# URBAN ECOLOGICAL FOOTPRINT ANALYSIS AS AN EVALUATION TOOL FOR SUSTAINABILITY: ANALYSIS OF THE BUILT-UP LAND FOOTPRINT OF ALEXANDRIA CITY, EGYPT

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ABSTRACT

With fast urbanization, numerous cities are confronting different environmental issues, leading to local environmental degradation. It is basic to make a scientific assessment so that convenient solutions can be proposed by looking at the local realities. Numerous assessment strategies have been suggested such as emerge analysis, material flow analysis, data development analysis and ecological footprint analysis. Among them, ecological footprint analysis (EFA) has been implemented as a useful analytical and planning tool for assessing urban sustainability in numerous cities. The aim of this research is to use one of the EFA components that is the built-up land footprint ($EF_{Built\text{-}up\ land}$) to evaluate the sustainability in Alexandria, Egypt, in terms of settlements. In order to assess a sophisticated picture of $EF_{Built\text{-}up\ land}$ of Alexandria, the researchers will collect all relevant data for the years 2005 to 2017 and calculate the $EF_{Built\text{-}up\ land}$ and $BC_{Built\text{-}up\ land}$ during this time-series (2005–2017). The research concludes that the Alexandria's $EF_{Built\text{-}up\ land}$ exceeds its bio-capacity ($BC_{Built\text{-}up\ land}$), resulting in an ecological deficit ($EF_D$). Consequently, the element of built-up land in Alexandria is considered an unsustainable system. Finally, the researcher will propose guidelines to respond to the findings so that the city can shift towards a sustainable evolution direction for Alexandria's vision of 2050.

*Keywords: built-up land footprint, ecological footprint analysis, urban sustainability, sustainable development.*

## 1 INTRODUCTION

The rapid outgrowth of cities boosts a few challenges, such as water contamination, air quality degradation, biodiversity misfortune, exhaustion of land resources, and noise [1], [2]. With concerted human bounces, the increasing effects of cities are growing beyond the city limits and raising global interests, such as global climate change and cross-border air pollution [3]. The accumulative consumption of resources and the emission of pollutants may surpass the security limits of municipal bio-capacity and bring genuine impendence to the population and the local environment [4]. This seeks that city authorities and their inhabitants cooperate together to realize global sustainability [5].

In order to realize sustainable urban evolution and meet desires of city inhabitants, city authorities ought to develop innovative asset and environmental management strategies so that overall environmental efficiency can be amended. This policy-making procedure ought to be relied on the scientific assessment of urban evolution so that the main factors obstructing sustainable urban evolution can be distinguished. Scholastically, numerous assessment methods, such as Ecological Footprint Analysis (EFA) [6], Emerge Analysis [7], Data Envelopment Analysis [8] and the Analytical Hierarchy Process (AHP) [9] have been implemented globally. In this research, the Environmental Footprint Analysis (EFA) technique will be utilized. EFA is defined as "A synthetic method to trail human impacts on the regenerative capacity of an environmental system through identifying the amount of bio-productive land required to support average annual consumption and waste production of a given entity under prevailing technologies" [10]. The aim of this paper is to use the EFA

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methodology to assess the sustainability of Alexandria, with a focus on one element of EFA components, the built-up component. The objectives are to conduct a review on the measurement and tools of the Ecological Footprint (EF), evaluate the availability and quality of the data desired to make this sort of analysis, as well as suggesting guidelines for responding to the evaluation for the Alexandria city's 2050 vision.

In general, EFA is an appropriate way to assess the overall sustainability of a given city. Alexandria was selected as a case study for several reasons; due to it is a Mediterranean city with a high resource consumption and facing serious environmental challenges, many contacts were made with the approval of the city government, allowing access to data, and allowing meaningful investigations with local authorities, Alexandria city faces some political challenges, especially after the revolution of 25 January 2011, where the exploitation of the security vacuum led to a rapid illegal increase in the built-up area, there is an imbalance between the pattern of consumption and production (overconsumption) in the city for reasons such as overpopulation, rapid urbanization and the absorption of pollutants, and finally, with rapid urbanization, Alexandria faces many environmental matters, leading to local degradation. In this case study, the researchers used the EFA method for assessing the built-up land footprint ($EF_{\text{Built-up land}}$).

