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# *A GIS-based model for predicting changes in land use pattern up to 2100 Case study: Coastal zone of Behaira Governorate, Egypt*

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## 1. Introduction

The coastal zone of the Nile Delta is expected to be largely susceptible to sea level rise (SLR) impacts, which will take place in the future. The assessment of potential vulnerability to the SLR will be largely determined the magnitude and spatial extent of SLR impacts. Such an assessment requires profiling future land use pattern, which represents the physical assets in the future. This, in turn, highlights the need for modeling potential changes in land use pattern in the future.

The main objective of this assessment report is to develop a GIS-based model for profiling future land use pattern in the Nile Delta coastal zone. Furthermore, the developed model will be applied to quantify the change in various categories of land uses. This, ultimately, can contribute to the process of assessing potential vulnerability of the Nile Delta coastal zones to sea level rise.

## 2. Background (Modeling land use changes)

Recently, efforts to develop models for predicting changes in land use patterns expanded greatly to meet the need for land management and support decision-=making process in the field of planning (Poceweiz, et al., 2008). Generally, models for predicting changes in land use patterns assist in quantify the changes in various types of land use and identify the spatial extent of these changes (Veldkamp & Lambin, 2001).

The need for modeling changes in land use pattern was highlighted due to the significant impacts of land use changes on natural resources (de Koning, et al., 1999), (Bolca, et al., 2007) and (Veldkamp & Verburg, 2004). Furthermore, the importance of modeling land use change was emphasized by the need for assessing potential vulnerability to those future hazards that would expected to take place gradually such as SLR impacts. In this respect it should be noted that modeling land use pattern in the future is of great importance in measuring potential vulnerability as land use pattern profiles the economic and social assets of a community and consequently determines the vulnerability level of this community to sea level rise. In other words, the rationale for modeling land use change in the future is partially arisen from the need for assessing the potential vulnerability to sea level rise.

In general land use changes are driven by a wide range of biophysical and socioeconomic driving forces, which temporally and spatially interact to produce land use changes (Veldkamp & Verburg, 2004) and (Verburg, et al., 1999). Accordingly, for modeling potential changes in land use patterns, there is a need firstly to identify these drivers (Veldkamp & Lambin, 2001) and (de Koning, et al., 1999). Therefore, it was argued that the modeling land use change depends largely on the data availability and quality (Veldkamp & Verburg, 2004).

Some land use models were initially developed to predict land use change assumed that historical trends of land use changes will continue in the future. This type of models, which was called trend-based model (TBM), relied mainly on remotely sensed data to quantify the historical trend of land use changes (Poceweiz, et al., 2008). For example, Poceweiz, et al. (2008) assessed employing TBM in predicting land use changes compared to survey-based landowners decsion models.

Other land use models were developed to describe and analyze spatial patterns of land use change under different agricultural scenarios. CLUE model (Conversion Land Use and its Effects) is one of the main examples for such type of models. CLUE model was employed to develop future base-line scenarios for land use changes on the basis of a wide range of biophysical and socioeconomic drivers, (de Koning, et al., 1999) and (Verburg, et al., 1999).

Also, one of the most common integrated models that were widely employed to simulate and predict land use changes and their spatial distribution in the future is cellular automation and Markov model. According to this model, based on historical trends of land use changes, Markov model is firstly employed to produce a transition probability matrix for various types of land use. This matrix records the probability that each parcel of certain category of land use will change to the other category. Yet, such transition probability matrix does not provide any sense of spatial extent of land use changes. Therefore, as a supplementary model, cellular automation model is usually adopted to identify the land use category of each parcel of land in the future based on Markov probability matrix produced earlier and the land use categories of its neighbors (adjacent parcels) (Guan, et al., 2011), (Rimal, 2011) and (Ye & Bai, 2008).

It should be noted that despite GIS has been employed repeatedly in predicting land use change, the use of GIS was mainly restricted to visualize and analyze land use changes, see for example (Bolca, et al., 2007) and (Rimal, 2011). Actually, the great capabilities of GIS in terms of spatial analysis can contribute largely to modeling and predicting land use changes in the future. Accordingly, the suggested model in this assessment report can be considered as an attempt to employ these great capabilities in modeling the future changes in land use patterns.

## 3. Study area

The coastal zone of behaira Governorate, the study area, includes two of the administrative sections (Markaz) of Behaira governorate, Egypt, namely, Edku and Rosetta. These two administrative sections, which cover a total area of 430.21 km$^2$, are further subdivided into 20 localities (Figure 1). According to 2006 Census, the study area had a total population size of 354108 (CAPMS, 2008).

