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Spatial Resilience of Megacities based on Conceptual Model from Concept to Implementation. Case Study: Greater Cairo, Egypt

Ahmed Abdelhalim M Hassan

(Ahmed Abdelhalim M Hassan, Institute of Landscape Ecology, Muenster University, Robert-Koch str.28, D-48149 Muenster, Germany, e-mail: ahmedahalim@uni-muenster.de)

1 ABSTRACT

Analysis and understanding of megacities' properties such as rapid spatial growth, rate of population increase and development, loss of fertile land, urban sprawl, water and air pollution, and others are becoming a sophisticated and a complicated task in environmental management approaches especially in developing countries. The European Environment Agency recommends a concept which distinguishes driving forces, pressures, states, impacts, and responses (DPSIR) to develop a strategy for integrated environmental assessments.

In this study, the DPSIR model is used to identify and to determine the framework to find and describe the development indicators of megacity in relation to ecology and environment and also to provide a deduction of main transformer indicators in Greater Cairo.

Accordingly, the relationship between the human activities (society) and the dynamic processes of land-use cover change are understood and implemented into management strategies. Hence, the population growth and fast increase of investments represent the main drivers which lead to environmental and spatial changes in land use and land-cover. As a result of exerting pressure, the state of urbanization and losses of fertile land are major indicators of transformation that shows dynamic processes through the DPSIR chain. Therefore, the spatial monitoring can identify hot-spots (objects) of changes. Based on the application of DPSIR model and their looping mechanism, new planning strategies could be elaborated to improve management of a megacity such as Greater Cairo.

2 INTRODUCTION

Megacities are increasingly vulnerable systems because they often harbour pronounced poverty, social inequality, growing pressure and environmental degradation, all of which are linked together by a complex system supplying goods and services (Megacity report 2005 http://www.yearofplanetearth.org/). That figures out the scale of the challenge to understand and analyse megacity's indicators such as rapid growth, rate of population and development, loss of fertile lands, urbanization sprawl, water and air pollution, and others in developing countries. So, this is one of the main challenges faces the studies of a rapid development of big cities; because the fast growth is accompanied by dramatic changes in the socio-environmental structure and land utilisation.

To monitor such complex changes for sustainable information and to integrate and manage the relation between indicators, a conceptual model and a good tool to support the management of ecosystems is needed. In a similar way, Ines et al., 2004 stated that, determination of indicators is an excellent way of representing the environmental components avoiding the measurement of too many parameters. Indicators are often adopted to avoid and reduce the complexity of environmental data. However, most conceptual models deal with ecosystem in one direction of analysis such as; from top to down (i.e., hierarchy constitutes), key constitutes to link and find relation between elements, and fuzzy which concerns with the changed core and fuzzy boundary in system. Furthermore, Cumming et al. (2005) defined a resilience social-ecological system as consisting of essential actors, components, and interaction. And the system identity consists of maintaining these elements through space and time. The state of susceptibility to harm from exposure to stress associated with environmental and social change is mentioned as "Vulnerability" by Adger (2006). Regarding the sustainable development and sustainability, Norberg and Cumming (2008) responded them as "the equitable, ethical, and efficient use of natural resources".

3 CONCEPTUAL MODEL

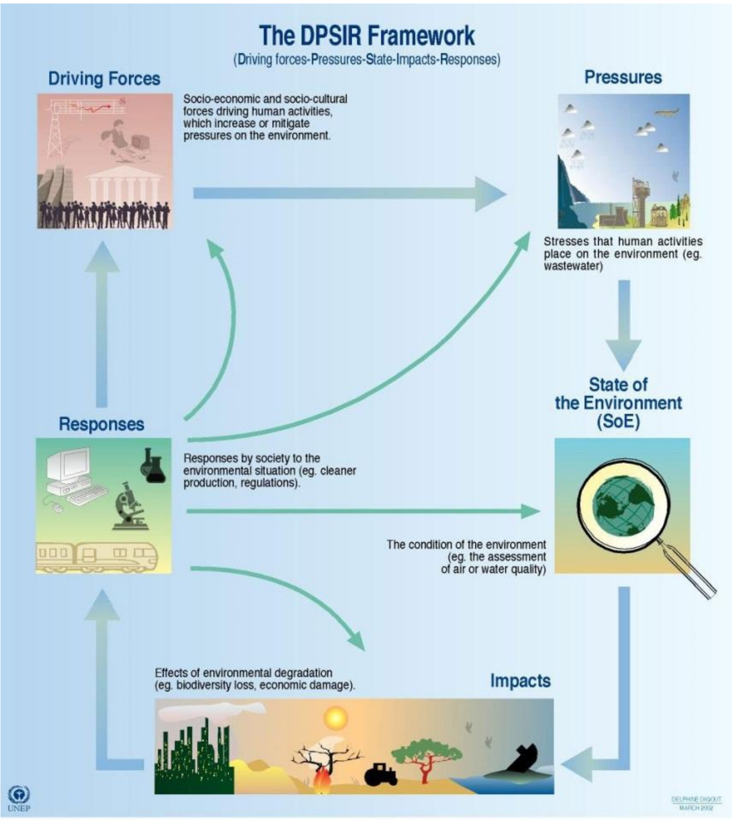
Because of the spatial and temporal scope of the phenomena addressed by social ecological system (SES) theory ranges from local to global and over time scales that are relevant to human usage of natural resources (Pickett et al., 2007).