This paper is coordinated as follows: following this introduction, Section 2 characterized the research methodology, including the case study area, the calculation procedure, data collection, and analysis. Section 3 displays research findings and discussion. Finally, the conclusions are drawn in Section 4.

## 2 RESEARCH METHODOLOGY

### 2.1 Case study area

Alexandria city is located on the Mediterranean Sea 210 km north of Cairo (see Fig. 1) it is the second-largest city in Egypt, with a population of 5.1 million residents, more than 95% of whom live in Alexandria and the rest live in the new city of Burj El Arab and its surroundings [11], [12].

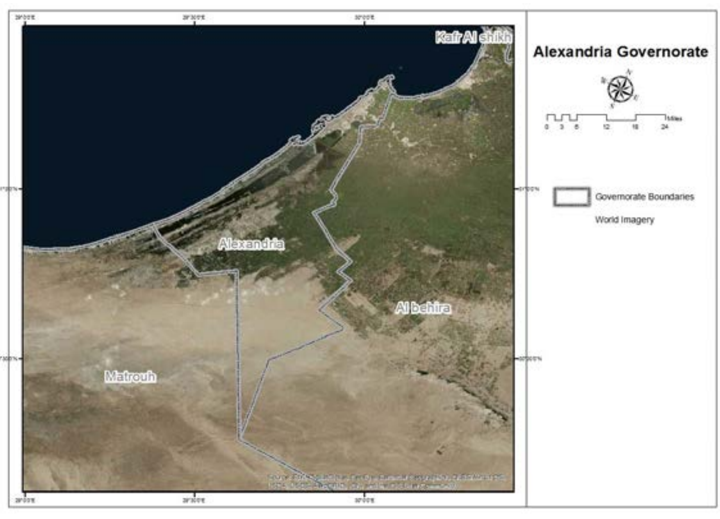


Figure 1: Satellite Map of Alexandria city. *(Source: Google Maps, 2019 [12].)*

Alexandria is a significant industrial region due to the natural gas and oil pipelines from Suez. Alexandria is also a popular tourist destination. In 2005, Alexandria had a total area of 2,299.97 $km^2$ (including its urban areas and rural areas) and a population of 3.8 million, with a built-up area of 1675.5 $km^2$. In 2017, official data records the variables of the total area and built land unchanged, with the population rising to 5.1 million [11]–[13].

### 2.2 Data Sources and Collection

In order to conduct the analysis of the built-up land footprint of Alexandria city, data is required to calculate the area of built-up land ($A_{Built\text{-}up\ land}$), Equivalence Factor (EQF), Yield Factor (YF), and the number of populations in any given year. In order to source required data, the researchers reviewed published technical and governmental reports and papers, web pages, and statistical reports. To establish how EFA could be measured and what type of data should be collected, journal articles were consulted. The EFA method provided valuable insights on decision-making processes and how sustainable urban policies can be proposed.

Data on global production and land use for yield factors are derived from the Food and Agriculture Organization (FAO) website (data publicly available from this website: http://www.fao.org/faostat/en/#compare) [19]. Equivalence Factors are collected from Living Planet Report (WWF, 1999–2017) [20] and National Footprint Accounts (NFA, 1999–2017) [21]. Data related to the city of Alexandria was derived from Alexandria's Statistical Yearbooks (Alexandria Municipal Government, 2005–2017) [11], CAPMAS annual reports (Central Agency for Public Mobilization and Statistics, 2005–2017) [13], Regional Centre of Urban planning and Development for the vision of 2050, 2018 [25], Ministry of Housing, and FAOSTAT (Food and Agriculture Organization of United Nations statistics) [19]. Data for Alexandria is necessary to calculate the yield factor of the city for the year of 2005 to 2017.

