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ORIGINAL ARTICLES

Urban Sprawl of greater Cairo and its Impact on the Agricultural Land Using Remote Sensing and Digital Soil Map

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ABSTRACT

Urban sprawl is one of the main problems that threaten the limited highly fertile land of Egypt. In this research, satellite images of Land sat TM 1992 and Egypt-sat-1, 2009 has been used to study the urban sprawl and its impact on agricultural land in Cairo and Giza. Maximum likelihood supervised classification, and hybrid classification using ancillary data, visual interpretation and expert knowledge of this area through GIS further refined the classification results. Post-classification change detection techniques were applied for monitoring the urban sprawl in the study area. Ground truth collected during several field trips conducted in 2009 and topographic map of 1992 was used to assess the accuracy of the classification results. Using ancillary data, visual interpretation and expert knowledge of the area through GIS further refined the classification results. Post-classification change detection technique was used to produce change image through cross-tabulation. Combining the soil and land capability maps, in one hand, and the urban thematic layers, in other hand, using GIS, made it possible to point out the risk of urban expansion at the expense of the highly capability class. During the (1992 – 2009) period, the high capable soils (Class I) decreased from 615.2 to 494.2 km^2 (19.7 % of the total area). The moderate capable soils decreased from 145.9 to 122.2 km^2 (16.2 %), while the marginally capable soils decreased from 1558.3 to 1440.1 km^2 (7.6 %), during the same period. The urban settlement increased from 244.8 to 740.7 km^2, representing 202.5 % of the total area

Key words: urbanization, Surface sealing, Remote Sensing, GIS, Land cover changes, Land use policy.

Introduction

Urbanization is one of the most widespread anthropogenic causes of the loss of arable land (Lopez *et al*., 2001). Encroachment of urban settlements on agricultural lands may have dire consequences. The continuous increase in population density increasing pressure on areas already inhabited and caused a decrease in area per capita from 0.12 ha in 1950 to 0.06 ha in 1990 (Suliman, 1991) and to 0.04 ha in 2009 (CAPMAS, 2009). Although urban areas currently cover only 3% of the Earth's land surface, they have marked effects on environmental conditions at both local and global scales (Herold *et al*., 2003; Liu and Lathrop, 2002), including climate change (Grimm *et al*., 2000). Since ecosystems in urban areas are strongly influenced by anthropogenic activities, considerably more attention is currently being directed towards monitoring changes in urban land use and land cover (Stow and Chen, 2002).

Therefore, determining the trend and the rate of land cover conversion are necessary for the development planner in order to establish rational land use policy (Shalaby and Tateishi, 2007). For this purpose, the temporal dynamics of remote sensing data can play an important role in monitoring and analyzing land cover changes. Accurate and up-to-date land cover change information is necessary to understand both human causes and environmental consequences of such changes (Aboel Ghar *et al*., 2004). As a consequence, information about land use/land cover is essential for any kind of natural resource management and action planning. Accurate information about land use/land cover changes of an area is essential for understanding the interactions between human and natural resources for better management of decision making (Lu *et al*., 2004). The importance of properly mapping land use/land cover and its change as well as updating it through time has been acknowledged by various research workers for the decision making activities; as for example, application of land cover change in an urban environment by Deng *et al*., (2005). Urban sprawl causes loss of agricultural land, which results in substantial changes on agricultural ecosystems. Monitoring these changes and planning urban development can be achieved using multi-temporal remotely sensed data (Yikalo and Pedro, 2010). Soil properties, such as soil texture and structure, particle-size distribution, soil reaction, and bulk density, help us to understand and predict how soils react and respond to different uses. Construction activities, compaction, and surface sealing dramatically change soil properties and can sometimes result in a reduced ability to perform the critical functions or activities of natural soil. Not all kinds of soil are suitable for the many urban uses that are required.

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Sandy soils are better drained than clay soils, and some soil layers that are exposed during construction have low strength and are easily compacted. When exposed, bedrock and hardpans are difficult to manage. Knowledge of the soils on the site is needed prior to construction.

