



A remote sensing and GIS-based analysis of urban sprawl in Soran District, Iraqi Kurdistan



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Received: 11 July 2019 / Accepted: 26 November 2019 / Published online: 4 December 2019
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Abstract

Determination of spatial and temporal patterns of urban growth has become one of the most significant challenges in monitoring and assessing current and future trends of the urban growth issue. Soran district has witnessed very rapid growth in the last two decades, mostly because of its economic, commercial and social attractions. The aim of this work is to study the growth and sprawl dynamics through the land use and land cover (LULC) maps for the area at three different periods (1998, 2008, and 2018) particularly in the urban areas employing GIS and RS techniques. Three Landsat images, Enhanced Thematic Mapper plus in the 1998, Thematic Mapper in the 2008 and Landsat Operational Land (LOL) in the 2018 were used to assess the changes of urban encroachment. A supervised classification technique by maximum likelihood classifier has been employed to create a classified image and has been assessed based on Kappa index. The results obtained showed that the urbanized area increased from 4.51 to 14.93 km² from 1998 to 2018. This study demonstrated that the substantial changes in LULC in Soran district since the end of 1990s are directly related to and influenced by the main and secondary roads development on spatial expansion and land use change.

Keywords Urbanization · Socio-political · Municipality · Urban expansion · Riparian zone

1 Introduction

Urban sprawling refers to the growth of urban areas resulting from uncontrolled, uncoordinated and unplanned growth [29]. In most cities around the world, the urban growth phenomena have become unsustainable in many respects [2]. Moreover, urbanization itself is a common concern throughout the world where people leave rural areas and accumulate in major cities [3].

Urbanization either spreads radially around a well-established city or linearly along the highways, which is often referred to as sprawl dispersed development [37]. Normally, a settlement which is controlled by the natural factors including flat area, rivers, and mountains is described as the clustered settlement pattern [30]. Soran

district urbanization pattern can be described as clustered settlement since it is surrounded by rivers and mountains.

Humans have influenced the Earth environment by changing the dynamics of land use/land cover [15]. In the last five decades, human activities around the world negatively affected most of land use land cover (LULC) categories [16]. The land has become scarce because of the enormous agricultural and population pressure [33]. The farmland displacement, urban sprawl, and deforestation, which leads to habitat destruction, loss of arable land, and to the decline of natural greenery areas are characteristics of rapid land cover change [39].

LULC rapid change is attributed to several direct and potential sprawling factors [17]. Direct factors would involve the infrastructure construction, settlement

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expansion, and industry development factors, whereas potential factors include technology, economy, population, policies, wars, and natural factors [9].

On the other hand, another relevant factor that supports growth and development in cities is the transportation infrastructure of primary and secondary road networks [5] that show the spatial structure of population distribution [43]. Consequently, urban expansion and transportation are essentially interrelated [23]. These landscape dynamics can be well understood using multi-temporal satellite imagery for digital change detection techniques [33].

The significance of this work highlights the challenges embedded in the analysis of an urban sprawl in the very rapid development of Soran district in Kurdistan following the 1990–2003 major postwar socio-political upheaval in Iraq, and secondly, it demonstrates that sprawl is a real and measurable phenomenon. Thus, analyzing the sprawl over a period of time through RS and GIS techniques will help in understanding the nature and growth of this phenomenon, which suggests the future directions and patterns of sprawling growth.

Satellite images are significant source for land use/land cover information as they offer rapid, periodic and accurate data acquisition from RS [40] system. Landsat data are widely used in the study of the LULC change. Information on LULC change and urban growth study is essential for urban planners and local governments futuristic plans for sustainable development in any area [38].

One of the most relevant factors that relates to RS is classification. Certain types of algorithms are used to provide suitable classification accuracy [28]. Maximum likelihood classification (MLC), the most commonly supervised method, was used. In this context, the training areas are used in supervised technique [13]. The mapping of LULC can be delineated from fine and coarse resolutions [31].

