Landscape transformation processes in two large and two small cities in Egypt and Jordan over the last five decades using remote sensing data

Abstract

Much research has tackled the physical expansion of urban growth and concomitant rural-urban transformation of land use in many parts of the world, but this phenomenon remained largely overlooked in the Middle East and North Africa (MENA) region. To fill this knowledge gap, this study investigated land use changes from the 1970s to 2018 in the cities of Luxor and Cairo in Egypt and of Aqaba and Amman in Jordan using different Landsat datasets. Land cover classifications were performed with Maximum Likelihood Algorithm and Spectral Angle Mapper. In all four cities peri-urban green areas shrunk or shifted due to increased expansion of built-up areas. The largest reduction of peri-urban green areas were observed for Amman and Luxor, which decreased by 122.4 km² and 17.2 km², respectively, over the study period. For Cairo, an increase of peri-urban green area by 29 km² was detected, but its location shifted over the last five decades due to urban expansion. Green areas (urban and peri-urban) on a per-capita basis were 4.6, 12, 91, and 142 m^2/capita for Aqaba, Cairo, Amman, and Luxor, respectively, in 2018. Land cover changes reflected critical political events like the so-called "Arab Spring", international treaties, recent migration waves and population growth. Rapid increases in urban built-up area put pressure on scarce land and water resources in the peri-urban fringes, thereby potentially leading to environmental stress. Effective city planning is needed to address the multiple challenges and competing interests of urban and peri-urban environments.

Keywords: Landsat images; Land use and land cover; MENA; Peri-urban green areas; Rural-urban transition; Water and food shortage.

1. Introduction

Urban growth leads to land use and land cover changes in and around agglomerations. These changes are particularly large in many poor countries characterized by rapid population growth (UN-Habitat, 2014). Urban expansion is not limited to large metropolitan areas, but it equally occurs in mid-sized and small cities (Gouda et al., 2016). The expansion of urban areas challenges the continued existence of cropland, and specifically the growth of small and medium sized settlements on the periphery of metropolitan areas may jeopardize local food security (Robson et al., 2012; Seto & Ramankutty, 2016). Since urban water demands rise, also competition for water is increasing between urban and agricultural sectors (Flörke et al., 2018).

On a local scale, urban and peri-urban agriculture (UPA) plays an important role for food security, income generation and recycling of waste, which has been well documented (Levasseur et al., 2007; Prain and Lee-Smith, 2010). Whereas UPA was widely studied in regions such as sub-Saharan Africa, information on the extent of UPA in Middle East and North Africa (MENA) cities remains scarce (Graefe et al., 2019). As this region is characterized by low annual rainfall, it has a high fraction of irrigated cropland (peri-) urban areas (Thebo et al., 2014).

In Egypt agricultural production entirely depends on the availability of irrigation water but increasingly also on the encroachment of urban settlements into arable land (UNDP, 2009; Lenney et al., 1996). In the Greater Cairo Metropolitan Region most open areas are now engulfed by highways and peripheral areas of surrounding villages, which led to an increase of the city’s urban area by 135 % between 1984 and 2013 (Osman et al., 2016a,b). Similar changes were noted in Luxor, where agricultural land increased by about 1,940 ha from 1987 to 2011 (Ahmed et al., 2013).

In their analysis of spatial and temporal urban expansion on agricultural land for the Greater Amman Municipality (Jordan) Al-Kofahi et al. (2018) found that it had declined by 50 % from 2003 to 2015. However, 14 % of Greater Amman still classifies as agricultural land where strong municipal support has encouraged the development of UPA (Tawk et al., 2011; Al-Kofahi et al., 2018). Al Farajat (2001) stated that Aqaba has become important for heavy industry, as a free trade zone and for tourism, resulting in rapid urbanization. This change in land use has led to major groundwater pollution from human and industrial sources.

Urban growth using Landsat data has been widely studied in India (Wakode et al., 2013; Bhatta, 2009; Jat et al., 2008), the US (Masek et al., 2000; Sexton et al., 2013), as well as other regions (Bagan and Yagamata, 2012; Kaya and Curran, 2006). In the Middle East research focused on the Gulf countries, such as Saudi Arabia (Rahman 2016; Alqurashi et al, 2016), the UAE (Yagoub, 2004), and Kuwait (Kwarteng and Chavez, 1998). However, comparative studies on urban growth dynamics within one region are scarce, and particularly the eastern MENA region has been rarely studied. To interpret rural-urban transformation there, it is important to consider the broader political context shaping dynamics in urban growth and cultivated areas. The so-called "Arab Spring" for instance affected enforcement of land use and building regulations in Egypt. Due to conflicts and geopolitical instability, the MENA region received several waves of refugees as a consequence of wars in neighbouring countries. This needs particular attention when studying landscape transformation processes. Sudden increase in population due to forced migration often results in increased water demand, thus diverting water from the agricultural sector towards municipal and drinking purposes. Given the low precipitation rates in the region, a sudden increase in population, accompanied by increased food demand, does not directly lead to increased agricultural production, as food policies need to match water policies. Therefore it is necessary to situate the analysis of land transformation in the biophysical context of water resources scarcity.

In view of the rapid rural-urban transformation in MENA cities, the main objective of this study was to quantify patterns of urban expansion and its effects on agricultural land from the 1970s to 2018 for four MENA cities differing in size and growth dynamics. For this purpose GIS-based remote sensing analysis was employed using different tools in ERDAS IMAGINE 2014 and open source approaches implemented in QGIS and R.

2. Methods

2.1. Study areas

For the present study, we selected a major and a minor city each in two MENA countries, Cairo and Luxor in Egypt, and Amman and Aqaba in Jordan (Fig. 1+2). Cairo, Luxor, and Aqaba share the common characteristics of a hot desert climate with low annual rainfall, mean temperatures > 20°C, and location at altitudes < 100 m asl. Amman is characterized by a slightly cooler and more humid climate due to its location at an altitude of 860 m asl (Table 1).

Cairo is the capital of Egypt and with 9,570,400 inhabitants in 2017 the country's largest city. Its metropolitan area is with 3,085 km^2 one of the biggest in Africa and the largest in the MENA region and the Arab world. Luxor, in contrast, is located on the Eastern bank of the Nile River in southern Egypt at a distance of 670 km from Cairo. In 2012, the population of Luxor was 506,588, but increased to 1,300,000 in 2018, whereas the urban area remained equal with approximately 714 km^2. Luxor's main activities are tourism and agriculture, whereby 95 % of Luxor's water is consumed by the agricultural sector (Ahmed et al., 2013).

Amman is the capital and most populous city of Jordan. In 2017, it had 4,007,500 inhabitants on a land area of 1,680 km^2, while the governorate of Amman comprises an area of 7,579 km^2. Aqaba is the only coastal city in Jordan and the administrative centre of the Aqaba Governorate. In 2017, the city had a population of 198,500 and a land area of 375 km^2 (http://dosweb.dos.gov.jo/), which is partly occupied by an industrial free trade zone, but also for tourism.

[Table 1, Fig. 1+2 near here]

2.2. Data acquisition and pre-processing

The official administrative boundaries of the study areas were imported as shapefiles from the spatial database provided by DIVA-GIS (http://www.diva-gis.org/gdata) into QGIS 2.18.18. Some enhancements and corrections were required on the city boundaries based on recent google maps, which were used as a background in the QGIS working space. Google maps were generated after installing OpenLayers plugin to QGIS. Initial image inspection revealed that the obvious areas of rural-urban transformation were much smaller than the cities' total areas, given that the remaining area consists of desert, barren land or mountains. Hence, the area analysed from each city was visually selected to be within the cities' administrative boundaries and to cover at least twice the area where the rural urban transformation happened until 2018. These study boundaries were kept constant for image processing, classifications and analysis across years.