### 2.3 The application of Ecological Footprint Analysis (EFA) approach

EF exemplifies the demand for ecosystem products in terms of consumption resources sorts (such as water, food, transportation, energy, buildings, wastes and materials), whereas bio-capacity (BC) is defined as "The ability of an ecosystem to produce useful biological materials and to absorb carbon dioxide emissions, usually referring to the supply of available to serve each use" [14], and on the other side, Bio-capacity represents the supply for bio-productive land types. Overall, Ecological Footprint Analysis classifies biologically productive lands into six types: croplands, grazing lands, forest lands, fishing lands, built lands and energy land (carbon sequestration land) [6]–[14]. Wackernagel et al. [15] states that EFA methods are measured in global hectares.

#### 2.3.1 Processes for measuring Yield Factors (YF) and Equivalence Factors (EQF)

In order to compare EFA method with BC method of a given city, the YF and EQF must be assessed, as the both are utilized to transform actual areas which is measured in Hectares (Ha) of different land sorts into Global Hectares (gha) [16], [17]. Noticed that both EF and BC are measured in a common unit is Global Hectare (gha).

Yield factors (YF) are described as "The extent to which a biologically productive area in a given area is more (or less) productive than the global average of the same bio-productive area" [18]. YF can be measured in terms of the yearly accessibility of applicable products. Eqn 1 is used for calculating the YF of cropland that produces more than one product. For this land use type, the YF is calculated by the following eqn (2) below. $YF_{Cropland}$

equals to $YF_{Built\text{-}up\ land}$ [15] as it is based on assumption that built-up land converted from agricultural land and built on fertile area, thus, figures are calculated for the period of 2005–2017 based on FAOSTAT reports [19]. The results of $YF_{Built\text{-}up\ land}$ of Alexandria for the period of 2005–2017 are elaborated in Table 1.

$$\mathbf{YF_N^L} = \frac{\sum \mathbf{A_W}}{\sum \mathbf{A_N}}, \text{where } \mathbf{A_N} = \frac{\mathbf{P_N}}{\mathbf{Y_N}} \text{ and } \mathbf{A_W} = \frac{\mathbf{P_N}}{\mathbf{Y_W}}, \tag{1}$$

where

- $\mathbf{YF_N^L}$ is Yield factor for a given country and land use type, wha $nha^{-1}$
- $\mathbf{A_N}$ is Area harvested for a given quantity of product in a given country, $nha^{-1}$
- $\mathbf{A_W}$ is Area that would be required to produce a given quantity of product using world average land, wha-1
- $\mathbf{P_N}$ is Amount of given product extracted, or waste generated in a country, t $yr^{-1}$
- $\mathbf{Y_N}$ is National yield for product extraction, t $nha^{-1}$ $yr^{-1}$
- $\mathbf{Y_W}$ is World-average yield for product extraction, t $wha^{-1}$ $yr^{-1}$

Table 1: Cropland yield factors equal to built-up land yield factor in Alexandria 2005–2017. *(Source: Researchers, 2019.)*

| Year | Built-up land's yield factor of Alexandria wha/nha |
|---|---|
| 2005 | 5.95369 wha/nha |
| 2010 | 3.77956 wha/nha |
| 2012 | 3.04384 wha/nha |
| 2015 | 4.03704 wha/nha |
| 2017 | 6.05597 wha/nha |

Equivalence factors (EQF) are described as "The average global potential productivity of certain productive areas and are used to normalize different land types so that the results can be grouped into one unit (global hectare)". Variable EQFs are obtained from World wildlife Fund; Living Planet (WWF) reports [20], and National Footprint Accountings (NFAs) reports [21] are widely utilized in this study, so that the outcomes can be comparable. The Equivalence Factor is a constant number for all the countries globally, but it changes slightly from year to year [22]. A time series of equivalence factors from 2005 to 2017 are shown in Table 2.

