ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

URBAN DYNAMICS OF ISTANBUL: EXPLORING URBAN COMPLEXITY VIA THE SPATIAL DISTRIBUTION OF ACTIVITIES

M.Sc. THESIS

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JUNE 2024

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İSTANBUL'UN KENTSEL DİNAMİKLERİ: FAALİYETLERİN MEKANSAL DAĞILIMI ARACILIĞIYLA KENTSEL KARMAŞIKLIĞIN KEŞFİ

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To my Family,

FOREWORD

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I hope this research's findings contribute meaningfully to the body of knowledge in big data analysis in urban sciences and address some pertinent issues related to urban complexity.

June 2024 Reyhaneh YOUNESI SANDI

TABLE OF CONTENTS

Page

FOREWORD ..... **ix**
TABLE OF CONTENTS ..... **xi**
ABBREVIATIONS ..... **xiii**
SYMBOLS ..... **xv**
LIST OF TABLES ..... **xvii**
LIST OF FIGURES ..... **xix**
SUMMARY ..... **xxi**
ÖZET ..... **xxv**
1. INTRODUCTION **1**
1.1 Research Questions 3
1.2 Unveiling Activity Patterns in Istanbul 3
2. UNDERSTANDING URBAN COMPLEXITY: THEORETICAL INSIGHTS AND BACKGROUND **5**
2.1 Concept of Complexity and Complex Systems 5
2.1.1 Entities, relationships, and subsystems 6
2.1.2 Non-linear systems 7
2.1.3 Dynamics of open systems 8
2.1.4 Adaptation 8
2.1.5 Edge of chaos 9
2.1.6 Unpredictability 9
2.1.7 Butterfly effect 9
2.2 Approaches to Complex System Analysis and Modeling 10
2.2.1 Algorithmic complexity 10
2.2.2 Deterministic complexity 10
2.2.3 Integrated complexity (aggregate) 11
2.2.4 New approach quest 11
2.3 Complex Urban Systems 13
2.4 Diversification in Urban Functions as a Measure of Metropolitan Complexity 21
2.5 Shaping Dimensions of Urban Complexity 23
2.6 Understanding Urban Complexity via the Activities Network 26
3. INVESTIGATIVE FRAMEWORK: UNDERSTANDING URBAN DYNAMICS AND ACTIVITY PATTERNS **33**
3.1 Case Study 34
3.1.1 Istanbul's transformation: from imperial prosperity to decline (1800–1950) 35
3.1.2 Unplanned urbanization: the making of an industrial metropolis (1950–1980) 36
3.1.3 Transformation of the urban structure in the neo-liberal age (post-1980s) 38

3.1.4 Urban Transformation Since the 1990s 44
3.1.5 Reimagining Istanbul in Post-2002: Impact of Neoliberal Policies 46
3.2 Data 48
3.3 Analysis 52
3.3.1 Richness index 52
3.3.2 Simpson's index 53
3.3.3 Shannon-weiner diversity index 55
3.3.4 Pielou's evenness index 56
3.3.5 Biodiversity index 57
3.3.6 Kernel density 60
4. UNCOVERING URBAN ACTIVITY DIVERSITY AND INTENSITY PATTERNS: INSIGHTS AND ANALYSIS 61
4.1 Diversity Of Activities 61
4.1.1 Richness index 61
4.1.2 Simpson's index 63
4.1.3 Shannon-weiner diversity index 65
4.1.4 Pielou's evenness index 67
4.1.5 Biodiversity index 69
4.2 Intensity of activities 71
4.3 Discussion 83
5. CONCLUSION 87
REFERENCES 91
CURRICULUM VITAE 109

ABBREVIATIONS

CBC	**:** Central Business District
AKP	**:** Justice and Development Party(Adalet ve Kalkınma Partisi)
TOKİ	**:** Turkey's government-backed housing agency (Toplu Konut İdaresi Başkanlığı)
SMD	**:** Social Media Data
GIS	**:** Geographic Information System
LBSN	**:** Location-Based Social Networking
POI	**:** Point of Interest
API	**:** Application Programming Interface
VGI	**:** Volunteered Geographic Information
SWDI	**:** Shannon-Wiener Diversity Index
KDE	**:** Kernel Density Estimation
FDI	**:** Foreign Direct Investment
ICT	**:** Information and Communication Technology

SYMBOLS

D	**:** Simpson's index
H	**:** Shannon-weiner index
J	**:** Pielou's evenness index
$\mathbf{H_{max}}$	**:** The maximum possible value of H for the given species richness
$\mathbf{p_i}$	**:** The proportion of individuals of species *ii*
S	**:** The species richness
ln	**:** The natural logarithm
$\mathbf{n_i}$	**:** The number of individuals in species *i*i
$\frac{\mathbf{n_i}}{N}$	**:** The proportion of individuals of species *i*i
N	**:** The total number of individuals of all species

LIST OF TABLES

Page

Table 2.1 : Shaping Dimensions of Urban Complexity **26**
Table 4.1 : Simpson's Index..... **64**
Table 4.2 : Shannon-Weiner Diversity Index..... **66**
Table 4.3 : Pielou's Evenness Index **68**
Table 4.4 : Biodiversity Index..... **70**
Table 4.5 : Activity Category..... **72**

LIST OF FIGURES

Page

Figure 2.1 : Interactions between Entities, Subsystems, and Supersystems within the Complex System (Tutanç, 2023)..... **6**
Figure 2.2 : Unknown Variables (Ben Ramalingam, Harry Jones, Toussaint Reba, John Young, 2021). **7**
Figure 2.3 : Complex Urban System, Subsystem Components (Tutanç, 2023) **16**
Figure 2.4 : Spanish cities functional system in the pre-crisis period (2000-2008) (Miguel et al., 2017)..... **18**
Figure 2.5 : Future vision of Spanish cities functional system (2030) (Miguel et al., 2017) **18**
Figure 2.6 : Three Phases of Urbanization (Brenner & Schmid, 2015)..... **20**
Figure 2.7 : Diversification Aspects (Carlucci et al., 2020) **23**
Figure 3.1 : Methodology diagram. **33**
Figure 3.2 : Historical development stages of Istanbul (Enlil, et al, 2011). **36**
Figure 3.3 : Sprawl of industrial and residential areas in Istanbul during (1950–1980) (Kaptan, 1991)..... **38**
Figure 3.4 : Legal status of residential areas in Istanbul (Kaptan, 1991). **39**
Figure 3.5 : Land-use pattern in the central areas of Istanbul before 1980 (Kaptan, 1991). **41**
Figure 3.6 : Land-use pattern in the central areas of Istanbul after 1980. Note the expansion towards north on the European side and towards east on the Anatolian side replacing the former industrial areas (Kaptan, 1991)..... **41**
Figure 3.7 : Spread of gated communities in the Istanbul metropolitan area. Source: Adapted from IMP Housing and Quality of Life Group – 2006..... **43**
Figure 3.8 : Decentralization of industry to 'organized industrial areas' in the outskirts (Kaptan, 1991)..... **45**
Figure 3.9 : Fikirtepe reconstruction project (Tarakci, et al, 2022). **47**
Figure 3.10 : Venue distribution. **51**
Figure 4.1 : Richness Index..... **62**
Figure 4.2 : Simpson's Index. **65**
Figure 4.3 : Shannon-Weiner Diversity Index **67**
Figure 4.4 : Pielou's Evenness Index. **68**
Figure 4.5 : Activity Category. **71**
Figure 4.6 : Sports & Recreation **73**
Figure 4.7 : Food & Dining..... **74**
Figure 4.8 : Entertainment & Culture. **75**
Figure 4.9 : Education & Learning **76**
Figure 4.10 : Transportation & Travel. **77**
Figure 4.11 : Retail & Shopping. **78**
Figure 4.12 : Health & Wellness. **79**
Figure 4.13 : Government & Civic. **80**
Figure 4.14 : Lodging & Accommodation. **81**

Figure 4.15 : Nature & Outdoors**. 82**

URBAN DYNAMICS OF ISTANBUL: EXPLORING URBAN COMPLEXITY VIA THE SPATIAL DISTRIBUTION OF ACTIVITIES

SUMMARY

Urban dynamics form a complex tapestry woven from the interplay of physical structures, socio-economic elements, and human activity patterns. With its rich history and evolving spatial landscape, Istanbul presents a compelling case for exploring these dynamics. Despite valuable insights, challenges remain in fully understanding Istanbul's complexity. The city's continuous population growth, polycentric development, and uneven distribution complicate the evaluation of segregation patterns. These challenges highlight the need for innovative methods to interpret diversity within Istanbul's evolving urban landscape. Using these innovative methods in the research keeps the reader engaged and opens up new avenues for understanding and interpreting urban dynamics.

On the other hand, technological advancements have transformed urban studies, introducing methods such as mobile phone data and Points of Interest (POI) data to analyze human activities and land use dynamics. This research explores the spatial distribution of activities in Istanbul, aiming to unravel the city's complexity using big data. It addresses the following questions: How does the dispersion of activities across Istanbul contribute to the city's overall complexity? How does the dispersion of activity in different areas of Istanbul impact the character and dynamics of those regions?

This study stands out in its approach, leveraging theoretical insights from the literature review and diversity and intensity indices findings to address the research queries. By examining activity distribution within different neighborhoods or districts, we gain insight into each region's unique characteristics and evolving nature, shedding light on the socio-economic, cultural, and spatial dynamics shaping Istanbul's urban landscape.

The study's use of advanced spatial analysis tools and a comprehensive dataset enhances its robustness. By leveraging data from Foursquare, the research offers a detailed examination of human activities and their spatial distribution. Integrating multiple diversity indices allows for a nuanced analysis of activity patterns, capturing both the richness and evenness of activities across different regions of Istanbul. This multifaceted approach ensures the study provides a holistic view of the city's urban dynamics. The research also addresses the challenges of using big data in urban studies. While VGI-based POIs offer significant potential, data completeness, and accuracy issues must be carefully managed. The study's reliance on an official POI dataset ensures higher data reliability, setting a precedent for future research in urban studies. The methodological rigor of this research contributes to its credibility and potential impact on urban planning practices.

The dataset, provided by Professor Dingqi Yang, is a comprehensive collection of long-term check-in data from Foursquare, spanning April 2012 to January 2014. This dataset, which includes over 33 million check-ins from approximately 267,000 users

at more than 3.6 million venues across 415 cities in 77 countries, provides a robust foundation for analyzing urban dynamics. The study employs ecological methods to analyze activity diversity inspired by species counting in a forest. Diversity indices such as Simpson's Index and the Shannon-Weiner Diversity Index gauge the number and distribution of activities, while Pielou's Evenness Index measures activity distribution uniformity. The study also explores alpha, beta, and gamma diversity scales to assess activity diversity at local and citywide levels. Kernel Density Estimation is utilized to visualize activity intensity, highlighting high-concentration areas. This comprehensive dataset ensures the validity and reliability of the research, instilling confidence in the reader about the robustness of the study's findings.

Istanbul, a city steeped in history and brimming with modern vibrancy, is a microcosm of urban complexity. This complexity is not simply due to its rich cultural heritage or geographic location spanning two continents but also because of the diverse array of activities across its varied neighborhoods. The intricate distribution of activities, encompassing their variety and intensity, weaves a complex tapestry that shapes Istanbul's unique character and contributes to its dynamism. The variety of activities throughout Istanbul is a testament to the city's multifaceted identity. From the vibrant commercial centers of Eminönü and Karaköy, where the echoes of centuries-old trade routes still resonate, to the modern art galleries and performance spaces of Beyoğlu, Istanbul offers a diverse array of experiences. Historical sites like the Hagia Sophia and Topkapı Palace stand alongside bustling bazaars and tranquil parks, creating a rich urban environment that caters to a wide range of interests and preferences. This diversity of activities, each with unique charm and appeal, will intrigue and fascinate the reader, providing a deeper understanding of Istanbul's urban landscape.

A striking observation from the maps is the uneven distribution of activities across Istanbul. Central districts like Beyoğlu, Şişli, and Beşiktaş emerge as vibrant hubs, boasting a high concentration of diverse activities, including entertainment, culture, retail, dining, health services, and government institutions. This concentration aligns with Istanbul's historical core and its ongoing role as a significant cultural and economic center. However, as we move from the city center, the density and variety of activities decrease. Suburban areas like Kadıköy and Üsküdar offer a more moderate mix of amenities. At the same time, outer districts like Esenyurt and Avcılar exhibit a sparser distribution, particularly in sports and recreation, entertainment, and health categories. This unevenness reflects the complex interplay of historical development, socio-economic factors, and urban planning decisions that have shaped Istanbul's landscape over time.

The intensity of activities in specific areas of Istanbul is another critical factor in understanding its complexity. Business districts like Levent and Maslak pulsate with activity during the workweek, while tourist hotspots like Sultanahmet and the Bosphorus shores experience a constant influx of visitors. Residential neighborhoods have their unique rhythms, with cafes, restaurants, and markets bustling with activity at different times of the day. This varying intensity creates a dynamic urban landscape, where the pace of life shifts from one neighborhood to the next. The contrast between the Princes' Islands' tranquil atmosphere and Taksim Square's frenetic energy exemplifies this diversity. Understanding the intensity of activities is crucial for urban planners and policymakers, as it can reveal areas that may require additional infrastructure or resources to support their demands.

Moreover, the intensity of activities can also have social and cultural implications. High-density areas foster a greater sense of community and belonging, while lower-intensity areas may offer more opportunities for individual expression and creativity. This underscores the importance of urban planners and policymakers in managing and shaping the urban intensity, making the reader feel empowered and responsible for the city's development.

Policies should focus on increasing activity diversity in more homogeneous regions like Esenyurt and Kagithane. Encouraging a mix of commercial, cultural, and residential developments can foster more dynamic and resilient urban environments. Conversely, ensuring adequate infrastructure and services in high-intensity areas such as Fatih and Şişli is crucial. These districts require continuous investment to support their dense activity concentrations and maintain their roles as critical urban centers. Ultimately, urban planning should aim to balance development across Istanbul, addressing disparities in activity intensity and diversity. This includes promoting equitable economic opportunities and improving amenities in peripheral areas like Tuzla and Şile to enhance their attractiveness and functionality. Moreover, incorporating green spaces and ecological elements in urban planning can enhance biodiversity and improve quality of life. This approach aligns with the theoretical emphasis on integrating natural elements into urban environments to support sustainability and resilience.

Future research should build on the findings of this study to further explore the complexities of urban dynamics. Enhancing data quality and addressing the limitations associated with VGI-based POIs are critical steps for advancing urban studies. Comparative studies with other cities can validate the findings and identify contextual variations in urban dynamics. Temporal analysis can provide a dynamic perspective on the evolution of urban complexity, capturing trends and changes over time. Integrating diverse data sources, such as satellite imagery and transportation data, can enrich the comprehensiveness of urban analysis. Incorporating demographic data, such as age and nationality, can offer deeper insights into the patterns of activity dispersion and specialization across different neighborhoods.

Matching activity data with land use information is another important avenue for future research. Understanding how different land uses correlate with activity diversity and intensity can provide a more holistic view of urban dynamics. Researchers can identify land-use types contributing to high activity diversity and intensity by overlaying activity data with land-use maps. This information can inform urban planning decisions, helping to create more vibrant and functional urban spaces. Investigating the factors influencing sustainable development within metropolitan areas is crucial for future research. Analyzing how activity diversity and intensity relate to environmental sustainability, social equity, and economic viability can help develop strategies to promote sustainable urban growth. Understanding the impact of diverse activities on sustainability can guide policymakers in creating balanced development plans supporting economic growth and environmental preservation.

In conclusion, this research comprehensively analyzes Istanbul's urban dynamics, focusing on the spatial distribution of activities and their impact on urban complexity. The study highlights the importance of activity diversity and intensity in shaping the urban landscape, offering valuable insights for urban planning and development.

İSTANBUL'UN KENTSEL DİNAMİKLERİ: FAALİYETLERİN MEKANSAL DAĞILIMI ARACILIĞIYLA KENTSEL KARMAŞIKLIĞIN KEŞFİ

ÖZET

Kentsel dinamikler, fiziksel yapılar, sosyo-ekonomik unsurlar ve insan hareketi desenlerinin etkileşiminden oluşan karmaşık bir dokudur. Tarihi zenginliği ve gelişen mekânsal yapısıyla İstanbul, bu dinamikleri keşfetmek için etkileyici bir örnek sunmaktadır. Değerli içgörülere rağmen, İstanbul'un karmaşıklığını tam olarak anlamada zorluklar devam etmektedir. Şehrin sürekli nüfus artışı, çok merkezli gelişimi ve düzensiz dağılımı, ayrışım desenlerini değerlendirmenin önünü açmaktadır. Bu zorluklar, İstanbul'un gelişen kentsel manzarasında çeşitliliği yorumlamak için yenilikçi yöntemlere olan ihtiyacı vurgulamaktadır.

Diğer taraftan, teknolojik ilerlemeler, kentsel çalışmaları dönüştürmüş ve insan faaliyetlerini ve arazi kullanım dinamiklerini analiz etmek için mobil telefon verileri ve Nokta İlgi (POI) verileri gibi yöntemleri tanıtmıştır. VGI (Gönüllü Coğrafi Bilgi) tabanlı POI'lerin vaatlerine rağmen, veri tamlığı, doğruluğu ve taksonomi ile ilgili zorluklar devam etmektedir. Bu araştırma, resmi bir POI veri kümesini kullanarak dikkatli veri seçiminin önemini vurgulayan bir yaklaşımla kendini ayırmaktadır. Bu araştırma, İstanbul'daki aktivitelerin mekânsal dağılımını inceleyerek şehrin karmaşıklığını büyük veri kullanarak çözmeyi amaçlamaktadır. Araştırmanın yanıtlamayı hedeflediği sorular şunlardır: İstanbul genelindeki aktivitelerin dağılması şehrin toplam karmaşıklığına nasıl katkıda bulunmaktadır? İstanbul'un farklı bölgelerindeki aktivitelerin dağılması, o bölgelerin karakterini ve dinamiklerini nasıl etkilemektedir?

Araştırma sorularına yanıt ararken, literatür taramasından elde edilen teorik bilgiler ve çeşitlilik ile yoğunluk indekslerinin bulgularından yararlanılmaktadır. İlk olarak, İstanbul genelindeki aktivitelerin dağılımının şehrin karmaşıklığını nasıl zenginleştirdiğini araştırıyoruz. Farklı alanlarda aktivitelerin çeşitliliği ve yayılması, İstanbul'un çok yönlü doğasına nasıl katkıda bulunuyor, bu konuya dalıyoruz. İkinci olarak, İstanbul'un farklı bölgelerindeki aktivitelerin dağılması, bu bölgelerin kimliğini ve dinamiklerini nasıl etkiliyor, inceliyoruz. Farklı mahalleler veya ilçelerdeki faaliyet dağılımını inceleyerek her bölgenin benzersiz özelliklerini ve gelişen doğasını anlamaya çalışıyoruz, böylece İstanbul'un kentsel manzarasını şekillendiren sosyo-ekonomik, kültürel ve mekânsal dinamiklere ışık tutuyoruz.

Bu araştırmanın önemi, kentsel karmaşıklıkla ilgili teorik kavramlar ile pratik kentsel planlama uygulamaları arasındaki boşluğu kapatmaktadır. İstanbul'a odaklanarak, bu çalışma dünya genelindeki diğer hızla büyüyen metropol alanları için uygulanabilir içgörüler sunmaktadır. İstanbul, tarihi derinliği, coğrafi çeşitliliği ve sosyo-ekonomik dönüşümleri nedeniyle ideal bir vaka çalışmasıdır. Araştırmanın kullandığı metodoloji, diğer kentsel bağlamlarda tekrar edilebilir nitelikte tasarlanmış olup, kentsel karmaşıklığın daha geniş bir anlayışına katkıda bulunmaktadır.

Çalışmanın gelişmiş mekânsal analiz araçları ve kapsamlı veri kümesi kullanımı, sağlamlığını artırmaktadır. Foursquare'den elde edilen veriler, insan aktiviteleri ve mekânsal dağılımının ayrıntılı bir incelemesini sunar. Birden fazla çeşitlilik indeksinin entegrasyonu, İstanbul'daki farklı bölgelerdeki faaliyet desenlerinin hem zenginliğini hem de eşitliğini yakalayan incelikli bir analiz sağlar. Bu çok yönlü yaklaşım, şehrin kentsel dinamiklerine bütünsel bir bakış sunar. Araştırma, büyük verinin kentsel çalışmalardaki zorluklarını da ele almaktadır. VGI tabanlı POI'lerin önemli potansiyeline rağmen, veri tamlığı ve doğruluğu ile ilgili sorunlar dikkatlice yönetilmelidir. Araştırmanın resmi bir POI veri kümesine dayanması, veri güvenilirliğinin yüksek olmasını sağlar ve kentsel çalışmalarda gelecekteki araştırmalar için bir örnek teşkil eder. Bu araştırmanın metodolojik titizliği, güvenilirliğine ve kentsel planlama uygulamalarındaki potansiyel etkisine katkıda bulunmaktadır.

Veri seti, Profesör Dingqi Yang tarafından sağlanmış olup, Nisan 2012'den Ocak 2014'e kadar olan uzun dönemli check-in verilerini içermektedir. Bu veri seti, 77 ülkede 415 şehirde yaklaşık 267.000 kullanıcıdan 33 milyondan fazla check-in ve 3.6 milyon mekân içermektedir. Türkiye, özellikle İstanbul'a odaklanarak, veri seti mekân özellikleri (ID, ad, kategori ve koordinatlar) sunmaktadır. 22 ay boyunca İstanbul'da 339.247 mekân tanımlanmış olup, bu güçlü bir temel sağlamaktadır. Çalışma, aktivitelerin çeşitliliğini analiz etmek için ekolojik yöntemler kullanmaktadır, bu da ormanda tür sayımı ile ilham alınmıştır. Çeşitlilik indeksleri, Simpson İndeksi ve Shannon-Weiner Çeşitlilik İndeksi, aktivitelerin sayısını ve dağılımını ölçerken, Pielou'nun Eşitlik İndeksi faaliyet dağılımının eşitliğini ölçer. Çalışma ayrıca, yerel ve şehir genelindeki aktivitelerin çeşitliliğini değerlendirmek için alfa, beta ve gama çeşitlilik ölçeklerini de keşfetmektedir. Aktivite yoğunluğunu görselleştirmek için Kernel Yoğunluk Tahmini kullanılarak yüksek konsantrasyonlu bölgeler vurgulanmaktadır.

Tarihi bir geçmişe ve modern canlılığa sahip İstanbul, kentsel karmaşıklığın bir mikrokozmosudur. Bu karmaşıklık, yalnızca kültürel mirası veya iki kıta arasındaki coğrafi konumuyla değil, aynı zamanda aktivitelerin farklı mahallelerde nasıl dağıldığıyla da doğrudan ilişkilidir. Aktivitelerin karmaşık dağılımı, İstanbul'un eşsiz karakterini şekillendiren ve dinamizmine katkıda bulunan karmaşık bir dokuyu örmektedir. İstanbul genelinde bulunan aktivitelerin çeşitliliği, şehrin çok yönlü kimliğinin bir kanıtıdır. Eminönü ve Karaköy gibi canlı ticaret merkezlerinden, Beyoğlu'ndaki modern sanat galerileri ve performans alanlarına kadar, İstanbul, geniş bir ilgi ve tercih yelpazesi sunmaktadır. Hagia Sophia ve Topkapı Sarayı gibi tarihi yerler, hareketli pazarlar ve huzurlu parklarla yan yana gelerek, çeşitli ilgi alanlarına hitap eden zengin bir kentsel ortam yaratmaktadır. Ancak bu çeşitlilik eşit olarak dağılmamaktadır. Farklı mahalleler, farklı türde aktivitelerde uzmanlaşarak belirgin yerel kimlikler oluşturur. Örneğin, Nişantaşı lüks moda butikleri ile ünlüyken, Kadıköy alternatif kültür ve gece hayatı için dinamik bir merkezdir. Bu uzmanlaşma, kentsel deneyimi zenginleştirerek, hem sakinler hem de ziyaretçiler için çok çeşitli seçenekler sunar ve sürekli bir keşif duygusu oluşturur.

Haritalardan elde edilen çarpıcı bir gözlem, İstanbul genelindeki aktivitelerin düzensiz dağılımıdır. Beyoğlu, Şişli ve Beşiktaş gibi merkezi bölgeler, eğlence, kültür, perakende, yemek, sağlık hizmetleri ve hükümet kurumları gibi çeşitli aktivitelerle yüksek yoğunlukta bölgeler olarak öne çıkmaktadır. Bu yoğunlaşma, İstanbul'un tarihsel çekirdeği ve devam eden kültürel ve ekonomik merkezi rolü ile uyumludur. Ancak, şehir merkezinden uzaklaştıkça, faaliyetlerin yoğunluğu ve çeşitliliği azalır.

Kadıköy ve Üsküdar gibi banliyö bölgeleri daha dengeli bir hizmet yelpazesi sunarken, Esenyurt ve Avcılar gibi dış bölgelerde özellikle spor, eğlence ve sağlık kategorilerinde daha seyrek bir dağılım görülmektedir. Bu düzensizlik, İstanbul'un tarihsel gelişimi, sosyo-ekonomik faktörler ve kentsel planlama kararlarının karmaşık etkileşimini yansıtmaktadır.

Belirli bölgelerdeki aktivite yoğunluğu, İstanbul'un karmaşıklığını anlamada bir başka önemli faktördür. İş bölgeleri olan Levent ve Maslak hafta içi yoğun bir aktivite gösterirken, turist merkezleri olan Sultanahmet ve Boğaz kıyıları sürekli ziyaretçi akınına uğramaktadır. Konut bölgeleri de farklı gün saatlerinde kafe, restoran ve pazarlarla kendi ritmlerini geliştirmektedir. Bu değişken yoğunluk, bir mahalleden diğerine yaşam temposunun değiştiği dinamik bir kentsel manzara yaratmaktadır. Prens Adaları'nın huzurlu atmosferi ile Taksim Meydanı'nın çılgın enerjisi arasındaki fark bu çeşitliliği örneklemektedir. Aktivite yoğunluğunu anlamak, kentsel planlamacılar ve politika yapıcılar için kritik öneme sahiptir, çünkü bu, desteklenmesi gereken altyapı veya kaynakları ortaya çıkarabilir. Ayrıca, aktivite yoğunluğu sosyal ve kültürel etkiler de yaratabilir. Yüksek yoğunluklu bölgeler daha büyük bir topluluk ve aidiyet duygusu teşvik edebilirken, daha düşük yoğunluklu bölgeler bireysel ifade ve yaratıcılık fırsatları sunabilir.

Politikalar, Esenyurt ve Kağıthane gibi daha homojen bölgelerde aktivite çeşitliliğini artırmaya odaklanmalıdır. Ticaret, kültür ve konut geliştirmelerinin karışımını teşvik etmek, daha dinamik ve dayanıklı kentsel ortamlar yaratabilir. Öte yandan, Fatih ve Şişli gibi yüksek yoğunluklu bölgelerde altyapı ve hizmetlerin yeterli olduğundan emin olmak önemlidir. Bu bölgeler, yoğun aktivite konsantrasyonlarını desteklemek ve ana kentsel merkezler olarak rollerini sürdürmek için sürekli yatırım gerektirmektedir. Sonuç olarak, kentsel planlama, İstanbul genelinde gelişimi dengelemeyi hedeflemelidir, aktivite yoğunluğu ve çeşitliliğindeki eşitsizlikleri ele almalıdır. Bu, ekonomik fırsatları dengeli bir şekilde teşvik etmek ve Tuzla ve Şile gibi çevresel bölgelerdeki olanakları ve işlevselliği artırmak anlamına gelir. Ayrıca, kentsel planlamada yeşil alanlar ve ekolojik unsurları dahil etmek, biyolojik çeşitliliği artırabilir ve yaşam kalitesini iyileştirebilir. Bu yaklaşım, sürdürülebilirliği ve dayanıklılığı desteklemek için doğal unsurları kentsel çevrelere entegre etme teorik vurgusuyla uyumludur.

Gelecek araştırmalar, bu çalışmanın bulgularının üzerine inşa edilerek kentsel dinamiklerin karmaşıklığını daha derinlemesine keşfetmelidir. Veri kalitesini artırmak ve VGI tabanlı POI'lerle ilgili sınırlamaları ele almak, kentsel çalışmalarda ilerlemek için kritik adımlardır. Diğer şehirlerle karşılaştırmalı çalışmalar, bulguları doğrulayıp kentsel dinamiklerdeki bağlamsal farklılıkları belirleyebilir. Zamansal analizler, kentsel karmaşıklığın evrimine dinamik bir bakış açısı sunarak eğilimler ve değişiklikleri yakalayabilir. Uydu görüntüleri ve ulaşım verileri gibi çeşitli veri kaynaklarının entegrasyonu, kentsel analizlerin kapsamını zenginleştirebilir. Yaş ve milliyet gibi demografik verilerin dahil edilmesi, farklı mahallelerdeki aktivite dağılımı ve uzmanlaşma desenleri hakkında daha derin içgörüler sunabilir.

