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SPATIO-TEMPORAL ANALYSIS OF LAND USE AND LAND COVER CHANGES IN ARID REGION OF SAUDI ARABIA

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ABSTRACT: Changes in land use/land cover (LU/LC) are a major factor driving global environmental change, especially in arid and semi-arid regions. As a result, expansion of agriculture and urbanization is occurring in ecologically fragile lands. This paper analyzed and assessed land use/land cover changes in an agricultural center Tabuk in Saudi Arabia, object-based classification technique (OBC) using Landsat images for seven years (1985, 1990, 1995, 2000, 2005, 2009, and 2015) were used for LU/LC analysis. The urban growth type for Tabuk was measured using Urban Growth Analysis Tool (UGAT) within a GIS. The study found an increase in urban areas from 48 km^2 in 1985 to 315 km^2 in 2015. A significant increase of 61% in agricultural land, from 1985 (112 km^2) to (577 km^2) in 2015. This expansion is occurring at the expense of the barren land with a loss of 768 km^2. An overall classification accuracy ranged from 94% to 97% across all images. The urban growth type for Tabuk was determined as 72% to be of the extension-type over the study period, with urban areas expanding in a direction towards the northwest and west area. Assessing spatial and temporal LU/LC change has aided to understand the impacts of expanding agriculture and urban areas. The LU/LC maps could aid government planners and decision-makers to analyze and manage agricultural and urban growth.

Keywords: Change detection; Land Use /land cover (LU/LC); OBC; Remote sensing; GIS; Urban Growth Type

1. INTRODUCTION

Land use/land cover changes are a major factor driving global environmental change, especially in arid and semi-arid regions where water and land resources are limited. Saudi Arabi has changed dramatically over 30 years due to economic development from the high value of oil income and rapid growth of urban population [1]. The Government has introduced plans and programs to increase agricultural productivity by augmenting agricultural areas to ensure consistent development of the country [2]. In 1980, Saudi's government encourage agriculture development by implementing wheat subsides with a view to enhancing food self-sufficiency [3], however, because of the high demand of water for irrigation, in 2003, the government put plans in place to restrict water use. The arid climatic conditions in Saudi Arabia limit the areas suitable for agriculture, hence most agricultural areas dependent on groundwater due to low and irregular rainfall. Groundwater from deep aquifers (fossil water) in Saudi Arabia is not rechargeable, and only shallow aquifers are recharged after heavy rainfall (Al-Ibrahim, 1991). Tabuk is an important agricultural centre in Saudi Arabia which is highly susceptible to land degradation and water stress.

Migration plays an important role in population distribution between administrative regions of Saudi Arabia, and between rural and urban areas within the same region [4]. The imbalance of population distribution, however, has negative impacts for demands on resources and space [5]. Tabuk is known as the north gate of Saudi Arabia and considered the main northern route for pilgrims travelling to Makkah from northern countries. Tabuk also supports large numbers of military personnel associated with Defense Forces based in the region, which create settlements pressure and urban problems.

A general lack of understanding, inadequate planning, agricultural mismanagement and urban expansion leads to major changes in LU/LC, and can impact hydrological processes [6]. Such changes have resulted in the further deterioration of the desert ecosystem [3]. Urban development together with human activities such as unsustainable agricultural practices, unplanned urbanization, and excessive use of groundwater in Tabuk have resulted in environmental problems across the city. Al Harbi [7] concluded that Tabuk is exposed to a high risk of environmental damage from 'desertification'. Rapid change in LU/LC over a 20-year period resulted in agricultural land use moving into fragile areas.

A modelling study for Michigan USA on the effects of urban growth on groundwater, predicted that urban growth dependent on groundwater supply is not sustainable [8]. Such studies highlight the issues of urban expansion for cities relying solely on groundwater. To prevent further damage to the environment, land use change should be assessed [9]. Assessing spatial and temporal LU/LC change to increase awareness and understanding of environmental impacts is an important task.

Temporal and spatial observation of change over specific time periods can provide reliable information for mapping and to analyse LU/LC change at local, regional and global scales [10]. A variety of techniques have been used to detect changes in LU/LC, including post-classification comparisons. The selection of an appropriate classification method is essential for extracting an accurate information from satellite data. Supervised and unsupervised classifications are two traditional pixel-based approaches to image classification [11].

Object-based classification (OBC), or object-based image analysis (OBIA) has gained popularity [12, 13]. The key to OBC is to exhibit features such as image textural; spectral and spatial information to obtain an accurate analysis [14]. Object-based classification provided higher accuracy compared to urban class pixel-based classifications for a mixed urban-agricultural arid region of Arizona [15]–[16]. Previous research combined remote sensing data with spatial metrics for assessing and mapping urban sprawl, urban structures, sprawl direction, and urban growth pattern [17]–[18]–[19].