Table 2: Equivalence factor for the built-up land in Alexandria 2005–2017. *(Source: NFA Report [21] and Living Planet Report [20], 2005–2017.)*

| Year | Equivalence factor | Source |
|---|---|---|
| 2005 | 2.39 | NFA and WWF reports, 2005 |
| 2010 | 2.43 | NFA report, 2010 |
| 2012 | 2.46 | NFA report, 2012 |
| 2015 | 2.51 | NFA report, 2015 |
| 2017 | 2.56 | NFA report, 2017 |

2.3.2 Built-up land Footprint (EFBuilt-up land)

The built-up land footprint is defined as “The area of land covered by human infrastructure such as transportation, housing, industrial structures, and reservoirs for hydropower”. Monfreda et al. [18] supposes that the $EF_{Built\text{-}up\ land}$ converted from fertile cropland areas. Within the Settlements zone, some are paved; whereas other zones stay as bio-productive region like gardens or parks [23]. Consequently, the built-up area ($A_{Built\text{-}up\ land}$) is equal to the same value of cropland because it substitutes and is revealed for productivity as it is utilizing the $YF_{Cropland}$ in measuring the $EF_{Built\text{-}up\ land}$ as shown in eqn (2) [16].

$$\mathbf{ef_{built-up}(gha)} = \frac{\mathbf{A\ (ha)\times EQF\left(\frac{gha}{ha}\right)\times YF}}{\mathbf{N}}, \quad (2)$$

where

- $\mathbf{ef_{built\text{-}up}}$ is the Ecological Footprint of built-up in global hectare per capita
- **A** is the area of the built-up land in hectare
- **EQF** is the equivalence factor of the built-up land in global hectare per hectare
- **YF** is the yield factor of built-up which is equal to the yield factor of the cropland
- **N** is the number of population in the city

2.4 Measurement of Bio-capacity (BC)

When measuring the Bio-capacity (BC) of a given land use type, it is regular to allot 12% of accessible supply land to secure domestic biodiversity. The aggregate of BC of a given city can be measured by the following eqn (3), calculation of BC is used for five land types only that are fishing grounds, Forest land, cropland, built-up land, and grazing land [16]–[23].

$$\mathbf{BC} = \frac{\mathbf{A\times EQF\times YF\times(100-12)\%}}{\mathbf{N}}, \quad (3)$$

where

- **BC** is the total bio-capacity of a given land type
- **A** is the total available supply in a given year for the j type of land
- **EQF** is the Equivalence Factor of a given land type
- **YF** is the Yield Factor of a given land type
- **N** is the Number of Population

2.5 Ecological Deficit/Reserve

An Ecological Deficit/Reserve ($EF_{D\ or\ R}$) is measured by subtracting the EF from BC to decide in case there is an $EF_D$ or $EF_R$ as shown in eqn (4). If EF surpasses BC, an $EF_D$ exists, and the framework is considered unsustainable. Alternately, in case BC surpasses EF, an $EF_R$ exists, at that point such a framework is considered sustainable [16]

$$\mathbf{EF_D = EF - BC}, \quad (4)$$

where

- $\mathbf{EF_D}$ is the ecological deficit
- **EF** is the ecological footprint by consumption categories
- **BC** is the bio-capacity by bio-productive areas, where EF > BC, $EF_D$ exists unsustainable, while EF < BC, $EF_D$ does not exist, sustainable

## 3 RESULTS AND DISCUSSION

### 3.1 The total Ecological Footprints (EFBuilt-up land) and bio-capacities (BCBuilt-up land) for the built-up land component of Alexandria for the period of 2005–2017

The difference between $EF_{Built\text{-}up\ land}$, $BC_{Built\text{-}up\ land}$, and $EF_D$, demonstrates the "ecological balance" of the study framework, that can at that point be utilized to recognize to what extent the local ecological can back up the local activities. Fig. 2 displays the $EF_{Built\text{-}up\ land}$, $BC_{Built\text{-}up\ land}$, and $EF_{D\ (Built\text{-}up\ land)}$ for Alexandria from 2005 to 2017.