Change detection is the process of determining and/or describing changes in land-cover and land-use properties based on co-registered multi-temporal remote sensing data. The basic premise in using remote sensing data for change detection is that the process can identify changes between two or more dates that is uncharacteristic of normal variation. Numerous researchers have addressed the problem of accurately monitoring land-cover and land-use change in a wide variety of environments (e.g. Singh, 1989; Almutairi and Warner, 2010; Shalaby and Tateishi, 2007; Muchoney and Haack, 1994). Many studies have discussed land cover and land use changes in arid, semi-arid regions (e. g. Mendoza and Etter, 2002; Rembold *et al*., 2000; Lambin and Ehrlich, 1997; Lenney *et al*., 1996; Ram and Kolarkar, 1993; Sadek, 1993), these studies showed that urban expansion usually occurs through the loss of agriculture land. There are many techniques available to detect and record differences (e.g. image differencing, ratios or correlation) and theses might be attributable to changes in land cover (Deng *et al*., 2008; Li and Yeh, 2004; Maldonado *et al*., 2002; Yuan *et al*., 1999; Stow *et al*., 1996; Singh, 1989). However, the simple detection of change is rarely sufficient in itself: information is generally required about the initial and final land cover or types or land uses, the "from-to" analysis (Khorram *et al*., 1999). Post-classification comparisons of derived thematic maps go beyond simple change detection and attempt to quantify the different types of change. The degree of success depends upon the reliability of the maps made by image classification. Broadly speaking, large scale changes such as widespread logging or major urban development might be mapped easily; whereas evolutionary changes such as, erosion, succession, colonization or degradation, the boundaries may be indistinct and class-labels uncertain (Foody and Boyd, 1999; Khorram *et al*., 1999; Shalaby and Tateishi, 2007).

The objective of this study is to assess and monitor the urban sprawl of greater Cairo (Cairo and Giza) and its impact on agricultural land using multi temporal remote sensing data and digital soil map.

2. Study area:

Greater Cairo which includes Cairo and Giza is currently the most populated city of Africa, and by some accounts the thirteenth most populous city in the world. Cairo is the administrative center of Egypt. Cairo and Giza are located in northern Egypt, known as Lower Egypt, 165 kilometers south of the Mediterranean Sea and 120 kilometers west of the Gulf of Suez and Suez Canal (Figure 1). Cairo and Giza governorates cover an area of 5502.5 km^2. The study area has a hot dry climate and rain is very rare. It experiences its hottest temperatures in July and August, averaging 28 °C, with a maximum of around 35 °C. Winter temperatures are normally in the range of 10° to 19 °C.