There is a need to accurately define LU/LC change using geospatial techniques to support environmental planning. To date, little attention has been paid to environmental and socio-economic stability in Tabuk, which lacks spatial and temporal information about LU/LC changes. Assessing LU/LC change, therefore, can provide essential information to aid environmental management and planning. The aim of this work is to assess land use and land cover change in arid Tabuk from 1985 to 2015.

2. MATERIALS AND METHODS

2.1 Study Area

The study area within Tabuk province covers an area of approx. 4212 km^2, and is located at an altitude of 600-800 m above mean sea level; between 28˚23` to 28˚39 N and 36˚35` to 36˚57 E in the north-western region of Saudi Arabia (Fig. 1). The province is considered arid with an annual rainfall 40 mm, mostly occurring between November and January with snowfalls every 2-3 years. The primary land use in Tabuk is agricultural, and is considered to be the most important area in Saudi Arabia for commercial production. Wheat, fruit, and export flowers (to Europe) are the main agricultural products in the study area.

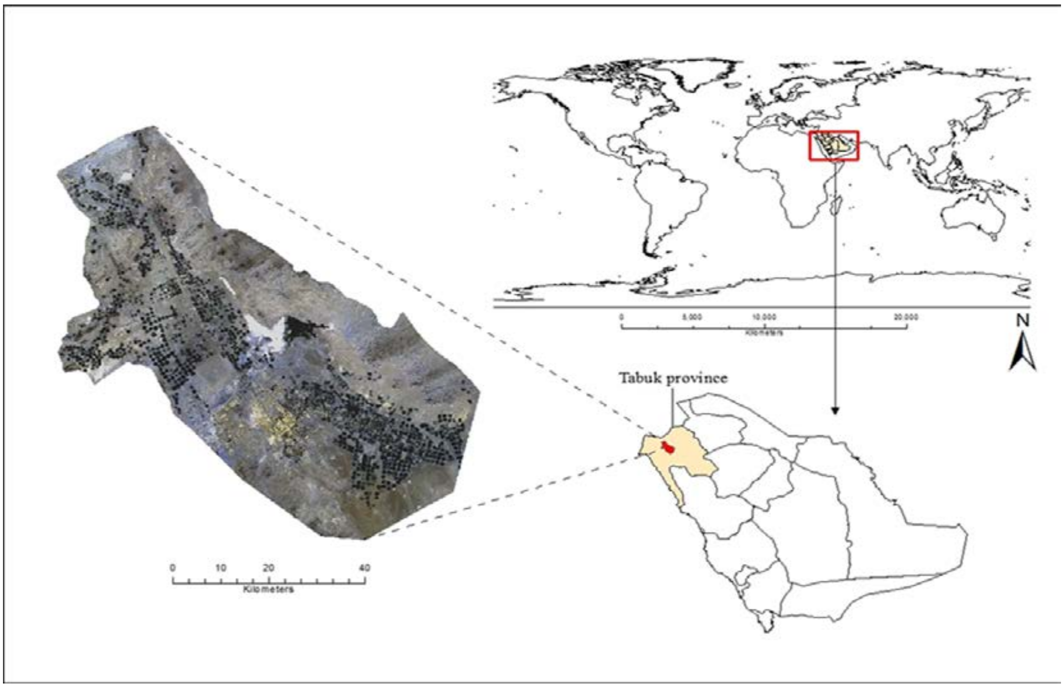

Fig. 1 Location of the study area Tabuk, within Tabuk province Saudi Arabia (source: Landsat-8 image 2015)

2.2 Dataset and Image Pre-processing

Landsat Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+) and Operational Land Imager (OLI) (path 173 and row 40) for 1985, 1990, 1995, 2000, 2005, 2009 and 2015 were downloaded from Earth Explore. Images were selected during March and April of any given year to provide uniformity when detecting and assessing LU/LC change. Images were geometrically corrected and rectified to the Universal Transverse Mercator (UTM) coordinate system. Landsat images acquired at two or more different periods have different amounts of haze and dust in the atmosphere and required atmospheric correction to overcome these differences [20]. Dark object subtraction (DOS) was used to correct Landsat imageries for atmospheric scattering.

2.3 Image Classification (Segmentation)

The land use/cover classification scheme by Anderson [21] was modified to account for local field knowledge and conditions of the study area to define four types of land cover including barren land, urban areas, agricultural land and water (Table 1). The focus in this study is on agricultural land and urban area (water was determined to cover only 1%). ENVI software at scale level 10, merge level 97 and texture kernel size 3 was used to perform segmentation processes. The parameters were selected based on good results obtained. An overlay procedure was done using a GIS function with the help of available referenced data for all segmented images.