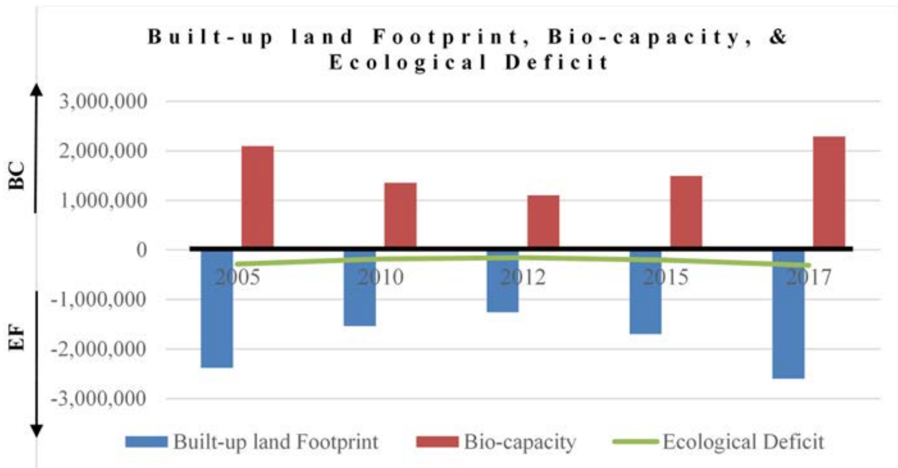


Figure 2: EFBuilt-up land, BCBuilt-up land, and EFD (Built-up land) in Alexandria City for the period of 2005–2017 (unit: 1000000 gha). *(Source: Researchers, 2019.)*

The total Ecological Footprint for the built-up land ($EF_{Built\text{-}up\ land}$) in Alexandria was increased rapidly from 2,382,645 global hectares (gha) in 2005 to 2,599,304 gha in 2017 as a result of 12 years' rapid growth, but the $EF_{Built\text{-}up\ land}$ improved between the period of 2010 till 2015 due to the decrease of $EF_{Built\text{-}up\ land}$ from 2010 which is 1,539,014 to 1,257,128 gha in 2012. Even though, improvement of $EF_{Built\text{-}up\ land}$ was observed within these two years due to the decrease of bio-capacity for the built-up land, then it starts to increase continuously since 2015 which is 1,699,024 gha till 2017. Meanwhile, the total bio-capacity for the built-up land ($BC_{Built\text{-}up\ land}$) was 2,096,727 gha in 2005, increasing to 2,287,387 gha in 2017, resulting in ecological deficit ($EF_D$) of 285,918 gha in 2005 and 311,917 gha in 2017 as the $BC_{Built\text{-}up\ land}$ is changed from year to year because of the different variables of the city's populations, Yield Factor and Equivalence Factor. However, the $BC_{Built\text{-}up\ land}$ in 2010 decreased from 1,354,332 gha to 1,102,645 gha in 2012 and then it is increased in 2015 to 1,1495,141 gha continuously till 2017 due to the decrease of Yield Factor between 2010 till 2015 that means the local productivity is decreased (unstable). The $EF_{Built\text{-}up\ land}$ for Alexandria (2,599,304 gha) is higher than the world average which is about (1,778,033 gha) in 2017 (NFA, 2017) [21], that means we will need more bio-productive areas to supply more resources. In order to have an increased BCBuilt-up land for Alexandria, Yield factor ought to be increased.

### 3.2 Per capita Ecological Footprint (EFBuilt-up land) assessment for the built-up land in Alexandria

After measuring the total built-up land footprint, the researchers also calculated the built-up land footprint per capita to know human needs for the built-up land and whether it exceeds its bio-capacity. The population of Alexandria will increase in the future and so, the city cannot absorb the expected population increase of 8.9 million in 2050, therefore, it needs other ecological systems to solve this issue.