In this point of view, some authors described and simplified the system complexity of the real world to capture key aspects of interest of social ecological system.

Holling (1995) simulated hierarchies framework of complex system based on agent-based model, and he at (2001) proposed that social-ecological system are composed of series of interconnected adaptive cycle at different scales. While, Kay and Boyle (2008) assumed hierarchies of structures and processes; focuses on flows, feedbacks, and thresholds based on self-organization of resources dissipation (energy). And, Ostrom (2009) divided the social-ecological system (SES) into four interacting levels: resource units, a resources system, a governance system, and users, which aimed to identify relevant variable and provide a common set of variables for organizing comparisons of similar SES.

In order to develop a strategy for integrated environmental assessment, The European Environment Agency (EEA) recommended a concept, which distinguished driving forces, pressures, states, impacts, and responses (DPSIR) (Figure. 1) that has been developed by OECD (The Organisation for Economic Co-operation and Development).

Furthermore, DSPIR described by Kristensen (2004), Mara et al. (2007) and others as a logic relations and causal links of the bulk of socio-environmental reactions starting with ‘driving forces’ (functions and activities that exert pressures on the environment) through ‘pressures’ (the act of driving forces on the environment) to ‘states’ (the influence of acting pressure on the environment) leading to ‘impacts’ (the reactions of environment due to changes of states) , which eventually may lead to political “responses” (prioritisation, target setting, indicators).



Source : Global International Water Assessment (GIWA), 2001; European Environment Agency (EEA), Copenhagen.

Fig. 1: DPSIR scheme.

4 STUDY AREA

The selected area of study is the metropolitan area of Greater Cairo and its surroundings, which is known as the capital of Egypt and one of the fastest growing megacities worldwide (Figure 2). The area covers about 600 km2, encompassing major parts of the governorates of Cairo, Giza, Six October, and Helwan. The Nile forms the administrative division between these governorates, with Cairo and Helwan on the east bank of the river and, Giza and Six October on the west bank. The area includes a variety of land uses associated with a complex mix of land cover, such as a central business district (CBD), urban/ suburban residential areas and some rural areas (e.g. cultivated areas and soil). This area has encountered rapid urban development and population growth in the last 20 years.

Consequently, immense strain put on cultivated areas in the greater Cairo from a serious problem of urbanization. This problem has caused an irretrievable loss of very fertile suitable soils. A very severe status and rate characterized the problem while the risk is severe.

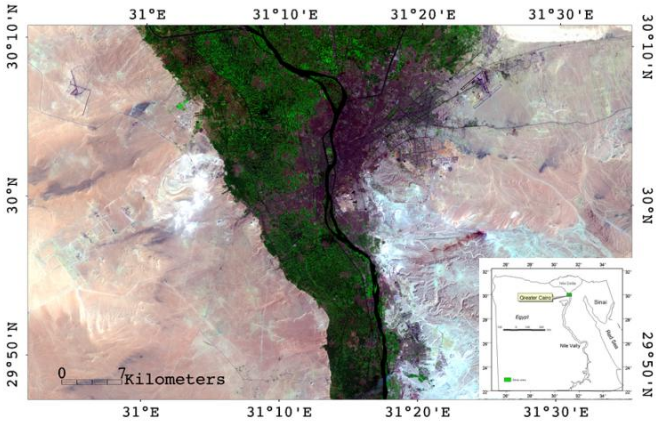


Fig. 2: Location of the study area

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5 GREATER CAIRO MODULES IN THE LIGHT OF THE DPSIR FRAMEWORK

There is many socio-ecological indicators are identified in Greater Cairo metropolis (Figure 3) which are concern the rapid increasing and physical change of the city. This means that, the scope of conceptual framework for such megacity (G.C) in current study would be included historical and/or temporal questions, such as how rapid development drive land use and land cover changes.