Aktivite verilerini arazi kullanımı bilgileriyle eşleştirmek, gelecekteki araştırmalar için önemli bir yol olabilir. Farklı arazi kullanımlarının aktivite çeşitliliği ve yoğunluğu ile nasıl ilişkilendiğini anlamak, kentsel dinamiklerin daha bütünsel bir görünümünü sağlayabilir. Aktivite verilerini arazi kullanımı haritalarıyla örtüştürerek, yüksek aktivite çeşitliliği ve yoğunluğuna katkıda bulunan arazi kullanım türlerini belirlemek mümkündür. Bu bilgi, kentsel planlama kararlarını bilgilendirebilir, daha canlı ve

işlevsel kentsel alanlar yaratılmasına yardımcı olabilir. Sürdürülebilir kalkınmanın kentsel alanlardaki etkilerini araştırmak da gelecekteki araştırmalar için kritik önemdedir. Aktivite çeşitliliği ve yoğunluğunun çevresel sürdürülebilirlik, sosyal eşitlik ve ekonomik geçerlilikle ilişkisini analiz etmek, sürdürülebilir kentsel büyümeyi teşvik edecek stratejiler geliştirmeye yardımcı olabilir. Çeşitli aktivitelerin sürdürülebilirlik üzerindeki etkisini anlamak, politika yapıcıların ekonomik büyümeyi ve çevresel korumayı destekleyen dengeli gelişim planları oluşturmalarına rehberlik edebilir.

Sonuç olarak, bu araştırma, İstanbul'un kentsel dinamiklerini kapsamlı bir şekilde analiz ederek aktivitelerin mekânsal dağılımı ve bunların kentsel karmaşıklık üzerindeki etkilerine odaklanmaktadır. Çalışma, kentsel manzarayı şekillendirmede aktivite çeşitliliği ve yoğunluğunun önemini vurgular ve kentsel planlama ve gelişim için değerli içgörüler sunar. Gelişmiş mekânsal analiz araçları ve sağlam bir veri kümesi kullanarak, araştırma, kentsel karmaşıklığın daha derin bir anlayışına katkıda bulunur ve bu alandaki gelecekteki çalışmalara bir temel sağlar. Bulgular, aktivite çeşitliliği ve eşit dağılımını teşvik eden sürdürülebilir kalkınma uygulamalarına duyulan ihtiyacı vurgular, kentsel ortamların dayanıklılığını ve yaşanabilirliğini artırır.

1. INTRODUCTION

Urban dynamics constitute a multifaceted tapestry woven by the intricate interplay of myriad factors, ranging from physical structures and socio-economic elements to the dynamic patterns of human activities. Within this realm, the city of Istanbul is a compelling subject for exploration, a metropolis that encapsulates a rich history and a spatial evolution that mirrors the complexities of contemporary urban environments. This thesis aims to explore the urban dynamics of Istanbul, with a particular emphasis on uncovering the spatial distribution of activities to understand the city's inherent complexity.

The literature surrounding urban complexity is a theoretical foundation for this research, drawing from disciplines as diverse as ecology, information theory, and urban studies. Network analysis, rooted in statistical physics, has proven instrumental in understanding complex systems, emphasizing the interconnectedness of elementary units (Latora & Russo, 2017; Arenas et al., 2008). Urban complexity, within the unique context of an urban ecosystem, involves a nuanced interplay of variables such as urban morphology, building density, and proximity to essential activities (Salat & Bourdic, 2012; Salvati, 2018).

The city-as-an-ecosystem framework further enriches our comprehension, recognizing urban attributes as dynamic information repositories contributing to intricate networks regulating the city's functions, akin to species interactions in ecosystems (Rueda, 1995; Newman & Jennings, 2008). This study aligns with this comprehensive approach, aiming to contribute to a broader understanding of the dynamic interplay between spatial organization, activity diversity, and overall urban complexity.

As technology progresses, the examination of information organization in urban spaces has developed, incorporating advanced methods such as mobile phone data and Points of Interest (POI) data to offer detailed insights into human activities and land use dynamics (Tranos & Nijkamp, 2015; Toole et al., 2012). Nevertheless, despite the potential of Volunteered Geographic Information (VGI)-based POIs, data

completeness, accuracy, and taxonomy challenges persist (Jiang et al., 2015). This study sets itself apart by utilizing an official POI dataset, contributing to the evolving methodologies in urban studies, and highlighting careful data selection.

Our exploration of Istanbul as a case study has unveiled the city's complex and dynamic evolution, grounded in its rich history and compelling spatial development. The distinct peripheral growth, marked by a shift from a central core-dominated metropolis to an expanding suburban periphery post-1950s, reflects the transformative impact of increased automobile usage and significant construction projects like the Bosporus Bridge. Istanbul, functioning as a pivotal regional gateway, experienced a resurgence in the 1990s, leading to theories about its global metropolis status and characterizations as a divided city with social/spatial polarization.

Despite valuable insights, challenges persist in a comprehensive understanding of Istanbul's complexity. The city's persistent population growth, polycentric development, uneven population distribution, and scarcity of geographic data present hurdles in evaluating and making temporal comparisons of segregation. Innovative and indirect methods are necessary to interpret diversity within Istanbul's ever-evolving urban fabric. Overall, Istanbul is a multifaceted and evolving case study, offering valuable lessons for understanding urban complexity in the context of spatial and social transformations.

The research questions guiding this investigation revolve around the intensity and diversity of activities in different regions of Istanbul and their impact on urban complexity. The methodology adopts an applied developmental research approach, utilizing the Richness index, Simpson's index, Shannon index, Pielou's Evenness index, and Biodiversity index to unveil geographical clustering, confirming distinct patterns in diversity distribution, and kernel density analysis to analyze the intensity of activities in Istanbul.

This research seeks to bridge the gap in our understanding of Istanbul's urban dynamics, shedding light on the complexities that define its landscape. By employing a comprehensive methodology and leveraging advanced spatial analysis tools, the research aims to contribute valuable insights for informed decision-making in urban planning, ultimately enhancing the overall urban experience.

1.1 Research Questions

The research aims to delve into the unique aspects of the intensity and diversity of activities across various regions of Istanbul, explicitly focusing on understanding the implications of these elements on urban complexity. The study will address the following research inquiries, which are crucial in shedding light on the dynamics of urban activities and their influence on the city's overall complexity.

- How does the dispersion of activities across Istanbul contribute to the city's overall complexity?
- How does the dispersion of activity in different areas of Istanbul impact the character and dynamics of those regions?

1.2 Unveiling Activity Patterns in Istanbul

A dataset provided by Professor Dingqi Yang, which contained long-term check-in data from Foursquare, was used for this research. This data covers around 22 months, from April 2012 to January 2014, and includes over 33 million check-ins made by nearly 267,000 users at more than 3.6 million venues. These venues are spread across 415 cities in 77 countries, with each city being a popular location for Foursquare users, having at least 10,000 check-ins. The focus of this study was on the data related to Turkey, explicitly narrowing it down to Istanbul. The collected data for this research includes attributes such as venue ID, name, category, and coordinates. Over 22 months, around 339,247 venues were identified in Istanbul.

In the study's analysis, a unique approach was taken by applying methods used in ecology to understand diversity, such as counting species in a forest. This approach was instrumental in determining the number of activities and how evenly they were distributed across the city. Tools like Simpson's Index and Shannon-Weiner Diversity Index were used to measure diversity, providing insights into the number of activities and their even distribution. Pielou's evenness index was also used to measure the even distribution of activities.

Various diversity scales—alpha, beta, and gamma—were explored to understand activity diversity within specific areas and the city. This exploration was instrumental in understanding which activities are unique to specific neighborhoods. The use of

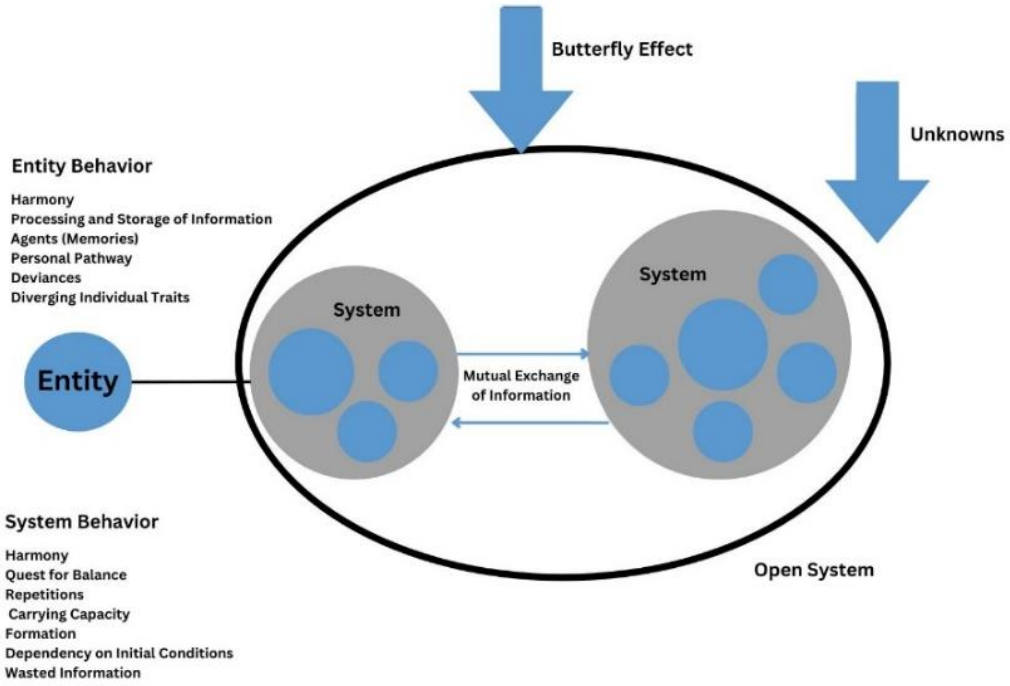
kernel Density estimation was particularly significant, as it allowed for the visualization of areas with higher activity concentration, making the research more engaging and informative.

2. UNDERSTANDING URBAN COMPLEXITY: THEORETICAL INSIGHTS AND BACKGROUND

2.1 Concept of Complexity and Complex Systems

The term "complex" stems from the Latin word "plectere," which describes intertwined or tangled structures (Mitchell, 2009). Put, complexity implies difficulty in resolution. To grasp its essence, juxtaposing it with contrasting terms like simplicity or chaos can aid comprehension. Complexity denotes situations that are challenging to unravel, unlike simple ones, which are easily decipherable. While complexity and chaos share similarities, they differ because complex systems entail numerous nonlinear and recursive relationships, making them inherently insoluble (Cilliers, 2011). Complex systems are pervasive across various scientific fields like biology, mathematics, and physics and non-scientific domains like art and cinema. Initially categorized under chaos theory until the 1960s, complex systems gained recognition for their distinct characteristics, especially as societies approached saturation and interacted more frequently, giving rise to diverse network relationships. Consequently, the study of complex systems proliferated in spatial and sociological research. Both chaos and complexity involve myriad entities and interrelationships, rendering them challenging to study and predict. Systems, akin to living organisms, undergo constant change, prompted by external factors or internal dynamics, leading to the pursuit of new orders. Here lies the differentiation between chaotic and complex systems. Chaos yields repetitive patterns governed by established rules, whereas complexity lacks such rules, adapting and evolving with each cycle. Adaptive complex systems deviate from repetitions, altering the rules upon which activities rely. In contrast to chaotic systems, which can revert to equilibrium when specific rules are followed, complex systems tend to adaptability and rule-making. The behavior, interactions, and dynamism of entities comprising a complex system have become focal points across scientific disciplines. The dynamics of motion studied by Aristotle and later by Newton form the basis of this dynamism, wherein seemingly mindless entities coalesce to generate intelligence, such as ants forming a cohesive army or cells in the body collectively

combating disease. Consequently, studying complex systems emphasizes a holistic perspective rather than individual entity analysis. The prominent features of the complex system in this context can be listed as follows, as summarized in Figure 2.1:



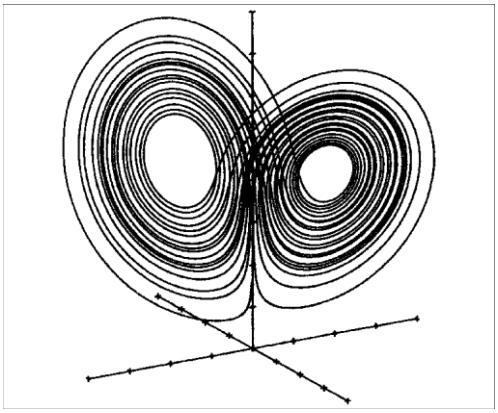
Interactions between Entities, Subsystems, and Supersystems within the Complex System (Tutanç, 2023).

2.1.1 Entities, relationships, and subsystems

One fundamental characteristic of a complex system is its composition of numerous entities and relationships among them (Bryne, 1998). Each entity within the system possesses distinct attributes and forms different types of relationships. These relationships establish order within the system but are also influenced and altered by external factors. In other words, relationships find their balance as conditions change, forming order. The complex system components can each represent subsystems with distinct processes and arrangements. For example, cities have sub-regions containing diverse social, economic, and spatial systems.

2.1.2 Non-linear systems

Numerous studies and equations in various fields have aimed to elucidate linear systems. According to Byrne and Callaghan (2013), a linear system deviates from this linearity while progressing along a straight line. Mitchell (2009) posits that if a system were linear, mathematical calculations based on initial conditions and known variables could predict outcomes accurately. However, a system's non-linearity closely correlates with its carrying capacity and rate of change. In linear systems, such as population growth, effects like birth and death rates increase proportionally over time. Nevertheless, even with mathematical calculations, environmental conditions, and internal factors necessitate changes and adaptations for the population to reach its carrying capacity. This underscores the significance of initial conditions (population) before external factors. Mitchell illustrates this by placing 20 rabbits on an island with a carrying capacity of 12, where the population will decrease to 12 within a year, irrespective of birth and death rates. For complex systems, certain concepts help identify points of deviation from linearity, such as bifurcation points, indicating divergence. For instance, the population may reach different values under the influence of birth and death variables (Manson, 2001). Another concept is "strange attractors" (see Figure 2.2), where the values of the system tend to go beyond the linear path. Each entity in the system has its trajectories and predicted variables, but unknown variables cause deviations from the linear path. For instance, changes in population or economy are system variables. Unexpected changes like natural disasters cause the system to deviate from linearity, diverge at different points, and seek new orders (Byrne & Callaghan, 2013).



Unknown Variables (Ben et al., 2021).

2.1.3 Dynamics of Open Systems

Complex systems are characterized as systems with an open input-output relationship, contributing significantly to their unpredictability and complexity (Cilliers, 2005). Within a complex system, numerous subsystems exist, each with its internal relationships and order. Moreover, the interaction with external systems due to being an open system leads to various changes within the system. Unlike approaches such as adaptation theory, which focuses solely on the environment and suggests that other systems change depending on the environment, the characteristic of being an open system in complex systems implies changes for both the influencer and the influenced. This phenomenon, termed co-evolution, results in systems adapting to their environment, with those unable to adapt being eliminated. However, in the process of co-evolution, it is argued that the environment can also be affected by organizations, and organizations can somehow renew themselves (Sayğan & Uçar, 2015). On the other hand, the theory of Autopoiesis, proposed by Humberto Maturana and Francisco Varela in 1980, suggests that systems interact with the external environment only to ensure their internal organization and development. According to this theory, systems are essentially closed within themselves but open to the external environment (Sayğan, 2014).

2.1.4 Adaptation

Complex systems seek new orders to establish equilibrium amid the influence of internal and external variables. Once exposed to change, these systems cannot revert to their previous orders. Memory and self-organization are vital elements in adaptation (Cilliers, 1998). Understanding the initial states of complex systems influences their current state. Knowing the initial values is crucial for determining the system's development over time. System entities, called decision-making agents, play a significant role in using memory. The storage and utilization of information during the adaptation process facilitate the positive development of the system. Kaufmann, the researcher who first introduced organizational theory in the 1960s, argued that Darwin's definition, which emphasized the dominance of the environment and the survival of the fittest, was incomplete. Self-organization, the system's ability to respond to new situations without predefined rules, is the second component of the adaptation process (Sayğan, 2014). What is crucial in self-organization is the absence

of a responsible decision-maker or designer. In the face of changing conditions, the system collectively develops and acts with a typical response. Self-organizing systems can create cities, roads, markets, communities, and more. As adaptation is a process where both sides change, feedback becomes essential. Positive feedback leads to the system's continued development and existence, while negative feedback may hinder the positive outcome of the adaptation process.

2.1.5 Edge of chaos

Complex systems, characterized by dynamic processes, frequently diverge from equilibrium and seek new balances. Chris Langton's concept of being at the edge, first utilized in 1980s anthropology and computer technology, posits that systems operating at the edge of chaos can generate more creative and varied solutions (Sayğan, 2014). However, this process can be detrimental for systems incapable of functioning under such conditions.

2.1.6 Unpredictability

The unpredictability in complex systems arises from the system's nonlinearity, causing entities to deviate from linear paths due to the influence of various variables. Additionally, the interconnectedness of numerous entities within the system makes detecting changes challenging (Cilliers, 1998). In the 1940s, Shannon explained the unpredictability of systems in thermodynamics using entropy, where he equated energy within the thermodynamic system to information. He proposed that as information increases, unpredictability and entropy also increase (Shannon, 1948). However, information is evaluated within the system's characteristics and evolves based on the system's properties, leading to variations in the shape of information among systems. Moreover, the emergence of new forms of meaning resulting from relationships beyond the pure meaning of information further contributes to unpredictability.

2.1.7 Butterfly effect

The concept of complexity highlights an important feature known as the butterfly effect. According to this idea, a small event occurring in one place can lead to significant consequences elsewhere. Lorenz (1972) famously illustrated this concept in meteorological research, suggesting that flapping a butterfly's wings in Brazil could

trigger a large storm in Texas. This analogy is often cited as the oldest and most fundamental example of the butterfly effect. Alongside the butterfly effect, situations arise where the initial conditions have minimal impact on the outcome (Ghys, 2012).

2.2 Approaches to Complex System Analysis and Modeling

Studies on complex systems are classified into three categories based on their scopes and approaches. The selection of research approaches stems from acknowledging the difficulty in knowing and understanding the entities that comprise the system. Therefore, while some approaches accept working with the knowledge that can be perceived, others acknowledge that the system can be understood through representation. On the other hand, some approaches conduct their studies based on the necessity of understanding the relationships between the entities that constitute the system due to the complexity of comprehending the system itself. These studies have introduced the concept of time as a new subject in understanding the system through relationships and dynamics. At this point, the question arises regarding how to obtain accurate information and the appropriate method for interpreting the information obtained.

2.2.1 Algorithmic complexity

Algorithmic complexity is utilized in classifying the unknown within a specific domain. However, the limitations of knowledge and data result in the classification being confined to certain types and locations of information. Applying this approach in social sciences appears challenging as it cannot capture human perception, experiences, and thoughts (O'Sullivan, 2004; Manson, 2001).

2.2.2 Deterministic complexity

Deterministic complexity is built upon contextuality, probabilities, and chaos. It exhibits an approach focused on repetitions within chaotic environments and argues that the system can be understood or solved through mathematical equations. In other words, it is based on representationalism. According to this approach, there are different systems within the system, and knowledge about the overarching system can be obtained by interpreting the subsystems. Trends, such as attractors like population predictions, are identified. Situations where population explosions or excessive deaths

occur can be attributed to these trends. Feedback loops are crucial in predicting the process and outcome in deterministic complexity, relying on initial information. Similar to regular variables, some variables are unpredictable and can lead to changes in potential outcomes. This method is typically modeled using computer solutions (O'Sullivan, 2004; Manson, 2001).

2.2.3 Integrated complexity (aggregate)

Integrated complexity attempts to understand the whole by comprehending the multiple relationships between units. Integrated complexity relies on the unpredictability of behaviors exhibited by the units forming the system; the cause of behavior and its resulting outcome are unpredictable. It is argued that knowing or understanding everything in a complex system is impossible, but insights can be gained from understanding relationships at a general level. In analyzing the system, examinations are first conducted at the level of entities, followed by interpretations at the system level. While interpretation at the system scale may seem inevitably reductionist, it does not adopt a representational approach. Unlike deterministic complexity, it does not use mathematical modeling; instead, methods such as agent-based models (ABM) and Cellular Automata (CA), which simulate complex systems, are employed. The importance of the environment's influence on system changes and the significance of learning and memory in adapting to the environment are emphasized. Integrated complexity is considered the most compatible approach for studying social sciences compared to others. Therefore, it is a commonly used approach, especially among geographers, who use it to understand the impacts of local actors on a larger scale (O'Sullivan, 2004).

2.2.4 New approach quest

In comprehending complex systems, contemporary analytical scientific methodologies are deemed insufficient to decipher the entities constituting the system and their dynamic relationships and delineate its boundaries. Therefore, there is an ongoing search for new approaches in these areas. Cilliers (2005) argues that complex systems, predominantly associated with living mechanisms, necessitate the involvement of scientific methods and conceptual reasoning for understanding. Similarly, De Roo (2020) emphasizes the importance of deriving reality from measurable data but contends that it becomes meaningful only when combined with relativity. This stems

from the inadequacy of the modern approach's ontological foundation, highlighting the need for an approach that seeks to understand the system in its entirety rather than relying on reductionist methods.

In reductionist approaches, symbols correspond to each content within the system, and there are predictable relationships between symbols, resulting in the knowledge acquired from the analysis remaining at the level of meaning. The rule-based approach guides the analysis or interprets the outcome based on predetermined assumptions or results. Moreover, the observer's perspective directly influences the interpretation, and the framework of the system is drawn based on the interpreter's viewpoint. However, the necessity arises in complex systems to evaluate the system and its constituent entities independently due to their diverse characteristics and relationships. Since complex systems consist of relationships between subsystems, they should be approached holistically, and subsystems should be evaluated together.

Furthermore, due to the interaction with the environment, defining the boundaries and framework of the system becomes challenging. Here, the presence, purpose, and description of the observer/decision-maker should be questioned. On the other hand, how knowledge is obtained, particularly in sociology, is shifting towards interpreting information gathered from different groups, termed Social Collectivism by Becker. In this context, defining relationships, delineating the system's framework, and defining system rules, although seemingly qualitative, can also transition into quantitative methods.

Introducing components like time and technology facilitates ease and new methods in complex system approaches. Mainly since the 1980s, the connectivism approach, based on the functioning of neurons in the brain, has been developed, focusing on the brain's learning and response mechanisms. The relationships between neurons and their responses under changing conditions and the intensity of relationships (weight) emerge as crucial factors in understanding the system and its adaptability. When the exchange between neurons is considered as information exchange within the system, many scientists argue that complex systems possess more information than simple systems due to their properties, such as adaptability, memory, and measurement, but also incur more information loss (entropy) at specific points in the process. This perspective provides clues on managing the loss of information and transforming it into usable form.

In scientific research, as time has been added as a new topic in understanding the relationships between the system and entities, communication-based approaches have also been developed to reveal the values of entities and the concept of time in planning. Integrating time into planning has been a recent topic of discussion.

2.3 Complex Urban Systems

The exploration of cities as systems began with references to various fields of science and continues in this manner today. A well-known example often cited in literature defining the city as a system is Christopher Alexander's statement in 1965 that "a city is not a tree." According to this definition, cities do not grow solely in a branching pattern like tree roots but instead resemble a semi-lattice system. A city system comprises many entities with horizontal, vertical, and convoluted relationships. Some relationships exist between artificial city elements and remain constant, while others involve variable elements. Both artificial and variable elements have the power to influence each other (Alexander, 1966); cited in (Crawford, 2016).

There is a pharmacy in Berkeley at the corner of Hearst and Euclid. Outside the pharmacy is a traffic light and a newspaper box selling daily newspapers at the entrance. While waiting at the red light, some people glance at the newspapers, and some even buy them. This situation creates an interactive relationship between traffic lights and newspaper boxes. The newspaper box, the newspapers inside it, the money coming out of people's pockets and going into the box, the people waiting at the red light, and those glancing at the newspaper—all contribute to forming a system. From the designer's perspective, the unchanging part of this system is of particular interest. The newspaper stands, the traffic light, and the sidewalk between them make up the fixed part of the system. The changing parts of the system—people, newspapers, money, and electrical impulses—are elements that can work together. I define the fixed part as a unit of the city. This unit derives its consistency from the forces that hold its elements together and the dynamic consistency of the more extensive living system that includes it as an unchanging part.

According to De Roo (2012), the most potent concept defining complex urban systems is the notion of wicked problems developed by Rittel and West Churchman in the 1960s. Rittel and West Churchman introduce planning issues as unsolvable problems, describing them as unique, variable, not easily solvable, and interconnected with other

problems (Rittel, 1972; as cited in De Roo, 2012). Ludwig von Bertalanffy's system theory (1968) and Jay W. would also be another source during the same period.

Forrester's system dynamics (1961) is also among the approaches defining the city as a system (Güell, 2017). The foundation of the current bottom-up system analysis approach, focusing on the understanding of existence and entities in complex urban systems, was laid by Prigogine in the 1940s. Prigogine stated that the city, drawing references from physics, consists of repetitive structures. Subsequently, physicist Peter Allen worked on Central Place Theory in this context, leading to the exploration of complexity and self-organization concepts in conjunction with the city (Portugali, Complexity Theories of Cities: Achievements Criticism and Potentials, 2012). Another discussion regarding complex urban systems that emerged in the 1940s and remains relevant today is the debate on urban systems' artificial and organic formation. British planner Geddes, with a background in biology, argued in the 1940s that the city is not a mechanical but an organic structure (Geddes, 1949; as cited in Batty and Marshall, 2012). Geddes' description of the city system as organic, in parallel with Darwinian approaches, contradicts the top-down and rational planning understanding of urban planning (Geddes, 1949; as cited in Batty and Marshall, 2012). This approach asserts that the city exists more from human movements and relationships than from its artificial environments, such as buildings and roads, raising questions about the necessity and effectiveness of urban planning. Subsequently, Geddes shifted towards an approach to urban systems that includes both artificial environments and organic formations in his work (Batty & Marshall, 2012). Following Geddes, the wars and economic crises worldwide brought the top-down planning approach back into focus with different concerns, and plans similar to Ebenezer Howard’s Garden City design were implemented in many places. However, towards the end of the 20th century, it was once again understood that there was a need for a planning approach that falls between organic and artificial urban system approaches. Reading urban systems through the relationships of entities that constitute the city and their interactions with the external environment has ended the approach that viewed cities as accumulations of social groups and economic activities, forming hierarchical structures.

The city being defined as a higher system composed of subsystems, in conjunction with the concept of complexity, has led to studies defining urban space, social structure, governance, and organizational structure as complex systems with their

temporal dimensions. Figure 2.3 illustrates the urban complex system, defining its subsystems (components), subsystem characteristics, and their interrelationships. Temporal complexity, spatial complexity, and complexity in decision-making processes (organizational) are defined by Aydın as subsystems in the urban growth process (Aydın, 2015). Authors like Abbott and Portugali also add the definition of social complexity to this description (Abbott, 2007; Portugali, 2012). Accordingly, spatial complex systems are defined by relationships between spatial functions and structures, different scales, and dependencies. In the short and long term, there are changing relationships and dependencies between every entity and function in space. These relationships also require examination based on their magnitude and impact at different scales. Although spatial complex systems describe a system composed of tangible entities, understanding the mentioned relationships and dimensions requires a conceptual and relational approach. When spatial complexity is considered to reflect the physical and social dimensions of urban planning, governments develop tools to shape space. Urban planning: the way space is defined, planning approaches, governance structure, and the role of governance reflects how governance approaches the city. The behaviors of entities forming the system and the tools of adaptation produced in this direction vary in every system, depending on the characteristics of the entities constituting the system. The behaviors of entities can sometimes lead to the emergence of new tools, surpassing control mechanisms. Decision-makers include city administration, organizations at different levels, and individuals (Middleton Kelly, 2003). The influence of each decision-maker and the steps they take in the decision-making process are different. The influence of decision-makers on each other, their relationships, and the complexity created by unexpected internal and external influences can lead to decision-making processes containing more unknowns. All these processes and the complexity created by decision-makers are called organizational complexity.