Landsat TM, ETM+ and LOL [14], Satellite Pour l'Observation de la Terre (SPOT) [11], Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) [1], Ikonos (Pereira and Caetano, [32]), Pleiades [12], Worldview [22], and aerial photographs [20] have been employed in the mapping analysis of land use classes and in the monitoring of their changes.

Soran district has expanded rapidly in the 1990s into a large city. It has gained real importance from 1991 onwards due to its strategic location on a major international commercial route, which resulted in considerable spread with the establishment of new residential and commercial areas. Furthermore, and following the imposition of food and petrol products embargo on Kurdistan region by the former Iraqi regime from October 1991 onwards, almost two-thirds of the United Nations (UN) budget for humanitarian operations in Iraq went to the three northern

governorates: Erbil, Sulaymaniyah and Duhok. Thus, a 'winterization plan' was launched by UN, which involved food and kerosene distribution in these three Northern governorates. It is worth to mention that, the Non-Governmental Organizations (NGOs) such as UNICEF (United Nations Children's Fund), the World Food Program (WFP), and CARE International had a significant role in goods distribution. As a result, these improvements encouraged the refugees to return back [25]. Therefore, Soran district was one of the cities that has enjoyed a period of economic development, enhanced political stability, and a growing local recognition especially after April 9, 2003 or Post-Saddam period [36].

2 Materials and methods

2.1 Study area

Soran district is located in the northeast of Erbil governorate about 100 km from the Erbil city center. It is surrounded by several major mountain ranges, including the mountains of Korek, Handren, Zozk, Hassan Bag, and Bradost. Thus, winter snowfall is common on these mountains. The study area was carried out on the Soran municipality with a geographical coordinates $36^{\circ} 42' 04''$ N to $36^{\circ} 37' 30''$ N latitude and $44^{\circ} 30' 01''$ to $44^{\circ} 34' 30''$ E longitude at an average altitude of 700 m above sea level, covering an administrative area spread over 43 square kilometers (Fig. 1). Soran district is a residential, industrial and agricultural area.

Soran district has hot, dry summers, and cool to cold, damp, humid winters (Soran Iraqi Kurdistan, [35]). The mean monthly temperature recorded in Soran station is

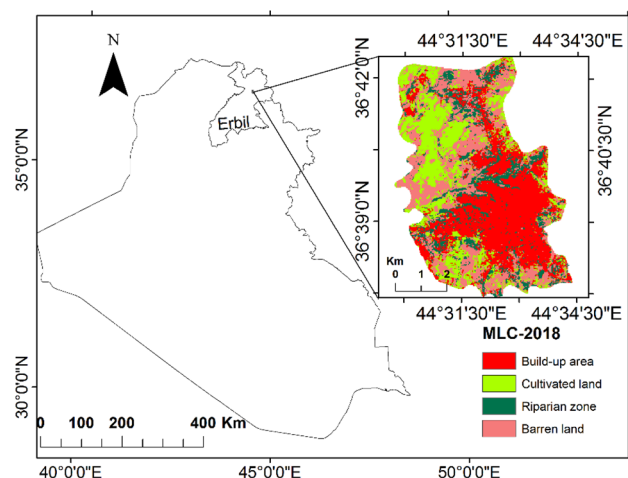


Fig. 1 Location map of Soran district in the Kurdistan Region of Iraq

10 °C in January and 40 °C in July. Precipitation is highly seasonal and peaks during November and April.

Soran city stands as a strong example of explosive urban growth following a major political upheaval and demographic change. Kurdish refugees started to return to Soran district from Iran as early as the 1990s, having fled to Iran between 1974 and 1989 during the second Iraqi–Kurdish War and the Al-Anfal Campaign. As a result of this influx, the population grew in 1991 from 27,000 (Soran Iraqi Kurdistan, [35]) to about 196,895 in 2018 according to Kurdistan Regional Statistics Office [24]. Consequently, Soran district passes through a tremendous urban pressure as a result of unusual rapid population growth after 2003.