Table 3 puts the final outcomes of per capita $EF_{Built\text{-}up\ land}$, $BC_{Built\text{-}up\ land}$, and $EF_{D\ (Built\text{-}up\ land)}$ for the built-up land in Alexandria for the period of 2005–2017. Fig. 3 displays the different values of per capita $EF_{Built\text{-}up\ land}$ through the years. For Alexandria, the per capita $EF_{Built\text{-}up\ land}$ decreased from 0.61791 cap/gha in 2005 to 0.50189 cap/gha in 2017, with a decrease rate of 11.602%. But, that does not mean the $EF_{Built\text{-}up\ land}$ is improving which the per capita $EF_{Built\text{-}up\ land}$ starts to increase continuously since 2015 till 2017, even though there was an improvement happened from 2010 to 2015 due to the decrease of $EF_{Built\text{-}up\ land}$ from 0.61791 cap/gha in 2005 to 0.34994 cap/gha in 2010. It has decreased the double a result of 5 years' extension of urbanization till reached to 0.35009 cap/gha in 2015 from that time, the raising of per capita $EF_{Built\text{-}up\ land}$ due to land encroachment and demolition of buildings within the living space in Alexandria. Consequently, a great disparity exists in Alexandria for the period of 2005–2017.

Table 3: Per capita of EFBuilt-up land, BCBuilt-up land, and EFD (Built-up land) of Alexandria in 2005–2017 (unit: global hectare). *(Source: Researchers, 2019.)*

| Years | Ecological footprint | Bio-capacity | Ecological deficit |
|---|---|---|---|
| 2005 | 0.61791 cap/gha | 0.54376 cap/gha | 0.07415 |
| 2010 | 0.34994 cap/gha | 0.30795 cap/gha | 0.04199 |
| 2012 | 0.27539 cap/gha | 0.24154 cap/gha | 0.03385 |
| 2015 | 0.35009 cap/gha | 0.30808 cap/gha | 0.04201 |
| 2017 | 0.50189 cap/gha | 0.44166 cap/gha | 0.06023 |

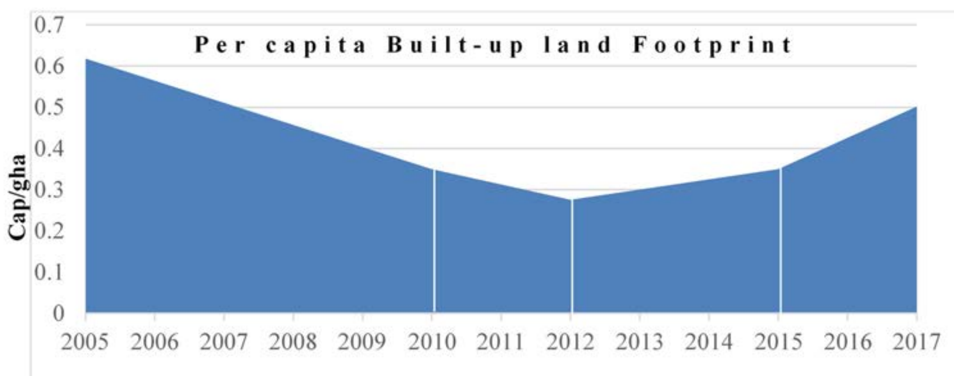


Figure 3: Per capita EFBuilt-up land of Alexandria in 2005–2017 (unit: gha/cap). *(Source: Researchers, 2019.)*

As such, per capita $BC_{Built\text{-}up\ land}$ in Alexandria is also different, and Fig. 4 shows the detailed results between the different periods. The per capita bio-capacity for the built-up land in Alexandria decreased from 0.54376 cap/gha in 2005 to 0.44166 cap/gha in 2017, with a decrease rate of 10.21%. Such a smaller value is mainly due to the fact that Alexandria has much smaller urbanized areas but with a higher population density. With such values, the per capita ecological deficit for the built-up land in Alexandria decreased from 0.07415 cap/gha in 2005 to 0.04199 cap/gha in 2010, but $EF_D$ increased from 2015 (about 0.04201 cap/ha) to 0.06023 cap/ha in 2017, indicating that on average person living in Alexandria demands 2.5 times more bio-productive built-up land areas to support his/her urban life. It also reflects a clear difference through the years in terms of living standards, urbanization rate, and industrial development levels.

