Utilization of Remote Sensing and GIS to Examine Urban Growth in the City of Riyadh, Saudi Arabia

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***Abstract*—This study examines the current land cover and their changes within the capital city of Riyadh, Saudi Arabia over the past two decades and based on those changes, predict the spatial growth of the city for the year 2020. Specifically, the study first utilized maximum likelihood classification technique to classify Landsat data for the years 1990, 2000, and 2014. Based on the classified data and using Cellular Automata model, the study also simulated the spatial growth of the city in 2020. With an overall classification accuracy of 86%, 90%, and 92%, results show that the city grew at a very fast pace. In 1990, the city had an urban area of 603 km^2, while in 2014, the urban area increased to 1720 km^2 (an increase of over 185%). The CA growth model predicted that the urban area will increase to 2221 km^2 in 2020 and grow in the south-western and north-eastern parts of the city. The paper concludes with some recommendations for sustainable urban growth of the city in the near future.**

***Index Terms*—cellular automata model, GIS, land cover change, remote sensing, Riyadh**

I. Introduction

Over the past several decades, cities in the Middle East in general and Saudi Arabia in particular have experienced rapid urban expansion and population growth. It is estimated that by 2025, 88% of the Kingdom's population will be living in one of the major cities and the Kingdom's capital city of Riyadh is the fastest growing city in terms of size and population [1]. This rapid population growth and urban expansion in the cities will have several short and long-term consequences including construction of new residential communities, unavailability of public transportation, shortage of vacant lands, decreasing of affordable housing, and increase in urban temperature and formation of heat islands.

The recent advancement of geospatial technologies have made it an essential tool for monitoring land use and land cover changes and examining the effects of natural hazards, pollutions, and environmental degradation in the surface of the earth in an efficient and affordable manner [2]-[4]. With the help of remote sensing and GIS data, urban planners and policy makers are now identifying and managing the rapidly growing parts of various major cities in the world including Beijing, Tokyo, Atlanta, Kolkata-Howrah, and Dhaka [5]-[9]. They are also using the data for modeling and predicting the future growth of cities [10]-[11].

The goal of this study is to assess the current land cover within the city of Riyadh and examine their changes over the past two and half decades. It will do so by first classifying recent and historical remotely sensed Landsat data and then detecting their changes. Based on the classified data, this study will also model the spatial growth of the city in 2020 using the Cellular Automata (CA). Finally, it makes some recommendations for sustainable growth of the city in the future. In the following sections, the description of the study area is presented in section II. Section III focuses on the methodology used in this study. The results are presented in section IV. Finally, the concluding remarks and direction for future research will be given in section V.

II. Study Area

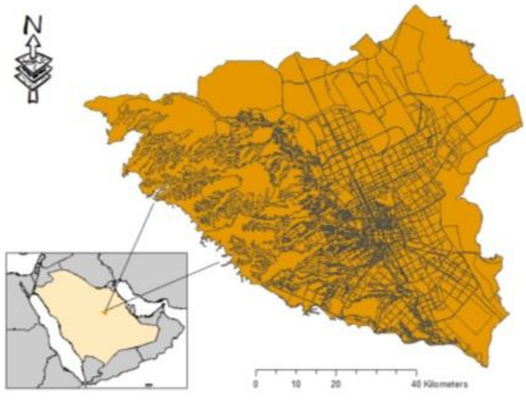

Figure 1. Location of the study area within the Kingdom of Saudi Arabia.

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The study focuses on Saudi Arabia's capital city of Riyadh, located in the center of the Arabian Peninsula approximately 600 meters above the sea level. While the city is fairly flat in the eastern parts, the hilly terrain and the Wadi Hanifa occupies the western half of the city. With a population of 5.25 million that is growing faster than any other city in the gulf region, Riyadh is currently divided into twenty sub-municipalities [1]. During summer, the city experiences dry arid climate with temperatures varying 22^{o}C-43^{o}C while in the winter, it fluctuates between 8^{o}C-28^{o}C. The entire city of Riyadh was chosen as the study area (Fig. 1).

III. Data and Methodology

To complete this study, temporal Landsat data for the past 2.5 decades were freely acquired from U.S. Geological Survey's (USGS) EROS data center. Specifics of the Landsat data are provided in Table I. The data sets were delivered in "Level 1T" format with geometric and systematic radiometric accuracy provided by ground control points. After preprocessing, the images were classified using Maximum Likelihood classification method and examined for accuracy. The following four major land cover classes were identified in the study area: urban built up area, soil/sand, vegetation/agricultural area, and water. Details about the land cover types associated with each classified class are given in Table II. Once classified, the results were exported in ArcGIS 10.1 raster format for detecting changes and further analysis. For accuracy assessment, 200 ground truth points were randomly selected (using stratified random sampling method) from the field. Among them, 80 points were for built-up class, 50 for vegetation, 50 for Soils, and 20 for water areas. Ground truth points were compared to the classified results using the error matrix. Based on the values of the error matrix, User's Accuracy, Producer's Accuracy, Overall Accuracy, and Kappa Coefficients were calculated to examine the accuracy of the classified images.