Table 1 Land use/cover classification scheme

No.	Class	Description
1	barren land	desert sand, mountain, bare exposed rock, and dry salt flats
2	urban areas	residential, commercial and industrial areas, settlements, and transportation infrastructure
3	agricultural land	cropland and pasture fields, grassland, greenhouses, and fallow land
4	water	ponds and a small lake

2.4 Change Detection and Accuracy Assessment

Post-classification comparisons were used to detect the nature change of LU/LC by determining ‘from–to’ change by comparing classified images individually across different dates [22]. The nature of LU/LC change maps (‘from –to’) were for seven epochs, namely 1985–1990, 1990–1995, 1995-2000, 2000-2005, 2005-2009, 2009-2015, and 1985–2015.

Accuracy assessment measures the degree of closeness to true values. Error matrix is a common method in the accuracy assessment process, including overall accuracy, producer’s accuracy, user’s accuracy, and kappa coefficient [23]–[24]. Around 500 randomly distributed points were identified on the reference image and attributed to the four categories. A topographical map, high-resolution images, and field data were used as reference data to assess the image classification accuracy.

2.5 Urban Growth Analysis Tool (UGAT)

The dataset of classified images was reclassified into urban and non-urban areas. Spatial metrics and statistics technique using UGAT was adopted [19] to analyze urban spatial growth and type of change over a 30-year period. The municipality of Tabuk was set as the Tabuk central area with 1 km^2 multi-ring buffer implemented over the study area, using the average percentage of urban development for all built-up pixels. The direction of the urban growth for Tabuk city is presented. The result of urban development pattern for different periods described as extension, infill or leapfrog development, over open space.

3. RESULTS

LU/LC maps showed a clear increase in irrigated agricultural land and urban areas over a 30-year period (Fig. 2). Agriculture in 1985 centered north of the city and in the outer northwestern areas. The trend for agricultural expansion in 2015 was spread northwest and southeast of Tabuk city. The agricultural land covered an area of 112 km^2 in 1985 compared to 577 km^2 in 2015 (Table 2), a steep increase of 61%. Agricultural crops in Tabuk are cultivated under a controlled center pivot irrigation system. OBC was effective in showing the expansion of the urban area of Tabuk. The built-up area in 1985 was mainly confined to the Tabuk city centre. In contrast, the built-up area in 2015 had sprawled across a much wider area. Agricultural land pushed to the north and northeast of the city, increasing by 28% from 48 km^2 in 1985 to 315 km^2 in 2015 (Table 2).

Table 2 Temporal change in land use/land cover for Tabuk

Year	Land cover categories		
	Barren and (km^2)	Urban area (km^2)	Agricultural land (km^2)
1985	3986	48.3	112.5
1990	3927	64.4	152.3
1995	3840	88.1	226.7
2000	3652	122.1	357.8
2005	3465	145.0	528.3
2009	3405	203.6	524.4
2015	3218	315.1	576.6

Both agricultural development and urbanization show similar trends over barren land (Fig. 3). From 1985 to 2015, around 768 km^2 (11%) of desert areas were converted to agricultural land and urban area. In the 2005-2009 epoch, agricultural land had reduced c. 4 km^2 from 528 km^2 to 524 km^2. In 2015, however, an increase in agricultural land by 52 km^2 was observed.