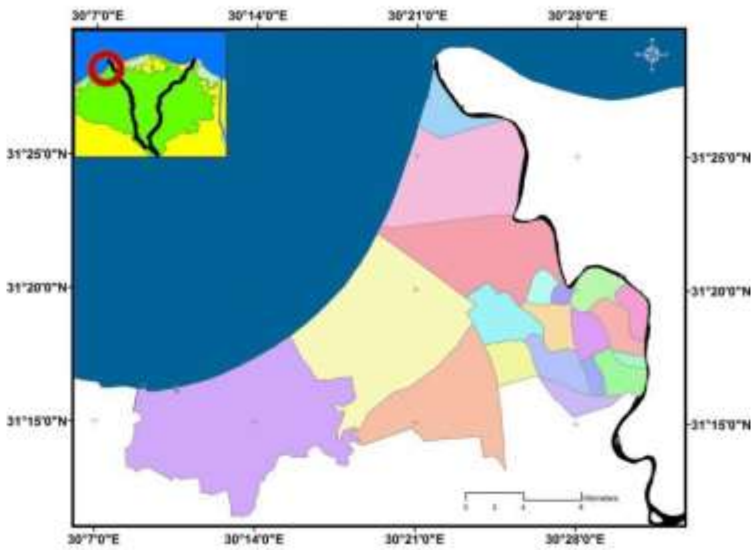



Figure (1): Administrative divisions of the study area

The population of the study area experienced a moderate annual growth rate ranging between 1.8 and 2.34% with an average of 1.87% during the period 1996-2006. Such an average annual growth rate is relatively low compared to the annual growth rate during the period between 1986 and 1996, which was 2.53 on average. This can be explained by the decreasing fertility rate. Accordingly, such a decline in the annual population growth rate can be used as an indicator to improved demographic characteristics in the study area (CAPMAS, 2008), (CAPMAS, 1998) and (CAPMAS, 1988).

The land use/land cover pattern of the study area is dominated by cultivated land, which covers about 65.28% of the total area. Also, considerable proportion of the study area is occupied by wetlands covering about 29.53% of the total study area. The built-up area of human settlements represents about 2.70%. Meanwhile, about 119.22 $km^2$ are still undeveloped areas, accounting for 8.63% of the total study area (Figure 2).

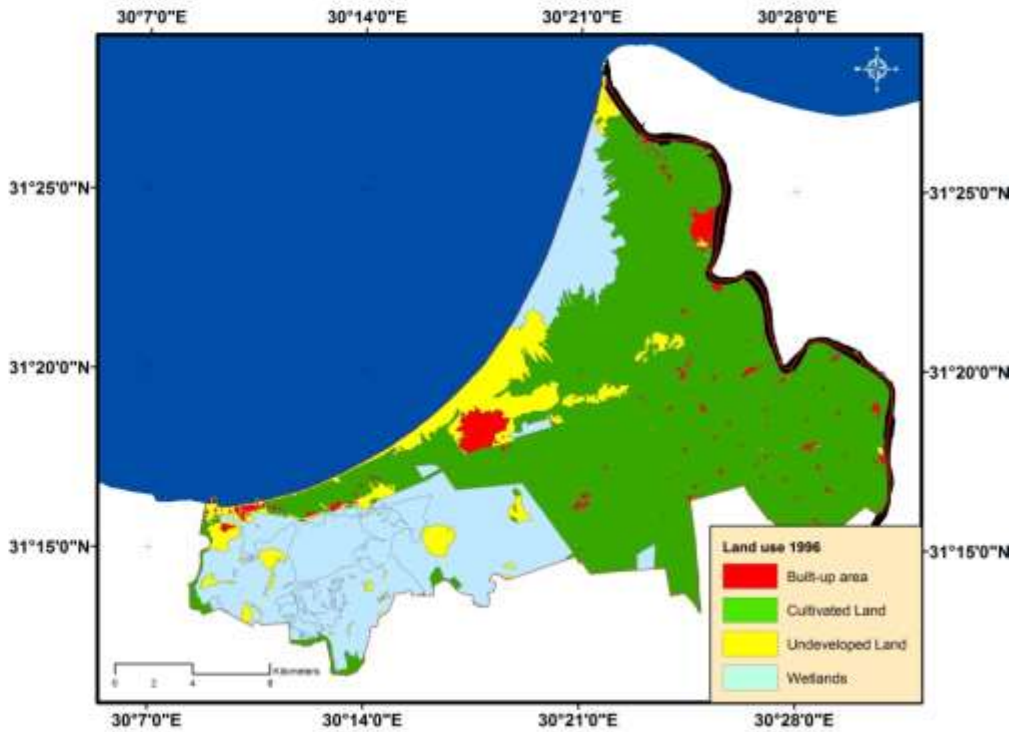



Figure (2): Land use/land cover in the study area 1996

## 4. The suggested model

The suggested model for predicting the changes in land use/land cover pattern in the study area was based on three main assumptions including:

1. The built-up area of human settlements is largely determined by its population size. This means that the population increase is the main driving force of built-up area expansion. In other word, any increase in population size will contribute to increasing demands for land, which leads ultimately to expansion of the built up area.
2. Homogeneous expansion of built-up area at all directions. This implies that the built-up area will expand at all directions at the same rate.
3. Existence of a number of physical constraints that restrict the expansion of built-up area in certain parts of the area. These constrains are generally determined by the site characteristics (e.g. existence of coastline).

Based on these three assumptions, a methodology of five main steps was developed to predict the changes in land use/land cover in the study area up to 2100. Each of these steps will be discussed in the following sub-sections.

### 4.1 Delineating current land use/land cover pattern

Initially, there was a need to produce a base map for the study area illustrating the various categories of land use/land cover. For that purpose, a topographic map for the study area was used. The most recent topographic map for the study area produced in 2000. The study area and was covered by a topographic maps scale 1:50,000 sheets no. NH36-M1d. Using ArcGIS 10, this map was registered and rectified to UTM WGS 84 Zone 36N, coordinate system (Transverse Mercator projection). Thereafter, the registered and rectified map was used in digitizing the base map of the study area and all various categories of land use/land cover. Simultaneously, data on most recent administrative subdivisions of the study area at locality level was collected from Information and Decision Support Center (IDSC), The Egyptian Cabinet. This data was used in spatial data editing and delineating administrative subdivisions of localities in the study area. Also, demographic data about the study area at locality levels were acquired from Central Agency for Public Mobilization and Statistics (CAPMAS).

The land use/land cover layer was overlaid (overlay intersect) with the administrative subdivision layer, which represents the localities of the study area. The main outcome of this step was the area of various categories of land use/land cover, particularly built-up area of human settlements at each locality.

## 4.2 Estimating the relationship between built-up area and population size

To estimate and quantify the relationship between built-up area in the localities of the study area as a dependent variable and the population size of the same localities in 1996 as an independent variable (driving force), linear regression analysis was employed (Table 1 and figure 3).

Table (1): Linear regression matrix

| Source | SS | df | MS |
|---|---|---|---|
| Model | 1.8419e+13 | 1 | 1.8419e+13 |
| Residual | 1.2475e+12 | 18 | 6.9308e+10 |
| Total | 1.9666e+13 | 19 | 1.0351e+12 |

| | |
|---|---|
| Number of obs | = 20 |
| F( 1, 18) | = 265.75 |
| Prob > F | = 0.0000 |
| R-squared | = 0.9366 |
| Adj R-squared | = 0.9330 |
| Root MSE | = 2.6e+05 |

| built_up | Coef. | Std. Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| pop1986 | 45.97988 | 2.820533 | 16.30 | 0.000 | 40.05417 | 51.9056 |
| _cons | -132320.3 | 72069.96 | -1.84 | 0.083 | -283733.6 | 19093.09 |

It was found that:

- *p-value* of *F-test* was ≤ 0.05, which indicates that the independent variable in the employed regression model is potentially useful for predicting the dependent variable in a linear model.
- $R^2$ was 0.9366, which indicated that about 96% of the dependent variable (built-up area) can be explained by the independent variable (population size).