Researchers have widely addressed the impacts of population growth on urban sprawl. El Garouani et al. [10] highlighted the acceleration rate of population growth that has generated a large urban sprawl of Fez city in Morocco. Hegazy and Kaloop [18] argued how Mansoura and Talkha cities in Daqahlia governorate in Egypt are expanding rapidly with varying growth rates and patterns, whereas Belal and Moghanm [7] showed the case of urban expansion that causes loss of productive agricultural lands in Tanta and Quttour districts in Egypt. Finally, measuring the LULC change is necessary for future urban planning at local and global level reported Singh and Singh [34].

This study analyzes the urban sprawl of Soran district in the past two decades and shows how various features have affected the spatial pattern of this urban sprawl.

Table 1 Information of satellite data used for this study

Satellite data	Acquisition date	Path/row	Spatial res. (m)	Bands
Landsat 7 ETM+	25 August 1998	169/035	30	1, 2, 3, 4, 5, 7
Landsat 5 TM	19 July 2008	169/035	30	1, 2, 3, 4, 5, 7
Landsat 8 OLI	28 September 2018	169/035	30	2, 3, 4, 5, 6, 7

Table 2 Land use/land cover classes used in this article and their descriptions

Class name	Description
Urban/built-up area	Residential, industrial, transportation and communications
Barren land	Area of thin soil, sand and mountain rocks almost having no vegetation
Riparian zone	The interface between land and a stream
Cultivated land	Crop fields and vegetable lands

2.2 Data used

Digital image processing of ETM+ in the 1998 (spatial resolution 30 m), TM acquired in the 2008 (30 m), and LOL in the 2018 (30 m) were treated by ENVI 5.3 and ARCGIS 10.3 software. The images were used to explore the land use/land cover change and to estimate physical extent of urban area of Soran district for three-time series during the same season. Table 1 shows the information related to the satellite images used in this study.

Three scenes during the dry season of Landsat imagery 30 m resolution were downloaded from Earth Explorer (USGS) [42]. The dry season provides a better view of the surface although distinguishing wetlands from other types of vegetation. The obtained images were clipped with Soran municipality boundaries. The land cover types found in the area included build-up areas, barren land, cultivated land and riparian zone.

The scenes were selected to be geometrically corrected and calibrated. The data of ground truth were adapted for each single classifier produced by its spectral signatures for producing series of classification maps.

2.3 Classification system

A modified version of the Anderson LULC classification system [4] was used in this study. Classification scheme and detailed descriptions are given in Table 2. A MLC, which is a supervised classification system and is the most popularly used algorithm in image classification [17, 19], was applied for LULC mapping from the three images. Six bands except thermal bands for Landsat 5, 7 and 8 were used as input for maximum likelihood classification system. A total of two hundred and forty sampling points, sixty sampling points for each class in the city of Soran district, were collected to compare the uses of existing situation of satellite images. Training sites were carefully selected using high resolution from images; worldview 2 image (50 cm) to compare image Landsat 5 TM 2008 and Pleiades (50 cm) to compare it with 2018 OLI satellite image, whereas for Landsat image 7 ETM+1998 an expert knowledge of the study was gained from the Municipality Department of Soran district.

Thus, these images were used as base maps to maximize the accuracy of classification in the images.

Concerning the accuracy assessment, a confusion matrix, which is a table that shows correspondence between the result of a classification and a reference image, was used as the quantitative method of characterizing image classification accuracy. Pixel values were extracted from reference points, created an error matrix, calculated the overall percent accuracy, and the user's and producer's accuracies [26].

Soran district was divided into four zones from the central pixel based on spatial directions. The spatial directions approach is carried out according to known geographical trends, either four or eight. Four directions (instead of eight) were selected in this approach to quantitatively and spatially obtain additional details about the studied case for a realistic evaluation that would support planners and decision makers in Soran district create sustainable plans for the future [2].

