Six decades of urban growth using remote sensing and GIS in the city of Bandar Abbas, Iran

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Abstract. Bandar Abbas is the capital city of Hormozgan province, is the south of Iran. The city has witnessed rapid growth in the last three decades, mostly because of its economic, commercial and social attractions. However, forms and operations of urban sprawl may vary in important manners according to determine geographical and historical characteristics, and these difference need to be reviewed with creation geodatabase of spatial and attribute data during past periods until now of urban formation and expansion. We implemented this research to understand Bandar Abbas city growth dynamic during last six decades using aerial photo, Remote Sensing (RS) data and Geographical Information System (GIS), to investigate its sprawl for the during six decades and to prepare a basis for urban planning and management. We calibrated it with geospatial data derived from a time series of aerial photos and satellite images. Treated remote sensing data covering the six decades were used to calculate land use/cover and urban growth. The application of classification techniques to the remote sensing data enabled the extraction of eight main types of land use: agricultural, barren, coastal, hole, river, rocky hill, urban, and built-up. Growth was calculated through Shannon’s entropy model. The urbanized area increased from 403.77 ha to 4959.59 ha from 1956 to 2012, a rate almost five times that of the population growth observed in the same period. Such findings make the case of Bandar Abbas important for several reasons. First, Bandar Abbas has undergone a rapid increase in urban sprawl according to urban growth indicators. Second, the urban sprawl quickly grew from medium-sized to large a process considered inappropriate according to physical and structural limitations on urban growth. Lastly, the excessive extension of the built-up boundary in the city resulted in the loss of coastal land and open space, two main sources of tourist attraction and economic sustainable development.

1. Introduction

Today, urban sprawl is introduced as one of the urban development processes. The event of urban development is comprehensive and general process and has a wide range of concepts. The urban development process should be discussed based on its history and effective factors such as social and economic factors over time. During the past two centuries, we have been witnessing the expansion of large cities and the growth of the space under their spatial influence. This process in many countries has been this way: the change in the model of life of residents caused new urban areas. Nowadays, a wide section of people live on the margins of cities, towns, and residential areas adjacent to cities. The people who live adjacent to the urban areas are completely under the influence of urban life styles, values, and expectations. In fact, urban centers are considered as center for the employment of non-agricultural activities and include employment activities such as industry and services. Also, the cities have been regarded over time as the centers of cultural, social, and intellectual development. Urban development is a process brought about by the emergence of a world dominated by cities and urban values. Here, it is very important that to distinguish between two main processes of urban development including: the sprawl of the city and urban growth [4].
Urban sprawl is the shape of land use representing low levels of eight separate dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity. Density is the average number of residential units per square mile of developable land in an urban region. Continuity is the degree to which developable land has been built upon at urban densities in a continuous style. Concentration is the degree to which development is positioned disproportionately in a few square miles of the total urban area rather than spread evenly. Clustering is the degree to which development has been firmly bunched to minimize the amount of land in each mile of developable land occupied for residential or nonresidential use. Centrality is the degree to which residential or nonresidential development (or both) is located near the central business district of an urban area. Nuclearity is the extent to which an urban area is characterized by a mononuclear pattern of development (as opposed to a polynuclear pattern). Mixed uses refer to the degree to which a small area is used for multiple purposes and the degree to which this practice is prevalent throughout a region. Proximity is the degree to which lands used for various purposes are located near each other across an urban region [10]. Given these characteristics, urban sprawl is a hazard to sustainable urban development because it implies growth in the use of land, water, energy, and other resources as well as in the amount of contaminants and waste. Monitoring and forecasting urban sprawl are the basic sources of information required in long-term planning and development. For balanced development, urban authorities need tools to monitor how the land is used, to estimate future demand, and to take steps to guarantee the capability of future supply. For better planning of urban growth and infrastructure, urban authorities need to understand the urban sprawl phenomenon and the directions it may take in years to come.