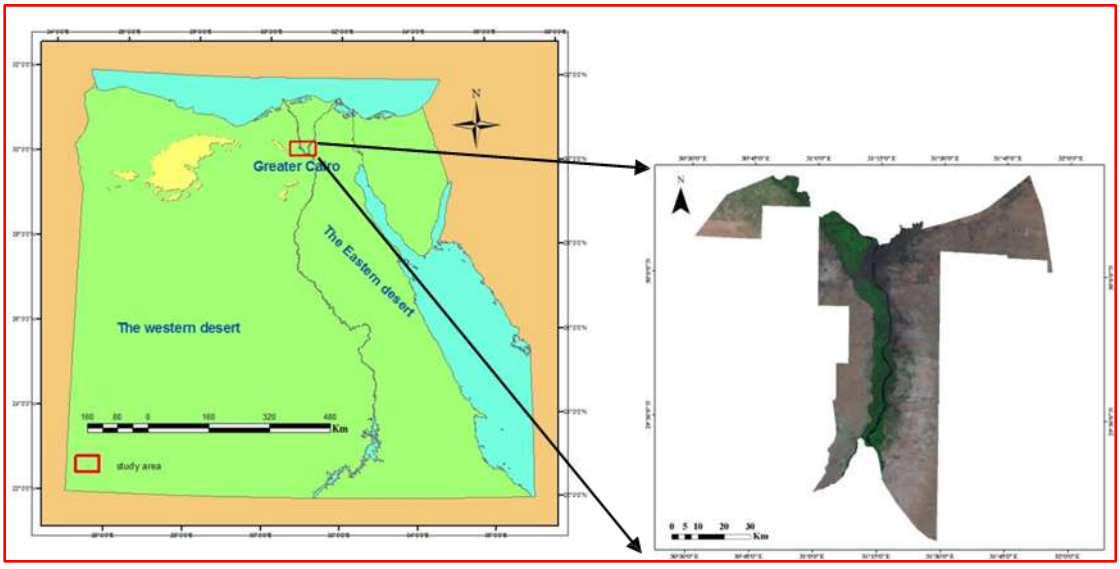

Fig. 1: Location map of the study area

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Materials and Methods

Materials:

Soil maps:

The soil maps of Egypt (ASRT, 1982) are the main materials collected and converted to digital format. The collected soil maps cover the alluvial arable land and their interference with Desert fringes. These maps include 2 map sheets at a scale of 1 : 100,000 in analogue format, covering the study area.

Topographic maps:

Topographic maps at scale 1: 50,000 covering Cairo and Giza, produced by the Egyptian General Survey Authority (EGSA) were converted to a digital format.

Satellite data:

A number of 3 Egyptsat-1images dated 2009 and 1 Land sat satellite image dated 1992 were used to study the urban sprawl in Cairo and Giza. The specification of the satellite used were be as illustrated in table (1).

Table 1: Specification of Land sat TM and Egypt Sat-1 images.

Band	Spectral resolution (m)			Spatial resolution (μm)		
	Land sat TM	Land sat ETM+	Egypt Sat-1	Land sat TM	Land sat ETM+	Egypt Sat-1
1	30	30	7.8	0.45–0.52	0.45–0.52	0.51–0.59
2	30	30	7.8	0.52–0.60	0.53–0.61	0.61–0.68
3	30	30	7.8	0.63–0.69	0.63–0.69	0.80–0.89
4	30	30	--	0.76–0.90	0.78–0.90	--
5	30	30	7.8	1.55–1.75	1.55–1.75	1.1–1.7
6	120	60	--	10.4–12.5	10.4–12.5	--
7	30	30	--	2.08–2.35	2.09–2.35	--
8	--	30	7.8	--	0.52–0.90	0.5–0.89

3.2. Methods:

3.2.1. Geometric correction:

Accurate per-pixel registration of multi-temporal satellite data are essential for change detection because registration errors could be inferred as land use/cover changes, leading to an overestimation of actual change (Stow, 1999). Change detection analysis is performed on a pixel-by-pixel basis; therefore any mis-registration greater than one pixel will provide an anomalous result for that pixel. To overcome this problem, the root mean square error (RMSE) between any two dates should not exceed 0.5 pixels (Lunetta and Elvidge, 1998).

In this study, geometric correction was carried out using ground control points from digital topographic maps (UTM, WGS84) to Geo-code the image of 1992, then this image was used to register the other three images; the RMSE between different images was less that 0.4 pixels, which is acceptable.

3.2.2. Image enhancement and visual interpretation:

The goal of image enhancement is to improve the visual interpretability of an image by increasing the apparent distinction between the features. The process of visually interpreting digitally enhanced imagery attempts to optimize the complementary abilities of the human mind and the computer. The mind is excellent at interpreting spatial attributes of an image and is capable of identifying obscure or subtle features (Lillesand and Kiefer, 1994). Contrast stretching was applied to all images and the False Color Composites (FCC) were produced. These FCC are visually interpreted using on-screen digitizing to delineate urban areas in the two different dates.