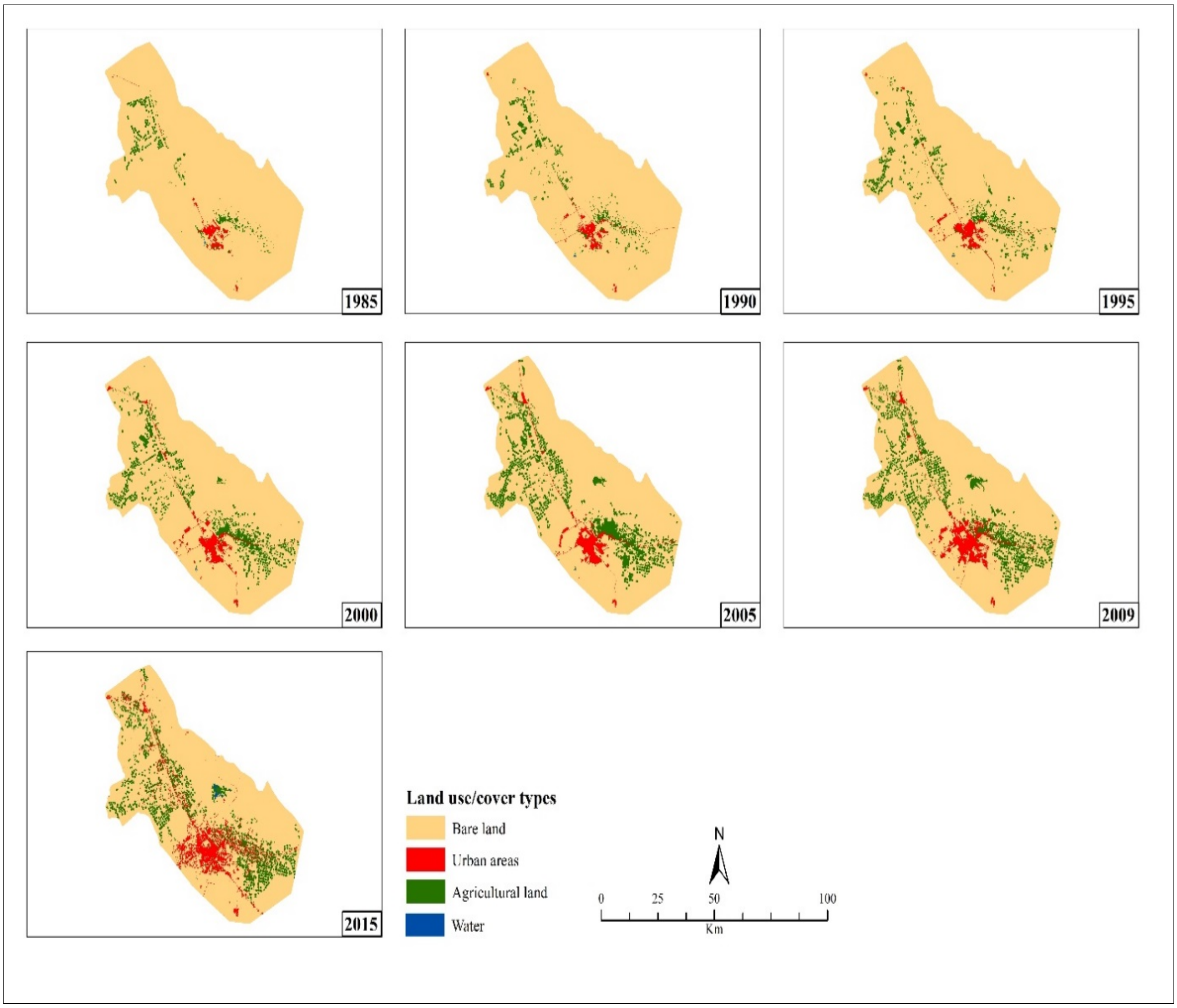

Fig. 2 Land use/land cover classification in Tabuk from 1985 to 2015

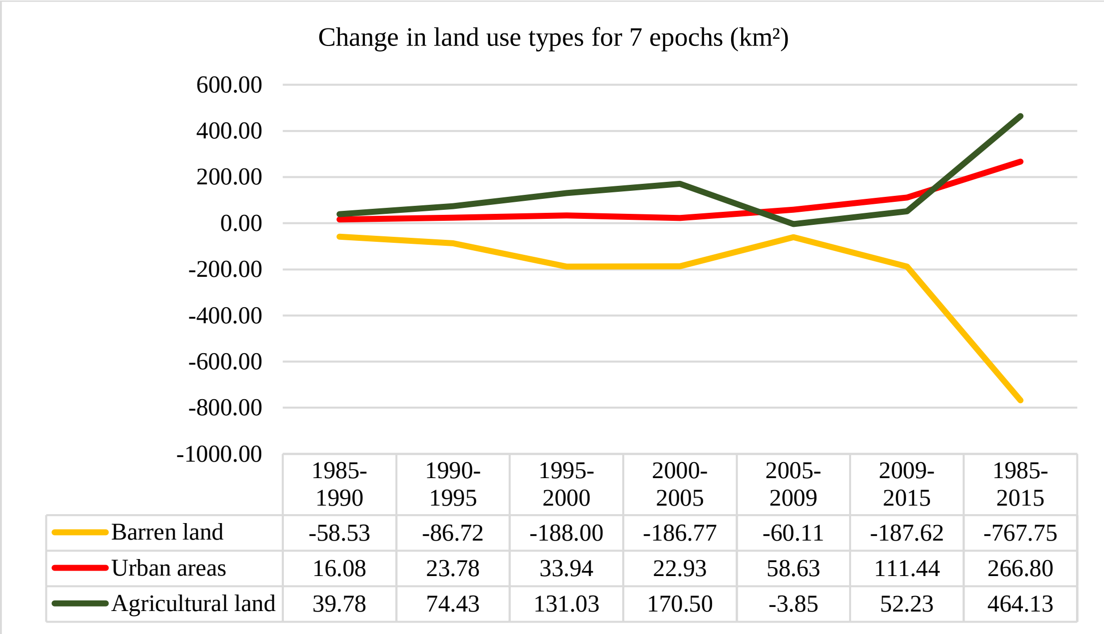

Fig. 3 Gain or loss of land use types across seven epochs

Table 3 Overall accuracy and Kappa coefficient of LU/LC classification

Year	Class	User accuracy	Producers accuracy	Overall Accuracy	Kappa coefficient
1985	Bare land	92	100	94	0.91
	Urban	100	81		
	Agriculture	95	93		
1990	Bare land	96	100	97	0.96
	Urban	98	92		
	Agriculture	99	98		
1995	Bare land	93	98	94	0.91
	Urban	98	85		
	Agriculture	94	97		
2000	Bare land	100	99	96	0.94
	Urban	90	89		
	Agriculture	97	92		
2005	Bare land	92	99	96	0.94
	Urban	99	87		
	Agriculture	99	100		
2009	Bare land	96	99	96	0.95
	Urban	97	98		
	Agriculture	96	96		
2015	Bare land	92	100	97	0.95
	Urban	98	98		
	Agriculture	99	94		