Temporal complexity encompasses dynamism, dependence on the initial event in nonlinear processes, and uncertainty. While time has been a concept developed in other sciences for defining systems, it is still an area of ongoing research in defining cities. Finally, social complexity within urban systems is described as the actors in society and their relationships, the change of these actors, and the uncertainty of their values (Abbott, 2007). At this point, the necessity of understanding the entities forming the

city and their relationships comes to the forefront. Based on Geddes' organic city definition, Portugali elaborated on spatial and social complexity in his article "What Makes City Complex," explaining why a city's artificial and organic structures create a complex urban environment. While the city has a built upper system and infrastructure systems (buildings, roads, bridges, etc.), it also has an organic system created by human agents. What makes the city complex is that humans create the artificial environment and guide human behavior within this artificial environment. The artificial environment also indicates the relationship established among humans with complex structures. Portugali added time, i.e., the system's dynamism, through city dwellers (agents). In this regard, Portugali argues, similar to Endel Tulving's concept of the prospective brain in 1983, that humans can be the architects and planners of their cities. This ability stems from knowing their past and foreseeing their future. Like the defense of organic planning, he argues that planners need to reposition themselves from an outsider plan for non-existing behaviors and masses to position themselves internally, like one of the inhabitants (Portugali, 2012). Every dimension constituting the complex urban system is interconnected and influential on each other. Each system is considered an open system that changes, transforms, and adapts by adding the time dimension. Systems tend to organize and develop together using their internal potentials and capacities.

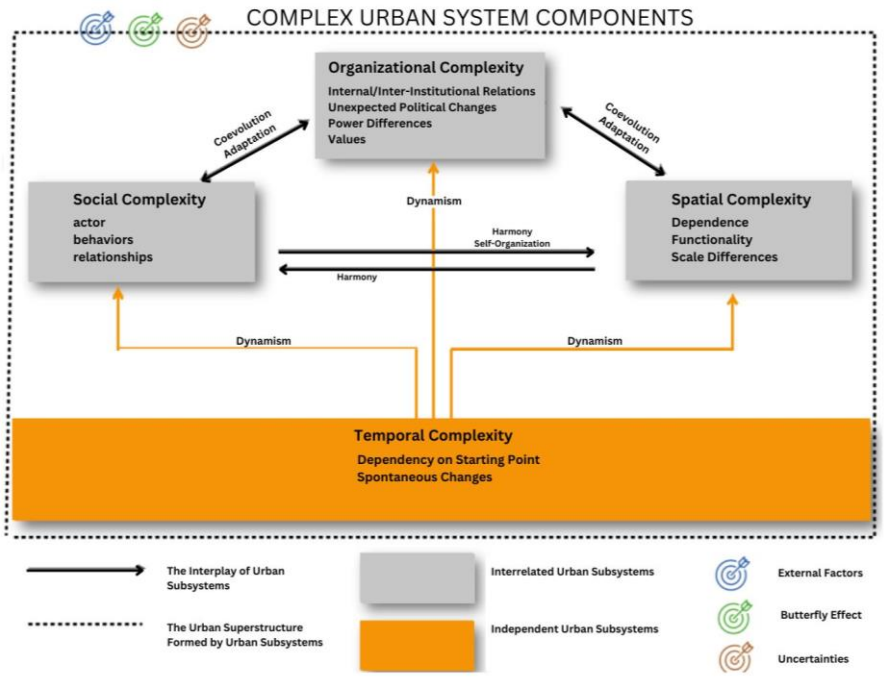


Figure 2.1 : Complex Urban System, Subsystem Components (Tutanç, 2023).

Researchers in Spain, led by Miguel et al., have proposed an innovative conceptual framework for approaching the city as a system (Figure 2.5). It aims to formulate the city concept and identify variables within the system to understand urban systematic approaches better, incorporating foresight. The model was used during the development of the urban vision within the scope of the 2030 Horizon by the Madrid municipality. The model, with its four main principles (Miguel et al., 2017), stands as a beacon of innovation in urban planning.

- The model takes a holistic view of the urban system, addressing local actors, sectoral relationships, and functional connections, utilizing conceptual or process diagrams.
- New tools facilitating participation have been developed.
- Planners have been involved in understanding and adapting to changes alongside participants (co-evolution), and tools enabling this have been developed, ensuring the model's adaptability to evolving urban landscapes.
- Instead of traditional quantitative methods, the planner has developed a method to understand processes and relationships.

According to the model, the urban system consists of the desires of every actor in the city (businesses, residents, tourists), the services/subsystems that meet these desires (political, environmental, economic, and social), and their spatial reflections (Figure 2.4). The entire city system, supported by technological infrastructure and obstacles facing the system, is depicted to influence the entire model (Miguel et al., 2017).

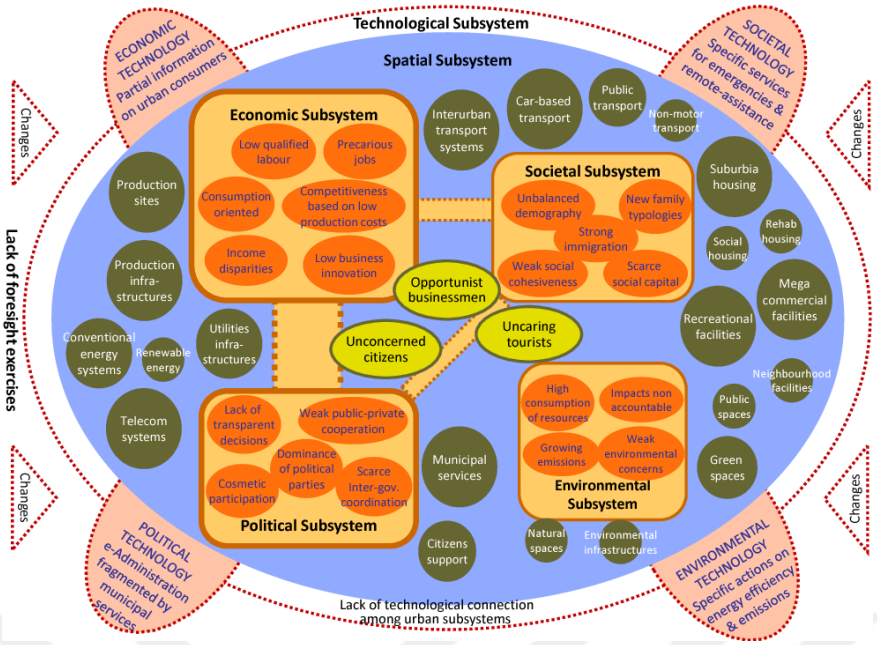


Figure 2.2 : Spanish cities functional system in the pre-crisis period (2000-2008) (Miguel et al., 2017).

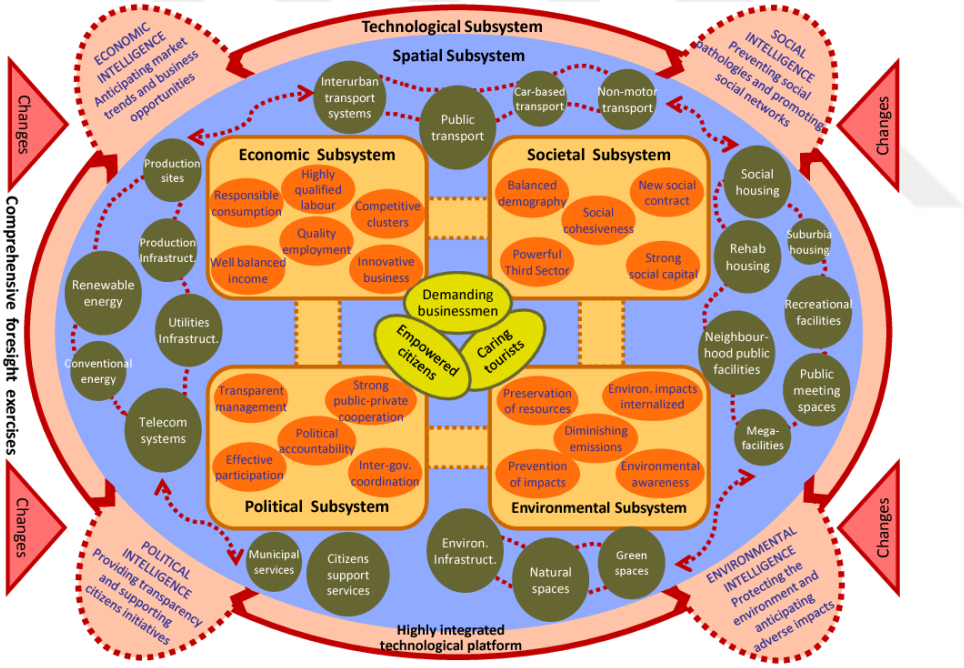


Figure 2.3 : Future vision of Spanish cities functional system (2030) (Miguel et al., 2017).

The definition of the city as a system, extending beyond physical elements to conceptualize it as an entity or phenomenon, has been supported by various approaches, emphasizing the city's inclusion as part of different systems and its dynamic nature. Viewing the city through the lens of complex systems has brought attention to the issues of scale and time. The consideration of urbanization alongside

spatial and ecological systems emerged with the Chicago School in the 1920s, where writers like Writh and Burges described cities as spaces where various social structures converge. However, this description mainly focused on economic aspects, overlooking identity and individual characteristics. In the same period, Jacobs critiqued the traditional planning system in the United States, arguing that self-organizing social structures create order while planning disregards this order and the desires of individuals. In the 1970s, Lefebvre and Harvey characterized space as created by capitalist systems and subjected to socio-economic restructuring. Lefebvre highlighted urbanization components such as the influx of labor due to industrialization, city population growth, and spatial transformations. Similarly, Harvey viewed space as a tool of capitalism, emphasizing its role in creating social inequality through exchange value. Post-1980s, urbanization began to be defined by the concentration of industrial, service, and logistical activities in specific areas and the spatial impacts of these concentrations. The changes brought about by globalization on cities and their surroundings led to various perspectives and studies on defining the rapidly changing urban system. However, current studies focus on understanding urbanization as an ongoing process rather than viewing the city as static. Therefore, recent research approaches urbanization from different angles to explain processes at various scales. A common thread in these approaches is the recognition of urbanization's global impact and its relationship with the dynamics of the smallest entities constituting the city. The entities forming the city (humans, environment, structures, etc.) interact to create a system, and larger systems are also subject to change and have the power to transform one another.

Characterizing urban space necessitates rethinking the concept of scale due to the relationships between urban entities and other systems. Considering urbanization as a dynamic process, planetary urbanization has emerged as a significant perspective in defining urban systems (Yetişkul, 2020). According to Brenner, defining cities solely based on agglomeration and population distributions is insufficient. Various dynamics influence urban areas in time and space beyond their boundaries, and approaching delineating cities is inadequate in understanding these dynamics. Agglomerations should be evaluated in operational areas at global, regional, and urban scales, considering the metabolic social transformations they generate (Brenner & Katsikis, 2020). Brenner builds upon Lefebvre's concept of urbanization to include dynamic

urban formations beyond city centers and rural areas, defining a third type of urbanization (Figure 2.6). This includes the concentrated city, referring to the city center formed by agglomerations; the extended city, representing the urban sprawl created by or in service to agglomerations; and the differentiated city, characterized by various socio-metabolic formations (Brenner & Katsikis, 2020). Initially defined as activities and services outside the city to serve urban needs, urban expansion extends beyond the city, engaging with activities at different scales. Within this framework, socio-spatial transformations occur due to the influence of activities proximate or distant to the city center, leading to dynamic and adaptable opportunity spaces. These spaces undergo spatial, managerial, and daily life formations that vary across contexts (Brenner & Schmid, 2015).

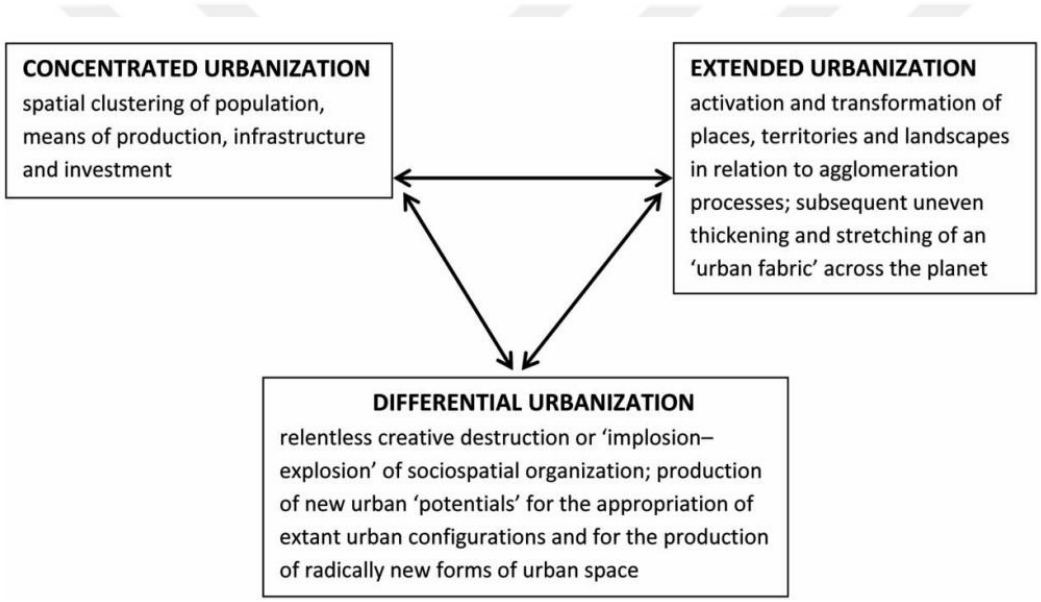


Figure 2.4 : Three Phases of Urbanization (Brenner & Schmid, 2015).

Urry argues that within a complex system, there exists the potential for opportunities on a global scale. He suggests that the minor components of the system tend to perpetuate their cycles rather than actively striving to change the world. However, the unpredictability of their impact on the entire system can lead to the emergence of opportunities. In other words, unexpected events resulting from imbalances in the global system may create different chances (Urry, 2002).

2.4 Diversification in Urban Functions as a Measure of Metropolitan Complexity

As cities continue to grow outward and become more spread out, there has been much talk lately about how the shape of a city relates to what it does (Burger & Meijers, 2012; Hirt, 2012; Kroll & Kabisch, 2012; Markusen & Schrock, 2006). Cities are essential for helping nearby areas grow, but each city develops uniquely (Meijers & Burger, 2010). How a city looks and what it does are closely linked to how it grows, especially when cities have many different things inside them (Talen, 2006).

How cities grow outward, whether they fill empty spaces, expand at the edges, or jump over areas in between, has been studied extensively in research. Researchers look into what causes these different patterns, like whether it is because of how easy it is to get around, the economy, or other specific factors of a place (Jiao et al., 2018; Mustafa et al., 2018; Sun & Zhao, 2018). These patterns can show up differently depending on the situation: even areas with different rankings in the city's hierarchy might end up looking similar, while areas with similar size and population density might have very different layouts, with different kinds of businesses and social activities going on (O'Donoghue, 1999).

Usually, the kinds of things people do in a city follow a pattern along a spectrum: activities tend to concentrate in the inner city and nearby urban centers, leading to a more diverse mix of things happening (O'Donoghue & Townshend, 2005; Parr, 2004; Zambon et al., 2018). Also, how cities grow and change is not just about adding more stuff on the outskirts anymore; it is becoming more spread out and decentralized over time, with different areas developing their centers of activity (Duranton & Puga, 2000; Ottaviano & Peri, 2006; Zambon et al., 2017).

The expansion of settlements around smaller centers has reshaped the traditional layout of cities, impacting their diversity (Parr, 2008; Pili et al., 2017; Turok & Bailey, 2004). This suburban growth creates a continuous urban area with medium-density neighborhoods spread across a fragmented landscape, leading to varied effects on urban complexity (Di Feliciantonio & Salvati, 2015; Hahs & McDonnell, 2006; Salvati, 2013, 2014; Salvati & Carlucci, 2016; Serra et al., 2014; Torrens, 2008; Vasanen, 2012). As metropolitan areas evolve due to this dispersed development, assessing their diversity using different metrics becomes challenging (Dahly & Adair,

2007; Ellerman, 2005; Munafo` et al., 2013; Salvati et al., 2016a). Analyzing socioeconomic changes along urban gradients through diverse approaches helps distinguish between urban cores and suburban regions, aiding in policy-making for urban and rural areas (Colantoni et al., 2015; Comer & Greene, 2015; Cuadrado-Ciuraneta et al., 2017; Duvernoy et al., 2018).

Adding to the complexity of modern cities, the variety of functions and the disorderliness of urban areas are seen as essential aspects of city growth in Europe (Batty & Longley, 1994; Cabral et al., 2013; Kazemzadeh-Zow et al., 2017; Page et al., 2001). European cities, on average, have a more fabulous mix of different activities compared to towns in North America (e.g., Carlucci et al., 2017). Specifically, cities in the Mediterranean region of Europe show a mix of different elements and a disorderly layout, reflecting their shared characteristics but also their unique history, economic development, and settlement patterns (Beriatos & Gospodini, 2004; Di Feliciantonio & Salvati, 2015; Grekousis et al., 2013; Zitti et al., 2015). Economic differences and social separation have significantly affected how these cities have grown, leading to disparities between different areas and a messy layout (De Rosa, 2016; Malheiros, 2002; Maloutas, 2007; Rontos et al., 2016). Mediterranean cities have often expanded without much regulation, resulting in chaotic urban layouts that reflect a diverse but disconnected economic base (Colantoni et al., 2016; Maloutas, 1993; Stanley, 2012). Over time, these cities have developed into complex systems with economic gaps, social isolation, scattered settlements, and a fragmented layout (Carlucci et al., 2017). This shows how Mediterranean cities have undergone significant changes, leading to widespread cities with disconnected functions (Pili et al., 2017). The work by Carlucci et al. (2019) offers a new way of understanding complex city systems by using a variety of indicators and spatial data.

Carlucci et al. (2019) looked at 12 different aspects of how cities vary (see Figure 2.7), which are vital parts of what makes cities complex. These aspects include what the land is used for, how much of it is covered with buildings, what the buildings are used for, how tall they are, how old they are, and what they are made of. They also looked at what kinds of jobs people have, their education level, age, where they are from, and how much money they make.

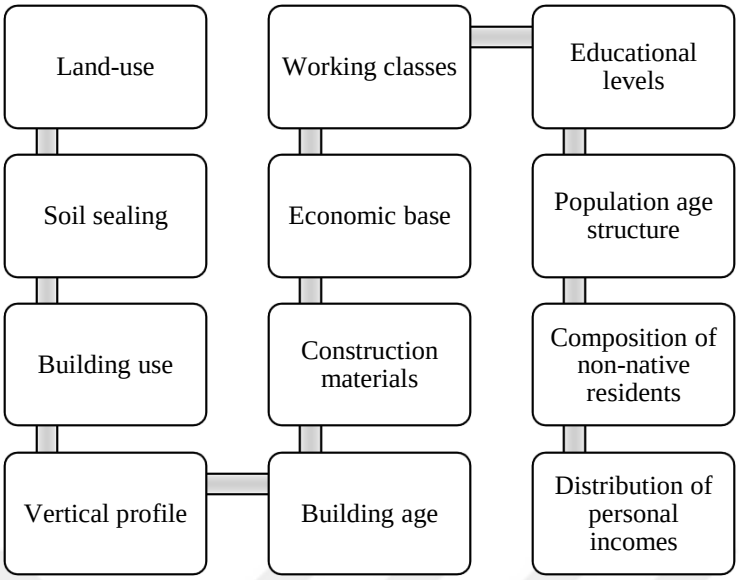


Figure 2.5 : Diversification Aspects (Carlucci et al., 2020).

2.5 Shaping Dimensions of Urban Complexity

Cities are complicated systems where they trade people, stuff, energy, and information with each other and nature daily. Money and jobs influence how cities grow and change and how the city is set up. These things all work together in a cycle that makes cities more and more complicated over time (Frenken et al., 2007; Haase et al., 2010; De Rosa & Salvati, 2016; Portugali, 2006). Each city has its structure, with different parts of different sizes and of different importance. Cities are crucial for making money and helping society grow, and they are where many different activities happen. Urban areas are significant for coming up with new ideas and businesses. Studies show that businesses like being in places with many different things going on, which helps them grow and be more creative (Duranton & Puga, 2001; Ellerman, 2005; Stanley, 2012; Thisse, 2018). Urban regions generate new ideas and businesses (Ejermo, 2005; O'Donoghue & Townshend, 2005; Markusen & Schrock, 2006; Florida et al., 2017). Evidence shows that businesses prefer being in diverse places that offer more opportunities for growth and social interactions, an environment that is competitive and open to the world, and a place where new ideas can thrive (Desrochers, 2001; Andersson et al., 2005; Desrochers & Hospers, 2007; Smets & Salman, 2008).

When making cities lively and competitive, having different kinds of land use and a mix of people is essential (Jacobs, 1969; Fincher & Jacobs, 1998; O'Donoghue, 1999;

Hirt, 2012; Sun & Zhao, 2018). Cities bring together many different businesses and people needed for new ideas and starting new businesses (Hill, 1988; Duranton & Puga, 2000; Rosenthal & Strange, 2001; Frenken et al., 2007). Many different things are daily in cities (e.g., Viladecans-Marsal, 2004; Ottaviano & Peri, 2006; Grant & Perrott, 2009; Kroll & Kabisch, 2012). This shows that cities have different types of businesses, jobs, and social structures (Davies & Donoghue, 1993; O'Donoghue & Townshend, 2005; Burger & Meijers, 2012; Youn et al., 2016).

Smaller neighborhoods are becoming more specialized in many urban areas, while more prominent metropolitan regions are growing and changing (Munafò et al., 2013; Van Oort et al., 2015; Hirt, 2016). As a result, these extensive city areas adjust their social and economic structures because of things that happen inside and outside (Desrochers & Hospers, 2007; Venerandi et al., 2017; Zambon et al., 2018). This leads to a mix of different land uses and activities, essential for making cities complex and exciting (Jacobs, 1969). When different types of places are close to each other, it makes it easier for people to meet and for businesses to grow (Thomas et al., 2012). So, understanding how all these different parts of the city interact and change is essential for figuring out what makes big city areas complex (Salvati et al., 2016).

According to this way of thinking, big cities with meaningful jobs and a mix of different social groups are expected to have the most variety in how they look and do (Hirt, 2012; Psycharis et al., 2014; Zambon et al., 2017). This variety includes different kinds of buildings, spaces like parks and shops, and how streets are laid out, all of which help define what makes a city a nice place to live (Montgomery, 1998). The idea is that the way people and businesses are spread out across the city, along with how big and rich different parts of the city are and how they connect, are all critical features of what makes a city unique (Iceland, 2004; Hospers, 2006; Dahly & Adair, 2007; Comer & Greene, 2015). Moreover, this same idea can be applied to more extensive areas, like regions with one or more main centers of growth (Kleinhans, 2004; Maloutas, 2007; Inostroza, 2014; Jiao et al., 2018).

Previous studies have shown that looking closely at the different structures in big cities helps us understand two main things: (1) the significant challenges cities face as they grow and (2) how different parts of the city are connected. For example, researchers used entropy measures to see how different types of businesses in a city affect each other, based on ideas from Jacobs. They found that when businesses are related, it

helps create more jobs, while having unrelated businesses can lead to more unemployment (Frenken et al., 2007; Hou & Wu, 2009; Cabral et al., 2013). This can also make social inequalities worse by separating different social groups (Yang & Jargowsky, 2006; Stanley, 2012; Van Oort et al., 2015).

Other studies have examined how diverse a city is in terms of its buildings, how old they are, or how much of the land is covered by buildings. These things can show how complex a city's economy is in different areas (Wood, 2003; Meijers & Burger, 2010; Van Criekingen, 2010; Serra et al., 2014; Zambon et al., 2017). For example, Salvati (2014) devised a way to measure the varied levels of buildings covering the ground in different regions of Europe. Based on Pielou's evenness index, this method was found to help figure out which areas are the main centers of a city and which are on the outskirts, better than other methods (Zitti et al., 2015). This helps us study how big cities grow and change over time (Salvati et al., 2016).

The study by Salvati and Carlucci (2019) explores the differences and similarities among different cities, drawing inspiration from Jacobs' ideas dating back to 1969. It proposes a practical approach to comprehending cities' complexity and interconnectedness with local surroundings. As examined in this study, urban complexity encompasses various aspects of a city, including social dynamics, economic activities, and spatial layout, to understand how they interplay uniquely in each city. To make sense of these diverse aspects, the study develops a summary that assesses 12 factors related to a city's social, economic, and spatial diversity. This analysis reveals how cities evolve based on their distinct blend of built environment and activities (Ellerman, 2005; Ejermo, 2005; Frenken et al., 2007).

Complexity theory offers insights into understanding cities as intricate systems, akin to how social philosophy aids in understanding society (Portugali, 2006). By employing complexity theory, we can understand how cities are interconnected with their surrounding spaces and places, thereby understanding urban evolution more deeply. This perspective has gained popularity in urban studies and can provide insights into how cities perform and recover from challenges (Boeing, 2018). Examining various metrics from diverse sources aids in comprehending the complexity of cities and their ability to adapt and evolve (Salvati & Serra, 2016).

Measuring urban complexity poses challenges. Boeing (2018) suggests that assessing different dimensions of complexity can enhance our understanding. These dimensions encompass time dynamics, visual aspects, spatial arrangements, scale considerations, and connectivity patterns. Understanding the dynamics of urban growth and change is crucial for formulating policies that foster cities' resilience and sustainability (Di Feliciantonio & Salvati, 2015; Cuadrado-Ciuraneta et al., 2017; Duvernoy et al., 2018). Table 2.1 summarizes all the factors present in the literature on urban complexity.

Table 2.1 : Shaping Dimensions of Urban Complexity.

Research area	Researchers
Decoding City Business Dynamics with Entropy Measures	Frenken et al., 2007; Hou and Wu, 2009; Cabral et al., 2013
Businesses' Impact on Social Inequalities	Yang and Jargowsky, 2006; Stanley, 2012; Van Oort et al., 2015
City Diversity: Buildings, Age, and Land Use Reflect Economic Complexity	Wood, 2003; Meijers and Burger, 2010; Van Criekingen, 2010; Serra et al., 2014; Zambon et al., 2017
Measuring Building Coverage Variation Across European Regions	Salvati, 2014
Urban Complexity Growth and Transformation Over Time	Salvati, 2014
Unveiling Cities as Intricate Systems, Inspired by Social Philosophy by Complexity Theory	Portugali, 2006
Multi-Dimensional Assessment of Complexity in Urban Studies	Boeing, 2018
Dynamics of Urban Complexity: Towards Resilient, Sustainable Cities	Di Feliciantonio and Salvati, 2015; Cuadrado-Ciuraneta et al., 2017; Duvernoy et al., 2018

2.6 Understanding Urban Complexity via the Activities Network

Recently, there has been more focus on understanding how complex networks work. Network analysis has become vital because it helps us understand how real-world systems, which are often very complicated, behave. The idea is that the complex behaviors we see in these systems come from how their essential parts interact (Latora & Russo, 2017; Arenas et al., 2008). Traditionally, this field has learned much from statistical physics, especially in comparing different types of random graphs to real-world network data (Jaynes, 1957; Anand & Bianconi, 2009).

Additionally, combining network analysis with information theory has led to valuable insights. This mix of different fields helps us adapt classic ideas and methods to understand better complex networks (Dehmer, 2008; Mowshowitz & Dehmer, 2012). This interdisciplinary approach gives us a deeper understanding of the complexities

within networks. Especially studying how much randomness there is in actual network data and looking at critical structural features using algorithmic information theory has improved our understanding of network complexities (Dehmer & Mowshowitz, 2011; Morzy et al., 2017; Zenil et al., 2018).

As we learn more about complex networks, different methods work together to help us understand how interconnected systems behave. This collaboration between approaches helps us uncover the many different aspects of these systems, giving us valuable insights into how they work in real-life situations.

The term 'complexity' comes up a lot in research, especially when authors are trying to create measures of information for specific purposes (Margalef, 1974; Smith & Jenks, 2006; Bonchev & Rouvray, 2005; Parrott, 2010; Cudworth & Hobden, 2021). In the context of cities, complexity is seen as the result of many different factors interacting in intricate ways over space and time (Salat & Bourdic, 2012; Salvati & Carlucci, 2019). One crucial factor is the layout of the city itself. For example, how close buildings are to each other and vital places can affect how complex the city feels (Salat & Bourdic, 2012; Salvati, 2018; López-Baeza et al., 2017).

As researchers explore the various aspects of complexity, their work shows how ideas from information theory, ecology, and urban dynamics come together to understand city life better (Smith & Jenks, 2005; Bonchev & Rouvray, 2005; Parrott, 2010). This is not just about theories; it also looks at real-life situations where we can see how information affects cities' structure and function.