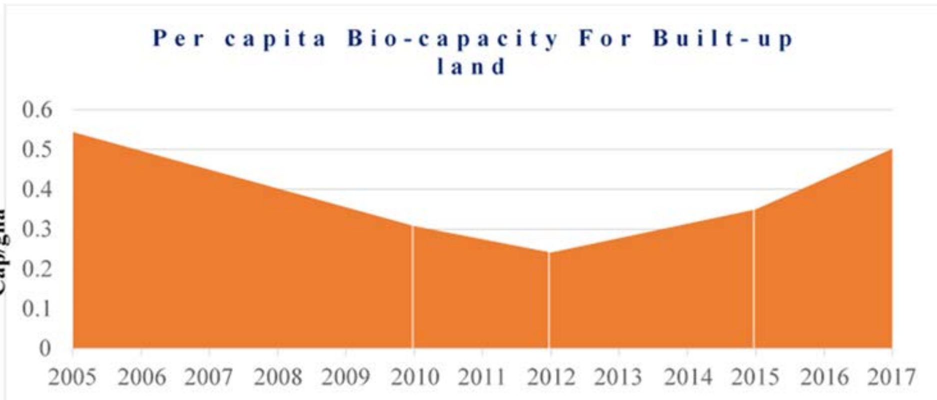


Figure 4: Per capita BCBuilt-up land of Alexandria in 2005–2017 (unit: gha/cap). *(Source: Researchers, 2019.)*

In conclusion, Alexandria is considered as an unsustainable city according to the results of this research, because the Ecological Footprint for the built-up land is still exceeding the Bio-capacity even it seems from the studies and measurements that the built-up land Footprint becomes better but still there is an Ecological deficit of 12% through the years.

### 3.3 Discussion

The research outcomes show an obvious disparity in $EF_{Built\text{-}up\ land}$ during the years, that require a supplementary discussion for illustrating some concerning parts. First, Alexandria differs in both the demand for (EF) and supply of consumption resources during the time, driving to different $EF_{Built\text{-}up\ land}$. Second, the area of built-up land in Alexandria city (km$^2$ with a total population of 5.1 million inhabitants) indicates to the both urbanized areas and rural areas, that sets up the research limits, whereas actually, the real area of built-up land in Alexandria is about (1900 km$^2$ with a population of 5.2 million inhabitants) (see Fig. 5) [24].

This can be considered as a limitation, as the study totally relies on official data for the calculations in the absence of statistical data for the urbanized Alexandria. Though, researchers ratify that the research outcomes can still give worthy insights. Fig. 5 shows different maps through GIS illustrating the built-up land area extension to Alexandria through the following years: 1987, 2000, and 2017 [24].

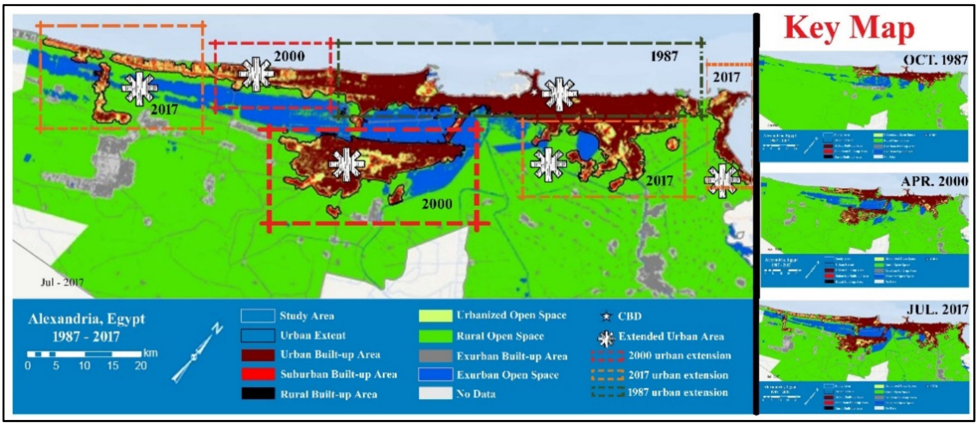


Figure 5: GIS Maps of Alexandria, showing the built-up land area extension over the time. *(Source: Atlas, 2019 [24].)*