3.2.3. Digital soil mapping:

The soil map of the study area was extracted from the available soil map of Egypt produced by the Academy of Scientific Research and Technology (ASRT 1982); the original nomenclature of soil order, suborders and great groups has been updated according to the latest American Soil Taxonomy of USDA (2010). The transformation of the soil map (produced in 1982) into a digital format was done. The study area is covered by two soil map sheets. These sheets were scanned and geometrically corrected using UTM coordinate system

and WGS84 projection. On-screen digitizing was used to convert the two sheets into vector formats and then edge matching was performed using ArcGIS 9.3. In order to maintain a valid database, another editing session has taken place after edge-matching of the thematic maps covering the study area. The powerful integrated functionalities (i.e. Topology rules, networks and relations) in the ArcGIS system enabled accurate refinement. Editing during this stage was to modify the geometry of the features and/or their attributes without affecting the spatial context of the map neither the previously stored attribute data.

A semi-detailed survey was done throughout the investigated area to gain an appreciation on the soil patterns, the land forms and landscape characteristics. The laboratory analysis of the study area, reported by ASRT (1982) has been compiled in the database and incorporated into the attribute table of the soil map (Pavasovic 1993; Nguyen 2001).

Compilation of laboratory analysis results:

A number of 15 soil samples representing the different soil units of the study area have been analyzed in the lab for soil chemical and physical characteristics (i.e. soil texture, CaCO3 content, CEC, EC, ESP, pH, soluble cations and anions and organic matter content). The results of these analyses have been compiled in the database tables and then incorporated into the attribute table of the soil maps in order to be used later for any specific studies (Nguyen Quec Dinh2001) and (Pavasovic, 1993).

Land capability mapping:

Land Capability classes were defined according to the rating of soil properties adapted from FAO (1989). The influence of each land quality is determined by a set of interacting single or compound land characteristics. Each land quality is assessed qualitatively according to its liability to the concerned constraint as shown in table (2).

Table 2: Description of land capability classes, adapted from Sideruis (1989) and FAO (1985).

Rating	Capability classes	Description*
I	Very highly capable	Very low grade of liability /absence of risk
II	Highly capable	Low grade of liability/ low risk
III	Moderately capable	Medium grade of liability/medium risk
IV	Low capable	High grade of liability/ high risk
V	Very low capable	Very high grade of liability/very high risk

*Adopted to arid condition

The class distinctions are defined in common numerical terms, thus permitting objective comparison between different kinds of land use. The assessment of land quality was based on several factors (i.e. drainage conditions, texture and structure, % coarse fragments, soil depth, % $CaCO_3$, CEC, soil salinity (EC) and exchangeable sodium percentage (ESP).

The Urban land cover class was overlaid on the soil capability map and then the areas lost from different land capability classes due to urban sprawl was calculated.

Urban sprawl detection:

Regardless of the technique used, the success of change detection from imagery will depend on both the nature of the change involved and the success of the image preprocessing and the classification procedures. If the nature of the change within a particular scene is either abrupt or at a scale appropriate to the imagery collected then change should be relatively easy to detect; problems occur only if spatial change is subtly distributed and hence not obvious within any image pixel (Milne 1988). In the case of the study area chosen, field observation and measurements have shown that the change in land cover between the two dates was both marked and abrupt. In this study post-classification change detection technique was applied. Post-classification is the most obvious method of change detection, which requires the comparison of independently produced classified images. Post-classification comparison proved to be the most effective technique, because data from two dates are separately classified, thereby minimizing the problem of normalizing for atmospheric and sensor differences between different dates. The Urban land cover class was extracted from the visual interpretation of the satellite images, and then cross-tabulation analysis was carried out to study the spatial distribution and areas of urban sprawl (1992 and 2009) on different soil types, ArcGIS 9.2 software was used for this function.