The author mentioned that the application of DPSIR-model on monitoring of mega-city meets most of components identified and described in other previous theories and frameworks concern the social economical system.

So, in this study, the DPSIR model used to identify and to determine a framework to find and describe the development indicators of megacity in relation to ecology and environment, and also to provide a deduction of main transformer indicators in Greater Cairo Metropolis.

Hence, the environmental status scheme (DPSIR), which could be applied for G.C is described as following (Figure 4).

By using the DPSIR scheme mentioned above, the relationship between the driving forces and the dynamic process of land use are guided in G.C. Hence the population growth and fast growing of investments (human activity) were representing the main drivers, which lead to environmental and spatial changes in land uses and planning. As a result of exerting pressure on the land, the states of Urbanization and loss of fertile land will be concerned in this study as major transformer indicators implemented and linked between dynamic processes through the DPSIR chain. Moreover, the spatial monitoring was applied to determine what and where the effect of the failures were and to put them into place responses to manage these changes.

Accordingly, the relationship between the human activities (society) and the dynamic processes of land-use cover change would be understood and implemented into management plan.

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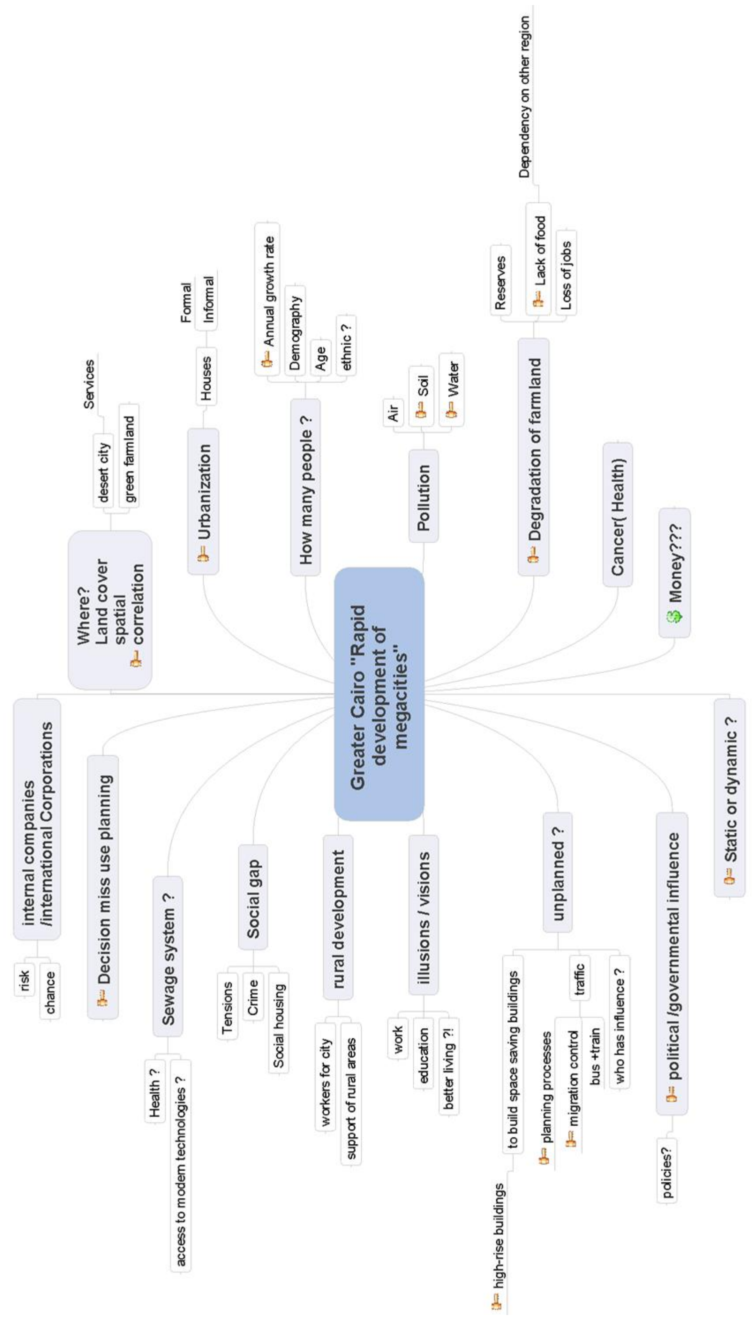


Fig. 3: The main megacity's indicators.