Conventional surveying and mapping techniques for estimating urban sprawl are costly and time consuming, and the information obtained from them is inaccessible for most urban areas, particularly in undeveloped countries. Consequently, increasing research is directed toward the mapping and monitoring of urban sprawl by using geographic information systems (GIS) and remote sensing techniques [19]. Population growth primarily affects urban sprawl, which is a significant feature of the urbanization process in developed countries, such as the US, China, India, Australia, Canada, and several European countries [9]. Urban sprawl is expanding to countries with large populations and to several developing countries, such as China ([22],[23],[24]), India ([3],[13]), and Turkey [17]. However, the different aspects of and reasons behind urban sprawl are studied still less extensively in the developing world. More examples of how this process occurs in specific areas are needed to discover methods, causes, and insights that improve our understanding of the urbanization process in areas where the process is more important.

This study presents the case of the city of Bandar Abbas in southern Iran. Both Bandar Abbas and Iran as a whole are interesting and relevant cases of explosive urban growth. According to the first Iranian census (in 1956), the number of Iranian cities was 199, and the proportion of the urban population was 31.8% of the total. In 2010, the number of cities had increased to 1200, and the proportion of the urban population exceeded 68.37% of the total ([8],[11]). This study aims to investigate the urban sprawl of Bandar Abbas in the past six decades and to analyze how various features have affected the spatial pattern of this urban sprawl. Section 2 introduces the study area. Section 3 discusses the materials and methods used in generating data through different aerial photos and satellite images. Section 4 considers the correlation between population and urban growth variables. Section 5 discusses and presents more specific land transformation processes. Section 6 concludes the paper and summarizes the observed characteristics of the urban sprawl of Bandar Abbas.

2. Study Area

Bandar Abbas, the capital of Hormozgan Province, is a commercial port city along the southern coast of Iran facing the Persian Gulf. The study area is located at a latitude of 27°8' N to 27°15' N and at a longitude of 56°13' to 56°22'. It has a land area of approximately 100 km² (Figure 1) and includes four
regions and 70 districts. The city occupies a strategic position on the narrow Strait of Hormuz, and it is the site of the main base of the Iranian Navy. Bandar Abbas lies on flat ground with an average altitude of 9 m above sea level. The nearest elevated areas are Geno Mountain 17 km to the north and Pooladi Mountain 16 km northwest of the city. The population of Bandar Abbas was 0.72 million in 2012 and, given the present growth rate, is expected to rise to 0.95 million in 2030. For future urban growth and infrastructure planning, urban authorities need to understand the nature of the urban sprawl in Bandar Abbas, its distribution, and the directions it is likely to take in years to come. The most important economic activities in Bandar Abbas include heavy industries (commercial ports, fishing ports, oil and gas refinery, and other industries), which employ about 74% of the active population. Thus, the city experiences rapid growth to the point that, among Iranian cities with a population larger than 300,000, it has the highest growth in terms of urban land development.

3. Materials and methods

Understanding the dynamic phenomenon of urban sprawl/growth requires the identification of urban sprawl patterns, the computation of landscape criteria, and the analysis of built-up area change. The identification of built-up area change is a fundamental input in urban planning, management, and environmental analysis. The specific aerial photos and satellite images used were obtained from aerial photos (1956, 1965, 1957, 1987, and 2001), Landsat Multi-Spectral Scanner from 1979 (one of the first satellite image acquisitions over Bandar Abbas), Landsat Thematic Mapper from 1990, Landsat ETM+ from 2001, ASTER from 2005, IRS LISS-III from 2008, and GeoEye-1 from 2012, an image captured by a different sensor. Some ancillary data were also used. Three-dimensional digital topographical maps with a scale of 1:2000 were used for image georeferencing; digital elevation modeling (DEM), the basis for the land use/cover map; and the increased accuracy of the overall estimation. These nationwide maps were prepared in 2001 through the photogrammetric processing of 1:2000 scale aerial photographs. Other supporting data included the demographic censuses of Bandar Abbas. All satellite and supporting data used in this study are presented in Table 1 and Figure 2 briefly illustrates the flowchart of entire methodology.

