

Spatial Metrics to Quantify Urban Sprawl in Greater Cairo Metropolitan Region

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Spatial Metrics to Quantify Urban Sprawl in Greater Cairo Metropolitan Region

空間指標によるカイロ大都市圏における都市化の特徴の解析

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On the subject of urban sprawl in recent Egypt, this research takes Giza governorate the western part of Greater Cairo Metropolitan Region (GCMR) as a case and puts forward that urban sprawl can be estimated from spatial disposition, sprawl efficacy and outer influences; and then evolves a geo-spatial indicators system for quantifying sprawl. Various data sources were selected, including land use maps, digitized map of the highways and town centers, and population statistical data, etc. The results demonstrated that Building land in Cairo has kept quick growing with considerable amount of low efficacy and dysfunctional spatial disposition.

Keywords : Urban Sprawl, Growth Efficiency, Sprawl measurements, Remote Sensing, Egypt
アーバンスプロール, 成長効率, スプロール測定, リモートセンシング, エジプト

1. INTRODUCTION

Notwithstanding the government's attempt to contain it Egypt has experienced a rapid urbanization over the past five decades. Official Governmental efforts started in 1956 with the introduction of first urban development plan for Greater Cairo Metropolitan Region (GCMR). Later it was followed by new plans in 1973, 1982, 1991, and 2006¹⁾. The population of GCMR was around 16-18 million inhabitants, which corresponds to nearly a quarter of Egypt's population of 72,798 million inhabitants in 2006 and about half of the country's urban population.¹⁾ The labor force is growing at over 3.0 % per year, due to the considerable youth lump in the population pyramid¹⁾.

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In GCMR more than 7 million inhabitants live in informal areas; 80 % are on privately owned arable lands^{2),3)}. Urban sprawl in GCMR is mainly classified into two classes: (1) Urban sprawl on previous arable lands over and (2) urban sprawl on previous State land⁴⁾. The Urban sprawl areas have expanded particularly on private arable lands, and less frequently on publicly owned desert land. Based on the UNDP (2004)²⁾, by 2025, around 50% of Egypt's urban population is anticipated to dwell in Urban sprawled areas.

Cairo is located on the Nile valley where the Nile's flow is calm and with desert hills both to the desert (Fig. 1) Historic Cairo (i.e. pre-1860) was limited the higher ground near to the eastern hills. GCMR is consisting of the entire of Cairo Governorate and the urban areas of Giza governorate (west of the Nile) and Qaliubia Governorate (north of Cairo Governorate). Governorates are the major areas of municipal administration in Egypt. Cairo is not only the Political capital of Egypt but also its service, social, economic, and administrative hub.

A research using satellite images estimated that the surface area was covered by urban sprawl in GCMR between 1991 -1998 has grown by 3.4 % per year, while the population living in the urban sprawl areas grew by 3.2 % per year⁵⁾. MOP & GTZ (2004)⁶⁾ mentioned that erosion of ara-

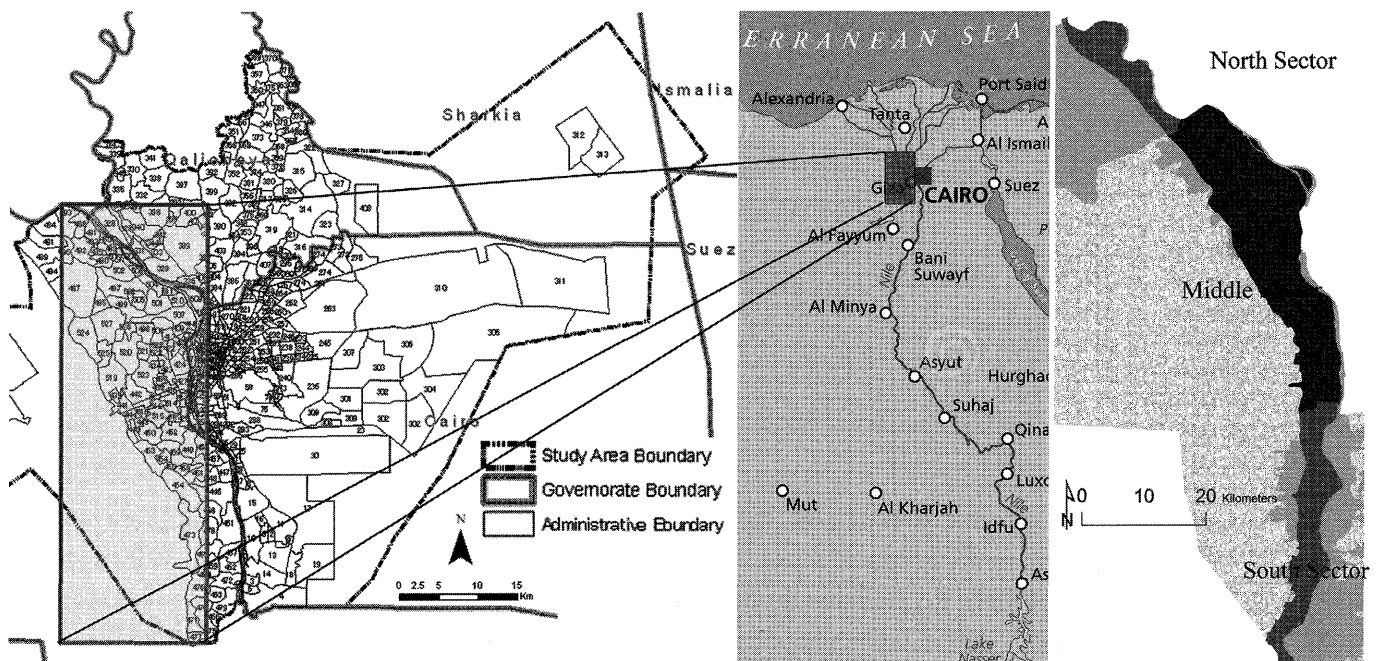


Fig. 1 Study Sectors Location within Egypt

Source: JICA, 2008¹⁾

Table 1 Urban and Population Growth in Giza Sectors (Middle, North, South) 1984, 2004, and 2013