Different authors have different ideas about urban complexity, showing the need to consider cities as a whole. This means considering how the economy works, who lives there, and how different areas relate. These relationships shape and constantly change cities (Salat & Bourdic, 2012; Salvati & Carlucci, 2019). Urban complexity is not something that stays the same—it is constantly evolving because of how things interact and change in cities. Essentially, 'complexity' helps us understand all the different parts of city life, and as researchers study it more, we better understand how cities work.

The idea of complexity looks at how many different parts of a system interact with each other (Bonchev & Buck, 2005). However, complexity is more than just interactions—it also includes uncertainties and random events that affect the balance between order and disorder in cities (Batty, 2005; Smith & Jenks, 2006).

Understanding urban complexity means looking at all the different elements and how they interact, which can be explained by the concept of 'diversity' (Alberti et al., 2018; Rueda, 1995).

When we look at cities, we see that people and their organizations change and develop over time, showing how much information they can hold and how they affect what happens now and in the future (Fernández-Güell et al., 2021). This viewpoint highlights how complexity in cities is subtle and constantly changing.

We look at different aspects of complexity in cities using numbers, like evaluating how complex networks are (Bonchev & Buck, 2005), studying complexity in cities in more detail (Batty, 2005), and thinking about how complexity relates to ecological and cognitive processes (Smith & Jenks, 2006; Alberti et al., 2018). Including complexity, diversity, and intelligence in intelligent city projects shows how important it is to understand how cities work (Fernández-Güell et al., 2021). Also, using information theory, like Shannon entropy, helps us measure how cities develop and how complex they are (Zachary & Dobson, 2021). Overall, complexity in cities is complicated, involving many things that interact and change over time in the city landscape. This complex mix shapes cities, so we must look at them from all angles and use advanced tools to understand and manage these complexities.

Studying how information is organized in cities involves gathering knowledge from geography, urban studies, and other fields (Healey, 2006; Franck & Stevens, 2006; Friedmann, 2021; Luckan, 2021; Portugali, 2021). This approach brings together different areas of study to discover diverse patterns in urban spaces and understand how information is arranged through various uses, activities, and things in cities.

Researchers often study the complexity of different things in cities using information like what types of land are used and where exciting places are located (Abdullahi et al., 2015; Dritsa & Biloria, 2021; Liu et al., 2020; Xue et al., 2020; Zhang et al., 2021). This information helps us understand how urban areas change over time, including what people buy, how easy it is to get around, how many buildings there are, and many other details about the city.

Rueda Palenzuela et al. (2022) pointed out that Barcelona, especially in the Eixample district, shows many different things happening thanks to more buildings and intelligent business plans. They also looked at social media to see how people talk

about things like liveliness in cities (Yue et al., 2017; Barreca et al., 2020; Tu et al., 2020). This research combines looking at maps and using big data techniques to count different things and understand how people interact with the city.

Recently, new technologies have been used to understand how busy places are and where people go, offering an alternative to old-fashioned surveys that only ask a few people and might not always be accurate. Shoval (2008) looked at GPS data to see how visitors affect cities, showing how new data sources can help us study cities better. However, GPS data usually only cover small areas. Now, many people have smartphones that can track where they go very precisely, and we can use this detailed data to understand cities better in both space and time, which has become a growing area of research (Tranos & Nijkamp, 2015).

Recent studies have used mobile phone data to predict how people move around (Song et al., 2010) and determine where communities and geographic areas start and end (Calabrese et al., 2011). These studies help us better understand cities using much data covering extensive areas and details. Other research has looked into how cities work (Ratti et al., 2006; Reades et al., 2009; Louail et al., 2014) and how land is used (Toole et al., 2012; Jacobs-Crisioni et al., 2014; Pei et al., 2014), showing that mobile phone data can be a reliable way to understand both how people move around and how land is used.

Much research has examined how different types of land use are mixed, using different measures like entropy, job ratio, accessibility, density, centricity, and network connectivity (Litman & Steele, 2014). Entropy is one of the most common measures used and has been used in many places (Cervero, 1989; Frank & Pivo, 1994). Nevertheless, some recent findings suggest that entropy might show more uncertainty than diversity because of how it is calculated (Jost, 2006; Christian et al., 2011). We need more research to improve these measures of mixed land use. Also, many studies on land use rely on official or self-reported data, which often do not cover things very well regarding how often they are sampled and how detailed they are in space and time. For instance, when we look at small businesses in residential buildings, the data we have about what land is used for might not show this diversity. So, the maps we have of land use at the level of individual parcels might not show all the differences in different areas (Handy, 1996).

In the rapidly changing field of urban studies, the rise of Information and Communication Technology (ICT) has been a game-changer. ICT offers new ways to access and analyze data, allowing researchers to delve into cities with more detail than ever before. This has opened up exciting possibilities for studying the complex workings of urban environments. One key area of focus has been the use of Points of Interest (POI) data, which has become increasingly available thanks to mapping apps and social media check-ins.

Batty (2010) keenly observed the growing potential of ICT and stressed the importance of using these opportunities to gain a deeper understanding of urban dynamics. Using Points of Interest (POI) data in urban studies has become popular because POI categories align well with standardized land use codes. Researchers have recognized this alignment and have been working to establish meaningful connections between POIs and land use classifications. For instance, Liu and Long (2015) demonstrated the possibility of inferring land use at the parcel level from Points of Interest (POIs) using Volunteered Geographic Information (VGI), showing how practical this approach can be in capturing the complex patterns of urban land use.

Jiang et al. (2015) also investigated how Points of Interest (POIs) could be used to estimate employment density, offering valuable insights into the potential of POIs for detailed and segmented land use analyses. Their research highlighted that, especially at finer scales, POIs could provide more accurate estimations than traditional parcel-level land use maps, revealing details that might be missed at broader spatial levels. Notably, both studies rigorously compared their findings to conventional land use datasets, uncovering differences often attributed to limitations in traditional data, such as outdated information or insufficient spatial detail.

As urban research progresses, it is essential to recognize the drawbacks linked to VGI-based POIs, which include concerns about data accuracy, completeness, and classification. To address these challenges, this study uses an official POI dataset from a navigation database to alleviate some of the issues inherent in VGI-based POIs. By doing this, the research adds to the ongoing discussion about evolving methods in urban studies, emphasizing the significance of careful data selection and thoughtful interpretation of results to enhance our understanding of urban dynamics.

In conclusion, this review has explored the complex world of urban complexity, drawing from various fields like ecology, information theory, and urban studies. We have learned how diversity and information organization are vital in shaping cities' complexity. Our study fits into this broader perspective by using geospatial data and detailed measurements of human activities to gain deeper insights into urban complexity. We plan to apply this approach to Istanbul, examining how activities are spread and varied across the city and how this affects urban complexity. Through our research, we aim to contribute to a better understanding of how spatial organization, activity diversity, and overall complexity interact in urban environments. By carefully analyzing these factors, we hope to shed light on the intricate nature of Istanbul's urban landscape and better grasp the factors influencing its complexity.

3. INVESTIGATIVE FRAMEWORK: UNDERSTANDING URBAN DYNAMICS AND ACTIVITY PATTERNS

The thesis is an applied developmental research, primarily serving a descriptive-analytical purpose. The methodology involves gathering information from secondary sources such as library documents and big data. Diversity indexes like Simpson's Index, Shannon-Weiner Diversity Index, and Eveness Pielou's Index are applied to evaluate activity diversity in each region. The Kernel Density tool is employed to assess activity intensity. Figure 3.1 shows a summary of the methodology used.

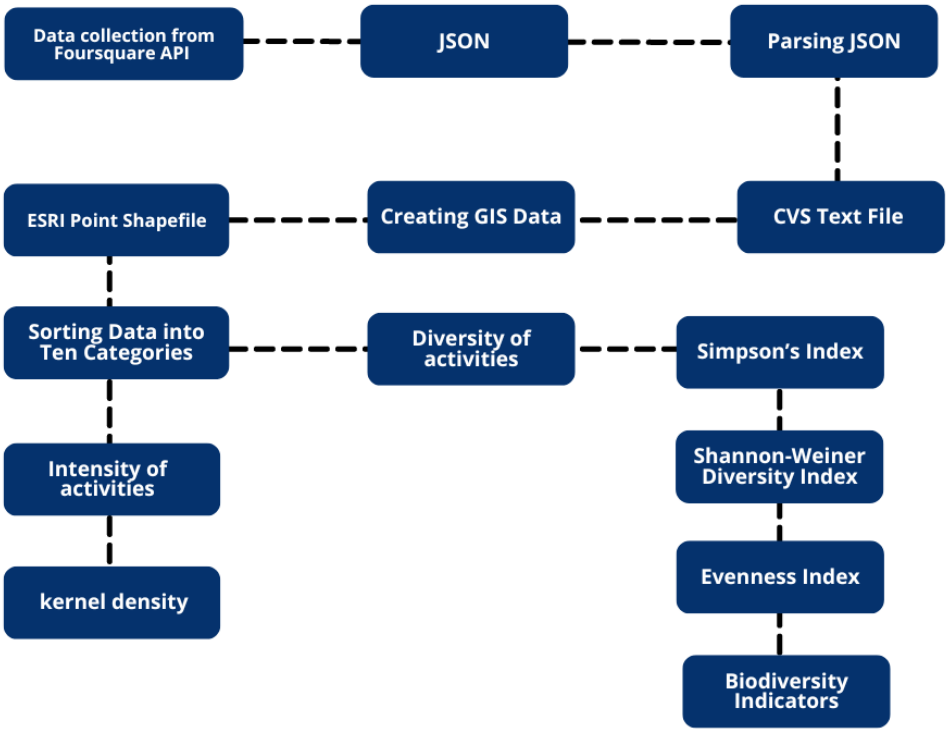


Figure 3.1 : Methodology diagram.

3.1 Case Study

For centuries, Istanbul held a powerful position as a center of political and economic influence. This dominance briefly dipped in the early 20th century, but by the mid-century, the city regained its importance. Since the 1990s, globalization has impacted Istanbul in both positive and negative ways. This global shift involved deregulation, privatization, and increased international trade and investment. Advancements in communication and transportation further fueled Istanbul’s position on the global stage (Enlil et al., 2011).

One result of globalization is a new global geography of production. Manufacturing has scattered worldwide, while specialized services like finance and consulting have grown in importance. These specialized services are concentrated in a small number of major global cities. This trend has led to a new city ranking system (Friedmann, 1986). Major cities like New York, London, and Tokyo were considered the top tier in this new system. According to these rankings, Istanbul falls into the "third tier" (Beaverstock et al., 1999).

Cities worldwide compete to attract businesses, tourists, and skilled workers. They all strive to become significant financial, cultural, and tourism hubs. Unfortunately, this competition has led to many cities adopting similar development strategies, resulting in uninspired copycat projects (Swyngedouw et al., 2002). Examples of these repetitive projects include luxury developments like high-rise office buildings, upscale shopping centers, and expensive restaurants. This focus on luxury development has contributed to a growing income gap between the wealthy and the poor in many cities, including Istanbul.

Despite these challenges, Istanbul has become a focal point for Turkey's economic development efforts in this new era of global competition. The city is crucial in integrating Turkey's economy with the global market. Several factors contributed to Istanbul's renewed importance. The collapse of the Soviet Union, the rise of economic ties among Turkic-speaking countries, and the ongoing political instability in the Middle East all created a new regional environment. With its size, history, and strategic location, Istanbul is well-positioned as a significant trade and economic center in this new regional landscape. Although not the official capital, Istanbul remains Turkey's largest and most influential city (Enlil et al., 2011).

3.1.1 Istanbul's transformation: from imperial prosperity to decline (1800–1950)

From the 1800s to the mid-20th century, Istanbul underwent significant transformations. During the mid-19th century, the Ottoman Empire initiated a series of reforms to modernize the state and society. These reforms included secularizing the legal system and integrating Ottoman markets with the industrializing West, notably through the 1838 Anglo-Turkish Commercial Treaty. This period saw foreign trade growth and early modern industries in Istanbul, which became a crucial node in European commercial networks (Enlil, 1994).

The socio-economic landscape of Istanbul also changed, marked by the rise of a bureaucratic elite and a commercial bourgeoisie, predominantly consisting of Armenian, Greek, and Jewish communities, alongside foreign residents. These groups were central to Istanbul's economic and social changes, contributing to population growth and urban expansion. By the late 19th century, Istanbul's population had more than doubled, developing new commercial and residential areas like Galata and Pera, which became centers of trade, finance, and European-influenced cultural life (Shaw, 1979; Karpat, 1985).

However, the early 20th century brought dramatic changes. The fall of the Ottoman Empire post-World War I and the establishment of the Turkish Republic in 1923 shifted the administrative capital to Ankara, diminishing Istanbul's political and economic significance. The city also experienced a significant population decline, exacerbated by the departure of non-Muslim communities, mainly Greeks, resulting in a more homogenized population and the loss of a dynamic middle class (Tekeli, 1992).

National priorities and the global Great Depression hampered efforts to revitalize Istanbul's economy. The early Republican government focused on rebuilding war-stricken Anatolian towns and developing the new capital, Ankara. Consequently, Istanbul did not benefit significantly from these efforts, and its industrialization lagged (Tekeli, 1992).

In response to the urban challenges, French planner Henri Prost was invited to create a master plan for Istanbul, approved in 1939. Prost's plan aimed to condense the sprawling city by prioritizing vehicular traffic, opening new roads, and integrating scattered urban areas. This plan sought to rejuvenate desolate parts of the city, especially within the Istanbul Peninsula (Tekeli, 1992).

By the 1950s, Istanbul faced a new challenge: managing a rapidly growing population and the proliferation of informal housing. Squatter settlements, known as Gecekondus, emerged near industrial zones and urban fringes. These settlements, often built on public land, became the primary source of new housing, creating numerous informal neighborhoods within and outside the old city walls (Tekeli, 1992).

Figure 3.2 highlights the historical overview of Istanbul's significant socio-economic and urban transformations, from its evolution from a flourishing metropolis to a shrinking city and its subsequent efforts to adapt to new challenges.

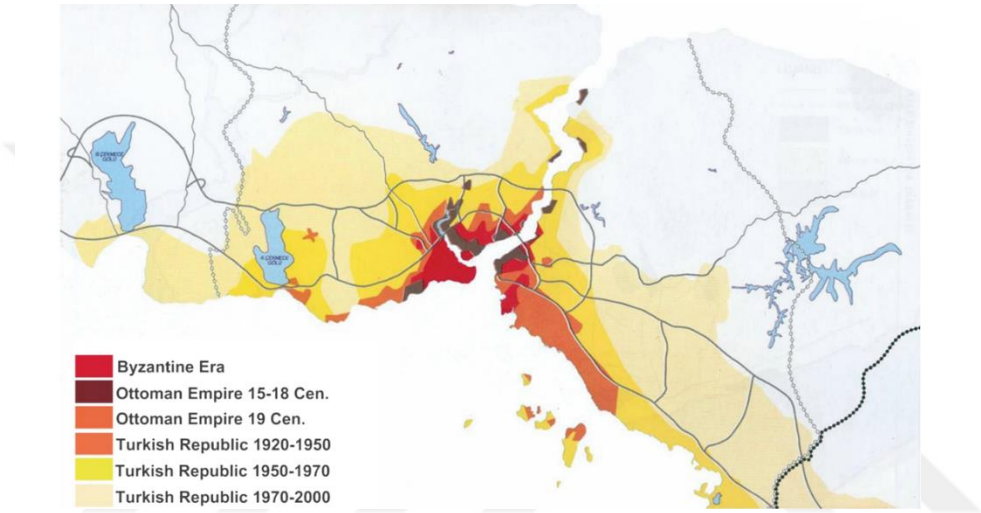


Figure 3.2 : Historical development stages of Istanbul (Enlil, et al, 2011).

3.1.2 Unplanned urbanization: the making of an industrial metropolis (1950–1980)

In the early 1950s, Istanbul experienced a brief period of import growth, followed by a shift towards import-substituting industrialization in the early 1960s. This period saw significant industrial growth, increased working-class employment, and accelerated rural-to-urban migration. Concurrently, mechanization and commercialization of agriculture in the 1950s led to a decline in rural employment, prompting a large migration from rural Anatolia to urban areas. The democratization of Turkey's political structure, which led to a multi-party liberal democratic system, facilitated the growth of local governments and politicians. This shift eventually recognized squatters' property rights to some extent (Tekeli, 1992).

By 1960, state policies increasingly shaped Turkish economic growth, with the establishment of the State Planning Organization tasked with preparing national, sectoral, and regional development plans. The mixed economic system favored the

growth of holding companies organized by family dynasties close to the state and policies supporting wage rises and trade union recognition. Istanbul became central to these changes, with 65% of new enterprises established in Turkey located in the city. Under the First and Second Five-Year National Development Plans, Istanbul received the majority of public expenditure, doubling industrial enterprises between 1950 and 1964 (Tekeli, 1992). By the 1980s, Istanbul had become an oversized industrial city, with nearly half of Turkey's small and large-scale industries (Güvenç, 1993).

Transformation of the spatial structure in the 'City of Hope'

Istanbul's population doubled from about 1 million in 1950 to 2.2 million by 1970 and grew to 2.9 million by 1980. This rapid population growth transformed the city's geography. Before the 1970s, Istanbul's urban form was determined by micro-climatic conditions and natural thresholds like forests and bodies of water. However, mid-20th-century economic and population growth and new transportation technologies led to urban sprawl that disregarded these natural boundaries. The construction of the E-5 international motorway and the first bridge over the Bosporus significantly altered Istanbul's urban development (Yenen et al., 1993).

Unplanned industrial developments began to emerge along the E-5 corridor, which extended parallel to the coasts of the Marmara Sea and inland on both the European and Asian sides of the city. These industrial areas were followed by illegal housing for the working classes and urban poor, further exacerbating urban sprawl. By 1980, urbanized areas stretched 50 kilometers from the city center, leading to inadequate municipal services and threatening vital natural resources (Sengezer & Enlil, 1999).

New alliances and emergent socio-spatial forms

Without significant housing provision by the public sector or private industrial employers, migrants had to create solutions—limited public housing policies mainly targeted middle- and upper-middle-income groups. Consequently, many migrants built squatter settlements, or "gecekondus," on public land. Although authorities occasionally demolished some gecekondu settlements, local politicians seeking votes often re-evaluated squatters as a source of support. Amnesties were granted from time to time, legalizing these settlements and allowing settlers to convert modest houses into more substantial apartment buildings, leading to the commercialization of gecekondu areas and the emergence of "squatter lords" (Öncü, 1988; Enlil et al., 1998).

From the mid-1970s, the possibilities of seizing public land diminished, leading newcomers to buy split-deed plots on the city's outskirts. Today, more than half of Istanbul's population lives in illegally formed housing environments. The scarcity of urban land, increasing population, and rising land values led to another form of improvised housing production known as "build and sell" (yap-sat). This system involved alliances between landowners and small capital owners or contractors, leading to dense concrete and steel-reinforced apartment building neighborhoods, significantly altering the city's landscape between 1950 and 1980 (Enlil, 2003a).

Overall, Istanbul's transformation from 1950 to 1980 was characterized by rapid industrial growth, urban sprawl, and improvised housing solutions, which reshaped the city's socio-spatial structure and environmental landscape (see Figure 3.3) (Tekeli, 1992).

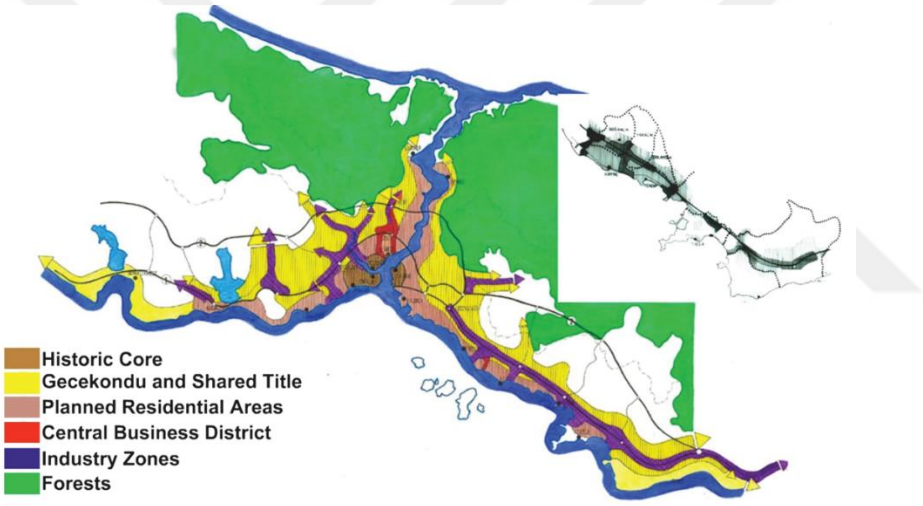


Figure 3.3 : Sprawl of industrial and residential areas in Istanbul during (1950–1980) (Kaptan, 1991).

3.1.3 Transformation of the urban structure in the neo-liberal age (post-1980s)

Following military rule in Turkey (1980-1983), economic policies shifted dramatically. The government aimed to stimulate a free market by reducing regulations and state involvement. This “neoliberal” approach focused on integrating Turkey into global markets through export growth and attracting foreign investment. These reforms included promoting the banking sector and international finance, establishing trade zones, making the Turkish Lira convertible to other currencies, privatizing state-owned businesses, and granting more autonomy to local governments. Figure 3.4 illustrates the legal status of residential areas in Istanbul, providing a detailed overview

of the zoning regulations and land use classifications that have shaped the city's development. (Kaptan, 199).

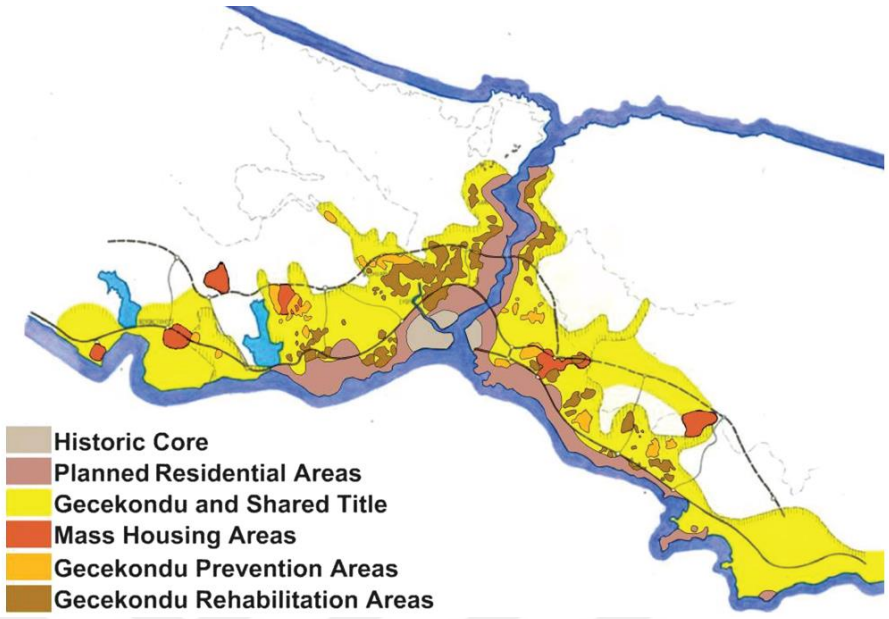


Figure 3.4 : Legal status of residential areas in Istanbul (Kaptan, 1991).

Three fundamental policy changes impacted significant cities like Istanbul. First, new laws allowed metropolitan governments to raise more revenue through taxes, providing them with funds for large infrastructure projects. Second, the government established a fund and agency specifically for mass housing projects, with Istanbul receiving a significant share of these resources. Finally, a new two-tiered metropolitan governance structure was created for Istanbul, Ankara, and Izmir. This transferred some control from the central government to these cities' metropolitan municipalities, which oversaw coordination and administration. Additionally, a lower tier of district municipalities with elected officials was established. These district municipalities gained substantial planning authority, giving them more influence over urban development. Many reforms were further strengthened or expanded after the AKP government came to power in 2002(Kaptan, 1991; Keyder & Oncu, 1994).

Since the 1980s, national policies have aimed to transform Istanbul into a hub for integrating Turkey's economy with global markets through neoliberal strategies. Istanbul has undergone significant economic and urban changes over the past three decades. Istanbul's economic base started to change. While a third of Turkey's industry remained in the city, there was a notable shift from manufacturing to finance and service sectors between the 1980s and 1990s. Jobs in areas like finance, insurance, and

real estate boomed. Consumer services and retail activities also grew substantially (Aksoy, 1996).

Foreign direct investment (FDI) significantly increased from 1983 onwards, with most of this growth happening after 1990. The service sector attracted a larger share of FDI compared to manufacturing. Much of this foreign investment was concentrated in Istanbul, particularly banking and finance. These economic changes were reflected in Istanbul's rapidly changing urban landscape. The city became a showcase of Turkey's new era of internationalism. The government aimed to enhance Istanbul's image and brand it as a destination for tourism, business conferences, and international organizations. This led to approvals for high-profile office developments, luxury hotels, and new transportation hubs (Ekinci, 1993).

The Act on the Promotion of Tourism, enacted in 1982, was an essential planning tool. It allowed the central government to designate strategic areas as "Tourism Centers," offering incentives for investors. This act also bypassed local planning regulations and allowed increased building rights in these designated areas. Many areas in Istanbul were declared as tourism or business centers, allowing the construction of high-rise office towers and luxury hotels. This policy spurred the expansion of the CBD northwards along the Büyükdere-Maslak axis, attracting significant banks, financial service companies, and multinational corporations. Eminönü and Beyoğlu districts, once the historic center for finance and commerce, lost their importance as businesses relocated to the new areas.

The construction of two bridges across the Bosporus in the 1970s,1980s, and 1990s further facilitated the CBD's expansion northwards. These bridges improved accessibility to areas along the Büyükdere-Maslak axis and international airports. The metro system also improved connections between the CBD, the cultural center around Taksim, and upscale suburbs. The Istanbul skyline was dramatically transformed within two decades, with office towers and luxury apartments dwarfing historical landmarks like minarets. Many international hotels, some overlooking the Bosporus, were built during this period. These large-scale developments significantly altered the city's traditional urban fabric(Ozdemir, 2002). Figure 3.5 illustrates the land-use pattern in the central areas of Istanbul before 1980, capturing the traditional urban layout and functional zones.

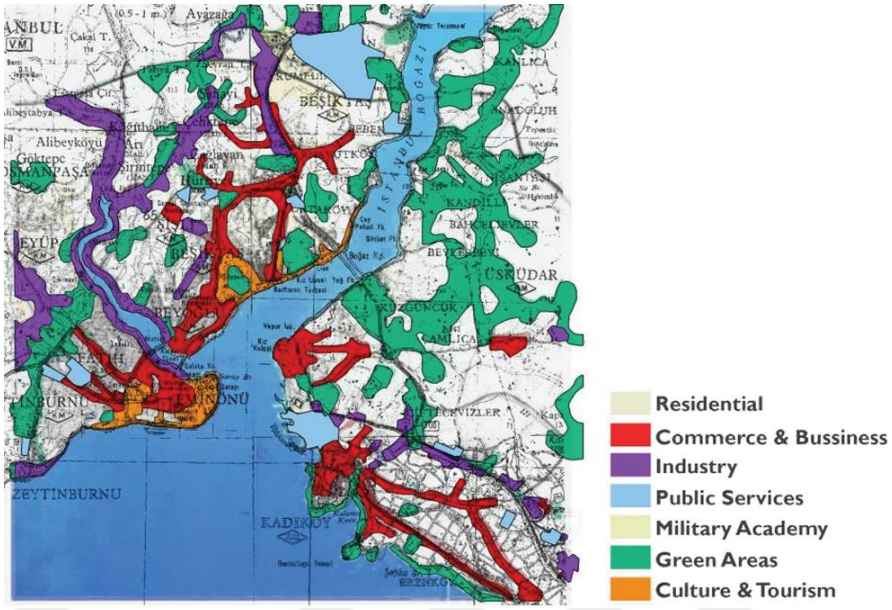


Figure 3.5 : Land-use pattern in the central areas of Istanbul before 1980 (Kaptan, 1991).