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Results and Discussion

Soils of Greater Cairo:

The soil map of Cairo and Giza was extracted from the soil map of Egypt (ASRT, 1982), which classified using the American Soil Taxonomy (USDA, 1975). The produced map (Figure 2) has been updated according to the latest edition (USDA, 2010), as well as, the soil units were accurately identified using number of field missions for collecting soil pits and profiles. The obtained results indicate that the *Typic Torriorthents*is the major sub great group, covering 1149.4 km^2, representing 20.9 % of the total area. The second most dominant soil is the *Vertic Torrifluvents* sub-great group which covers an area of 494.2 or 8.9 %. The *Typic Quartizipsamments*is the third largest sub-great group in the study area, it covers an area of 293.40 km^2 or 5.3 %. The sub-great group *Typic Torrifluvents* covers an area of 93.4 km^2 (1.7% of the total area). *Typic Haplocalcids, Typic Haplogypsidsand and Typic Petrogypsids* sub-great groups exhibit an area of 61.7, 69.0 and 28.0 km^2 respectively. The Rocky land covers an area of 2455.8 km^2 representing 44.6 % of the study area.

The urban settlement covered an area of 244.8 km^2 representing 4.5 of the study area in 1992, and is almost tripled to 740.7 km^2 representing 13.5 % of the study area in 2009.

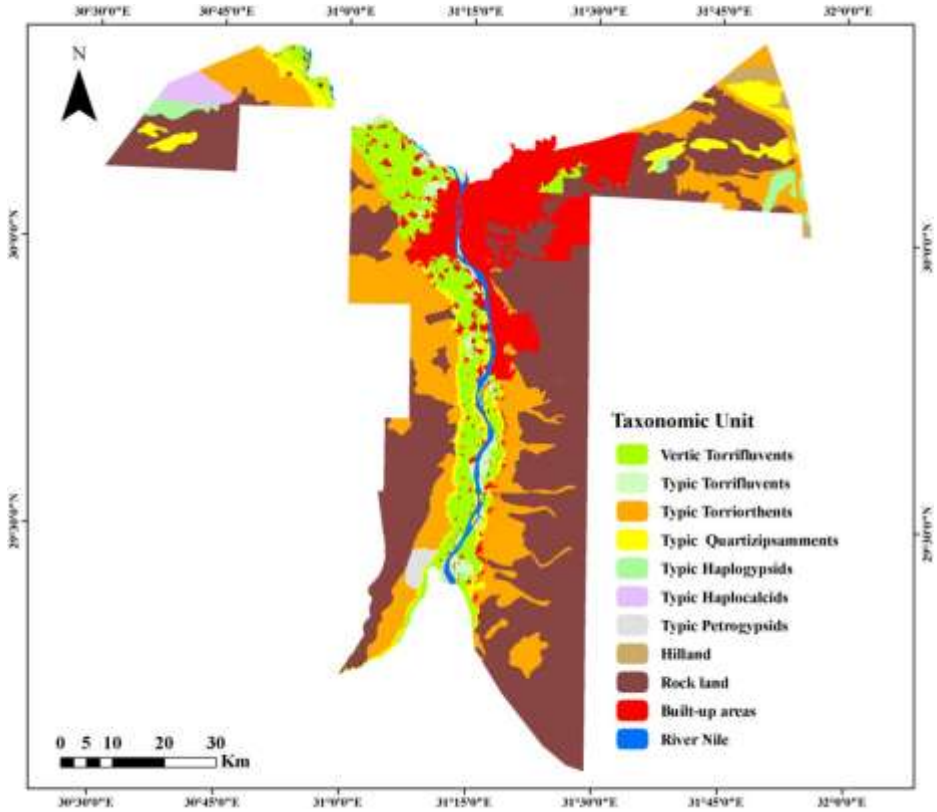

Fig. 2: Soil map of Great Cairo over laid by urban settlement as of the year 2009.

Urban sprawl:

The False Color Composites (FCC, generated from bands 4, 3 and 2) were visually interpreted through on screen digitizing to map urban settlement. The urban settlement of the Cairo and Giza in 1992 and 2009 are overlaid together to show urban sprawl as shown in figure (3). In order to study the impact of urban sprawl on the soils of Cairo and Giza, ArcGIS 9.3 provided the opportunity for integrated analysis of spatial data. The urban layers are overlaid on top of the soil map to measure the expansion of urban settlements on the expense of agricultural land.

