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Quantitative analysis of urban sprawl in Al-Baydah city - Libya, using GIS and remote sensing techniques

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Abstract

Determining the spatio-temporal manners of urban sprawl is considered one of the most influential challenges in evaluating the present and future directions of the urban expansion issue. Random growth is considered as a kind of meeting the needs of the human being and expressing the achievement of its basic requirements when the state is unable to solve them. This paper aims to assess the sprawl and growth dynamics between 2010 and 2020 in Al-Baydah City, Libya using remote sensing and GIS techniques. Three Landsat TM, ETM+, and OLI images dated 2010, 2015, and 2020 were used to generate urban maps of the research area. The chi-square test and urban expansion intensity index (UEI) were used to assess urban growth patterns in the study zone. The results of the study confirmed that urban growth in the city has increased from 17.7 km2 in 2010 to 35.9 km2 in 2020, indicating that the city's expanding intensity index has risen as well. The results displayed that Al-Baydah city has unbalanced urban growth and its urban development had a high freedom degree during the period from 2010 to 2020.

Keywords: Urban expansion, Informal settlement, Expected growth, Built-up area.

Introduction

The phenomenon of informal settlements is a global issue around the world. However, the causes and patterns may vary from country to country where random growth is considered as a kind of meeting the needs of the human being and expressing the achievement of its basic requirements when the state is unable to solve (Hansen, 2010). Random growth is only a kind of self-solutions that is taken by a citizen to find a solution to the housing and economic problems he faces. (UN-HABITAT, 2010). Informal settlements take many forms, varying according to the environments in which they were raised. Despite the negatives they suffer, they have the positives that provide a great opportunity to deal with these areas, especially if we consider the human dimension as the basis (Jaeger, 2010) .

Informal settlements are ever-changing, movable, and a regular challenge. The residents in that settlements doing in ways that are deleterious to the environment, and have a massive impact on it (UNECE, 2008). The challenge of informal settlements must be addressed, resulting in the environment regaining stability again and reducing the impacts of human settlements (Ziningi, 2017). There are several definitions of informal settlements. The most well-known definition is that they are areas where inhabitants face a lack of one or more of the following: durable housing, sufficient living spaces, easy access to clean water, adequate sanitation, and security of ownership. They also differ in size, shape, pattern, and population (UN-HABITAT, 2003). The environmental impacts of informal settlements include soil erosion, as well as water, land, and air pollution. Studies have shown that informal settlements are a challenge to the environment, such as deforestation to have space for settlement development, lack of both sewage and water supply systems, in addition to waste disposal within slums, which led to air, water, and soil pollution (Pearsall and Christman, 2012). Environmental risks often occur in informal settlements. We constantly find that living in these areas threatens the quality of life as there are no available alternative options (Chadha Behera et al. 2007). Geographic Information System (GIS) is now widely used to study, monitor, and model urban growth and land use. GIS tools can be used to find, map, and evaluate physical changes and patterns of urban growth across landscapes. GIS can also be used to give a future picture of the spatial pattern of unplanned development within an area, in addition to linking interrelationships between the social and geophysical characteristics of informal settlements, and to help in project modeling (Kombe, 2005). GIS helps authorities, urban planners, and other stakeholders in their proactive management by monitoring the spatial dynamics of informal settlements of the current and future expansion of informal settlements (Musa, 2020).