The USGS Global Visualization Viewer (GloVis; https://glovis.usgs.gov/) server was used to download Landsat 4-5 Thematic Mappers (TM) for images of the 1980s, 1990s and early 2000s, and Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) database for the most recent images of 2018 (Table 2). All images used in this study are from the agricultural summer period (March - August) during which zero cloud cover allowed for high image quality. During this period, all green areas were clearly visible in both countries. In Egypt, agricultural activities are continuing throughout the entire year, due to the well-established irrigation infrastructure following the High Aswan Dam construction in 1970 (Abu-Zeid, 1997). In Amman green areas increase after the rainy season (from

November to May) and in Aqaba green areas are irrigated year round by municipal treated wastewater and groundwater (Al Farajat, 2001).

[Table 2 near here]

2.3 Image classification and accuracy assessment

2.3.1 Supervised classification using Maximum Likelihood Algorithm

All image bands (except thermal bands) were stacked and subsets manually clipped according to the study areas' predefined boundaries. Subsequently, a Supervised Maximum Likelihood classification (MLC) was applied by using Earth Resource Data Analysis System (ERDAS) IMAGINE 2014 for all study areas. The maximum likelihood algorithm is based on the likelihood that each pixel belongs to a particular class. It assumes that (i) likelihoods are equal for all classes, (ii) input bands are uniformly distributed, and (iii) data is normally distributed in each band of the classification (Vorovencii & Muntean, 2013). To double check classification results a code was created in RStudio, which is exemplarily shown for Luxor 2000 (Appendix A).

A total of 24 signature files were created for the classification training of all study areas across all years of analysis. The general land cover classes were "Urban", "Urban+Green" (buildings with gardens and dense shrubs), "Peri-Urban Green" (agricultural lands, shrubs and forests that are outside the urban region), "Barren lands", and "Deserts" and "Mountains" (Table 3). We thereby defined „Peri-Urban Green" as areas covered by vegetation (agricultural lands, shrubs and forests) that are outside of but directly adjacent to built-up areas. We deliberately omitted a "rural" land cover class from our analysis, since due to the arid climate prevailing throughout the year no transition from peri-urban to rural areas is visible, but instead we observe an abrupt (almost digital) change from built-up areas and/or peri-urban green to land cover classes "Desert/barren" and "Mountain/barren". In addition, historical demographic data of the four cities was collected to relate the share of the land cover classes to a per capita basis (dosweb.dos.gov.jo; http://egypt.opendataforafrica.org/).

[Table 3 near here]

2.3.2. Supervised classification using Semi-Automatic Calssification Plugin (SCP) on QGIS

The Semi-Automatic Classification Plugin (SCP) is a free open source plugin for QGIS that allows to carry out supervised and unsupervised classification of remote sensing images (Congedo, 2016). The Spectral Angle Mapper (SAM) algorithm was used in the Supervised classification by SCP to compare its classification results with the Maximum

Likelihood Classification (MLC) made by ERDAS IMAGINE and R. The Spectral Angle Mapper (SAM) is based on identifying pixel spectra through its angular information only. The length of the vector increases or decreases according to the overall illumination (increases or decreases due to the presence of sunlight or shadows), but its angular orientation will remain constant. Two features match if the angle is smaller than a specified tolerance value (Kruse et al., 1993).

2.3.3. Normalized difference vegetation index (NDVI)

The Normalized Difference Vegetation Index (NDVI) was applied as an additional tool to detect green areas in Aqaba. This city has very limited green areas with weak vegetation cover, which were hardly recognized by automatic classification and visual inspection. The NDVI was calculated using Band 4 for NIR and Band 3 for Red from Landsat 4-5. NDVI calculations were performed with R. For the code of Aqaba 2000 please refer to Appendix B.

The NDVI quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). Healthy vegetation (chlorophyll) reflects more near-infrared (NIR) and green light than other wavelengths, but it absorbs more red and blue light. The NDVI is calculated from these individual measurements as follows:

$$\mathrm{NDVI} = \frac{\mathrm{NIR}-\mathrm{Red}}{\mathrm{NIR}+\mathrm{Red}} \qquad \text{Equation 1}$$

where NIR and red stand for the spectral reflectance measurements acquired in the near-infrared and the red (visible) regions, respectively (GISGeography, 2018). Negative values of NDVI correspond to water. NDVI values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, or snow. Lastly, low, positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate high dense vegetation like temperate and tropical rainforests (values approaching 1; NASA, 2000).

2.3.4. Change detection and post-classification

For change detection, we applied the post-classification comparison as previously described by Singh et al. (1989), Paolini et al. (2006) and Brinkmann et al. (2011). It is based on overlaying two or more independently produced spectral classification results, whereby change areas are identified from one image to another taken at a different time. An analysis of cross-tabulation was performed to project the land transformation in each city. Accuracy of the classified maps was only determined by Kappa coefficients and overall accuracy. To avoid possible biases in post-classification comparison resulting from different spatial resolutions, visual on-screen interpretation with reference maps along with the automatic classification on all landsat images series were applied (Ruelland et al., 2010).

3. Results

3.1. Luxor

In the 1970s the urban area of Luxor had an extent of only 3.1 km² and was largely limited to the Eastern bank of the Nile River, surrounded by large agricultural areas extending over 192 km². Urban areas gradually emerged on the Eastern and Western banks of the Nile River (Fig. 6a+b), and increased to 91 km² by 2018 (encompassing 0.5% of the total area of interest in 1975, but more than >15% in 2018). From 1975 to 2000 a decrease in agricultural areas was observed and new cultivated areas in the deserts were developed. From 2011 to 2018, apparent urbanization rates increased again, which was accompanied by a reduction of agricultural areas of 2% (Fig. 8a+b). From 1975 to 2018, agricultural areas in the surroundings of Luxor decreased by 793 ha. Most urban expansion occurred into desert areas.

While the city grew into the former peri-urban zone, new cultivated areas emerged in the peri-urban fringes at the border with the desert, especially after 1994, the year of the New Esna Barrage inauguration (Ahmed et al., 2013) which was constructed on the Nile River 90 km upstream of Luxor city, and replaced the old Esna Barrage to control and improve the performance of water distribution and to cover increasing needs for water (El Gamal et al., 2007). The total peri-urban green area is not representative for the overall land transformation processes, as newly cultivated areas substituted part of the peri-urban areas lost by urbanization. To better understand this replacement process, change detection was used to quantify green area changes within the administrative city boundary (Fig. 1), comprising urban and peri-urban areas (Fig. 3). From 1990 to 2011, around 94.5 km² were cultivated in the peri-urban zoneIn 1984 arable lands in Luxor had only very little vegetation, which reflected the Nile River's low flow during this period, as a consequence of the severe drought in the Nile Basin countries between 1978 to 1987. However, in our study these areas were classified as agricultural, not barren lands.

To validate the accuracy of the analytical procedures, a Spectral Angle Mapper (SAM) algorithm by QGIS-SCP and the Maximum Likelihood Classification (MLC) implemented in R were used in the classification process for Luxor 2000 (Fig. 4). The analysis showed a very good agreement between MLC and SAM algorithms, as the accuracies were 98 % for the desert, 94 % for the green and 97 % for the urban landcover class.