Study Sector	1984		2004		2013	
	Urban (ha)	Population No.	Urban (ha)	Population No.	Urban (ha)	Population No.
North	187,37	51240	588,26	95323	891,10	111814
Middle	8354,80	1807909	12962,04	3363552	18470,98	3945166
South	861,70	237512	1770,80	441883	2773,10	518292

ble lands, since 1980, is estimated at about 1 million Acres which represents around 12% of total agricultural land in Egypt. This coincides to an annual lack of 0.6% of Egypt's total arable lands. El-Hefnawi (2005)⁷⁾ mentioned that estimated amount of all arable lands property categorized to urban sprawl areas is US \$ 46.2 billion, in addition to informal areas which are US \$ 16.9 billion, and also US \$ 63.1 billion as cost for informal buildings over arable land with total number of 7.9 million informal units.

SIMS (2003)⁸⁾, UNDP (2004)²⁾, MOP>Z (2004)⁶⁾ mentioned that urban sprawl in the past decade was quite serious, and the tendency of scattered development and sprawling growth will hinder the Egyptian development process if the urbanization could not be kept under control. Lately, the unfavorable influences of urban sprawl have got more visible, and the concerned government has started to search solutions for urban sprawl.

Knowledge of the Spatio-temporal pattern of urban sprawl is important to understand the size and functional changes of the urban sprawl. Spatial metrics were computed to quantify the patterns of urban dynamics, that aid in understanding spatial patterns of various land cover features in the region⁹⁾. Quantifying the urban sprawl patterns and its change is essential for monitoring and assessing the urbanization process

and its ecological consequences^{10), 11), 12), 13)}. Spatial metrics have been widely used to study the structure, dynamic pattern with the underlying social, economic and political processes of urbanization^{14), 15), 16), 17)}. This has provided useful information for implementing holistic approaches in the regional land-use planning¹⁸⁾. Aguilera & Talavera, (2009)¹⁹⁾ Reviews the spatial characteristics of metropolitan growth including analysis^{20), 21), 22), 23)} the study of urban sprawl. Applications of urban sprawl metrics include urban sprawl spatial disposition (area index, shape index, discontinuous development, strip development, and leapfrog development index), geographical applications by taking advantage of the properties of these metrics^{24), 25), 26)} and measurement of ecological sustainability³⁾.

These studies also confirmed that Spatio-temporal data along with urban sprawl metrics would help in understanding and evaluating the spatio-temporal patterns of urban sprawl dynamics required for appropriate management measures. According to the GCMR Development Plan, a 20-year vision document for Giza governorate as a part of GCMR, there has been a 44.47 % increase in the Regions spatial extent in the period 2004-2013, resulting in the higher degree of sprawl at outskirts.

All in all, we applied Giza governorate as a case study in

this paper to understand the urban sprawl dynamics in the context of metropolitan region of the developing countries. This study aims to quantify the changings of Giza urban sprawl dynamics through the selected spatial indices which aiming ultimately to help the decision-makers in GCMR on adjusting the urban sprawl.

2. IDENTIFYING URBAN SPRAWL INDICES FOR GIZA GOVERNORATE

Recent researches submitted indicators for quantifying sprawl, among which the weightiest ones are submitted by Sierra Club, Smart Growth America. Sierra Club,(1998)²⁷⁾ classified main metropolitans in USA by four sprawl indicators: time cost on traffic; comparison of land-use and population growth; population moving from inner region to outskirts. USA To-day, (2001)²⁸⁾ submits the share of population beyond as an indicator for quantifying sprawl. They implemented a research to find the influences of sprawl on life goodness in which four indicators were used to quantify urban sprawl: vitalization of inner region; hodgepodge of residence, residential density; service facilities and accessibility of transportation network.

In developing countries, researchers used repeated indices to quantify the urban sprawl. These indices are usually known as spatial indices. Spatial indices are numeric measurements that quantify spatial patterning of land-cover patches, entire landscape mosaics of a geographic area, or land-cover categories⁹⁾. Some papers have participated to quantify sprawl by setting up multi-indicators by GIS analysis or explanatory statistical analysis^{29), 30), 31)}. These indicators cover various features including traffic, resources consumption, employment, population, living goodness, architecture aesthetics. Common used indicators: spatial disposition like proximity, accessibility, fragmentation or; residential density, population density, employment density; growth rate like built-up area growth rate, population growth rate; and others like land-use efficacy, per-capita land consumption.^{32), 33), 34), 35)}. The start of research in multidimensional indices of urban sprawl was established by Galster et al., 2001³⁶⁾. They classified land use patterns into eight dimensions: nuclearity, clustering, centrality, density, heterogeneity, proximity, concentration, and continuity.