Accuracy assessment for LU/LC classification generated an overall accuracy ranging from 94% to 97% across all image years and Kappa Coefficient was >0.91; a satisfactory classification accuracy level of remotely sensed data for LU/LC [21]. User accuracy of individual classes ranged from 92% to 100%, and producer accuracy of individual classes ranged from 81% to 100% (Table 3).

3.1 Population Growth and Spatio-Temporal Analysis of Urban Growth

Urban expansion is based on the relationship between built-up area and population of an area. The latest demographic survey of Tabuk Province for 2016 revealed an increase of population from 165 000 in 1985 to 890 922 in 2015. The major urban growth was noticed between the period 2009 to 2015 with around 112 km^2 as a gain of built-up area (Fig. 4).

Table 4 Area of urban growth attributed to each urban growth type

	Urban growth type (km^2)		
Epoch	Extension	Infill	Leapfrog
1985 to 1990	31.64	4.22	7.33
1990 to 1995	31.28	9.73	8.73
1995 to 2000	41.99	6.98	16.09
2000 to 2005	58.96	7.49	8.82
2005 to 2009	91.97	3.96	19.97
2009 to 2015	133.19	25.68	30.47

The urban growth types of Tabuk in each epoch were identified using Urban Growth Analysis Tool (UGAT). The result indicated that extension type development in Tabuk was the main urban growth type (72%), whereas infill growth type measured only 11 % (Fig 5). Leapfrog growth type accounted for 17 % of total urban land (Table 4). The extension growth direction clearly expanded toward the north-west and west of Tabuk city (Fig. 5 and Fig. 6).