In Libya, the phenomenon of informal settlements growth outside the urban plans of cities is one of the challenges facing the urban plans. It takes in its concept and forms a different form from the general concept of these areas, as it has not appeared only in the past years when its spread increased significantly and very fast in comparison to some other developing countries. It is known as the growth that occurs outside the approved urban plans, while the growth within the plans was defined as opposite growth (Libya Ministry of Housing, 2016). Libya is not an exception to this phenomenon due to the rapid population and economic growth, resulting in increased demand for land for both population and economy. Rapid urban growth has become a complex environmental issue due to the multiplicity of its patterns. The different causes and the impact on the ecosystem understanding spatial patterns of growth urban is one of the most important challenges for researchers, planners, and decision-makers to realize the principle of urban development sustainable (Mustafa et al., 2020). Alhaddad (2017) said, administrative reasons, such as poor planning and organization that resulted in a lack of residential schemes, contributed to the emergence of social and physical motivations to take over the lands, in addition to economic motivations that took advantage of the scarcity of housing schemes and the high rate of housing shortage, are also among the causes. All of these factors, as well as a failure to enforce urban rules and regulations, are to blame for urban sprawl in the Al-Jabal Al-Akhdar region.

The main aim of this paper is to assess the sprawl and growth dynamics during the period from 2010 to 2020 in Al-Baydah City, Libya using remote sensing and GIS techniques.

Materials and methods

Study area

Al-Baydah city is located in the Al-Jabal Al-Akhdar plateau in northeastern Libya (Fig. 1), with an altitude of about 624 m above sea level between longitude 32.76° E and Latitude 21.44° N. It is surrounded by pine forests, cypresses, and agricultural lands (Al-Mukhtar U, 2005). It was founded in the past in 414 BC, under the name of the Greek town of Blagrae. Al-Baydah is now the capital of the Al-Jabal Al-Akhdar region and its largest city and main administrative center, with a population of 209.978 people in 2012(Bureau Statistics census Libya, 2012). Al - Jabal Al - Akhdar region constitutes 1% of the area of Libya, contains 75% of the biodiversity, and 1100 plants of the species registered in Libya (Libyan

Environment General Authority, 2010). The climate of the study area, in general, is the Mediterranean climate, which is warm, rainy in winter, hot, and dry in summer, and the prevailing winds are from north to northwest in winter, northeast, and sometimes southern in summer. In this mountain station, the mean annual temperature is about 16.5°C. The mean monthly temperature ranges between 15°C in April and 23.6°C in July (the warmest month of the year) and decreases to 9°C and 10°C in January and February, respectively throughout 1985- 2019. Al-Baydah station received the highest rainfall in northeast Libya during the period at 563 mm yr^{-1}, whereas rainfall ranged between 53 mm in October to 123 mm in January. Overall, the diversity of natural factors in Al Jabal Al-Akhdar, such as elevation, landforms, and location next to the sea and natural vegetation, have led to differences in temperature and rainfall across the region (Ageena, 2010; Bukhechiem, 2006). However, the differences are minor between the coastal stations and the mountain stations.

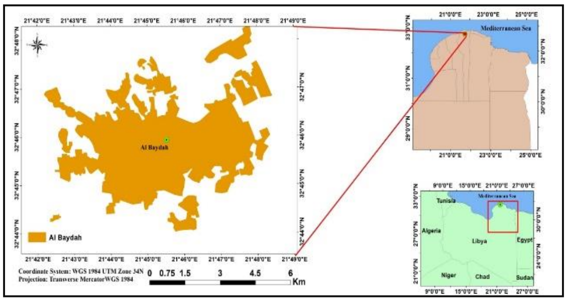

Figure (1): Location map of the study area

Methodology

To achieve the aim of this study, three Landsat TM, ETM+, OLI images obtained during the period from 2010 and 2020 were used with a spatial resolution of 30 m. The images were downloaded from http://reverb.echo.nasa.gov/reverb. Landsat images were atmospherically corrected using the FLAASH model based on the MODTRAN radioactive transfer code. The images were processed using ArcMap 10.2. The study area was divided into eight geographic directions to estimate urban sprawl direction. The maximum likelihood supervised classification technique was utilized to classify the images and extract the built-up regions. The high-resolution images supplied by Google Earth™ were used to enhance the accuracy of the classified images. Pearson's chi-square technique and urban expansion intensity index was utilized to compute the urban expansions.

Satellite data used in the present study is displayed in Table 1.