3 Result visualization

3.1 Classification accuracy assessment

Tables 3, 4, 5 show the accuracy assessment with overall accuracy, producer's accuracy, user's accuracy, and Kappa coefficient for the classified maps for 1998, 2008, and 2018 [26]. Moreover, the overall classification accuracies for 1998, 2008 and 2018 are 74%, 86% and 88%, respectively. The Kappa coefficient for 1998, 2008 and 2018 images is 0.65, 0.81 and 0.84, respectively.

3.2 Landscape structure and dynamics

The classified images provide the information about the land use pattern of the study area. The red color represents the urban built-up area, light green color shows the cultivated land, dark green color shows the riparian zone, and orange color shows the barren land. The LULC maps are shown in (Fig. 2) for three points in time. The directions in

Table 3 Error matrix of the land use/land cover map for year 1998

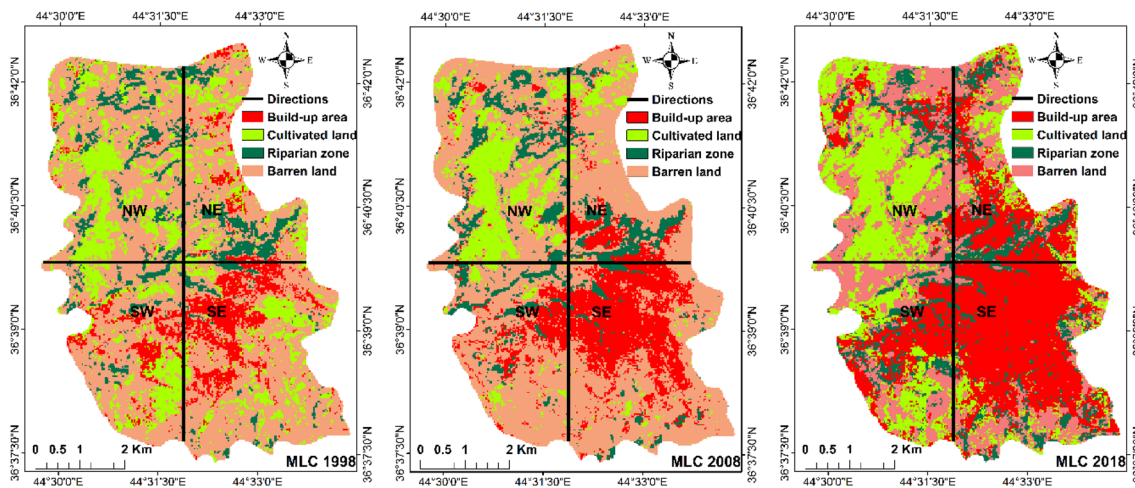
Landsat 7 ETM+(1998)						
Class	1	2	3	4	Total	User's accuracy (%)
1-Build-up area	43	5	7	6	61	70
2-Cultivated land	7	42	6	4	59	71
3-Riparian zone	3	6	47	4	60	78
4-Barren land	5	5	4	46	60	74
Total	58	58	64	60	240	
Producer's accuracy	74	72	73	77		
Overall accuracy	% 74					
Kappa	0.65					

Table 4 Error matrix of land use/land cover map for year 2008

Landsat 5 TM (2008)						
Class	1	2	3	4	Total	User's accuracy (%)
1-Build-up area	52	3	2	3	60	86
2-Cultivated land	3	51	4	2	60	85
3-Riparian zone	1	2	53	3	59	89
4-Barren land	2	4	3	52	61	85
Total	58	60	62	60	240	
Producer's accuracy	89	85	85	86		
Overall accuracy	% 86					
Kappa	0.81					

Table 5 Error matrix of land use/land cover map for year 2018

Landsat OLI (2018) Class	Landsat OLI (2018)				Total	User's accuracy (%)
	1	2	3	4		
1-Build-up area	53	3	2	3	61	87
2-Cultivated land	4	52	2	1	59	88
3-Riparian zone	1	2	54	3	60	90
4-Barren land	2	4	1	53	60	88
Total	60	61	59	60	240	
Producer's accuracy	88	85	91	88		
Overall accuracy	% 88					
Kappa	0.84					

**Fig. 2** LULC distribution and zone maps of Soran district from classification using maximum likelihood classification for years 1998, 2008, and 2018

this study were northeast (NE), southwest (SW), northwest (NW), and southeast (SE).