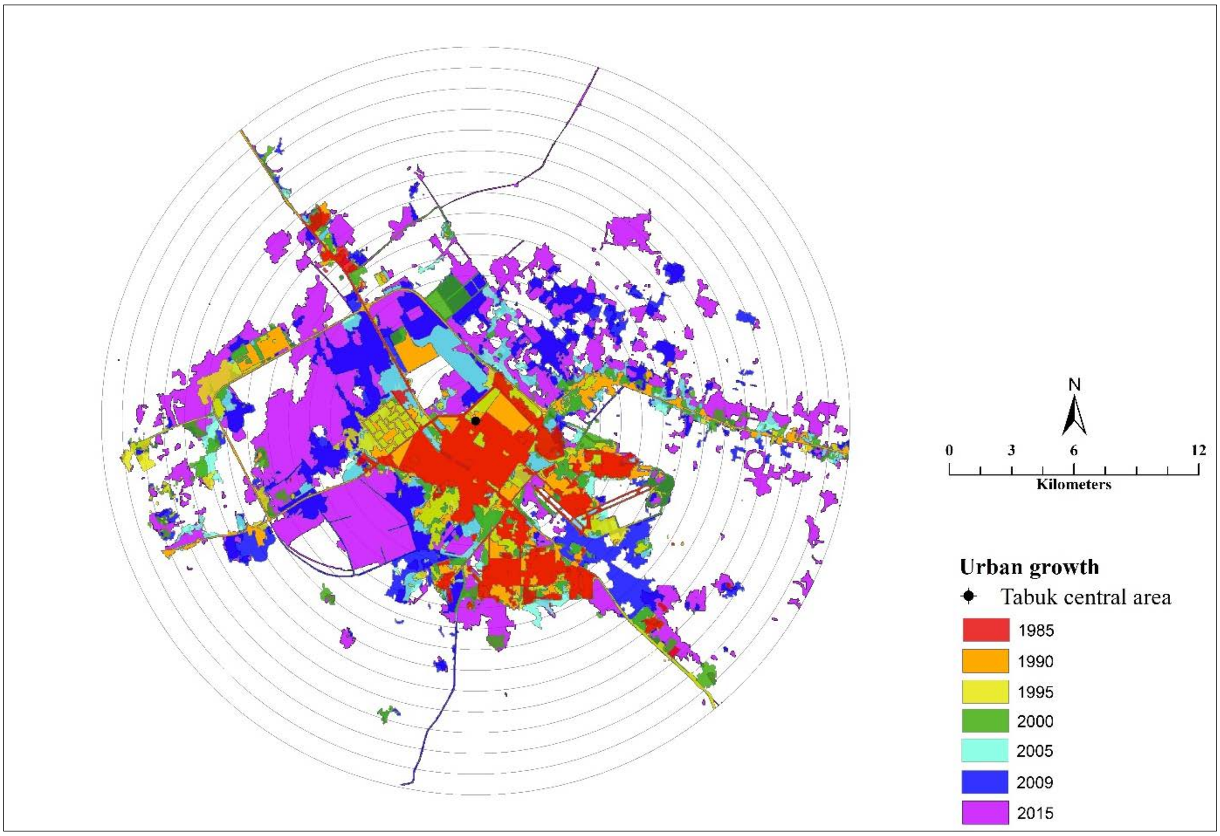

Fig. 4 Urban growth map over 30 years with 15 rings indicating the difference in the urban growth during the studied years

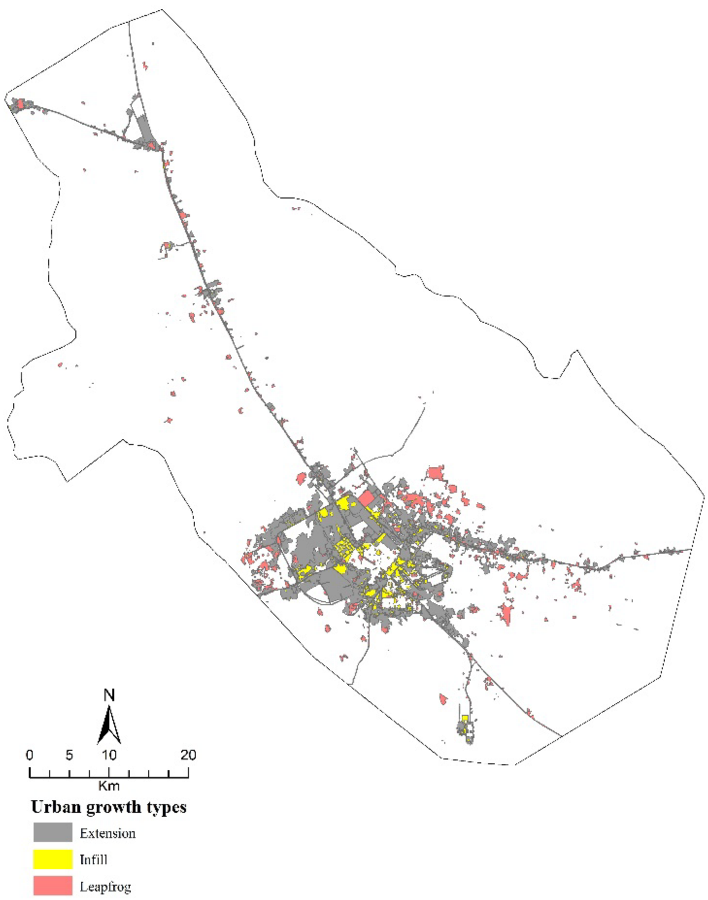

Fig. 5 Urban growth over a 30-year period showed main growth type of development was the extension type

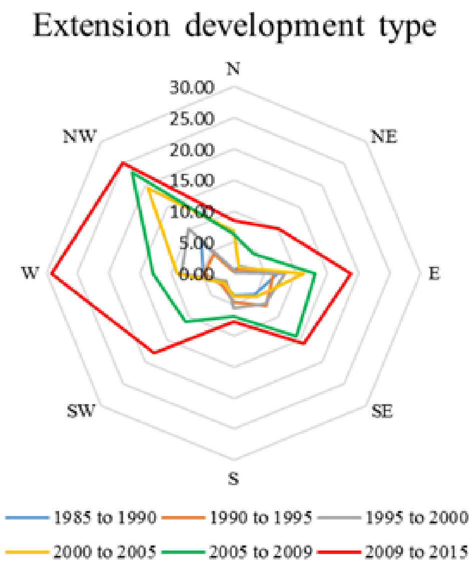

Fig. 6 The trend of urban growth in Tabuk city for each epoch expanding to the northwest and west directions follows the Saq aquifer

4. DISCUSSION

Satellite Data and GIS are complementary and have proven to be effective in providing information about the change in agriculture and urban expansion within this study. Quantitative results from the OBC provided a basis to help understand spatio-temporal LU/LC change pattern for Tabuk. The view of Galletti and Myint [16], that OBC is suitable for assessing area under mixed urban agriculture in arid regions, is supported by the results found in this study. Social and economic change in Tabuk city over a 30-year period can be attributed to migration and increases in the military force leading to increased urbanization that has changed the demography of the city [3]. Al Humaidi [4] showed that migration in the Tabuk region for 1999 was the fourth largest after Riyadh, Makkah (Mecca), and Eastern regions. Many of the younger generation choose to leave the Nomadic way of life, drawn to the city by economic gain and social benefits [25]. People choose to move to Tabuk to gain better health service, education and increased job opportunities. The continued increase in population leads to a significant impact on the physical and economic infrastructure, and the spatial and social interaction within Tabuk city [5]. Increasing population growth through migration impacts services for urban areas [26], while the additional pressure on limited natural resources and the subsequent rise in food insecurity [27].

