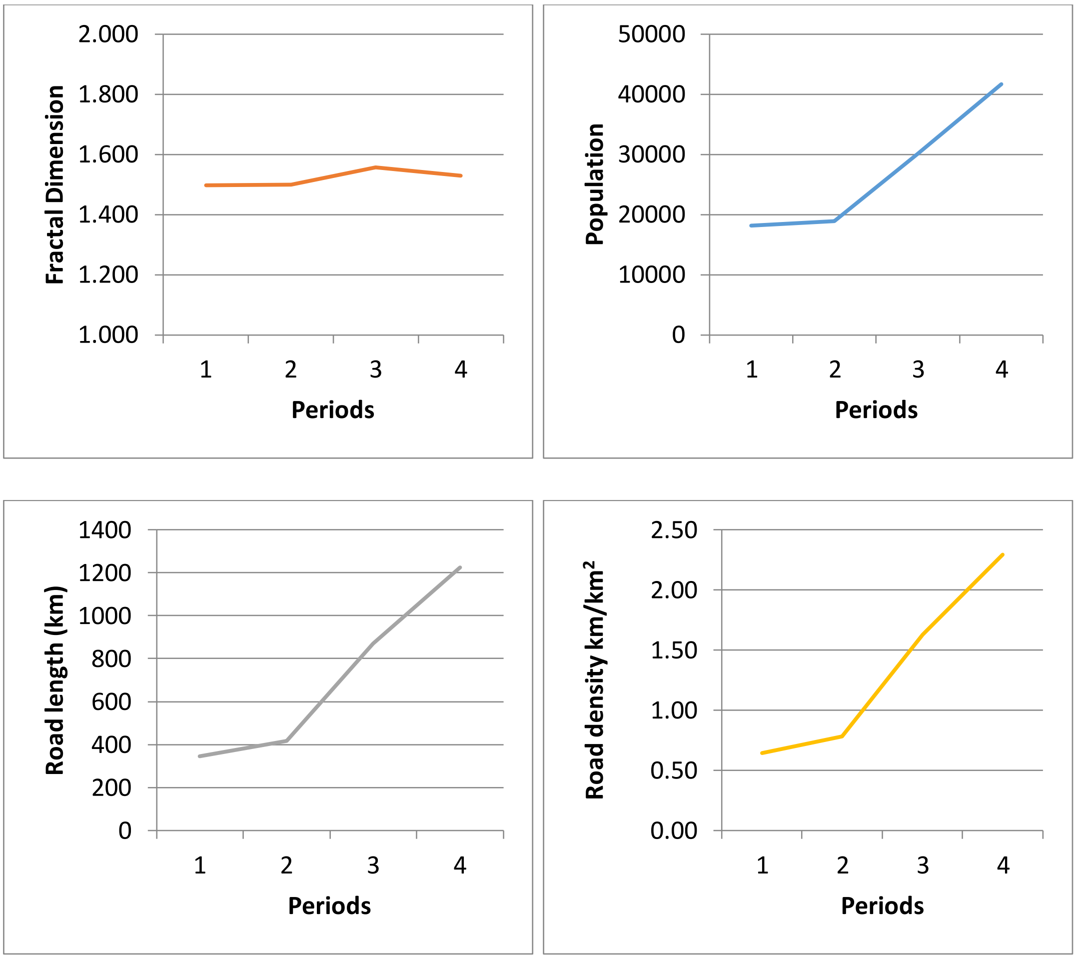



Figure 5-37 Population, road length/density and fractal dimension change for *Dikili*

*Bergama* is a multitude district and involving the largest rural population after *Ödemiş*. The complexity of the rural network including the cropland divisions demonstrates the complexity of the agricultural features of *Bergama*. The plain is fed by the *Bakırçay* River. Despite of the densification of the district center through the following periods, the rural network mainly has been conserved its character.

For the early 1960s determined as initial stage, fractal dimension of *Bergama* is calculated “1,500” which is above the mean value of districts and close to the value of the whole region’s fractal dimension which is “1,502”. For the second period, this value increased to “1,502” which is above the average fractal dimension of other districts “1,343“ of *İzmir* and below the whole systems’ fractal dimension “1,583”. A rapid increase is observed in the complexity level during the second half of 1990s since the fractal dimension increased to “1,590” which is one of the highest values among all districts. Fractal dimension value of *Bergama* stayed above the mean of the all districts during this period. However, in the fourth period covering the years between 2012 and 2017, fractal dimension decreased to “1,512” which is still above the mean value of districts (Figure 5-38).

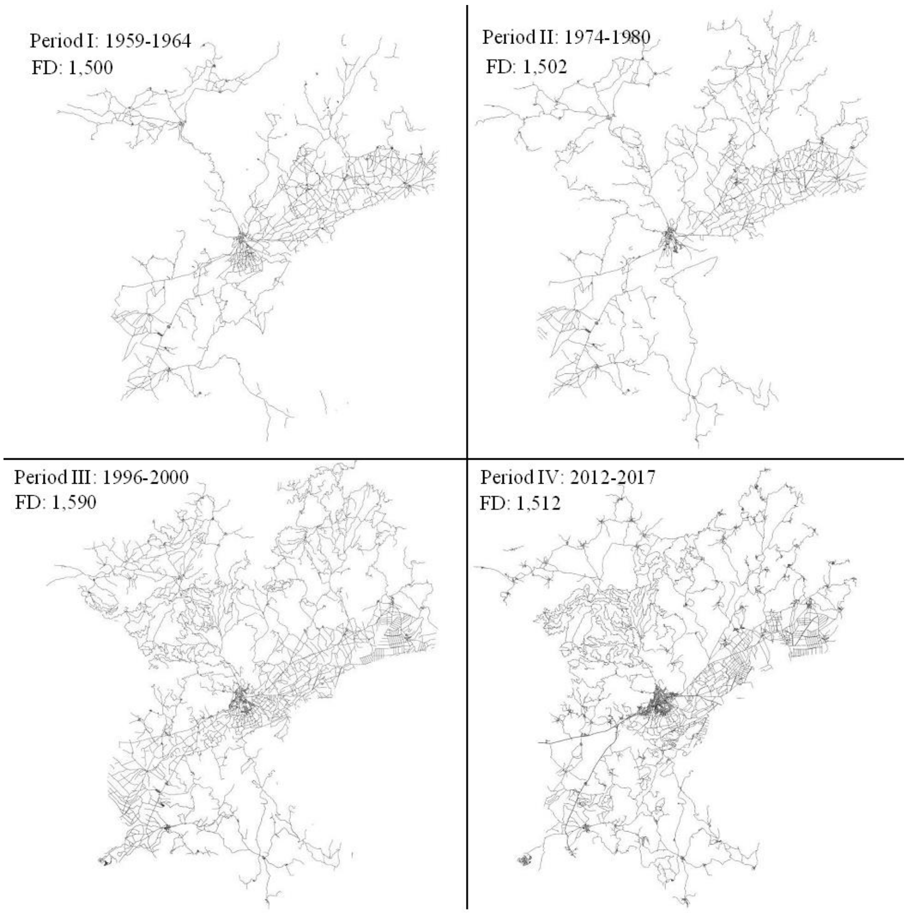



Figure 5-38 Fractal dimension change of Bergama District

Although main pattern of the network does not change over the periods, center of the district densified in terms of transportation network. Road network length and density sharply increased between the second and the third periods while increase rate decreased between the third and the last periods. Despite of the network development, *Bergama* lost population between the last two periods similar to other districts having rural character rather than urban functions (Figure 5-39).

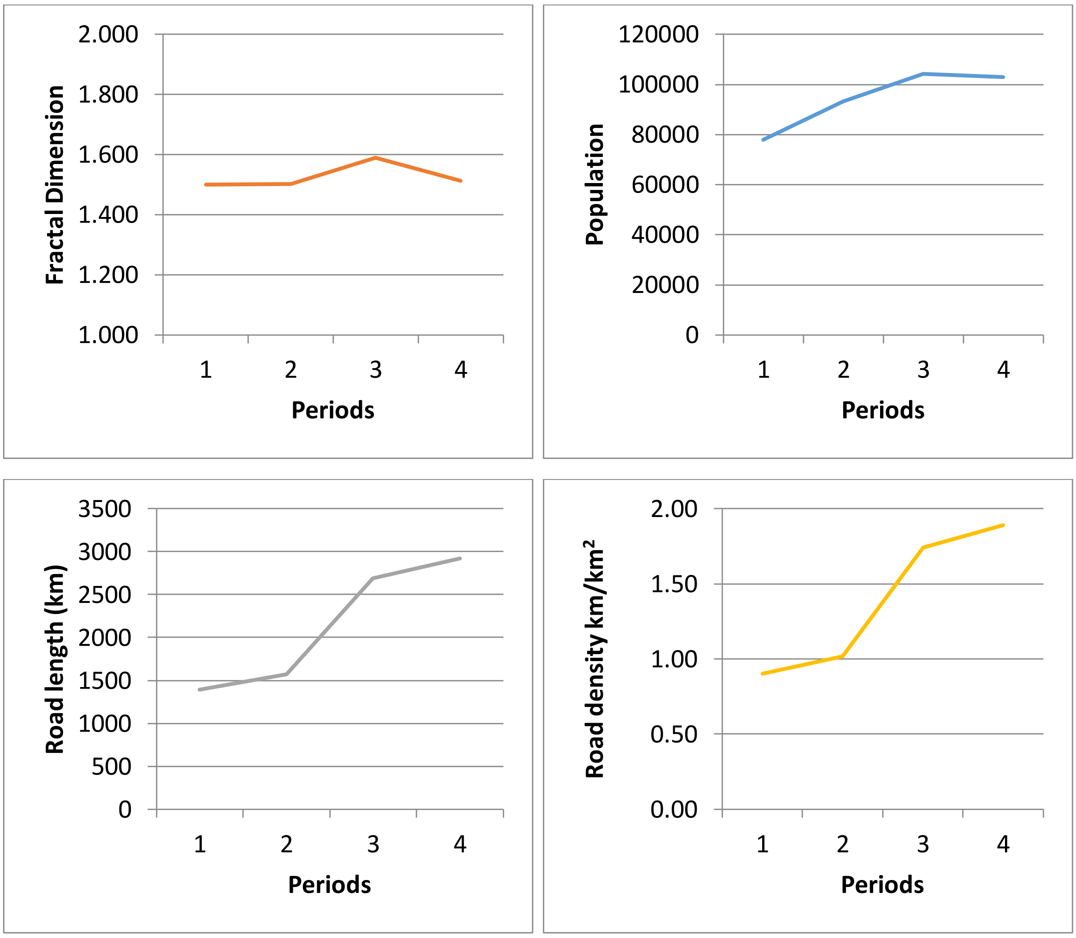



Figure 5-39 Population, road length/density and fractal dimension change for *Bergama*

The last district of the northern sub-region is *Kınık* which also have a rural character and agricultural network integrity with *Bergama*. The district is located on the southern part of the *Bergama* plain. The rural divisions are not observed in the road system during the last period covering the time span from 2012 to 2017. The other visual observation can be expressed as a little densification around the district center and a close village on the west of the district center *Poyracık.*

As observed from Figure 5-40, in the first initial period, fractal dimension of *Kınık* is calculated “1,507” which is above the mean fractal dimension of the districts and below the whole İzmir Region similar to *Bergama*. The value decreased to “1,274” for the time period from 1974 to 1980 which is still below the mean fractal dimension value, “1,374” and the total network “1,581”.  The decrease can be observed as a result of the loss in low-degree road structure which expresses agricultural sub-divisions. The network again enriched during the third period which resulted in the increase in fractal dimension to “1,655”. Due to the similar reason, during the second period, fractal dimension of the network system again decreased to “1,522” in the fourth period which is above the district’s average, “1,492” and the whole İzmir Region’s values which is “1,724”.

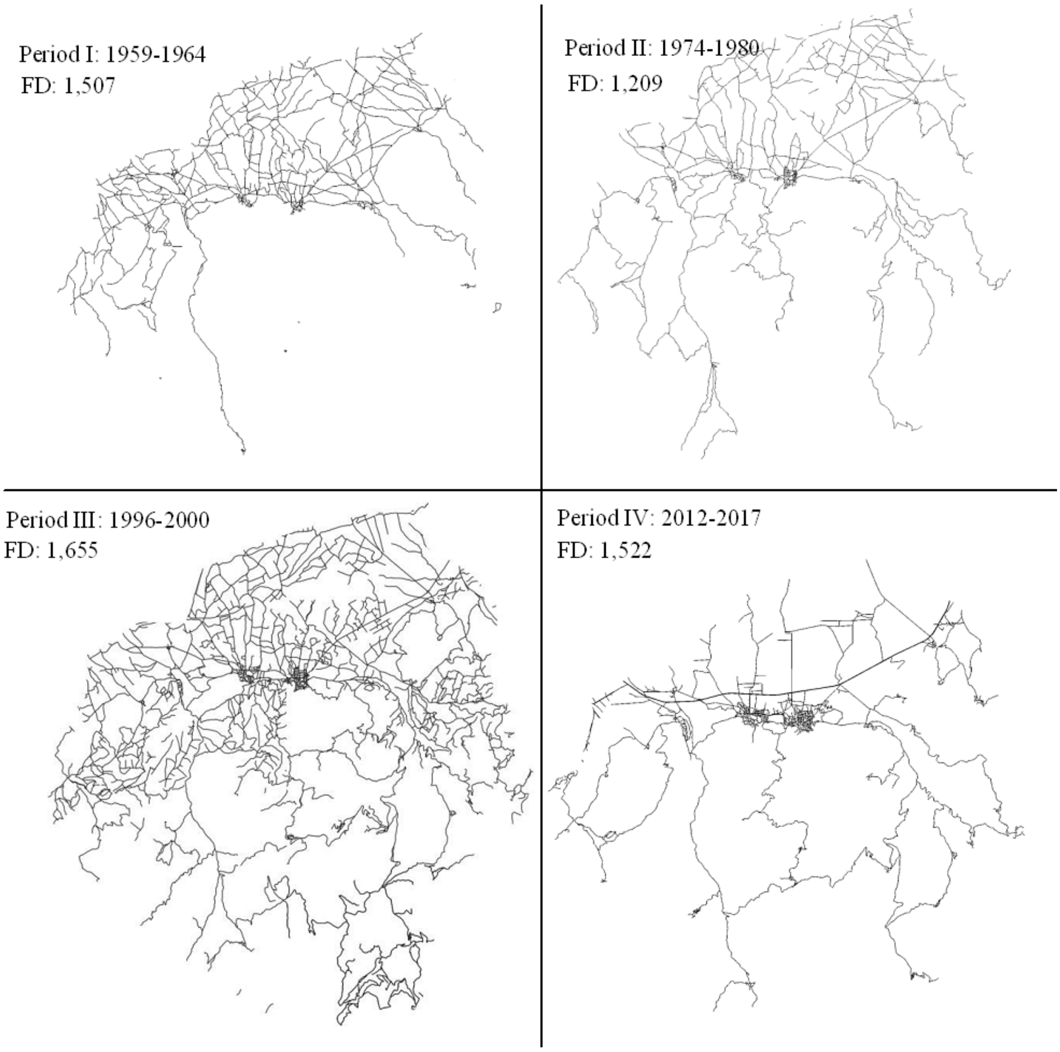



Figure 5-40 Fractal dimension change of Kınık District

Decline in rural areas involving agriculture based settlements can be observed in *Kınık* in terms of population change. The district is one of the seven districts subjected to population loss between the third and fourth periods. Population density has decreased even there exists network and population development until 1990s. Total road length and density also declined due to loss in agriculture based dirt road network (Figure 5-41).

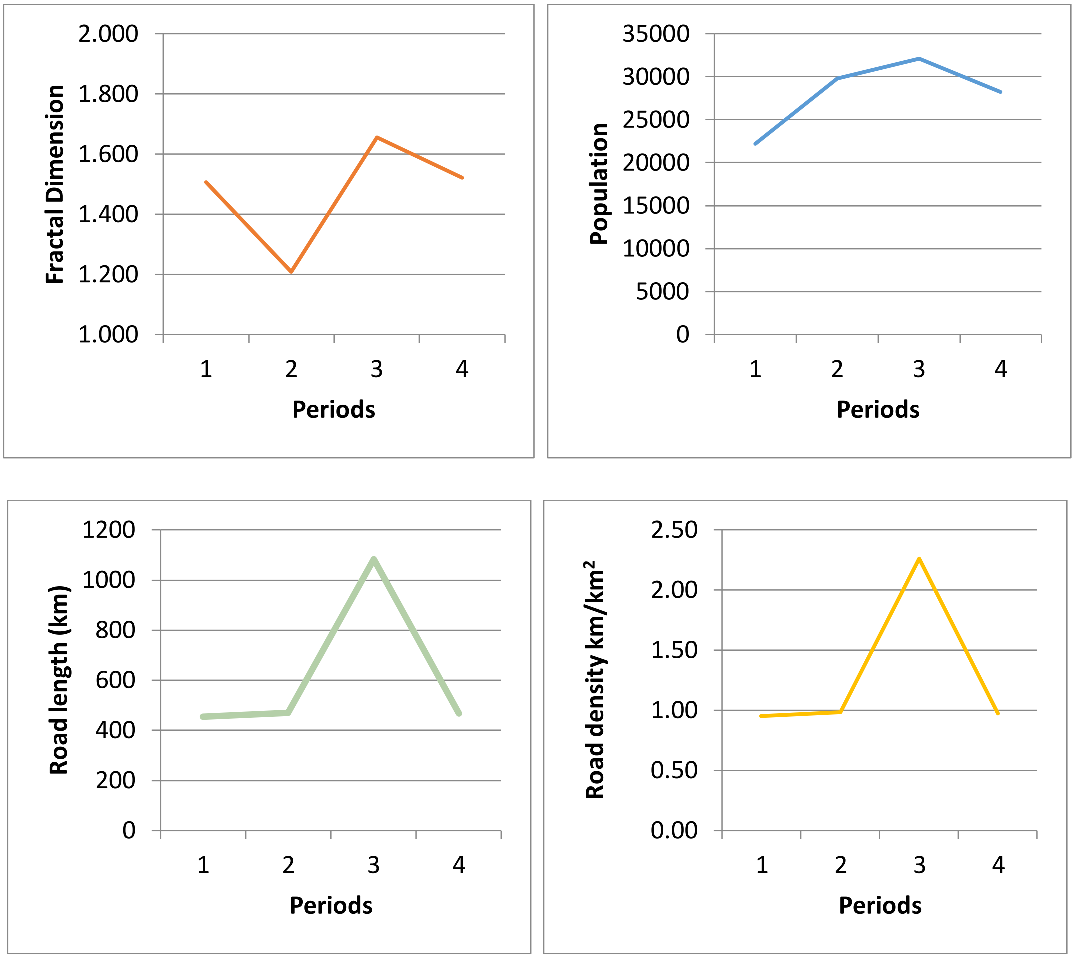



Figure 5-41 Population, road length/density and fractal dimension change for *Kınık*

### 5.3.4 The Eastern sub-region

The eastern sub-region is characterized as an agricultural network zone consisting of rural centers and villages. For this reason, network of the eastern sub-region possess cropland divisions rather than urbanized road system. This is a result of the ecosystem of plains enriched by the *Küçük Menderes* river. Despite of the the agricultural potential, the plains also took advantage of industrial and peripheral urban development due to low infrastructure cost in recent decades. Districts in the northern sub-region can be specified as, *Kemalpaşa, Bayındır, Tire, Ödemiş, Kiraz* and *Beydağ.*

The first district of the eastern sub-region is *Kemalpaşa* district frames metropolitan *İzmir* from the east. Due to its proximity to central core, agricultural character of *Kemalpaşa* evolved into industry and services. Increased density in network as well as development of nodal agglomerations can be observed within the third period.

For the first period (1959-1964), fractal dimension value of *Kemalpaşa* is above the average fractal dimension of all districts and the whole İzmir region as; “1,505”. In the second period impliying the second half of 1970s, the value is quite similar and calculated “1,511.” Although the district developed in terms of peripheral activities, fractal dimension decreased to ”1,495”. In the third period fractal dimension stay below the mean fractal dimension of the districts, “1,521” and accordingly below the fractal dimension of the İzmir Region’s network which is “1,819”. In the last period further development of the district including industrial quarters, between 2012 and 2017 the value is increased to “1,526” which is still above the mean of the all districts, “1,492” while below the İzmir Region’s fractal dimension; “1,724” (Figure 5-42).

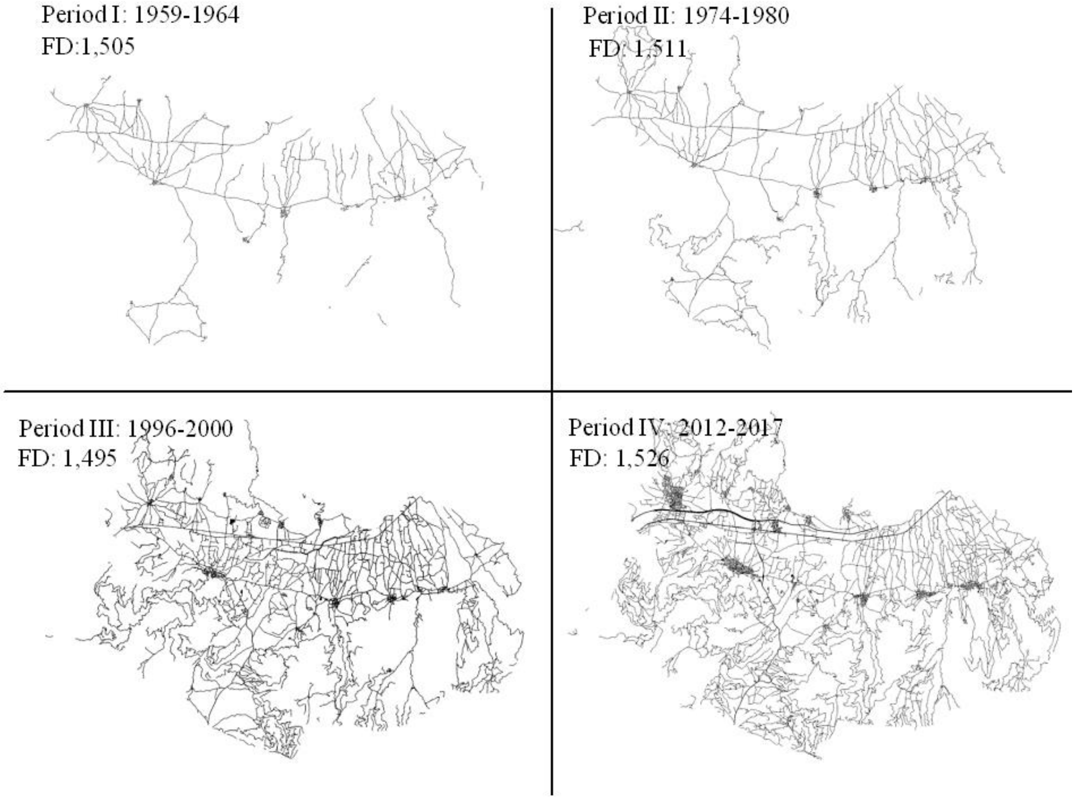



Figure 5-42 *Fractal dimension change of Kemalpaşa District*

The change of fractal dimension, population and road network is observed in Figure 5-43. As observed visually length and density of the road network of *Kemalpaşa* increased continuously during all periods. The rapid development in terms of network growth is observed between the second and third periods then the rate has started to decrease after 2000. On the other hand, population growth continued by preserving the trend in the third and the last periods. In the last period, *İstiklal* neighborhood grew as much as the district center due to development of industrial based corridor development along *Manisa-Turgutlu* road.

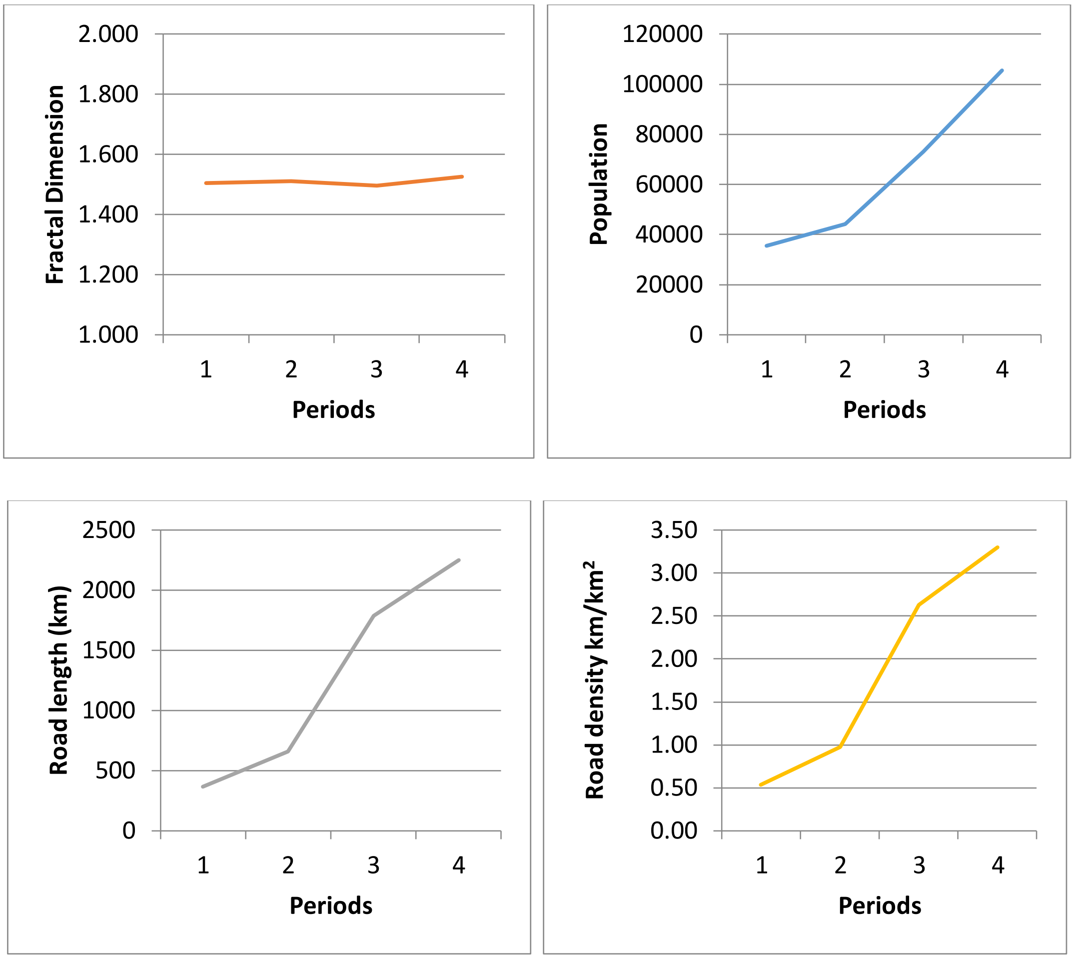



Figure 5-43 Population, road length/density and fractal dimension change for *Kemalpaşa*

The other district of the eastern sub-region is *Bayındır,* which fits the agricultural character of the sub-region. In the initial period, *Bayındır* has the lowest fractal dimension value which is calculated "1,062". By the increase of vertical connections the value increased to 1,508 in the second period covering a time span from 1974 to 1980. Despite of the further growth in the road system fractal dimension value decreased to "1,495" in late 1990s and increased again in the last period and reached to "1,528" (Figure 5-44). In the first and the third periods, fractal dimension of *Bayındır* is below the mean value of other districts. As a part of the system, complexity level always remained below the fractal dimension of whole İzmir Region which are; “1,502”, “1,581”, “1,819” and “1,724” respectively.

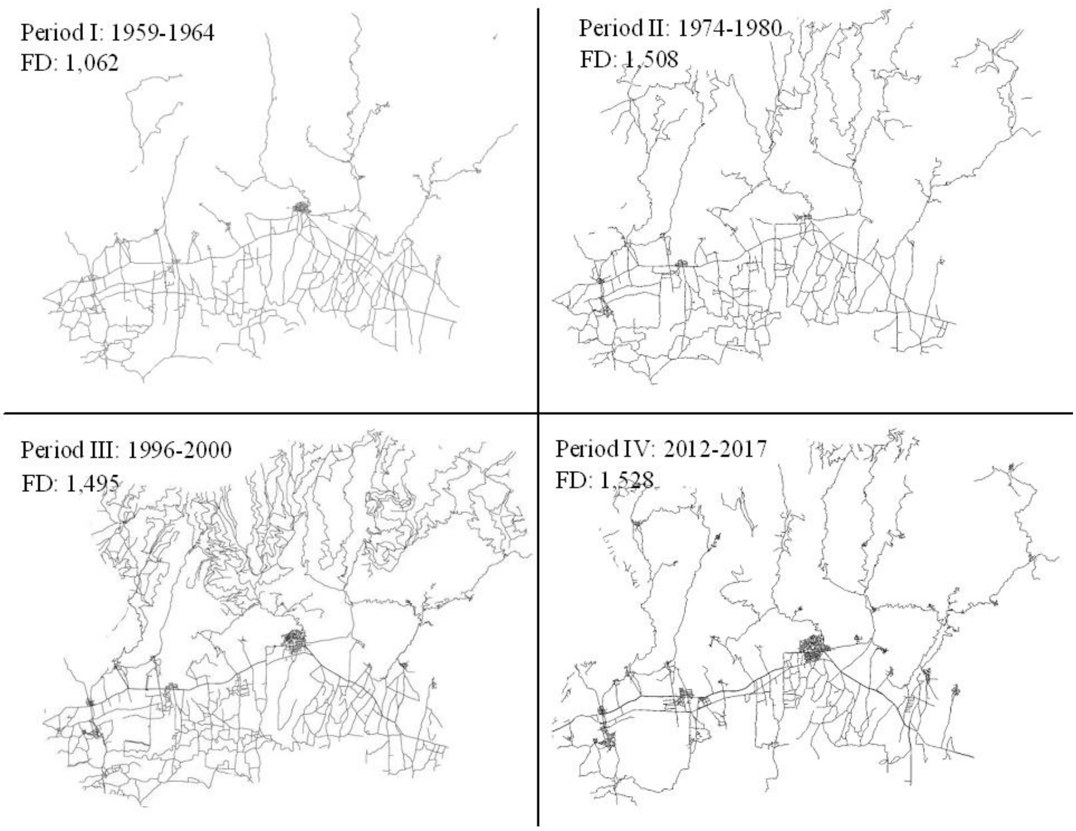



Figure 5-44 Fractal dimension change of Bayındır District

Population loss of the district can be easily observed similar to other districts having a dominant rural character. For the first period, *Bayındır* is the fifth most populous district after the central core but it decreased to the last 10 districts for the last period. Negative growth rate in population can also be observed in road network length like observed in *Kınık* (Figure 5-45). The gradual evanescence of the network can be interpreted as the consequence of cropland and farmer population loss.