The aerial photos taken of the city of Bandar Abbas, at 5 time periods are vertical and panchromatic. After taking aerial photos, the photogrammetric operations were done for mosaicking of the photos and geo-referencing them in order to extract topographic maps. The geo-referencing of the aerial photos is done by using triangulating operations, benchmark points prepared by the mapping organization, and topographic maps. It’s worth mentioning that geometric corrections required are done during the operation of the photogrammetry on the photos in order to reduce error and increase the accuracy of interpretation. After doing the process of photogrammetry and geo-referencing of aerial photos the stereoscopy of complications and 3D vision are made possible and by using this method, the range of sprawl and growth of cities can be identified and determined.
Table 1. Data used in this study.

| Data                  | Pass&Row | Year | Spatial Resolution/Scale(m) |
|-----------------------|----------|------|-----------------------------|
| **Aerial Photos**     |          |      |                             |
| 56-302                | 1956     | 1:20000 |
| 68-438                | 1965     | 1:5000  |
| 74-665                | 1975     | 1:15000 |
| 88-459                | 1987     | 1:10000 |
| 2793                  | 2001     | 1:10000 |
| **Satellite Images**  |          |      |                             |
| Landsat MSS           | 172/41   | 05-Feb-1979 | 79          |
| Landsat ETM+          | 160/41   | 07-Apr-2001 | 15-30       |
| Aster                 | 2653487  | 17-May-2005 | 15-90       |
| IRS (Panchromatic Band)| 75-52-D | 21-Jul-2008 | 5.8         |
| GeoEye-1              |          | 31-Dec-2012 | 0.5         |
| **Secondary Data**    |          |      |                             |
| 3-D topographic map   |          | 2001 | 1:2000                      |
| DEM                   |          | 2001 | 1m vertical                |
| Iranian Censuses      |          |      |                             |
| 1976–1986–1991–       |          |      |                             |
| UN Iran censuses      |          | 1996–2006 |                         |
| 1995-2025             |          |      |                             |

To convert satellite images the method of nearest-neighbor resampling is used so that the original value of each pixel is maintained with the use of this procedure. The satellite images and various sensors are different in terms of the spatial resolution. The way to solve this problem is to replace the images with high resolution for comparison with the images with low resolution. Topographic maps with scale 1:25000 (prepared by Iran's mapping organization 1987-1989) and 1:500 (prepared by geography organization of the country 2002-2004) are used in order to control and analyze the accuracy of the accuracy of classification of aerial photos and satellite images in the present study. Also, the land use map of Bandar Abbas with a scale of 1:2000 (prepared by the Ministry of Roads and Urbanization Urban Development Master Plan 2004-2006) in order to check the accuracy of aerial photos and satellite images in 2001 and 2012. It should be noted that 1300 sampling points in the city of Bandar Abbas were used to compare the uses of existing situation and increasing the accuracy of the geo-reference of aerial photos and satellite images.

![Figure 2. Flowchart of image analysis.](image-url)

The central point of the city is considered as the central place of growth of city, which is in fact, the initial nucleus of formation of the city of Bandar Abbas located currently in the southwest of the city.
(the big market of city). The drawn circles are concentric and include the entire scope of the study from the center of city (nucleus of formation). Hence, the circles have been drawn in a way which include the regions constructed based on the radius of 500 meters from each other and different geographic directions. This division has been made so that the process of changes in construction in different parts and direction could be statistically compared. It should be noted that the radius of circle must be so large that it include all of urban boundary and constructed lands within it. Essentially, the structure of urban boundary is a dynamic process and greatly changes in different directions by the passing of time. However, in this study, the largest boundary is considered in the last period of time. Thus, the circle drawn is based on the last photo taken related to the GeoEye-1 satellite image in 2012.