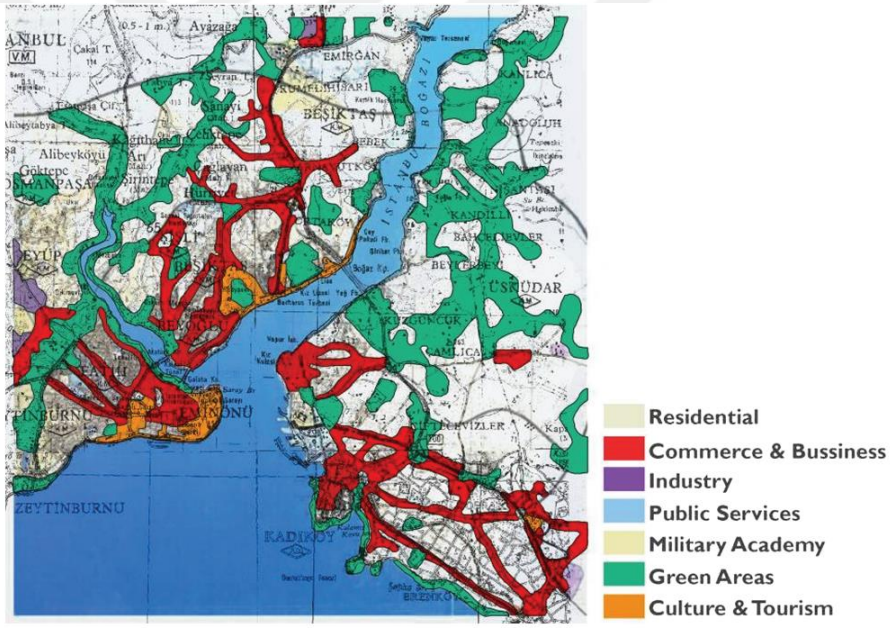


Figure 3.6 : Land-use pattern in the central areas of Istanbul after 1980. Note the expansion towards north on the European side and towards east on the Anatolian side replacing the former industrial areas (Kaptan, 1991).

During the 1990s, several projects were undertaken to improve Istanbul's international connectivity. These included the second bridge over the Bosporus, the Trans-European Motorway, the expansion of Atatürk International Airport, and the construction of a new international airport on the Asian side named after Sabiha Gökçen.

Until the 1980s, Istanbul's social and residential areas were pretty well-defined. Wealthy residents lived in apartments along the coastlines, while a middle-income belt

existed between these areas and the E-5 highway. Beyond the E-5 highway, new migrants primarily occupied informal settlements (Gecekondus) and split-deed housing. This pattern dramatically changed after the 1980s due to several factors. First, Istanbul's population boomed, putting a strain on available land. Building costs also increased, making it difficult to construct new housing using the traditional "yap-sat" method (build-and-sell by small builders). Consequently, housing production in the 1980s fell by half. Less public land was also available for expanding informal settlements (Keyder & Oncu, 1994).

Second, economic policies implemented since the 1980s favored wealthy individuals and international tastes, widening the income gap in the city. The government capitalized on this by modifying the Mass Housing Act and establishing the Mass Housing Fund (MHF) to develop a market for privately owned housing. This led to a significant increase in housing production, with over 100,000 units built by MHF in Istanbul between 1984 and 1999. These new housing projects were significant developments with high-rise, nearly identical apartment blocks located primarily along major highways. This contrasted significantly with the "yap-sat" model's piecemeal approach by small builders. The new model transformed housing into a profitable investment for large companies investing in hotels and office towers (Tokatlı & Boyacı, 1999). Figure 3.6 shows the land-use pattern in the central areas of Istanbul after 1980, noting the expansion towards the north on the European side and towards the east on the Anatolian side, which replaced former industrial areas.

These developments significantly impacted the city's form and social composition. The high-rise, high-density suburbs created by mass housing projects offered more homogenous environments. Middle-income and upwardly mobile residents from Gecekondus moved into these new areas, leaving behind their older neighborhoods(Tokatlı & Boyacı, 1999).

The rise of gated communities is a striking example of Istanbul's new social divisions. These communities house the city's wealthy professionals and executives. Initially, they were built as exclusive groups of villas on hills overlooking the Bosporus or luxury apartments in the suburbs close to the new business district (CBD). Examples include Kemer Country on the European side, Avrupa Konaklari, Beykoz Konaklari, and Acarkent on the Asian side. Later developments included luxury apartments within high-rise buildings integrated with shopping malls and office complexes, like

Akmerkez, Metro City, and the Sapphire building. As Istanbul's elite grew, so did the number of gated communities. These communities rapidly spread to the outskirts, where informal settlements (Gecekondus) used to be. This created a situation where wealthy and poor residents lived very close geographically yet completely separated by walls and security measures (Tokatlı & Boyacı, 1999). Figure 3.7 illustrates the spread of gated communities across the Istanbul metropolitan area.

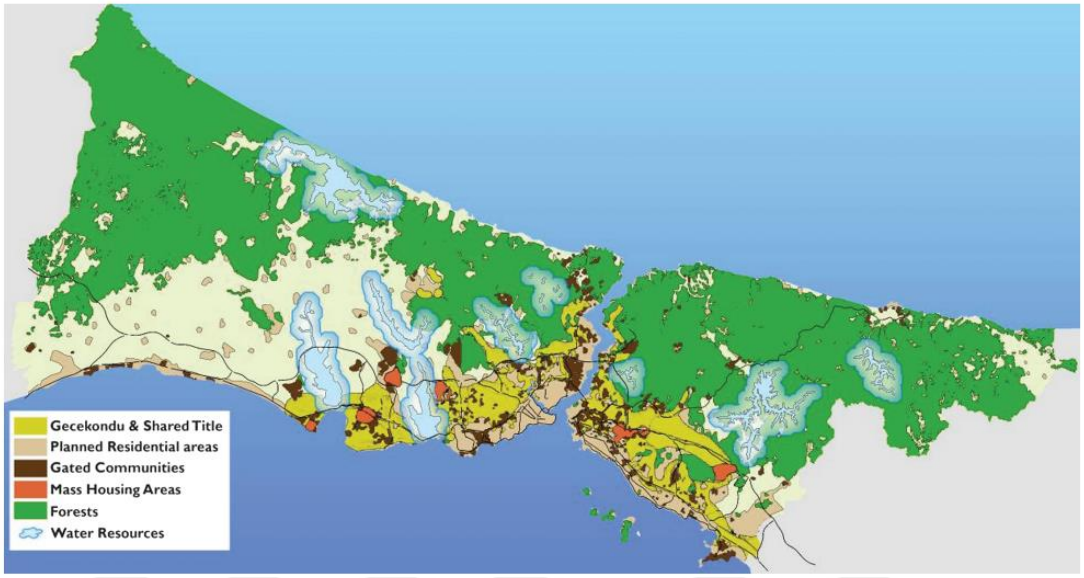


Figure 3.7 : Spread of gated communities in the Istanbul metropolitan area. (Source: Adapted from IMP Housing and Quality of Life Group – 2006).

Historically, Istanbul's neighborhoods had varying levels of prestige, but people of different income levels often lived nearby. In the new developments, major roads like the E-5 highway became the sharpest dividing line between the wealthy and the poor migrants. However, there were still areas where different social classes co-existed. Even on the prestigious Bosporus shore, the rich lived along the coast, the middle class occupied backstreets, and Gecekondus existed nearby. Everyone used the same streets, shops, and parks. The rise of gated communities, with their walls, guards, and surveillance systems, has disrupted this pattern. These communities offer a "totalized" lifestyle, utterly separate from the rest of the city. The middle class soon followed the elite's lead. They sought to imitate the wealthy lifestyle and increase their social status by moving to similar gated communities on the outskirts. This trend accelerated after the 1999 earthquake, as many upper- and middle-class residents sought safety in well-built homes. This fueled the demand for illegal developments in the forests and water basins north of the city. Most recently, luxury housing complexes have been built in

Istanbul's older suburbs. These developments further reshaped the city's social and physical landscape (Keyder & Oncu, 1993).

3.1.4 Urban Transformation Since the 1990s

Since the early 1900s, wealthy residents of Istanbul's historic center have gradually moved to more upscale neighborhoods. This left behind older, run-down areas that became home to waves of migrants from Anatolia. Initially, these migrants might improve their situation and move to the outskirts of informal settlements (Gecekondus) once they have an opportunity. However, after the 1980s, new migrant settlements flourished on the outskirts as large land areas became available for development.

As a result, poverty in Istanbul is often associated with these migrant communities on the periphery. However, it is essential to remember that some migrants did manage to escape poverty through informal networks that helped them secure land and eventually profit from rising housing demand. The historic center offered fewer such opportunities, becoming increasingly filled with former migrants who lacked the resources or connections to improve their situation, especially Kurdish migrants who arrived after the 1990s. The decline of the central industry also reduced job prospects for later generations in these areas.

Many neglected neighborhood residents now struggle to make ends meet, relying on informal jobs like street vending. They represent a new urban poor category, similar to the underclass seen in Western cities. Despite the social stigma attached to these areas, there is a strong sense of community and social networks that help residents cope with poverty (Isık & Pınarcıog˘lu, 2001).

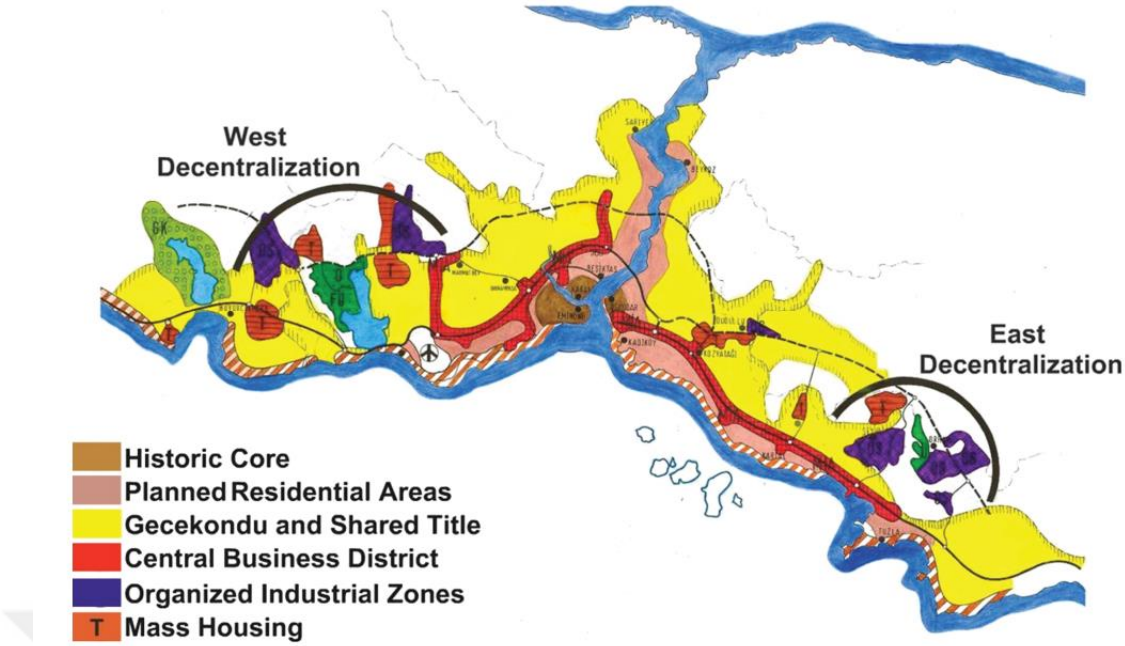


Figure 3.8 : Decentralization of industry to ‘organized industrial areas’ in the outskirts (Kaptan, 1991).

Istanbul's historic center is experiencing a very different transformation than neglected neighborhoods. The Beyoglu district exemplifies this trend, with clear signs of gentrification. Gentrification began in the 1980s in areas like Kuzguncuk and Cihangir and has since become a significant driver of urban change. Artists and intellectuals were the first to move into these areas, paving the way for further development.

The most visible example is Istiklal Boulevard, which was transformed into a pedestrian zone with a nostalgic tram line. Modern shops, embassies, and nightclubs line the street, creating a new cosmopolitan hub. Investment has aimed to create a trendy atmosphere with a touch of nostalgia-fueled by media and cultural events. Beyoglu is now a center for entertainment, with cinemas, theaters, cafes, restaurants, and art venues. Big companies have played a vital role in this transformation, restoring historic buildings and attracting a new "cultural class" of residents and business owners. Real estate agents capitalized on this trend, with foreign ownership laws and historic building restoration acts further boosting property values. By the mid-2000s, Istanbul had become a top destination for property investors in Turkey and the Middle East (Enlil, 2000). Figure 3.8 illustrates the changes mentioned earlier in land use.

3.1.5 Reimagining Istanbul in Post-2002: Impact of Neoliberal Policies

In the period following 2002, the impact of neoliberal policies on urban areas, particularly in Istanbul, has been significant. While listing every effect of these policies due to space constraints is not feasible, several vital events highlight their influence. The combination of the global city concept and the aftermath of the 1999 earthquake led to the formation of an urban rent coalition in Istanbul. This coalition capitalized on rising land values and increased property prices driven by demand from affluent Turkish and Middle Eastern populations who saw real estate as a secure investment.

One notable example of urban renewal occurred in Ayazma Gecekondu village on the outskirts of Istanbul. The Housing Development Administration of Turkey (TOKİ) offered residents the chance to buy newly constructed apartments in Halkali-Bezirganbahce at a monthly rate, with those holding property deeds given the option to return to Ayazma by paying the difference in housing values. However, despite formal agreements, this process effectively led to eviction for most residents, with only a few choosing to stay. Despite local opposition, the relocation proceeded, resulting in dissatisfaction among those who moved to the new TOKİ towers, who found themselves unable to afford the rent. Furthermore, living conditions in these towers were inferior to those in their previous homes in Ayazma. This forced migration essentially amounted to dispossession, as residents were compelled to pay rent for new accommodations or relinquish what they previously owned.

In 2005, legislation such as Law No. 5366 aimed to revitalize historic and cultural properties in Istanbul's slum areas through renewal and reuse, leading to the demolition of settlements in Sulukule, Tarlabasi, Suleymaniye, and Fener-Balat. Similar tactics observed in Ayazma were repeated in these areas, with residents offered housing in exchange for paying the difference in property values, leading to the de facto eviction and dispossession of local communities, notably impacting the Roma community in Sulukule. The culmination of the urban rent coalition's influence is evident in three mega projects in Istanbul: the Istanbul Finance Center, the third bridge over the Bosporus, and the third airport project. While debates continue regarding the costs and benefits of these projects, undeniable consequences include the rise in land values near these developments and the perpetuation of urban development trends (Enlil, 2011).

In this period, another vital reconstruction project emerged, namely the Fikirtepe reconstruction project(Figure 3.9), which significantly shaped the urban landscape of Istanbul's Kadıköy district. Originating as a squatter settlement in the late 1950s, Fikirtepe underwent legal regularization in 1984, granting joint-owned title deeds to its residents. However, subsequent urban renewal efforts encountered legal challenges. They were subjected to cancellation and redesignation as a risky area in 2013—the project aimed to revitalize the area, leveraging its strategic location and enhancing property values. Through extensive land assembly, 4794 individual plots were consolidated into 61 larger parcels, facilitating the development of gated housing communities catering to higher-income groups. Despite notable progress, the project faced ongoing challenges, including the need for stakeholder consensus-building (Tarakci et al., 2022).

Figure 3.9 : Fikirtepe reconstruction project (Tarakci, et al, 2022).

Istanbul, boasting 39 districts and a population exceeding 15 million, reigns Turkey's largest city and ranks among Europe's most prominent. Our study of Istanbul revealed how its rich history and development have made it a complex and ever-changing city. The way the city has grown outward, with suburbs becoming more important than the central area since the 1950s, shows the enormous impact of more cars and building projects like the famous Bosporus Bridge. Istanbul's role as a critical center in the

region led to its renewed importance in the 1990s. This led some to believe it is a global city, but others see it as divided along social and economic lines.

Understanding Istanbul's full complexity is a difficult task. The city's constant population growth, multiple development centers, uneven population spread, and lack of geographic data make it hard to assess segregation over time and compare different periods. We need new indirect methods to understand the variety within Istanbul's ever-changing urban environment. Overall, Istanbul is a multifaceted and evolving example that provides valuable lessons for understanding how cities become complex through changes in their physical and social makeup.

3.2 Data

The rapid urbanization of societies globally has presented unprecedented challenges for sustainable development, particularly in urban environments. Traditional urban planning methods have struggled to keep pace with the dynamic and complex social, ecological, and technological interactions shaping contemporary cities (Kitchin, 2014). However, the emergence of big data analytics, especially from social media platforms, offers new opportunities to enhance our understanding of urban dynamics and inform sustainable development efforts (Batty et al., 2012).

Social media-derived data (SMD) provide a rich source of information on human behavior, preferences, and interactions within urban environments, thereby enabling researchers and policymakers to gain valuable insights into the complexities of urban life (Liu et al., 2018). Numerous studies have demonstrated the diverse applications of SMD in advancing sustainable urban development goals across various domains. Geolocated data from platforms such as Twitter, Instagram, and Flickr have been used to analyze park visitation patterns, predict natural disasters, assess mental health indicators, and study urban mobility patterns (Liu et al., 2018; Jiang et al., 2020; Xu et al., 2018). Here are examples of research utilizing social media-derived data (SMD).

Park Visitation Patterns: Research conducted by Zhang et al. (2019) utilized SMD from Instagram to analyze park visitation patterns in Los Angeles, California. By geolocating and analyzing posts from Instagram users, the study provided insights into visitor demographics, preferred park amenities, and the temporal distribution of park

usage. This information has implications for optimizing park management and enhancing visitor experiences while promoting environmental sustainability.

Public Health Assessment: Jiang et al. (2018) conducted a study utilizing geolocated data from Twitter to assess public health indicators in urban areas. Analyzing tweet content and geotags, the researchers inferred trends in mental health indicators such as stress and depression across different neighborhoods. This information can inform public health interventions and resource allocation strategies to address mental health disparities in urban populations.

Transportation Planning: In a study by Wang et al. (2020), SMD from ride-sharing platforms such as Uber and Lyft were used to analyze transportation patterns and demand in New York City. By analyzing ride request data and pickup/drop-off locations, the researchers identified areas with high transportation demand and potential gaps in public transit coverage. This information can inform transportation planning efforts aimed at improving accessibility and reducing congestion in urban areas.

Environmental Monitoring: Liu et al. (2019) conducted research utilizing SMD from Flickr to monitor environmental changes in urban areas. By analyzing geotagged photos, the researchers tracked changes in green space coverage, urban development patterns, and pollution levels over time. This information can support environmental monitoring efforts and inform land use planning decisions to promote ecological sustainability in urban environments.

Community Engagement and Decision-Making: Smith et al. (2017) conducted a study utilizing SMD from community engagement platforms such as Nextdoor and SeeClickFix to assess resident perceptions and preferences regarding urban development projects. Analyzing user-generated content and spatially referenced data, the researchers identified key concerns and priorities among residents, which informed decision-making processes and facilitated community engagement in sustainable urban development initiatives.

These examples illustrate the diverse applications of SMD in advancing sustainable urban development goals across various domains, including environmental sustainability, public health, transportation planning, environmental monitoring, and community engagement. By leveraging the wealth of data available from social media

platforms, researchers and policymakers can gain valuable insights into urban dynamics and inform evidence-based decision-making processes.

Foursquare and Facebook Place, known as location-based social networks (LBSNs), are two types of SMDs that provide a distinctive platform where users can connect based on specific locations, setting them apart from traditional social media like Twitter and Facebook. These platforms utilize location data and web services, allowing users to save information about places of interest, share reviews, and communicate with others. Unlike typical social media, LBSNs directly gather data about land use from users' activities and indirectly from their activity descriptions. Additionally, direct land use information can be acquired through Points of Interest (POI) surveys, aiding in understanding and mapping urban landscapes. Through these methods, LBSNs enhance comprehension of urban dynamics, facilitating social connections and providing insights into people's interactions and use of urban spaces (Yang et al., 2019).

Foursquare, launched in 2009, transformed location-based social networking. Initially designed as a mobile app for users to check in at venues and share their locations, Foursquare evolved into a comprehensive platform offering location-based recommendations, reviews, and social networking. This unique blend of social interaction and location data made it a valuable tool for city exploration, venue discovery, and social connection.

As Foursquare's user base expanded, so did its data repository, accumulating vast location-based information, including user-generated reviews, ratings, and tips for millions of venues globally. Leveraging this data, Foursquare introduced personalized recommendations tailored to users' preferences and past behavior. Whether users sought the best coffee shop or a trendy restaurant, Foursquare's recommendation engine provided valuable insights based on their tastes and location history.

The dataset used in this research was obtained from Professor Dingqi Yang's page, where all the necessary data was available. Specifically, the dataset comprises long-term global-scale check-in data collected from Foursquare, spanning approximately 22 months, from April 2012 to January 2014. It encompasses a vast volume of information, including 33,278,683 check-ins recorded by 266,909 users across 3,680,126 venues. These venues are located in 415 cities across 77 countries, with each

city being among the most frequently checked-in locations by Foursquare users worldwide, each containing a minimum of 10,000 check-ins. The focus of this study was narrowed down to data regarding Turkey and further narrowed down to Istanbul.

The data collection phase involves web programming using APIs and processing collected data into a spatial database. Following data collection through a Python program, a data cleaning process converts text information gathered by the program into GIS data. The collected data includes venue ID, name, category, and coordinates. Over 22 months, around 339,247 venues were identified in Istanbul, with their distribution across various regions illustrated in the diagram below.

Figure 3.10 presents data regarding the number of venues in each district of Istanbul, offering valuable insights into the distribution of venues across the city. For instance, in districts such as Atasehir, Beyoglu, and Kadikoy, the number of venues appears relatively high, ranging from 12,767 to 30,452. Conversely, some districts, like Sancaktepe and Sultanbeyli, exhibit notably lower counts, with only 2,304 and 1,198 venues, respectively.

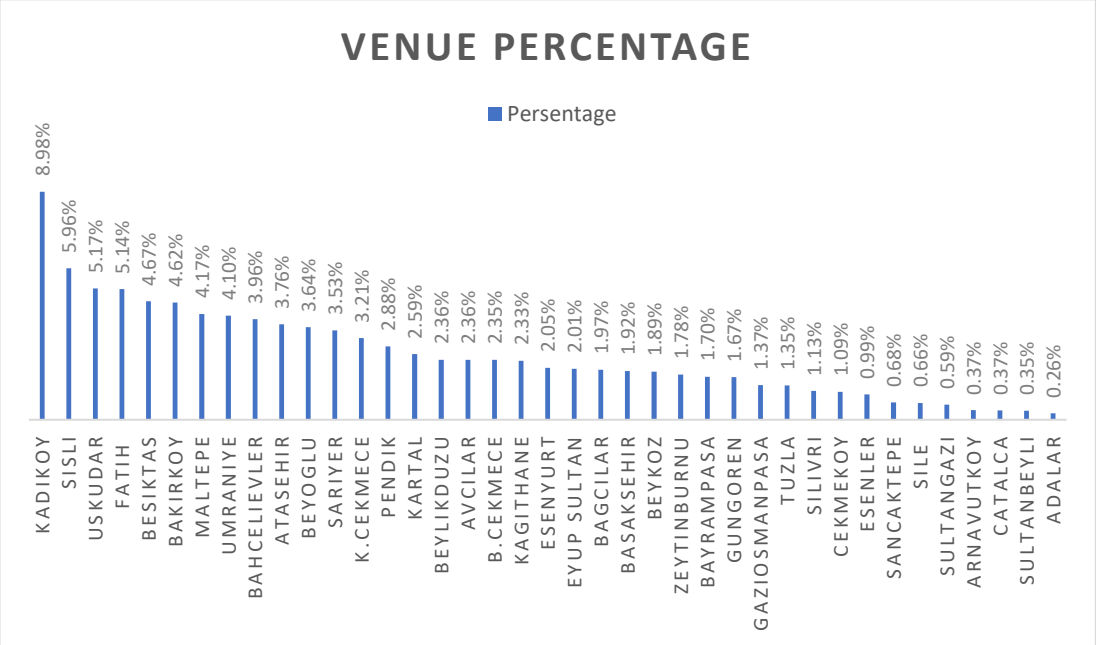


Figure 3.10 : Venue distribution.

- **Commercial centers**

Ataşehir, Beşiktaş, Şişli

- **Historical centers**

Fatih, Üsküdar, Kadıköy, Beyoğlu

- **New development areas**

Kartal, Pendik, Büyükçekmece, Beylikdüzü

- **Expanded development areas**

Bakırköy, Maltepe, Ümraniye, Kağıthane, Sarıyer

- **Sprawl development**

Çatalca, Sultanbeyli, Arnavutköy, Çekmeköy

3.3 Analysis

In our study of urban activity diversity in Istanbul, we adopt an approach inspired by ecological diversity indices (Simpson, 1949; Shannon, 1948; Pielou, 1966). This includes examining the richness and distribution of activities across the city (alpha, beta, and gamma diversity) and quantifying activity intensity using Kernel Density estimation.

3.3.1 Richness index

The Richness Index is a measure used to quantify biodiversity within a given ecosystem, initially designed for ecological studies. Recently, urban scientists have adopted this index to assess the diversity of elements in urban environments, such as green spaces, building types, and social amenities. For instance, Shanahan et al. (2014) used the index to compare biodiversity across different urban parks, finding that parks with higher species richness contributed more to urban biodiversity and resident well-being.

The Richness Index is also applied to analyze the diversity of urban forms, including the variety of building types, land uses, and architectural styles within a city. Blanco et al. (2009) demonstrated that cities with a higher diversity of urban forms are more resilient to economic and environmental changes. Using the Richness Index, they quantified the diversity of building types and correlated it with urban resilience.

Social scientists use the Richness Index to measure the diversity of cultural and social amenities, such as schools, hospitals, and recreational facilities. For example, Gómez and Barton (2013) applied the index to assess the diversity of cultural amenities in

different neighborhoods, showing that areas with higher cultural richness had better social outcomes and higher levels of community engagement.

In exploring Istanbul's activity diversity, we use statistical tools to measure the variety and spread of different urban pursuits. Similar to how diversity measures in ecology show the variety of life, here they help us understand the range of activities in the city. Activity richness, like counting species in ecology, is a crucial measure denoted as S. This gives us a more complete picture of diversity, considering the number and distribution of activities.

3.3.2 Simpson's index

The Simpson Index, a measure initially developed for biodiversity studies, quantifies diversity within a community by considering the number of species present and their relative abundance. This index has found extensive application in urban science, particularly in studies on urban ecology, socio-economic diversity, and land use patterns.

Several case studies illustrate the application of the Simpson Index in urban science. A study by Ziter et al. (2017) used the index to evaluate the impact of green infrastructure on urban biodiversity in Minneapolis, Minnesota. Their findings showed that areas with diverse plant species, as indicated by a high Simpson Index, supported more robust urban ecosystems. Similarly, a study by Talen (2006) on urban form and social diversity in Chicago utilized the Simpson Index to measure the variety of housing types and the distribution of different demographic groups, highlighting areas with high social and structural diversity levels.

The Simpson Index assesses the diversity of green spaces and vegetation in urban ecology. McKinney (2002) explored how urbanization impacts species diversity and found that the Simpson Index can effectively highlight differences in biodiversity across urban, suburban, and rural areas. Urban environments typically show lower biodiversity than less disturbed areas, and the Simpson Index helps quantify this difference clearly and clearly.

The Simpson Index is also applied to measure socio-economic diversity within cities. In this context, it examines the distribution of various socio-economic groups across urban neighborhoods. Reardon and O'Sullivan (2004) demonstrated that the Simpson Index could be adapted to analyze the diversity of income groups, revealing significant

segregation and integration patterns within urban settings. This application provides insights into social equity and the distribution of resources, which are crucial for urban planning and policy-making.

In land use studies, the Simpson Index helps understand the diversity of land use types within urban areas. For instance, Wu (2000) applied the index to assess land use types in different city zones. The results indicated that higher land use diversity, as measured by the Simpson Index, correlates with better urban resilience and functionality. This measure helps planners ensure a balanced mix of residential, commercial, and industrial areas, promoting sustainable urban development.

Simpson (1949) devised a way to measure diversity using probability. The lower the diversity, the higher the chance that if you randomly pick two individuals, they will be the same species. If there is no diversity (just one species), then there is a 100% chance that two randomly picked individuals will be the same.

Here is how Simpson's index is calculated:

$$D = \sum_{i=1}^{S} \left(\frac{n_i}{N}\right)^2 \tag{3.1}$$

In this formula:

- n_i is the number of individuals in species ii,
- N is the total number of individuals of all species,
- $\frac{n_i}{N}$ is the proportion of individuals of species ii,
- S is the species richness, meaning the total number of species.

The value of Simpson's Index can range from 0 to 1. A value of 0 means infinite diversity, while 1 means no diversity at all.

3.3.3 Shannon-weiner diversity index

The Shannon-Weiner Diversity Index (SWDI) is a mathematical tool widely used to measure biodiversity. It was first suggested by Claude Shannon in 1948 and is related to the idea of uncertainty. It considers the number of species (richness) and the evenness of their distribution (proportional abundance). Initially applied in ecological studies, the SWDI has significant applications in urban science. For instance, a study by Huang et al. (2020) employed the SWDI to compare plant diversity across different urban parks in Beijing. Their findings indicated that larger parks with more varied habitats had higher diversity indices, suggesting better ecological health and resilience.