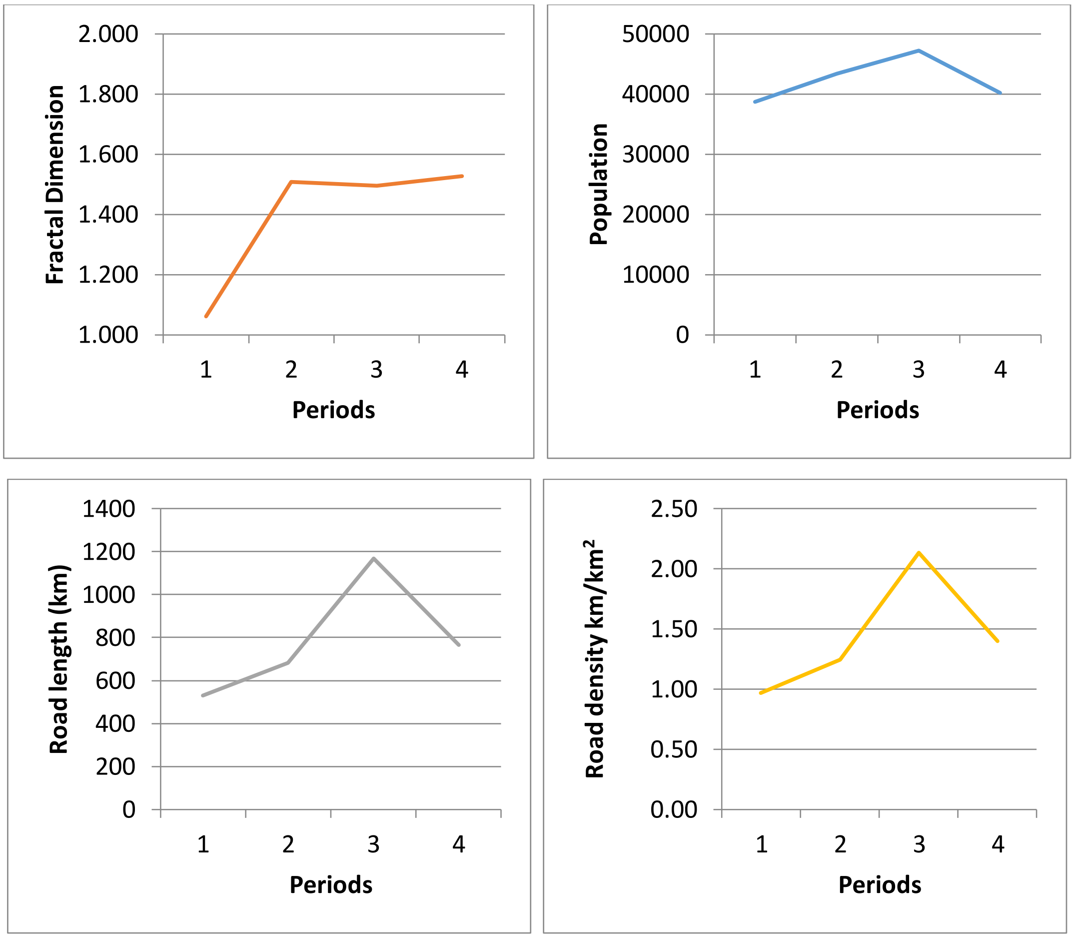



Figure 5-45 Population, road length/density and fractal dimension change for *Bayındır*

The other district presenting rural character is *Tire*, whose plain is fed by the *Küçük Menderes River*. In addition to organized industrial zone, *Tire has been* known as cooperative of dairy products since late 1960s which has started to develop for the last two decades. The fractal dimension and network change of the district is presented in Figure 5-46. The initial fractal dimension of the district is calculated "1,506" for the first period covering a time span from 1959 to 1964. This value is both above the fractal dimension of the mean fractal dimension of all districts and the whole İzmir Regions' fractal dimension which are "1,313" and "1,502". In the second period, network growth resulted in the decrease of complexity level since fractal dimension of the district decreased to "1,215" which is both below the average fractal dimension of districts, “1,343” and the İzmir’s total network, “1,581”. In the third period fractal dimension increased again to “1,500” which is still below the average fractal dimension of districts, “1,521” and the whole system “1,819”. The flourish of the network determined in late 1990s diminished during the last period while fractal dimension of the district’s network increased to 1,524”. This value is above the mean fractal dimension of all districts, “1,492” while below the value of the whole system “1,724”.

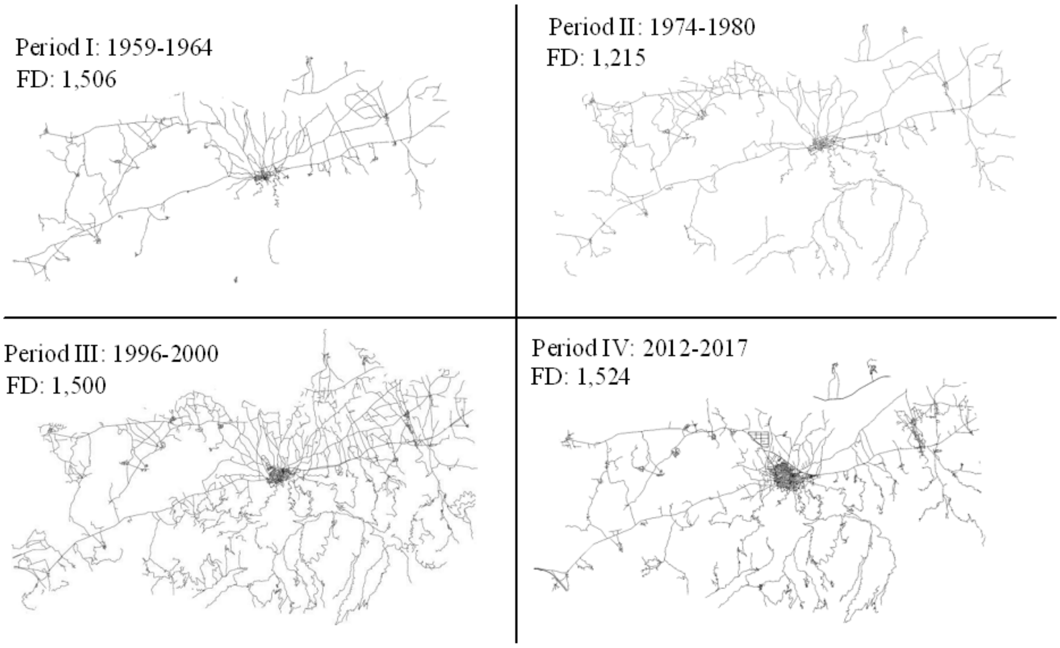



Figure 5-46 Fractal dimension change of Tire District

Since economy of *Tire* has been nourished by industry and organized agricultural production, a steady increase in population can be observed. However, population increase rate decreased after 2000. Similar to *Kınık* and *Bayındır,* the district lost road network by the last period due to decrease in dirt roads. *Tire* is the third district subjected to the longest road network district between the third and the last periods after *Kınık* and *Bayındır.* Population, road network length and fractal dimension change of *Tire* is observed in Figure 5-47.

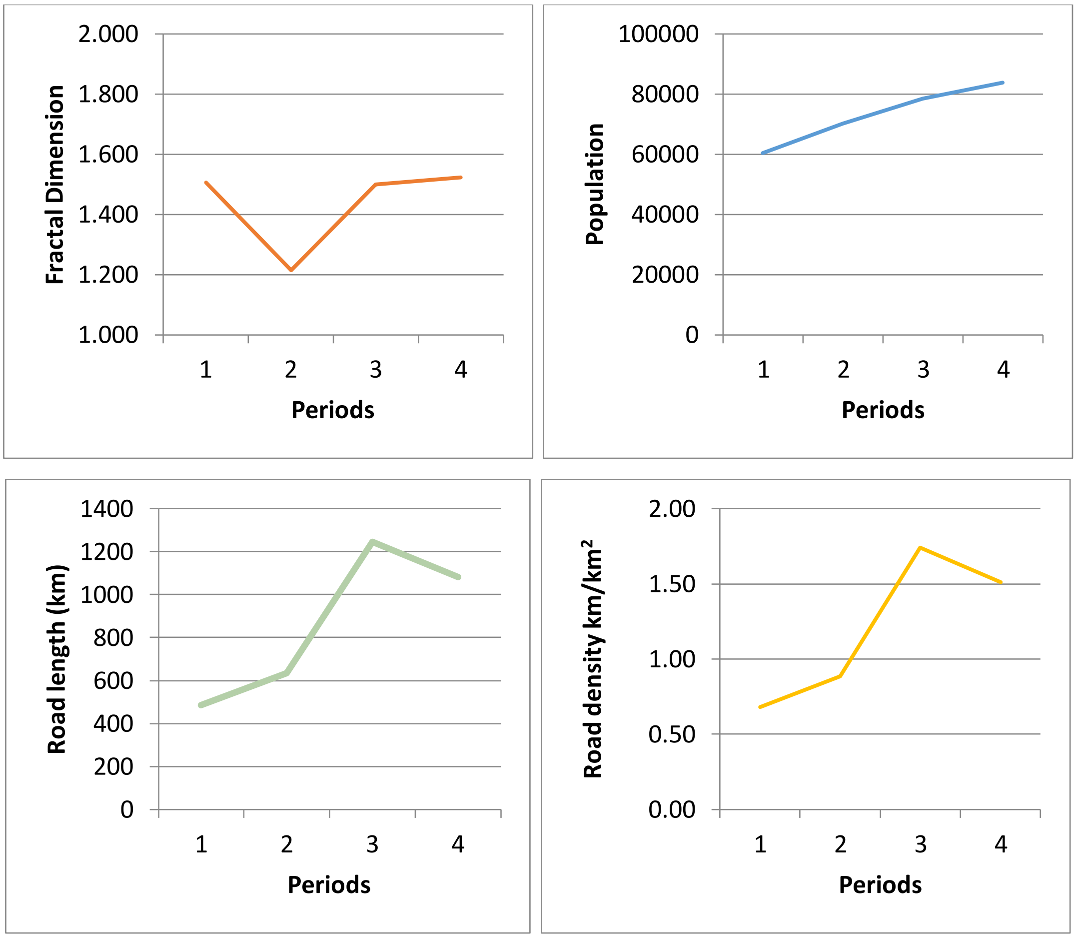



Figure 5-47 Population, road length/density and fractal dimension change for *Tire*

*Ödemiş* is another district having rural character involving the largest rural population ratio among all districts. The district is a part of the *Küçük Menderes Basin*. The initial structure between 1959 and 1964 has a fractal dimension above the average dimension value of all district and the whole districts by "1,518". In the second period, fractal dimension decreased to "1,511" which is above the mean value of districts "1,343"whereas below the İzmir Regions' fractal dimension "1,581". Despite of the the growth in network, fractal dimension of *Ödemiş* district decreased to "1,486" in the third period which is both below the mean fractal dimension of districts "1,521" and İzmir Region's value "1,819". The last period complexity of the system again increased and the dimension is calculated as

“1,514” close to the values of the first and the second periods. This value exceeded the mean value of other districts “1,492” while below the whole İzmir Regions’ fractal dimension “1,724“ like all other districts (Figure 5-48).

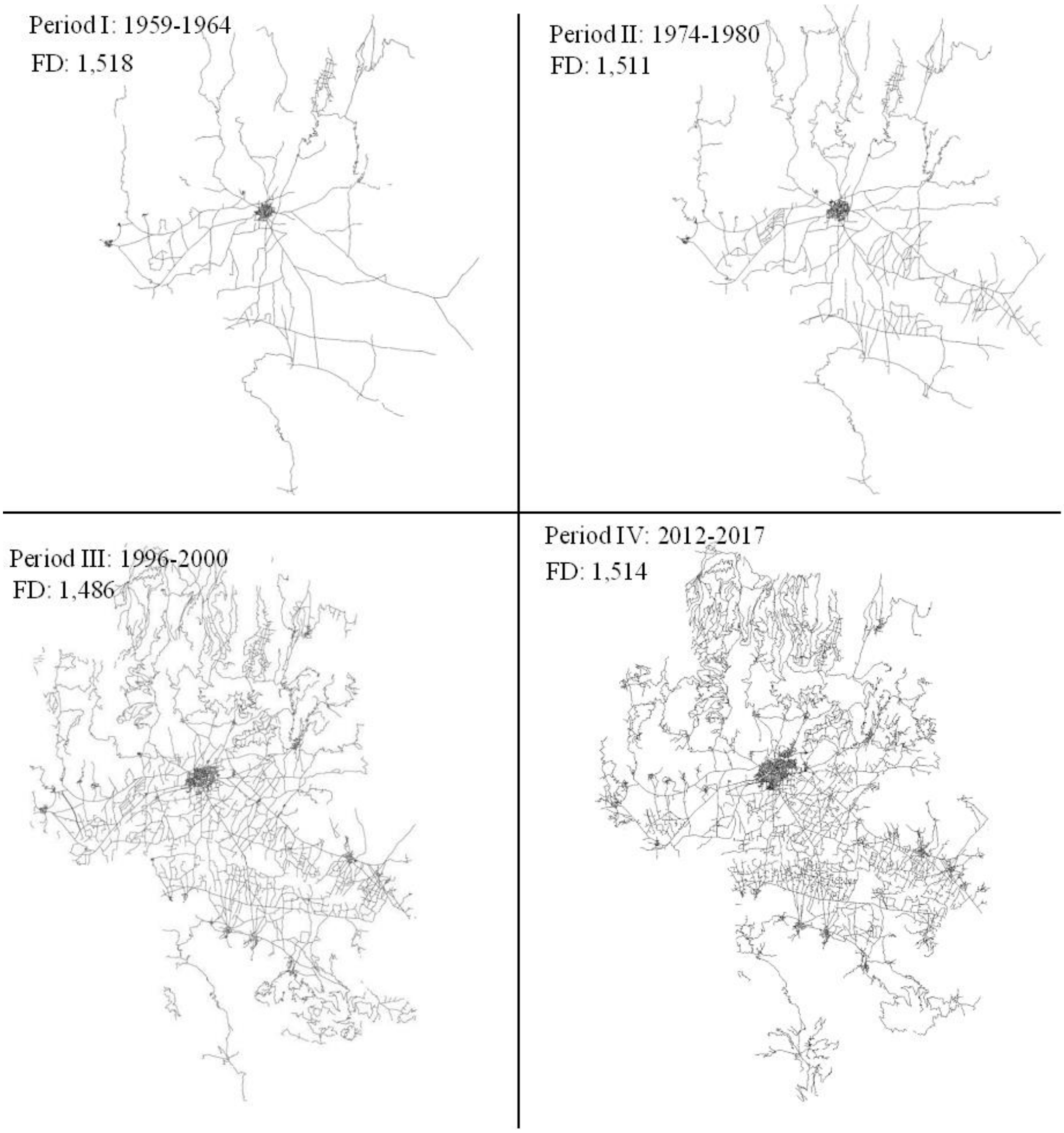



Figure 5-48 Fractal dimension change of Ödemiş District

When the road network length, density and population are examined (Figure 5-49), it is observed that growth rate of the road length and density reaches to the highest value for the second and third periods. On the other hand, population growth rate comparatively decreased after the third period similar to other districts having rural dominant character.

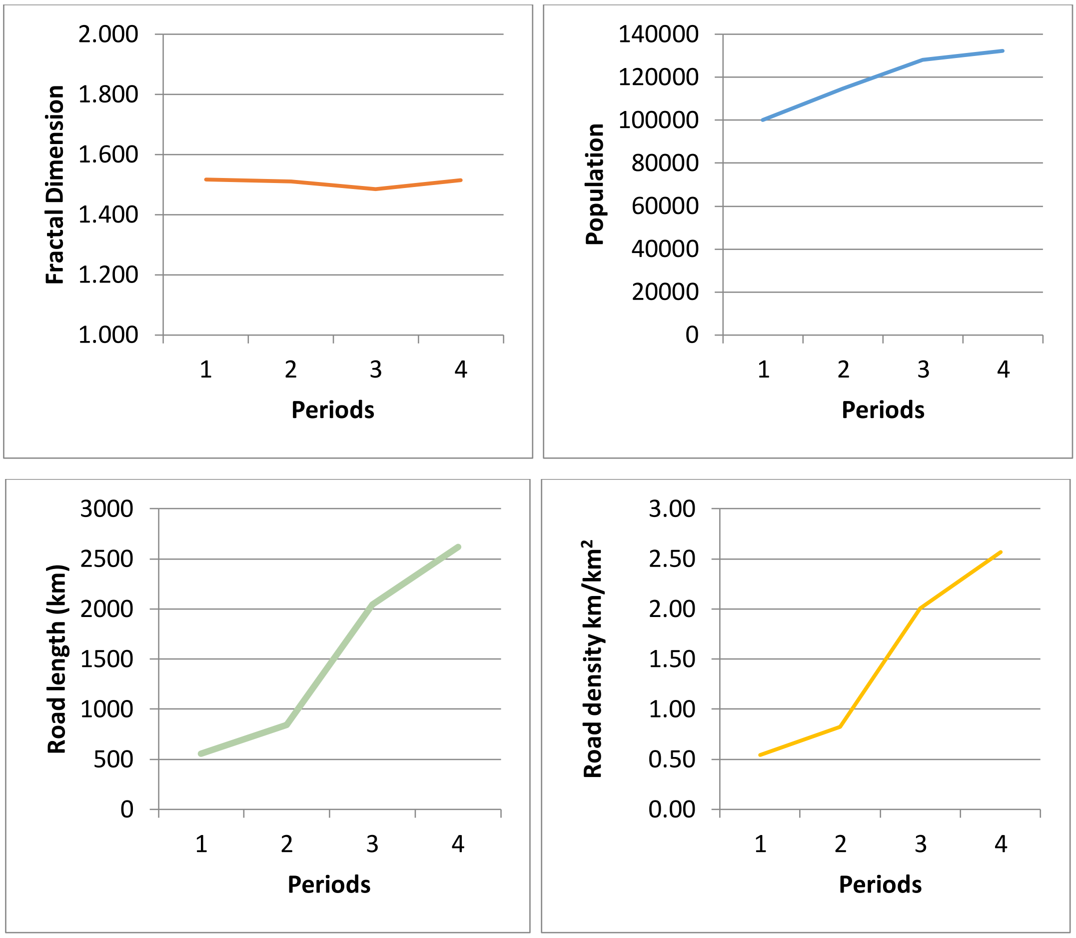



Figure 5-49 Population, road length/density and fractal dimension change for *Ödemiş*

*Kiraz* is the other rural district having the lowest ranking in terms of socioeconomic development among all districts since it is the only district of *İzmir* categorized in the fourth development stage by the State Planning Organization (2004). The fractal dimension change of the district is presented in Figure 5-50. The initial fractal dimension of the district's network is calculated "1,538" which is the second highest value among all districts both above the mean fractal dimension of all districts and the İzmir Regions' value. In the second period, growth in the network resulted in a lower fractal dimension which is “1,497”. In late 1970s, the fractal dimension value exceeded the mean of all districts “1,343“ while calculated below the *İzmir’*s fractal value which is “1,581”. In the third period covering the time span from 1996 to 2000, fractal dimension increased to “1,551” which is again above the mean of all districts “1,521“ while below the whole İzmir Regions’ value “1,819“. In the last period some degree of growth in dirt roads are added to the system which resulted in a decrease in complexity by a fractal dimension of “1,513”. Complexity of *Kiraz* exceeded the average fractal dimension value in the last period as well.

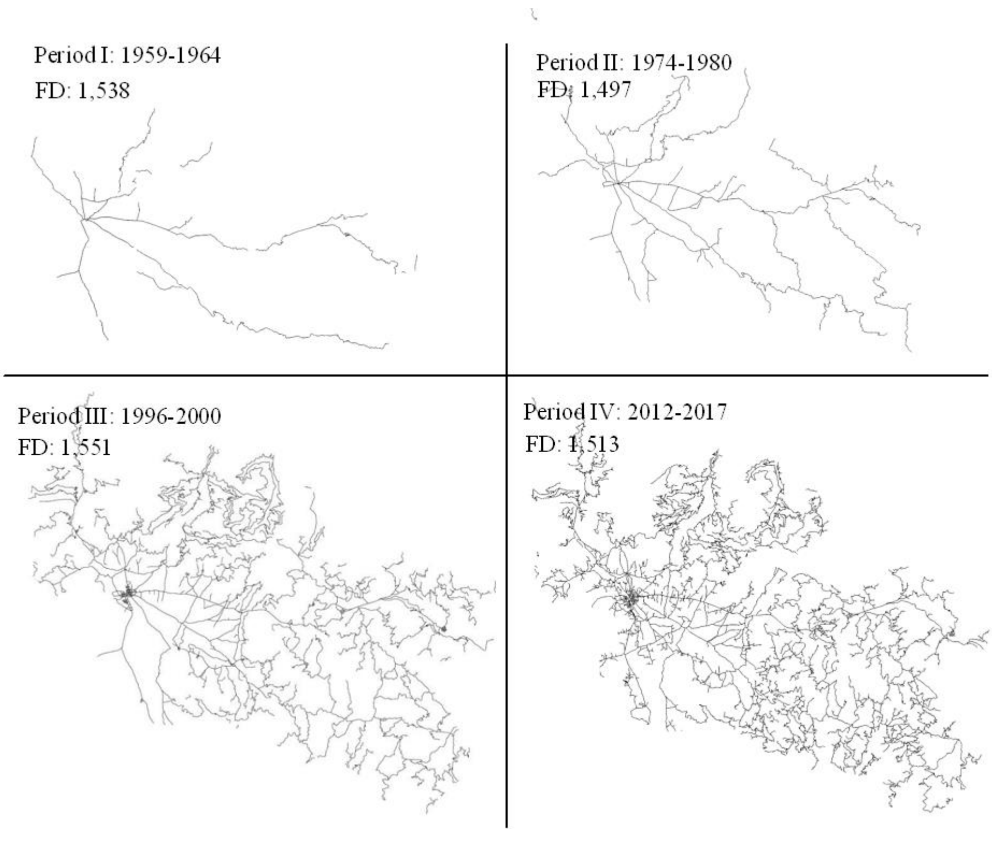



Figure 5-50 Fractal dimension change of Kiraz District

The steepest increase in the road length and density is observed between the second and third period. In 2000s, the road network development has been continued while population declined with a negative growth rate similar to pure rural districts (Figure 5-51).

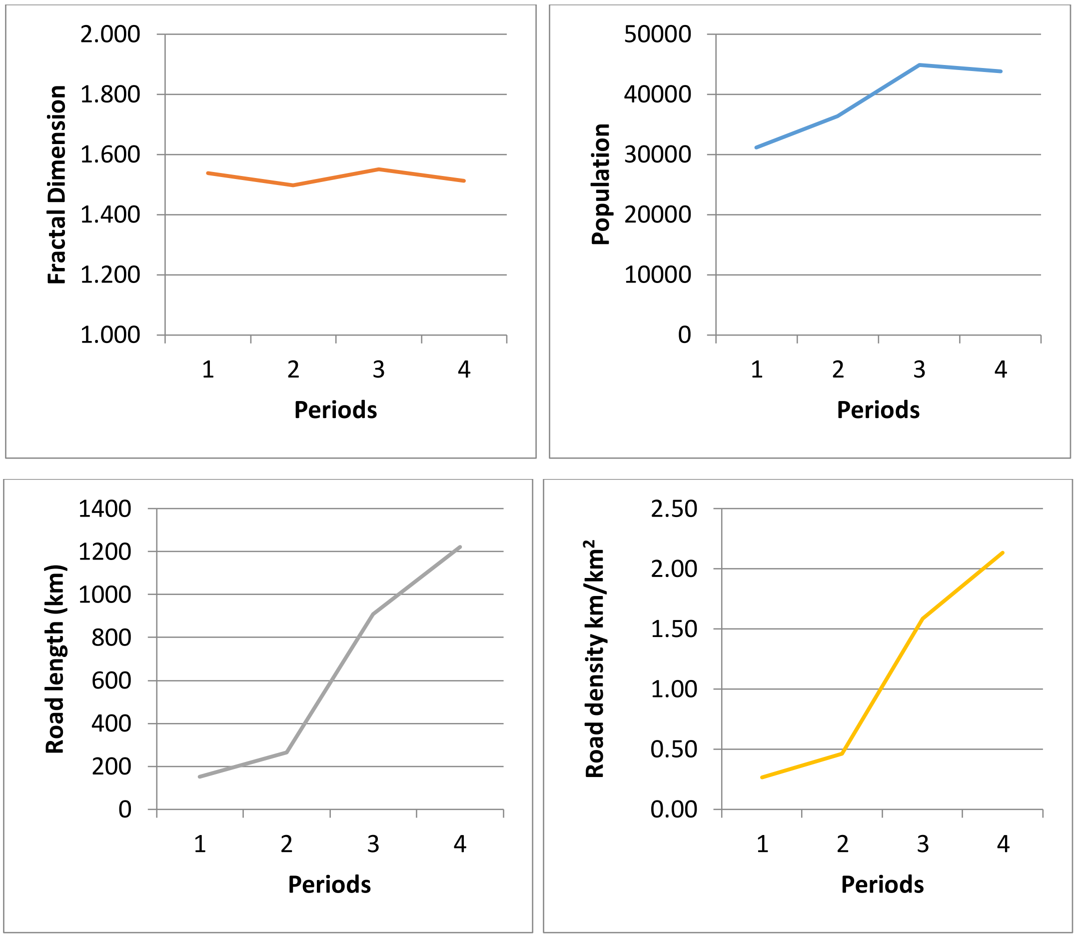



Figure 5-51 Population, road length/density and fractal dimension change for *Kiraz*

*Beydağ* is the furthest district to the central core in terms of geographical distance. The district is closer to the city of *Aydın* than *İzmir.* Similar to *Kiraz* and *Ödemiş*, the district is characterized by a fertile plain fed by the *Küçük Menderes River.* In first two periods, fractal dimension is calculated relatively low for *Beydağ* with respect to other districts. The initial fractal dimension covering the time span from 1959 to 1964 calculated as "1,049" and "1,001" from mid-1970s to 1980 which are the lowest values. In the third period fractal dimension increased to "1,489" that the district center can be firstly visualized by the network system. The value is still below the mean fractal dimension of all districts which is “1,492”. In the fourth period, fractal dimension of *Beydağ* decreased to “1,233” which is again the lowest value among all districts (Figure 5-52).

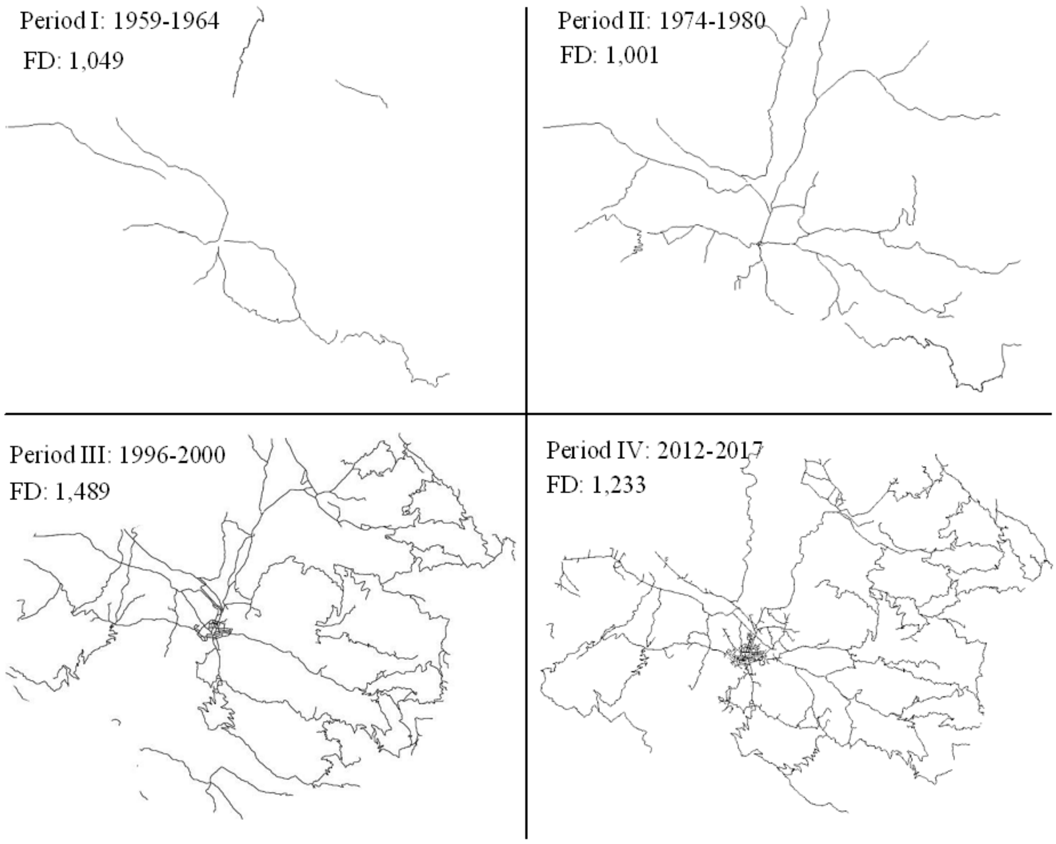



Figure 5-52 Fractal dimension change of Beydağ District

The road length and density continuously increased while the sharpest increase is observed between the second and the third periods. Like some rural districts population of *Beydağ* decreased between the third and the last period (Figure 5-53). Meanwhile *Beydağ* is the only district having negative population growth rate between the second and the third time periods. In other words, population decline has started in *Beydağ* in 1990s.

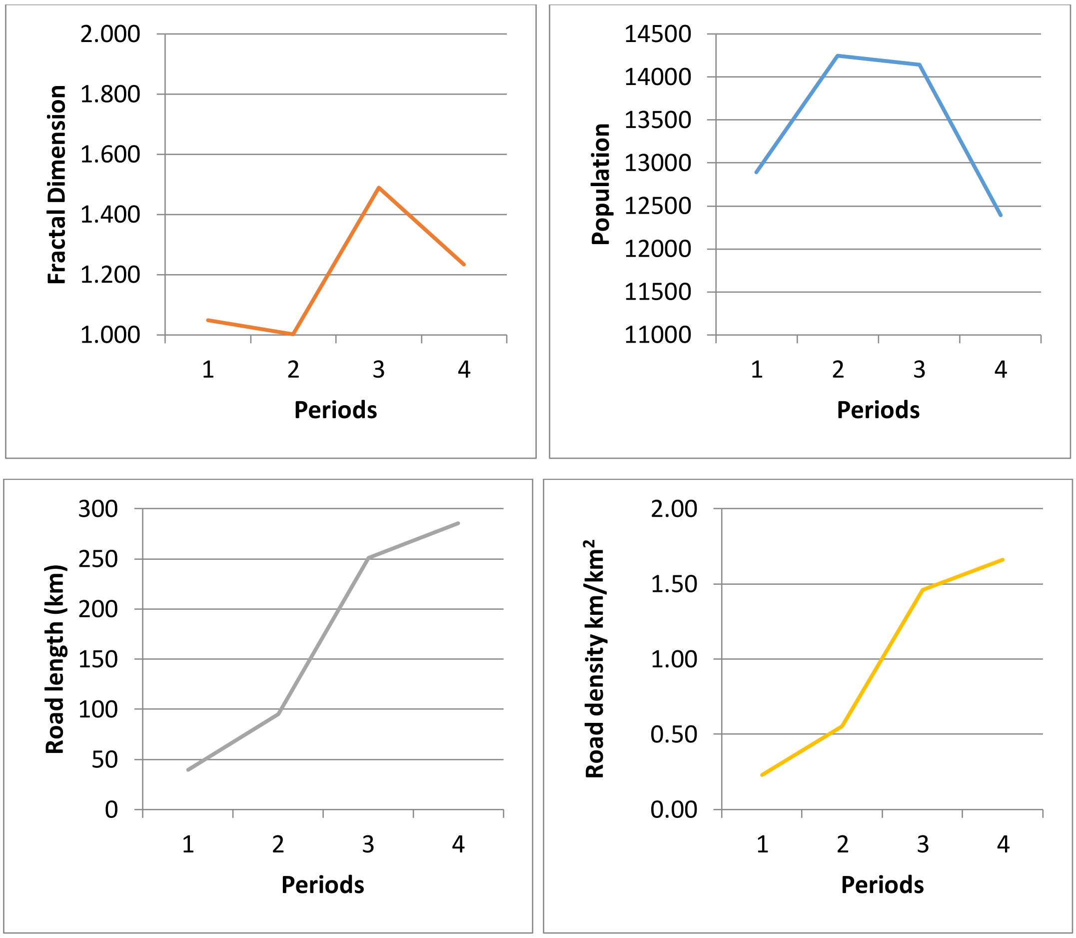



Figure 5-53 Population, road length/density and fractal dimension change for *Beydağ*

### 5.3.5 The Southern sub-region

The southern sub-region is consists of *Torbalı, Selçuk, Menderes* and *Seferihisar* districts. These districts present different character that lie the northern, the southern sub-region has heterogeneous characteristics involving industrial activity, agricultural production, tourism destinations and coastal calm towns.