Cutsinger et al., (2005)³⁷⁾ improved the multidimensional indices measures by using a dozen conceptually featured dimensions of land use patterns which were operationalized for 50 considerable US metropolitan areas. Under the name of sprawl indices, Angel et al., (2007)³⁸⁾ have submitted five indices for quantifying manifestations of sprawl and five

groups of indices for quantifying the sprawl. Under each group they have used diversified indices to quantify the urban sprawl case studies. But, they have not endorsed any standard sill that can be used for identifying a sprawling region from a non-sprawling region.

In addition to that, in China as a developing country Jiang et al., (2007)²⁶⁾ suggested a dozen of 'geospatial indicators' for quantifying the urban sprawl. They suggested an incorporated sprawl index that consolidates 13 indicators. This concept decreases the explanation effort. But their concept needs immense inputs of temporal data like GDP, floor-area ratio, land-use maps, land-use master planning, maps of region centers, maps of highways, and population. Since, developing countries denies rare of such type of temporal data; most of these indicators are laborious to get. Furthermore, they did not indicate to any sill to classify a region as sprawling or non-sprawling. Nevertheless, this type of temporal analysis is serviceable to differentiate among regions or various zones of a region at various dates. Whether a region is being more sprawling or not, with the alteration of time, can be well described by this pattern of analysis.

All in all, most of the international researches took the entire region as an analysis unit to estimate these indicators, which could strictly differentiate the sprawling situation of the region, but the inner differentia of sprawl in a given region could not be well described. Furthermore, some indicators are submitted based on the context of Western urbanization; therefore, they are not so appropriate for quantifying sprawl in Giza governorate, such as the share of detached house. In addition, some necessary statistic data are not sequent enough to estimate certain indicator, such as the density of employment.

In developing Countries, some indicators were developed for quantifying urban sprawl which could be used for reference in Giza case study. Those indicators include: Growth scale, such as urban sprawl area³⁹⁾; growth speed, such as annual growth rate⁴⁰⁾; landscape disposition, such as isolation index, shape index, fractural dimension⁴¹⁾; and spatial attributes such as built-up area, annual growth density⁴²⁾. The last three types of indicators are appropriate for quantifying widespread cases of sprawl, but not convenient in identifying inner differentia. The annual growth density and built-up area density could successfully characterize the sprawl attributes of strong change and low density, but they are until now feeble in identifying the particular spatial patterns of urban sprawl.

To summarize, the common international sprawl indicators could not be clearly used in the GCMR context. No

existent indicators on urban sprawl in the Egyptian context could be clearly used to quantify the urban sprawl either. So, this paper submits a combination of geo-spatial indicators for quantifying sprawl based on the special case of Giza governorate the western part of GCMR in Egypt.

We define Urban sprawl in GCMR as an ascendancy of low density urban areas structures with mutation of previously monocentric compact region into polycentric, discontinuous, spontaneous urban pattern de-concentration of urban functions in incorporation with urban sprawl into rural communities in addition to that it witnessed dissident development conflicting to purposes of spatial planning concepts and ideas; and Pertinent impacts on the urban community by the neoteric spatial pattern, like traffic flood. Consequently, the analysis of the urban sprawl phenomenon must be accentuated from this multidimensional perspective.

Based on the previous working definition, ten of geo-spatial indicators have been determined: spatial disposition, growth efficacy, and outer influences to quantify sprawl in Giza. These measure included, five indicators such as size and shape of land use patches which espoused to identify the spatial disposition of Giza's urban sprawl. Two indicators included horizontal building density and population density were used to dissect the efficacy of urban sprawl. Another three indicators included arable land erosion, open space erosion, and traffic encumbrance are submitted to specify the influences on environment, agriculture, and region life. Due to the rare of statistic data, the description of spatial differential of economic output is not appropriate yet in addition to other influences of urban sprawl, such as energy consumption, which are not included in the indicators system due to data scarce.

3. METHODS AND DATA

3.1 Research Study Sectors of Giza Governorate

Administration hierarchy Egyptian municipalities follow an old centralized system introduced 1960s when country become a socialist state. Municipality services and information such as; municipal budgets, transportation networks, census data, etc. are organized based on that hierarchy. We have followed this hierarchy and divided the main study area of Giza governorate sector in to three sub-sectors for this study (Fig. 1).

3.2 Data sources

Data included population at local administrative level of GCMR collected from the national census in 2006⁵⁾, land use maps in 2005 from GOPP land use surveys, the existing GCMR land-use master planning (2007–2027), and vector

maps of highways and local municipalities centers digitized from the hardcopy of Giza geographical base map .

Method for computing indicators are as followed: 1) data elaboration by which to procedure various data to set up workable database for each index; 2) adapt all indices by spatial analysis to consolidate all of them into the same grid platform of 120m×120m; 3) Calibration conversion by which to normalize these indicators with diverse dimensions; and 4) AHP was applied to make ranking and weighting⁴³⁾ for the applied various urban sprawl indices, and then sum up all calibrated indicators into one integrated sprawl index (ISI). The formula is given: $ISI = 0.02 AI + 0.03 Si + 0.21 DDI + 0.23 SDI + 0.13 LDI + 0.06 HDI + 0.07 PDI + 0.10 AII + 0.04 OSH + 0.10 TII$. Where ISI stands for the integrated urban sprawl index, each sum term stands for one of 10 indicators respectively; operator reflects the correlation with urban sprawl. We used the equal interval method to classify the indices calculation output to categories.