Urban planners and managers utilize the SWDI to make informed land use and development decisions. A McKinney (2008) study used the index to evaluate the impact of urban sprawl on bird species diversity. The results demonstrated that areas with higher urbanization had lower SWDI values, indicating reduced biodiversity. This information is crucial for developing strategies to mitigate the adverse effects of urbanization on wildlife.

The SWDI also helps understand the relationship between human activities and ecological health in urban settings. For example, research by Sushinsky et al. (2013) applied the SWDI to study the diversity of insect populations in residential areas with varying garden maintenance practices. Their study revealed that gardens with more diverse plant species supported higher insect diversity, illustrating the importance of gardening practices in promoting urban biodiversity.

Pollution is a significant concern in urban areas, and the SWDI is a valuable tool for assessing its impact on biodiversity. A study by Singh and Gupta (2012) used the index to measure the diversity of aquatic life in urban rivers subjected to different pollution levels. Their findings showed that heavily polluted rivers had significantly lower SWDI values, highlighting the detrimental effects of pollution on aquatic ecosystems.

The SWDI is also employed to evaluate the success of urban ecological restoration projects. For instance, a study by Aronson et al. (2017) used the index to compare the biodiversity of restored urban wetlands with that of natural and degraded ones. The restored wetlands had higher SWDI values than degraded ones but were still lower than natural wetlands, indicating partial success in restoration efforts.

The Shannon-Weiner Diversity Index is a versatile and valuable tool in urban science. It offers insights into the biodiversity and ecological health of urban areas. Its applications range from evaluating the impact of urbanization and pollution to guiding urban planning and restoration projects. By providing a quantitative measure of diversity, the SWDI helps researchers and policymakers understand and improve the complex socio-ecological systems within cities. Our studies have used it to measure the diversity and uniformity of activities in different areas of Istanbul.

Here is how the Shannon-Weiner index is calculated:

$$H = -\sum_{i=1}^{S} p_i . \ln(p_i) \tag{3.2}$$

In this formula:

- p_i is the proportion of individuals of species ii,
- ln stands for the natural logarithm,
- S is the species richness, which means the total number of species.

The value of H can range from 0 to H_{max} which varies depending on how many species there are. H_{max} is different for each community. Sometimes, the Shannon-Weiner Index is denoted as H'.

3.3.4 Pielou's evenness index

Pielou's Evenness Index (J) is a valuable metric for understanding species distribution and relative abundance within urban ecosystems. It quantifies the equitability of species abundance in a given area, providing insights into the evenness of species distribution within urban habitats (Pielou, 1966). The index complements measures of species richness by indicating whether a community is dominated by a few species or evenly balanced across multiple species.

Numerous studies have applied Pielou's Evenness Index to assess worldwide biodiversity patterns in urban areas. For example, research in cities such as New York, Berlin, and Singapore has used this index to compare species composition and evenness across different urban habitats, such as parks, gardens, and green spaces

(Magurran, 2004). These studies have revealed varying levels of evenness influenced by factors like habitat structure, land use history, and management practices.

Applying Pielou's Evenness Index contributes valuable information for urban planners and conservationists aiming to enhance city biodiversity. By identifying areas with low evenness, decision-makers can prioritize habitat restoration, green infrastructure development, and sustainable management practices to promote more balanced and resilient urban ecosystems (McDonnell & Hahs, 2015). Moreover, monitoring changes in evenness over time provides early warnings of ecological degradation and guides adaptive management strategies to mitigate urban impacts on biodiversity. In our research, we used this index to assess the uniformity of activities in different areas of Istanbul. Pielou's evenness index is measured by:

$$J = \frac{H}{H_{max}} \tag{3.3}$$

In this formula:

- H is the Shannon-Weiner Diversity Index,
- H_{max} is the maximum possible value of H for the given species richness.

The value of J can range from 0 to 1, where higher values mean a more even species distribution. When $J = 1$, it is perfectly even.

Both J and D can also indicate species dominance in a community, which is the opposite of diversity. A low J suggests that one or a few species dominate the community.

3.3.5 Biodiversity index

Urban biodiversity encompasses the variety of living organisms in urban areas, including the relationships among species and their environments. We focus on three leading indices: alpha, beta, and gamma diversity. In his seminal paper, Whittaker (1972) introduced the concepts of alpha, beta, and gamma diversity. These concepts have been further explored and clarified in works such as those by Magurran (2004) and Jost (2007). Tuomisto (2010) also provided a standardized terminology for these measures. Alpha, beta, and gamma biodiversity are essential metrics for assessing and

managing biodiversity at different spatial scales. This review synthesizes recent research on using these metrics in urban science, highlighting their roles, applications, and implications for urban planning and conservation.

- **Alpha biodiversity**

Alpha biodiversity refers to species diversity within a specific area or ecosystem. In urban settings, this metric is crucial for understanding the richness and abundance of species in localized environments such as parks, green roofs, and street trees.

Studies have demonstrated that various factors, including land use, habitat connectivity, and anthropogenic pressures, can influence alpha biodiversity in urban areas. For instance, Aronson et al. (2014) found that urban green spaces with diverse plantings supported higher species richness and functional diversity levels than monocultures, suggesting that enhancing habitat heterogeneity can boost local biodiversity.

Furthermore, the incorporation of native species and the creation of microhabitats are key strategies to enhance alpha biodiversity in cities. A study by Murtaza et al. (2019) in Lahore, Pakistan, revealed that native vegetation in urban parks significantly increased the local bird and insect diversity, underscoring the importance of preserving and restoring native habitats in urban landscapes.

- **Beta biodiversity**

Beta biodiversity measures the variation in species composition between different habitats or areas. This metric is particularly relevant for understanding how urbanization affects species turnover and the connectivity between urban green spaces.

Urbanization often leads to habitat fragmentation, resulting in higher beta diversity as different patches may harbor distinct species assemblages. For example, a study by Beninde et al. (2015) in Berlin, Germany, showed that urban green spaces varied significantly in species composition, driven by differences in size, isolation, and habitat quality. This suggests that maintaining a network of interconnected green spaces can mitigate the effects of fragmentation and promote species dispersal.

Beta biodiversity is also essential for assessing the impacts of urban sprawl on surrounding natural areas. Research by McKinney (2008) indicated that urban-rural gradients often exhibit distinct patterns of species turnover, with suburban areas acting

as transitional zones that facilitate or hinder species movement between urban and rural habitats.

- **Gamma biodiversity**

Gamma biodiversity represents the total species diversity across a landscape or region. In the context of urban science, gamma diversity provides a comprehensive view of how urbanization influences regional biodiversity patterns.

Efforts to preserve gamma biodiversity in urban regions focus on creating and maintaining a mosaic of habitats that collectively support a wide range of species. An integrated approach, considering both green infrastructure within cities and surrounding natural landscapes, is crucial. Seto et al. (2012) emphasized that urban planning should incorporate biodiversity conservation at multiple scales to sustain gamma diversity, advocating for regional planning frameworks that balance development and conservation.

Moreover, urban areas can contribute to gamma biodiversity by providing refuge for certain species and acting as stepping stones in fragmented landscapes. A study by Hall et al. (2017) highlighted that urban environments, if well-managed, could enhance regional biodiversity by supporting populations of species that are declining in more natural habitats due to agricultural or industrial pressures.

Applying alpha, beta, and gamma biodiversity metrics in urban science is vital for understanding and managing urban ecosystems. These metrics offer insights into species richness, composition, and diversity patterns across different spatial scales, informing strategies for biodiversity conservation in urban settings. Enhancing urban biodiversity requires a multifaceted approach that includes habitat creation, connectivity, and regional planning, ensuring that cities contribute positively to global biodiversity goals. In our exploration of urban activity diversity, we have borrowed methods from ecology to gauge species diversity. It helps us see which activities are unique to specific neighborhoods compared to others. By using these measures, we hope to understand the range and distribution of activities in the city better, which can help city planners make decisions to create diverse and lively urban spaces.

3.3.6 Kernel density

Urban science increasingly relies on advanced analytical techniques to understand spatial patterns and dynamics within cities. One such technique, Kernel Density Estimation (KDE), has gained prominence for its ability to depict the intensity and distribution of phenomena across urban landscapes.

Kernel Density Estimation (KDE) is a nonparametric method for estimating the probability density function of a random variable based on a sample of points in space. In urban science, KDE is beneficial for visualizing and analyzing the spatial distributions of various urban phenomena, such as population density, crime incidents, infrastructure usage, and environmental factors.

KDE is widely applied in demography and urban planning to visualize population density gradients across cities. By aggregating census or survey data, researchers can create smoothed density surfaces that reveal population concentrations, migration patterns, and urban sprawl dynamics (Openshaw, 1984).

Law enforcement and criminologists utilize KDE to identify crime hotspots and assess the spatial clustering of criminal activities within urban areas. By mapping crime incident locations, KDE helps allocate resources efficiently and implement targeted crime prevention strategies (Chainey & Ratcliffe, 2005).

Urban transportation planners employ KDE to analyze traffic flows, pedestrian movement patterns, and transit ridership. By examining the spatial distribution of transportation-related data points, KDE assists in optimizing infrastructure investments and improving urban mobility (Cai & Li, 2016).

Environmental scientists utilize KDE to model the spatial distribution of pollutants, green spaces, and biodiversity hotspots within urban ecosystems. This enables environmental health assessments and supports sustainable urban development initiatives (Brenner & Jimenez, 2013).

In this research, the Kernel Density method was utilized to measure the intensity of activities within specific categories. quantitatively

4. UNCOVERING URBAN ACTIVITY DIVERSITY AND INTENSITY PATTERNS: INSIGHTS AND ANALYSIS

4.1 Diversity Of Activities

4.1.1 Richness index

The study aims to measure activities across various Istanbul regions using diversity indices. These indices, analogous to their application in ecological research for understanding species diversity, provide valuable insights into the prevalence and scarcity of different activities in each area. Diversity indices are essential for researchers examining community structure, offering a mathematical representation of activity diversity. Unlike a mere count of activities, diversity indices consider the proportional representation of different activities. In this research, the Shannon-Weiner diversity index, commonly employed in biological sciences to measure biodiversity, is utilized to evaluate activity diversity. The results, outlined in Figure 4.1, depict the spectrum of activities in each region, contributing to a comprehensive comprehension of community composition.

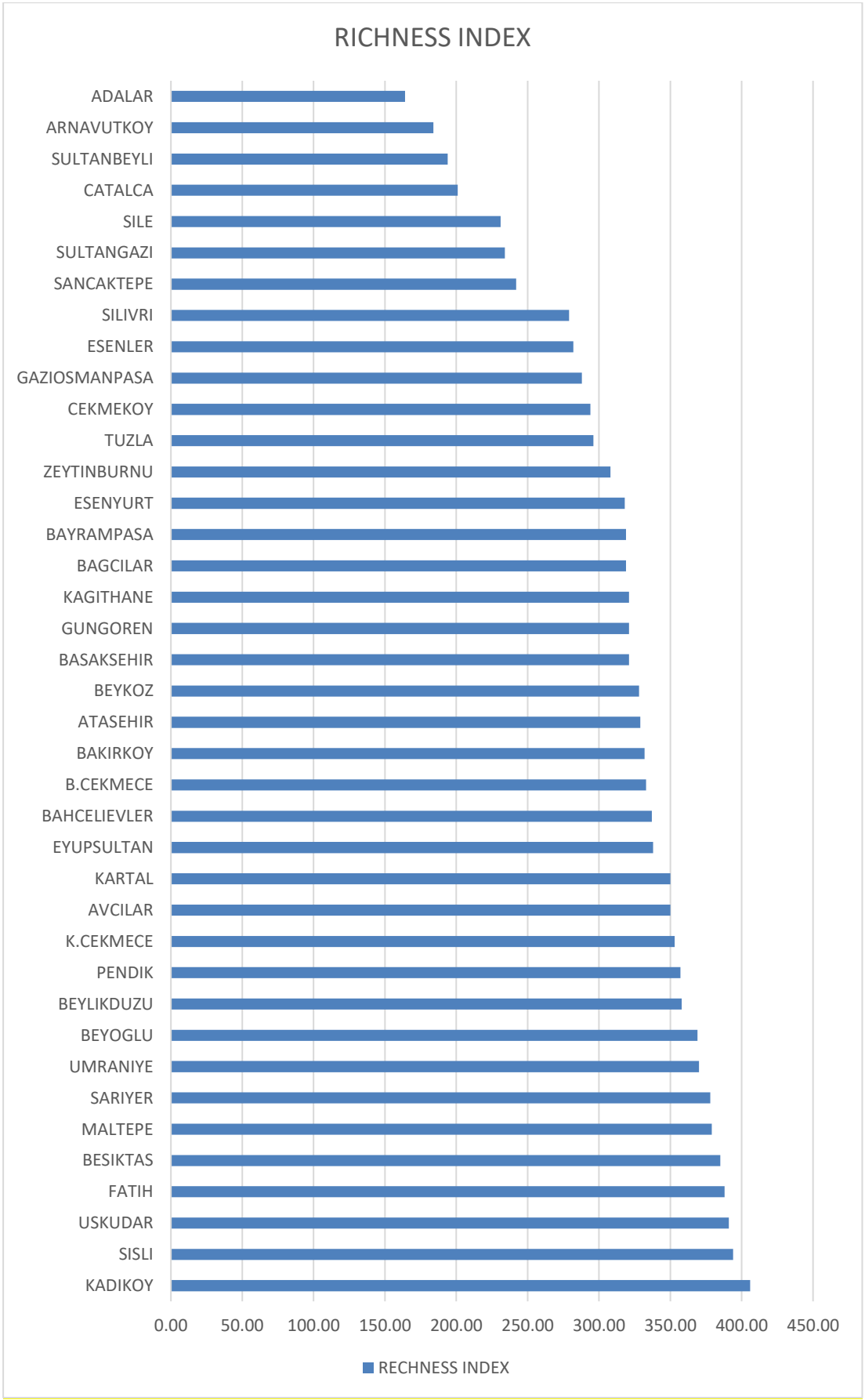


Figure 4.1 : Richness Index.

4.1.2 Simpson’s index

This analysis aims to evaluate the diversity of activities across Istanbul's districts using Simpson's Diversity Index, categorizing them into four groups based on their respective index values. Simpson's Diversity Index offers a quantitative measure to assess the diversity of activities within a given area (Table 4.1). It considers the number of activities present and the abundance of each activity. The index ranges from 0 to 1, where 0 represents infinite diversity (maximum diversity), and 1 represents no diversity (complete homogeneity).

- **Highly diverse (0.015238- 0.048373)**

Highly diverse areas exhibit a wide range of activities. These areas often display vibrant dynamics, fostering interactions among diverse groups and offering many opportunities for engagement and exploration. According to Figure 4.2, districts with Simpson's Index values indicating high activity diversity include Bakirkoy, Bahcelievler, B.Cekmece, Avcilar, Beyoglu, Atasehir, Fatih, Adalar, Sile, Sariyer, Tuzla, and Sisli.

- **Moderately diverse (0.051157- 0.06861)**

Moderately diverse areas possess a notable degree of variation or heterogeneity, albeit to a lesser extent than highly diverse areas. A discernible mix of activities within these regions or districts contributes to a diverse and dynamic environment. While not as varied as highly diverse areas, moderately diverse areas still offer a range of opportunities for interaction and exchange. Districts with moderate activity diversity levels include Silivri, Bagcilar, Besiktas, Arnavutkoy, Zeytinburnu, Esenler, Basaksehir, Gungoren, Sultanbeyli, Catalca, Sancaktepe, Pendik, Kadikoy, Eyupsultan, Bayrampasa, and Sultangazi(see Figure 4.2).

- **Moderately homogeneous (0.070178- 0.086028)**

Moderately homogeneous areas demonstrate a degree of uniformity or similarity across activities. While there may be some variation, these regions or districts exhibit sure consistency or commonality among their features. This homogeneity can contribute to cohesion or shared identity within the community. Based on Figure 4.2, Esenyurt, Umraniye, Kartal, Beykoz, Cekmekoy, Beylikduzu, K.Cekmece, and Uskudar include this feature.

- **Highly homogeneous (0.102845- 0.11045)**

Highly homogeneous areas are characterized by a high degree of uniformity or similarity in activities. There is minimal variation within these regions or districts, resulting in a relatively homogenous environment. This uniformity may stem from shared cultural, socioeconomic, or environmental factors, leading to a sense of cohesion but potentially limiting diversity and interaction. Regions include Maltepe, Kagithanem, and Gaziosmanpasa (see Figure 4.2).

Table 4.1 : Simpson's Index.

Group	Region	Simpson's Index	Region	Simpson's Index
Highly Diverse	Bakirkoy	0.015238	Fatih	0.032375
	Bahcelievler	0.019868	Adalar	0.043883
	B.Cekmece	0.022372	Sile	0.044434
	Avcilar	0.025765	Sariyer	0.047871
	Beyoglu	0.025952	Tuzla	0.048305
	Atasehir	0.028489	Sisli	0.048373
	Silivri	0.051157	Sultanbeyli	0.05784
Moderately Diverse	Bagcilar	0.051556	Catalca	0.060101
	Besiktas	0.052647	Sancaktepe	0.061249
	Arnavutkoy	0.053212	Pendik	0.063112
	Zeytinburnu	0.053344	Kadikoy	0.064703
	Esenler	0.053917	Eyupsultan	0.065796
Moderately Homogeneous	Basaksehir	0.054985	Bayrampasa	0.068144
	Gungoren	0.055892	Sultangazi	0.06861
	Esenyurt	0.070178	Cekmekoy	0.081002
	Umraniye	0.076402	Beylikduzu	0.081952
	Kartal	0.077354	K.Cekmece	0.082346
	Beykoz	0.077633	Uskudar	0.086028
Highly Homogeneous	Maltepe	0.102845	Gaziosmanpasa	0.11045
	Kagithane	0.106199		

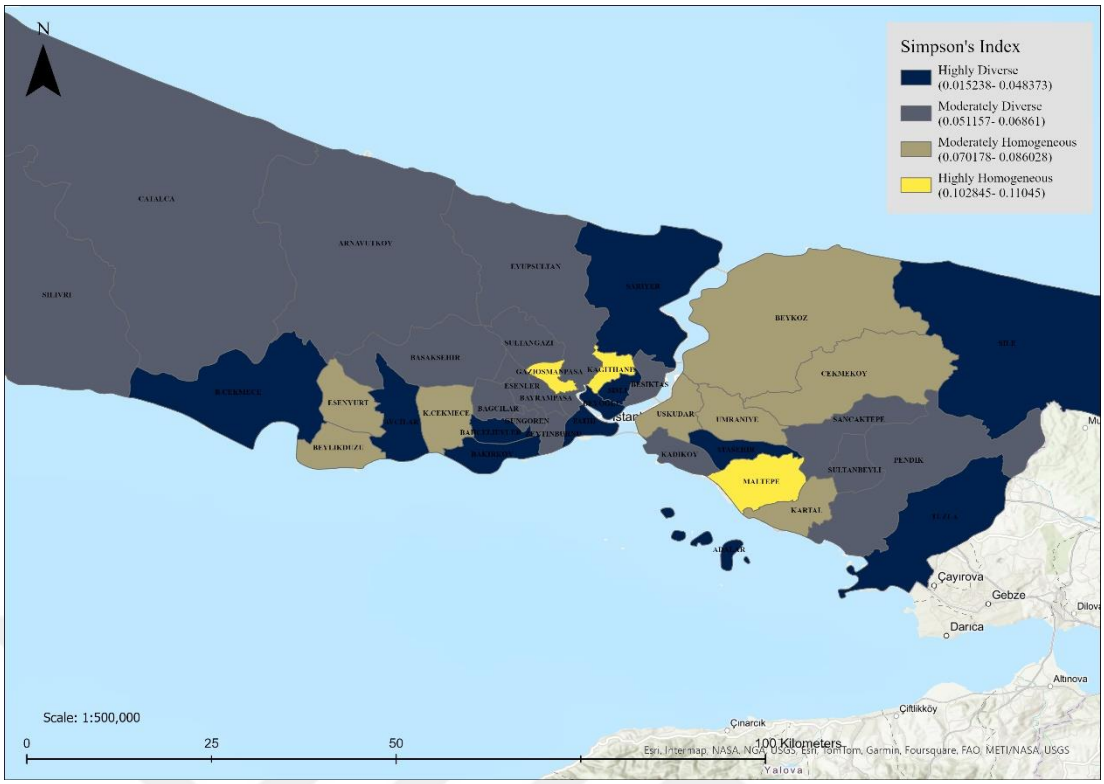


Figure 4.2 : Simpson's Index.

4.1.3 Shannon-weiner diversity index

This section uses the Shannon index to visually illustrate the distribution of diverse activities across Istanbul's districts (Table 4.2). Considering that the Simpson index does not cover the area, we performed an analysis based on the Shannon index in terms of area to show the diversity of activity per unit area in different areas of Istanbul. The geometrical interval classification method was chosen to categorize Shannon index values into specific groups for map depiction. The selection of the geometrical interval method stemmed from its capacity to provide a well-rounded approach, incorporating aspects from equal intervals, natural breaks, and quantile methods. This methodology ensures that the resulting map classifications accurately portray the diversity of activity distribution throughout Istanbul's districts. Shannon's Diversity Index considers the number of different categories (species, activities, etc.) and the evenness of their distribution. So, when the value of Shannon's Diversity Index is higher, it suggests that more categories are present and are more evenly distributed. Conversely, a lower value would suggest less diversity due to fewer categories present or, if present, not evenly distributed. Based on Figure 4.3, by moving away from the center to the west and east,

diversity decreases and evenness increases, except in Adalar and Sultanbeyli, due to the characteristics of these areas.

Table 4.2 : Shannon-Weiner Diversity Index.

Region	Shannon-Weiner Diversity Index
Kagithane	3.792632
Gaziosmanpasa	3.833907
Maltepe	3.905263
Esenyurt	3.96511
Arnavutkoy	3.966313
Beylikduzu	3.9934
Cekmekoy	4.000335
Umraniye	4.023815
Sancaktepe	4.046054
Kartal	4.051341
Sultangazi	4.051862
Catalca	4.052898
K.Cekmece	4.074088
Uskudar	4.08269
Sultanbeyli	4.08677
Adalar	4.104706
Beykoz	4.130983
Basaksehir	4.16497
Bayrampasa	4.184264
Gungoren	4.192693
Bagcilar	4.209422
Zeytinburnu	4.22842
Pendik	4.241646
Sile	4.243968
Tuzla	4.244369
Silivri	4.248049
Eyupsultan	4.248774
Esenler	4.260236
Kadikoy	4.268227
Sisli	4.315168
Besiktas	4.343798
Sariyer	4.433723
Atasehir	4.603762
Fatih	4.631359
Beyoglu	4.64439
Avcilar	4.671553
B.Cekmece	4.723346
Bahcelievler	4.76587
Bakirkoy	4.866378

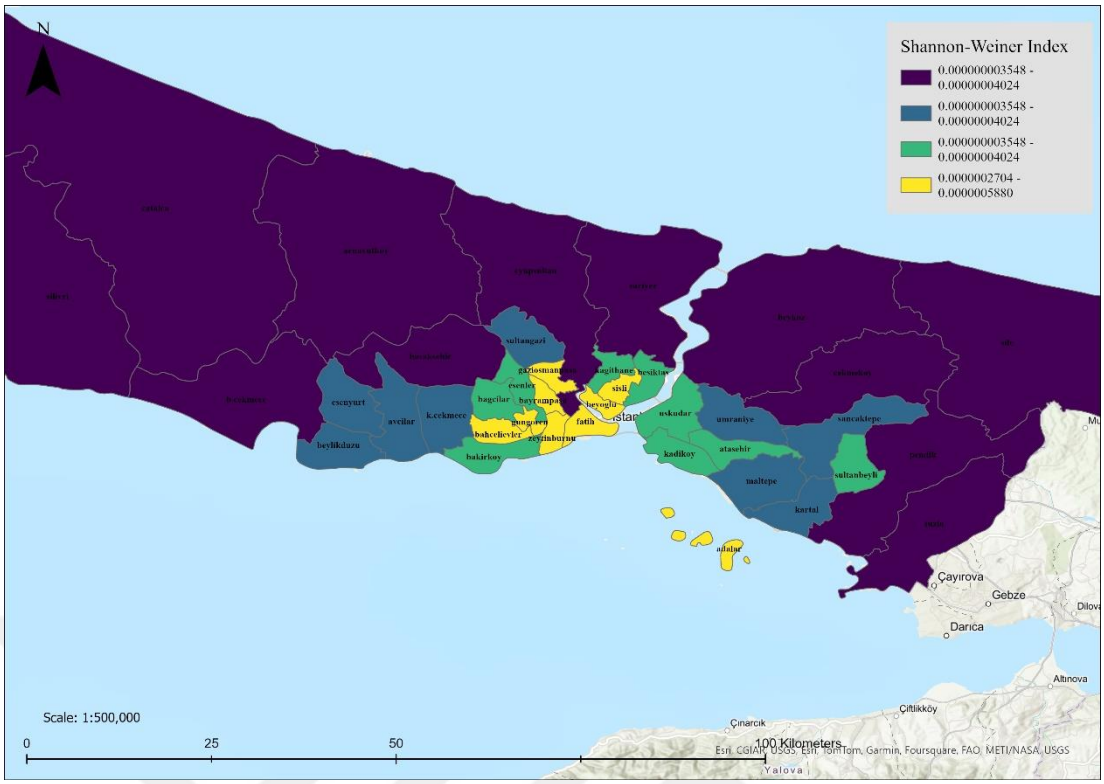


Figure 4.3 : Shannon-Weiner Diversity Index.

4.1.4 Pielou's evenness index

The Pielou's Evenness Index provides a valuable metric for assessing the evenness of activities across various regions. In this part, we analyze Pielou's Evenness Index values for different regions in Istanbul to categorize them based on the evenness of activities. Based on Pielou's Evenness Index values, we classified the Istanbul regions into three groups: high evenness, moderate evenness, and low evenness. Regions with $J > 0.8$ were categorized as having High Evenness, those with $0.7 < J \leq 0.79$ as having Moderate Evenness, and those with $J \leq 0.7$ as having Low Evenness (see Table 4.3).

Figure 4.4 illustrates that the analysis reveals varying evenness levels in the distribution of activities across Istanbul regions. Regions with High Evenness exhibit a more balanced distribution, while those with Moderate and Low Evenness show some skewness.

Table 4.3 : Pielou's Evenness Index.