6 CHANGE DETECTION BY USING REMOTE SENSING TECHNIQUES

Remotely-sensed information is of particular relevance in the worlds developing countries because it provides fundamental information on growth-related processes and their effect on the environment that are not available from other sources (Miller & Small, 2003). Hence, this study describes and discusses different remote sensing (RS) techniques to monitor and analyse dynamic expansion and change detection in Greater Cairo Metropolis. While the availability of different resolutions of satellite images, which launched in different dates by different sensors, encouraged most of spatial and environmental planners to specify different applications to improve spatially and spectrally historic data and collected information of the land. Furthermore, archived remote sensing data has been used to examine the possibilities of multi-temporal imagery for mapping and monitoring changes in land cover (Sobrino and Raissouni 2000). As well, monitoring information can then be combined with different layers to help predict which areas are affected in the past and which could be at risk in the future, allowing secure decisions to be taken where it is needed most. Therefore, successful utilization of remotely sensed data for land-cover and land-use monitoring requires careful selection of an appropriate data set and image processing techniques (Lunetta, 1998). Consequently, Landsat 5TM and 7 ETM+ provide an opportunity to extend the area and frequency with which we are able to monitor the Earth's surface with large geographic cover (Curtis 2001). This address that monitoring LULCC on large cities could be processed and give fast-recent information of alternative indicators, which are dynamically and dramatically transformed.

Recently, change detection of a particular object between two or more time periods, which lead to produce a quantitative spatial analysis in an area of interest (Macleod and

Congalton, 1998), are provided by several remote sensing satellite sensors. Thus, different satellite systems have different characteristics, e.g. resolutions, number of bands, and have their own importance for different application.

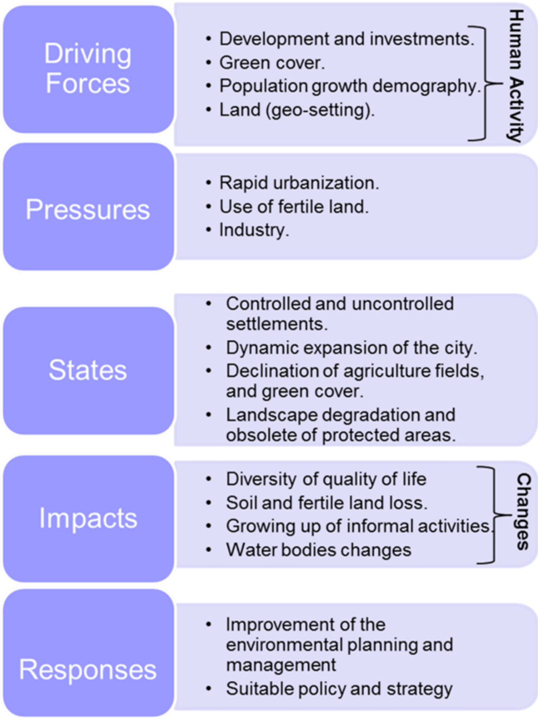


Fig. 4: General scheme of DPSIR for Greatre Cairo.

7 MATERIAL AND METHODOLOGY

7.1 Data

Beside the ground information, the selected satellite data and its time span represented the whole study area spatially, and two main phases concern the rapid development, expansion of infrastructure services, and investment economically. To classify the whole area of Greater Cairo metropolis during the last two decades of the last century and the first decade of new millennium, the low to medium resolution images of Thematic Mapper TM and Enhanced Thematic Mapper ETM were used with about 28 m pixel size.

The close relation between land use cover changes and economic growth and reforming has been putting on the track of change detection researchers and they emphasized some phrases. For example; Luc 2001 mentioned that a spatial econometric approach is not exclusively a consequence of the nature of the data, but may also be required to quantify the "spatial" components of a theoretical specification.

Therefore, the three different time series with sixteen years difference started from 1884 (which is considered as the reference year for the other images), then 1990, to 2006 have been chosen. Consequently, the time span from 1984 to 1990 represented the continuity of a phase of market economy which was introduced at the end of 1970´s by Sadat's regime (http://www.mideastweb.org/egypthistory.htm). From 1991 Mubarak undertook a number of important laws and decrees which have been significantly reformed the domestic economic program to reduce the size of the public sector and expand the role of the private sector (IDRC report 1996).