*Torbalı* is a peripheral district of the metropolitan *İzmir* having peripheral land uses like other districts surrounding the central core. Rural modes of production continue in the villages, also industrial firms prefer to locate along motorway and railway network. Due to mobility advantages, the district became a commuter's zone as well. In the initial period, fractal dimension is calculated "1,515" for *Torbalı* which exceeds the mean fractal dimension of districts "1,313" and the whole regions' "1,502". For the second period, this value does not solely change and it is determined as "1,502" which is still above the average fractal dimension of separated districts "1,343" while below the whole systems' dimension "1,581". In the third period covering a time span from 1996 to 2000, fractal dimension of *Torbalı* reaches to the highest value as "1,553". Despite of the increased complexity, fractal dimension of the district remained below the whole regions' value "1,819". In the last period after 2012, fractal dimension decreased to "1,533". Similar to the third period, value is below the whole İzmir Regions' fractal dimension "1,724"and above the mean value of the fractal dimension of all districts "1,492" (Figure 5-54).

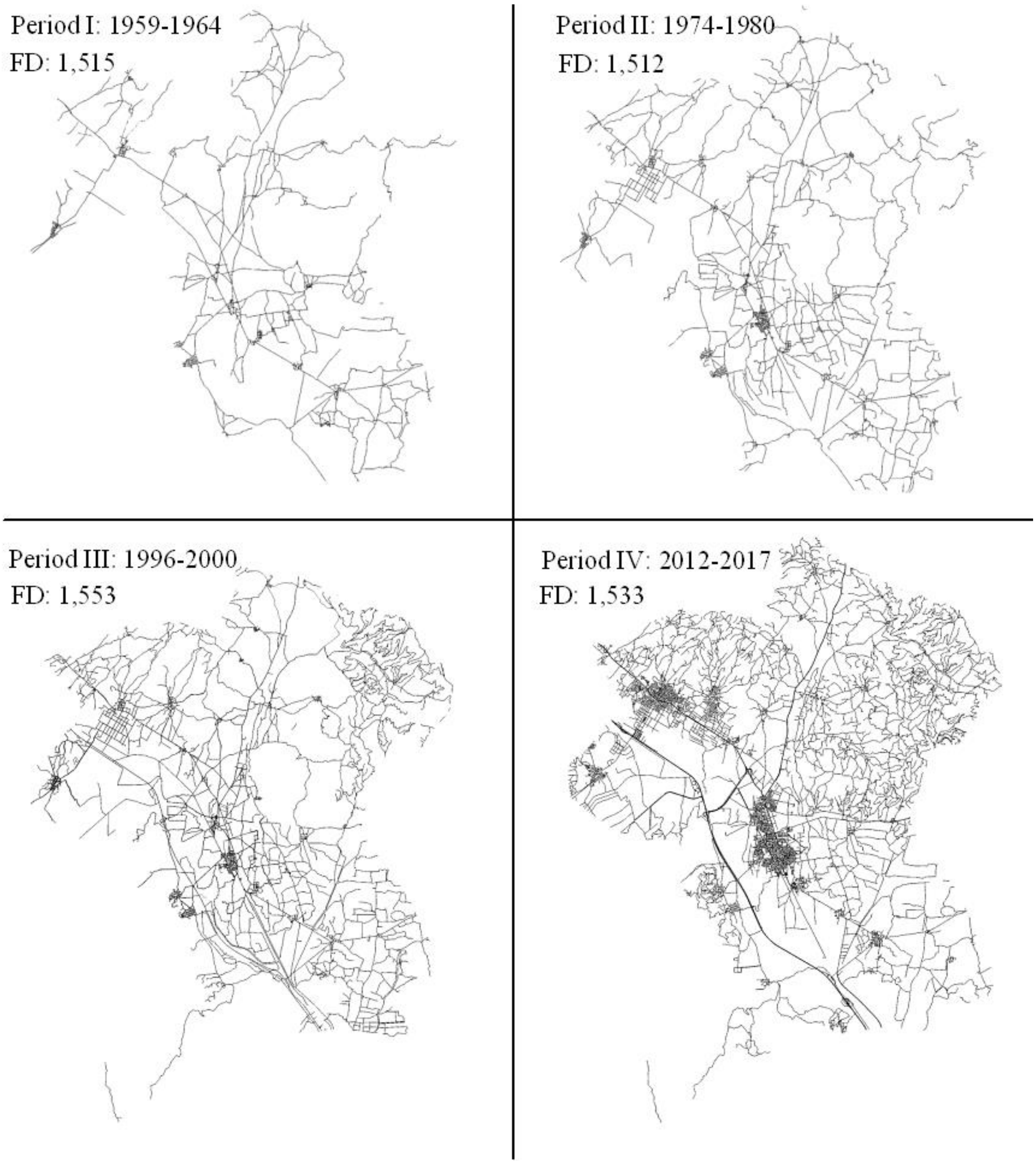



Figure 5-54 Fractal dimension change of Torbalı District

Beginning from mid 1970s, a stable growth rate of the network length of *Torbalı* can be observed. A continuous population growth rate can be observed as well. Furthermore, the highest population growth rate is observed in the last period unlike other peripheral or remote districts. The highest population growth rate is observed between the third and the fourth periods among all districts (Figure 5-55).

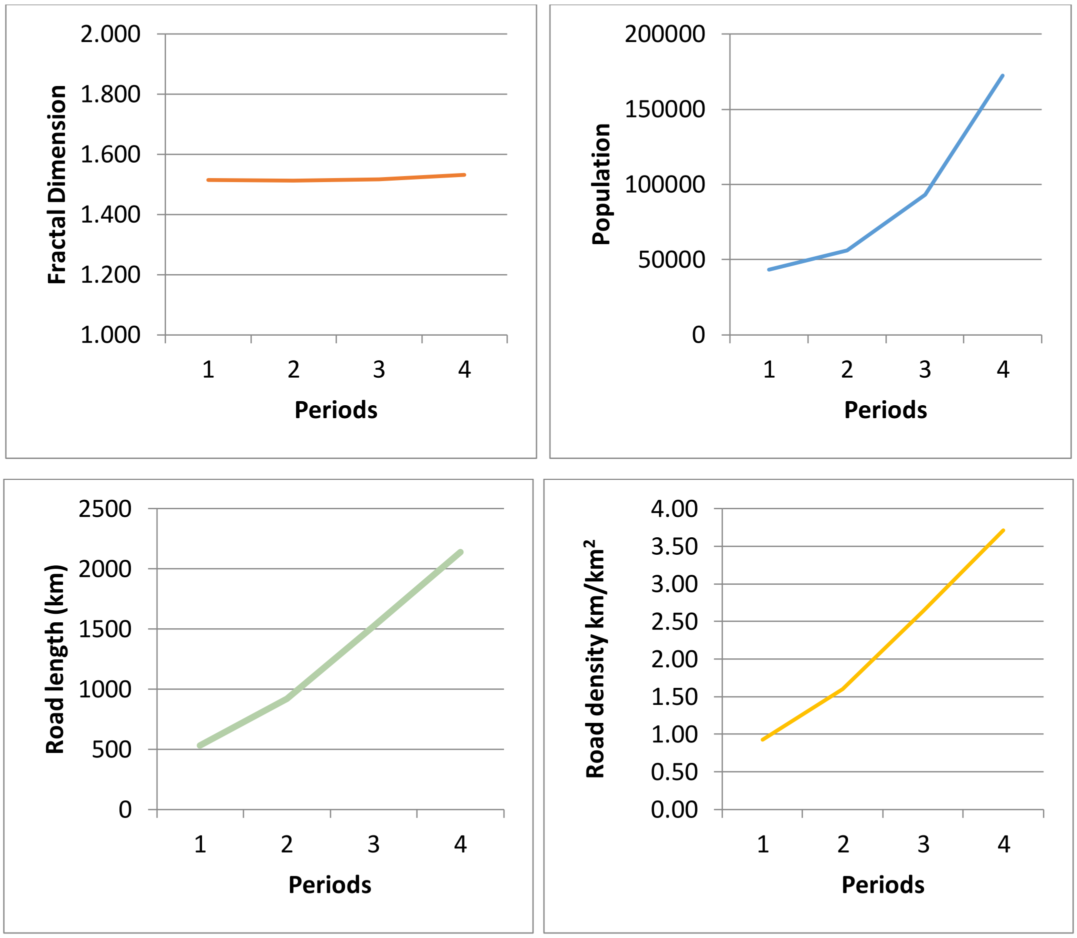



Figure 5-55 Population, road length/density and fractal dimension change for *Torbalı*

The other district of the southern sub-region is *Selçuk* which has close connection with *Aydın-Kuşadası.* On the other hand, integration of *Selçuk* with *İzmir* does not raptured due to railway and motorway connection with the metropolitan core. The district center is visually visible from the first period due to presence of the district center since ancient times. The initial fractal dimension of the network in late 1950s and early 1960s is calculated "1,512" which exceeds not only the mean fractal dimension of all districts "1,313" but also the whole İzmir Regions' value "1,502". Despite of the some degree of network growth, fractal dimension of the network decreased to "1,218" in the second period. In late 1970s, complexity level of *Selçuk* calculated below the mean fractal dimension of districts "1,343" and the whole network's value "1,581". For the third period, fractal dimension increased to "1,500" which is still below the mean fractal dimension "1,521" and *İzmir's* value "1,819". In the last period, fractal dimension is further increased to "1,558" that it exceeded the average fractal dimension of *İzmir's* districts "1,492" (Figure 5-56).

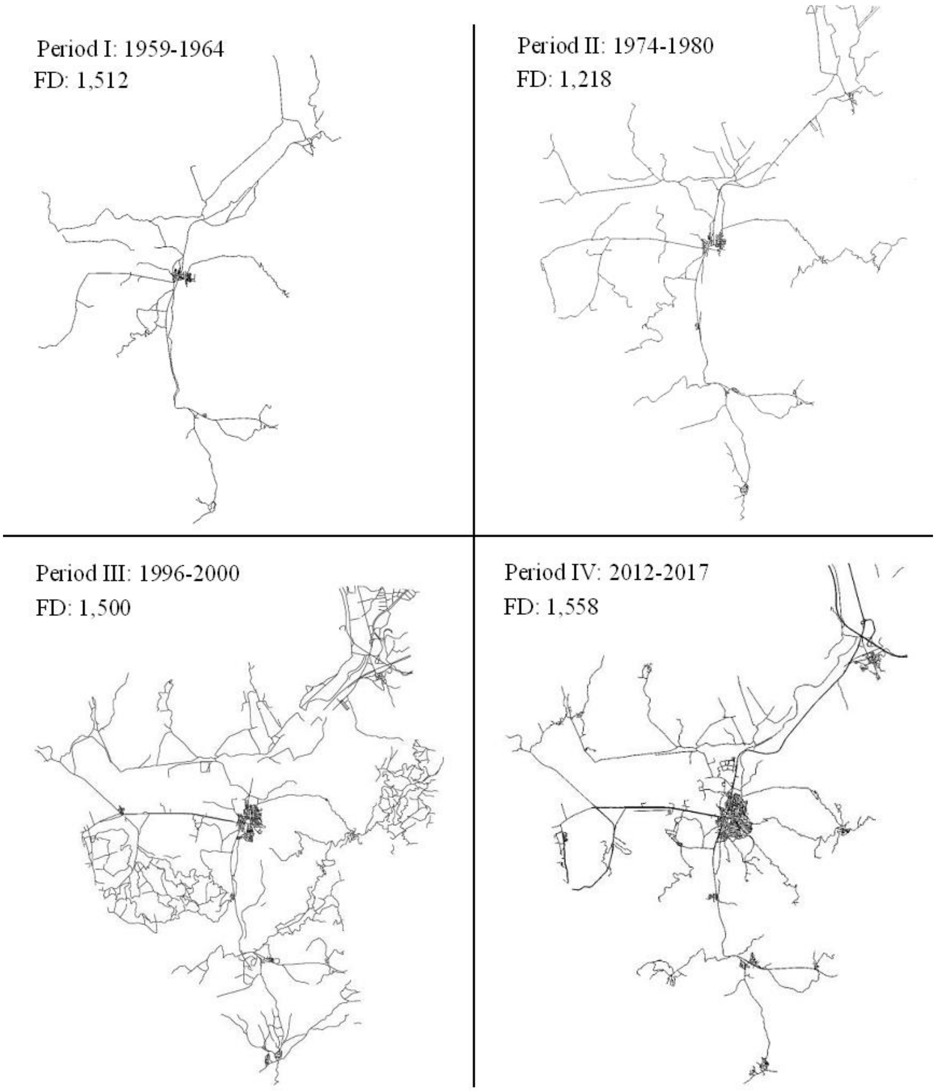



Figure 5-56 Fractal dimension change of Selçuk District

Like *Tire, Bayındır, Kınık* and *Foça,* road length and density decreased between the third and the last period. Although district central area grows, decrease in network length similarly resulted from decrease in the length of dirt roads.  On the other hand, between the first and the second periods the highest network growth is observed in *Selçuk*. Population is continuously increased through all periods while the highest rate is determined between the second and third period. Nevertheless, population growth rate decreased due to loss of rural population which took place after 2000 (Figure 5-57). The district is subjected to touristic attraction by the effect of coastal touristic activity as well as archeological, religious and cultural heritage sites. However, compared to *Çeşme, Dikili* and *Seferihisar*, district is less subjected to secondary housing.

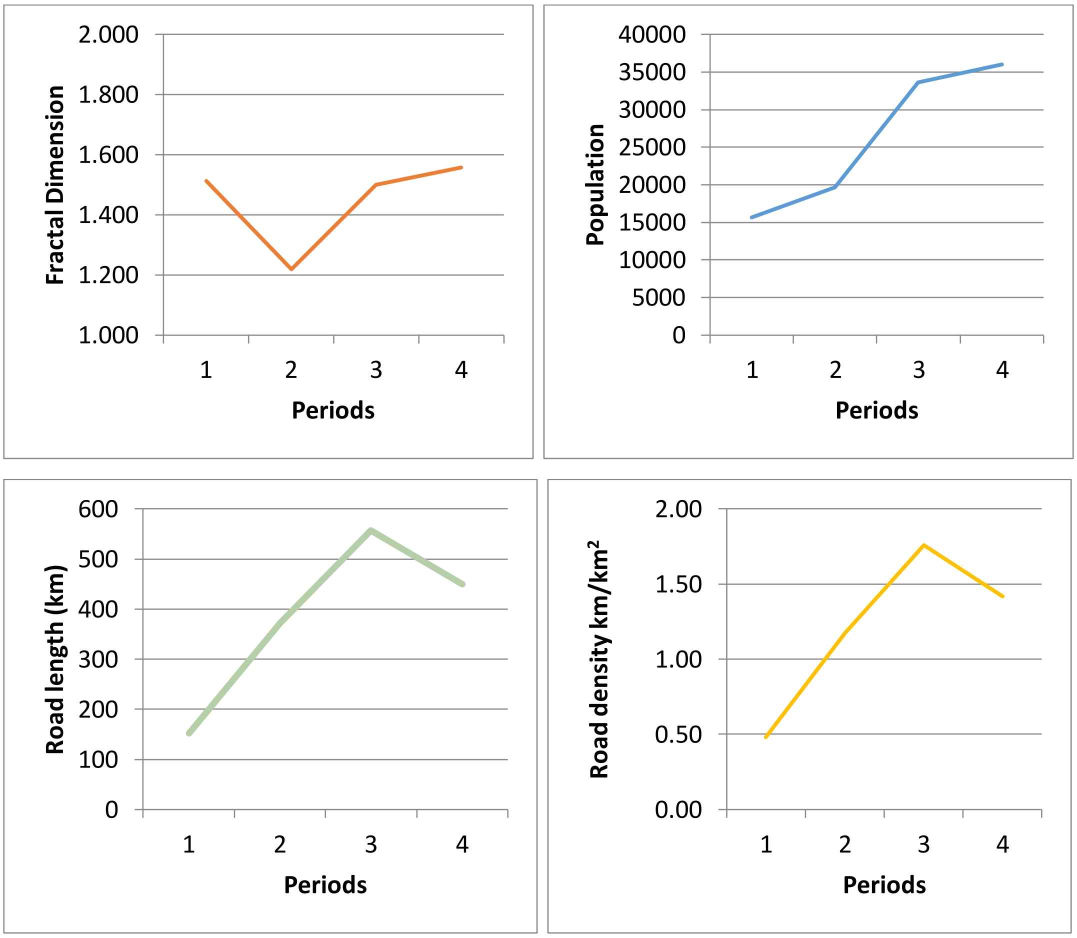



Figure 5-57 Population, road length/density and fractal dimension change for *Selçuk*

The other peripheral district in the southern sub-region is *Menderes.* Like *Kemalpaşa* and *Torbalı,* the district has a commuting character. The initial fractal dimension of the district is “1,572”, which is the highest value among all districts between the years 1959 and 1964. Furthermore, the value is higher than the İzmir Region’s fractal dimension “1,502” in the first period. In the second period, fractal dimension value declined to “1,515” which is still the mean fractal dimension of all districts “1,343” while below the whole network’s fractal dimension “1,581”. For the third period, value increased to “1,599” which is the highest value of four periods for *Torbalı.* Similar to the second period, calculated fractal dimension is above the districts’ mean “1,521” while below the whole network’s dimension “1,819”. In the last period fractal dimension is decreased to “1,523” still above the average fractal dimension value “1,492” and below the total network system “1,724” (Figure 5-58).

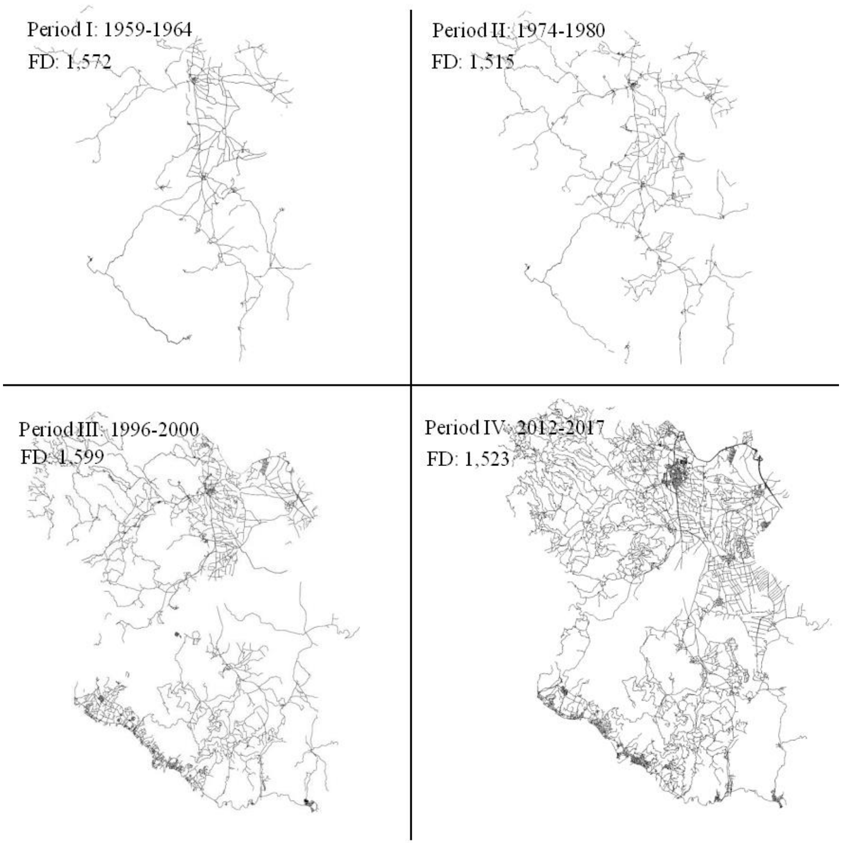



Figure 5-58 Fractal dimension change of Menderes District

As it is observed in *Selçuk,* road network length decreased from the third period to the fourth period. On the other hand, from second to the third period, the highest road network growth is observed in *Menderes* except *Karaburun.* Likewise population growth of *Menderes* is observed between the second and the third period that growth rate decreased between the last two periods (Figure 5-59). As a commuting zone, median age decreased in 1990s.

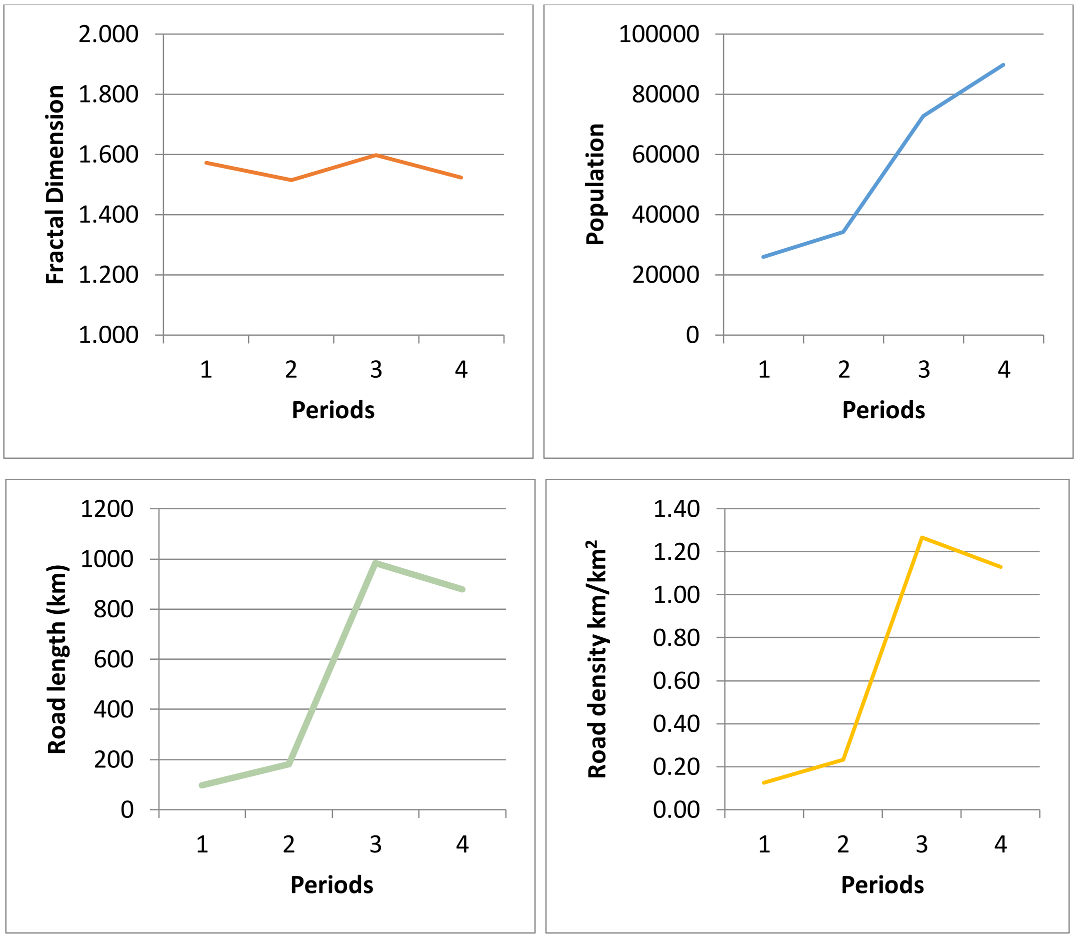



Figure 5-59 Population, road length/density and fractal dimension change for *Menderes*

The last district of the southern sub-region is *Seferihisar* district which is a popular calm coastal town like *Dikili, Urla, Foça* and *Karaburun.* The town center is the first *citta-slow* city of Turkey that resulted in immigration of the retired population and secondary housing development. The first fractal dimension of *Seferihisar* covering the time span from 1959 to 1964 is calculated as “1,498”. The value is higher than the mean of fractal dimension of districts “1,313” while below the İzmir Region’s fractal dimension value “1,502”. Despite low-degree road development, fractal dimension decreased to “1,186” in the second period which is the third lowest fractal dimension of 1974-1980 period after *Beydağ* and *Balçova.* The significant network development of the district can be visually observed in the third period which resulted in an increase of the fractal dimension value to “1,509”. Nevertheless, increase in the complexity is still below the mean value of the other districts “1,521” during late 1990s. The highest fractal dimension is calculated in the last period and it reached to “1,545” (Figure 5-60). Although fractal dimension of the all districts are below the fractal dimension value of the whole system, *Seferihisar’s* dimension exceeded firstly the mean fractal dimension of the fourth period (1,492).

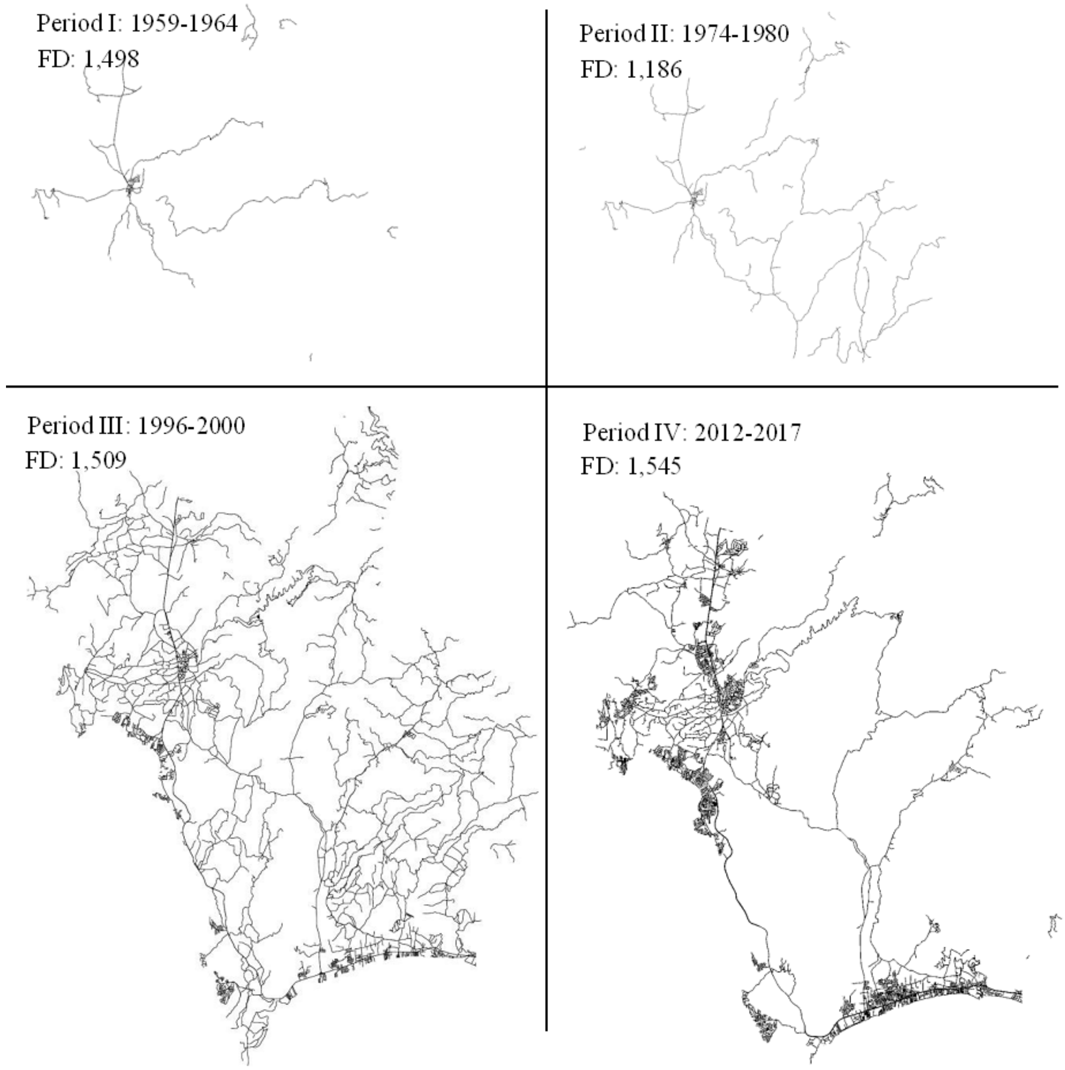



Figure 5-60 Fractal dimension change of Seferihisar District

As observed from Figure 5-61, both fractal dimension and population of *Seferihisar* is decreased from the first to second period and increased from second to the third period. Network length also peaks in the third period. However, decrease in dirt roads by increased inhabited area resulted in decrease in road network and density in the fourth period.

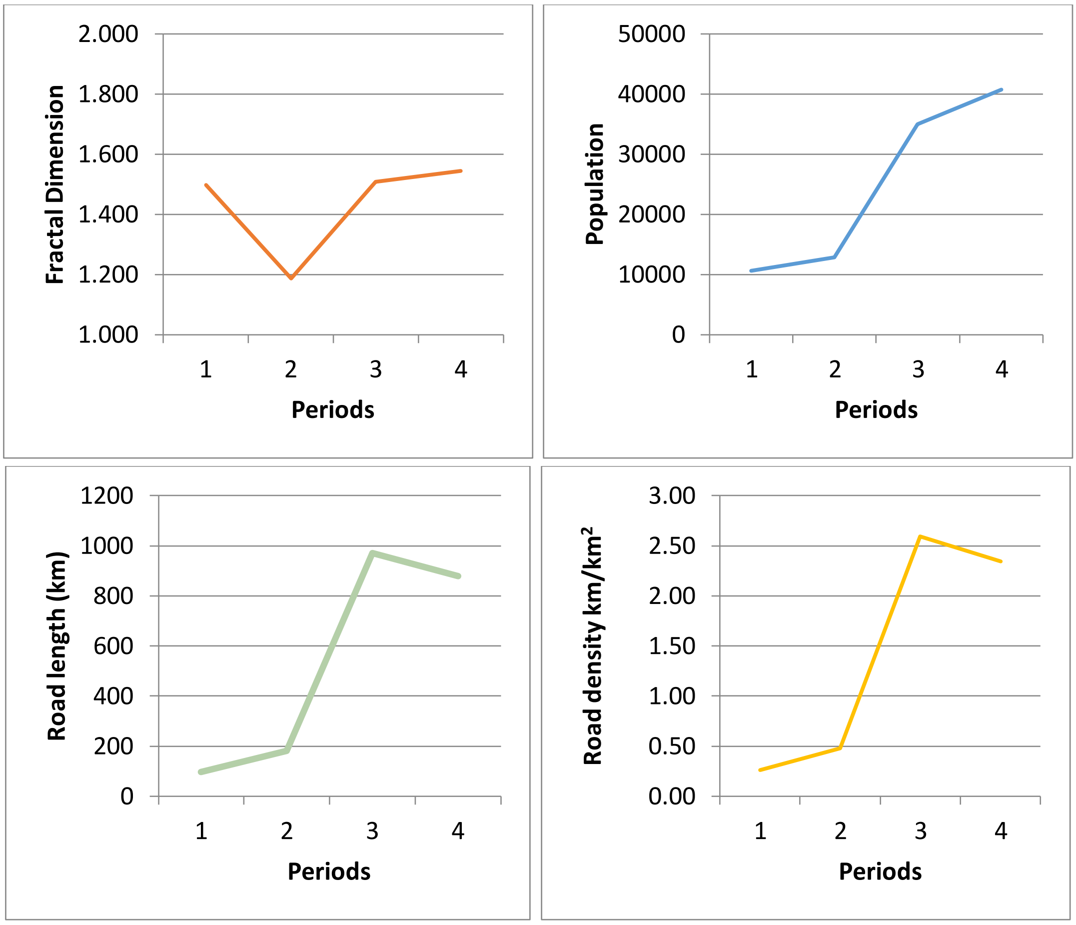



Figure 5-61 Population, road length/density and fractal dimension change for *Seferihisar*

## 5.4 Chapter Discussion

According to the proposed methodology, in this chapter firstly fractal dimension analyses of extended region are succeeded from 1953 to 2018. The first finding is that there occurs an increasing trend in complexity with two stable periods. Increase in fractal dimension in 1950s is followed by a stable period for approximately two decades. Then an increase observed again in 1990s which is again fallowed by stability as observed in chaotic behavior of cities involving fast and slow processes. The second finding is the relationship about growth of the extended region and complexity change. It can be interpreted that continuous growth in network and population of İzmir do not lead to increase in complexity. However, as observed from the literature review, a positive correlation is determined between fractal dimension and population.