Table (1): Satellite images data

Satellite	Acquisition date	resolution	Cloud %
Landsat 5 TM	12-08 2010	30-60 m	4
Landsat 7 ETM+	25-07-2015	30 m	0
Landsat 8 OLI, TIRS	8-09-2020	30 m	0

To compared the observed urban growth with theoretically anticipated urban growth using the following equation:

$$M\,ij^{E} = (M_i^{s} \times M_j^{s}) \div M_g$$

where: Mi^{S}; row total, Mj^{S}; column total, Mg ; grand total.

To calculate the degree of freedom of urban expansion for the study area using the following equation:

$$D = \frac{(\,observed\ growth - expected\ growth)2}{expectedgrowth}$$

The UEII for study area is calculated using the following equation:

$$UEIit = \frac{\left[\frac{ULAi,b\ -\ ULAi,a}{t}\right]}{TLAi} * 100$$

Where, $UEIit$ shows the annual average expansion intensity index of spatial direction during the specific time t; $ULAi,a$ and $ULAi,b$ show the starting and ending the built-up area of spatial direction; $TLAi$ show the total land area of spatial direction.

(Al-Sharif et al. 2014; Faraj & Mohamed, 2020; Mustafa et al., 2020; Punia, 2012; Ren et al., 2013).

Results and discussion

According to the findings of this research, urban growth in Al-Baydah city expanded from 17.707 km^2 in 2010 to 35.952 km^2 in 2020, as shown in Table (2) Figures 2&3. It was observed that urban growth has increased rapidly during the period from 2010 to 2020. This is since Al-Baydah city is considered the headquarters of the largest municipalities of Al-Jabal Al-Akhdar, and is close to services and commercial activities, and others. This rapid increase in the built-up area, including residential, commercial, industrial, and network infrastructure, results from population and commercial growth in the city. The long periods of unstable conditions pushed the population to search for cheap and suitable land for construction outside the approved city plans, which greatly contributed to the worsening of the problem of uncontrolled urban growth or what is known as urban sprawl. As it becomes clear to us by dividing the area into multiple geographical directions, the north and east zones were the highest in terms of urban growth Because it is close to the City Business District (CBD), followed by the northeast and Southwest zones Because the land there is cheap.

Table (2): Built-up areas in Al-Baydah city in different directions and times, km^2

Directions/ years	N	NE	E	SE	S	SW	W	NW	Total
2010	2.136	2.687	1.851	2.314	1.145	3.674	1.670	2.230	17.707
2015	3.244	3.445	2.479	2.326	1.163	3.954	1.665	2.965	21.241
2020	6.945	6.247	6.539	3.362	3.698	5.181	2.643	4.371	35.952

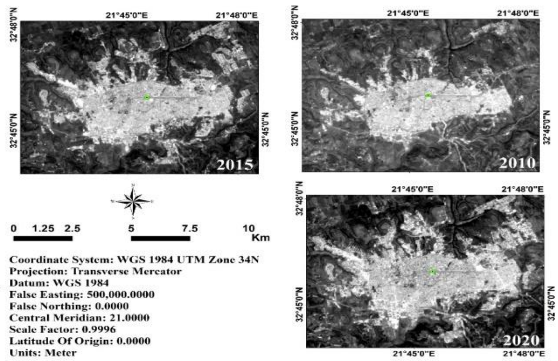

Figure (2): Satellite image scenes of Built-up areas growth in Al-Baydah city (2010-2020)

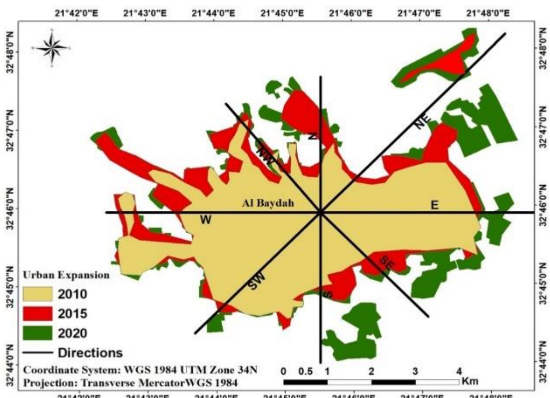

Figure (3): Division of the urban area based on the approach of spatial direction AL Baydah City