[Fig. 3 + 4 near here]

3.2. Cairo

The urban area of Cairo had an extent of only 47.5 km² in 1972, but increased by 887 km² over the next 46 years, resulting in an urban area of 935 km² in 2018. This expansion took mainly place on barren land, which decreased by 1,079 km² during the same period. Urban green areas extended over 99 km² in 1972, which increased to 256 km² in 2018. This corresponds to 2.6-fold increase of urban green areas, compared to a nearly 20-fold increase of urban (built-up) area.

Agricultural areas (peri-urban green) increased by 29 km² during the study period, which were in 1970s mainly concentrated in the north-western area of Cairo. This zone became gradually urbanized, and peri-urban green areas completely disappeared at this site until 2011. In the meantime, however, a new peri-urban green area in the north of Cairo appeared, which is clearly visible in the satellite image of 2018 (Fig. 6c+d). In general, peri-urban green areas of Cairo are very limited, and ranged from 3 % (84.4 km²) in 1972 to around 4 % (113.3 km²) in 2018, in relation to the total area of interest (Fig. 8d). Urban areas in contrast increased from 1.6 % in 1972 to more than 32 % in 2018, resulting in urbanization rates of around 133% from 2000 to 2011, and 200% from 2011 to 2018 (Fig. 8e).

[Fig. 6 + 8 near here]

3.3. Aqaba

The area of interest for Aqaba amounts to 168.1 km^2. Urban areas increased from 1 km² in 1975 to 43.1 km² in 2018. This expansion took mainly place on barren land, but also peri-urban green areas decreased by 325 ha during the same period. Peri-urban green areas in Aqaba were very restricted during the entire study period (Fig. 7a+b). The highest extent of peri-urban green areas was observed in 2000, with a share of 4% of the total area (634 ha), which decreased to 0.5% (92 ha) in 2018 as a consequence of urbanization. Sudden increases in urbanization rates accompanied by decreases in green areas were noticed after 2000 and 2011 (Fig. 9a+b).

3.4. Amman

The area of interest for Amman has a size of 1,760.1 km^2. Woodlands and shrubs in the north and west, agricultural lands in the south, and barren lands and mountains in the east surround the urban area of Amman (Fi. 7c+d). The urban area occupied 12.8 km² in 1984, and increased by 281 km² until 2018. Urban green areas in contrast increased by only 125 ha during the same period, whereas peri-urban agricultural areas were reduced by 122 km². Urbanization rates in Amman were most pronounced in the late 1990s (Fig. 9d+e).

The growth patterns of the city of Amman are similar to Luxor, as in both cities peri-urban green areas were replaced by urban areas, while at the same time new cultivated lands emerged at different locations. For this reason, an area change detection was applied for the peri-urban green zone of Amman. From 2000 to 2011 a vast expansion in urban and cultivated lands occurred (Fig. 5).

[Fig. 5; 7; 9 near here]

3.5. Comparing urbanization dynamics of the four cities

Our study showed that the larger the city the larger the absolute increase of the urban area over the last decades. The land cover class "urban green" was only detected in the two larger cities, Cairo and Amman, whereas it does not seem to play a major role in Luxor and Aqaba. Before the 21st century urban green areas dominated over urban built-up areas in Cairo and Amman, whereas from 2000 onwards a transition towards a reduction in urban green space took place, which decreased to 30% and below until 2018.

Peri-urban green (which is partly composed of peri-urban gardens and agriculture, but may also comprise shrubs and forests) has the largest areal extent in Amman (382 km² in 2018) and Luxor (183.9 km² in 2018). In Luxor, peri-urban green occupies as twice as much space as the urban built-up area, and in Amman, it occupies 90% of the urban built-up area. In Cairo and Aqaba in contrast, peri-urban green occupies only a size of 10% and 2%, respectively, of the total urban area. The strongest decrease (in absolute values) of the agricultural area was observed for Amman, which decreased by 122.4 km² from 1984 to 2018. For Luxor a reduction of 17.2 km² and for Aqaba of 3.3 km² was estimated for the same time period, whereas it increased in Cairo.

Historical demographic data of the four cities was collected to relate the share of the land cover classes "peri-urban green" and "urban green" to a per capita basis (Fig. 8 c+f, Fig. 9 c+f). The analysis showed that green areas per capita declined dramatically over the study period. For 2018 values were lowest for Aqaba with 4.6 m^2/capita and Cairo with 12 m^2/capita. In Amman it dropped from 500 m^2/capita in 1975 to < 91 m^2/capita in 2018 and in Luxor from 2,070 m^2/capita to < 142 m^2/capita during the same period.

4. Discussion

4.1 Methods and tools used for satellite image classification

The two approaches, Maximum likelihood classification (MLC) applied in ERDAS IMAGINE 2014 and R coding and Spectral Angling Mapping (SAM) algorithm implemented in QGIS-SCP yielded similar classification results. This may be expected when pixel spectra from different classes are well distributed in feature space with uniform illumination, which was the case in the images with zero clouds. It also leads to a high likelihood that angular information alone provides good separation (Richards, 1999). All of our images could be accurately classified. Some error confusion only occured in the images of the 1970s (especially for Aqaba 1975), which was most likely due to a poor resolution and hardly distuingishable colours of mountains, barren lands, and roads. For most of the images the overall classification accuracy was higher than 95 % and Kappa coefficients were higher than 0.91.

4.2. Land cover changes over the last five decades and their drivers

Growth of built-up areas occurs mostly along major transportation systems, and cropland is one of the most affected land uses through urban growth (Bagan & Yamagata, 2012; Wakode et al., 2014). Dynamics of urbanization and urban growth in developing countries are usually linked to demographic factors (Jedwab et al., 2017). Many driving forces of land use changes are well documented (Lambin et al., 2001), but interpretation remains difficult, since it is the result of many often interacting factors including population growth and climate variability (Leblanc et al., 2007). Political, social and economic reasons are playing important roles in land use changes (Hersperger et al., 2018).

Urbanization rates were highest for Cairo and Aqaba, the largest and smallest cities in this study. In both cities, urban expansion mostly occurred on desert areas, which was the dominating land cover class outside the cities. However, in the Nile delta urban expansion also occurred on highly fertile soils (Shalaby & Moghanm, 2015). Spatial patterns of urban growth in Cairo mainly followed transportation corridors (Hou et al., 2016). Luxor and Amman share similar land transformation processes. Urban encroachment mainly occurred into the peri-urban green areas, whereas cultivation and/or degradation of agricultural/green areas could be observed in the transition zone from the peri-urban space to the desert. Between 1990 and 2011, and especially after the construction of New Esna Barrage in 1994, Luxor gained around 94.5 km² of cultivated lands at the peri-urban fringe, but at the same time lost around 37 km² (Fig. 9 a+b). Amman had around 120 km² of cultivated land at the peri-urban fringe between 2000 and 2011, but in the meantime lost almost the same area (Fig. 9d+e). Encompassing a lager time span than our study, Al Rawashdeh & Saleh (2006) estimated that Amman lost 23% of its fertile land between 1918 and 2002.

New water projects can help to compensate urbanization-related losses of agricultural areas, as it became evident for Luxor through the construction of the New Esna Barrage in 1994. This led to the cultivation of new land outside the city. It is well known that the extension of roads and infrastructure plays a considerable role for urban agglomerations (Fang & Yub, 2017). Another main driver for the Egyptian case study cities was the so called "Arab Spring", which started in 2011, and is considered one of the main political and social reasons for the sudden increase in the urbanization rates and the concomitant decline of the peri-urban agricultural/green areas in Cairo and Luxor after 2011 (Khamis et al., 2015). During this period governmental authorities lost control, hence many people grabbed the chance and converted irrigated agricultural land into housing areas.