After examining complexity of extended region, whole İzmir Region is examined for four periods. While in extended region analysis, fractal dimension values of 1998 and 2018 are calculated the same, fractal dimension value of İzmir Region decreased in the last period. From first to second and the second to third period, fractal dimension values increased and reached to the peak in the third period. Road length and density of the network continuously increased and the highest increase rate is determined between the second and the third periods. In addition, the highest population growth rate is recorded between the first to the second period for İzmir. Similar to the interpretations of the extended region analysis, growth of the region does not mean increase in complexity after 1990s. Furthermore, a positive correlation between fractal dimension and population is observed. Partially relevant to the expected results from literature background, a positive correlation between fractal dimension and total road length of İzmir Region is observed only for the third period and any significant relationship could not be determined between fractal dimension and network density.

For central districts, slight changes observed that fractal dimension increased until the fourth period and decreased in the last period. This finding is parallel with the arguments about an ongoing shrinkage of the central core of İzmir presented in Chapter 4. In the last period the metropolitan periphery gained complexity like Aliağa and Menemen. Furthermore, the districts inhabited by shifted central activity from Konak experienced increased fractal dimension like Bornova, Güzelbahçe and Karabağlar.

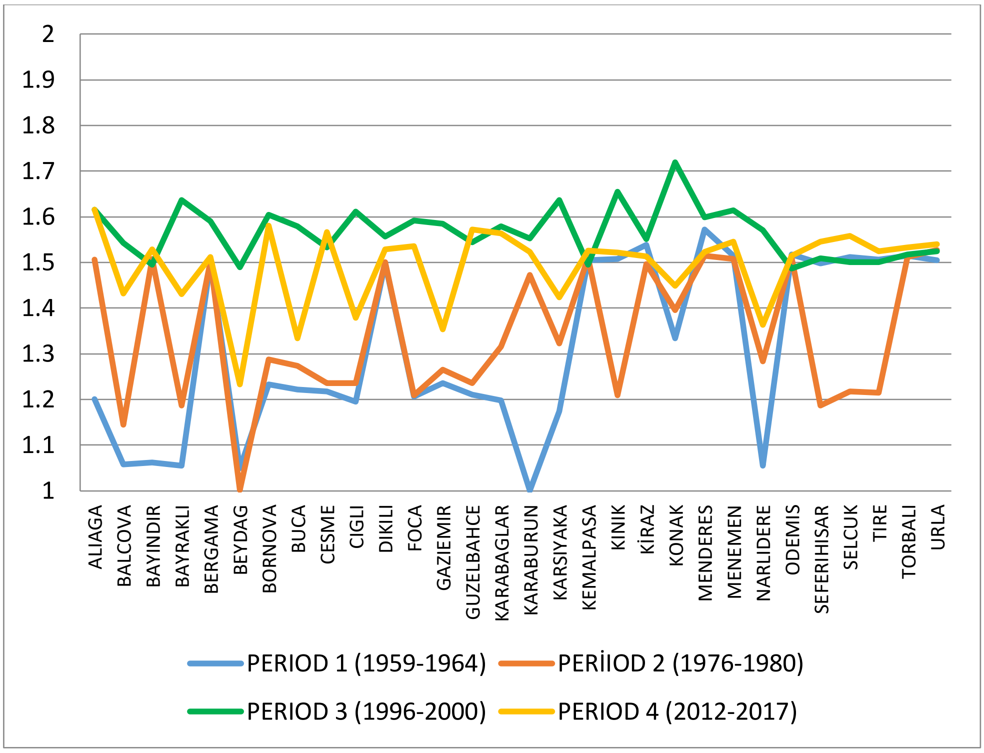



Figure 5-62 Fractal Dimensions of Districts from first to the fourth period

How the parameters including population, road length and fractal dimension changed and which districts shared a similar pattern is the another outocme of this chapter. *Central Core, Gaziemir, Karşıyaka-Bayraklı, Çiğli* and *Menemen* are subjected to continous growth in every parameter except a decline in fractal dimension in the fourth period. *Menderes* experienced declineboth in terms of road length and fractal dimension as a possible outcome of the diminished dirt roads. In the fourth period, decline in all parameters is observed in *Foça* and *Kınık.* Those findings could be interpreted that from the third the fourth period, not only the central core but also the metropolitan periphery is subjected to decline in complexity. However, decline in central core is much more visible. Decrease in the road length observed in *Menderes* is also observed for the districts as *Tire, Kiraz, Selçuk* and *Seferihisar* as a result of the transition from non-urban network. In other words, findings of the analyses provide relevancies with the literature background.

# CHAPTER 6

# COMPLEXITY OF IZMIR REGION

Complex urban systems solely involve the relational aspects of urban-regional pattern. By examining each district from 1959 to 2017 in four periods, inter-relations among districts and each district's emergence with the whole system come in sight. Furthermore, alterations and statistical relations population and fractal measures are investigated. Firstly, change in population dynamics including gross size, density and percentage change of the total population for each district are examined for four periods. Afterwards, fractal dimensions of the districts and their relations with other districts as well as the whole system are examined including cluster analysis.

Furthermore, complexity of an urban region is based on micro changes leading to macro changes in the system based on emergence. In other words, complexity of regional systems appears intrinsically. In order to identify the complexity of the system, two main questions arise as;

(i)What are the relationships among settlements and settlement parameters with respect to districts

(ii) What is the endogenous patch-work or parts of the whole system in terms of different complexity levels

In this part of the study, relational aspects of exogeneous complexity by statistical analysis and the bottom-up complexity pattern of İzmir region is presented for each four periods by sub-fractal analysis are conducted.

## 6.1 Relational Analysis of Complexity and Growth of Districts

As a synthesis of the findings of the analysis presented in Chapter 5, relational aspects of population growth, population density and fractal dimension is examined. In addition clustering trend of districts in terms of complexity measure is investigated by cluster analysis.

### 6.1.1 Change of Population in İzmir

The first parameter to evaluate the İzmir Region's system is population. Population of the each district for each period is determined by the contemporary district divisions supplied by General Directorate of Land Registry and Cadastre. By estimating population to the end year of each period, 1964, 1980, 2000 and 2017 population of each districts are re-calculated. When population distribution is investigated, it is observed that agglomeration nodes altered through periods except the central core.

In the initial period it is observed that central core is the most populated area. However, the second most populated district is *Ödemiş*, which is followed by *Karşıyaka-Bayraklı* united district. When population distribution of the initial period covering a time span from 1959 to 1964 examined, two agglomerated sub-regions can be observed in the east as well and in the north around *Bergama*. The first five districts having the highest population are *(i) central core (ii) Ödemiş, (iii) Karşıyaka-Bayraklı, (iv) Bergama* and *(v) Tire*. In other words, it can be interpreted that agriculture dominant districts fed by the *Küçük Menderes* and the *Gediz* Rivers are also concentration locations. The five least populated districts are determined from the lowest to highest are *(i) Güzelbahçe, (ii) Karaburun, (iii) Foça, (iv) Çeşme* and *(v) Seferihisar*. After *Gaziemir, Güzelbahçe* is the smallest district in size which can be the reason of the lower population size despite it's central location. Contemporary calm-costal touristic towns are the districts which are least populated in 1959-1964 period.

In the first period approximately 48% of İzmir's population live around the Bay including *Central Core, Karşıyaka-Bayraklı* and *Çiğili.* On the other hand, dominance of rural district centers is also visible. Three of the first five districts having the highest population share of *İzmir* are geographically close connected to the central core and provide inhabitance to nearly 20% of the total population of the whole İzmir Region.

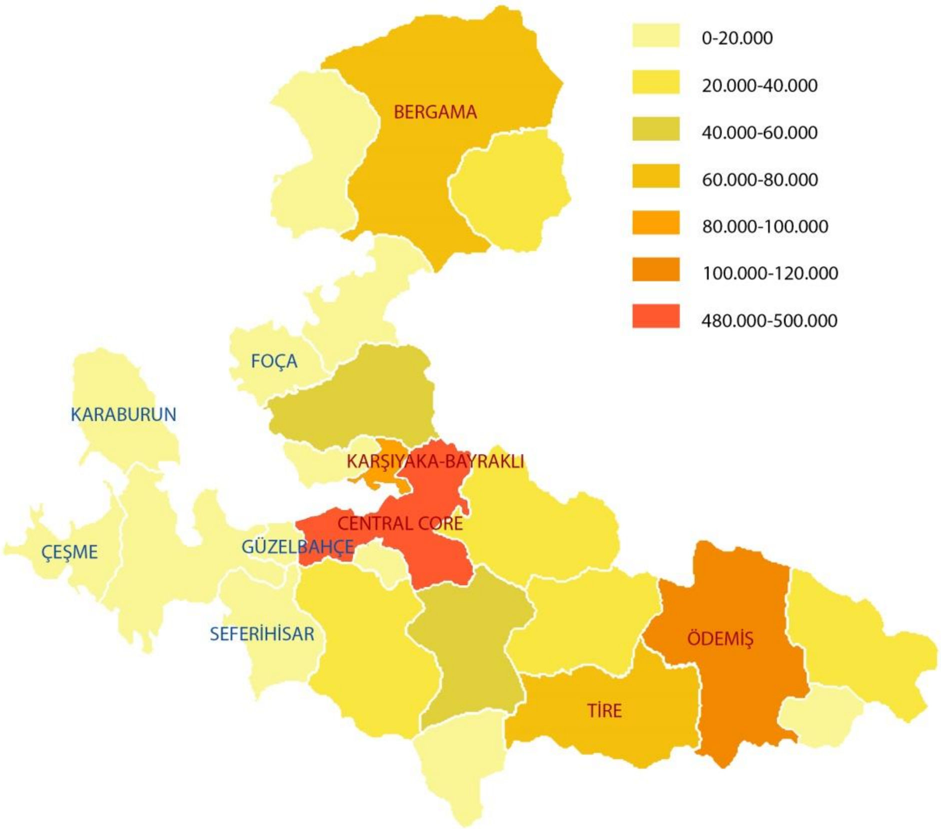



Figure 6-1 Population distribution of districts in the first period (1959-1964)

The other measure in order to identify agglomerations central gravity effect is density measure. It is observed that the densest districts are observed around the Bay. The densest four districts are *(i) Karşıyaka-Bayraklı, (ii) Central Core, (iii) Gaziemir* and *Çiğli.* Those are followed by *Ödemiş.* In other words, it can be observed that an agglomeration in terms of population can be seen in the eastern sub-region in the first period as a relatively rural organization. The network pattern of the eastern sub-region also promotes cultivation based relations. The northern sub-region does not display population density despite population size and similar cultivation based network pattern. Similar to gross population results, coastal towns like *Çeşme, Seferihisar, Dikili* and *Karaburun* are the least dense districts of the İzmir Region.

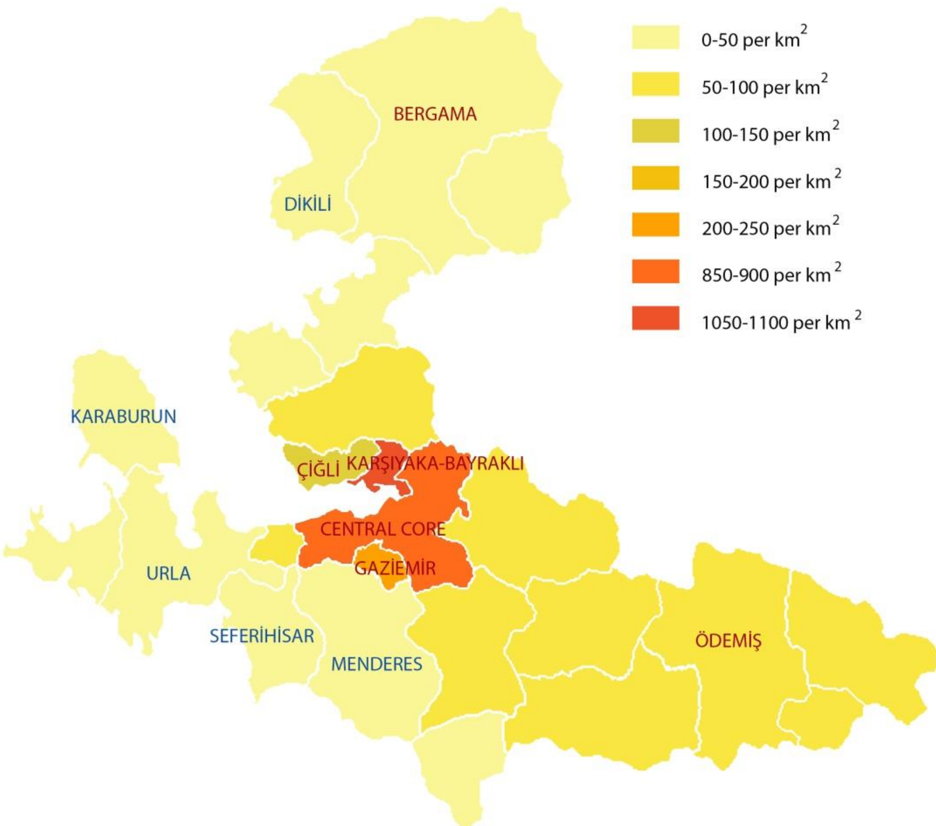



Figure 6-2 Population density distribution of districts in the first period (1959-1964)

From 1965 to 1980 total population of the İzmir Region is increased by 60% which resulted in differences in population distribution and gravity nodes or spines. In the second period pull effect of the central core increased that the highest population growth rate observed in *Karşıyak-Bayraklı* and in the *central core.* Moreover, population increase takes place along the Bay's coastal spines. *Çiğli* became one of the five districts providing inhabitance to the highest percentage of the İzmir Region's population. Likewise *Güzelbahçe* is determined is the third district subjected to the highest population growth. The lowest growth rates observed in the rural districts like Dikili, *Karaburun, Beydağ* and *Bayındır.* The rural districts close to metropolitan region like *Kemalpaşa, Torbalı* and *Bayındır* gained population. However, remote rural districts in the eastern part comparatively loose population like *Tire* and *Beydağ.* Meanwhile, *Beydağ* became one of the five districts having the lowest population share. For present touristic attraction zones, lower population share is still visible in *Dikili, Foça, Karaburun, Çeşme, Seferihisar* and *Selçuk.*

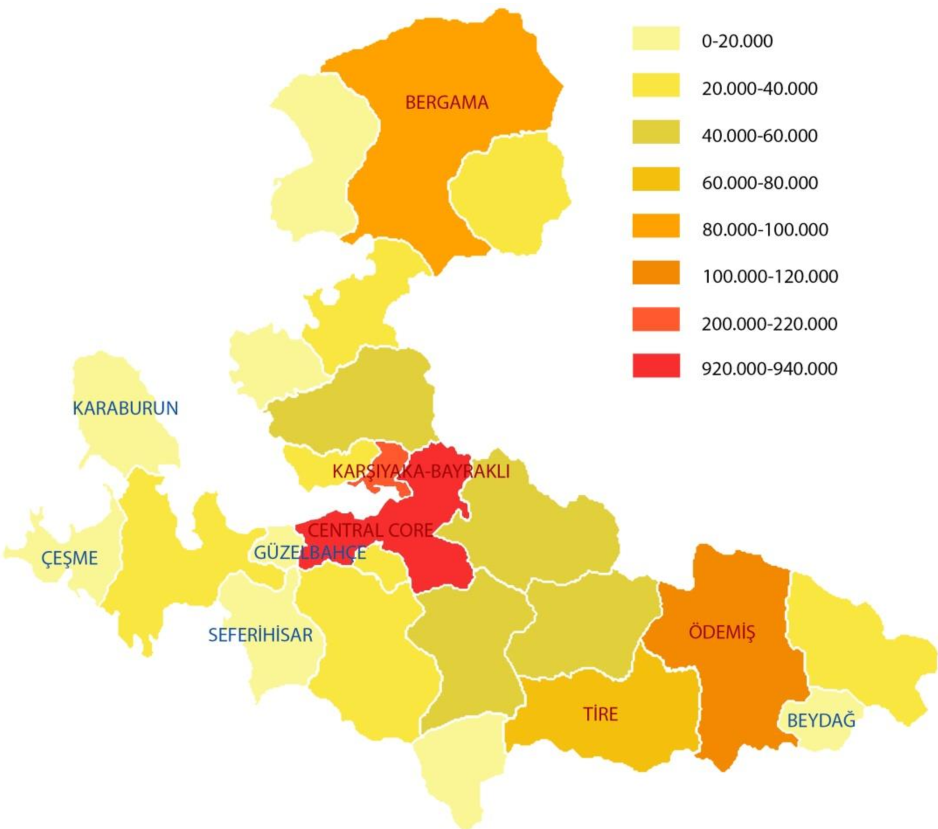



Figure 6-3 Population distribution of districts in the second period (1976-1980)

Quite similar agglomeration trend can be observed in the second period covering the time span from 1976 to 1980. Central core of *İzmir* enlarged along the Bay which resulted in the densification of *Central Core, Karşıyaka-Bayraklı, Gaziemir* and *Güzelbahçe.* The difference can be visualized along northern and the eastern sub-regions. *Bergama* and *Ödemiş* remained the gravity points of the northern and the eastern rural organization. In the northern sub-region *Aliağa* also gained density while *Ödemiş* became the most dense district of the eastern sub-region.

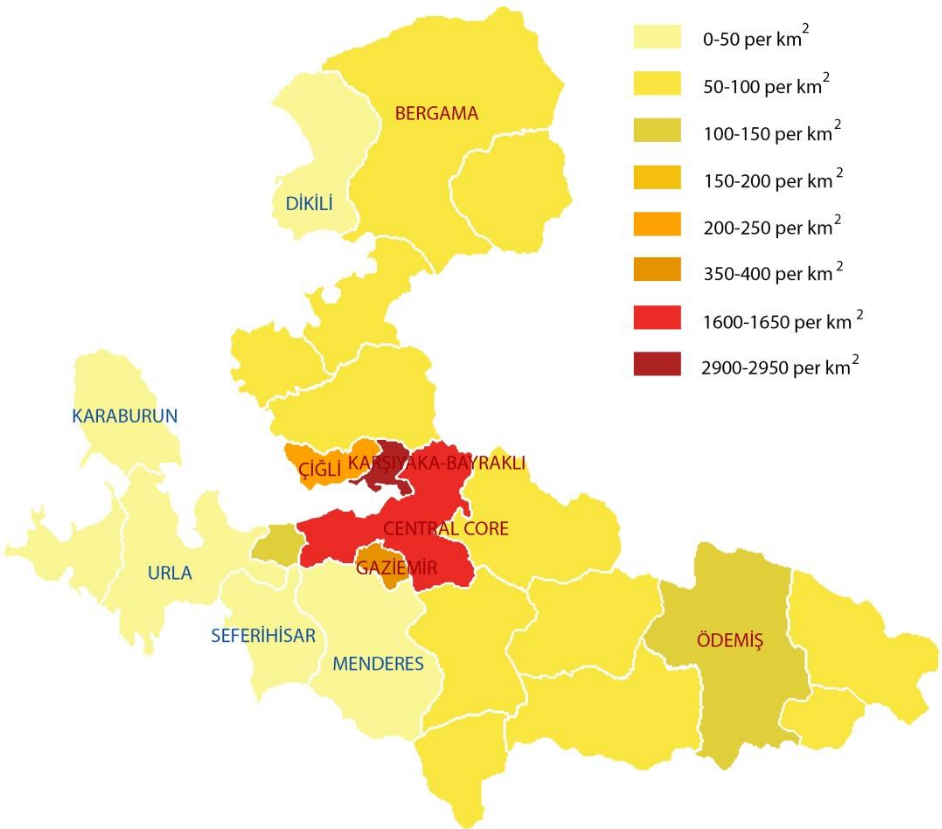



Figure 6-4 Population density distribution of districts in the second period (1976-1980)

In the third period covering the time span from 1996 to 2000, not only population size but also distribution of the population altered with respect the preliminary periods. Annual population increase rate of the total İzmir Region decreased by 0,5%. In district scale, population growth rate decreased with respect to the annual growth rate between the first and the second period for the central core and *Karşıyaka-Bayraklı* districts. On the other hand, main population increase took place in peripheral metropolitan areas like *Gaziemir* and *Çiğli.* Different from the first two periods, they are followed by *Seferihisar* and *Çeşme* which became to be known as calm touristic destinations. Between the second and the third periods, a negative population growth rate is firstly observed in the district of *Beydağ.* Similar to *Beydağ, Kınık, Bayındır, Ödemiş* and *Tire* have the least population growth rates. In other words, the rural organization around the fertile plain fed by the *Küçük Menderes River* dispersed in terms of population size. Likewise, the similar rural organization around *Bergama* loose population dominance as well. *Kınık* became one of the five districts having the least population share while *Bergama* losses the rank in the first five districts having the largest population share observed in preliminary periods. The northern sub-regions' development mainly took place around *Çiğli, Menemen* and *Aliağa* related to non-agricultural industrial and commercial services. A similar development spine is visible from the central core to the south as *Torbalı.*

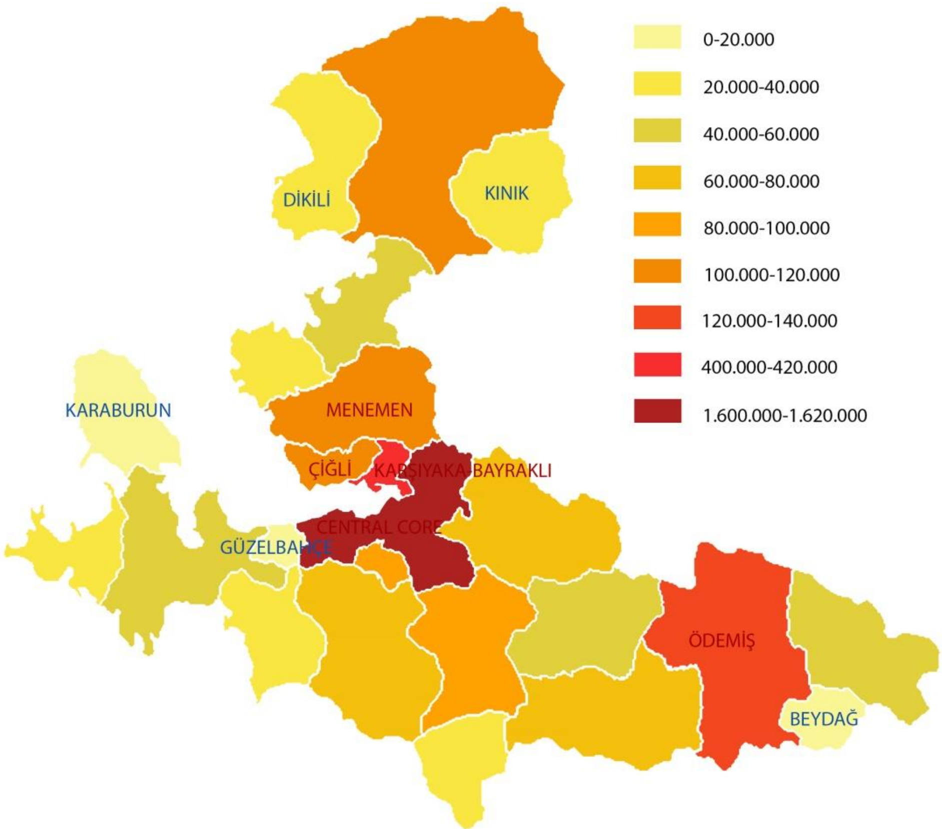



Figure 6-5 Population distribution of districts in the third period (1996-2000)

Increased push effect of the central core can also be observed for population density pattern. Approximately 70% of the İzmir Region's population lives in the districts around the Bay. Therefore, the densest districts are all located around the Bay. In the third period, *Ödemiş* and *Bergama* have not been featured in the most dense five districts. Due to smaller sizes *Güzelbahçe* and *Gaziemir* could not be recognized in total population size. However, they are recorded under the most dense districts as they are; (i) *Karşıyaka-Bayraklı, (ii) Central Core, (iii) Gaziemir, (iv) Çiğli* and *Güzelbahçe.* The diffusion of the northern sub-region is also visible in population density. While *Bergama* is the one of the densest districts in previous periods, it is recorded in the third period as one of the five least densely populated. Likewise, *Kınık* also become less uninhabited with respect to first two periods.

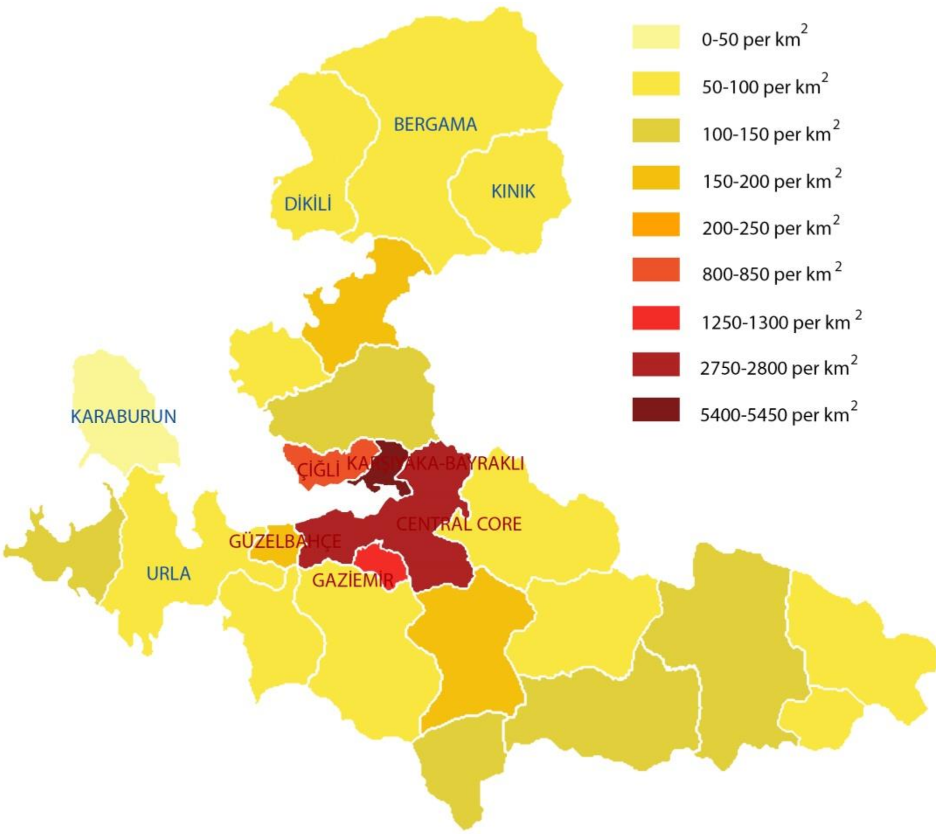



Figure 6-6 Population density distribution of districts in the third period (1996-2000)

Population growth decreased between the third and the last period to the smallest value that annual growth rate approximately calculated as; 4% between the first and the second period, 3,5% between the second and the third period while 1,5% between the third and the last periods. Population share of the central core decreased while close peripheral districts around the Bay gained population. However, the highest population growth took place in outer periphery. The first two districts subjected to the highest rate of population increase are; *Torbalı,* and *Aliağa.* They are followed by inner suburban districts including *Güzelbahçe, Çiğli* and *Gaziemir*. In addition to *Beydağ,* the number of districts experienced negative population growth rise to seven including *Bergama* which is a pull node of the northern rural sub-region. The other declined districts are; *Kiraz, Kınık, Bayındır,* *Foça* and *Karaburun*. In other words, rural population loss is visible in all İzmir Region after 2000.