The urban area expanding with population growth and encroaching into agricultural areas could cause major environmental implications for Tabuk. The city of Amman, Jordan experienced similar issues when the population and unplanned housing increased at the cost of agricultural land, resulting in planning and environmental problems [26]. Population size impacts the amount of agricultural land and water needed to grow food [28]. The results of this study showed a dramatic increase of agricultural land from 1985-2015 due to population growth. Rapid population growth and resource mismanagement can result in soil erosion and land degradation, causing imbalances in the environment [29].

A considerable increase in agricultural land and built-up area in Tabuk was attributed to increasing demand for land for a growing population. The sharp increase in land use change to agriculture around Tabuk city reflects the implementation of wheat subsidies introduced in the 1980’s [31]. The Saudi government encouraged agricultural projects, such as Astra farms and Tabuk Agriculture Development Company (TADCO), with a view to increasing food self-sufficiency for the growing population. The loss of agricultural area during the 2005 to 2009 epoch coincides with implementing the 2003 government policy to conserve fossil water use [31].

The trend for agricultural land to expand to the northwest and west of Tabuk city follows the Saq aquifer for ease of water access; such development is unsustainable. Increased demand for water for agricultural and urban use coincided with decreasing groundwater levels of the Saq aquifer reported by Al-Ahmadi [6]. High demand for irrigation required for the increased area of agriculture places immense pressure on valuable and scarce water reserves for Saudi Arabia [30]. Irrigation of agricultural land in Tabuk using the axial irrigation pivot technique exhibits low efficiency for water usage for agriculture development in arid areas reliant on fossil groundwater [31], contributing to unsustainable practices. More than 80% water used for agriculture, industry and daily consumption is drawn annually from a non-renewable water supply in Saudi Arabia, and places the country in extremely high water stress and promotes water quality deterioration [32]. Desert climate and unsustainable human activity are contributing heavily to stress on groundwater sources and depleting water resources in Saudi Arabia [34]. Groundwater availability in Saudi Arabia is crucial to meeting fundamental requirements of an increasing population and subsequent agricultural demands.

5. CONCLUSION

Fast expanding agricultural land and urban areas in Tabuk pose serious environmental threats that require urgent attention. Increasing agricultural land and urban expansion relying solely on fossil groundwater resources is unsustainable and requires diligent management procedures.