7.2 Image processing

If A series of processing operations was performed on these images. The images were georeferenced using UTM map projection for zone 36 and WGS84 datum. The images were resampled to 30 m for bands 1, 2, 3, 4, 5, 7, to 15 m for panchromatic and to 60 m for thermal bands using the nearest neighbour technique. In order to produce a test area, false colour composites from ETM+ bands 7, 5 and 3 were used, while all of the six bands (ETM+ bands 1, 2, 3, 4, 5 and7) were used for pixel-based classification.

7.3 Object-based classification

Since pixel-based analysis in complexly structured land-use and land-cover (LU/LC) areas is limited because the semantic information necessary to interpret an image is usually not represented in single pixels, and also, the statistical independence assumption pixel-based classifications involve the DN values individually without considering the neighbourhood pixels (Castelli et al., 1999), the Object segmentation module was used for object-oriented analysis and classification.

Segmentation is the main process in the classification module in eCognition Developer software and its aim is to create meaningful objects. This means that an image object should ideally represent the pattern of each object in question. This pattern combined with further derivative colour and texture properties can be used to initially classify the image by classifying the generated image objects.

Thereby we found that, the classes are organized within a process tree and sophisticated class hierarchy that has been compatible with the concept of DPSIR framework and it looping mechanism.

In other hand, the multi-scale behaviour of the objects can construct a semantic hierarchy by detecting a number of small objects, which could be aggregated to form larger objects (Matinfar et al. 2007). The latter is used for back-forward analysis.

8 IMPLEMENTATION OF LUCC BY USING DPSIR

The main selected elements of land use / land cover (LULC), which have been examined and classified, are investigate the relation between human activity and landscape surface in Greater Cairo (G.C) and expose their linkage status and impact. For the sake of classification and monitoring, the six land classes were considered to refer to the urbanization (dense and lose), cultivated, surface water, desert (hinterland), cultivated-to-urban areas, and bare soil. These classes provide a practical means to dynamic change in spatial resilience to achieve management objectives, and also, they can be used for predicting coming changes and assessing development challenges.

As we addressed before the needs of conceptual model to explore key aspects of human-environment relations in Greater Cairo metropolis, here is the first impression of the implementation of DPSIR model to clarify the interaction between different stages in this model and land classes selected for Greater Cairo regarding the back-forward mechanism (Figure. 6).

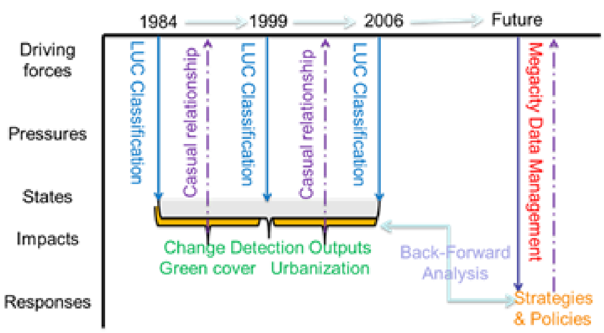
According to, Luc (2001) concluded that the uses of an appropriate" spatial" methodology can one hope to discover the "true" underlying relationships. This study assumed that the land classes or indicators in the term of land use/cover classification are representing the spatial driving forces, exerted pressures, and affected states of increasing or shrinks of Greater Cairo. In spite of the population rate are changed through the time span but it is represented here as static indicator during the spatial classification of each selected year. While the other indicators defined as anthropogenic drivers such as "urbanization, cultivation, and artificial water bodies" and natural drivers such as (natural surface water and geo-cover). These indicators defined as dynamic drivers which could be detected and monitored spatially by using remote sensing techniques. As a result, the impacts of the human activity could be reanalysed and implied as driving forces in sub-scheme of DPSIR, that mechanism is called here internal looping process or reiterate analysis.

Therefore, this study modified the DPSIR scheme to be adapted and used effectively in back-forward manner in spatial analysis of a Megacity knotty system. That permits to reselect elements (objects) within the system and repeat the analytical process through the system framework. This process named by author as "Looping Mechanism" of spatial analysis and resilience.