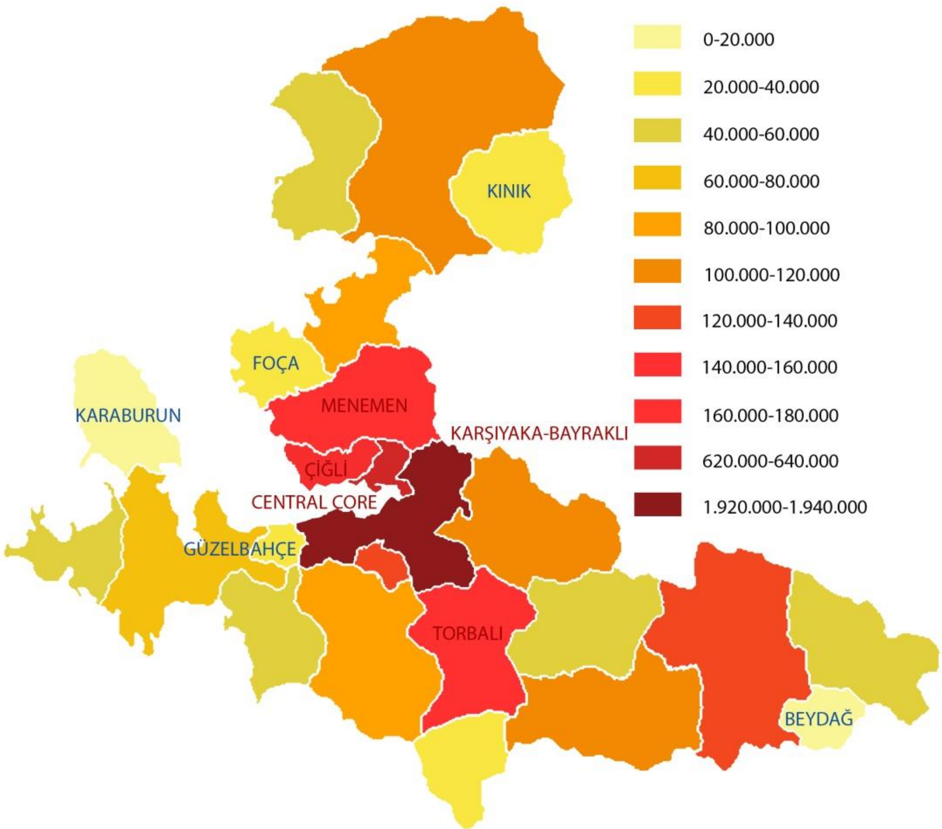



Figure 6-7 Population distribution of districts in the fourth period (2012-2017)

In the last period spinal development from north and to the south can be visualized from population agglomeration. Population growth in *Menemen, Torbalı, Çiğli* in the north and *Güzelbahçe, Torbalı* in the south is determined. In addition to *Menemen, Torbalı* also become one of the most populous districts. Furthermore, population on the west axis of the Bay including *Urla* and *Çeşme* gained population while *Karaburun* remained as the least populated district. By examining the population density distribution, the vertical spine from *Aliağa-Menemen* to *Torbalı* can be visualized. The other peripheral districts like *Menderes* and *Kemalpaşa* gained density as well. While the most dense districts are identified around the Bay, the least dense are dispersed in the rural dominancy quarters which are; *(i) Karaburun, (ii) Kınık, (iii) Bergama, (iv) Beydağ* and *(v) Bayındır.*

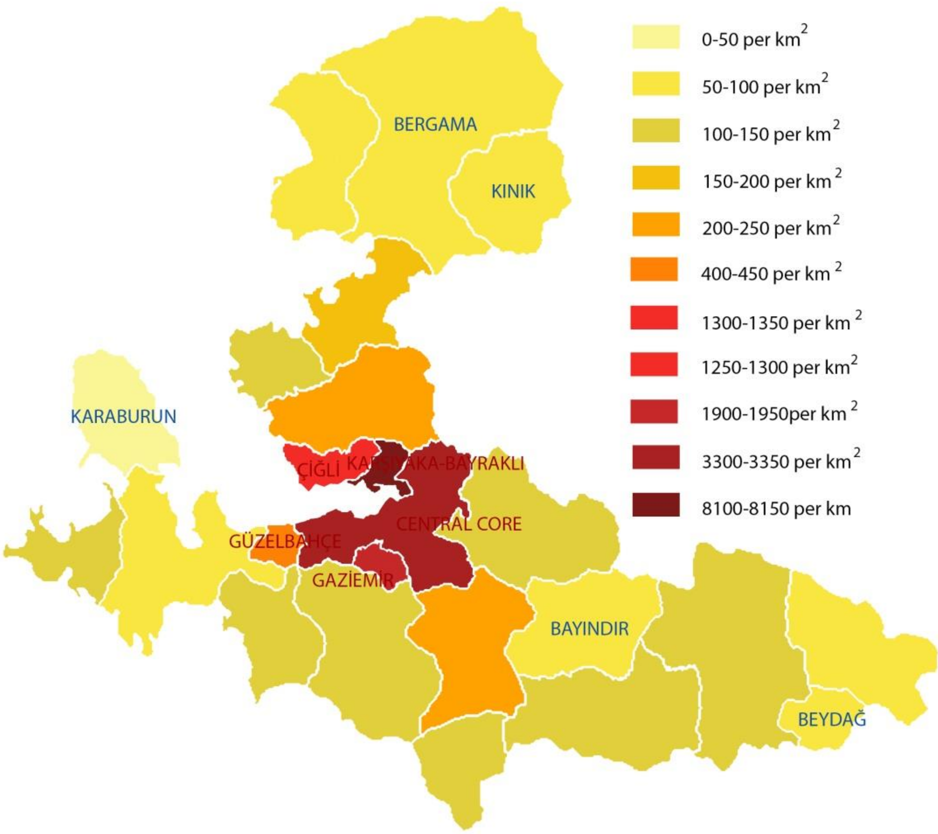



Figure 6-8 Population density distribution of districts in the fourth period (2012-2017)

### 6.1.2 Change of Fractal Dimension in İzmir

Fractal analysis of the districts possess quite different pattern which implies that complexity alteration of the parts does not purely reflects the complexity of the whole system despite, all are derived from the same network. In terms of investigating the part-whole relationship with respect to regional complexity, firstly the relationships between fractal dimension values of the whole İzmir Region with districts are identified. It is observed that from the first to the second periods, mean of the fractal dimension of districts is below the whole system's fractal dimension. The gap widened in the third period and narrowed down again in the fourth period. Furthermore, difference between median and the mean fractal dimension values also enlarged in the third period. In other words, complexity of the whole system mostly exceeded the parts' in 1990s.

The other significant inference is that heterogeneity in complexity of the İzmir Region's network decreased at most in the third period. Standard deviations of the fractal dimension values of the districts are calculated as for the four periods; (i) 0.332, (ii) 0.166, (iii) 0.049 and (iv) 0.082 respectively. Meanwhile the gap between the minimum and maximum extreme values also reaches to the narrowest point in the third period. This can be interpreted as that heterogeneity in complexity level of the parts decreased until the third period and then increased again. Those trends could also be observed in the fractal dimension values of the whole İzmir Region. In other words, level of integrity increased until 1990s while decreased again after 2000.

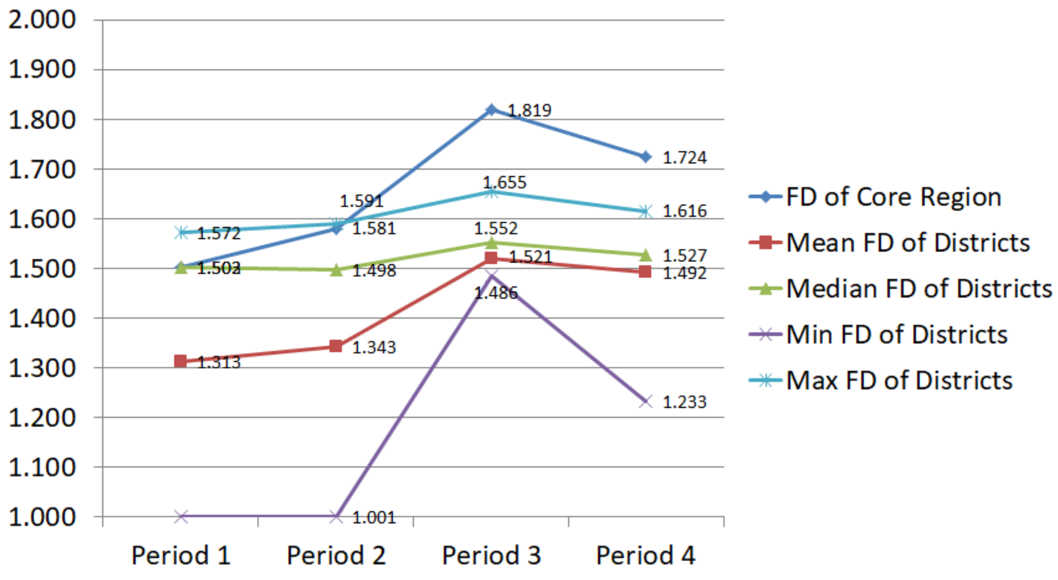



Figure 6-9 Descriptive statistics of fractal dimensions of the whole and the parts

One of the main results of the part and whole relationship, main outcome is observed that complexity of the whole system exceeded the parts in time. When first period, as the initial period, examined eight districts' fractal dimension are calculated above the whole systems' fractal dimension. In addition, fractal dimension values of six districts are calculated above mean value of fractal dimension of all districts. All districts calculated above the whole systems' fractal value are rural districts during the 1959 to 1964 time span as they are; *(i) Menderes, (ii) Kiraz, (iii) Ödemiş, (iv) Torbalı, (v) Menemen, (vi) Selçuk, (vii) Urla* and (viii) *Tire.* Those six districts have rural character and exceed the mean value of the districts' fractal dimension. They are followed by *Konak*, which is the administrative and commercial center of the *İzmir* city. In other words, rich agricultural network pattern prevail against the whole system's complexity as well as more urbanized parts in the first period.

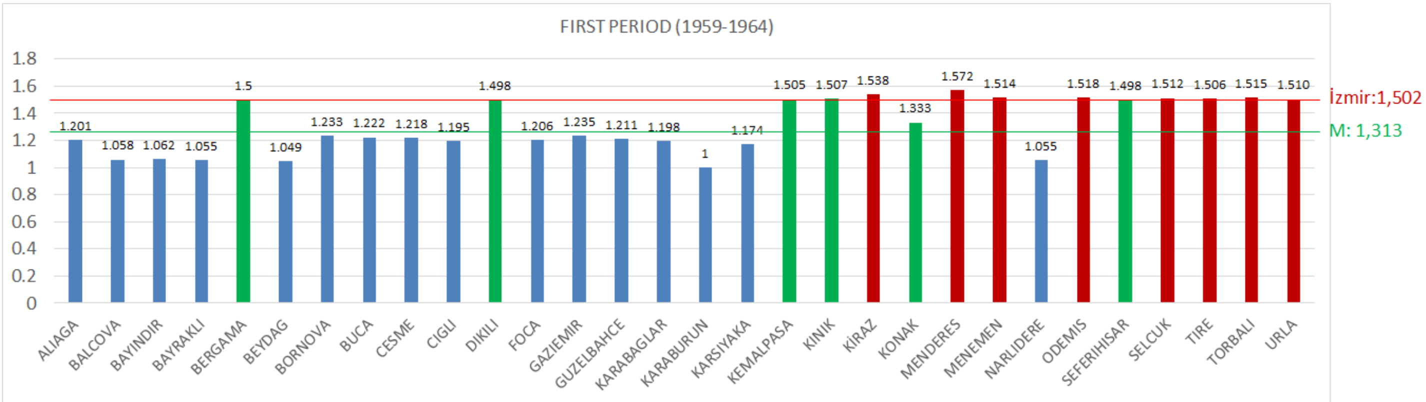



Figure 6-10 Fractal dimension of districts in the first period (1959-1964)

When spatial distribution of the fractal dimensions of the districts in the first period are examined a horizontal corridor from east to west can be observed in terms of higher fractal values along the fertile plain of the *Küçük Menderes River*. Another moderate level of complexity is determined around *Bergama*. Furthermore, the central districts around the Bay have higher fractal values. The highest value is calculated for *Menderes*. The first four districts having the highest fractal dimension value are *(i) Menderes, (ii) Kiraz, (iii) Ödemiş* and *(iv) Torbalı* organized around the fertile lands in the eastern sub-region. Complexity level of all is above the whole system's dimension. From the maps any degree of road is not drawn on the map inside the district borders of *Karaburun*. Therefore, fractal value of the district cannot be calculated. Except *Karaburun* the other four districts having the lowest fractal dimension in the first period are; (i) *Beydağ, (ii) Bayındır, (iii) Çiğli* and *(iv) Aliağa.*

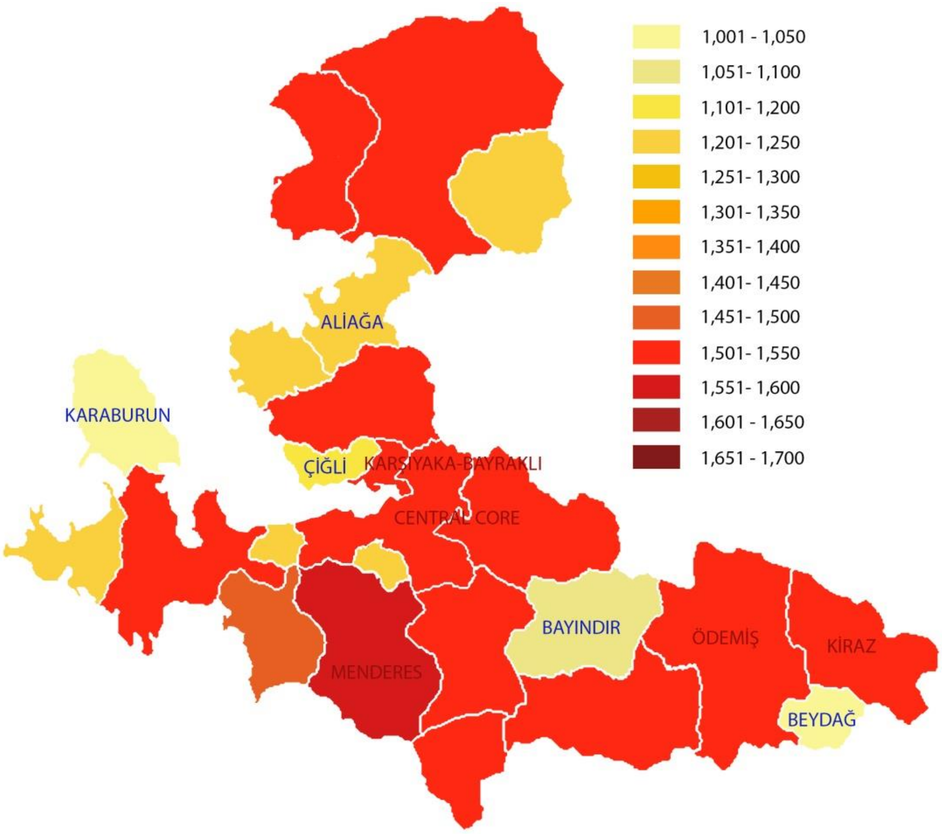



Figure 6-11 Fractal Dimension distribution of districts in the first period (1959-1964)

In the second period decreased gap between extreme values as well as between the İzmir Region's fractal dimension and the mean values of districts resulted in lower complexity level of the parts with respect to the whole. Any of the districts' fractal dimensions does not exceed the fractal dimension of the whole İzmir Region. On the other hand, 13 of 30 districts are calculated below the mean of the fractal dimension of districts. Although they have different characteristics neither of them are located around the Bay. In other words, central districts which are categorized under "The Bay" possess higher level of complexity.

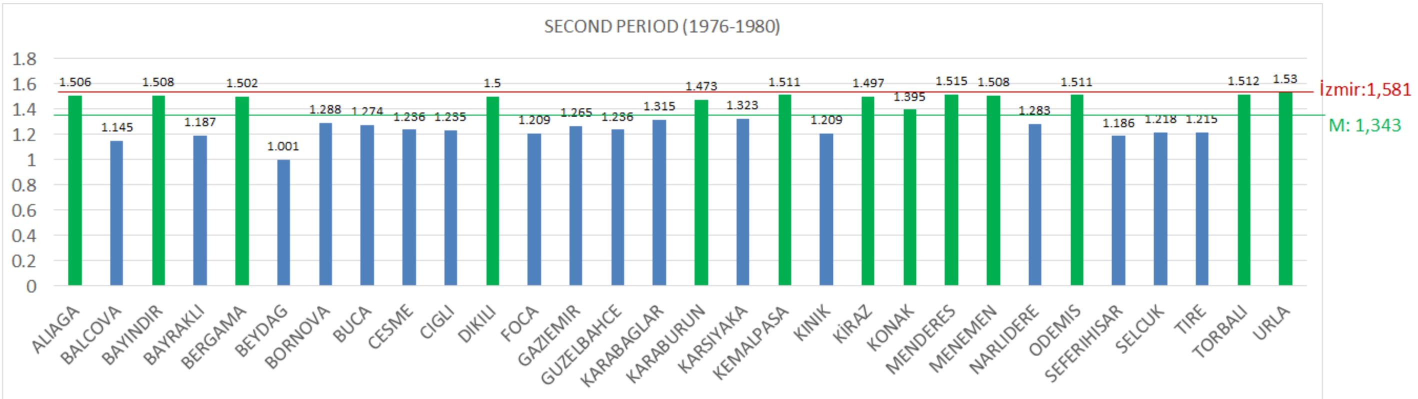



Figure 6-12 Fractal dimension of districts in second period (1976-1980)

The second period covering the time span from 1976 to 1980, axis of higher fractal dimension values can be visualized. *Central Core* and *Karşıyaka-Bayraklı* districts have the highest fractal dimension value. They are followed by *Urla* which have also considerably high fractal dimension with respect to neighbor districts. A higher level of complexity from the north to the Bay and to the south can be seen as well. Similar to the first period, lower fractal dimension values are scattered in the İzmir Region. In terms of complexity pattern, the second period could be defined as a transitionary period.

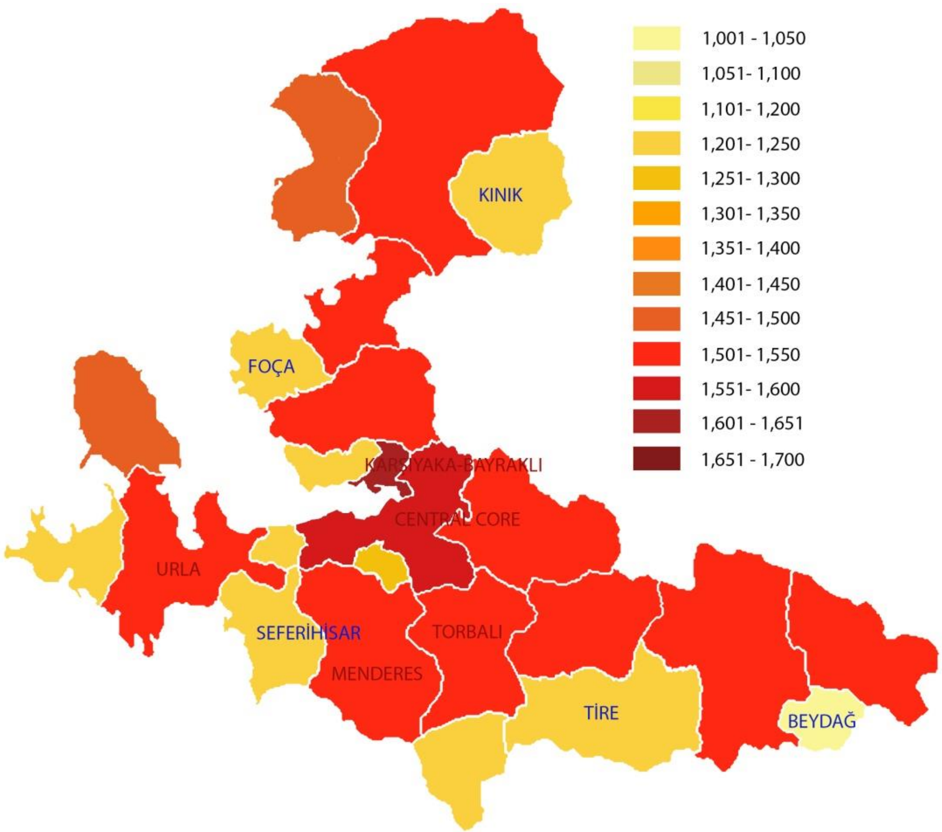



Figure 6-13 Fractal Dimension distribution of districts in the second period (1976-1980)

The highest complexity measures are observed in the third period. Despite of increased rates of the mean, and median values, the gap between extreme minimum and maximum fractal dimension of the districts are narrowed. This can be interpreted as increased complexity and compactness of the region also resulted in a homogeneity in the complexity level of the parts. Fractal dimension of the İzmir Region exceeds 1.8 which is a high value observed in the literature in urban centers. On the other hand, complexity of the parts cannot reach to the complexity level of the system as a whole. Any of the districts cannot exceed the fractal dimension of the İzmir's İzmir Region with a wider gap with respect to the second period. The other difference is the profile of the districts of which fractal dimension is calculated above the mean fractal dimension of the districts. Due to decreased extremities, fractal dimensions of 18 districts exceeded the mean fractal dimension. Furthermore, rather than rural remote parts, majority of them are metropolitan peripheral districts framing the Bay. Likewise central districts like *Gaziemir* and *Karabağlar* firstly exceeded the mean fractal value.

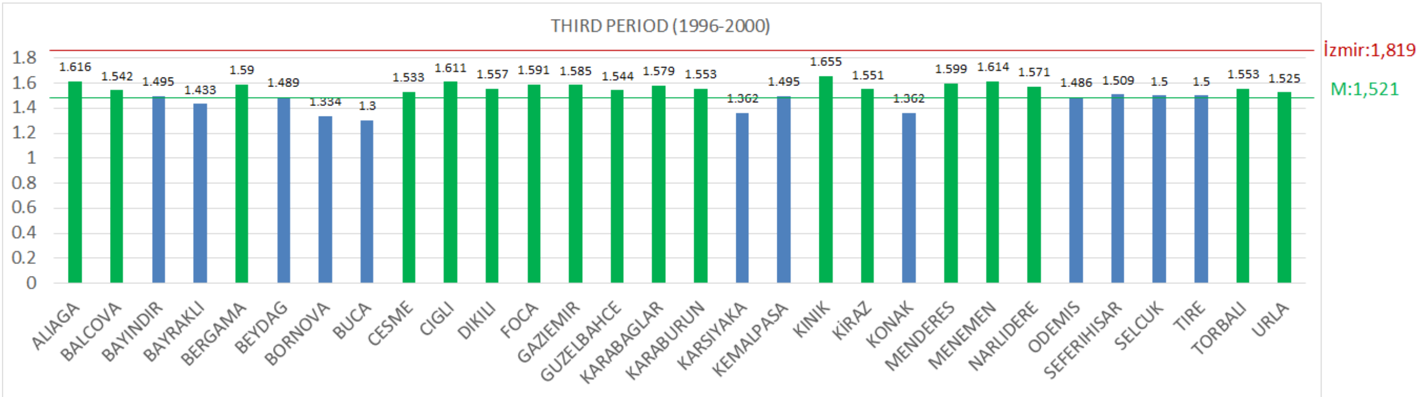



Figure 6-14 Fractal dimension of districts in the third period (1996-2000)

In the third period, higher fractal values with respect to the second period can be firstly observed. However, structure of the horizontal axis altered. The spine possessing higher fractal dimension values from the north to the core and to the south can be seen. The remote districts as *Kiraz, Kınık* and *Karaburun* reveal higher fractal dimension with respect to their neighboring districts. This can be interpreted as their isolated pattern involves an intrinsic complexity level. Different from the second period, the axial pattern in the eastern sub-region defining the *Küçük Menderes* plain dissolved in 1990s. The lowest fractal dimension values are calculated in the eastern sub-region as they are calculated for *(i) Ödemiş, (ii) Beydağ Kemalpaşa, (iii) Kınık* , (*iv) Bayındır* and *Tire* from lowest to the highest. The first five districts having the highest fractal dimension value is located in the northern side of the Bey as they are determined as; *(i)Kınık, (ii) Aliağa, (iii) Menemen, (iv) Karşyaka-Bayraklı* and *Çiğli.* This structure defines a complex pattern on the northern parts of the İzmir Region while complexity of the rural backbone of *İzmir* declined.

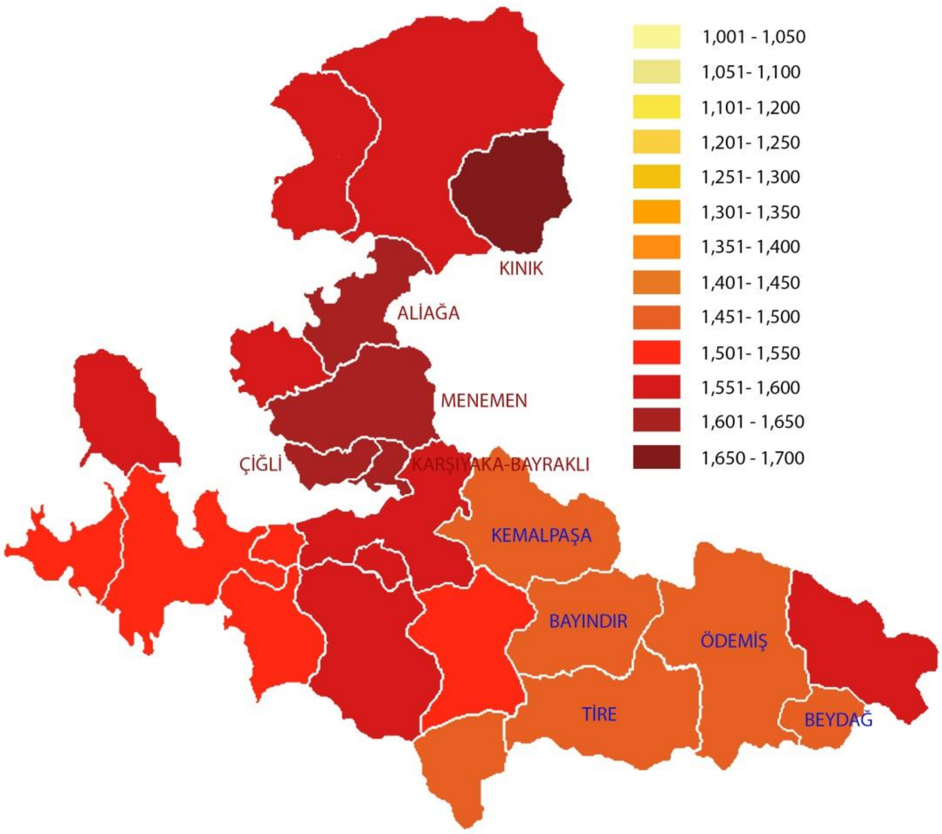



Figure 6-15 Fractal Dimension distribution of districts in the third period (1996-2000)

In addition to the decrease of the fractal dimension of the İzmir Region, fractal dimensions of the districts decreased as well. This resulted in decrease in median and mean values of the fractal dimension of districts accordingly. Moreover, gaps between the extreme values widened which can be interpreted as a more heterogenic fractal structure of the districts. Although difference in level of complexity between the districts and the whole system narrowed, any of the districts still does not exceed the İzmir's whole core system's fractal dimension. The number of districts exceeded the mean values of the districts rise to 20 in the last period.

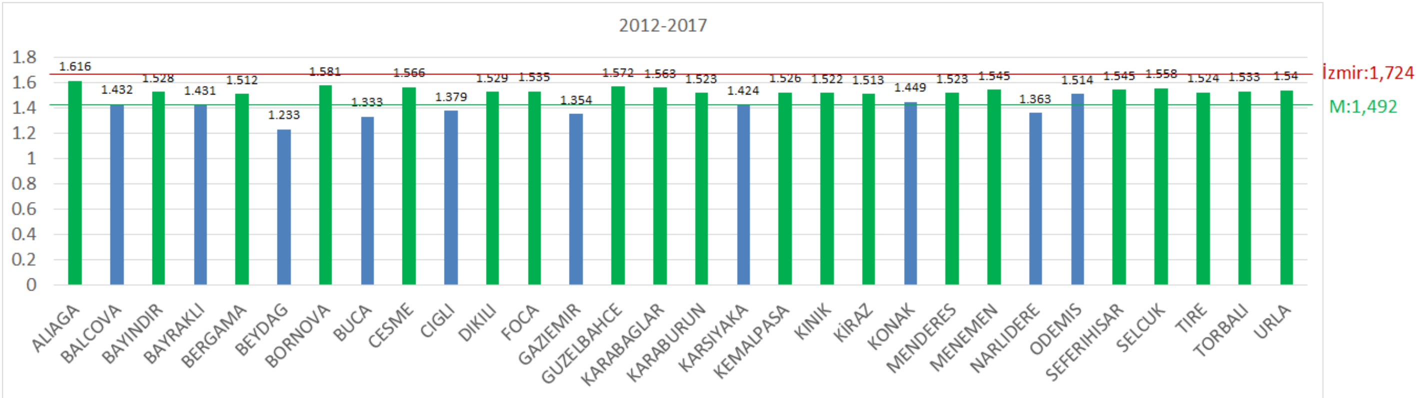



Figure 6-16 Fractal dimension of districts in the fourth period (2012-2017)

In the fourth period, new dynamics can be observed in terms of clustering of the higher and lower fractal dimension values. Firstly, the districts located at the north of the *Bay* subjected to decrease in fractal dimension as *Çiğli, Karşıyaka-Bayraklı and Menemen.* However, *Aliağa* preserve the level of complexity. The northern spine determined in the third period also dissolved by the decreased fractal dimension of *Bergama* that the district became one of the five districts having the lowest fractal dimension value. Increase in the level of complexity is observed in *Çeşme* and *Selçuk.* Decrease in network length in dirt roads in *Selçuk* resulted in a higher level of complexity. Furthermore, the districts along the southern coastline of the *Bay and* the central core can be observed as a cluster having higher fractal dimension values.

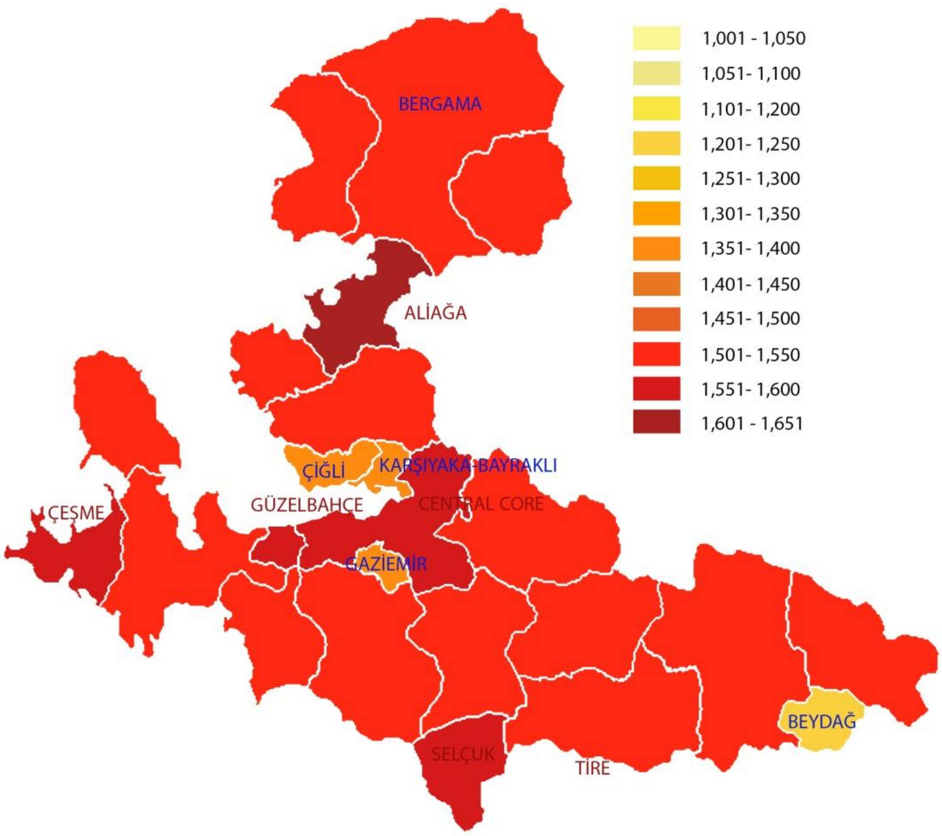



Figure 6-17 Fractal Dimension distribution of districts in the fourth period (2012-2017)

When the change rate of the fractal dimension of the districts is analyzed change in the fractal dimension of districts are observed intrinsically since their complexity level is also affected by the whole region's complexity change. Between the first and the second periods fractal dimension increase can be described from the west to east axis from *Çeşme* to *Kemalpaşa* including the Bay. The most significant decrease is determined along the *Küçük Menderes plain* except *Bayındır.* From second to the third period decrease in that axis becomes more visible while *Selçuk* and *Tire* observed an increase in fractal values. Increase in the fractal dimension around the Bay also continues as well. From third to the fourth period, the central quarters around the Bay subjected to decrease in fractal dimension while the eastern sub-region experienced increase in fractal dimension. Fractal dimension of coastal districts along the southern costs like *Çeşme, Seferihisar* and *Selçuk* experienced increase as well.

In each period, highest increases are observed by a scattered pattern. To illustrate, one of the highest decrease in fractal dimension observed in *Kınık* and *Seferihisar* since they are accomplished to have the highest increase from the second to the third period. Likewise, *Beydağ* is subjected to the highest decreases between the first and the second period as well as the third from the fourth period. Nevertheless, from second to the third period highest increase is recorded in the district. This fluctuating trend is also visible in *Bayındır, Kemalpaşa* and *Urla.* Although, time interval of the study is relatively small in order to understand the chaotic pattern of the districts, it can be observed that some districts are in steady state while some having fluctuating trend is in chaotic state.