The increased expansion of road infrastructure has its effect on urban expansion (Fig. 3). Moreover, lands in Soran district are being consumed at a faster rate in the centre growth and toward the SE in correlation with road infrastructure expansion increased with increasing population in 2018. More line roads are being constructed in 2018 outward from urban centers, which is also a prominent characteristic of sprawl.

3.3 Post classification comparison

The spatial distributions of the classes were extracted from each of the LULC distribution for the three images and are presented in Table 6.

The urban built-up area class increased significantly from 10.49% in 1998 to 18.91% in 2008, then after to 34.73% in 2018. Cultivated land decreased from 21.38%

in 1998 to 12.07% in 2008 and increased rapidly to 23.97% in 2018. A steady increase in riparian zone can be observed from 9.16% in 1998 to 10.63% in 2008, and then to 12.84% in 2018. On the other hand, barren land that existed in 1998 remained as it was in 2008, whereas the rate decreased sharply to 28.46% in 2018. Thus, the results show an expansion of urban/built-up areas in 2018, on the expense of barren areas decrease.

4 Discussion

4.1 Urban Sprawl expansion

The results brought out significant urban expansion of the city for the period 1998–2018. Hence, the built-up land has expanded more than threefold during the last 20 years from 4.51 to 14.93 km² showing a positive trend over time. However, the barren land is under stress due to population

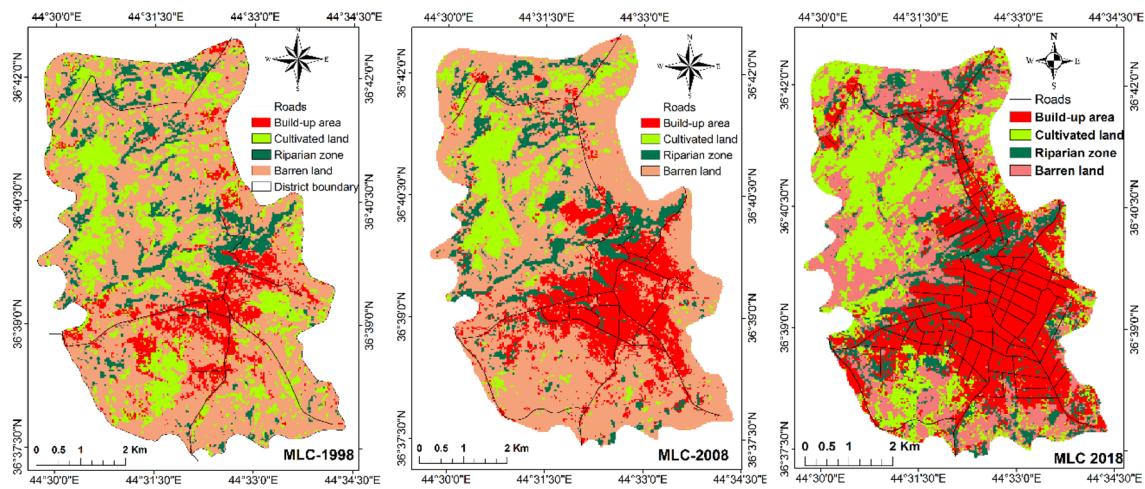


Fig. 3 Urban growth map based on land use changes and road network expansion of Soran district from classification using maximum likelihood classification for years 1998, 2008, and 2018