TABLE I. Remote Sensing Data Used in the Study

Date	Sensor	Path/Row	Format
15-Aug-90	Landsat -5	165/43 & 166/43	GeoTIFF
26-Aug-00	Landsat-7	165/43 & 166/43	GeoTIFF
25-Aug-14	Landsat-8	165/43 & 166/43	GeoTIFF

The second objective of this study was to examine how the city will grow in the near future. To do so, the Cellular Automata (CA) model, a dynamic and discrete system which behaves according to the neighborhood relationships was utilized through the freely available QGIS 2.4 software package to model urban growth of Riyadh in 2020. The accuracy of the model was analyzed by using the data from 1990 and 2000 to predict the growth of 2014 using the CA model. The predicted growth of 2014 was then compared with the classified map of 2014. Comparison was made by finding the differences between the classified map of 2014 (as reference map) and predicted map from the model using the model verification tool of QGIS. The QGIS verification tool compared pixel by pixel and produced kappa index value indicating the overall accuracy of the predicted urban growth model. Values close to 1 indicates high degree of accuracy.

TABLE II. Land Cover Types and Their Description

Land Cover Type	Description
Built-up	All Infrastructure including residential, mixed use, commercial, industrial areas, villages, road network.
Vegetation	Agricultural lands, grassland, natural vegetation, trees, gardens, parks, and play grounds.
Water Body	Swimming pools, ponds, and lakes.
Soil/Sand	Bare Soils, open spaces, excavation sites, developed land, Sand, and all land cover types.

IV. Results and Discussion

A. Land Cover Classification Results

Table III and Fig. 2 summarizes the classification results and areal distributions of the four major land covers of Riyadh. The accuracy assessment results for the three years are given in Table IV. The results show that the built-up area increased just slightly by 100 km^2 between 1990 and 2000. However, between 2000 and 2014, it increased from 707 km^2 to 1720 km^2 (an increase of over 143% from 2000). Such major increase can be attributed to several factors. First, due to the Government's funding of interest-free land grants caused an enormous growth of towns and cities all over the Kingdom, especially in the cities of Riyadh, Dammam, and Jeddah [12]. Second, due to weak planning policies, cities are experiencing lop-sided development and expansions [13]. Finally, economic prosperity and better employment opportunities in the cities are causing local Saudis and expatriates from neighboring Arab, South and Southeast Asian countries to migrate into the major cities.

While urban built up area increased within the study area, there was significant decrease in total area of vegetation. In 1990, 35.65 km^2 were classified as vegetation in the study area. However, in 2000, it decreased by 8.33% to 32.68 km^2. Between 2000 and 2014, more than 58% of the vegetation land (mostly agricultural lands in the outskirts of the city) decreased and today, it occupies only 13.46 km^2. When we examined the amount of water bodies available in the study area, we found that prior to 2000, it was less than 1% of the land. However, in 2014, the area of water bodies increased to 2.40 km^2. This phenomenon may be due of global climate and weather changes resulting in increase of annual precipitation. Such increase is causing flooding within the city and is causing extensive damage to infrastructures and killing dozen or more residents every year [14].

TABLE III. LAND COVER TYPES AND THEIR DISTRIBUTION IN KM^2 FOR 1990, 2000, AND 2014

Land Cover Type	1990	2000	2014	% Change 1990-2000	% Change 2000-2014
Built-up	603.00	707.00	1720.00	17.25	143.30
Vegetation	35.65	32.68	13.46	-8.33	-58.81
Water Body	0.80	0.90	2.40	12.50	167.00
Soil/Sand	4744.87	4643.74	3648.46	-2.13	-21.43

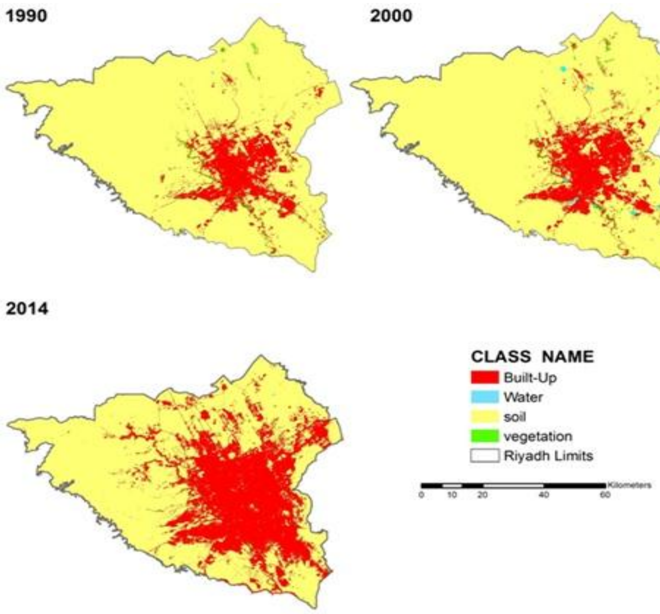

Figure 2. Distribution of land cover classes within the study area.