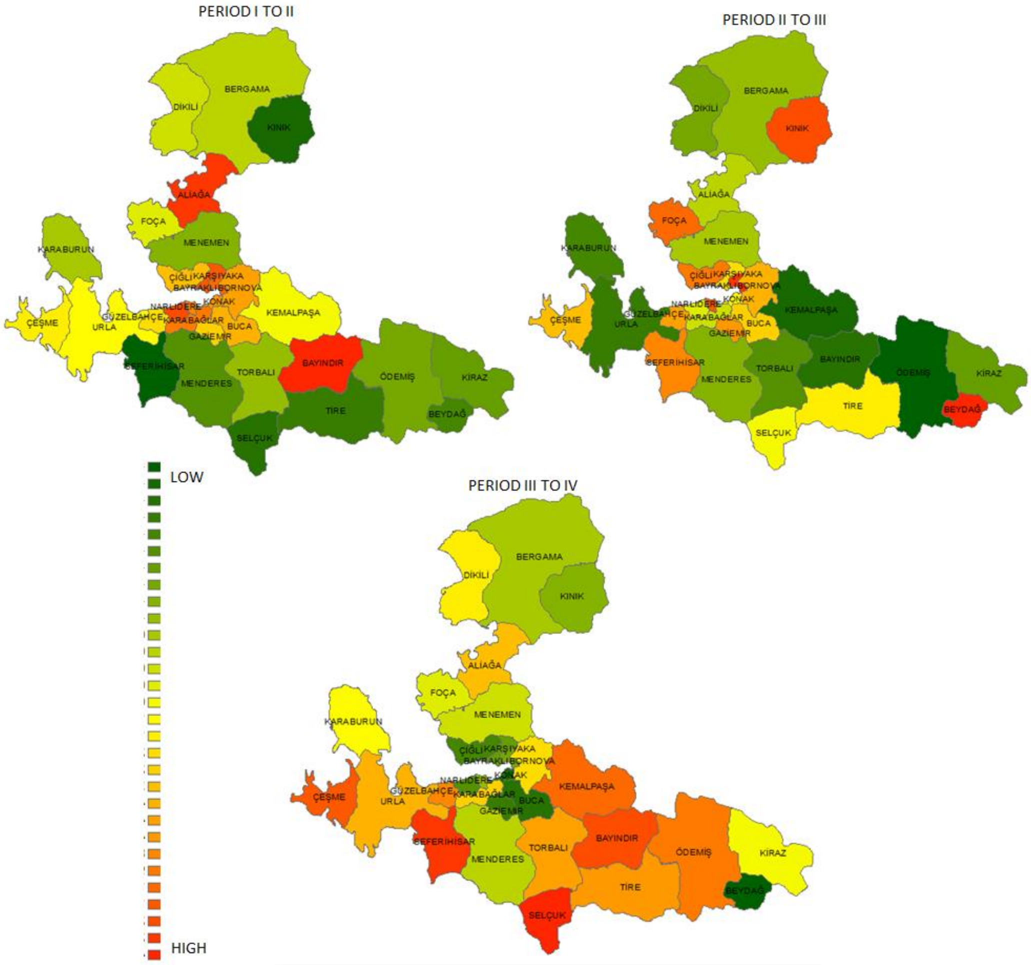



Figure 6-18 Fractal Dimension change of districts from the first to the fourth period

### 6.1.3 Relational Aspects of Fractal Dimension of İzmir

Statistical correlations between fractal dimension of the districts with respect to time and space is analyzed in order to seize the complexity pattern of the İzmir Region. Fractal dimensions of the districts in four periods are statistically analyzed whether there is a relationship with respect to time. In addition to correlation analysis, cluster analysis is studied whether a clustering trend in terms of fractal dimensions of the districts from late 1950s to present time exists. Furthermore, relationships between fractal dimension and the other parameters are conducted as;

*(i)Population*

*(ii)Population density*

*(ii)Acreage*

*(iv)Population density*

*(v) Network length*

*(vi)Network density*

Furthermore, relationship between fractal dimension change with *(i) population growth rate, (ii) network growth* rate are examined.

Firstly, fractal dimension of each period are analyzed whether there exist a statistically relevant correlation. A positive correlation between the first period (1959-1964) and the second period (1976-1980) is determined (*p<0,01)*. Between the other periods, any relevant relationship cannot be observed. In addition, correlation analysis has been run between districts including all four periods in order to understand the statistical relationship in terms of space. Positive statistically relevant correlations are determined for 14 districts. A rich triangular network is transpired among the districts in the northern and the eastern sub-regions. Furthermore, three horizontal relations are identified between *Çeşme-Güzelbahçe, Seferihisar-Torbalı* and *Kiraz-Menderes.* Those results could be interpreted that the similar fractal dimension change could be observed for the first two periods involving a continuous complexity pattern. However, regional dynamics altered during the third period in 1990s which may be resulted in the loose of significant correlation. In terms of correlative relations of the districts for four periods, it could be interpreted that districts in the northern sub-region and in the Bay fallow more similar complexity trend.

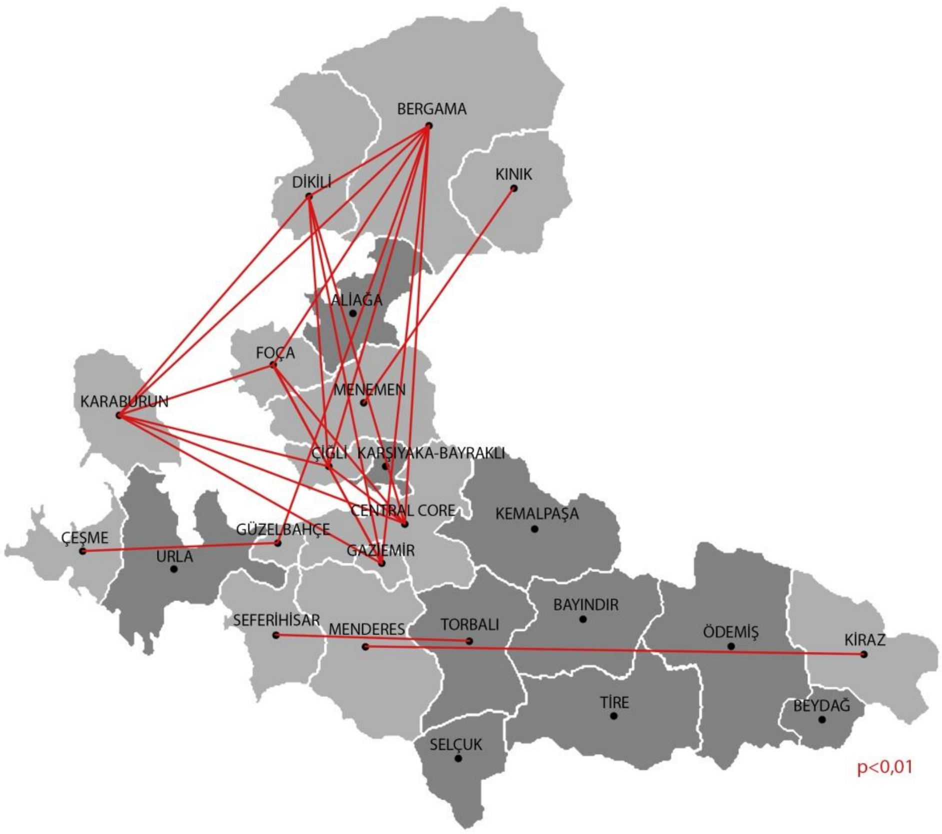



Figure 6-19 Statistical relationship between districts for all periods

In addition to correlative relations among districts, whether there exist clusters in terms of fractal dimension values are examined statistically. Fractal dimension values of all districts for four periods are firstly analyzed by hierarchical cluster analysis by using the nearest neighborhood method and Squared Euclidian distance in order to identify the outliers or extreme values. *Beydağ* is identified as an extreme case. Then, by using within groups-linkage method similar districts are investigated with respect to distance of each district with the other all. Eight clusters are identified from dendrogram while five districts do not fit in a cluster group. The number of clusters is verified by two-step cluster analysis by silhouette measure which measures how similar an object is to its own cluster (cohesion) compared to other clusters (separation). The average silhouette values is calculated as 0,4.

Hierarchical cluster analysis shows that *Central Core, Karşıyaka-Bayraklı Aliağa, Kınık* and *Beydağ* do not provide proximity with other districts in close distances with respect to fractal dimensions of all periods. Three districts in the southern part of the region as *Seferihisar, Selçuk* and *Tire* are forming a cluster. Despite none of them include interconnections in terms of correlation analysis, they have similar fractal dimension trends and all three have rural character enriched by more organized sectors like tourism or organized agricultural production. The second cluster is consisted of *Menderes, Menemen* and *Bergama.* All three districts have higher fractal dimension values with respect to mean of the districts and reached to their peak in the third period. All three are old districts existing since the Ottoman Period *(Menderes as Cumaovası)*, their rural network is fed by many villages involving an integrated agricultural based network pattern. They also experienced industrial or mining based modes of production beginning from 1990s. The isolated districts also compose two clusters as; *Kiraz-Dikili* and *Karaburun-Bayındır.* As the metropolitan small districts, *Çiğli* and *Gaziemir* are calculated as one cluster while more remote coastal towns as *Güzelbahçe, Çeşme* and *Foça* create a cluster. Multifunctional, organized semi-rural districts as *Kemalpaşa, Urla Torbalı* and *Ödemiş* also defined as one cluster.

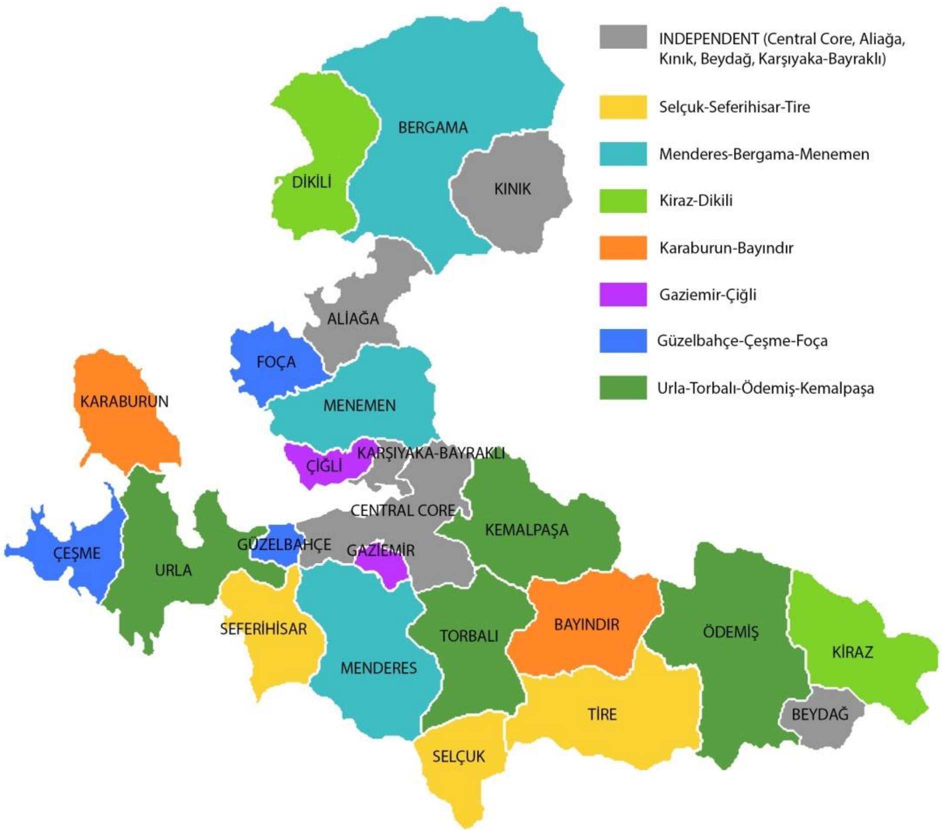



Figure 6-20 Hierarchical Cluster analysis of the fractal dimension of the districts for all periods

Despite hierarchical cluster analysis provide insights about the similarity/dissimilarity pattern of the districts, clustering is also run as fuzzy cluster analysis since city-region is aimed to be analyzed in order to understand the relations by a less deterministic and dynamic point of view. By fuzzy cluster analysis, firstly optimum cluster size is verified by cluster validity algorithms as; FCM, PCM and UPFC indices by “R Studio” software. Majority of the index values matrix proposes two clusters as the optimal number of clusters for fractal dimension values of districts for four periods.

Table 6-1 Results of the fuzzy cluster analysis of the districts in terms of fractal dimension values of four periods

| District | Cluster 1 | Cluster 2 |
|---|---|---|
| *Karaburun* | 0.570 | 0.430 |
| *Bayındır* | 0.626 | 0.374 |
| *Foça* | 0.825 | 0.175 |
| *Beydağ* | 0.679 | 0.321 |
| *Kınık* | 0.545 | 0.455 |
| *Kiraz* | 0.096 | 0.904 |
| *Bergama* | 0.118 | 0.882 |
| *Ödemiş* | 0.138 | 0.862 |
| *Tire* | 0.544 | 0.456 |
| *Selçuk* | 0.541 | 0.459 |
| *Çeşme* | 0.818 | 0.182 |
| *Seferihisar* | 0.572 | 0.427 |
| *Central Core* | 0.149 | 0.850 |
| *Menderes* | 0.144 | 0.856 |
| *Urla* | 0.097 | 0.903 |
| *Dikili* | 0.120 | 0.880 |
| *Kemalpaşa* | 0.233 | 0.767 |
| *Karşıyaka-Bayraklı* | 0.139 | 0.861 |
| *Menemen* | 0.748 | 0.252 |
| *Gaziemir* | 0.783 | 0.217 |
| *Çiğli* | 0.561 | 0.438 |
| *Aliağa* | 0.823 | 0.177 |
| *Güzelbahçe* | 0.823 | 0.177 |
| *Torbalı* | 0.092 | 0.908 |

The relative membership of the each district defines a more fuzzy system while there are resembling results with the deterministic clustering. The fuzziest districts in terms of cluster memberships are *Karaburun, Kınık, Tire* and *Selçuk.* The most stable districts in the first cluster are *Foça, Çeşme Aliağa* and *Güzelbahçe.* All of which do not exceed 0.825. However, second cluster have stronger stable memberships since all cluster members exceed the rate of membership ratio 0.850. Although measuring complexity is a multi-dimensional and non-predictable issue, there exists a tendency of clustering of the districts having more higher and stable fractal dimension.

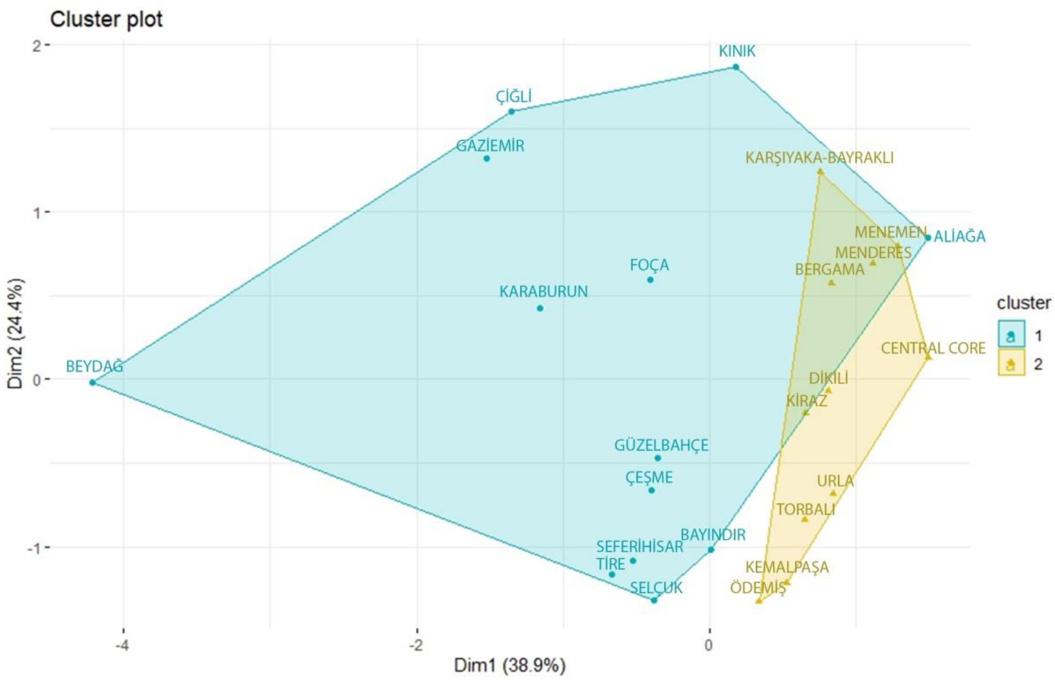



Figure 6-21 Cluster plot of the fuzzy cluster analysis of the districts in terms of fractal dimension values of four periods

When cluster plot of the districts are analyzed two outliers of the system can be interpreted *Beydağ* and *Central Core*. *Bergama*, *Menderes*, *Menemen*, *Dikili*, *Kiraz* and *Karşıyaka-Bayraklı* have two cluster memberships. The results also show that complexity in terms of fractal dimension of the network does not only depend on centrality since the parts which are called rural in terms of traditional urban-rural dichotomy may propose stable and higher fractal dimension values as observed in *Ödemiş.* Except Central Core, the other districts located in the second cluster more precisely are; *Kemalpaşa, Torbalı* and *Urla* which have rich rural network in first two periods and become metropolitan peripheral districts in the later.

### 6.1.4 Relational Aspects of Fractal Dimension with Growth Parameters

The statistical relationship between fractal dimension and different parameters are investigated in order to understand their effect on the complexity pattern of the system and whether the main arguments about those relationships discussed in the related literature is experienced for the İzmir's case. Furthermore, alterations in those relationships can be discussed with respect to periodical change in time. With respect to those aims, firstly statistical correlation analysis are run between fractal dimension and *(i), population, (ii) coverage area, (iii) population density, (iv) network length* and *(iv) network density.*

It is claimed that there exist a positive relationship between population and city size with fractal dimension while a meaningful relationship could not be identified with population density (Shen G. Q., 2002), (Batty & Xie, 1996), (Lan, Li, & Zhang, 2019). As observed in the extended region analysis, for the İzmir Region there exist significant positive correlation between fractal dimension and population in districts scale. For the first period there exist a positive relationship between the population of the first period with the fractal dimension of the first period ($p<0.01$). This positive relationship also continues in the fractal dimension of the second period ($p<0.01$). There exists a positive relationship between the population of the districts in the second period and their fractal dimension of the same period ($p<0.01$). However, a significant statistical relationship cannot be identified for the third and the fourth periods. Furthermore, direction of the correlation between population of the districts and the fractal dimension turned to negative in the fourth period. It can be interpreted that, there exist a positive correlation between population and fractal dimension until a threshold then the effect turn into negative by continuous increase in population for İzmir.

As further analysis of the relationship between population and fractal dimension central districts around the Bay is firstly analyzed consisting of *Central Core, Karşıyaka-Bayraklı, Güzelbahçe, Gaziemir* and *Çiğli.* Any significant relationship cannot be determined. When the rest of the districts are analyzed, a positive correlation can be identified for the first period ($p<0.01$) and for the second period ($p<0.05$). The direction of the relationship turns into negative for the last two periods although any statistical significance cannot be determined.

For the fractal dimension clusters determined by fuzzy cluster analysis, statistical relationship between population and fractal dimension of districts is analyzed. The districts having shared membership investigated for each cluster. Similar to the results of central districts, for the districts located in the first cluster, positive correlations are identified for the first period ($p<0.01$) and for the second period ($p<0.05$). Likewise, for the second cluster any significant relationship cannot be identified. In other words, population is correlated with the fractal dimension with respect to centrality, population threshold and complexity level. Relationship between population and fractal dimension weakens with higher centrality. Likewise, whether central or not with respect to metropolitan uses, there does not exist a correlation between fractal dimension and population for the districts having high and stable fractal dimension values. This relationship can be identified for less populated and less complex districts.

Similar to total population, fractal dimension change between the first and the second periods has a positive correlation with the population increase rate of that period ($p<0.05$). However, correlation of the fractal dimension change between the first and the second periods with the population growth rate for the fallowing periods as between the second to the third and the third to the fourth ($p<0.01$). This can be presented as relationships with respect to fractal dimension are not bounded by the period it is calculated for. On the contrary, cross-dimensional relations exist with respect to time.

Similar to the findings of related literature, any significant relationship cannot be identified between fractal dimension and population density. It is identified that both Pareto's law and Zipf's law can be associated with fractal distribution as there exist a positive correlation between fractal dimension and settlement size (Batty & Longley, 1994), (Chen & Zhou, 2003), (Frankhauser, 1998). Similar to population, positive relationship between fractal dimension of the districts and their acreage is determined only for the first two periods ($p<0.05$). However, the analysis is based on the administrative districts size rather than settlement borders. Therefore, a complete discussion cannot be interpreted with respect to network based fractal analysis with settlement sizes. This relationship is further investigated in terms of network length.

It is observed from the related literature about fractal analysis of the road system it is identified that there exist a positive correlation with fractal dimension and the network growth (Lu & Tang, 2004), (Chen, 2008), (Thomas & Frankhauser, 2013), (Chen & Jiang, 2016). Any statistically significant correlation cannot be identified for the first period. However, a positive correlation is determined for the second period between network length and fractal dimension ($p<0.05$). For the last two periods relationship cannot be identified for the related periods. Moreover, in the third and the fourth periods, direction of the relationship is turned from positive to negative.

The similar pattern is observed for the first fuzzy cluster of fractal dimension whereas any relationship cannot be observed for the second cluster. This relationship pattern is also observed in terms of centrality as well. Any relationship does not identified for the central districts around the Bay while a positive correlation is observed for the second period ($p<0.05$). Similar to population, it can be argued that the relationship between fractal dimension and network size is depend on centrality, stability and the level of the complexity. In other words, growth in network does not reflect on the complexity level for central or more complex districts. In terms of network density, and statistical correlation cannot be identified for none of the periods.

## 6.2 Chapter Discussion

In this chapter the relational aspects of complexity and population are investigated in order to identify how regional structure changed, which parts of the region have shared or similar patterns of development. Firstly, the hierarchy of districts in terms of population has been altered during the four periods. The first initial period is characterized by a growing core with population and network gain. Except the core, rest of the region is characterized by traditional rural pattern. Districts of *Ödemiş, Bergama* and *Tire* have the highest population share after the central districts. Those districts are central places of the agricultural network emerged through river basins. In the initial period, present touristic towns are inhabited by the least population. This trend is continued in the second period while the Bay gained more population with respect to other parts of the region. Despite increased dominance of the central core; *Bergama*, *Ödemiş* and *Tire* are still observed as one of the five populous districts of İzmir region. The third period defines a different pattern. Despite comparatively lower population growth rates observed between the first and the second period, population loss became more visible in the rural areas organized around the river basins. A negative population growth rate is firstly observed in *Beydağ*. Likewise, the least population growth rates are observed for *Kınık, Bayındır, Ödemiş* and *Tire*. *Bergama* also dropped below the first five districts having the highest population share. However, districts gained industrial investments and peripheral metropolitan quarters like *Çiğli, Menemen, Gaziemier* and *Aliağa* gained population. The other districts gained population are touristic coastal towns like *Seferihisar* and *Çeşme*. Despite decreased population growth rate, districts around the Bay are determined as the densest districts of the region. This finding could be interpreted as an increased push effect of the core. In the fourth period, population share of central core decreased while peripheral districts experienced the highest population growth rates like *Torbalı* and *Aliağa*. Population loss in remote rural accelerated since *Beydağ, Kiraz, Kınık, Bayındır, Foça* and *Karaburun* declined in terms of population. In the last period, in addition to the Bay, spinal development from north and to the south can be visualized in terms of population agglomeration and density. Those findings about population change over seven decades present main similarities with conceptualization of the region by background research. However, there exist supportive results and divergent findings in terms of complexity pattern of the region.

One of the most important finding of the study is that complexity alteration of the parts does not reflects the change in complexity level of the whole system despite, all are derived from the same network. In the first period, fractal dimension of six districts, all having rural character in that period, exceeded the fractal dimension of the whole İzmir Region. They are determined as (i) *Menderes*, (ii) *Kiraz*, (iii) *Ödemiş*, (iv) *Torbalı*, (v) *Menemen*, (vi) *Selçuk*, (vii) *Urla* and (viii) *Tire*. However; for fallowing periods complexity of the whole exceeded the parts. In the third period the gap between complexity of the parts and the whole reached to the peak. Furthermore, heterogeneity in complexity level of the parts decreased until the third period and then increased again in the fourth period. In other words, as the second important finding, increased complexity of the whole system emerged at the same time with narrowed gap between extreme fractal dimension values and less heterogenic complexity of the parts.

How the distribution of the most and the less complex district of the region altered in each period. For the first period, higher fractal values are observed along the fertile plain of the *Küçük Menderes* River. Furthermore, in the central districts around the Bay and around *Bergama* comparatively higher fractal dimension levels could be observed. The highest value is calculated for *Menderes*. In other words, between 1959 and 1964 complexity is firstly observed within non-urban network and secondly for metropolitan urban core. In the second period, comparatively more complex districts shifted around the Bay. The highest fractal dimension is calculated for *Karşıyaka-Bayraklı*, which is followed by central core. Nevertheless, rural corridors involving non-urban agricultural network pattern still have moderate fractal dimension values over “1,50”. The second period covering the time span between 1976 and 1980 could be summarized as the period of stronger metropolitan core with decreasing complexity of the rural backbone. In the third period another organization of the network is observed along development corridors. The most complex districts are located in the northern part of the region. An axis from the north to the central core and to the south became visible. While the network around the *Küçük Menderes* River loses its comparative complexity in the system, coastal districts exceeded the mean fractal dimension. With respect to those findings and the literature background it could be interpreted that late 1990s is characterized by the growth of peripheral metropolitan areas and coastal areas. When non-urban complexity has been diminished, peripheral uses and tourism destinations presents higher fractal values. The last period possess a decline in complexity both in terms of the whole and the parts despite further growth in network and population. The findings and regional structures are summarized in Table 6.2.

Table 6-2 Summary of Population, Fractal Dimension and Regional Structure

| Periods | Population | Population Density | Fractal Dimension | Regional Structure |
|---|---|---|---|---|
| **Period I** | High in the core, moderate in rural, low in the coastal parts | High in the core, moderate along Küçük Menderes Basin, low in coastal districts | High in both center and rural districts along river basins | Integrated (Complex urban and complex rural) |
| **Period II** | Higher in and around the center, moderate in rural centers | Higher in and around the central core, low in coastal and remote rural districts | Higher in central districts and moderate in rural basins | Monocentric regional structure (More complex urban) |
| **Period III** | High along Menemen-Center-Torbalı spine, moderate along the coasts and lower in rural | High around the İzmir Bay | Higher in the northern sub-region, decreased in the eastern sub-region | Complex axis along the corridors, regional metropolitan periphery |
| **Period IV** | High along Menemen-Center-Torbalı spine and metropolitan periphery | High along the northern spine and in spot industrial and touristic districts | Higher around the Bay and spot districts | Spot development with decreased integrity and centrality |

As the major aim of exogenous analysis, statistical relationships are examined with respect to fractal dimension. Firstly, fractal dimensions of the districts for each period are analyzed whether there are statistically relevant correlations or not. A positive significant correlation is observed only between the first and the second period. It is observed from regional background and district-base analysis that the second period is continuation of the initial period as a growing metropolitan core supported by rural network. Although there still exists non-urban areas in fallowing periods this dichotomous structure altered which could be interpretation of this finding. Secondly, districts are analyzed in terms of complexity among four periods by hard and soft cluster analyses. Hierarchical cluster analyses are run by nearest neighborhood method to identify extreme cases and by within groups-linkage method to identify similarities. The cluster formation shows that districts having similar regional growth trends through seven decades become member of the same cluster. By fuzzy cluster analysis, the relative membership of the each district is identified in terms of fractal dimension belonged to four periods. The main finding is that fractal dimension of the network does not only depend on centrality. Districts like *Kemalpaşa, Torbalı* and *Urla* which have traditional rural character in the first two periods and peripheral development areas in the last two periods propose stable and high fractal dimension values.

In Chapter 6, main findings about the relationship of fractal dimension with other parameters observed from literature review are also examined for regional road network in district level. A positive correlation between population and fractal dimension is found for extended region analyses as interpreted in related literature. For İzmir Region, this relationship is examined for each period for all districts. A significant statistical relationship could be identified for the first and the second period. The analyses are repeated for the Bay and the rest of the districts. Any significant relationship cannot be determined for the central area while a positive correlation can be identified for the first ($p<0.01$) and for the second period ($p<0.05$) for the rest. The analyses are also run for fuzzy cluster members. The findings show that there is not a correlation between fractal dimension and population for the districts having high and stable fractal dimension values. This relationship can be identified for less populated and less complex districts. In other words, population and fractal dimension relationship differs from related literature. However, similar to the findings of related literature, any significant relationship cannot be identified between fractal dimension and population density.

In addition to population, network size is the other parameter expected to have positive relationship with fractal dimension with respect to literature findings. Similar to population, positive relationship between fractal dimension of the districts and their acreage is determined only for the first two periods ($p<0.05$). The relationship is only identified for the second period between fractal dimension and road length. Despite inharmonious results with respect to literature findings, it is important to identify that the analyses are based on the administrative borders. Therefore, a complete discussion cannot be interpreted with respect to network based fractal analysis with settlement size or network length.

The other limitation about using administrative borders is about monitoring the complexity change. In order to understand how the parts are evolved in terms of complexity, changes in fractal dimension values are examined for each district. However, it is observed that fractal dimension change is sensitive to the size of the district and initial length of the network inside the district borders. For small districts in terms of size or network, little changes could lead to a major alteration in fractal dimension. This is also observed in hierarchical cluster analysis. Although district-based fractal analyses provide information about the complexity and growth trends, how complexity of parts of the system evolved is analyzed by sub-fractal analysis without appointing administrative borders in the next chapter.

# CHAPTER 7

## REPRESENTATION OF COMPLEXITY OF IZMIR BY SUB-FRACTAL ANALYSIS

The complexity of an urban region base on micro changes leading to macro changes in the system based on emergence. In other words, complexity of regional systems appears intrinsically. In order to identify the complexity of the system, two main questions arise such as;

(i) What is the endogenous patch-work or parts of the whole system in terms of different complexity levels?

(ii) How those parts of the system can be defined?

As it is stated in Chapter 3, fractal dimension of the parts of a fractal object can be measured by a mesh of non-overlapping boxes “Ns” with the size of “S”. The optimum mesh size can be attained by size based ratio optimization of the object. However, complexity theories present urban systems involve scaling, power law and hierarchy in terms of centrality. Therefore, the metabolism of the complexity of a city region’s parts could be obtained by space syntax tools via embeddedness level of large urban systems. The other method for attaining mesh size is to select available minimum pixel ratio of the system’s image that both methods are used in order to;

(i) Investigate the relationship between complexity and embeddedness and represent the region’s complexity without a given parameter,

(ii) Create comparable sub-fractal analyses of the system with respect to time,

## 7.1 Change of Complexity of İzmir Region with respect to Embedded Grid Size

Rather than analyzing complexity with respect to an exogenous border or territory, differentiation of complexity in the whole İzmir region's road system is provided by defining the mesh size through the fractal pattern in itself. For determination of the mesh size, space syntax approach is used since the axial maps involve fractal features, hierarchy and scaling which regional road systems have. Space syntax analysis can be defined as theories and techniques aiming to identify spatial characteristics of urban settlements via axial maps and convex spaces (Hillier & Hanson, 1984), (Volchenkov & Blanchard, 2008), (Hillier, Yang, & Turner, 2012).

There are various studies using syntactic tools for fractal generation or combination of two approaches for complexity analysis of urban systems. Kaya & Bölen (2017) investigated the morphogenetic pattern of İstanbul by using both space syntax and fractal analysis by resembling patterns of settlements to DNA of living organisms. Spatial parameters are classified into four categories as; (i) geometrical, (ii) topological, (iii) visibility-perception and (iv) complexity of urban patterns of İstanbul. Second and third parameters are constructed on syntatic values that fractal dimension analysis has been integrated to the study as a complexity measure. The sample cells are collected from a diagonal axis to catch different urban patterns. With building density ratios, global and local integration analysis, 3D enclosure analysis and lastly the fractal dimension of each cell is produced.