In Amman and Aqaba urbanization rates increased rapidly after 2000. Especially in Amman, this sudden increase can be related to the migration of refugees from areas of conflict such as Palestine (UNRWA, 2019), while refugees from Iraq came to Jordan after the 2003 Iraq war, and from Syria after 2011.

Between 2011 and 2018 agricultural and green areas in Amman and Aqaba declined rapidly. Drivers for Amman may be rapid urbanization and climate change, for Aqaba's development political decisions such as the 2015 agreement on management and utilization of the ground water in the Disi-Saq Aquifer between Jordan and Saudi Arabia were certainly important (Eckstein, 2015). Jordan seems to have sufficient productive areas available to buffer the effects of urban expansion on food production for the next decades, but effects of climate change may still result in an increase in irrigation requirements and cropland area (Koch et al., 2018).

4.3. Implications of urbanization for food security, urban agriculture and waste management

Several authors provide evidence that urban agglomerations largely depend on food produced outside urban and peri-urban areas (Drechsel et al., 2007; Porter et al., 2014; Zhou et al., 2012). Studies on geographical sources supplying food to urban centers, however, are scarce, which particularly refers to the MENA region. Both Egypt and Jordan highly depend on food imports, and are thus vulnerable to increasing food prices (Veninga & Ihle, 2018). In 2016, per capita imports of wheat, the most important staple crop in the region, were around

90 and 200 kg year^{-1} for Egypt and Jordan, respectively (Fig. 10). Per-capita wheat imports strongly increased in both countries in the late 70s, which can be mainly attributed to changes in the diet and population increase.

Urbanization creates new markets, and growing urban areas are important sales market for intensive peri-urban vegetable production (FAO, 2011). The importance of UPA to provide cities with fresh produce is very context-specific. For Egypt, a rather low success of urban agriculture and lacking institutional frameworks has been documented (Tawk et al., 2011). In Cairo crop production is rather confined to peri-urban areas, but can be also found in informal settlements. A contrasting picture was reported from Amman, where a high share of the land remains uncovered by buildings and is thus still available for agriculture (Tawk et al., 2011). Due to its market proximity the main target of UPA, however, is to supply cities with high value perishable fruits and vegetables, rather than staple crops.

Urban centers are strong nutrient sinks through the obviously high amount of food inflows, whereas rural areas export nutrients (Drechsel et al., 2007; Karg et al., 2016). The same applies for virtual water flows from production to consumption regions, which refers to the amount of water needed for the production of food commodities (Hoff et al., 2014; Akoto-Danso et al., 2019). To minimize environmental pollution and reduce waste loads an efficient municipal waste management is required. In this context, UPA has a well-known potential to absorb part of the solid and liquid waste accumulating in urban centers (Faruqui et al., 2008; Grard et al., 2015; Al-Ismaili et al., 2017). In many cases, however, areas designated for UPA heavily compete with other claims, such as for construction and housing. Competition does not only exist for space, but also for water, especially in water scarce regions such as MENA, since urban water demands are increasing (Flörke et al., 2018). Particularly in dry areas, growing cities will have priority for water supply, thereby reducing available water for agriculture, which leads to further losses of agricultural land (FAO, 2011). This pressure on resources became also evident in the present study, which highlighted decreasing green space in the cities of Cairo and Amman, and a partial displacement or shift of peri-urban green areas.

[Fig. 10 near hear]

4.4. Existing initiatives to overcome land and water scarcity

In view of the rapid transformation processes in urban and peri-urban areas of the study region, new options for non-traditional sources of water and land are needed. UN-Habitat proposes to minimize urban expansion by encouraging densification and development of more compact cities (Seto & Ramankutty, 2016). Egypt and Jordan already started constructing new plants for seawater desalination and reclaiming new areas to cover the growing future needs. In 2015, Egypt launched a national project for constructing new communities and reclaiming 6,070 km² in the western desert and Sinai. Groundwater from The Nubian Sandstone Aquifer will be the main source for irrigation and domestic purposes. In March 2017, a new seawater desalination plant was inaugurated in Aqaba to produce around 5 million m^3 clean water annually for drinking, agricultural, and industrial purposes. This in turn will reduce the high rates of groundwater consumption in the Disi aquifer (The Jordan Times, 2017). Jordan also signed a plan with Israel and Palestine for constructing the Red-Dead Sea Pipeline Project, which envisions producing fresh water through desalination (Josephs, 2013).

5. Conclusions

The current study shows that over the study period urbanization strongly affected land cover changes in and around the four case study cities. In all cases it became evident that peri-urban green areas had shrunk or shifted due to increased expansion of built-up areas. Only in Cairo a slight increase of peri-urban green area was observed. Whereas the land cover class "urban green" was non-existent in Luxor and Aqaba, it significantly decreased in Cairo and Amman. It has to be noted that changes in sensor quality and image resolution make time series analysis difficult when using landsat data for the detection of rural-urban transformation processes. This is particularly true for peri-urban areas which are often undergoing particularly dynamic transitions in space and structure. We have omitted this problem by summarizing this space as "peri-urban green" comprising peri-urban gardens and agricultural land. This may be justified for our study sites are they are surrounded by barren desserts, but typically warrants more detailed attention elsewhere. In the future approaches combining big data capabilities will allow likely to allow to fuse multi- and hyper-spectral reflectance data with 3-D models of plant and built-up structures offering more dynamic insights into the ecological consequences of land use and land cover changes.

Like elsewhere also in the four MENA cities of our study land use and land cover changes are a result of the combination of different drivers, which include population growth as well as political and economic reasons. Future research also comprising field surveys and land reconnaissance studies may allow a better understanding of the underlying environmental and socio-economic forces, which interact and lead to different effects on the dynamics and patterns of urban, peri-urban and rural areas across the MENA countries. As elsewhere effective city planning needs to address competing claims for housing and green space and to recognize the role that UPA can play for food production, income provision, waste recycling, and creation of green space.

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Table 1. Major characteristics of the case study cities Luxor and Cairo in Egypt and Aqaba and Amman in Jordan.

City	Area (km^2)	Population (2017-2018)	Altitude (m asl)	Coordinates	Mean annual temp. (°C)	Mean summer temp. (°C)	Mean rainfall ($mm\ yr^{-1}$)	Climate*
Luxor	714	1,300,000	76	25°41′N 32°39′E	24.6	40.0	0	BWh
Cairo	3,085	9,570,441	29	30°08'N 31°24'E	21.3	34.0	18	BWh
Aqaba	375	198,500	24	29°31′N 35°0′E	24.6	35.0	32	BWh
Amman	7,579	4,226,700	857	31°59'N 35°59'E	16.6	31.0	350	BSh

Source: https://www.weatherbase.com/, * Climate according to Köppen-Geiger classification

Table 2. Summary of satellite images used in the study of four cities in the MENA region.

City	Date	Landsat No.	Scanner	Pixel Size (m)
Luxor (path/row: 175/42)	30-06-1975	2	MSS	60*60
	06-06-1984	5	TM	30*30
	26-06-1990	5	TM	30*30
	08-08-2000	5	TM	30*30
	17-06-2011	5	TM	30*30
	07-06-2018	8	OLI/TIRS	30*30
Cairo (path/row: 176/39)	31-08-1972	1	MSS	60*60
	02-07-1984	5	TM	30*30
	03-07-1990	5	TM	30*30
	30-07-2000	5	TM	30*30
	13-07-2011	5	TM	30*30
	16-07-2018	8	OLI/TIRS	30*30
Aqaba (path/row: 174/40)	29-06-1975	2	MSS	60*60
	04-07-1984	5	TM	30*30
	21-07-1990	5	TM	30*30
	16-07-2000	5	TM	30*30
	15-07-2011	5	TM	30*30
	16-06-2018	8	OLI/TIRS	30*30
Amman (path/row: 174/38)	29-06-1975	2	MSS	60*60
	18-06-1984	5	TM	30*30
	18-05-1990	5	TM	30*30
	29-05-2000	5	TM	30*30
	12-07-2011	5	TM	30*30
	02-07-2018	8	OLI/TIRS	30*30

Table 3. Overview of land cover classes applied for each of the four cities in the MENA region.