4. RESULTS AND DISCUSSION

As for finding solutions to the negative impacts of urban sprawl in Giza, the first step is to understand the sprawl attributes in precise indices. However, the previous researches tried to understand the urban sprawl in such cases of GCMR in developing countries still concentrated on specific debate instead of quantitative analysis. Previous researches had no obvious answer on how to differentiate sprawl, estimate the extent of sprawl or estimate the policy impact. The existing methods for quantifying urban sprawl are fundamentally submitted within the context of Western advanced countries. So those methods are not precisely developed for understanding the spatial attributes and unique mechanism of urban sprawl within the context of metropolitan region in developing countries like GCMR.

In this paper, the following results founded that buildable-arable lands in Giza have kept a rapid expansion with a huge amount of low effectiveness and dysfunctional spatial distribution. The subsequent definite sprawl attributes are determined; conspicuous fragmentation and unevenness of landscape due to ineffective implementation of land use planning; inappropriate pattern of land use growth with exemplary discontinuous development, strip development and leapfrog development; low density of land use growth, low population density and economic output in the NDL; and other unfavorable influences on agriculture, environment and region life.

(1) The conspicuous fragmentation of new urban sprawl areas could be identified by AREA INDEX which shows

land use patches had conspicuous fragmentation tendency. From 2004- 2013, the patch number of non-arable lands grew by 19.3%; over the average patch size grew by 69.4%. The average patch size of the newly developed land (NDL) is 5.47 km², and 100% of them are more than 1 km² (Fig. 2). As Shape index shows, land use patches became more irregular forms. The average shape index of the NDL patch is 0.24, and the shape index is comparatively massive, ranging from 0.001 to 127.06. Only 3.6 % of them are over 0.24 (Fig. 3). As Discontinuous development index shows, 76.9 % of the NDL is neighboring to the previously developed lands (less than 100 m). The average range between the NDL

Table 2 Quantifying Spatial disposition of Urban Sprawl

Index	Calculation methods	Data source
AREA INDEX (AI)	AI= patch area of newly developed;	Land use maps 2004-2013
SHAPE INDEX (SI)	SI= $0.25 \times \text{Perimeter} / (\text{area})^{0.44}$	Land use maps 2004-2013
DISCONT. DEVELOP. (DDI)	DDI=distance between newly developed and previously developed land	Land use maps 2004-2013
STRIP. DEVELOP. INDEX (SDI)	SDI=distance between newly developed patches and high-ways	Land use maps; map of Major roads 2004-2013
LEAPFROG DEVELOP. INDEX (LDI)	LDI=distance between newly developed patches and county centers	Land use maps; map of centers (point) 2004-2013

Table 3 Quantifying Growth Efficacy of Urban Sprawl

Index	Calculation methods	Data source
HORIZONTAL DENSITY INDEX (HDI)	HDI=The share of non-arable lands area within neighborhood of 1 km ²	Land use maps 2004-2013
POPULATION DENSITY INDEX (PDI)	PDI=ratio of population to land area	Population at village level; land use map in 2004-2013

Table 4 Quantifying Outer influences of Urban Sprawl

Index	Calculation methods	Data source
AGRI. IMPACT (AII)	Overlay analysis; AII={1, 0}, 1 stands for arable land loss	Land use maps 2004-2013
O.SPACE IMPACT (OII)	Overlay analysis; OII={1, 0}, 1 stands for open space loss	Land use maps 2004-2013
TRAFFIC IMPACT (TII)	TII=simulated population×distance to urban units centers	map of centers (polygon) 2004-2013

to the previously developed lands is 76 m (Fig.4). As SDI demonstrates, the NDL has an exemplary feature of strip development, particularly urban land. The average distance between the urban NDL and highways is 388.9 m, and nearly 91.66% of the urban NDL is situated in the 1-km buffer of the highways (Fig. 5). As LDI demonstrates, the NDL has a typical feature of leapfrog development. The average distance between the NDL and county centers is about 149.4 m, and 71.11% of the NDL has a distance less 1 km to county centers (Fig. 6).

(2) Low efficiency of the urban sprawl which occurred

2004-2013 in Giza can be identified from HDI index, the horizontal density of the NDL is more than before. The average density of the NDL from 2004 to 2013 is 0.24, while the average density in 2004 is 0.15 (Fig. 7). Moreover, there is distinct spatial difference. For example, the density in urban areas situated in the North and south sectors is 0.16 which is 50% of that in the Middle sector (0.30) or 20% of that in the CBD (0.80) (Fig. 8).