The other studies of Yamu and van Nes (2017), (2020) and Frankhauser et al (2004) propose integrated models combining space syntax and fractal analysis. For Southern France, Vienna and Bratislava metropolitan regions, space syntax modeling integrated to multifractal strategic development pattern identification. In this study it is explained that rather than pattern recognition or development potential generation, syntactic tools could be used for defining the embeddedness of the parts of a fractal system by metric measures.

Serra (2017) analyzed the road network of inside of Oporto’s municipal metropolitan borders from local scale (400 meters) to the regional scale (30.000 meters) by closeness centrality analysis which is a measure of the average distance of each node to the entire network (Figure 7-1). The main outcomes of this study can be summarized as; at local scales like 400 meters, small centers can be visualized including small ancient towns, inner cores of larger settlements and emergent centers. By increasing the spatial scale, small centers disappear while the metropolitan core began to appear. This observation is reported to be maximized at 3800 meters while centrality disappears at larger scale while a very large central zone dominates the entire metropolitan region (from 14700 to 30000 radii). With respect to correlations depending on principal component analysis, three centrality scales are determined as; neighborhood (400-1200 meters), city (1200 to 8200) and region (8200 to 30000).

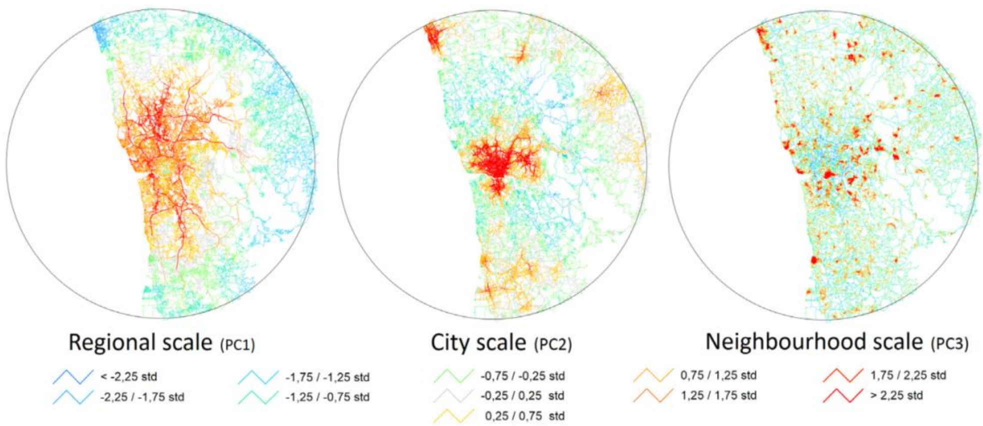



Figure 7-1 Centrality pattern by the principal component analysis (Serra, 2013, p. 192)

A wider study is conducted for the complete road network of United Kingdom that the results of the study are compared by spatial socio-economic variables and movement flows by correlation analysis (Serra, Hillier, & Karimi, 2015). Three graphs for centrality algorithms are used by metric radius as; node count, angular integration and angular choice. The metric radiuses attained from 10 kilometers to 50 kilometers. For vehicular movement it is found that all measures are capable of measuring centrality in terms of movement flow for medium radii (from 10.000 meters to 20000 meters as the best fit).

For the central area of Leeds Krenz (2017) analyzed closeness and betweenness centrality with segment length weighting on different radii from 100 meters to 6100 meters as well as "n". Then correlation analysis is run for each radius for different methodologies of segment maps. *The other study based on the differentiated radii effect is the study of Yang and Hillier (2007).* One of the sole approaches identifying the radius in a larger urban system is "patchwork theory". It is based on spatial differentiation of the background urban network into a patchwork of local areas. The patchwork structure represents metric and local effects. The effect of radius on centrality is explained by Yang (2007) as;

"$\mu(v,r)$, of node $v$ for radius $r$ as local metric mean depth as;

$$\mu(v,r) = \frac{1}{N(v,r)} \int_0^r x \frac{\partial N(v,x)}{\partial x} dx \tag{20}$$

where $x = x(v,u)$ is metric depth of node $u$ from the reference node $v$ and $N(v,r)$ is the number of nodes with $x(v,u) \leq r$ and

$$N(v,r) = \int_0^r \frac{N(v,x)}{\partial x} dx \tag{21}$$

$$\Theta(v,x) = \frac{\partial \log N(v,x)}{\partial \log x} = \frac{x}{N(v,x)} \cdot \frac{\partial N(v,x)}{\partial x}$$

Where the rate of change of node count $\Theta(v,x)$ *of metric mean depth so;*

$$\frac{\partial N(v,x)}{\partial x} = \frac{N(v,x)\Theta(v,x)}{x} \tag{22}$$

By substuting (22) into (20);

$$\mu(v,r)\, N(v,r) = \int_0^r N(v,x)\, \Theta(v,x)\, dx \tag{23}$$

where $\mu(v,r)$ $N(v,r)$ is total metric mean depth; differentiating both sides of equation (5) with respect to *r;*

$$\frac{\partial \mu(v,r)}{\partial r} N(v,r) + \mu(v,r)\frac{\partial \mu(v,r)}{\partial r} = N(v,r)\,\Theta(v,r) \quad (24)$$

$$\frac{\partial \mu(v,r)}{\partial r} N(v,r) + \mu(v,r)\frac{N(v,r)\Theta(v,r)}{r} = N(v,r)\,\Theta(v,r) \quad (25)$$

$$\frac{\partial \mu(v,r)}{\partial r} + \frac{\Theta(v,r)}{r}\,\mu(v,r) = \Theta(v,r) \quad (26)$$

Since metric mean depth and radius have the same linear dimension, the first derivative term in equation (26) must be independent of $r$ as; $\partial\mu(v,r)$ / $\partial$r = c($v$) < 1. Sı equation (26) can be expressed as;

$$\mu(v,r) = r\left(1 - \frac{c(v)}{\Theta(v,r}\right)\text{''} \quad (27)$$

By those equations it is expected that there is a positive correlation between node count change and metric mean depth. If radius increases, Yang (2007) explains three possible routes of development can be observed as;

*(i)* $\mu(v,r)$can increase while $\Theta(v,r)$ decreases,

*(ii)* $\mu(v,r)$can increase while $\Theta(v,r)$ remains stationary,

*(iii)* $\mu(v,r)$can increase while $\Theta(v,r)$ increases

It is noted that these different development routes induce an inversion of centrality that more central nodes at smaller radii tend to be decentralized at larger radii. This relationship depends on scaling between the radius and its node count (Yang, 2007), (Hillier, Turner, Yang, & Park, 2010). *The other sole explanation of the study of Yang and Hillier (2007) was conducted to find which syntatic variable can be used to illustrate the process of embeddedness of urban space.* As Hillier et al (2010) states Yang's measure of node count change of (NCr+r/2) / (NCr-r/2) produces a very similar result to MMDr (Metric mean depth at the given radius) means that one measure explains the other. In addition, Dalton (2005) explains that for restricted radiuses, simple segment count is the strongest component of the integration measure whereas the local urban correlations between total depth and integration break down for larger radii.

The axial model corresponds to a total network length of 7469, 11206, 25660 and 32671 kilometers for the each four periods respectively. Firstly the axial maps are produced via digitalized road network for each period. Then it is converted into a segment map. For each four periods different radii from 250 meters to 50.000 meters radii are analyzed including 250m, 500m, 1000m, 2000, 5000m, 10.000m, 20.000 m and 50.000 m in order to identify the neighborhood pedestrian scale to whole region's system. 50.000 meters is determined with respect to the size of the system that the network's widest elliptical approximated radius is 100 kilometers while the narrowest is 25 kilometers. For identifying the global system, analysis of radius "n" also calculated.

For each period, correlation analysis both for the total node count and node count change rates are run in order to identify in which radius this correlation level is calculated as the highest before the decentralization effect is observed. The results of the process of embeddedness of urban space in terms of changing radii is observed and compared with the centrality measures and then real world data acquired from the maps and literature search about regional history. For each period, the breaking point is observed as the centrality-embeddedness scale, in other words, a radius for local centrality is observed. Then sub-fractal analysis is conducted by Frac_Lac software by box-counting method by taking the mesh side equal to the radius obtained from syntactic measure.

For the first period, correlation analysis is conducted for both total node count change rate and total nodes with the metric mean depth. The correlation coefficients show that before the continuous increasing trend as the decentralization, radius of 5000 meters is observed as having the highest correlation rate as a breaking point. Representation of sub-fractal analysis with respect to 5000 meters radius is presented in Figure 7-2. In the first period, higher complexity levels could be observed in the northern sub-region and southern sub-region in rural pattern. Except central core, coastal effect in complexity level could not be observed. A scattered high complexity pattern is also observed in the eastern sub-region and the district center of Tire.

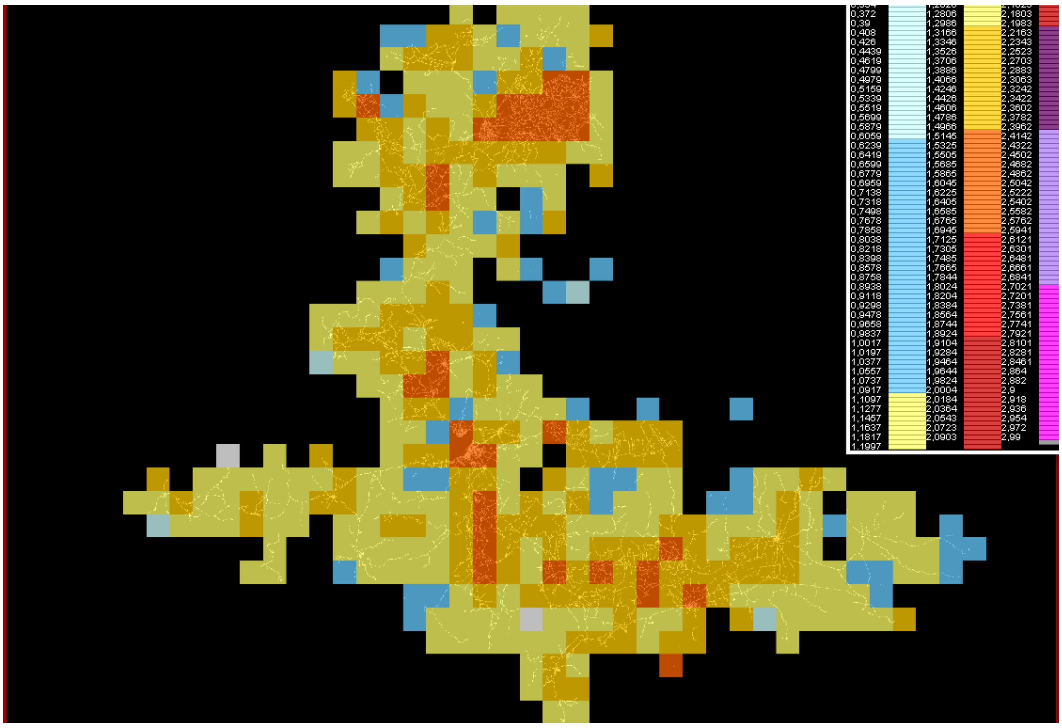


Figure 7-2 Sub-fractal analysis of the first period (1959-1964) for the radius 5000 meters

For the second period the correlation coefficients show that, the highest correlation is observed for the radius of 1000 meters for both node count and node count change. Representation of sub-fractal analysis with respect to 5000 meters radius is presented in Figure 7-3. For this period, the mesh size is decreased and more homogenized complexity pattern is observed. Higher fractal dimensions are observed around the central core while rural areas comparatively reach to lower complexity levels.

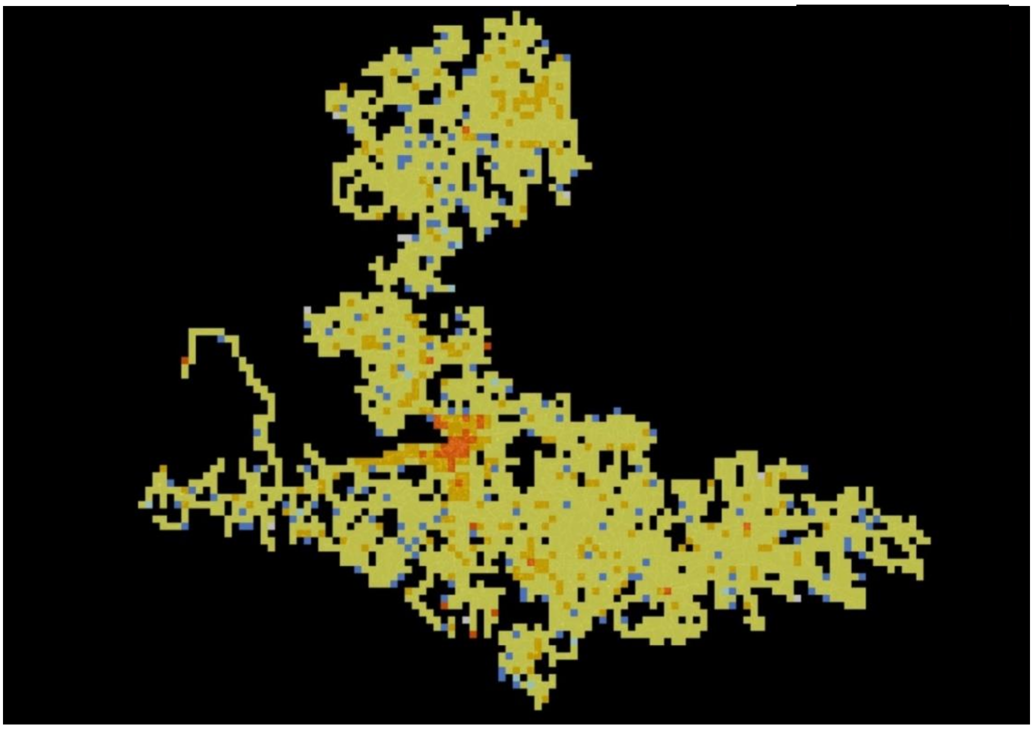


Figure 7-3 Sub-fractal analysis of the second period (1976-1980) for the radius 1000 meters

Since the period having the highest fractal dimension values both for the whole regional system and the districts' mean, system of *İzmir* region mainly altered from the second to the third period. The highest correlation fit in terms restricted metric radius is determined as 500 meters both for node count and node count change rate correlation with metric mean depth. The main outcome is observed as a revitalized higher complexity level of the parts. Enlarged central core still dominates the region by higher complexity like the previous period. Which is different from the first two periods is that complexity is mainly observed in urban areas including district centers and coastal towns different from the first period (Figure 7-4).

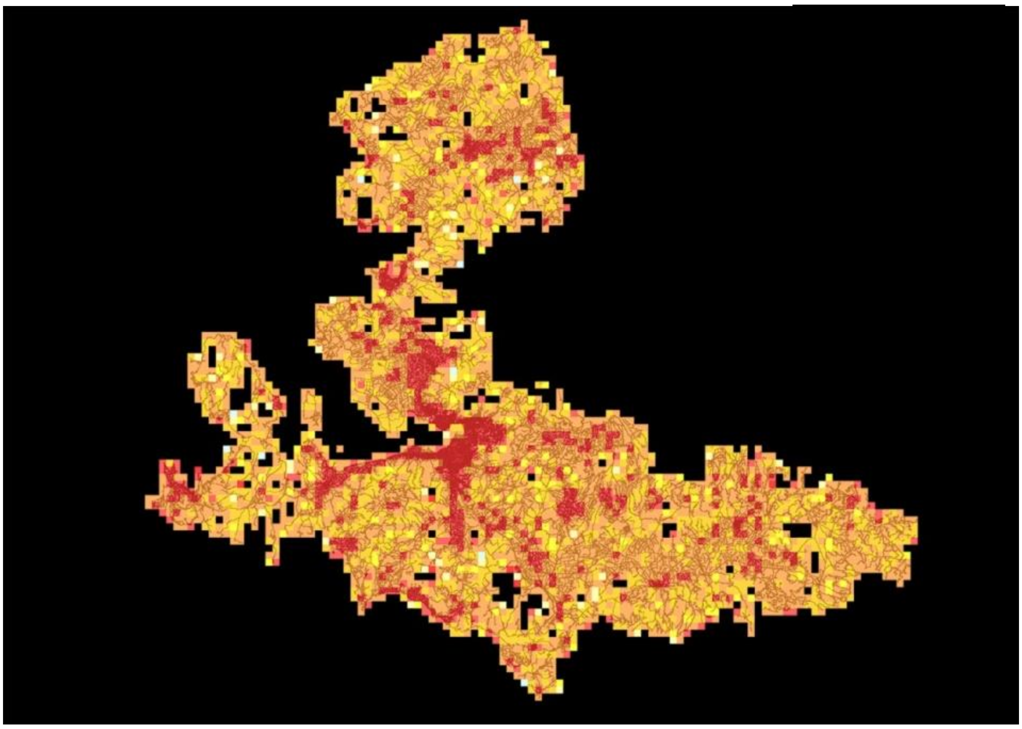


Figure 7-4 Sub-fractal analysis of the third period (1959-1964) for the radius 500 meters

The last period is characterized by increased network length, density with a decreased total fractal dimension of the whole system. For the last period, the turning point of the correlations is determined for the radius of 5000 meters. Increased radius of embeddedness is resulted in a clarified macroform of the central core which lies from the Bay to the north and south by an enlargement to the east. In addition, higher fractal dimension leap around the periphery of central core and coastal areas. Similar to the third period, higher complexity is mainly related with the existence of urban uses including industry, tourism or dense housing. Sub-fractal dimension analysis of the fourth period with respect to optimum radius is presented in Figure 7-5.

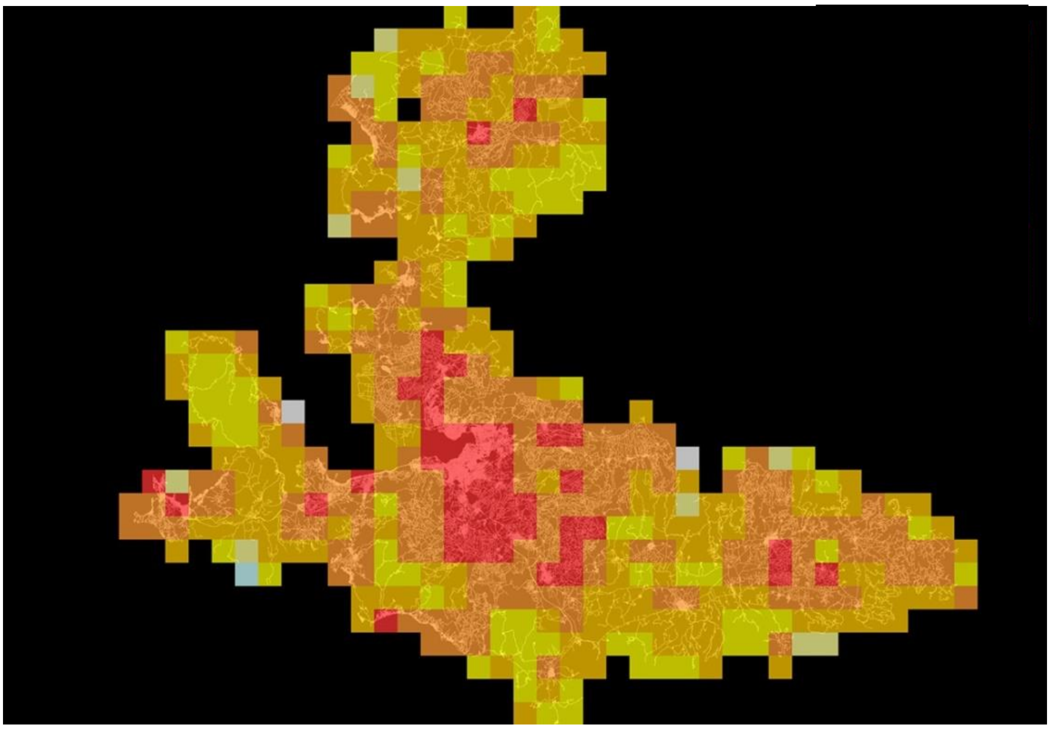


Figure 7-5 Sub-fractal analysis of the fourth period (2012-2017) for the radius 5000 meters

The change of the endogenous complexity through the four periods of the network system provides relevancies and differences with the exogenous analysis. System's fractal dimension increased until the third period and decreased in the fourth period again. Likewise, radius shows that the spatial embeddedness decreased until the third period while increased again in the fourth period. Even though, centrality expanded and complexity decreased, minimum and maximum fractal dimension values do not altered with respect to the previous period (Table 7-1).

Table 7-1 Change of embeddedness and complexity

| | r (m) | FD of the whole system | Mean FD of the parts |
|---|---|---|---|
| Period I (1959-1964) | 5000 | 1,502 | 1,313 |
| Period II (1976-1980) | 1000 | 1,581 | 1,343 |
| Period III (1996-2000) | 500 | 1,819 | 1,521 |
| Period IV (2012-2017) | 5000 | 1,724 | 1,492 |

Relevant to the exogenous and endogenous analysis, centrality occurs in the central core and in some districts acting as rural centers. Meanwhile, higher fractal values are observed in the rural areas in the northern, southern and the eastern parts of the region. Higher fractal values are both related to urbanity as well as fertile agricultural land reserves. Even they present higher complexity levels, centrality could not be observed in those areas. For the second period, complexity levels of agricultural pattern decreased while centrality increased with a spatial expansion. Both complexity and centrality is visualized with urbanity although, agricultural central districts still involve centrality. The network system mainly altered during the third period. It is observed that complexity levels of the ex-urban areas increased again. The main difference is that centrality spots could be observed through the region that rather than being completely rural, a transitionary pattern emerged. Furthermore, metropolitan core dispersed along corridors which create a blurriness of rural and urban patterns. In addition to peripheral developments, coastal towns gained centrality and complexity like an urban core. In the last period, the homogeneity in endogenous complexity levels decreased. While peripheral areas of the metropolitan core and the coastal lines present higher complexity levels, they do not possess centrality. In this period, embeddedness of the space as a measure of centrality increased again. In addition, fractal dimension values decreased except spot points in spite of population and network growth. All those developments could be argued as a result of urban sprawl that in the last period, growth is not related with the increased complexity and integration of the region.

## 7.2 Comparative Sub-fractal Analysis of İzmir Region

As the first aim of the study in order to investigate the endogenous complexity of *İzmir* region, sub-fractal analysis is conducted by *Frac_Lac* software by using box-counting method. The analysis is carried out by 1% image sub-scan as 500 meters radii in order to preserve all measures equal and to sustain comparable maps with respect to time.

From the sub-fractal analysis of the first period, except the empty pixels, fractal dimensions ranged from "1.1" to "1.7". The highest values are observed for the core central area, the vertical liner axis through the south, the *Bergama* region. Moreover, *Aliağa. Konak* and *Karşıyaka* can be observed as the districts having the highest complexity levels. *Buca, Gazimemir, Menemen* and their close vicinity is also observed as the areas having high fractal values as well. In the first period, coastal development along the Bay, mainly reaches to *Göztepe.* This period is characterized by higher complexity in the central core while heterogeneous complexity levels could be observed in smaller districts and rural network.

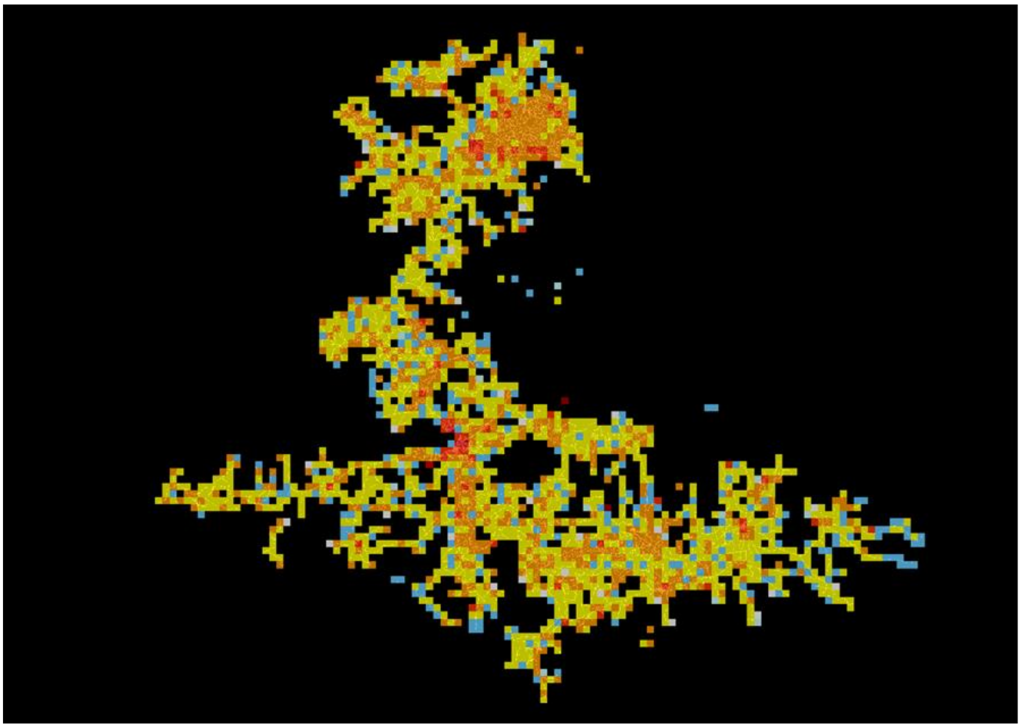


Figure 7-6 Sub-fractal analysis of the first period (1959-1964)

For the second period covering a time span from 1974 to 1980, it is seen that complexity levels of the rural patter declined with respect to the first period. The gap between the highest and the lowest values increased. The highest values are observed for the central core which exceeds "1.8". In other words, dominancy of the central core increased from the first to the second period. The variety of the complexity levels diminished from first to second period that the region became a more mono-centric system. Furthermore, complex metropolitan core area enlarged. *Konak, Karşıyaka* and *Bayraklı* possess higher fractal dimension values. However, in the second period, the northern coastal development does not linked to the *Alsancak-Kordon.* The similar discontinuous higher complexity values could be observed in *Gaziemir, Buca and Karabağlar.*

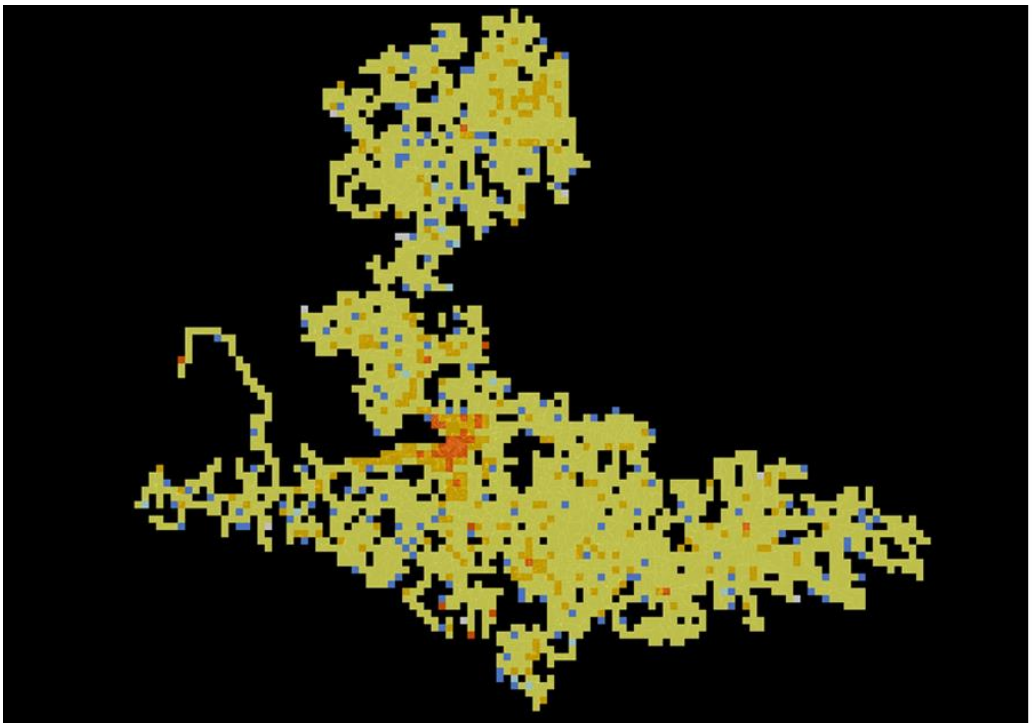


Figure 7-7 Sub-fractal analysis of the second period (1959-1964)

As the period having the highest fractal dimension values both for the whole regional system and the districts' mean, system of *İzmir* region manly altered in the third period. Sub-fractal analysis of the period presents higher fractal values with respect to the previous decades. The smallest value is calculated as "1.02" and the maximum is "1.903". The highest values are observed in the core central area including *Karşıyaka- Bayraklı, Buca, Karabağlar* and *Gaziemir*. Although, urban core have high sub-fractal values, regional complexity could be observed with a spatial variety with respect to the second period. Higher sub-fractal values concentrate around *Urla, Çeşme, Aliağa* and *Menderes* like the central core. Furthermore, scattered but higher fractal dimension values of the system could be observed around the vicinity of *Kemalpaşa, Torbalı* and *Seferihisar*. Transition of the agricultural divisions to peripheral development mainly resulted in higher complexity levels along the corridors. The eastern part of the region presents lower fractal values with spot complex nodes. The sub-regional pattern of *Bergama* still exists while dominancy of the integrated network diminished with respect to the first and the second periods. There exists a sole macro-form change for the regional center of *İzmir.* The peripheral districts became a part of the central core's system. A complete integration and continuity of the core could be observed for *Buca, Bornova, Karbağlar, Çiğli, Menemen, Menderes* and *Gaziemir*. The coastal development along the southern Bay reaches to *Urla*.

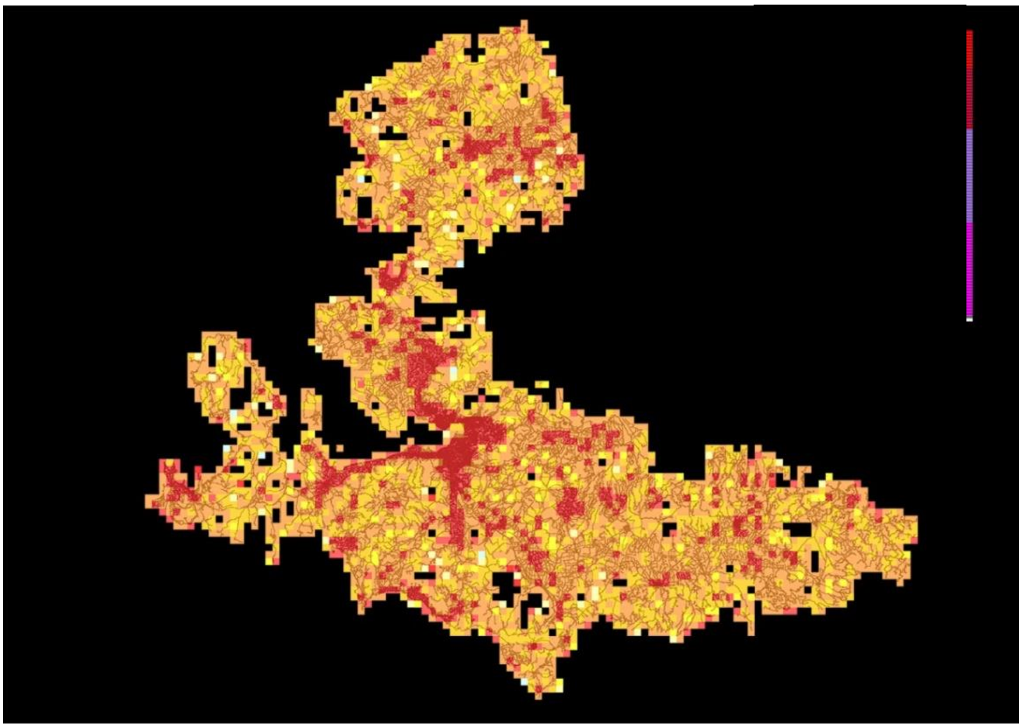


Figure 7-8 Sub-fractal analysis of the third period (1996-2000)

The last period is characterized by increased network length, density with a decreased total fractal dimension of the whole system. When regional sub-fractal analysis of the fourth period is analyzed it is observed that metropolitan central core enlarged with a degree of urban sprawl including discontinuous decentralization. The range of values does not much altered and varies from "1.01" to "1.92". However, distribution of the high and low values changed that core central area completely linked to *Menemen* as a northern corridor. Likewise, the corridor development along *the Bay-Gaziemir* and *Menderes* enlarged. The shift of the core also could be observed around *Torbalı* and *Kemalpaşa*. Higher spotted fractal dimension values could be observed in *Çeşme* peninsula and relatively low values could also be identified in some spots around *Urla*, *Seferihisar* and Bergama. With respect to the lower values observed in the third period, the district center of *Ödemiş* and the neighborhood of *Kaymakçı* represent higher fractal dimension values in the fourth period.