Luxor	Cairo	Aqaba	Amman
Urban (buildings, roads)	**Urban** (buildings, roads)	**Urban** (buildings, roads, industrial area, harbour)	**Urban** (buildings, roads)
Peri-Urban Green (shrub, agricultural land)	**Peri-Urban Green** (shrubs, agricultural land)	**Peri-Urban Green** (shrubs, agricultural land)	**Peri-Urban Green** (shrubs, forests, agricultural land)
-	**Urban+green** (buildings, gardens and shrubs)	**-**	**Urban+green** (buildings, gardens and shrubs)
Desert/barren	**Desert/barren**	**Mountain/barren**	**Mountain/barren**

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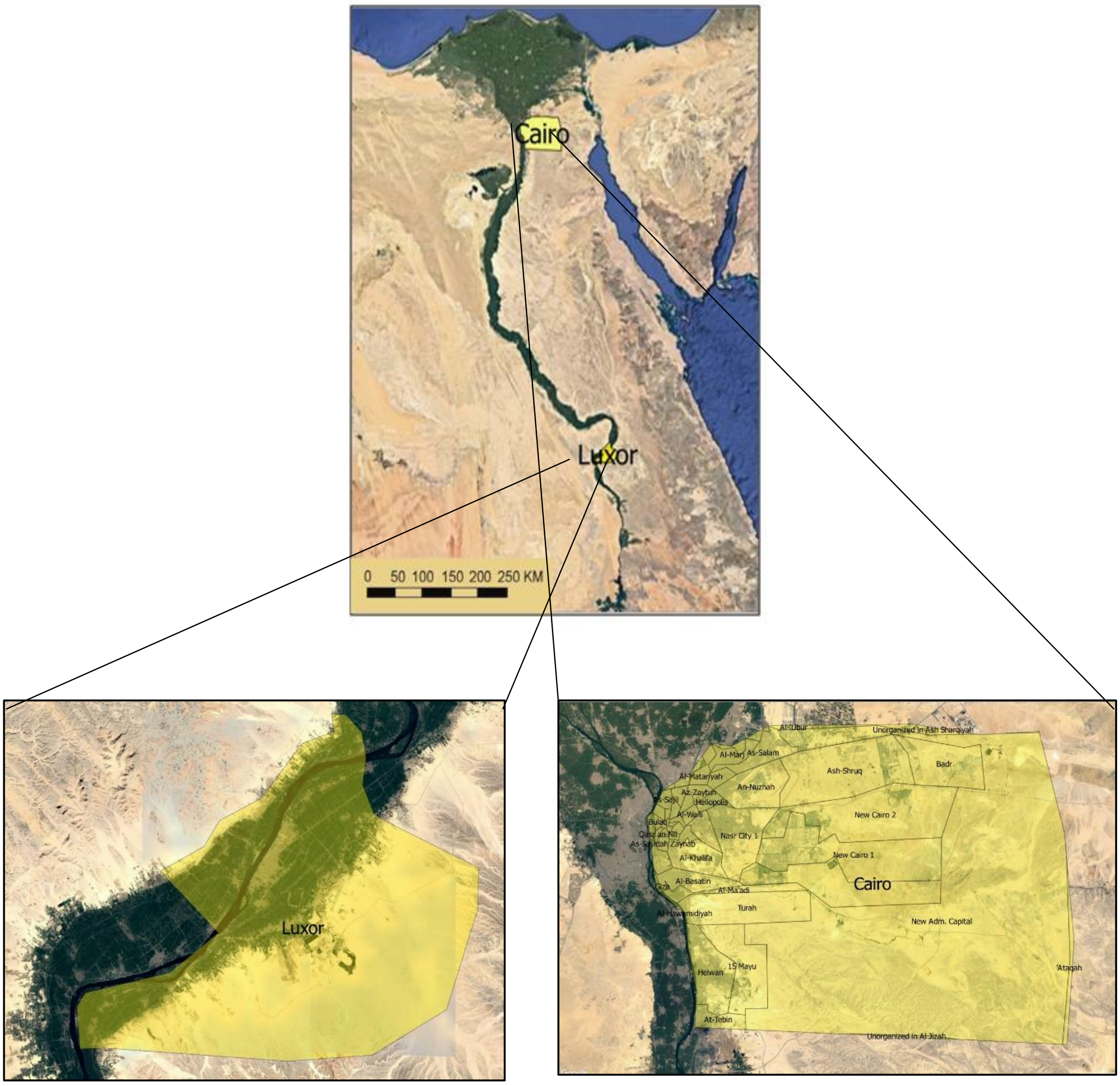

Fig. 1. Study areas of Luxor and Cairo in Egypt (Source: Google Earth).