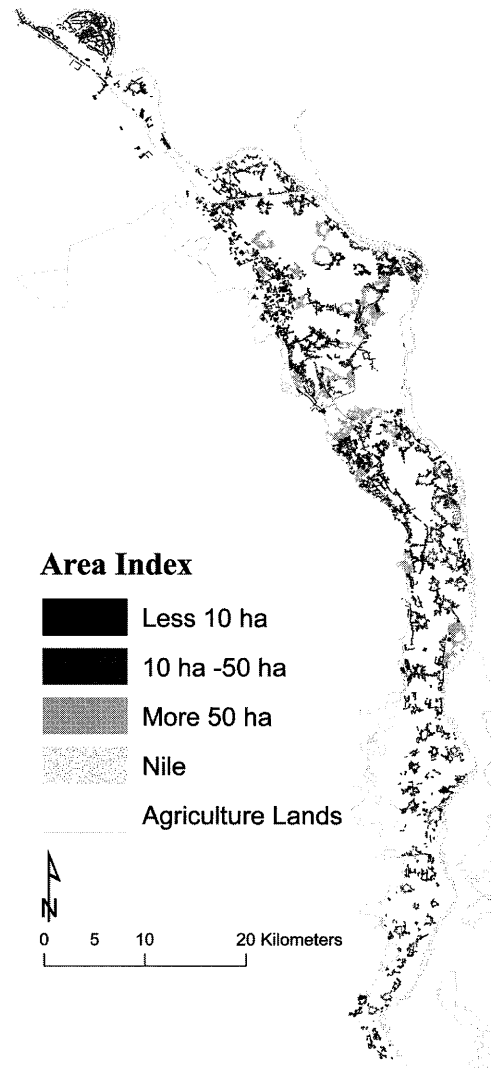


Fig. 2 Area Index

(3) Negative impacts on agriculture lands, environment and region life can be observed from the indices values of AII, OII and TII. Firstly, urban sprawl has led to enormous loss of high quality arable lands in the region's outskirts. 74.7 km² of the NDL were converted from arable land to informal urban areas from 2004 to 2013 (Fig. 9). Secondly, urban sprawl has restricted open spaces, such as water bodies; 5.33 km² of the NDL were Converted from open space from 2004 to 2013 (Fig. 10). Thirdly, the urban sprawl led to inconsiderable traffic onus and expanded the distance between