Group	Region	Pielou's Evenness Index	Region	Pielou's Evenness Index
Low Evenness	Kagithane	0.657138	Uskudar	0.684016
	Maltepe	0.657725	Esenyurt	0.688142
	Gaziosmanpasa	0.677015	Kartal	0.691599
	Beylikduzu	0.679088	K.cekmece	0.69447
	Umraniye	0.680445		
Moderate Evenness	Cekmekoy	0.703841	Sultangazi	0.742736
	Kadikoy	0.710619	Tuzla	0.745888
	Beykoz	0.713097	Sariyer	0.74706
	Pendik	0.721646	Silivri	0.754376
	Basaksehir	0.721652	Esenler	0.755106
	Sisli	0.722041	Arnavutkoy	0.760568
	Bayrampasa	0.725781	Catalca	0.764221
	Gungoren	0.726455	Sultanbeyli	0.775793
	Eyupsultan	0.729648	Fatih	0.776943
	Besiktas	0.729652	Sile	0.779795
	Bagcilar	0.730144	Beyoglu	0.785747
	Sancaktepe	0.737129	Atasehir	0.794292
	Zeytinburnu	0.737931	Avcilar	0.797475
High Evenness	Adalar	0.804865	Bahcelievler	0.818866
	B.cekmece	0.813228	Bakirkoy	0.838289

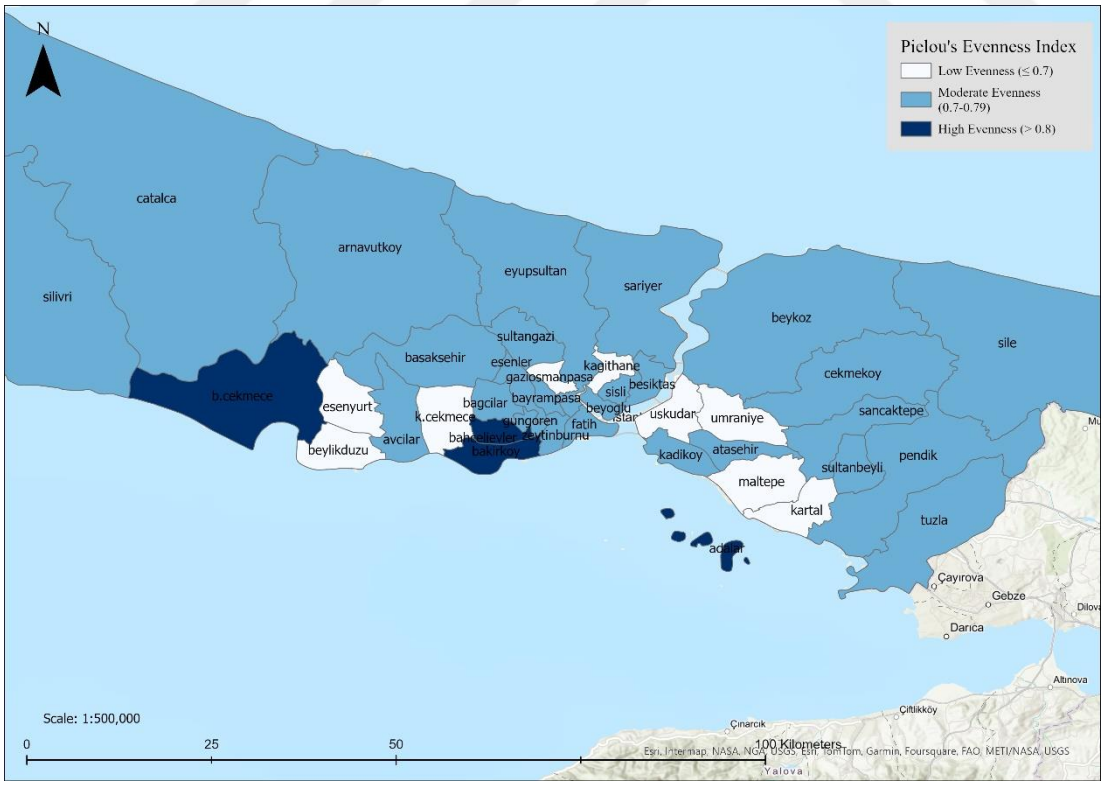


Figure 4.4 : Pielou's Evenness Index.

4.1.5 Biodiversity index

In this part, we assess the biodiversity indicators—alpha, beta, and gamma diversity—across different districts of Istanbul(see Table 4.4).

- **Alpha diversity**

Alpha diversity, representing species richness within a specific area, varies significantly across Istanbul's districts. For instance, districts like Kadikoy, Sisli, and Beyoglu exhibit exceptionally high alpha diversity, indicating diverse activities within these urban hubs. Conversely, districts like Adalar and Arnavutkoy display comparatively lower alpha diversity, suggesting fewer activities or species within their boundaries.

- **Gamma diversity**

Gamma diversity reflects the total number of activities across all districts of Istanbul. The gamma diversity value remains consistent across the city, with each district contributing to the overall biodiversity pool. This standardized measure, standing at 339,694, underscores the extensive array of activities dispersed throughout the entire region of Istanbul.

- **Beta diversity**

Beta diversity, indicating the rate of change in species composition across different areas, offers insights into the dissimilarities among Istanbul's districts. Districts with higher beta diversity values, such as Sancaktepe, Sariyer, and Sile, exhibit a more distinct composition of activities than others. Conversely, districts like Atasehir and Avcilar display lower beta diversity, signifying more remarkable similarities in their activity composition.

Table 4.4 : Biodiversity Index.

Region	Alpha	Beta	Gamma
Adalar	1033	328.8422	339694
Arnavutkoy	1452	233.949	339694
Atasehir	6855	49.55419	339694
Avcilar	6876	49.40285	339694
B.Cekmece	6859	49.5253	339694
Bagcilar	6845	49.62659	339694
Bahcelievler	6863	49.49643	339694
Bakirkoy	6858	49.53252	339694
Basaksehir	6847	49.61209	339694
Bayrampasa	6072	55.94433	339694
Besiktas	16210	20.95583	339694
Beykoz	6736	50.42963	339694
Beylikduzu	8369	40.58956	339694
Beyoglu	12717	26.7118	339694
Catalca	1455	233.4667	339694
Cekmekoy	4002	84.88106	339694
Esenler	3655	92.93953	339694
Esenyurt	7268	46.7383	339694
Eyupsultan	7154	47.48309	339694
Fatih	17836	19.04541	339694
Gaziosmanpasa	4925	68.9734	339694
Gungoren	6002	56.5968	339694
K.Cekmece	11257	30.17625	339694
Kadikoy	30858	11.0083	339694
Kagithane	8217	41.34039	339694
Kartal	9130	37.20635	339694
Maltepe	14519	23.39651	339694
Pendik	10142	33.49379	339694
Sancaktepe	2546	133.4226	339694
Sariyer	12340	27.52788	339694
Sile	2477	137.1393	339694
Silivri	4120	82.45	339694
Sisli	20620	16.47401	339694
Sultanbeyli	1392	244.033	339694
Sultangazi	2232	152.1927	339694
Tuzla	4884	69.55242	339694
Umraniye	14284	23.78143	339694
Uskudar	17920	18.95614	339694
Zeytinburnu	6340	53.5795	339694

4.2 Intensity of activities

To measure the intensity of activities using the density kernel method, it was essential to categorize the distribution of activities. Several articles categorized the data obtained from Four Square according to their purpose, such as Hasan et al. (2013) in 'Understanding Urban Human Activity and Mobility Patterns Using Large-scale Location-based Data from Online Social Media,' divided the data obtained from Four Square into six categories: Home, Work, Eating, Entertainment, Recreation, and Shopping. Zhan et al. (2014), in their research 'Inferring Urban Land Use Using Large-scale Social Media Check-in Data,' divided the data into nine categories: Home, Work, Eating, Entertainment, Recreation, Shopping, Social Services, Education, and Transportation. In another study titled 'Role of Urban Public Space and the Surrounding Environment in Promoting Sustainable Development from the Lens of Social Media' by Nguyen et al. (2019), the Four-Square data was categorized into seven categories: Open Space, Food and Drink, Life Service, Art and Entertainment, Shopping, Residence, and Office, and Education.

This review categorized the data into ten groups based on the research goal: Sports and Recreation, Food and dining, Entertainment and culture, Education and learning, Transportation and travel, Retail and shopping, Government and civil, Lodging and accommodation, and Nature and outdoors. The distribution of each group can be seen in Table 4.5.

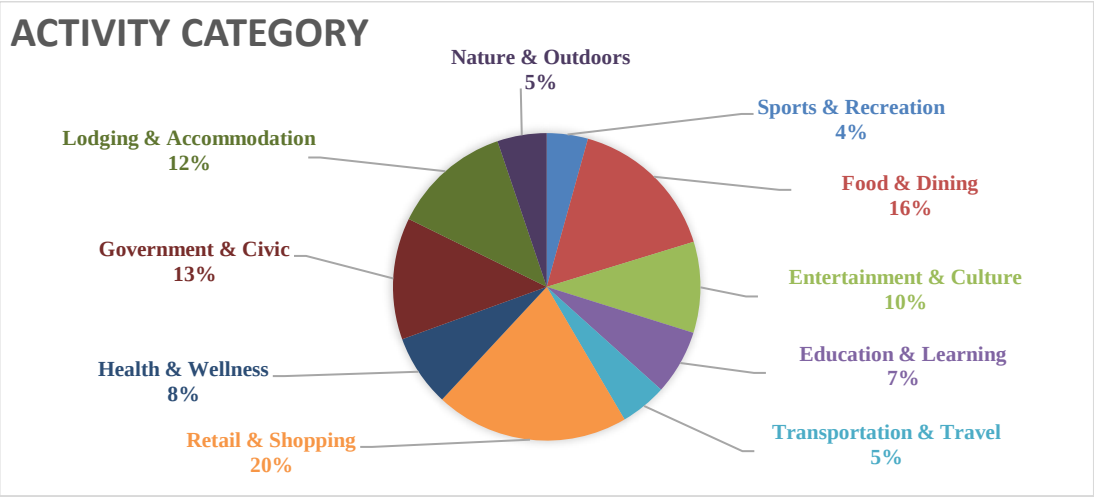


Figure 4.5 : Activity Category.

Figure 4.5 illustrates the distribution of activity groups across Istanbul, categorized into four distinct density levels: sparse, low, moderate, and high.

Table 4.5 : Activity Category.

Activity Category	Type of Visited Location
Sports & Recreation 4.33%	Athletic & Sport, Athletics & Sports, Baseball Field, Baseball Stadium, Basketball Court, Basketball Stadium, Beach, Bike Rental / Bike Share, Bowling Alley, Climbing Gym, College Baseball Diamond, Cricket Ground, College Basketball Court, College Cricket Pitch, College Football Field, College Gym, College Soccer Field, College Stadium, College Tennis Court, College Track, Cricket Ground, Dance Studio, Dog Run, Football Stadium, Golf Course, Gym, Gym / Fitness Center, Gym Pool, Hiking Trail, Hockey Arena, Hockey Field, Paintball Field, Playground, Racetrack, Tanning Salon, Yoga Studio, Rock Climbing Spot, Skate Park, Skating Rink, Ski Area, Ski Chairlift, Ski Chalet, Ski Lodge, Ski Trail, Soccer Field, Surf Spot, Tennis Court, Track, Trails, Volleyball Court, Water Park.
Food & Dining 15.94%	Afghan Restaurant, African Restaurant, American Restaurant, Arepa Restaurant, Argentinian Restaurant, Asian Restaurant, Australian Restaurant, BBQ Joint, Brazilian Restaurant, Bakery, Breakfast Spot, Brewery, Burger Joint, Burrito Place, Cafe, Cafeteria, Cajun / Creole Restaurant, Caribbean Restaurant, Cheese Shop, Chinese Restaurant, Coffee Shop, College Cafeteria, Cuban Restaurant, Cupcake Shop, Dim Sum Restaurant, Diner, Deli / Bodega, Doner Restaurant, Donut Shop, Dumpling Restaurant, Eastern European Restaurant, Ethiopian Restaurant, Falafel Restaurant, Filipino Restaurant, Fast Food Restaurant, Fish & Chips Shop, Food, Food Court, Food Truck, French Restaurant, Fried Chicken Joint, Frozen Yogurt, Gluten-free Restaurant, German Restaurant, Greek Restaurant, Hookah Bar, Hot Dog Joint, Indian Restaurant, Indonesian Restaurant, Italian Restaurant, Japanese Restaurant, Juice Bar, Kebab Restaurant, Kofte Restaurant, Kokore Restaurant, Korean Restaurant, Mac & Cheese Joint, Malaysian Restaurant, Manti Place, Mediterranean Restaurant, Mexican Restaurant, Meyhane, Middle Eastern Restaurant, Moroccan Restaurant, Paella Restaurant, Peruvian Restaurant, Pizza Place, Ramen / Noodle House, Portuguese Restaurant, Restaurant, Salad Place, Sandwich Place, Scandinavian Restaurant, Seafood Restaurant, Sake Bar, Snack Place, South American Restaurant, Southern / Soul Food Restaurant, Spanish Restaurant, Speakeasy, Steakhouse, Street Fair, Sushi Restaurant, Swiss Restaurant, Taco Place, Tapas Restaurant, Thai Restaurant, Turkish Restaurant, Vegetarian / Vegan Restaurant, Wings Joint.
Entertainment & Culture 9.57%	Apres Ski Bar, Aquarium, Arcade, Art Gallery, Art Museum, Arts & Entertainment, Bar, Beer Garden, Casino, Comedy Club, Concert Hall, Event Space, Festival, Flea Market, General Entertainment, Indie Movie Theater, Indie Theater, Jazz Club, Karaoke Bar, Movie Theater, Music Festival, Music School, Music Store, Music Venue, Opera House, Performing Arts Venue, Piano Bar, Pier, Planetarium, Plaza, Public Art, Radio Station, Rock Club, Sculpture Garden, Science Museum, Spiritual Center, Stadium, Strip Club, Synagogue, Theater, Theme Park, Theme Park Ride / Attraction, Toy / Game Store, Theater, Zoo.
Education & Learning 6.81%	Auditorium, College and university, College Academic Building, College Administrative Building, College Arts Building, College Auditorium, Daycare, College Classroom, College Communications Building, College Engineering Building, College History Building, College Lab, College Library, College Math Building, College Quad, College Rec Center, College Science Building, College Technology Building, College Theater, Community College, Conference, Conferences, Elementary School, General College & University, High School, Laboratory, Law School, Library, Medical School, Music School, School, Trade School, University.
Transportation & Travel 4.90%	Airport, Airport Food Court, Airport Gate, Airport Lounge, Airport Terminal, Airport Tram, Boat or Ferry, Bus Line, Bus Station, Car Dealership, Car Wash, EV Charging Station, Ferry, Harbor / Marina, Light Rail, Motorcycle Shop, Parking, Plane, Platform, Rental Car Location, Rest Area, Subway, Taxi, Train, Train Station, Travel & Transport, Travel Agency, Travel Lounge, Tourist Information Center.
Retail & Shopping 20.37%	Accessories Store, Adult Boutique, Antique Shop, Automotive Shop, Bookstore, Boutique, Arts and crafts Store, Bike Shop, Board Shop, Bagel Shop, Bridal Shop, Camera Store, Clothing Store, Butcher, Cosmetics Shop, Convenience Store, Department Store, College Bookstore, Dessert Shop, Health Food Store, Electronics Store, Farmers Market, Food & Drink Shop, Flower Shop, Furniture / Home Store, Gaming Cafe, Garden Center, Gift Shop, Grocery Store, Hardware Store, Hobby Shop, Home Cooking Restaurant, Jewelry Store, Kids Store, Lingerie Store, Liquor Store, Mall, Miscellaneous Shop, Mobile Phone Shop, Newsstand, Office, Optical Shop, Paper / Office Supplies Store, Pet Store, Real Estate Office, Record Shop, Shoe Store, Shop & Service, Smoke Shop, Sporting Goods Shop, Stable, Stables, Storage Facility, Thrift / Vintage Store, Video Game Store, Video Store, Vineyard, Whisky Bar, Wine Bar, Wine Shop, Winery, Women's Store.
Health & Wellness 7.55%	Dentist's Office, Doctor's Office, Drugstore / Pharmacy, Emergency Room, Eye Doctor, Hospital, Medical Center, Salon / Barbershop, Spa / Massage, Veterinarian, Nail Salon.
Government & Civic 12.81%	Bank, Cemetery, City, City Hall, Capitol Building, Campaign Office, Bridge, Building, Church, Castle, Courthouse, Credit Union, Embassy / Consulate, Fire Station, Government Building, Housing Development, Police Station, Funeral Home, Military Base, Mosque, Police Station, Post Office, Professional & Other Places, Recycling Facility, Polling Booth, Temple, Voting Booth.
Lodging & Accommodation 12.54%	Bed and breakfast, Boarding House, College Residence Hall, Hostel, Hotel, Motel, Residence, Residential Building (Apartment / Condo), Resort.
Nature & Outdoors 5.19%	Animal Shelter, Campground, Farm, Field, Garden, Island, Lake, Lighthouse, Mountain, Park, Pool, Outdoors and recreation, River, Road, Scenic Lookout, Park, Volcano, Well, Roof Deck.

- **Sports & Recreation**

Figure 4.6 shows that the highest density of sports and recreation activities is concentrated in the central districts of Istanbul, encompassing areas like Beşiktaş, Şişli, and Beyoğlu. A moderate density of sports and recreation activities is observed in several coastal areas along the Sea of Marmara and the Bosphorus, as well as in some suburban districts like Kadıköy, Üsküdar, Bakırköy, Kucukcekmece, and part of Esenyurt. The low density of Istanbul, particularly the center and western regions such as part of Fatih and Avcilar, Atasehir, Umraniye, and Maltepe, exhibits a sparse distribution of sports and recreation activities.

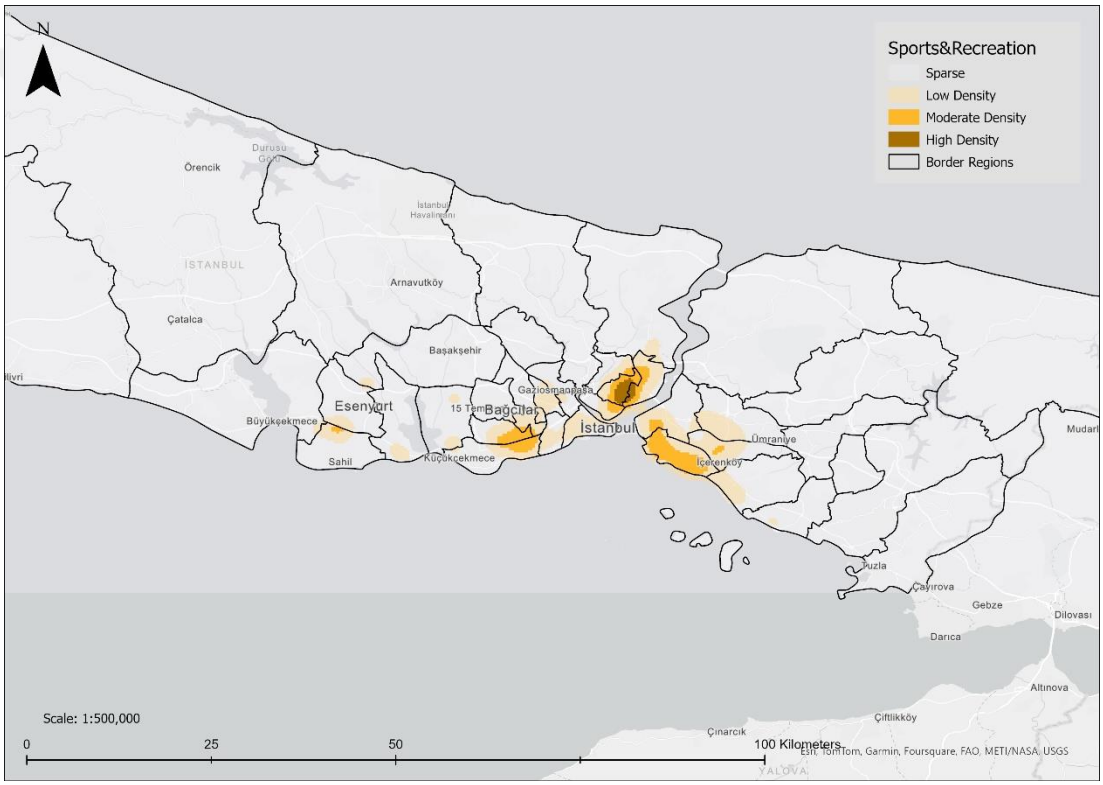


Figure 4.6 : Sports & Recreation.

- **Food & Dining**

Figure 4.7 states that the highest density of food and drink activities is concentrated in the central districts of Istanbul, encompassing areas like Beyoğlu, Şişli, Beşiktaş, and Kadıköy. A moderate density of food and drink activities is observed in several developing areas surrounding the city center, including Bakırköy. The low density of Istanbul, particularly the western regions like Uskudar, Atasehir, and part of Avcilar, exhibit sparse food and drink activities.

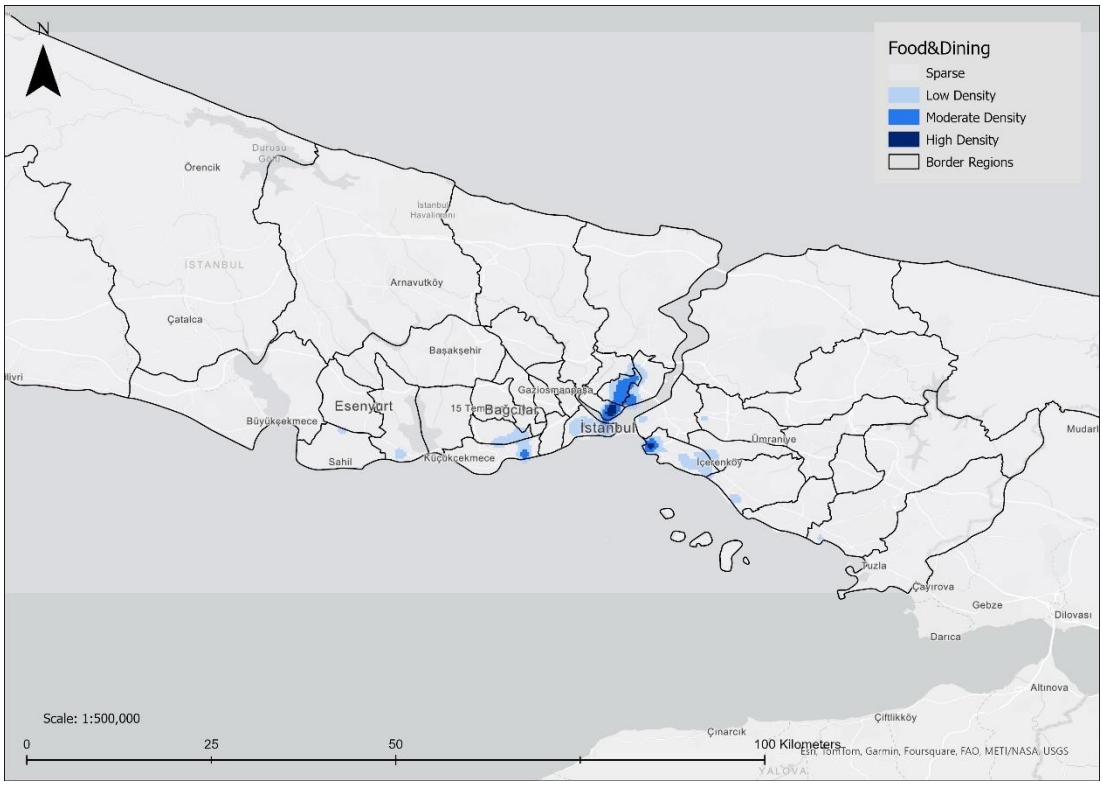


Figure 4.7 : Food & Dining.

- **Entertainment & Culture**

Figure 4.8 displays that the highest density of entertainment and cultural activities is concentrated in the central districts of Istanbul, encompassing areas like Beyoğlu, Şişli, Kadikoy, and Beşiktaş. This aligns with the city's historic core and status as a significant cultural and economic hub.

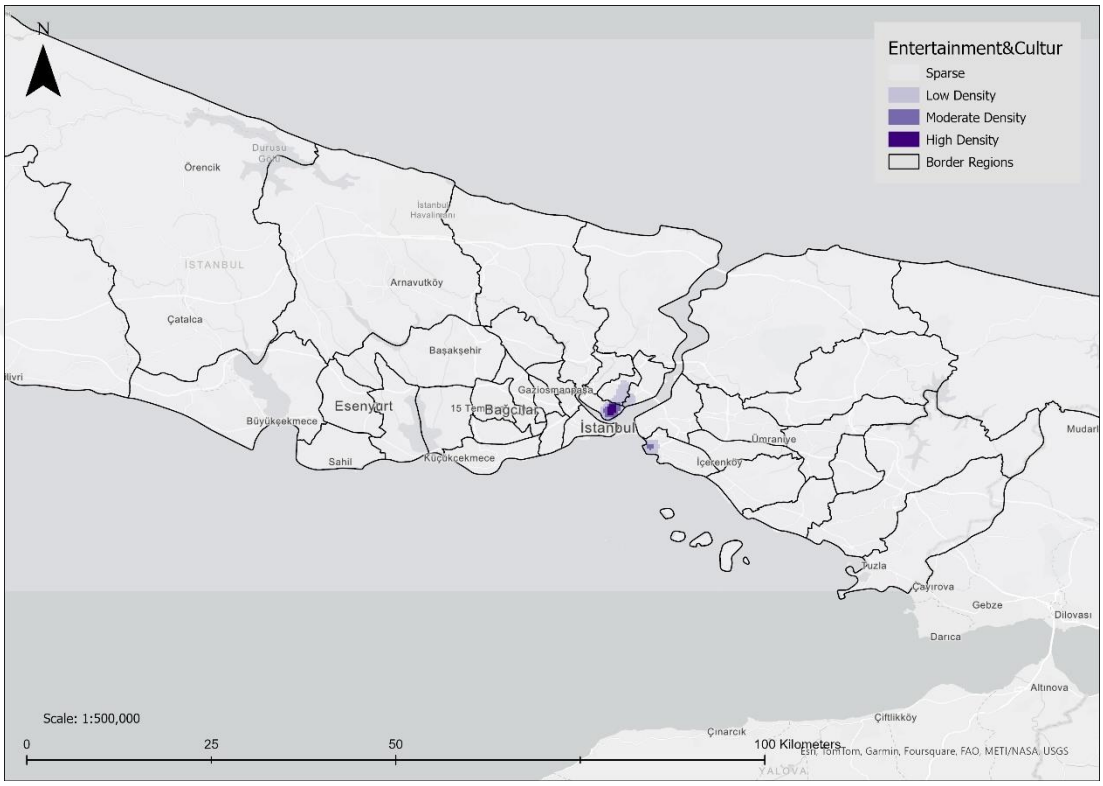


Figure 4.8 : Entertainment & Culture.

- **Education & Learning**

Figure 4.9 presents the highest density of educational activities concentrated in the central districts of Istanbul, encompassing areas like Fatih and Besiktas. A moderate density of education activities is observed in several developing areas surrounding the city center. These include districts like Avcilar, Kadikoy, Sariyer, and Sisli. The low density of the center of Istanbul, particularly Beylikduzu, Kucukcekmece, Uskudar, and Umraniye, exhibits a sparse distribution of education activities.

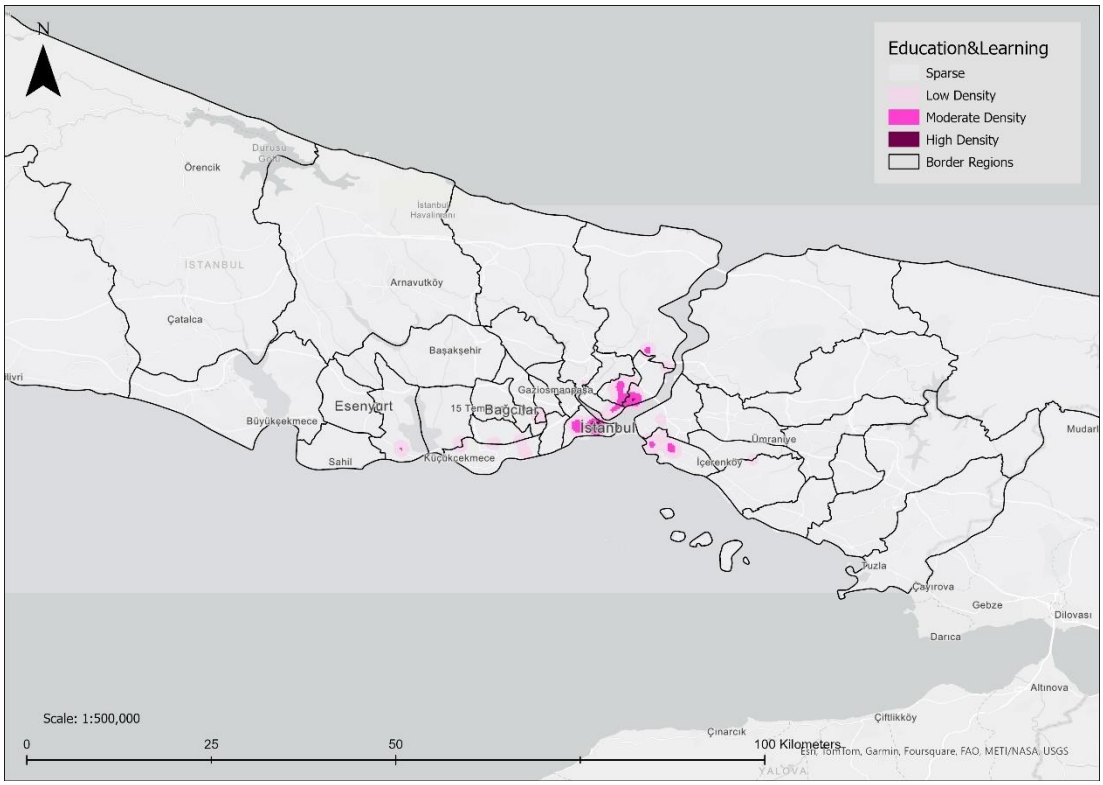


Figure 4.9 : Education & Learning.

- **Transportation & Travel**

Figure 4.10 indicates that the high density of transportation and travel activities is concentrated in the coastal district of Istanbul, Kucukcekmece. The low density of Istanbul, particularly the regions like Beyoglu, Sisli, Besiktas, Kadikoy, part of Fatih, Gaziosmanpasa, and Bahcelievler, exhibits a sparse distribution of transportation and travel activities. The areas around Istanbul's two major airports, Istanbul Airport (IST) and Sabiha Gökçen International Airport (SAW), show a density of transportation and travel activities.