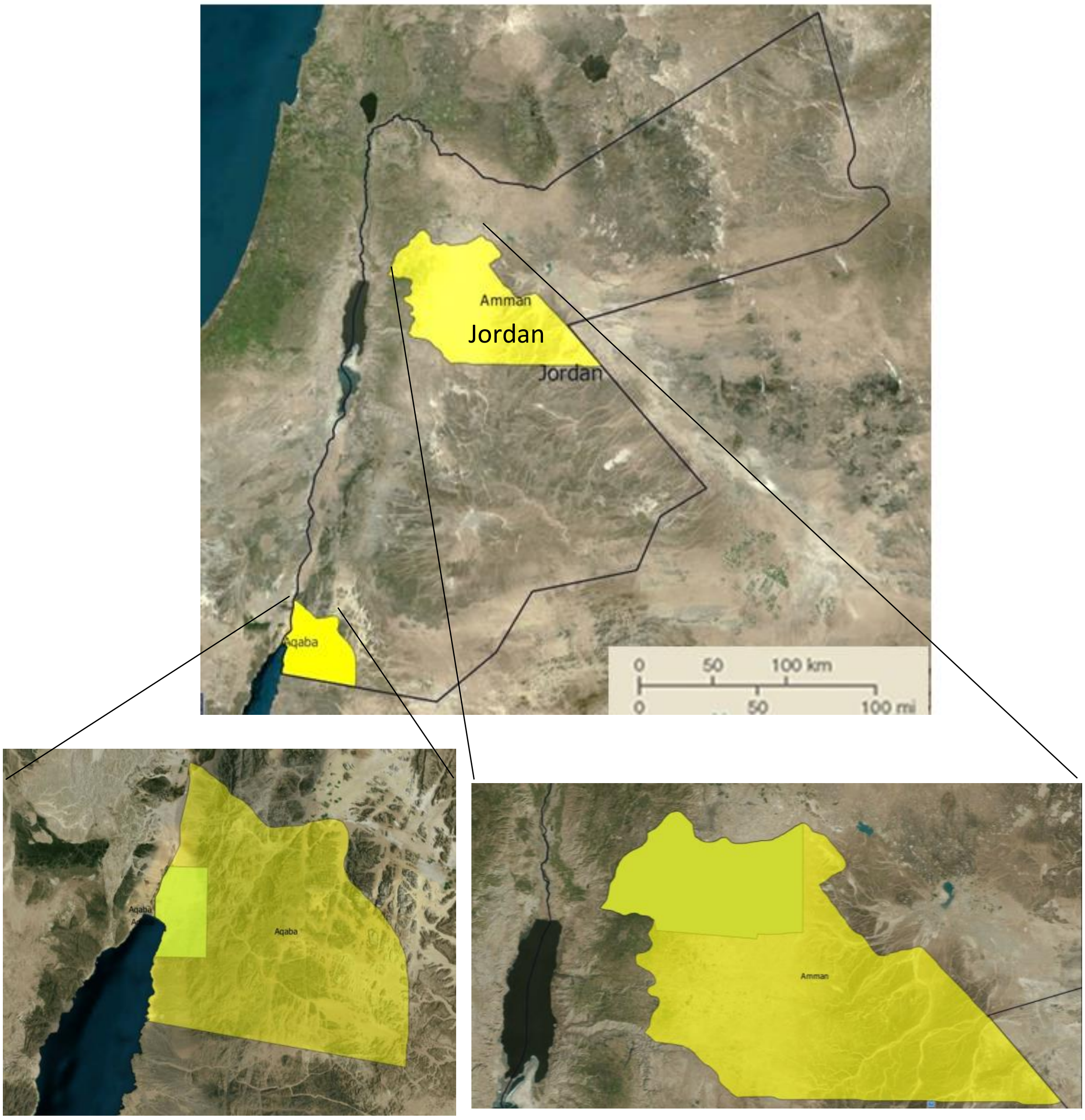

Fig. 2. Study areas of Aqaba and Amman in Jordan (Source: Google Earth).

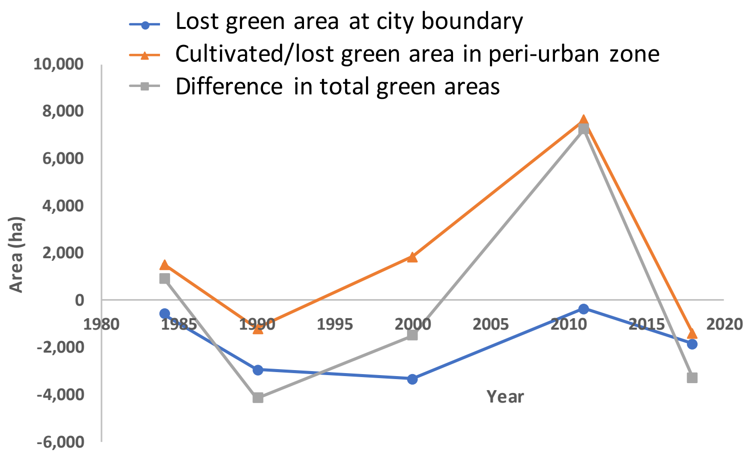

Fig. 3. Changes of peri-urban green areas in Luxor (Egypt) from 1984 to 2018.

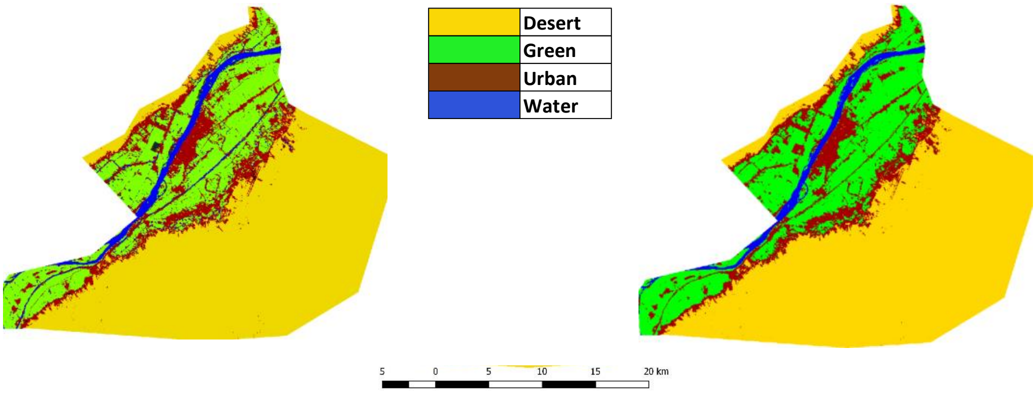

Fig. 4. Results of a supervised classification of land use for Luxor in 2000 using SAM algorithm by QGIS (left) and MLC by R coding (right).

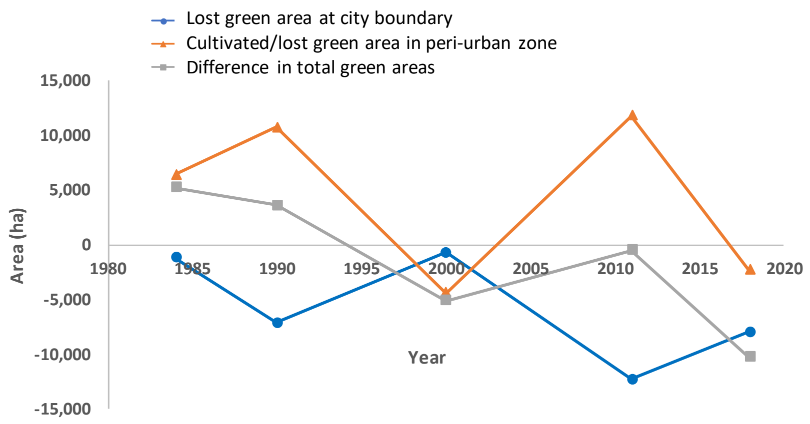

Fig. 5. Changes of peri-urban green area in Amman (Jordan) from 1984 to 2018.