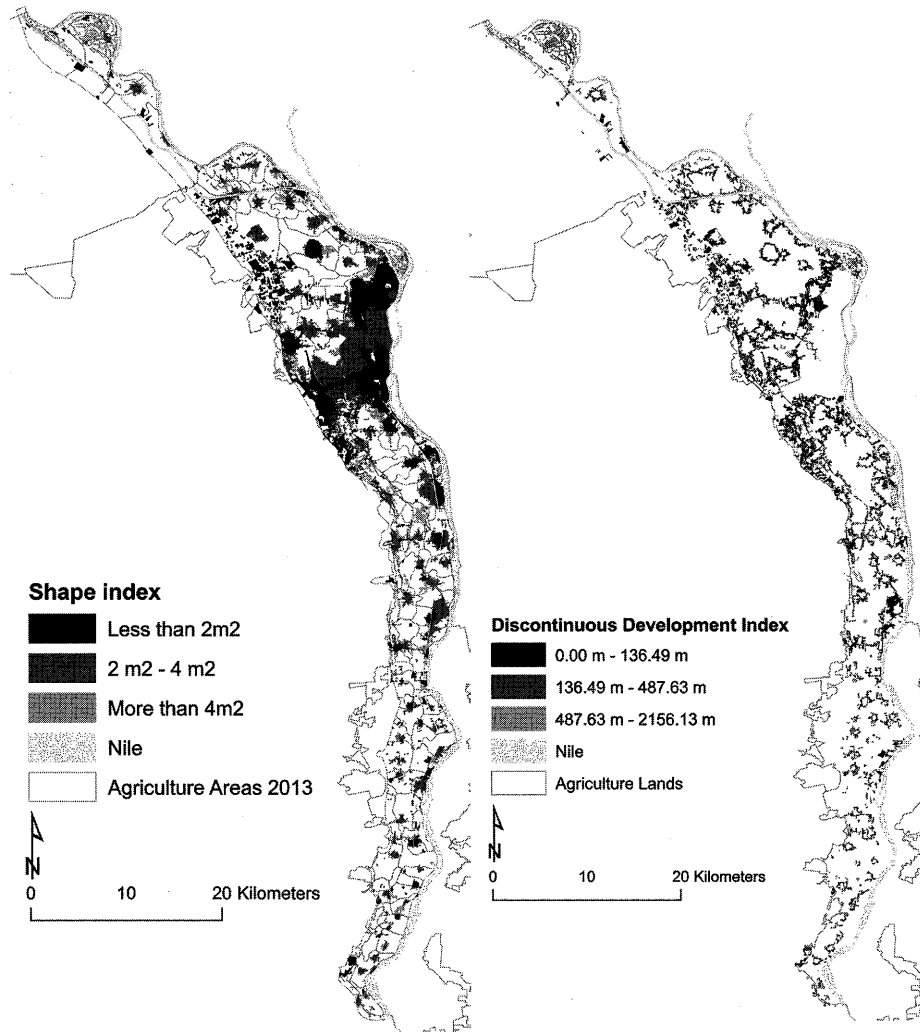


Fig. 3 Shape Index

Fig. 4 Discontinuous develop. index

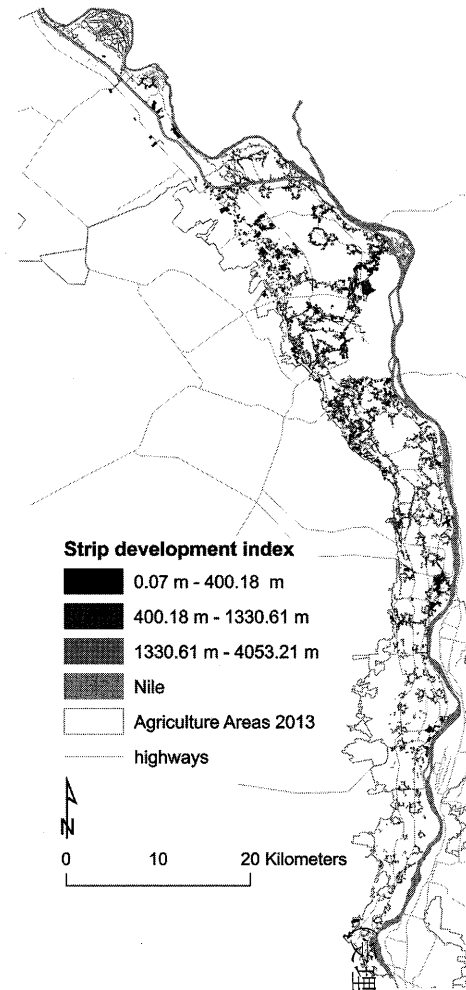


Fig. 5 Strip develop. index

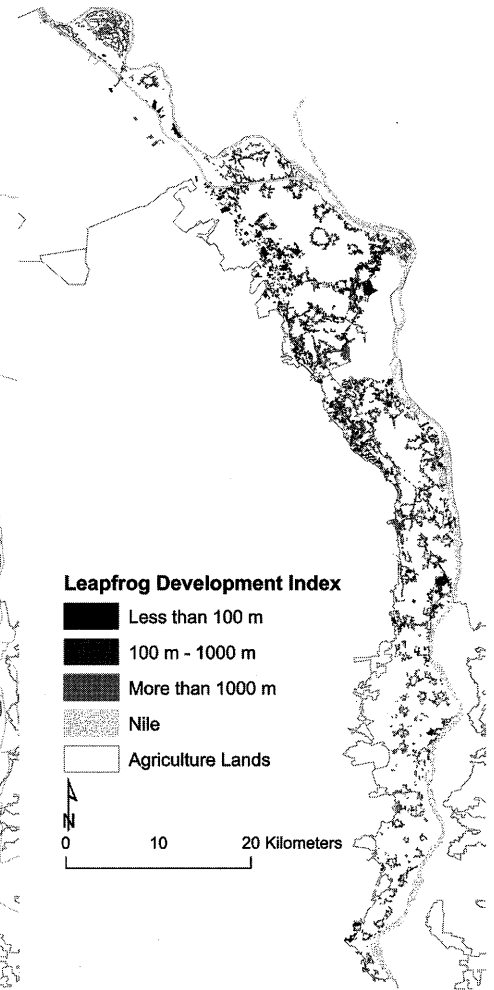


Fig. 6 Leapfrog develop. Index

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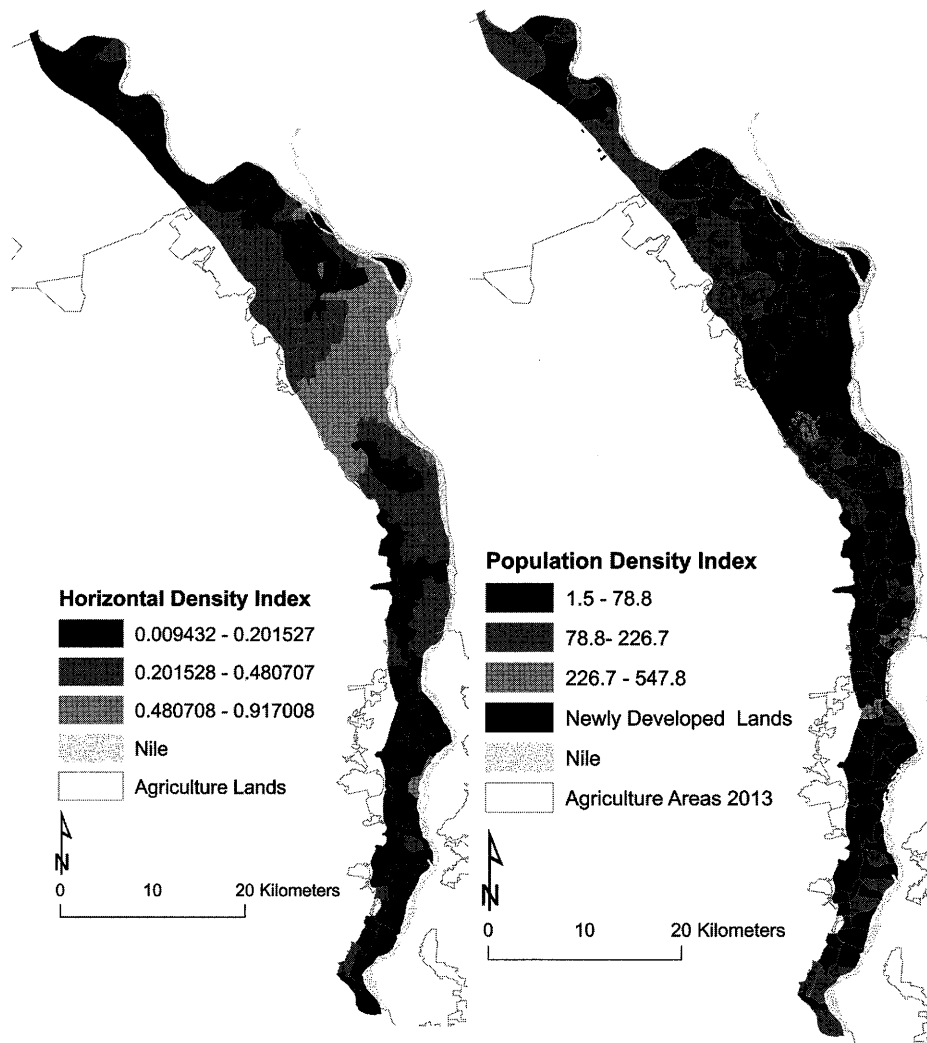