The results of this study have identified several factors in agricultural and urban area change that can contribute to the problems of land degradation in Tabuk city. Intensive crop irrigation of expanding agriculture across the Tabuk city increases the risk of land degradation from high soil salinity. Increasing population places additional pressure on the limited natural resources within this fragile, arid region. Educating farmers and residents about the major environmental problems, and supporting farmers to make the changes needed to halt the damaging processes must be a priority. Government planners and decision-makers should use integrated GIS techniques to regularly update and monitor land use changes. Remote sensing is vital for providing up-to-date and reliable data that can aid in detecting impacts of land use change. Modelling based studies to predict impacts on natural resources and provide a spatio-temporal dynamic of LU/LC change could be useful for future land use planning.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] F. A. Mubarak, "Urban growth boundary policy and residential suburbanization: Riyadh, Saudi Arabia," Habitat International, vol. 28, pp. 567-591, 12// 2004.
[2] M. S. Al-Shayaa, M. B. Baig, and G. S. Straquadine, "Agricultural extension in the Kingdom of Saudi Arabia: Difficult present and demanding future," J. Anim. Plant Sci, vol. 22, pp. 239-246, 2012.
[3] K. Al Harbi, "Discovering and detecting agricultural change in Eastern Tabuk - Saudi Arabia, using remote sensing technique.," Kuwaiti Geographic Society, vol. 283, 2003.
[4] I. A. Al Humaidi, "Internal Migration in Saudi Arabia: Its Magnitude and Trends," Journal of King Saud University, vol. 16, 2004.
[5] M. Bolca, B. Turkyilmaz, Y. Kurucu, U. Altinbas, M. T. Esetlili, and B. Gulgun, "Determination of impact of urbanization on agricultural land and wetland land use in Balçovas' Delta by remote sensing and GIS technique," Environmental monitoring and assessment, vol. 131, pp. 409-419, 2007.
[6] K. Al-Harbi, "Monitoring of agricultural area trend in Tabuk region–Saudi Arabia using Landsat TM and SPOT data," The Egyptian Journal of Remote Sensing and Space Science, vol. 13, pp. 37-42, 2010.
[7] M. E. Al-Ahmadi, "Hydrogeology of the Saq Aquifer Northwest of Tabuk, Northern Saudi Arabia.," Journal of King Abdulaziz University: Earth Sciences, vol. 20, pp. 51-66, 2009.
[8] M. L. Zellner and H. W. Reeves, "Examining the contradiction in 'sustainable urban growth': an example of groundwater sustainability," Journal of Environmental Planning and Management, vol. 55, pp. 545-562, 2012.
[9] E. K. Albalawi and L. Kumar, "Using remote sensing technology to detect, model and map desertification: a review," J Food Agr Env, vol. 11, pp. 791-797, 2013.
[10] J. B. Campbell and R. H. Wynne, Introduction to remote sensing: Guilford Press, 2011.
[11] T. Lillesand, R. W. Kiefer, and J. Chipman, Remote sensing and image interpretation. New York: John Wiley & Sons, 2014.
[12] V. Walter, "Object-based classification of remote sensing data for change detection," ISPRS Journal of photogrammetry and remote sensing, vol. 58, pp. 225-238, 2004.
[13] T. Blaschke, "Object based image analysis for remote sensing," ISPRS journal of photogrammetry and remote sensing, vol. 65, pp. 2-16, 2010.
[14] S. Lang, "Object-based image analysis for remote sensing applications: modeling reality–dealing with complexity," in Object-based image analysis, ed: Springer, 2008, pp. 3-27.
[15] S. W. Myint, P. Gober, A. Brazel, S. Grossman-Clarke, and Q. Weng, "Per-pixel vs. object-based classification of urban land cover extraction using high spatial resolution imagery," Remote Sensing of Environment, vol. 115, pp. 1145-1161, 5/15/ 2011.
[16] C. S. Galletti and S. W. Myint, "Land-use mapping in a mixed urban-agricultural arid landscape using object-based image analysis: A case study from Maricopa, Arizona," Remote Sensing, vol. 6, pp. 6089-6110, 2014.
[17] M. Herold, J. Scepan, and K. C. Clarke, "The use of remote sensing and landscape metrics to describe structures and changes in urban land uses," Env. and Planning A, vol. 34, pp. 1443-1458, 2002.
[18] W. Ji, J. Ma, R. W. Twibell, and K. Underhill, "Characterizing urban sprawl using multi-stage remote sensing images and landscape metrics," Computers, Environment and Urban Systems, vol. 30, pp. 861-879, 2006.
[19] S. Angel, J. Parent, and D. Civco, "Urban sprawl metrics: an analysis of global urban expansion using GIS," in Proceedings of ASPRS 2007 Annual Conference, Tampa, Florida May, 2007.
[20] P. S. Chavez, "Image-based atmospheric corrections-revisited and improved," Photogrammetric engineering and remote sensing, vol. 62, pp. 1025-1035, 1996.
[21] J. R. Anderson, A land use and land cover classification system for use with remote sensor data vol. 964: US Government Printing Office, 1976.
[22] C. James, Introduction to Remote Sensing. New York: The Guilford Press; 3 edition, 2002.
[23] D. Lu and Q. Weng, "A survey of image classification methods and techniques for improving classification performance," International journal of Remote sensing, vol. 28, pp. 823-870, 2007.
[24] G. Rees, The Remote Sensing Data Book: Cambridge University Press, 1999.
[25] Millennium Ecosystem Assessment, "Ecosystems and human well-being," 2005.
[26] Z. Makhamreha and N. Almanasyeha, "Analyzing the State and Pattern of Urban Growth and City Planning in Amman Using Satellite Images and GIS," European J. of Social Sciences, 24, pp. 225-264, 2011.
[27] S. Eckert, "Urban expansion and its impact on urban agriculture–remote sensing based change analysis of Kizinga and Mzinga valley–DAR ES SALAAM, Tanzania," in European Association of Remote Sensing Laboratories, EARSeL Proceedings, Strasbourg, France, 2011, pp. 46-55.
[28] J. Harte, "Human population as a dynamic factor in environmental degradation," Population and Environment, vol. 28, pp. 223-236, 2007.
[29] L. Wang and J. J. Qu, "Satellite remote sensing applications for surface soil moisture monitoring: A review," Frontiers of Earth Science in China, vol. 3, pp. 237-247, 2009.
[30] P. Vincent, Saudi Arabia: An Environmental Overview: CRC Press, 2008.
[31] O. K. Ouda, "Impacts of agricultural policy on irrigation water demand: A case study of Saudi Arabia," International Journal of Water Resources Development, vol. 30, pp. 282-292, 2014.
[32] F. Gassert, P. Reig, l. Tianyi, and m. Andrew, "Aqueduct country and river basin rankings a weighted aggregation of spatially distinct hydrological i," World Resources Institute, , vol. Working Paper, 2013.