The back-forward (Looping Mechanism) is working by two ways regarding new data or information coming from the change of time span and/or spatial information (resolution). The first one (main vision) is the flexibility to add and modify the data through the main framework (Figure 6). The second one (minor vision) is the ability to extract from the main framework a specific object and reanalyse and monitor it by using subsidiary DPSIR scheme (Figure 7). This means that, the monitoring system of spatial changes took place, which leads to irritation iterate of change detection program in any level of working flow and prospective date. For instance; choosing the green cover and urbanization changes as main objects to use them separately in work scheme and monitoring system has been applied (Figure 7).

9 RESULTS

The analyses of LU/LC state of each year in different time series show that, the mutual linking between the six environmental indicators is representing a first level of classification (Figure 8) (Table 1). This level of classification can lead directly to individual time response. This response is ineffective for growing cities and monitoring studies. As a result, the subsidiary DPSIR frameworks and other level of classification were applied to compare and detect the change of any key element (object) separately such as agriculture activity (green cover) and urban development through time span is based on and part of the main frame work and classification tree (Figure 7, 9&10).



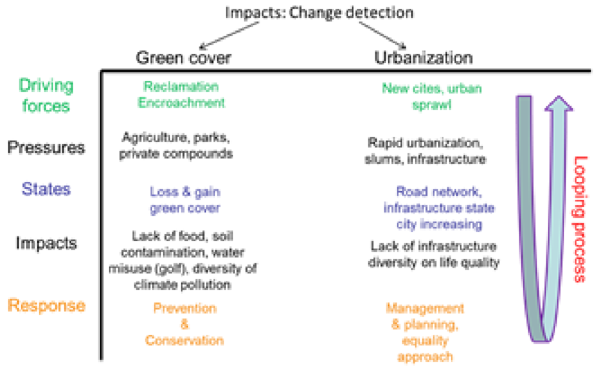


Fig. 6 (left): Implementation of LUCC analysis by DPSIR. Fig. 7 (right): Back-forward process analysis (Looping Mechanism)of changed indicators by using DPSIR for G.C.