Table 2. Assessment of satellite images classification.

| Year | Overall Accuracy (%) | Kappa coefficient |
|------|----------------------|------------------|
| 1979 | 97.59                | 0.94             |
| 2001 | 98.26                | 0.951            |
| 2005 | 97.11                | 0.93             |
| 2008 | 98.12                | 0.89             |
| 2012 | 99.86                | 0.98             |

We use Shannon’s entropy, a method widely applied in studies of urban sprawl. Shannon’s entropy is an indicator of spatial concentration or distribution and can be applied to any geographical variable. The entropy method, another urban sprawl metric, is the most widely used technique for measuring the extent of urban sprawl with the integration of remote sensing and GIS ([2], [3], [12], [13], [14], [19], [23]).

Shannon’s entropy ($H_n$) can be used to measure the degree of spatial concentration or dispersion of a geographical variable ($x_i$) among $n$ zones. Entropy is calculated according to:

$$n = -\sum_{i=1}^{n} P_i \log_e(P_i)$$  \hspace{1cm} (1)

where $P_i$ is the probability or proportion of a phenomenon (variable) occurring in the $i$th zone.

$$P_i = X_i / \sum_k^n X_k$$  \hspace{1cm} (2)

$X_i$ is the observed value of the phenomenon in the $i$th zone. For the purposes of this study, zones are defined as concentric circles around the city center or around a selected intersection of roads [23]. The value of entropy ranges from 0 to $\log_e(n)$. A value of 0 indicates that the distribution of the built-up areas is compact, whereas values close to $\log_e(n)$ indicate that the distribution of built-up areas is dispersed. High values of entropy indicate the occurrence of sprawl. The halfway mark of $\log_e(n)$ is generally considered as the threshold. If the entropy value crosses this threshold, the city is considered to be sprawling. Determining the threshold for this metric is robust and can be considered for any area under study.

For the purposes of the current study, 24 concentric circles and 32 geographic directions were determined, with a radius of 500 m between every two consecutive circles. The center of the circles was the historic district and the main core of the city. A zone was defined as the intersection of the city shape with the ring specified by two consecutive concentric circles. The operation was done in ArcGIS software covering a 10-year urban sprawl of the city (Figure 3).
4. Result and discussion

Data on urban sprawl in 1956, 1965, 1975, 1987, 2001, and 2012 were estimated from data on impervious (built-up) areas captured from aerial photos and satellite images. Map statistics created from remote sensing images show that the built-up area encompassed some 403.77 ha in the first image (1956). In this year, the population density was 43.86 people per ha (Figure 4). As shown in Figure 5, the physical growth and development of Bandar Abbas proceeded around the historical center and the main core in a continuous pattern. However, this tendency changed in the next periods. In the second image (1965), the urban area grew to 753.78 ha and followed an easterly, northerly, and northwesterly direction. Between 1965 and 1987, the growth of urban land increased to 125.45%, with 2914.64 ha of urban land in 1987, more than twice larger than that in the previous image. During this period, population grew by 98.51%. Between 1987 and 2001, the built-up area increased, and the urban spaces filled were the eastern and northern boundaries. The growth in urban land increased to 43.51%, with 4182.88 ha of urban land in 2001 (Table 3 and Figure 7).