TABLE IV. SUMMARY OF THE ACCURACY ASSESSMENT RESULTS FOR THE THREE CLASSIFIED IMAGES

Date	Producer's Accuracy	User's Accuracy	Overall Accuracy	Kappa Coefficient
15-Aug-90	88	84	86	79
26-Aug-00	91	84	90	78
25-Aug-14	93	92	92	91

B. *Land Cover Simulation for 2020*

In order to predict the spatial land cover growth for 2020, we utilized the CA model. The CA model required us to enter the raster classification results of 2000 (T_1) and 2014 (T_2). Based on the classification data, the model then predicted the land cover growth of 2020 (T_3). Detailed results and the 2020 prediction map from the CA model are shown in Table V and in Fig. 3. For 2020, the CA model simulated that in Riyadh, approximately 2221.77 km^2 will be converted to built-up area (an increase of 29% from 2014). Approximately 3184.73 km^2 will remain as soil/sand. There will be a slight decrease (8.96 km^2) in vegetation areas and increase in water 4.86 km^2 in the form of ponds and lakes. The results suggest that Riyadh city's pace of growth in urban built-up area is increasing faster than previous decades. It also indicates that Riyadh's main planning agency, the Arriyadh Development Authority's (ADA) prediction of 2130 km^2 for 2020 may occur within the next 2-3 years. Finally, the predicted growth map shows that Riyadh city is growing in all directions but most growth will occur in the south-west and north-east directions. However, the growth will be hindered in the City's western half due to hilly terrain and Wadi Hanifa.

TABLE V. AREA PREDICTED BY THE CA MODEL FOR EACH CLASS IN 2020

Class	Area (km^2)
Built-Up	2221.77
Vegetation	8.96
Water	4.86
Soil/Sand	3148.73

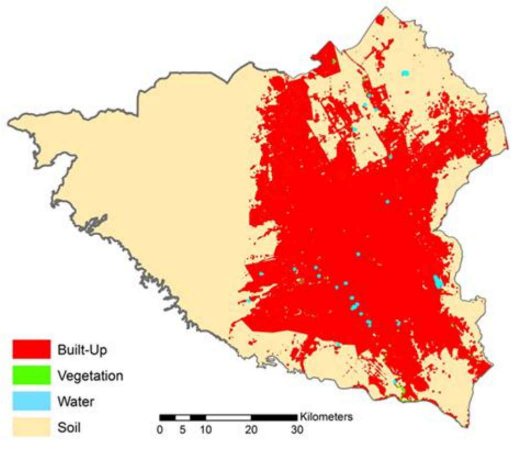

Figure 3. Distribution of land cover classes simulated by the CA model for the year 2020.

C. Accuracy of Cellular Automata (CA) Model

In addition to creating the land cover prediction maps, we also examined its accuracy using the QGIS pixel to pixel verification tool and calculating the kappa index value (indicating the overall accuracy of the predicted urban growth model). Values close to 1 would indicate high degree of accuracy. Details of the classified and predicted map of 2014 are shown in Fig. 4. In predicting built-up areas, the CA model estimated that 1,118.21 km^2 would be built-up area in 2014. The classified results showed that 1,720 km^2 is built-up land in Riyadh city, indicating an error of 34%. For vegetation, the predicted amount of vegetation is showing a decreasing trend between 2000 and 2014 and the percentage of error was much lower (-0.06% vs. -0.09%). Finally, we calculated that the prediction results produced an overall kappa index of 0.86 or 86%.