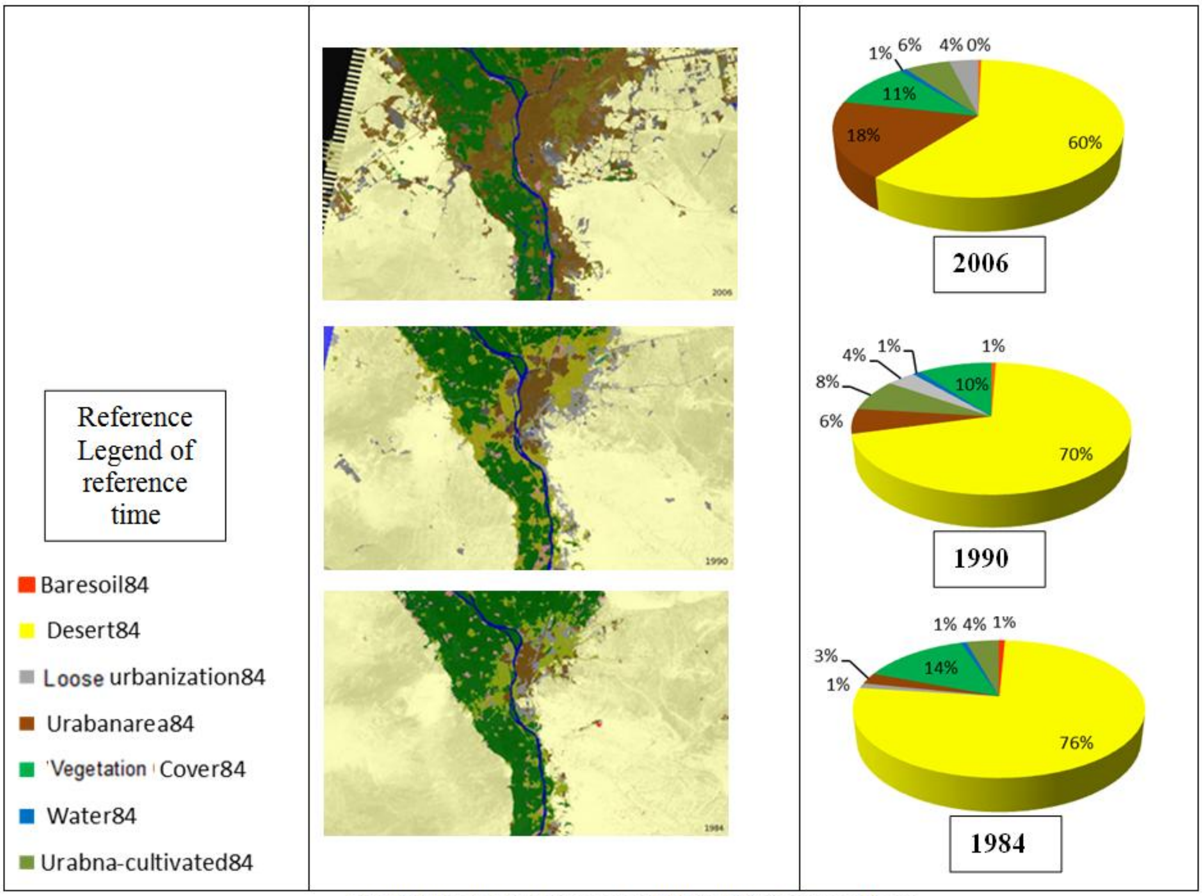


Fig. 8: The classified images and their distribution analysis.

LU/LC (Land use/cover)	1984 %	1990 %	2006 %
U (Urban areas)	3	6	18
CL (Cultivated land)	14	10	11
CU (Cultivated to urban)	4	8	6-
D (Desert area)	76	70	60+
BS (Bare soil)	1	1	0+
WB (Water Bodies)	1	1	1
(LU) Loose Urban	1	4	4

Table 1: Land cover-use change analysis of Greater Cairo.

There are two main contrasting aspects have been affecting the green activity in area of concern, the first one is the reclamation and the second one is encroachment. Additionally, the new cities and urban sprawl represent the main forces when the spatial development and dynamic of urbanization in Greater Cairo takes place.

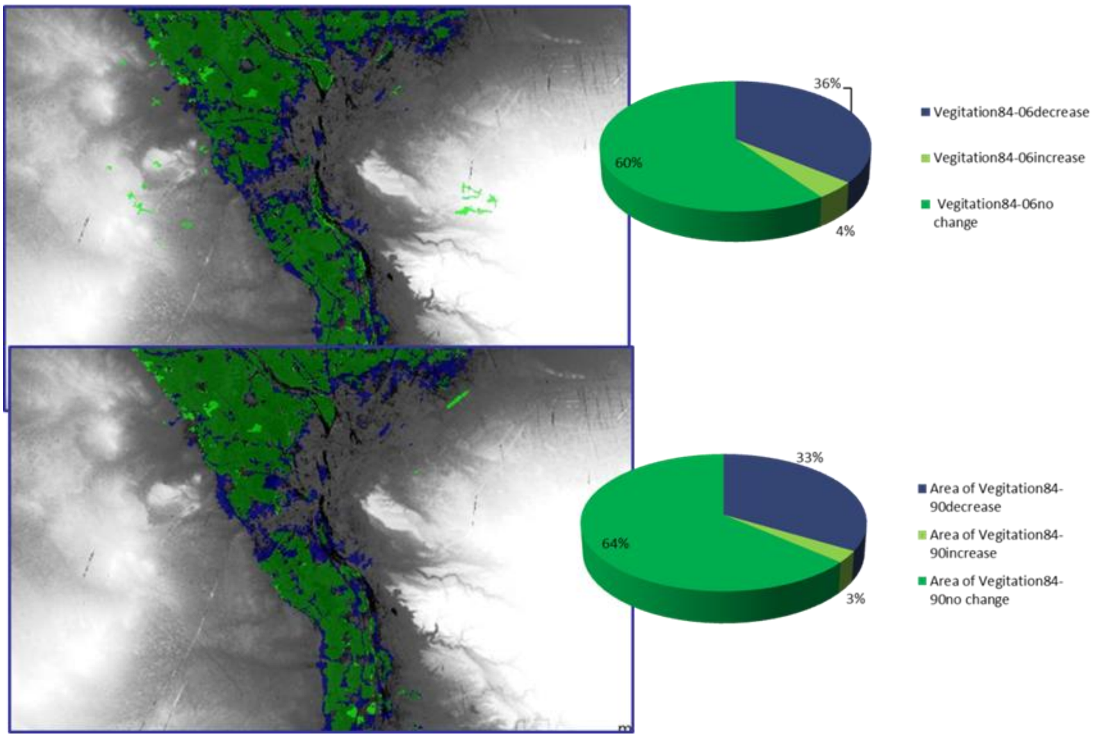


Figure 9. Green cover changes in G.C (Impact)

In these two sub-schemes, the two keys are used as drivers to move to another level of monitoring and classification which is strongly connected with the basic classification and main framework. Moreover, any change, addition, or erase of time span or image resolution rather than classification algorithms do not affect the main structure of the analytical framework and their subsidiary schemes. But, such changes can contribute smoothly and systematically to the interconnected sub-DPSIR-responses which can be aggregated and used to develop a data base of management planning and to update monitoring information.