Alexandria is developing rapidly, incorporating a big exploitation in its infrastructure, industrial work and gregarious revival, driving to a rapid increase in its $EF_{\text{Built-up land}}$. In this consideration, analysis through different years gave a better and comprehensive picture of the diverse improvement pathway, thus realizing the gap and facilitating the development of appropriate policies for the future. Although the total $A_{\text{Built-up land}}$ remains unstable, due to the huge population, the size of $EF_{\text{Built-up land}}$ is still larger since from 2005 to 2017, due to its early urban progress and a great gap between different time-series.

However, per capita $EF_{\text{Built-up land}}$ in 2017 at about 0.50189 cap/gha is already higher than the world average (0.061 gha/cap) [20], and this indicates that citizens consume more area of built-up land than its bio-capacity. Consequently, authorities in Alexandria ought to consider how to minimize the inhabitant's demands on consumption resources. Alexandria should focus more on the next course of development and cannot use such an excuse (low per capita $EF_{\text{Built-up land}}$) to disclose its responsibility. The technique interprets the production and consumption of various species resources into a common unit area, thus providing a genuine measurement of the BC and the EF so that an obvious layout of human influence on Earth can be given.

## 4 CONCLUSIONS

With quick urbanization, cities are getting to be the most contamination sources due to human needs. Scientific assessment of EFA can give worthy insights to decision-makers so that unsustainable evolution patterns can be identified, and convenient policies can be raised by considering local realities. This study fills the gap of research by using a case study area in Alexandria city, Egypt. The data has been collected for the different years so that their development pathways can be revealed. The comparing of $EF_{\text{Built-up land}}$ and $BC_{\text{Built-up land}}$ accounts through the different time-series can assist in recognizing the main elements impacting the sustainability of Alexandria city in case of settlements.

The findings of Alexandria display a high total $EF_{\text{Built-up land}}$ in comparing to its $BC_{\text{Built-up land}}$ during the years. Whereas, the per capita figures in Alexandria is much low, referring that a gap between the different years still exist. To improve its sustainable development, Alexandria must collaborate with similar cities and learn from the experiences of certain eco-cities and other environmental management expertise so that it can proceed across a more sustainable trend. Such an ecological cooperation via two similar cities may moreover give a great paradigm for other sister-cities via the two nations so that more cities can avail from their potential ecological cooperation. More scholarly endeavours ought to be made in arrange to overcome these challenges. For example, it is suggested an altered strategy by integrating "Emergy analysis" with traditional "Ecological Footprint" format of measurements [8]. Overall, there is no single assessment strategy can show all measurements of urban sustainability. Subsequently, it may be essential to advance coordinated/EFA for the built-up land with other assessment strategies so that more wide sustainable viewpoints can be tended for encouraging the convenient decision-makings.

In summary, Alexandria city needs huge bio-productive built-up land than it holds in order to back up its urban activities. The $EF_D$ in Alexandria is still grew from 2005 to 2017, referring to a rapid-urban evolution and local ecological degradation. It is recommended that the bio-productive built-up land area is to be increased which might be at odds with the future vision of the planned 2050. Therefore, decision-makers need to improve future plans and increase the bio-productive land (Built-up land) to reduce the $EF_D$.

Urban planners already are working on vision 2050, struggling with the expected increasing population growth. The decision-makers made a proposal for 2050. creating five new administrative districts, extended to Alexandria under the name of "GREATER ALEXANDRIA" [25]. Hence, this research is timely, to measure the total ecological footprint for the six types of bio-productive lands to assess the sustainability for supporting the vision 2050 and show the demands and supplies for built-up land.

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