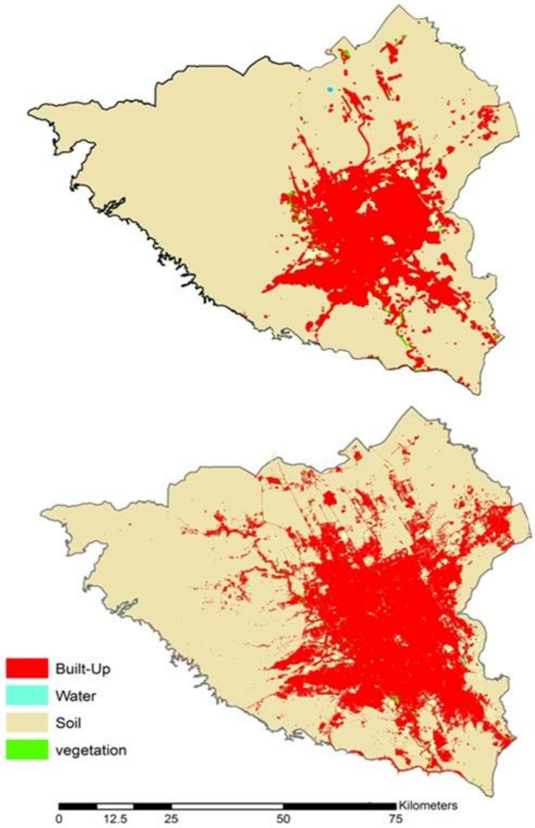

Figure 4. The CA model predicted (top) and classified (bottom) land covers for 2014.

D. Recommendations for Future Urban Growth

To ensure that the growth of Riyadh is in a sustainable manner in the near future, this study will make several recommendations. First, the city needs to establish spatial Data Infrastructures (SDI) to effectively manage, use, and access spatial data. It will allow the integration and processing of spatial data from various different sources and governmental organizations. It will be an effective tool for planners and the city manager to collect information related to growth and act accordingly. SDI has been already adopted by many countries worldwide. While ADA currently does not have any SDI system in place, it has already initiated a pilot project for exchanging and organizing spatial data with key agencies including Saudi Post, National Water Company, Saudi Telecom Company, and Riyadh Region Municipality. In the future, Saudi Arabia should institute a regional and national level SDI program to share data with all public and private agencies for controlling urban growth of other major cities in the Kingdom.

Second, Saudi Arabia should also initiate a program for measuring, mapping, and monitoring the urban spatial growth of its major cities at five year intervals using GIS and satellite remotely sensed imageries. These data and maps can serve as the base-map and backbone of the SDI program. Various governmental organizations can initiate and work jointly together to create such maps and systems including the Ministry of Municipality and Rural Affairs (MOMRA), ADA, and Saudi Center for Remote Sensing. Such coordination among the agencies will ensure creation of solutions to various urban issues such as development, energy crisis, transportation problems, and availability of affordable housing and economy of the City and the Kingdom.

Third, numerous American cities and authorities adopted to restrict urban sprawl and population growth through zoning restrictions, fees for development, limits on building permits, pollution taxes, and minimum lot size zoning, etc. [15]. While all of these approaches have some limitations and deficiencies (i.e. pollution tax will raise the cost of households and price of land may rise due to limited permits of building), they can be viable solutions to control urban growth of Riyadh.

Fourth, the city can control growth boundaries, zoning, or restrict urban services such as water, sewers, roads, and developing lands for housing. Controlled city will reduce the population due to gap in utility services and it will increase the population in other uncontrolled cities. It will also reduce the utility in uncontrolled cities due to population increase until the equilibrium point and resulting utilities will be the same in region. For example, controlled urban growth implemented in Portland reduced supply of land and mixed land use when compared to other cities in the region [16]-[17]. Studies have found that in U.S. cities, 7-22% of residential and commercial growth are shifting into existing urban areas and reducing total regional vehicle miles travel (VMT), congestion, and pollution emissions by 2-7% [18]. A study funded by the U.S. Environmental Protection Agency (EPA) for the cities of Denver, Boston, and Charlotte found that by changing building regulations and legislations, substantial energy conservation and emission reductions can be achieved if development shifts from the urban fringe to infill, or low density to mix land use and high density [19]. If a city imposes a limit on new dwellings and issues less number of dwelling permits than demand of permits, it will decrease the number of people who are willing to come to live in the city. However, it may increase the price of land and housing permits [19].

Finally, Riyadh may initiate future growth of the city by taking a smart growth approach of high density, mix land use with high rise building approach instead of villa type housing. The city also has to redesign the existing building bylaws. It may be possible to accommodate more people in same area as compared to low density villa type housing.

V. Conclusions

This study has utilized remote sensing imageries and Cellular Automata Model in a GIS platform to examine the land cover changes within the city of Riyadh between 1990 and 2014 and predict its growth for 2020. It also made some recommendations for the growth of the city in a sustainable manner. The study has found that the urban areas within the city have grown almost 150% over the past two and half decades. It predicted that in the next 5 years, the urban areas will grow to over 2,200 km^2 in the south-western and north-eastern parts of the city. While such urban expansion highlights the economic growth and prosperity of the Kingdom, it will have numerous social and environmental consequences. Future studies should focus on examining some of these consequences and finding ways to resolve them for the city of Riyadh.

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