The impact of this urban sprawl on agricultural land was evaluated and the statistical data, representing the spatial urban changes from 1992 to 2009 and its impact on different soil types are illustrated in Table 3. The built-up areas in Cairo and Giza increased from 244.8 km^2 in the year 1992 to 740.7 km^2 in the year 2009. The obtained data indicate that the urban expansion during the 1992 – 2009 was at the expense of the most fertile soils where, the *Vertic Torrifluvents* lost an area is 121.0 km^2 and *Typic Torrifluvents* lost an area of 17.9 km^2 while, the less fertile *Typic Torriorthents* lost 109.2 km^2 *and Typic Quartizipsamments* lost an area of 14.8 km^2.

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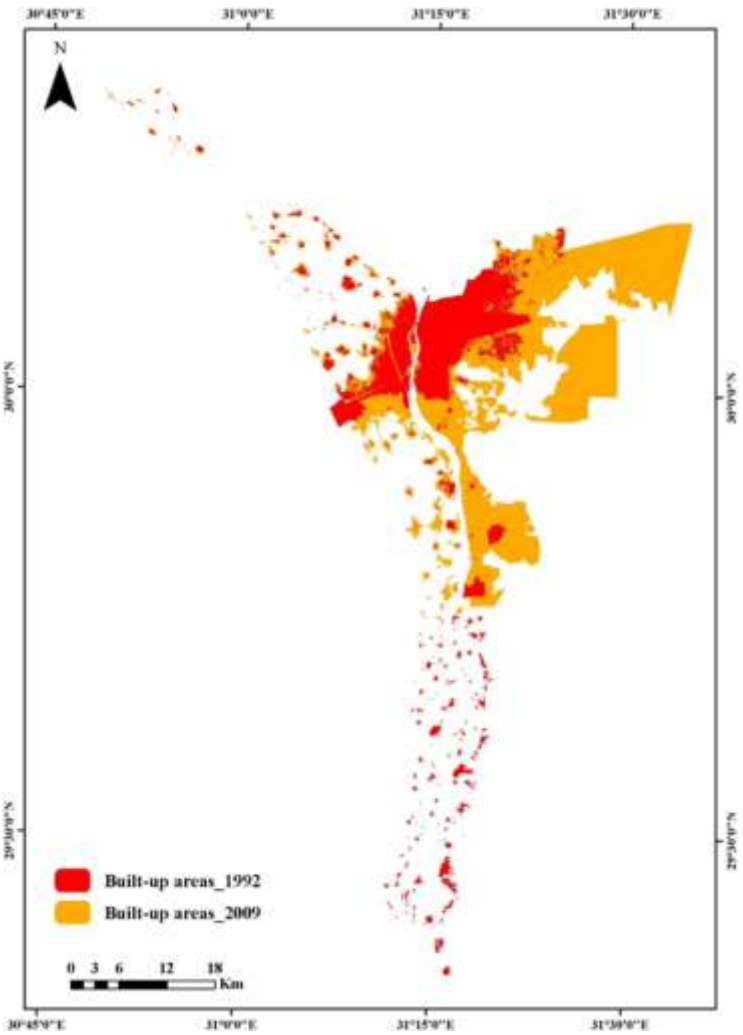

Fig. 3: Urban settlements in Greater Cairoin1992 and 2009.

Table 3: Areas of different soils in Cairo and Giza and their changes (inkm2) between1992and2009

Taxonomic Unit	1992	2009	Differencefrom1992and2009
Vertic Torrifluvents	615.19	494.15	-121.04
Typic Torrifluvents	111.29	93.40	-17.87
Typic Torriorthents	1258.57	1149.37	-109.20
Typic Quartizipsamments	308.17	293.41	-14.76
Typic Haplocalcids	61.71	61.71	0
Typic Haplogypsids	69.02	69.02	0
Typic Petrogypsids	28.01	28.01	0
Hilland	40.33	40.33	0
Rockland	2688.80	2455.79	-233.00
River Nile	76.57	76.50	0
Urban	244.82	740.70	495.87
Total	5502.48	5502.48	