| Year | Agricultural Land | Barren Land | Coastal Zone | Hole Land | Military Land | River | Rocky Hills | Urban Land |
|------|-------------------|-------------|--------------|-----------|---------------|-------|-------------|------------|
| 1956 | 155.62            | 2536.59     | 210.96       | 4.71      | 48.13         | 162.43| 2097.24     | 403.77     |
| 1965 | 133.26            | 2232.09     | 192.82       | 6.45      | 49.42         | 153.86| 2122.15     | 753.78     |
| 1975 | 49.94             | 2061.80     | 111.52       | 12.64     | 154.86        | 131.90| 1834.29     | 1292.81    |
| 1987 | 115.35            | 541.45      | 111.33       | 16.64     | 337.93        | 122.59| 1511.96     | 2914.64    |
| 2001 | 30.48             | 237.11      | 101.15       | 9.33      | 340.07        | 109.61| 661.28      | 4182.88    |
| 2012 | 6.92              | 47.46       | 60.31        | 8.65      | 296.63        | 72.05 | 262.16      | 4959.59    |
| Total | -148.70           | -2489.14    | -150.66      | +3.94     | +248.50       | -90.39| -            | 1835.08    |
| Change |                  |             |              |           |               |       |             | +4555.82   |
In the last studied period, Bandar Abbas presented major growth in the built-up area. The increase of urban land between 2000 and 2012 led to the occupation of much of the remaining vacant area by new construction. In 2012, urban uses occupied 4959.59 ha of the land, and the population density increased to 77.27 persons per ha. This expansion shows a chaotic pattern that, among other effects, reduces spatial harmonies [20]. Since 1956, urban sprawl has continued in a disproportionate, dispersed, and leapfrogging manner in addition to rapid growth. In other words, it has followed the classic features of sprawl (Figure 6).

As previously supposed, the analysis of changes in land use/cover through remotely sensed data facilitates the detection of the history of the relationships between human activities and the environment as well as the assessment of possible trends for landscape conversions, thereby creating accurate and multidimensional scenarios for developing environmentally sustainable strategies and management practices [7]. Furthermore, the analysis of the spatiotemporal characteristics of land use/cover change is necessary in the evaluation and understanding of the ecological repercussions of urbanization [6]. The overall accuracy and Kappa coefficient of all the images are presented in Table 2. According to [5], more than 50 samples are required to certify the classification accuracy assessment for each of the classes, which are dispersed across the image in a random stratified pattern. The high accuracy obtained in the present study may be the result of the rough classification, as only eight classes are used. Moreover, the created maps had different classification accuracies because of the different multispectral bands between the images and the differences in ground resolution. Lastly, no thoroughly spatial matching was conducted among the maps. After complete land use/cover maps were created, the complete coverage of the different classes was determined. The results of the changes in land use/cover are shown in Figure 6 and Table 3. The most substantial change was the transformation of barren land to impervious built-up areas. Within the time period of study, 2489.13...
ha of barren land was transformed into urban land use (e.g., residential, commercial, educational, green space, and transportation). The second main change is the conversion of barren land into military land. This change is also a significant deviation from the common direction of land replacement in many countries, in which military land is usually considered a limiting factor in urbanization. In Bandar Abbas, however, about 296.63 ha of barren land was converted for military use between 1965 and 2012. The third major change is the conversion of coastal zones into urban land, affecting some 150 ha. Coastal areas are important to economic development and tourism. Unfortunately, the coastal areas of Bandar Abbas have significantly changed as a result of the increase in growth of urban built-up areas since the 1950s. Irregular urban development in the coastal zones has violated regulations. The lack of adequate supervision and development planning has intensified the problem. Only the easternmost coastal city of Bandar Abbas has a concrete development plan. Other places located to the south and west of the city have been exposed to serious disasters because of irregular construction and the lack of supervision.