Fig. 7 Horizontal density index

Fig. 8 Population density index

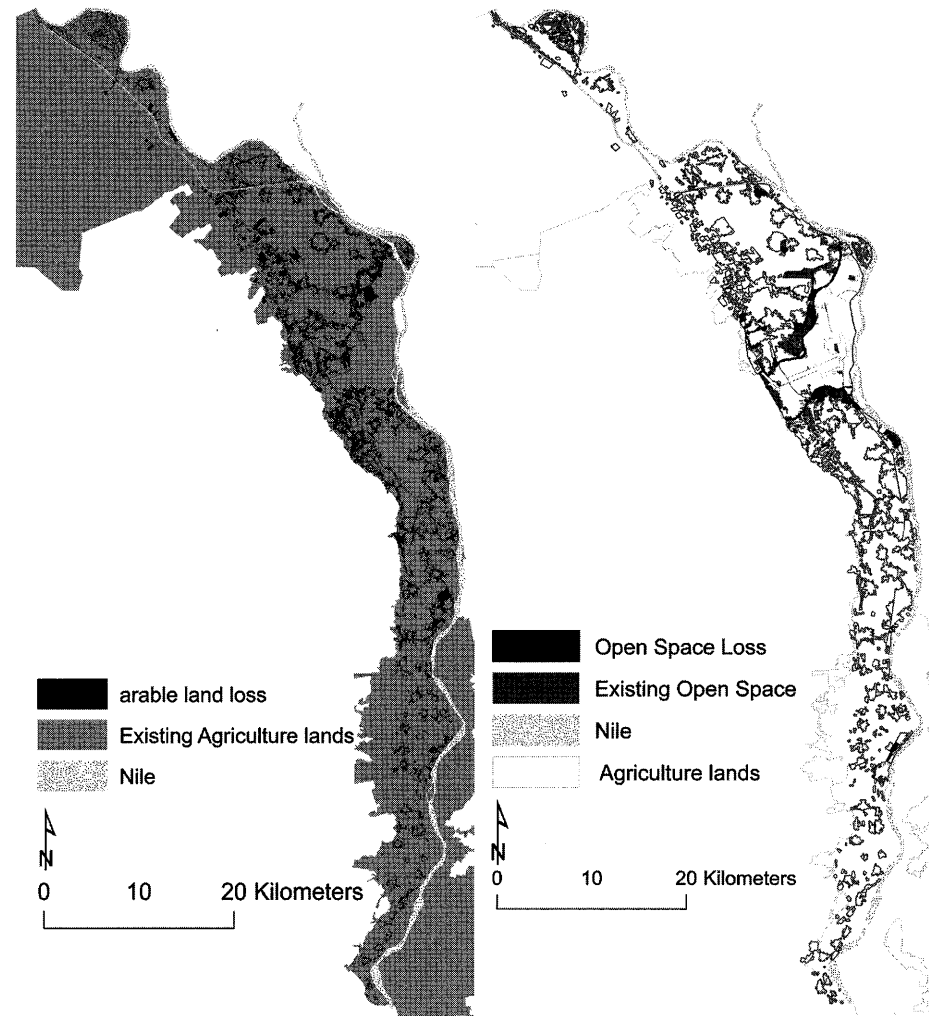


Fig. 9 Agriculture impact index

Fig. 10 Open space impact index

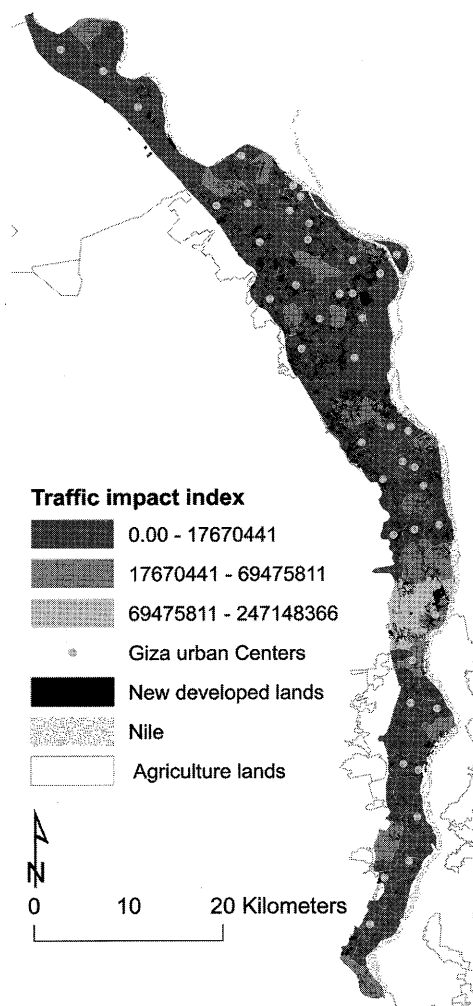


Fig. 11 Traffic impact index

the NDL and main urban core of Giza governorate (Fig. 11).

(4) Interior differentia of urban sprawl in Giza governorate was identified from the less rate of sprawling in the middle sector in comparison with the serious high rates of sprawling at the North and south sectors particularly in the area near major roads and surround county centers. Four examples of sprawling patterns included spontaneous and new spreading urban sprawl at urban fringe in North and south sectors, road influenced pattern along Regional roads, Edge growth development surround main cores of existing urban centers (Fig. 12).