Table 6 Results of land use/land cover classification statistics for 1998, 2008 and 2018 in square kilometers and percent

Class name	1998		2008		2018	
	km ²	%	km ²	%	km ²	%
Build-up area	4.51	10.49	8.13	18.91	14.93	34.73
Cultivated land	9.19	21.38	5.18	12.07	10.31	23.97
Riparian zone	3.91	9.16	4.57	10.63	5.63	12.84
Barren land	25.39	58.97	25.12	58.39	12.13	28.46
Total	43	100%	43	100%	43	100%

pressure and the associated demand for urban expansion (Table 6 and Fig. 4).

In order to identify, describe, and quantify differences between images of the same scene at different times, a GIS has been used to integrate urban/built-up areas class for the three images and generate a thematic map to examine dynamics of urban expansion. This analysis allowed to identify several changes occurring in different classes of the land use. The classified land use maps of built-up area and their spatial distributions for years 1998, 2008 and 2018 are shown in Fig. 4.

During the three periods, the encroachment of urban/built-up areas occurred to the direction of SE from the center of Soran district since 1998 as shown in Table 7, where the classified results indicate that the city is expanding and fanning out in the SE, NE and SW parts of the city. These areas are less hilly with no agricultural activities.

During the period 1998–2018, the NE zone grew by 2.33 km², the SE zone grew by 5.64 km² which has the maximum growth zone, and the SW zone grew by 1.49 km², while the NW zone grew by 0.86 km² (Table 8). Thus, the SE zone witnessed the largest growth, contrasted by the lowest NW growth marking the SE as general active growth

direction. This growth orientation could partly be caused by the international Hamilton road, which is a spectacular winding mountain road from Erbil to Iran and one of the most strategically important roads.

Numerically, since 1998, urban built-up areas of Soran district have been expanding at a faster rate especially in the last decade (2008–2018). Built-up area of the town was about 4.51 km² in 1998, 8.13 km² in 2008, and 14.13 km² in 2018 (Table 6). On average, the rate of expansion of the town was 0.36 km² per annum in the first decade (1998–2008) and about 0.68 km² in the second period (2008–2018). Thus, change detection resulted in evolution of urban areas and its implication with barren land, which revealed that the development in Soran district has developed as sprawl area.

As can be observed from Table 6 in 1998 and 2008, the majority of the area (about 25.39 km² and 25.12 km², out of 43 km² of the study area) in Soran district was barren land. Whereas in 2018 the build-up area dominated and covered 14.93 km² out of 43 km², then barren land took second class and covered 12.13 km². The urban expansion of Soran district was largely caused by the increasing built-up area of the town from 10.49% in 1998 to 34.73% in 2018. This in turn is due to the natural increase