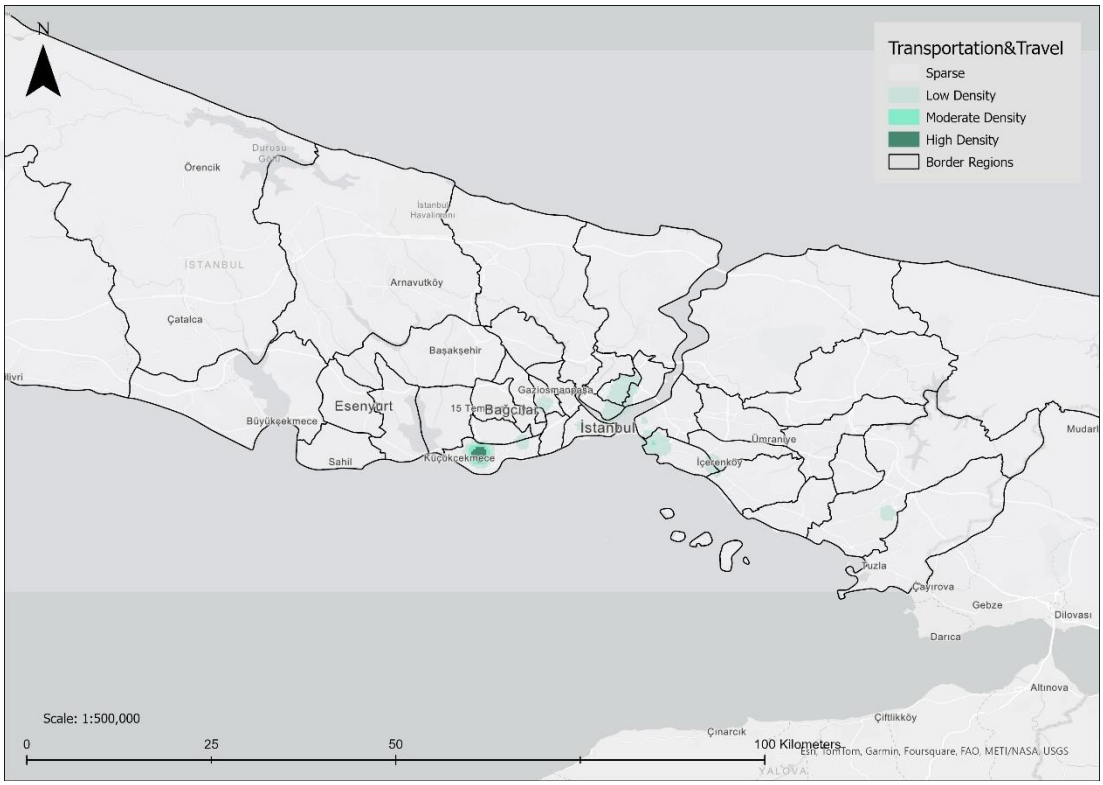


Figure 4.10 : Transportation & Travel.

- **Retail & Shopping**

Figure 4.11 demonstrates that the highest density of retail and shopping activities is concentrated in the central districts of Istanbul, encompassing areas like Şişli. A moderate density of retail and shopping activities is observed in several urban centers surrounding the city center, including Kadikoy, Fatih, Besiktas, and Beyoglu. Istanbul's low density exhibits a sparse distribution of retail and shopping activities, particularly in Maltepe, Uskudar, Umraniye, Gungoren, Kucukcekmece, and part of Sariyer.

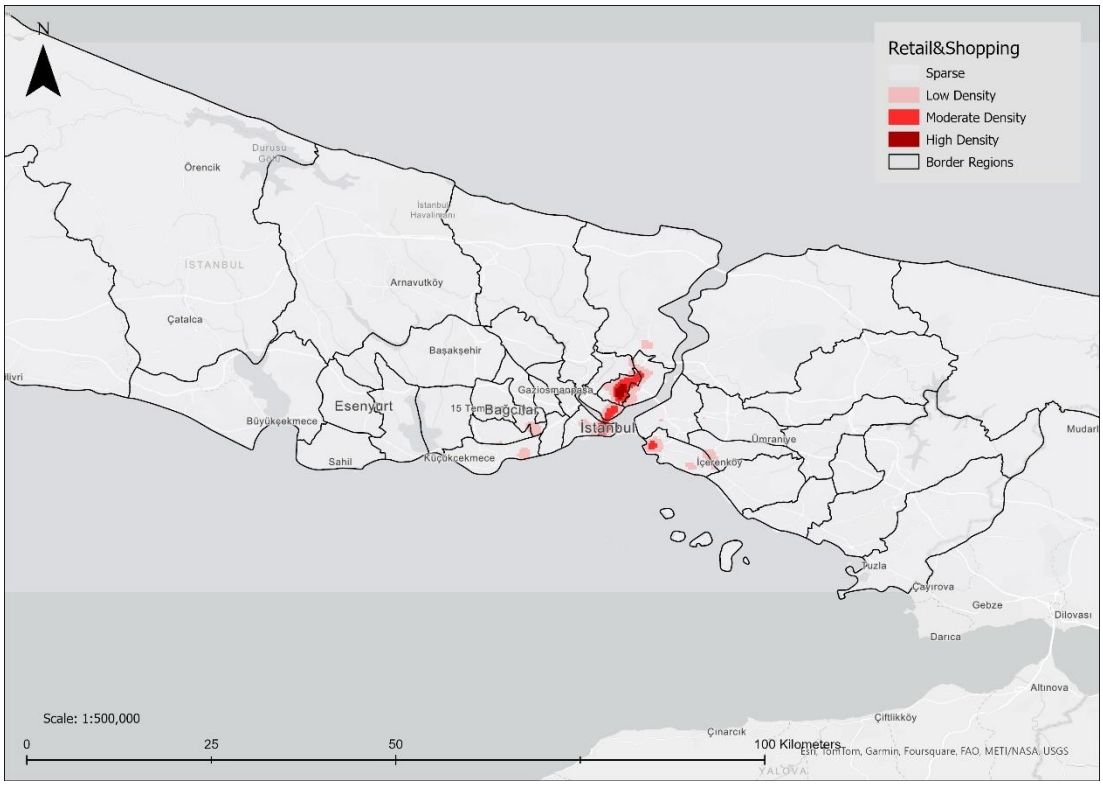


Figure 4.11 : Retail & Shopping.

- **Health & Wellness**

Figure 4.12 exhibits the high density of health and wellness activities concentrated in the central districts of Istanbul, encompassing areas like Şişli, Beşiktaş, and Beyoğlu. A moderate density of health and wellness activities is observed in several urban centers surrounding the city, including Bakırköy and part of Fatih. The low density of Istanbul, particularly the regions such as Kadıköy, Üsküdar, part of Esenyurt, Beylikduzu, Umraniye, Pendik, and Maltepe, exhibits a sparse distribution of health and wellness activities.

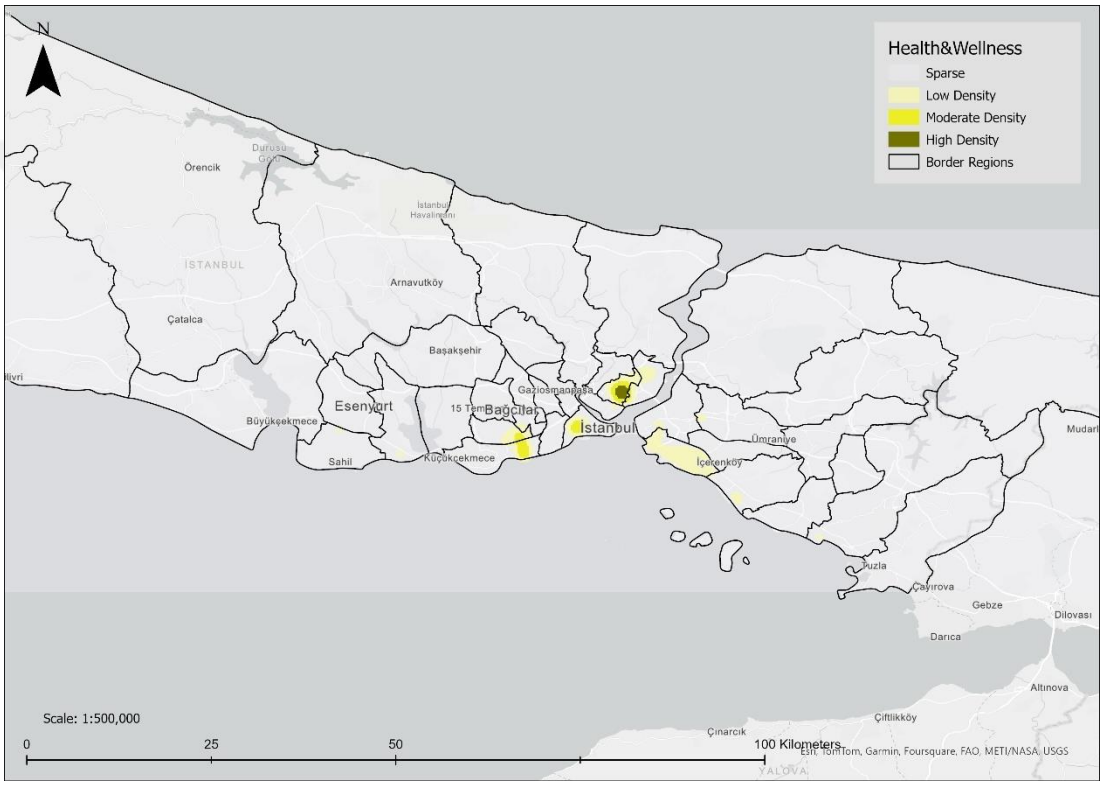


Figure 4.12 : Health & Wellness.

- **Government & Civic**

Figure 4.13 shows that the high density of government and civic activities is concentrated in the central districts of Istanbul, encompassing areas like Beyoğlu, Şişli, Beşiktaş. A moderate density of government and civic activities is observed in several urban centers surrounding the city, including part of Kadıköy, Kagithane, and Fatih. The low density of Istanbul, particularly the regions such as Uskudar, Umraniye, Atasehir, part of Pendik, Esenyurt, Avcilar, Kucukcekmece, Bakirkoy, Bahcelievler, Bagcilar, Zeytinburnu, Gaziosmanpasa, Bayrampasa, and Sariyer exhibits a sparse distribution of government and civic activities.

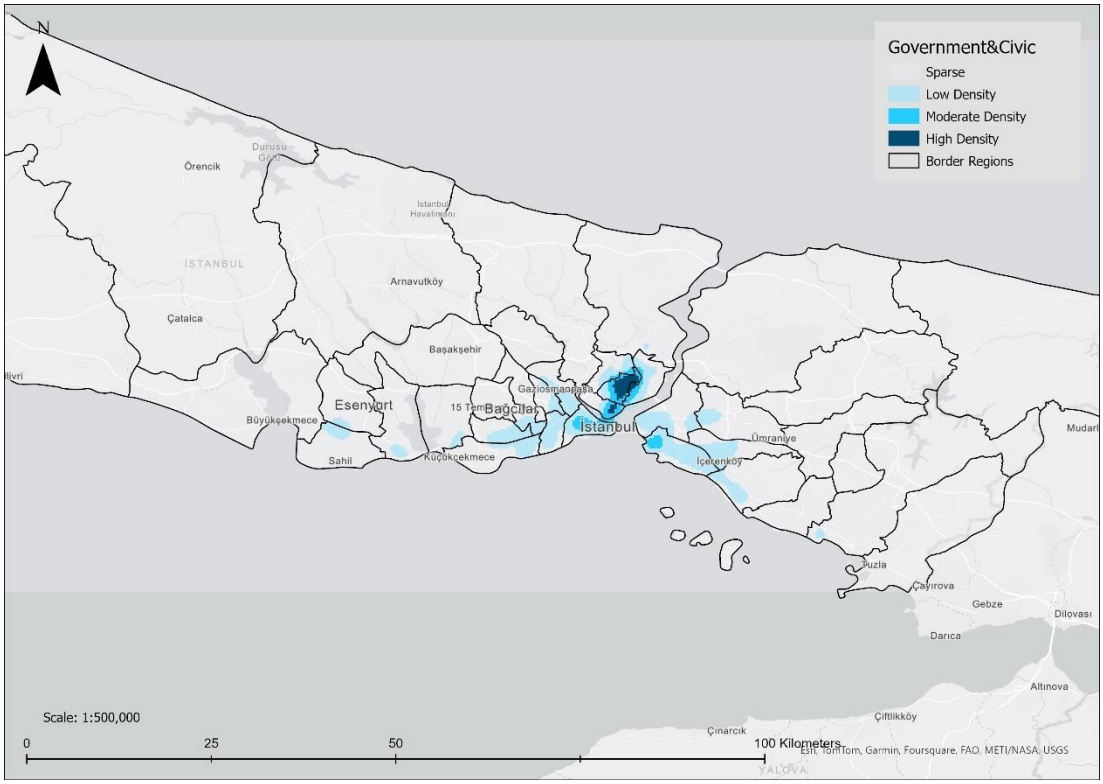


Figure 4.13 : Government & Civic.

- **Lodging & Accommodation**

Figure 4.14 presents the high density of lodging and accommodation activities concentrated in the central districts of Istanbul, encompassing areas like Beyoğlu, Şişli, Kadikoy, and Beşiktaş. A moderate density of lodging options is observed in several urban centers surrounding the city center, including Bakırköy, Kadıköy, Umraniye, Maltepe, Üsküdar, Fatih, part of Esenyurt, and Beylikduzu. The low density of Istanbul, particularly the regions such as part of Avcilar, Bagcilar, Gaziosmanpasa, Zeytinburnu, Buyukcekmece, Kartal, and Pendik, exhibits a sparse distribution of lodging and accommodation activities.

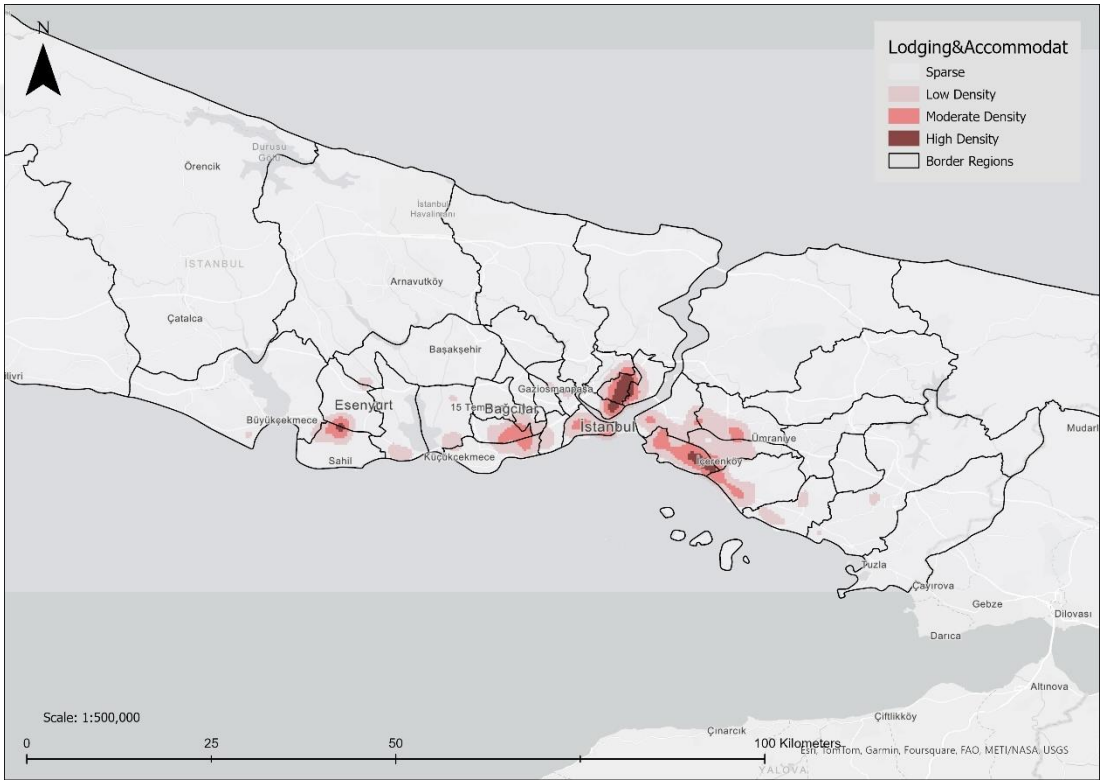


Figure 4.14 : Lodging & Accommodation.

- **Nature & Outdoors**

Istanbul's nature and outdoor activities are unevenly distributed throughout the city. The central areas boast well-established parks and green spaces, offering a respite from urban life. These spaces, however, are often limited in size and may not fully meet the demands of the dense population. According to the map, the northern and western peripheries, with their less developed landscapes. Coastal areas offer beaches, parks, and water-based activities, contributing to a higher concentration of outdoor activities. Densely populated zones like Esenyurt and Avcilar, often characterized by residential and commercial buildings, face a significant lack of natural spaces (see Figure 4.15).

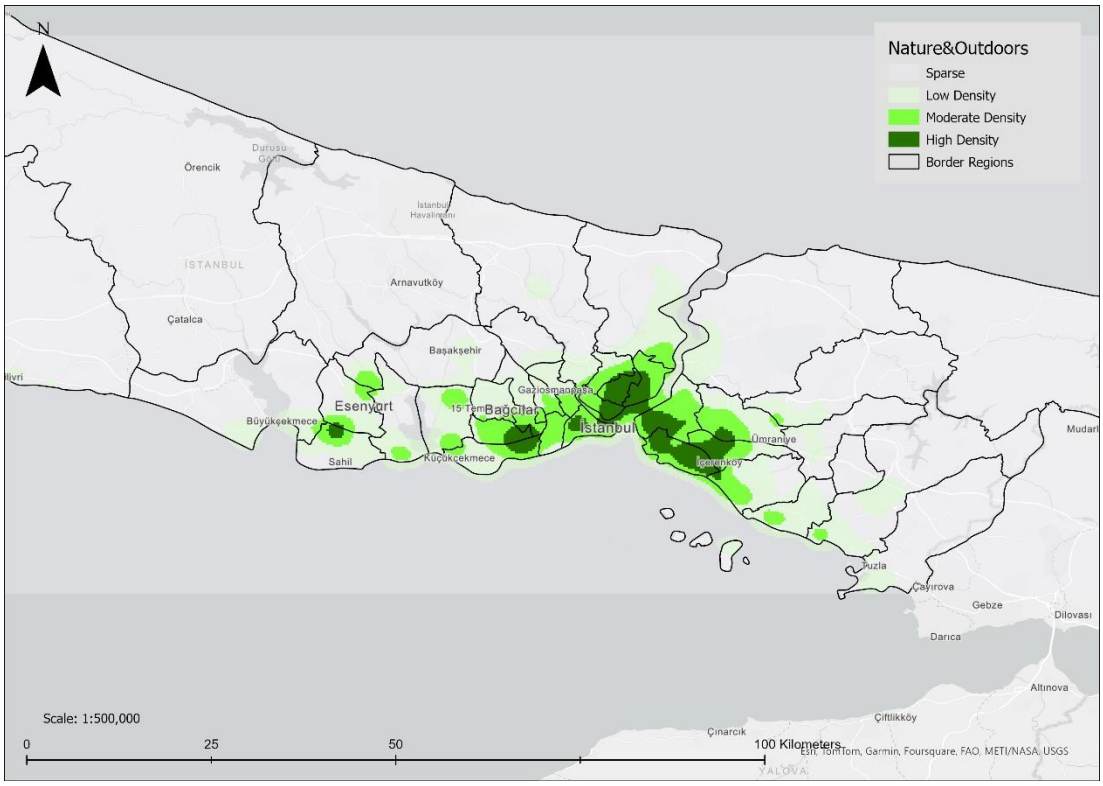


Figure 4.15 : Nature & Outdoors.

4.3 Discussion

In this part, we aim to address the research queries by leveraging the theoretical insights from the literature review and the findings extracted from this study's diversity and intensity indices. Firstly, we explore how the distribution of activities throughout Istanbul enriches the city's overall complexity. Essentially, we delve into how the variety and spread of activities across different areas contribute to Istanbul's multifaceted nature. This is crucial in understanding how the city functions as a dynamic urban entity, influenced by the diverse interactions among its components. Secondly, we investigate how the dispersion of activity within distinct regions of Istanbul influences the identity and dynamics of those particular areas. We can grasp each region's unique characteristics and evolving nature by examining how activities are distributed within different neighborhoods or districts. This highlights the socio-economic, cultural, and spatial dynamics shaping Istanbul's diverse urban landscape. By exploring these aspects, we gain a deeper understanding of Istanbul's complexity and the intricate interplay between its various components, ultimately contributing to the scholarly discourse on urban studies and regional development.

- **Exploring the Diversity**

Istanbul, a city steeped in history and brimming with modern vibrancy, is a microcosm of urban complexity. This complexity is not merely a result of its rich cultural heritage or geographic location straddling two continents but also a direct consequence of how activities are dispersed throughout its diverse neighborhoods. This intricate distribution of activities, encompassing their variety and intensity, weaves a complex tapestry that shapes Istanbul's unique character and contributes to its dynamism.

The variety of activities throughout Istanbul is a testament to the city's multifaceted identity. From the vibrant commercial centers of Eminönü and Karaköy, where the echoes of centuries-old trade routes still resonate, to the modern art galleries and performance spaces of Beyoğlu, Istanbul offers a diverse array of experiences. Historical sites like the Hagia Sophia and Topkapı Palace stand alongside bustling bazaars and tranquil parks, creating a rich urban environment that caters to a wide range of interests and preferences.

However, this diversity is not evenly distributed. Neighborhoods specialize in different activities, creating a mosaic of distinct local identities. Nişantaşı, for instance, is

renowned for its high-end fashion boutiques, while Kadıköy is a vibrant hub for alternative culture and nightlife. This specialization enriches the urban experience, providing residents and visitors with many choices and fostering a sense of continuous discovery.

- **Exploring the Intensity**

A striking observation from the maps is the uneven distribution of activities across Istanbul. Central districts like Beyoğlu, Şişli, and Beşiktaş emerge as vibrant hubs, boasting a high concentration of diverse activities, including entertainment, culture, retail, dining, health services, and government institutions. This concentration aligns with Istanbul's historical core and ongoing role as a significant cultural and economic center.

However, as we move from the city center, the density and variety of activities decrease. Suburban areas like Kadıköy and Üsküdar offer a more moderate mix of amenities. At the same time, outer districts like Esenyurt and Avcılar exhibit a sparser distribution, particularly in sports and recreation, entertainment, and health categories. This unevenness reflects the complex interplay of historical development, socio-economic factors, and urban planning decisions that have shaped Istanbul's landscape over time.

The intensity of activities in specific areas of Istanbul is another crucial factor in understanding its complexity. Business districts like Levent and Maslak pulsate with activity during the workweek, while tourist hotspots like Sultanahmet and the Bosphorus shores experience a constant influx of visitors. Residential neighborhoods have their unique rhythms, with cafes, restaurants, and markets bustling with activity at different times of the day.

This varying intensity creates a dynamic urban landscape, where the pace of life shifts from one neighborhood to the next. The contrast between the Princes' Islands' tranquil atmosphere and Taksim Square's frenetic energy exemplifies this diversity. Understanding the intensity of activities is crucial for urban planners and policymakers, as it can reveal areas that may require additional infrastructure or resources to support their demands.

Moreover, the intensity of activities can also have social and cultural implications. High-density areas may foster a greater sense of community and belonging, while

lower-intensity areas may offer more opportunities for individual expression and creativity.

Policies should focus on increasing activity diversity in more homogeneous regions like Esenyurt and Kagithane. Encouraging a mix of commercial, cultural, and residential developments can foster more dynamic and resilient urban environments. On the other hand, ensuring adequate infrastructure and services in high-intensity areas such as Fatih and Sisli is crucial. These districts require continuous investment to support their dense activity concentrations and to maintain their roles as critical urban centers.

Ultimately, urban planning should aim to balance development across Istanbul, addressing disparities in activity intensity and diversity. This includes promoting equitable economic opportunities and improving amenities in peripheral areas like Tuzla and Sile to enhance their attractiveness and functionality.

Moreover, Incorporating green spaces and ecological elements in urban planning can enhance biodiversity and improve quality of life. This approach aligns with the theoretical emphasis on integrating natural elements into urban environments to support sustainability and resilience.

In conclusion, the research visually represents the intricate tapestry of activity that defines Istanbul. By understanding the dispersion, specialization, and interdependence patterns, we gain valuable insights into the city's complex urban landscape. As Istanbul continues to grow and evolve, it is essential to consider the impact of activity dispersion on the city's overall complexity. The interplay between activity intensity and diversity is a critical determinant in defining the intricate tapestry of urban life in this dynamic city. Urban planners and policymakers must develop strategies that promote sustainable development, ensuring that the city's diverse neighborhoods can thrive while maintaining their unique identities. By understanding and embracing the complexities of activity dispersion, Istanbul can continue to flourish as a vibrant and dynamic metropolis. The knowledge obtained from this research can inform future urban planning efforts, ensuring that Istanbul continues to thrive as a dynamic and inclusive metropolis.

5. CONCLUSION

This study delves into the intricate distribution of activities within Istanbul, offering insights into the city's urban complexity. By examining the variety and intensity of activities, we gain a deeper understanding of the diverse landscape and dynamics that characterize Istanbul.

This thesis is positioned within applied developmental research, primarily focusing on descriptive and analytical purposes. The methodology involves collecting information from library documents. To evaluate the diversity of activities in each region, the study employs several diversity indices, including Simpson's Index, the Shannon-Weiner Diversity Index, and Pielou's Evenness Index. These indices offer a thorough assessment of the range of activities within Istanbul. Additionally, the study uses the Kernel Density tool to measure activity intensity, providing valuable insights into the concentration of activities throughout the city. The uneven distribution of activities across Istanbul's landscape underscores the multifaceted nature of its urban fabric, shaped by historical legacies, economic factors, and urban planning initiatives. Central areas pulse with a dense amalgamation of activities, while suburban and outlying regions exhibit varying degrees of intensity. Comprehending these patterns is paramount for effective urban planning and resource allocation. Moreover, the intensity of activities influences social interactions and cultural expressions within different city regions. As Istanbul continues to evolve, embracing the complexities inherent in the distribution of activities is imperative. Leveraging this understanding can facilitate sustainable development while preserving the city's distinct character.

Acknowledging certain limitations, particularly about the completeness, accuracy, and categorization of Volunteered Geographic Information (VGI)-based Points of Interest, is crucial. While official datasets mitigate some concerns, addressing these issues in future research endeavors is essential to enhance data quality and reliability. To advance our comprehension of urban dynamics and address current limitations, future research endeavors should explore the following avenues:

- **Enhancing data quality**

Develop methodologies to enhance the completeness and accuracy of big data sources, mitigating issues associated with user-generated content.

- **Comparative studies**

Extend the research by conducting comparative studies with other cities to validate findings and identify contextual variations in urban dynamics.

- **Temporal analysis**

Investigate temporal dynamics to capture trends and changes over time, providing a dynamic perspective on the evolution of urban complexity.

- **Integration of multiple data sources**

Explore integrating diverse data sources, such as satellite imagery and transportation data, to enrich urban analysis's comprehensiveness.

- **Incorporating demographic data**

Demographic data such as age, nationality, and other relevant factors can be incorporated for more precise analysis in future research. This additional data can provide deeper insights into the patterns of activity dispersion and specialization across different neighborhoods, enabling a more nuanced understanding of Istanbul's urban dynamics.

In conclusion, this research's findings underscore the importance of diversity and spatial distribution in shaping the intensity and complexity of activities across different areas of Istanbul. The interplay between diverse urban features and their spatial patterns contributes to the rich and intricate urban tapestry that defines the city's complexity.

- **Matching activity data with land use**

Future research should focus on matching the detailed activity data with land use information to provide a more holistic view of urban dynamics. Understanding how different land uses correlate with activity diversity and intensity can offer deeper insights into urban planning and development. By overlaying activity data with land use maps, researchers can identify the land-use types contributing to high activity diversity and intensity, facilitating more informed decision-making in urban planning.

- **Examining factors of sustainable development**

Investigating the factors influencing sustainable development within urban areas is crucial for future research. This includes analyzing how activity diversity and intensity relate to environmental sustainability, social equity, and economic viability. Researchers can develop strategies to promote sustainable urban growth by examining these factors. Understanding the impact of diverse activities on sustainability can help policymakers create balanced development plans that support economic growth and environmental preservation.

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OTHER PUBLICATIONS, PRESENTATIONS AND PATENTS:

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