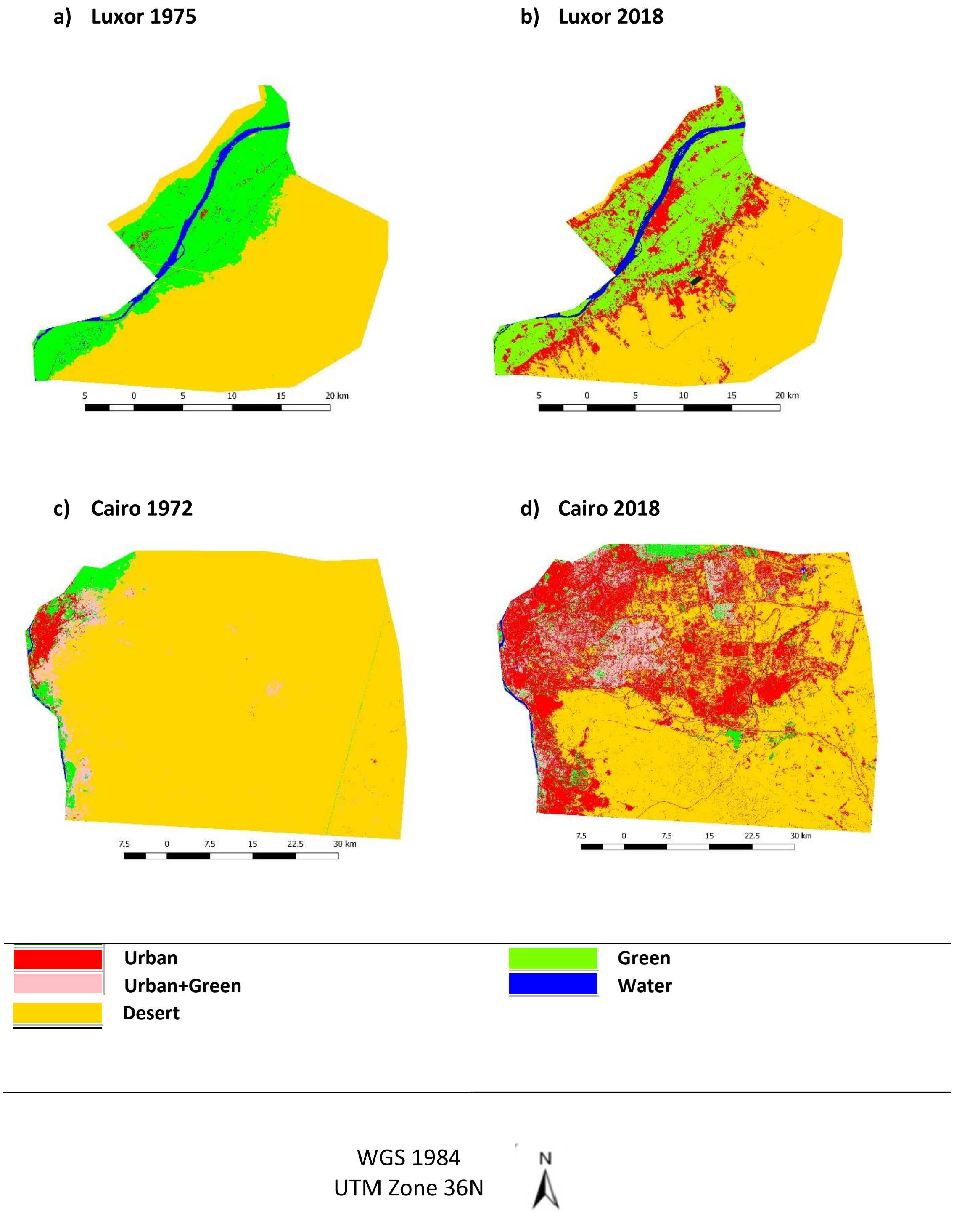

Fig. 6. Land cover changes over five decades in Luxor and Cairo, Egypt.

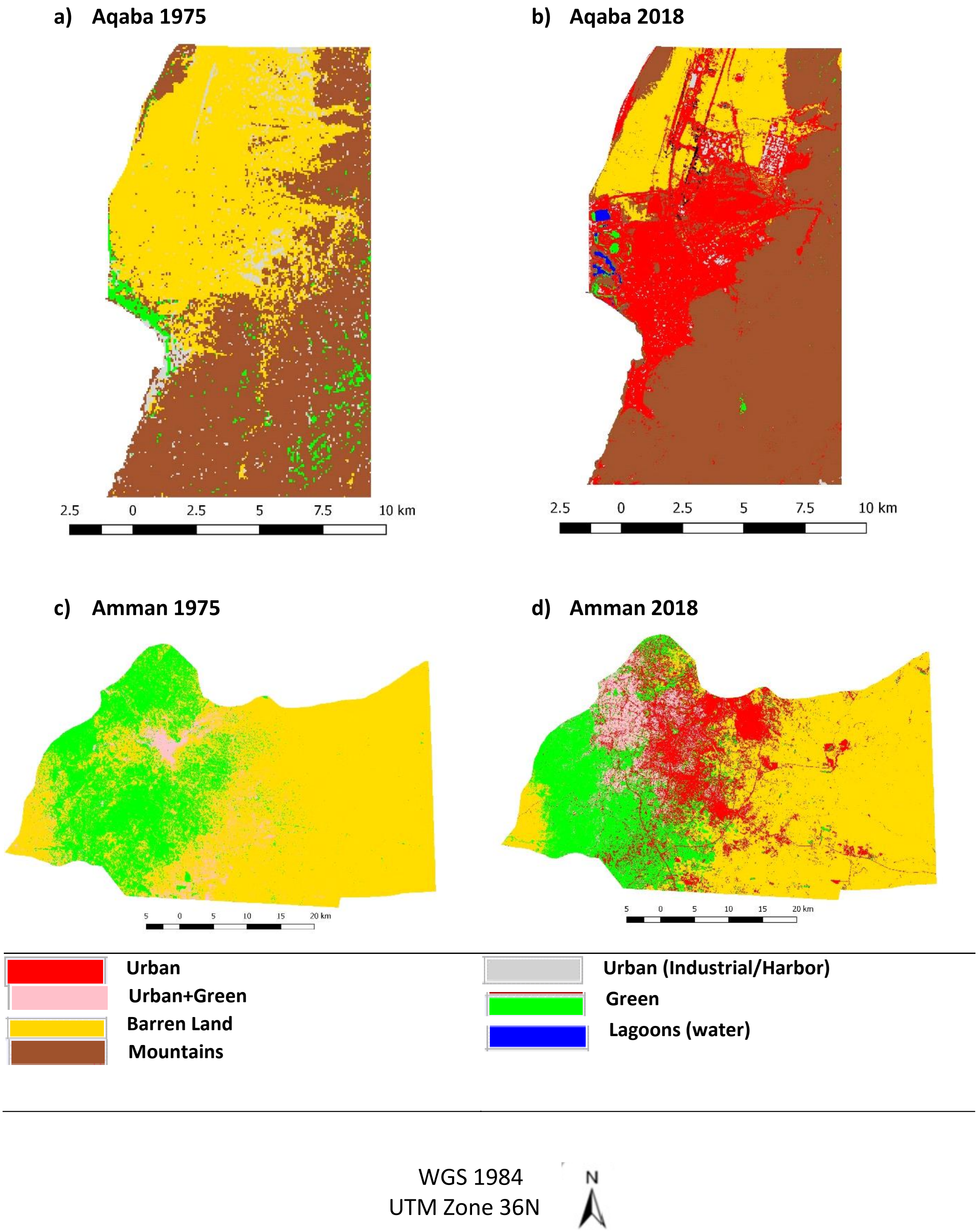

Fig. 7. Land cover changes over five decades in Aqaba and Amman, Jordan.