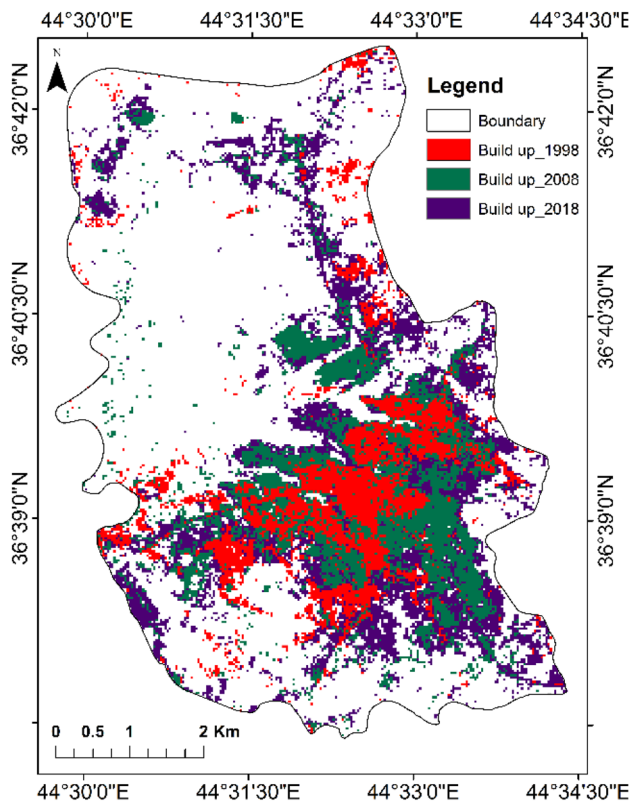


Fig. 4 The spatial changes of the urban expansion of Soran district in 1998, 2008, and 2018. Showing a steady increase in urban/built-up areas from 1998 to 2018

Table 7 Urban areas in km² in all zones from 1998 to 2018

Years	NE (km ²)	SE (km ²)	SW (km ²)	NW (km ²)	Whole city (km ²)
1998	0.62	2.64	1.05	0.13	4.44
2008	1.12	5.06	1.47	0.37	8.02
2018	2.95	8.28	2.54	0.99	14.76

in the population and rural to urban migration. Furthermore, most of these returnees were unable to return to their original villages which had been destroyed by the Iraqi regime’s army or unwilling to return to locations, and instead settled in Soran district [14]. Moreover, push and pull factors explain the processes that attract

Table 8 Observed growth in urban area (km²)

Years	NE (km ²)	SE (km ²)	SW (km ²)	NW (km ²)	Total change (km ²)
Change 1998–2008	0.50	2.42	0.42	0.24	3.58
Change 2008–2018	1.83	3.22	1.07	0.62	6.74
Total	2.33	5.64	1.49	0.86	10.32

migrants to the new location and clarify why people migrate from countryside to urban areas [16].

On the other hand, barren land has declined from 25.39 km² (58.97%) in 1998 to 12.13 km² (28.46%) in 2018. The decline of barren land was largest, and it was as high as 30.51%. Areas covered by riparian zone have increased by 0.66 km² in the first period (1998–2008) and by 2.21 km² in the second period (2008–2018). A significant change of cultivated land can be observed as it declined sharply in the first period from 21.38% in 1998 to 12.07% in 2008, but the change in second period was reversed, as it increased from 12.07% in 2008 to 23.97% in 2018. The expansions of build-up area and cultivation increase are directly related to the socioeconomic boom after the Fall of Baghdad in 2003. The people are increasingly trying to allocate comfort farms and summer houses, as a way of a more relaxed and prosperous way of life in the community.

The residential land use has the largest share of the built-up area in all times. Moreover, from 1998 to 2008, the built-up area increased by 8.02 km². The next period of physical expansion of the city was between 2008 and 2018, when the built-up area expanded by 14.76 km² (Fig. 5).

In order to evaluate whether the build-up areas are growing equally, four zones of the study area were selected namely NE, SE, SW, and NW. As shown in Fig. 6, the rate of expansion for these zones for the 1998–2008 period is 0.5, 2.42, 0.42 and 0.24 km²/year and 1.83, 3.22, 1.07 and 0.62 km²/year for the second period 2008–2018, respectively, which indicate that the SE zone witnessed the largest growth and NW witnessed the smallest growth, meaning that the study area grew mainly in a south easterly direction.

The impact of urban sprawl is seen mainly on barren land that decreased from 25.39 to 12.13 km²; thus, new urban development occurs mainly on barren land. The residential colonies have grown in the SE and NE, then SW parts, while the rest of the city still depicts dispersed built-up land patterns. The study had an overall classification accuracy of 81.7% and kappa coefficient of 0.722.