According to such approach, it is possible to examine the accuracy of using tool to analyse and mention the criteria of more affected objects (spots) for further processing and estimation of the change levels.

So, the sub-DPSIR scheme for urbanization shows that the impact in water is mainly dealing with the drinking water, unlike; the sub-scheme for green activity expresses its impact on irrigation water (Figure 7). This means that, the strategy of analysis and purposed plan has been oriented by selected object.

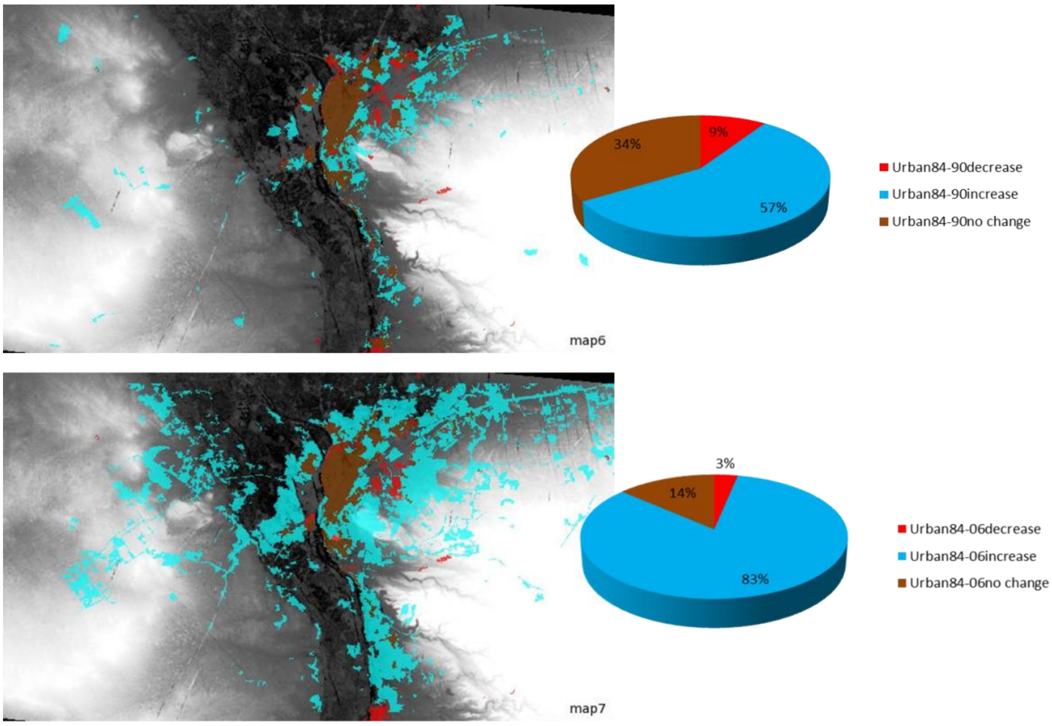


Figure 10. Urbanization changes in G.C (Impact)

10 CONCLUSIONS

- The spatial monitoring and change detection of megacity is not based only on the classification and remote sensing techniques but also on effective conceptual model to understand the environmental indicators and to identify the more effective hot-spots (objects) of changes.
- In this study we found that the applications of DPSIR model are useful to identify and analyse the causal link between the socio-environmental indicators of megacities (e.g. Greater Cairo metropolis) based on goal oriented and tracked flow of a conceptual scheme.
- Flexibility and elements interaction characters of DPSIR could be modified and used as looping process analysis for wide range of uses in different levels, approaches, scales and times.
- It could be concluded that, the object oriented classification technique is very compatible with DPSIR model in monitoring and change detection approach.
- New and modifies planning strategies could be elaborated based on the main DPSIR framework and its subsidiary schemes, these would contribute to improve management and support the decision makers and stakeholders to choice an individual element or group of elements to understand and response.
- The using of Socio – Envirronmental Models are useful to build knowledge system of megacites, that would be used for geo-spatial information service and data mining with what means (e.g. planning system, national and regional spatial development policies, other legislation, etc.).

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