Land capability and urban sprawl:

Land capability classification was performed and the urban settlement of 1992 and 2009 were overlaid on top of the soil capability map (figures 4 and 5). The highly capable soils (class I) lost a total area of 121.0 km^2 between 1992 and 2009 due to urbanization while the moderate capable souls (class II) lost a total area of 23.7 km^2 during the same period. The low capable soils (class III) lost an area of 118.2 between 1992 and 2009. The urban expansion of the not capable soil (class N) was estimated at 233.0 km^2 during the study period. A detailed quantification of the area of different land capability classes, their areas lost due to urbanization and urban settlements change between 1992 and 2009 are shown in table 4.

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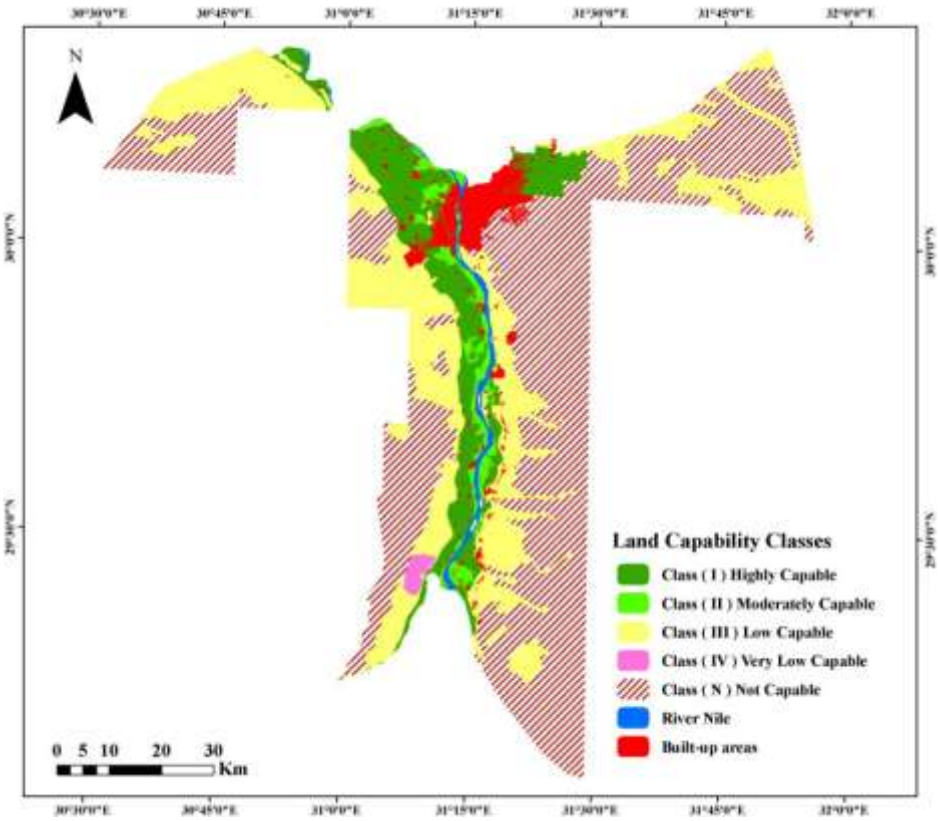

Fig. 4: Urban settlements, extracted from TM image of 1992, over laid on soil capability map.