(5) The integrated sprawl index (ISI) shows that NDL could be categorized into three categories: low, moderate, and high sprawling by natural break method (Fig. 12). High sprawling scored 19.9% in the north sector, while it was 46% in the south sector, and 25.8% in the middle Sector. Moderate sprawling scored 30.5% in the north sector, 28.1% in south sector, and 24.0% in the middle Sector. Low sprawling scored 49.6% in North, 74.5% in South, and 50.2% in middle sectors. In addition to that, serious sprawling fundamentally located in three spots particularly, in the farthest part of

Northern sector around the regional transportation network, middle and southern parts of Central sector near to CBD and surround main urban centers of cities and mother villages.

5. CONCLUSION

Urban expansion has been and will continue to cause one of the biggest human effects on land surface environment. Many cities, particularly in emerging economies, are faced with complicated problems of urban sprawl. Spatial and temporal studies on urban sprawl or urban areas expansion

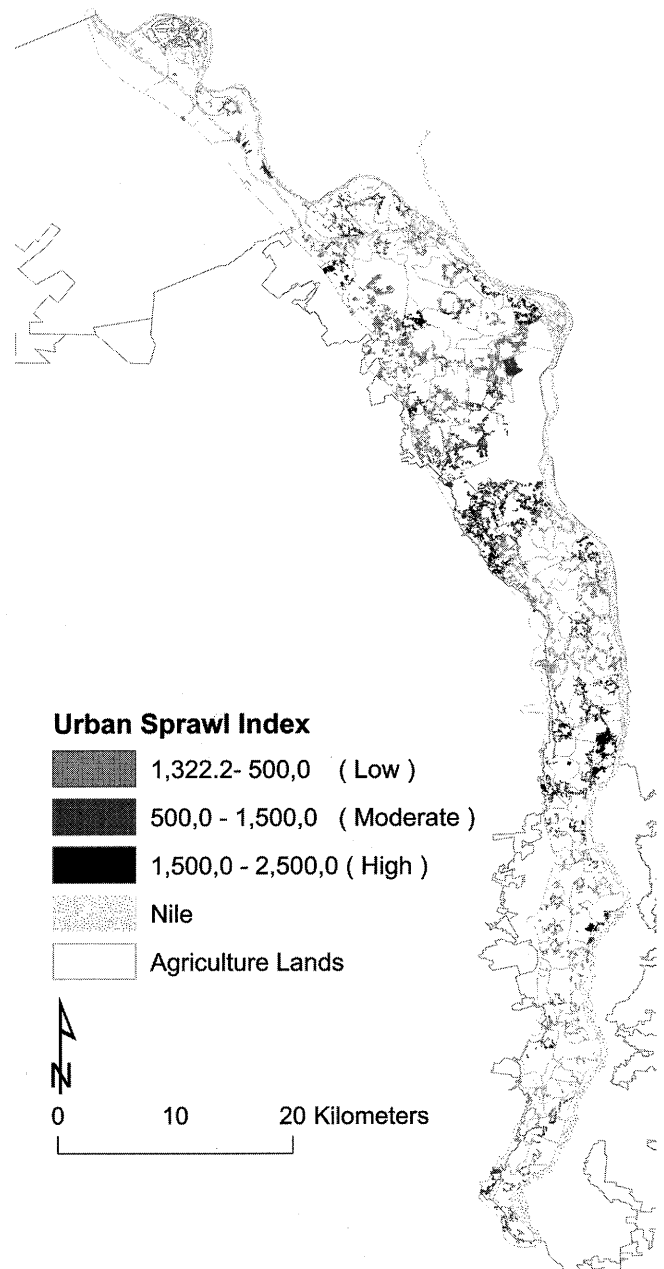


Fig. 12 Result of Integrated Urban Sprawl Index

are necessary for land planning and urban planning in Egypt, which is experiencing a rapid increase of land demand for construction in the context of economic development. Understanding the change in the spatial configuration of urban areas over time is essential for quantifying the effects of ur-

ban sprawl⁴⁵⁾.

The study results of the short-term sprawl revealed a notable expansion of urban areas between 2004 and 2013. The pattern of the urban sprawl types showed a tendency of leading the pattern of the whole landscape composed by the four different sprawl types to become regular in shape and clumped in distribution. The method used in the present study provided an effective way to the traditional empirical observation of urbanization for related studies. This method can be applied to investigate regional urban area expansion, the pattern change of the different urban sprawl types, and the related land effects of regional policy and economy. This method also bears high potential to be replicated or modified in the study on other regions undergoing rapid urban sprawl.

When the GCMR government's focused to develop the outskirts 's of the metropolitan region , has posed a challenge as unplanned developmental activities is leading to urban sprawl impinging basic amenities to the common man in the outskirts. Spatial indices in conjunction with the density gradient approach have been effective in capturing the patterns of urbanization at local levels. The techniques would aid as decision-support tools for unraveling the impacts of classical urban sprawl patterns in GCMR. A set of spatial indices describing the morphology of unplanned areas have been extracted along with temporal land uses. The extracted indices have indicated the areas of high likelihood of "unplannedness" considering the three dimensions (size/density/pattern). Local urban and rural planners need to put forward effective implementable adaptive plans to improve basic amenities in the sprawl localities. Temporal land use analysis along with urban density gradient across four directions has helped in visualizing the growth along with the cultural and industrial evolution.

Finally, because of the shortage in the existing study to analyse the relation between urban sprawl and ecosystems, the need to find new indices to describe this relation is crucial to understand urban sprawl dynamics in GCMR.

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