Table 4 presents the land-use and land-cover change matrix in the eight categories of land use selected for Bandar Abbas between 1956 and 2012. Urban or built-up land increased by 1028.32% (4152 ha), and military lands surrounding the city increased by 516.30% (248.5 ha). By contrast, barren land decreased by 1.87% (47.46 ha). In these results, the problems related to different pixel sizes were minimized, particularly in the case of the unlikely change of barren land into built-up areas. Based on the data from the maps and tables, urban sprawl is the main cause of the changes in land use in the city. The land-use map of 2006, which is related to the master plan of Bandar Abbas, illustrates that only 68.4% of the land is actively used for residential, commercial, educational, cultural, tourism, and transportation purposes, whereas about 31.6% is undeveloped and vacant [15]. This undeveloped land, nearly one third of the city area, has mostly three uses: vacant land and desolate homes (23.3 %), military land (5.46%), and coastal zone (2.84). These uses circumvent to a certain extent the irregular nature of urban sprawl and the alternative uses of abundant spaces left behind by the urbanization process, such as stores, workshops, and green spaces. Vacant land also offers an opportunity for developing infilling policies.
As discussed earlier, Shannon’s entropy is a well-known and functional method of identifying the growth of urban sprawl [14]. Table 5 show the absolute and relative Shannon’s entropy of Bandar Abbas. The growth of Bandar Abbas cannot be characterized as a complete sprawl because of the significant difference between the calculated absolute Shannon’s entropy and the maximum possible value of log(24), which represents dispersed development. During the study period, Shannon’s entropy established a moderately increasing rate, which indicates that Bandar Abbas grew toward dispersed development or sprawl. The rate of change of the built-up area per capita considerably increased from 1956 to 1987, and the slight increase in 2012 has subsided, indicating that the development has changed from a compact to a dispersed or sprawled pattern (Figure 7). The results present excellent harmonization between Shannon’s entropy and built-up per capita as two fast and simple criteria for assessing growth patterns.

![Figure 7. Changes in built-up area during the past sixty year.](image)

| Year | Absolute Shannon’s entropy | log(24) | Relative Shannon’s entropy |
|------|-----------------------------|---------|---------------------------|
| 1956 | 0.742541332 | 1.380211242 | 0.651245781 |
| 1965 | 0.794124236 | 0.672511408 | |
| 1975 | 0.853845671 | 0.697413781 | |
| 1987 | 0.952147319 | 0.701423211 | |
| 2001 | 0.970421045 | 0.714589453 | |
| 2012 | 0.996340724 | 0.723251987 | |

Table 5. Calculated values for absolute and relative Shannon’s entropy.
5. Conclusion

This study examined the urban sprawl of Bandar Abbas, one of the most important tourism, industrial, and commercial centers in southern Iran. Remote sensing and GIS techniques were used to monitor the dynamic phenomenon of sprawl with the help of aerial photos, satellite images, and census data. Bandar Abbas is a medium-sized city to the south of Iran that has experienced rapid urban sprawl since the mid-1970s. Since then, the physical size of the city has increased every 10 years or so. In particular, between 1987 and 2001, the new urban area added to Bandar Abbas was as large as the entire urban area developed in more than 2500 years of its history. As in many cities in developing countries, the sprawl in Bandar Abbas occurs in disorderly and unplanned patterns, influenced by the proximity of highways, towns, and villages and the differences in communication networks, industrial locations, and land rents. Moreover, irregular rapid and unplanned sprawl produces important problems, such as lack of security, sufficient service, and facilities for residents; lack of public transport systems; increase in commuting length; increase in energy consumption; and increase in air pollution. Lastly, the irregular sprawl of the urban area entails the loss of coastal tourism attractions, a factor that hinders economic growth and minimizes employment opportunities. As previously discussed, the total growth rates of the city and of its population from 1956 to 2012 are similar. Thus, based on the classification of sprawl proposed by [1], the growth of Bandar Abbas cannot be considered as a classic model of sprawl growth. Instead, if the study period is divided into smaller periods, the period between 1986 and 2001 clearly emerges as the period during which Bandar Abbas experienced sprawl accompanied with the conversion of large plots of coastal zone, barren land, and rocky hills into built-up areas. This pattern of growth is also supported by calculations of Shannon’s entropy, a functional method for identifying sprawl. The cases presented in this paper may instead be interpreted as presaging a possible sprawl in the future.

On methodological grounds, this study strengthens the high value of remote sensing in urban studies and environmental monitoring. Although many studies on a global scale have used aerial photos, satellite images, and remote sensing in the study of urban sprawl, few have studied Iranian cities ([16], [21], [18]). In light of the increase of urbanization and population growth and the decrease of suitable land for urban sprawl, the importance of the study of built-up area change and the preparation of development plans based on remote sensing and geospatial data is crucial for other cities in Iran, as well as other cities around the world, facing the threat of limited land for development.

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