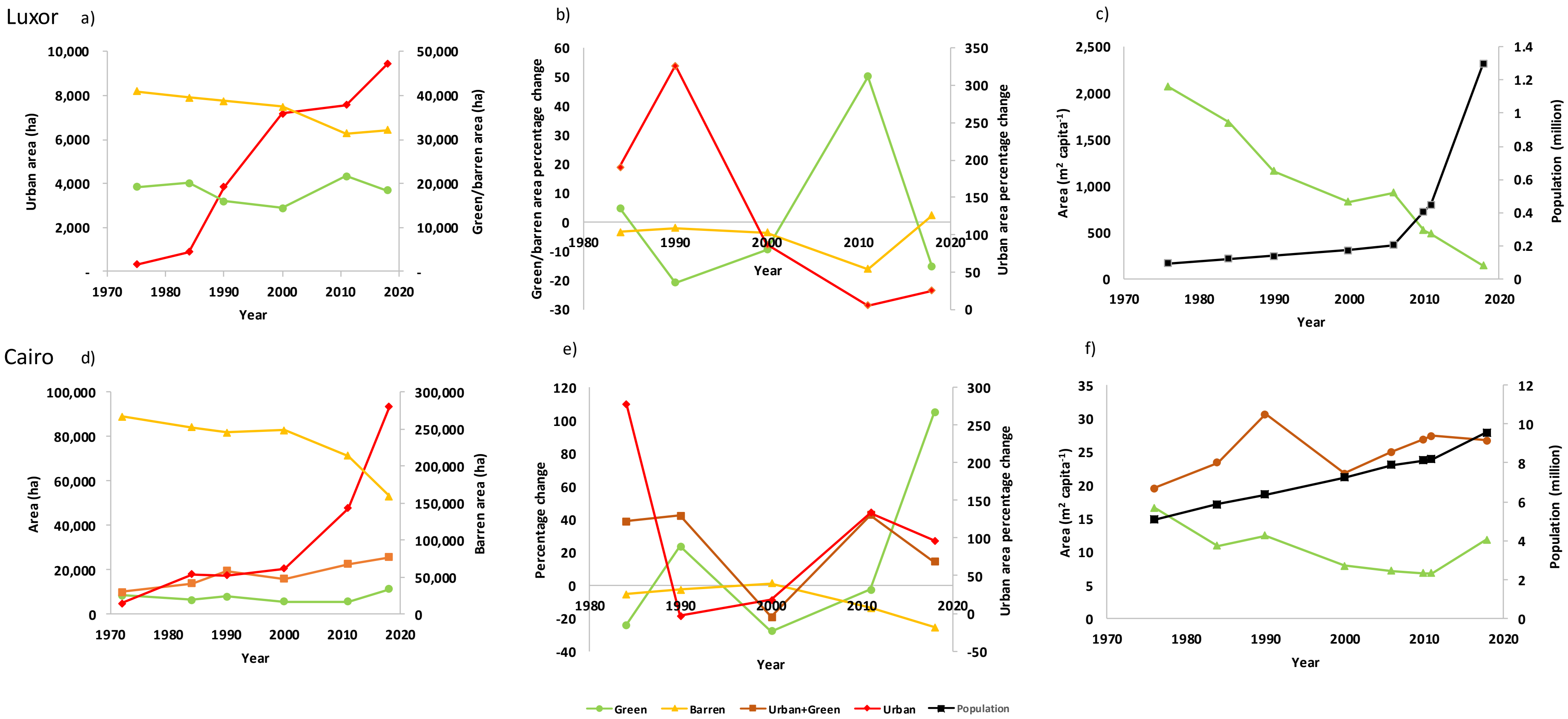

Fig. 8. Area changes (a+d), percentage changes (b+e) and per-capita changes (c+d) of different land cover classes over the last five decades in Luxor and Cairo, Egypt.

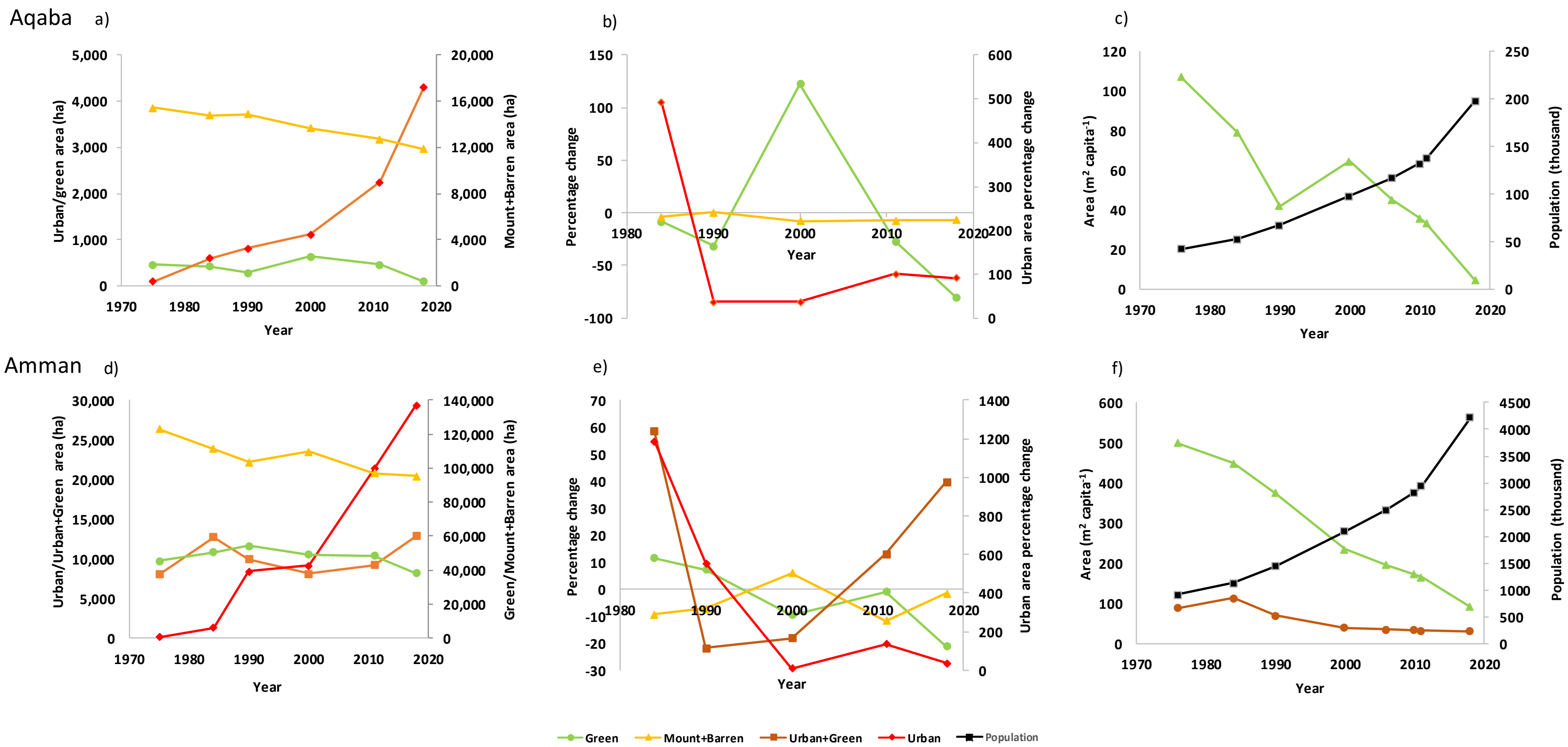

Fig. 9. Area changes (a+d), percentage changes (b+e) and per-capita changes (c+d) of different land cover classes over the last five decades in Aqaba and Amman, Jordan.

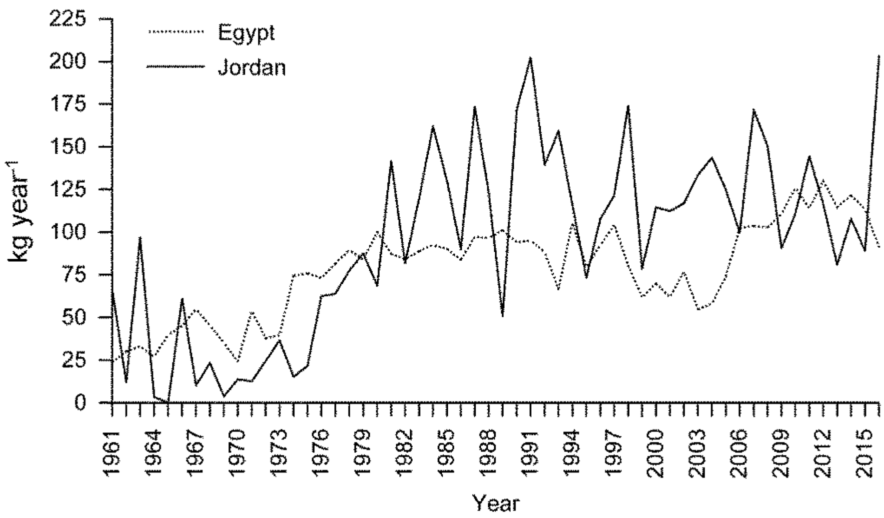

Fig. 10. Per capita imports of wheat in Egypt and Jordan from 1961 to 2016 (Source: www.fao.org/faostat/ and https://data.worldbank.org/).