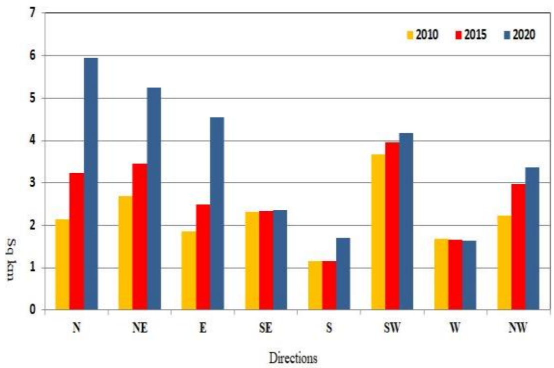

Figure (4): Comparison built up based on the approach of spatial direction (Al-baydah city)

Observed and expected of built-up area growth

As shown in Table (3), the largest increase in urban expansion was in the direction of the east, south, southeast, and northeast, and the expansion almost stopped in the direction of the west, north and northwest due to the presence of the archaeological area. In general, the increase in urban expansion for the period 2015 - 2020 was more significant than in the period 2010 – 2015; this confirms the steady growth of the phenomenon, its negative impact on agricultural lands, surrounding forests, and negative environmental influences.

Table (3): The observed growth of the built-up areas in Al-baydah city in different directions and periods (km^2)

Directions / Years	N	NE	E	SE	S	SW	W	NW	Total
2010 -2015	3.110	1.760	1.630	1.010	1.018	2.280	1.995	1.735	14.538
2015 -2020	2.701	1.802	2.060	0.036	2.535	0.227	1.978	0.406	11.745
	5.811	3.562	3.690	1.046	3.553	2.507	3.973	2.141	26.283

Table (4): The theoretically expected growth of urban expansion in Al-Baydah city in different directions and periods (km^2).

Directions / Years	N	NE	E	SE	S	SW	W	NW	Total
2010 -2015	3.214	1.970	2.041	0.579	1.965	1.387	2.197	1.184	14.537
2015 - 2020	2.597	1.592	1.649	0.467	1. 588	1.120	1.776	0 957	11.746

To comprehend the urban growth deviation, the empirical growth should be compared to the theoretically expected urban growth. The results indicated the statistically estimated theoretical anticipated urban area increase for all zones in each time duration (Table 4). The deviation of urban growth for each part and each period could be calculated by deducting theoretically anticipated growth from observed growth, as displayed in Figure (4). Positive values approved more growth than expectations, while negative values displayed less growth. The conclusions in Table (5) revealed that the empirical urban expansion in several zones (especially at built-up area fringes) varied from the expectations. Also, the variation is persisting, showing urbanization, and growing with time. Those higher deviations demonstrate the independence of the urban expansion. Based on these data, it can be deduced that in the period 2010 to 2020, there is a definite urban sprawl occurring in most zones of the study area.

Table (5) Subtraction of the observed and expected growth in Al-baydah city in different directions and periods (km^2)

Directions / Years	N	NE	E	SE	S	SW	W	NW
2010 -2015	-0.012	-0.376	-0.716	-1.024	1.160	0.161	0.464	0.344
2015 -2020	0.012	0.376	0.716	1.024	1.160	-0.161	-0.464	-0.344

Degree freedom of urban expansion

The chi-square is used to compute the freedom degree for urban expansion, which reflects the sustainability or the unsustainability of growth. The high freedom degree is a sign of the urban growth processes.

In Al-Baydah city, Table (6) revealed that the urban growth in the study was unsustainable during the period from 2010 to 2020. The degree of freedom of the regions is an alert of unbalanced growth within the region in the future. Higher degrees of freedom for a period can be thought of as higher asymmetry between regions in urban growth. However, we cannot conceive of higher freedom degree as sprawl, but we should regard it as a variance in urban growth.