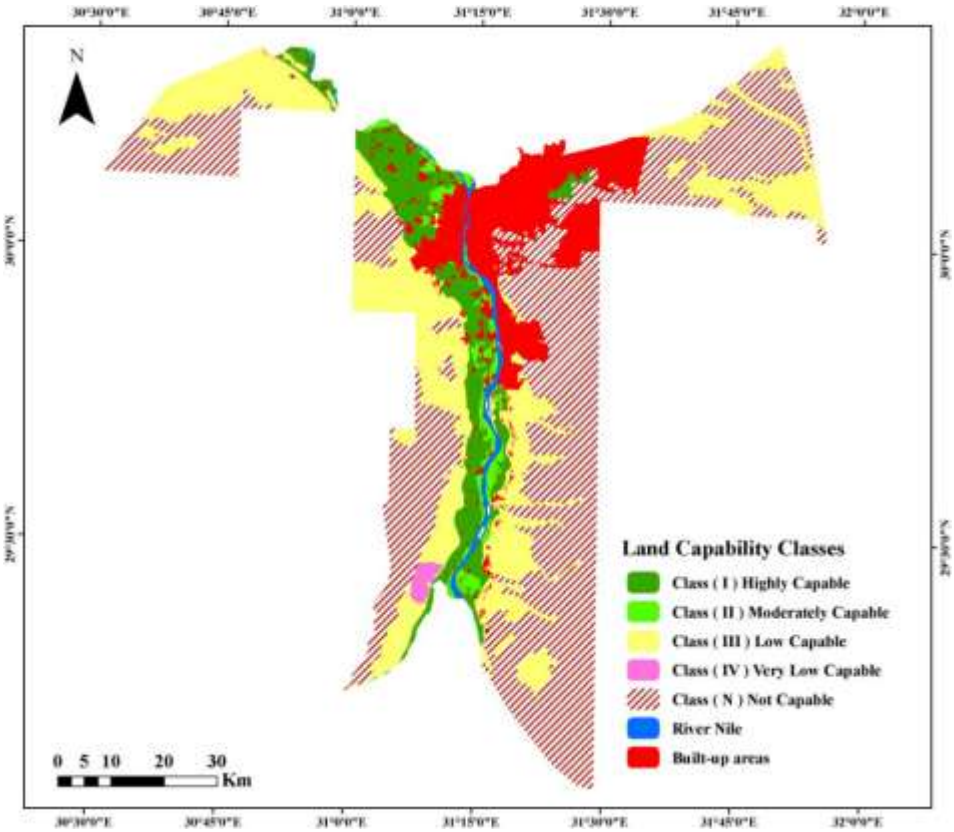

Fig. 5: Urban settlements, extracted from Egypt sat image of 2009, over laid on soil capability map.

Table 4: AreasofdifferentlandcapabilityclassesinCairoandGizaandtheirchanges(inkm2)between1992and 2009

Land Capability Classes	1992	2009	Differencebetween1992and2009
Class (I) Highly Capable	615.19	494.15	-121.04
Class (II) Moderately Capable	145.86	122.19	-23.67
Class (III) Low Capable	1558.29	1440.13	-118.16
Class (IV) Very Low Capable	28.01	28.01	0.00
Class (N) Not Capable	2833.73	2600.73	-233.00
River Nile	76.57	76.57	0.00
Built-upareas	244.82	740.70	495.88
Total	5502.48	5502.48	0.00

The recent legalization aiming to control construction on agricultural land did not prevent the unplanned urban invasion over the fertile land. This kind of unplanned urban expansion has severe environmental consequences causing many social and health problems. This is caused by inappropriate infrastructure including roads and sewage systems as well as clean water unavailability.

Conclusion:

The objective of this study was to evaluate the hazard of urban sprawl and its impact on agriculture land in greater Cairo using remote sensing and GIS. It was found that visual interpretation was an effective way for extracting an urban settlement accurately. The study area has undergone a very severe land cover change as a result of urbanization which resulted from rapid population growth. A Considerable increase in urban settlements has taken place at the expense of the most fertile land in the study area. GIS provided valuable information on the nature of urban sprawl through integration of soil digital database and urban map that resulted from visual interpretation.

The main causes of urbanization are the rapid population growth in addition to the economic growth. Urban sprawl is one of the dominant land degradation processes in the study area. This problem needs to be seriously studied, through multi-dimensional fields including socioeconomic, in order to preserve the precious and limited agricultural land and increase food production.

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