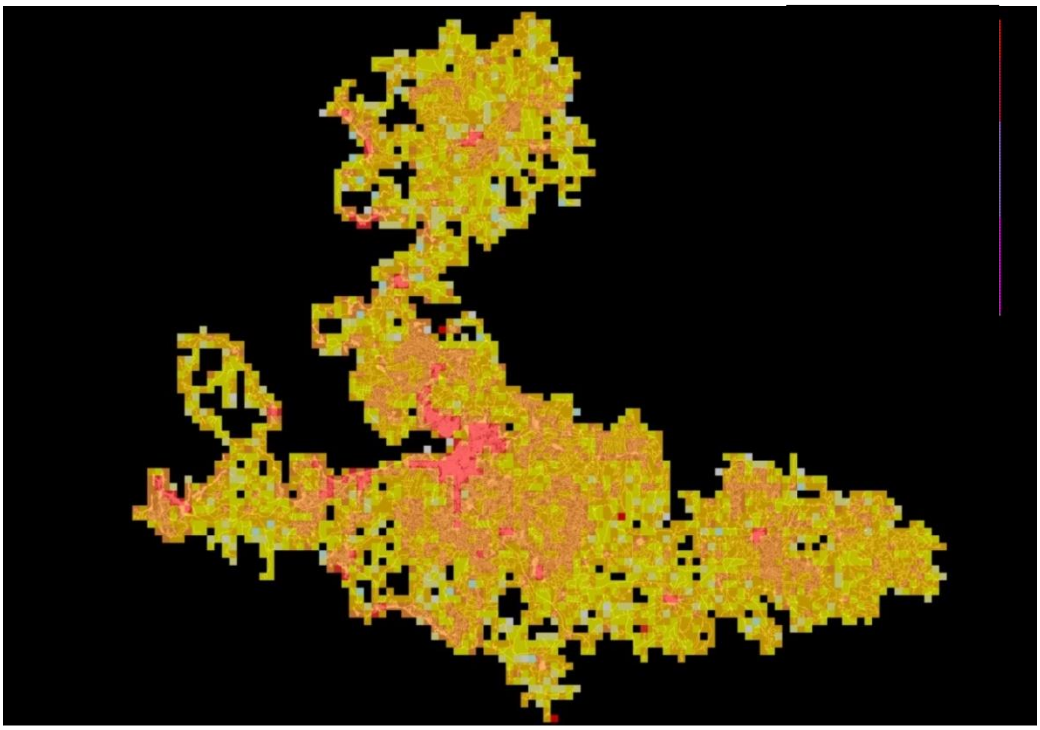


Figure 7-9 Sub-fractal analysis of the fourth period (2012-2017)

When the evolution of the region is analyzed by 3% pixel sub-scan analysis by 5000 meters radius, major changes of the system of the network could be observed. The dominancy of the rural complexity diminished from first to the second period. The monocentric structure of the second period evolved into a sprawled and polycentric pattern in addition to spot developments along the coasts in the third period. In the last period, higher fractal dimension values decreased in rural quarters. Rather than the monocentric structure observed in the second period, a sprawled and enlarged metropolitan network could be identified. Furthermore, spot higher fractal dimension values could be seen in rural district centers and coastal towns evolved into contemporary secondary housing and touristic quarters.

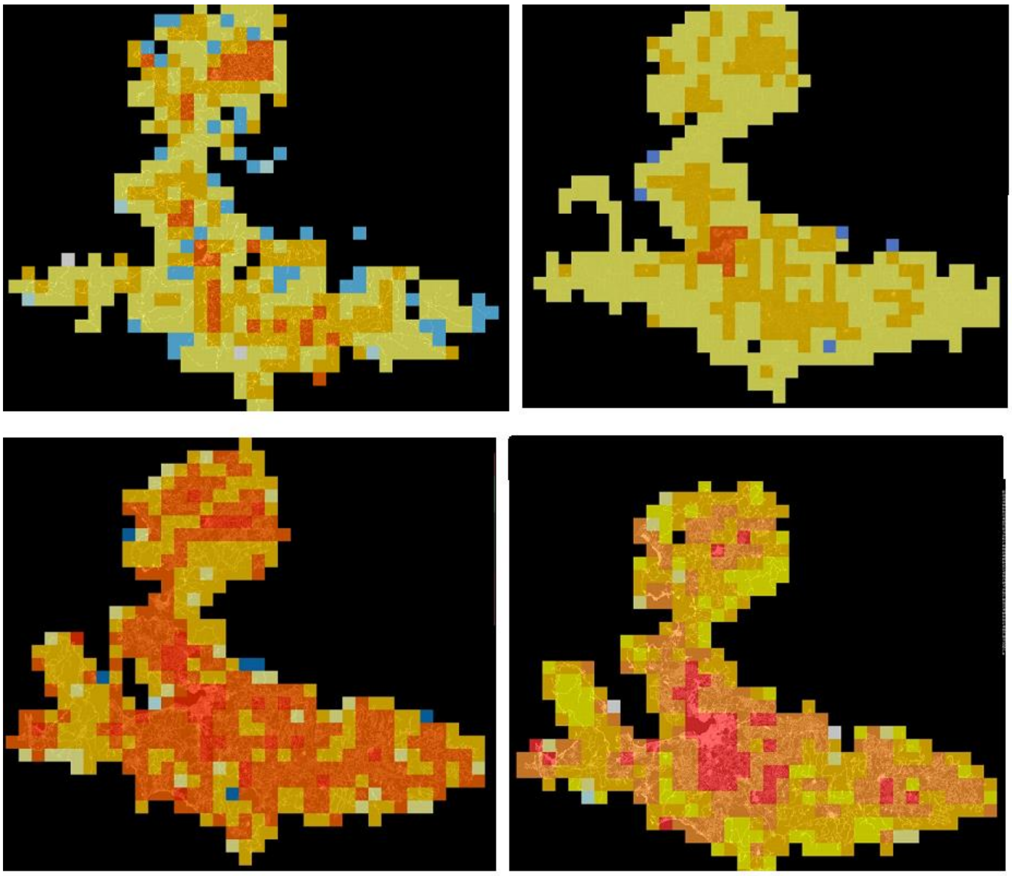


Figure 7-10 Comparative sub-fractal analysis from the first to the fourth period by (3% sub-scan)

Sub-fractal analysis of the central core presents the alterations in the complexity from the first to the fourth period covering a time span approximately seven decades. Complex areas are concentrated around Bayraklı, Karşıyaka, coastal Karabağlar vicinities in the first period. Due to irregular and integrated network they have, squatter zones are also observed as complex patterns in the first period.

In the last period, coastal development, densification of the whole metropolitan area could be observed. The discontinuous centrality which is started in the third period from Karşıyaka to Menemen is observed as a corridor development. Çiğli also became a part of this corridor. Bornova is also linked with Bayraklı with a similar pattern. The southern corridor presents more heterogeneous centrality and complexity values. From regional analysis the southern corridor sprawls both through Torbalı and Menderes. The coastal development of the Bay, reaches to Urla that neighborhoods of Yaka and district center of Urla presents integrated with the central core's organization.

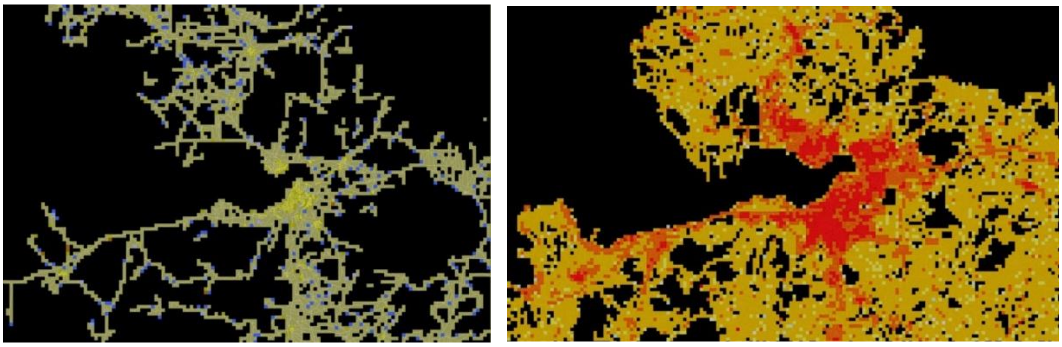


Figure 7-11 Sub-fractal analysis of the central core in the first and the fourth periods

## 7.3 Chapter Discussion

In this final chapter, a new method for regional complexity analyses as a modified sub-fractal analyses results are presented. The findings involve relevancies and differences with the exogenous analysis. As the first approach, mesh size is determined with respect to syntactic calculations. The radii of the each period are observed as; 5000 meters, 1000 meters, 500 meters and 5000 meters respectively. The system's fractal dimension increased until the third period and decreased in the fourth period again. Likewise, the radius showing the spatial embeddedness decreased until the third period while increased again in the fourth period. As the second approach, sub-fractal analyses are run by 1% image sub-scan by taking 500 meters radius in order to preserve all measures equal and to sustain comparable maps with respect to time. In the first period the highest values are observed for the core central area, the vertical liner axis through the south, the *Bergama* region which present similar but more refined finding of exogenous analyses. Relevant with background literature and settlement macro-form observed from the maps, coastal development along the Bay, mainly reaches to *Göztepe*. This period is characterized by higher complexity in the central core while heterogeneous complexity levels could be observed in smaller districts and in rural network. For the second period it is seen that complexity levels of the rural pattern declined with respect to the first period which is a relevant finding with exogenous analysis. The gap between the highest and the lowest values increased. Meanwhile, central core around the Bay possess higher complexity despite of lower values in the rest of the region as a mono-centric structure. The third period is observed as the period having the highest fractal dimension values both for the whole regional system and the districts by exogenous analysis. Likewise, sub-fractal analysis of the period presents higher fractal values with respect to the previous decades. The highest values are observed in the core central area. Nonetheless, regional complexity could be observed with a spatial variety with respect to the second period solely close to *Urla, Çeşme, Aliağa* and *Menderes*. Furthermore, scattered but higher fractal dimension values of the system could be observed around the vicinity of *Kemalpaşa, Torbalı* and *Seferihisar*. Transition of the agricultural divisions to peripheral development mainly resulted in higher complexity levels along the corridors. The peripheral districts became a part of the central core's system. The coastal development along the southern Bay reaches to *Urla* which fits to the regional background of *İzmir*. When regional sub-fractal analysis of the fourth period is analyzed it is observed that metropolitan central core enlarged with a degree of urban sprawl including discontinuous decentralization. The range of values is not much altered with respect to the third period. However, distribution of the high and low values changed. In the last period, core central area completely linked to *Menemen* as a northern corridor. Likewise, the corridor development along the Bay-*Gaziemir* and *Menderes* enlarged. The shift of the core also could be observed around *Torbalı* and *Kemalpaşa*. Higher spotted fractal dimension values could be observed in *Çeşme*. With respect to the lower values observed in the third period, the district center of *Ödemiş* and the neighborhood of *Kaymakçı* represent higher fractal dimension values in the fourth period. The coastal development of the Bay, reaches to *Urla* that neighborhoods of *Yaka* and district center of *Urla* presents integrated with the central core's organization.

When the findings of sub-fractal analyses of İzmir as endogenous complexity are investigated, it is observed that the dominancy of the rural complexity diminished from first to the second period. The monocentric structure of the second period evolved into a sprawled and polycentric pattern in addition to spot developments along the coasts in the third period. In the fourth period, it is seen that fractal dimension values decreased in rural quarters. Meanwhile, a sprawled and enlarged metropolitan network could be identified. Beginning from the third period and continued in the fourth period, spot higher fractal dimension values could be seen in rural district centers and coastal towns.

# CHAPTER 8

# CONCLUSION

Investigating development of urban areas with respect to complexity science has become a preliminary study area of urban and regional planning due to two main reasons. The first one is changing dynamics of centralization and decentralization processes and increased mobility of flows in global areas. The second is the changes in conceptualizations of urban geography by paradigm changes in natural and accordingly social sciences.

The first reason is argued under the head of global or planet scale urbanization concepts suggesting redevelopment of a new urban epistemology. The main claim is effects of urbanization could be observed in every piece of earth. Planetary urbanization arguments have also similarities with international trade and regional economic theories. They include agglomeration and de-agglomeration trends in global urban geography, dissolution of core and periphery structure, ease in flow of goods, firms, individuals and information by enhanced infrastructure. Under the light of those discussions the traditional concepts of urban, rural, core, periphery and region are challenged.

Those conceptions of urban epistemology mainly take its roots from philosophy of science, mainly natural sciences. As the core of the urban epistemology, space and time conception altered by paradigm change of classical physics. Both the linear and periodical time conception and Neo-Kantist representation of geography based on Euclidian geometry are challenged by relativity and emergence. Furthermore, deterministic and positivist conceptions and predictions changed by Uncertainty Principle of Quantum Theory, Chaos Theory and other contributions. Likewise to paradigm change in physics, dissolution of instrumental rationality, Game Theory, Schelling’s Theory altered the conceptions about decision making process of individuals which have two directional relationships in terms of production of space. Under the light of those conceptions, settlements and settlements systems have been conceptualized as complex, non-linear, non-predictable systems. Complexity science has been applied to cities and regions by different methods in order to create a conceptualization from a new epistemological point of view. Under the light of those arguments, this study aims to analyze the relationship between the complexity of İzmir Region, which involves a system of settlement network embedded in non-urban, semi urban or natural areas, with regional development trends in the long run. Furthermore, it is aimed to represent the endogenous complexity change of İzmir Region by developing a combined and revised method of fractal analysis.

## 8.1 Overview of the Research

In order to investigate the relationship between complexity approaches with regional change, a gradual literature review is presented in Chapter 2 and Chapter 3. Firstly, approaches sustained or altered from classical urban theories are explored. Then different complexity approaches regarding cities as complex systems are presented to identify appropriate methods with respect to data availability and context of the background. As observed from literature review about conceptualizing urban geography by complexity issues, division of rural and urban areas have become blurred. As a result, determination of urban boundary could be regarded as deterministic and uncertain. In other words, where the city begins and ends could not be represented by territorial differentiation since relations emerge through networks and nodes. Secondly, urbanism has been conceptualized as a metabolism. Traditional understanding of urban is altered and evolved through non-urban areas that involve intrinsic and exterior relations. Throughout those findings, a larger or regional context is aimed to be investigated comprehending urban, non-urban or partly urban areas. The other finding from complexity approaches can be explained that cities present chaotic behavior in the long run that steady states or slow processes is followed by fast processes and turbulences in the short run. In order to catch the chaotic motion, in this study it is aimed to examine the change of a region as much time as possible with respect to data availability.

Advances in technologies including satellite images and remote sensed data provide spatial information for complexity studies in the short run. For the decades before 2000s, aerial photographs could not be obtained for larger territories. Thus, maps are needed to be used to analyze larger time spans for complexity analysis. Since the main aim of this study involves comparative changes of the same spatial context with respect to time; detail level, symbols, signs as the language of maps are needed to be set as stable. Due to those reasons, for regional analysis of a long time span, standardized maps produced by public institutions are used. Two institutions produce regular and standardized maps for different purposes in the Republic of Turkey. First institution is General Directorate of Highways that produces highway maps for decades involving road network information. Secondly, General Directorate of Mapping produces military maps since early 20th century. Those maps are produced in different scales involving different detail. The most detailed maps are scaled to 1/25.000 having information about borders, transportation system, stain shaped macroform of major settlements, groves, wetlands and landmark notations. They have standardized legend which does not change with respect to location or time period the map is produced.

After investigation of the approaches and the source of data, selection criteria of the case study area are constructed with respect to classical urban models. The case study area is aimed to present hierarchy of central places which are accepted by both classical and complex approaches. Thus, rather than a mono-centric city, city-regions of Turkey which comprises network of settlements are evaluated that Muğla, Antalya, İstanbul and İzmir fit to that criteria. The second filter is observed as the variety of sectors the city region presents. İstanbul as a giant metropole is regarded as an extreme case of regional complexity analyses that does not involve traditional rural tissue. Likewise, Antalya and Muğla have poly-centric structure whereas settlement hierarchy is mainly organized with respect to coastal tourism. İzmir, as the third largest city of Turkey, have a metropolitan core while at the same time have a rich regional network of settlements specialized in different sectors. All non-urban wildlands, industrial quarters, farm-based classical rural zones, touristic settlements and large public investments could be observed around and inside the İzmir Region. Therefore, the case study area is selected as İzmir.

Then the data acquisition process and regional literature review are investigated for İzmir. The earliest standardized maps of two public institutions comprehending whole region are belonged to 1950s. As a result, time context of the study is determined with initial period started from 1950s. Except maps, the only available and regular data is observed as population before 1990s. Population data is acquired from Turkish Statistical Institute. Then complexity approaches presented in Chapter 2 are re-evaluated in order to determine which approaches could be applied with respect to available regional scale and long-run data. Since maps of public institutions do not involve building plots, fractal dimension analysis method is selected to investigate the complexity of İzmir region from 1950s to present time.

In Chapter 3 definition and methods for fractal analysis of settlements and settlement systems are presented. With respect to literature survey, firstly content of the study is determined. Fractal objects for regions as systems of cities involve transportation network, settlement macroforms and building plots. The acquired maps involve information of settlement stain macroforms and different hierarchies of road system among them. For seeking the complexity of the whole system without a lens of urban-rural dichotomy, road system is selected to be analyzed as the fractal object.

Then the context of the study area is decided with respect to findings of literature review about fractal analysis. Cities and city-systems are not perfectly self-similar and they are partially scale-free. In addition it is observed from regional background of İzmir presented in Chapter 4 that system of the region exceeds the provincial borders. Therefore, two contexts for regional analysis are determined which are (i) extended region and (ii) İzmir region. From complexity analysis of road network, it is observed from case studies that roads are determined as tresh-holds to preserve continuity of the network. Therefore, extended region is determined by taking roads as frame of the analysis covering an area described as outer periphery of İzmir in regional literature. The spatial frame of the study take Ayvalık, Sındırgı, Simav, Denizli, Yatağan, Milas and Didim as edges involving İzmir, Aydın and Manisa. For extended region analysis, eight highways maps are used obtained from General Directorate of Highways.

From literature review, it is observed that fractal dimension of cities and city systems have correlative relations with demographic, physical and economic parameters. For the time context of the study the only available data for İzmir is population which is recorded with respect to municipal borders for urban settlements and villages or townships for rural areas. Thus, the second context is determined as the administrative border of İzmir including province's and districts' borders in order to investigate relationships between population and complexity analysis. For İzmir region analysis, 1/25.000 scaled military maps are used obtained from General Directorate of Maps.

Since main aim of the study is to examine relationship between complexity pattern of the region with regional development trends, in Chapter 4 regional development background, conceptualizations of the region in the literature, regional plans and legal instruments are investigated. In addition to the development of the whole region, each district is briefly analyzed in terms of development trends as the parts of the region with respect to main aim of the study. The methods used for analyses are also presented in Chapter 4. According to the literature survey conducted in Chapter 3, box-counting method is selected for fractal analysis in order to identify the complexity of the regional system. Furthermore, correlation analysis is used to identify the relationship between fractal dimension and other variables including population, population density, acreage, road-length and road density. The resemblances and clustering trends are identified by hard and soft cluster analysis with respect to fractal dimensions of all periods. Results of the analysis for both contexts are presented in Chapter 5 while interpretations of the results and relational aspects of complexity are investigated in Chapter 6.

One of the differences of this study is to present a comprehensive methodology for investigating regional complexity of a multi-layered and multi-sectoral city region. Fractal analysis of whole road system of a large network is a preliminary study since the network involves every degree of road including dirt roads and it links many types of land-uses including forests, croplands, wetlands, touristic or industrial quarters the towns and the metropolitan city. It could be interpreted from related literature that higher complexity levels are related with urbanity since it has a positive relationship with city size and population. Furthermore, it is presented by world-wide and national studies that higher fractal dimension levels could be observed in central areas and it decreases with respect to sprawl. Rather than focusing on settlement macroform or urban road system, the context and the content of the study provide information about complexity of the non-urban in a city region. Secondly, the part and whole relationship in terms of complexity could be obtained for several decades. Lastly, the obtained relationships between fractal dimension with demographic and network based parameters could be re-investigated for regional scale.

In addition to expanding the existing methodology of fractal analysis of city systems, road systems and the regions, the other difference of the study is the attempt for constructing a methodology for investigating intrinsic, endogenous complexity of İzmir Region without identifying a territory or scale. In Chapter 7 endogenous complexity of İzmir Region is presented by sub-fractal analyses by using box-counting method. Two approaches are used for sub-fractal analyses for two purposes Firstly, mesh size of the sub-fractal analyses is decided from the intrinsic properties of the network by using syntactic measures. By re-interpretation of patch-work theory, the radius of embeddedness and local centrality is determined. For each period the radius presenting highest correlation between total node code count change rate and metric mean depth of the segment map before decentralization effect occurs is taken as the mesh size of sub-fractal analysis. This approach presents the endogenous complexity of the region without any given assumption or border. However, different mesh sizes cause in obstacles in comparing the change of the region with respect to time. Thus, 1% pixel ratio of the image of İzmir region is taken as the mesh size as the second approach in order to compare the change of the region with respect to time. Results of the analysis presented in Chapter 5, 6 and 7 and evaluated with respect to real world changes under related analysis.

## 8.2 Complexity and Relevancies with Regional Plans

The regional plans for previous decades are limited for İzmir Region. Before the first period, the last approved plan is the Plan of Aru, Özdeş and Canpolat in 1955. A linear macroform development is proposed along southern part of the Bay to Güzelyalı-Hatay direction. The frame of the plan could be discussed in terms of sub-fractal analyses of the first period. When he relevancy is investigated, the linear development decision fits to 1% sub-scan sub fractal analysis of the first period. The other functionalist decisions could not be handled since previous fractal dimension analyses are not studied due to unavailability in acquiring spatial data. The other study presented in Chapter 4 as the regional development scheme prepared in 1960s provides limited relevancy with extended region analysis. The development corridor along *Selcuk-Aydın-Denizli* and *Aydın-Salihli-Akhisar-Soma-Bergama* could be observed from the extended region maps. The integration of the region increased by a fractal dimension increase from 1.41 in 1953 o 1.3 in 1972.

In 1970s İzmir Metropolitan Office prepared a revised master plan for the central İzmir. The macro-form of the core is determined as linear again with further extension to the north/south axis from *Menemen* to *Gaziemir*. This macroform decision is relevant with the third period's complexity and population analyses by the help of decisions about transportation. The other major aim of creating new sub-centers is also relevant with the sub-fractal analyses of the second period in terms of their location and sizes. This result shows the location choice of sub-centers created with respect to existing dynamics while those concentrations disperse in the third period. The other major aim of the Plan which could be investigate by fractal dimension analyses is to prevent expansion of the squatters. The squatter belts are characterized by higher fractal dimensionality due to their irregular structure. From the second to third period, expansion of squatter belts could be observed from the analyses. In 1989, the Master Plan of Metropolitan Municipality is prepared by aiming to balance development pressure in the southern districts including the trade-based development of *Gaziemir*. This decision is relevant with the highest fractal dimension and population increase of *Gaziemir* from the second to the third period. The regional plan of İzmir Greater Municipality which is firstly prepared in 2012 provide more information about complexity analyses in terms of relevancy discussion because of the scale and context of the plan. The polycentric linear macroform of the metropolitan core proposed in the plan which could be observed from the sub-fractal analysis of the third period. However, a dissolved complexity structure is observed in terms of proposed macroform in the fourth period by a further extension to the west along the southern coast of the Bay. The plan also proposes a green belt for preventing the sprawl of southern metropolitan area. Nevertheless, sprawled structure and spotted developments are observed and even to enlarged in the last period. Despite those irrelevancies, the residential development decision in the eastern part of the metropolitan core resulted in higher population and fractal dimension values in *Kemalpaşa* which is relevant with the changes from the analyses of the third and the last period. Although, the total and the mean fractal dimension values decreased from the third to the fourth period in İzmir region, complexity of *Buca* and *Kemalpaşa* increased. The development areas in the plan are defined as; *Konak, Karabağlar, Karşıyaka, Çiğli, Bayraklı,Bornova, Buca, Gaziemir, Balçova* and *Narlıdere*. Furthermore, *Seferihisar, Menderes* and *Selçuk* in the west axis, *Menemen, Foça* and *Aliağa* are in the north axis, *Torbalı* and *Bayındır* in the south axis and *Kemalpaşa* in the east axis were defined as development areas in the regional plan. Since those decisions are not fully reflected to implementation plans, the relevancies could not be discussed by fractal analyses results. As a concluding remark it could be discussed that planning decisions could be observed in fractal dimension analyses and population change when they are implemented. In other words, top-down decisions have effects on complexity of the settlement system. However, development plans of İzmir Region are partially implemented. Thus, a further and detailed study is needed for a more comprehensive discussion of relevancies between planning decisions and complexity analyses of İzmir Region.

### 8.3 A Discussion for the Planning Practice

Fractal dimension is a complexity measure presenting the spatial quality, integrity and urban sprawl as observed in Chapter 3. In terms of planning practice, there are two ways to integrate fractal analysis to planning. The first one is using fractal analysis as an input variable for planning strategies. Secondly, fractal dimension could be regarded as a tool for spatial development. The first way includes approaches in terms of compactness and sprawl measures, quality of green spaces and development potentials. Regarding cities and regions as complex system is a developing phenomenon in planning including fractal analysis and integrated methods. The relationship between quality of life and fractal dimension is needed to be further studied. As the second way, fractal generation of urban pattern have begun to be studied in theoretical and real-world examples in lower scales mainly in the studies of urban design and architecture. Furthermore, in terms of using fractal logic in planning, simulation models like '*Fractalopolis*' have been used for urban and regional scale. The models allow concentrated decentralization and avoids uncontrolled sprawl. Centers, agglomerations and green areas are organized in accordance with hierarchical nesting. Generative models require GIS data of built environment, natural systems and demographic information that they are designed for future development strategies. Although developing fractal generation models provide insights about integrating complexity approach to strategic sustainable planning, historical and long-run analyses of cities or city-systems may provide another contribution in planning as self-organizing regions. They provide information about the growth dynamics of a self-organized pattern by a bottom-up perspective. Pattern of cities and city-systems emerge from complex interactions among various types of decision makers that planning is one of the sole intervention to those process. In other words, traditional planning provided top-down decisions in shaping the complex systems. Thus, how planned and unplanned decisions affected the complexity of the region could be observed as another study field. A new planning concept could be proposed based on fractal logic, but needed to be conceptualized to achieve sustainable development of metropolitan areas without excluding peri-urbanization. The approaches about urban metabolism and planetary urbanization arguments also call a new epistemology about new settlement structure. The two investigation fields could be integrated in both theoretical and practical manner.

With respect to those arguments, the outputs of the study could be used for urban and regional planning. Since the study involves a single case study of İzmir region, the findings could be re-evaluated for different regions. The sole findings which could provide contribution in planning decisions as;

-Fractal analysis of the regional road network could be used as a tool for complexity analysis,

-Complexity of the parts does not reflect the complexity of the whole and vice versa. However, heterogeneous complexity pattern presents higher fractal dimension of the whole system,

-Complexity is not only tied to urban uses and compactness or even the presence of a settlement because of the fact that non-urban networks may involve high fractal dimension levels,

-Rural decline in terms of population and agricultural network loss could be relational to decrease in complexity,

-Peri-urban transformations and urban sprawl to the non-urban or peri-urban areas could be observed with declined, stable or increased fractal dimension values,

-Network and population growth and increased compactness may not be relational to higher complexity

-Syntactic measurements could be integrated with fractal studies of road networks

To sum up, the findings could be used in planning, especially in strategic planning practices. However, all cities and countries have area-specific properties including their natural potential and limitations, economies, demographic structures, and functionality. Therefore, it is essential to approach different cases with respect to accepted facts in related literature and their local features.

### 8.4 Limitations and Future Research

There are several limitations to this study. Firstly, chaotic evolution of the cities could be observed in longer time-span (Portguali, 2000). For example, Batty & Longley (1987) studied the city of London in terms of space efficiency starting from 1820. Although time span of this study is limited due to data insufficiency, uneven development of the region after 1950s provide insights about fast and slow process of a complex system.

Related to the data availability issue, one of the highlighted aspects of the study was is the importance of data. Complexity approaches mainly operate through simple processes since the ontological assumption behind the complexity science is the acceptance of constructing deterministic solutions and equilibriums in complex systems. However models and approaches in complexity science is still developing that long-run data of structural morphology, population and socio-economic variables are precious for constructing and validating processes. Data limitation prohibits detailed analyses for the developing country cases. In order to investigate the statistical relationships of fractal dimension with real-world observations, variety in historical data could provide further contributions to the field. The more data may provide opportunity to investigate the regions as complex metabolisms. To illustrate, *İzmir* does not have a precise network edge like a ring-road or a geographical barrier except the *Aegean Sea*. As a result determination of such an edge for the extended region studies can be altered and studied with respect to agent-based approach or natural basins.

The other limitation could be the generalizability of the results that both in terms of method and cases. Fractal analysis of regional road network would be repeated to city systems of various sizes, functions and hierarchy. Another limitation of the study would be the modeling approach by integrating space syntax theory of patchwork to sub-fractal analysis in terms of defining mesh size. The results are compared with centrality analyses and real-world data obtained from maps and related literature. However, further investigation and revisions could be conducted for integrating different complexity approaches for different cases. Furthermore, investigating the effects of major planning decisions and implementations could be a meaningful contribution to regional complexity studies.

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## CURRICULUM VITAE

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### EDUCATION

| **Degree** | **Institution** | **Year of Graduation** |
|---|---|---|
| PhD | METU, City and Regional Planning | 2021 |
| MS | METU, Urban Design | 2014 |
| BS | METU, City and Regional Planning | 2010 |
| High School | Gazi Anatolian High School, Ankara | 2005 |

### WORK EXPERIENCE

| **Year** | **Place** | **Enrollment** |
|---|---|---|
| 2012-2021 | Ministry of Environment and Urbanization | Civil Servant |

### FOREIGN LANGUAGES

Advanced English

### PUBLICATIONS

Özdemir, S . (2018). Two Walls of Lefkoşa: The Validity of Division . İDEALKENT , 9 (23) , 30-57 . DOI: 10.31198/idealkent.416241.