Table (6) degree of freedom of time periods (Al-Baydah city)

Period	Degree of freedom
2010 - 2015	6
2015 - 2020	8

Urban expansion intensity index (UEII)

The UEII represents the potential future direction of urban growth. It examines the rate of urban land-use change, as well as the environmental impacts in different periods. The following are the sections of the UEII standard: Slow development is 0 to 0.28; low-speed development is 0.28 to 0.59; medium-speed development is 0.59-1.05; high-speed development is 1.05-1.92, and extremely high-speed development is >1.92.

Table (7) showed that UEII has reached a score of thirteen. This implies a rapid urban expansion in the research area, confirming the degree of urban growth freedom and indicating that Al-Baydah city urban growth is uneven and unsustainable. The significant increase in UEII gives a warning of the increasing phenomenon of urban sprawl.

Table (7) Urban expansion intensity index (Al-Baydah city)

Period	UEII
2010 - 2015	4
2015 - 2020	9

This study demonstrated that there is a notable urban sprawl in Al-Baydah City, Libya, over the past ten years. The built-up area was the predominant class while the agricultural zone decreased. These changes could be enhanced by a variety of socio-economic, political, demographic, development policies promoted and environmental factors. Tremendous conversion of productive lands to urban areas in the research area. This may include a long-term impact on environmental deterioration, soil degradation, climate change, and economic trouble.

Conclusion

Urban expansion change in Al-Baydah City, Libya was estimated and monitored between 2010 and 2020 by using remote sensing and GIS tools. Rapid urban sprawl has resulted in major changes. The study area witnessed a large urban sprawl that led to the disappearance of large areas of agricultural land in the region, as the urban area developed from 17.707 km^2 in 2010 to 35.952 km^2 in 2020. The degree of freedom indicator indicated that the urban growth in the study is unbalanced or unsustainable between 2010 and 2020. The high increase of UEII gives an alarm to the increasing urban sprawl phenomenon. This study confirmed the urgent need to create sustainable and effective policies to reduce the phenomenon of urban sprawl on agricultural lands, since Libya is characterized by limited agricultural land. Additional research is needed to employ appropriate measures in compliance with research-based planning for future urban growth.

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الملخص العربي

عنوان البحث: التحليل الكمي للزحف العمراني في مدينة البيضاء - ليبيا، باستخدام نظم المعلومات الجغرافية والاستشعار عن بعد

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التوسع العمراني هو ظاهرة مكانية تعكس المستوى المتزايد لأهمية المدن الكبرى. ولدراسة هذه الظاهرة تم اختيار مدينة البيضاء لفحص أنماط نموها العمراني. وقد تم التقاط ثلاث صور عن طريق الأقمار الصناعية لمنطقة الدراسة في تواريخ مختلفة (٢٠١٠ ، ٢٠١٥ و ٢٠٢٠) بدقة تقدر بـ ٣٠ مترًا ، باستخدام تقنيات GIS و RS ، لتوليد خرائط للتوسع العمراني للمدينة. والهدف الرئيسي من هذا العمل هو تحديد التوسع العمراني وتحليله في منطقة البيضاء الحضرية. حيث تم استخدام اختبار درجة الحرية ومؤشر كثافة التوسع الحضري ((UEIIلنصل إلى تقييم التوسعات الحضرية في منطقة الدراسة. وقد أظهرت النتائج أن منطقة البيضاء تشهد نمواً عمرانياً سريعاً جداً ، حيث ارتفعت من ١٧,٧٠٧ كلم مربع عام ٢٠١٠ إلى ٣٥,٩٥٢ كلم مربع عام ٢٠٢٠ ؛ أي أن مؤشر كثافة التوسع الحضري مرتفع، وكان تطورها العمراني بدرجة عالية من الحرية وغير متوازن.