Researchers have focused on successful remotely sensed classification as an essential source for many application processes [28]. The classification technique used to derive the LULC maps for 1998, 2008 and 2018

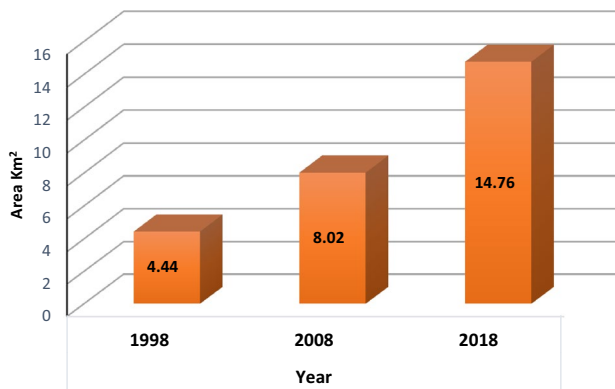


Fig. 5 Built-up area in 1998, 2008 and 2018 in km²

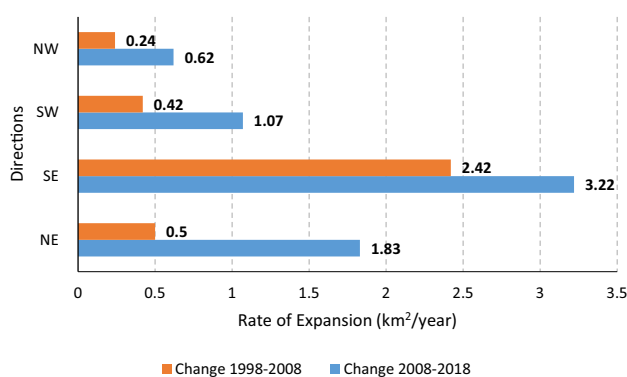


Fig. 6 Rate of expansion of urban areas in the periods 1998–2008 and 2008–2018

was MLC. The kappa coefficient for year 1998 was rated as substantial agreement 0.65, while for images 2008 and 2018 had the Kappa coefficients of 0.81 and 0.84, respectively, reflecting almost perfect agreement ([6]; [8]). However, the supervised classification produced good results with overall accuracies of 74%, 86%, and 88% for the years 1998, 2008, and 2018, respectively. One possible reason for variance between accuracies 1998 with 2008 and 2018 is that the high-resolution images worldview 2 (50 cm) and Pleiades (50 cm), which were treated as the reference data for the 2008 and 2018 Landsat images, respectively, are more precise than Landsat image 1998 that the expert knowledge from the Municipality Department of Soran district was interpreted.

Additionally, the land cover updating using RS classification techniques is an essential task especially in a rapidly urbanizing region, where fast development makes it necessary to monitor land cover change in a timely manner [27]. The updating is based on the application of digital interpretation techniques of high-resolution satellite data.

The data in a GIS have to be updated in order to maintain a valid representation of the 'real world' [21].

To conclude, the period 1998–2018 witnessed a rapid population growth, spatial expansion, land use change, advanced road construction and densification of central city, which usually mark the historical origins of growth and road infrastructure expansion [41].

5 Conclusions

Urban growth change and trend in Soran district were computed and assessed by using three different points 1998, 2008, and 2018 using GIS and remote sensing in order to evaluate the urban growth and sprawl patterns and to produce the land use and land cover map for the studied area. Rapid urbanization has led to significant changes. Urban expansion in Soran district during last 20 years effected the land resources, as well as a potential decrease in water quantity and quality in the town. It has pointed out that Soran district has experienced substantial changes in land cover and land use since the end of 1990s. These changes are induced by upgrading of many urban roads or construction of new road linked structures. Furthermore, the sprawl in Soran district particularly in the north and NE part occurs in disorderly and unplanned patterns, influenced by the proximity of villages and land rents. Further research is encouraged to use proper measures in accordance with scientific planning for the urban expansion of the city in the future.

Acknowledgements Many thanks to Dr. K. Kolo of the Scientific Research Centre (SRC) at Soran University for valuable comments on manuscript and to the (SRC) for providing the reference images.

Compliance with ethical standards

Conflict of interests Author has declared that no competing interests exist.

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