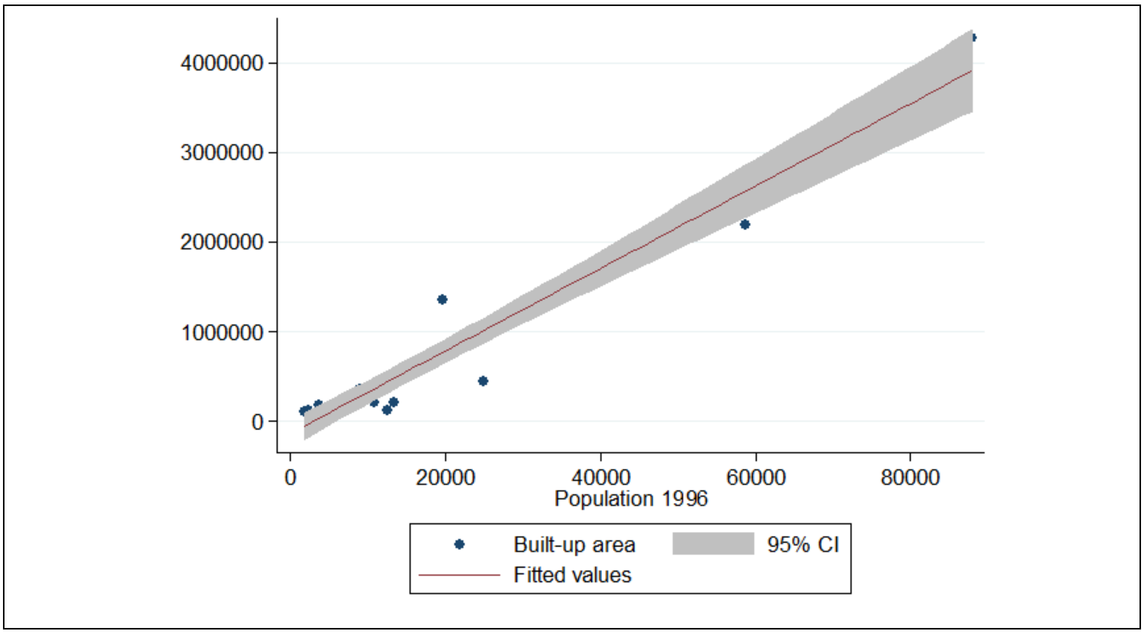


Figure (3): Curve fitting of built-up area vs. population size in the study area

### 4.3 Projecting the population size in each locality

Based on the last annual growth rate between 1996 and 2006, which ranged between 1.8 and 2.34% with an average of 1.87%, , the population size in each locality was projected in different point of times up to 2100 (Figure 4). In this respect it was estimated that the population size of the study area will reach as much as 2.35 million by 2100.

Thereafter, as built-up area in each locality consists of a number of land parcels, there was a need to estimate the population size of each parcel of built-up area within each locality. For that purpose, the population size of each parcel of built-up area was estimated proportionally on the basis of its share to the total built-up area of the locality supposing uniform or fixed built-up area per capita.

### 4.4 Estimating the built-up area of each parcel

Based on slope and intercept values estimated from the regression analysis carried out in step 4.2, built up area can be predicted according to the following equation

$$y = 45.98\, x - 132320$$

Where:

y = Built-up area of a human settlement by 2050
45.98 = Coefficient regression (Slope)
X = Projected population size of this settlement by 2050
- 132320 = Intercept (constant)

## 4.5 Allocating land use changes due to future expansion of built-up area

To allocate the land use changes due to future expansion of built-up area, there was a need to delineate the newly expanded built-up area and update the land use/land cover layer as a result of such expansion.

The spatial extent of the newly expanded built-up area in the future was predicted as a buffer zone on the basis of the fact that increasing the area of a polygon by a factor will lead to an increase in its perimeter by the same factor. The range of buffer zone representing the newly expanded built-up area was estimated through the following equation:

$$B = \sqrt{\frac{Be}{\pi}} - \sqrt{\frac{Ac}{\pi}}$$

Where:

$Be$ = Estimated built-up area in 2100

$Ac$ = Current built-up area

$\pi$ = 3.14159

This means that it is assumed implicitly that the buffer range is the difference between the radius of the two polygons; the current built-up area and estimated one.

Through Spatial Analysis Tools in ArcGIS 10, the estimated changes in land use/land cover were delineated as follows (Figure 4):

- Using proximity analysis tools (Buffer Tool) the estimated buffer range was employed to create buffer polygon around the current built-yup area representing the spatial extent of the newly expanded areas.
- The created buffer polygons were clipped by mask layer representing various limitations that constrain built-up area expansion such as coastline and the Nile branch.
- Next, the clipped feature class (Layer) was overlaid (union overlay) with the current built-up area to form the new built-up area by 2100.

- The elements of the created polygon layer that represent the new built-up areas were further dissolved as many of expanding built-up areas were intersected.
- Thereafter, the created layer of the new built-up area by 2100 was used in updating the current land use pattern as the development of human settlement will be on the account of other categories of land us/land cover such as cultivated land, wetlands and undeveloped land.

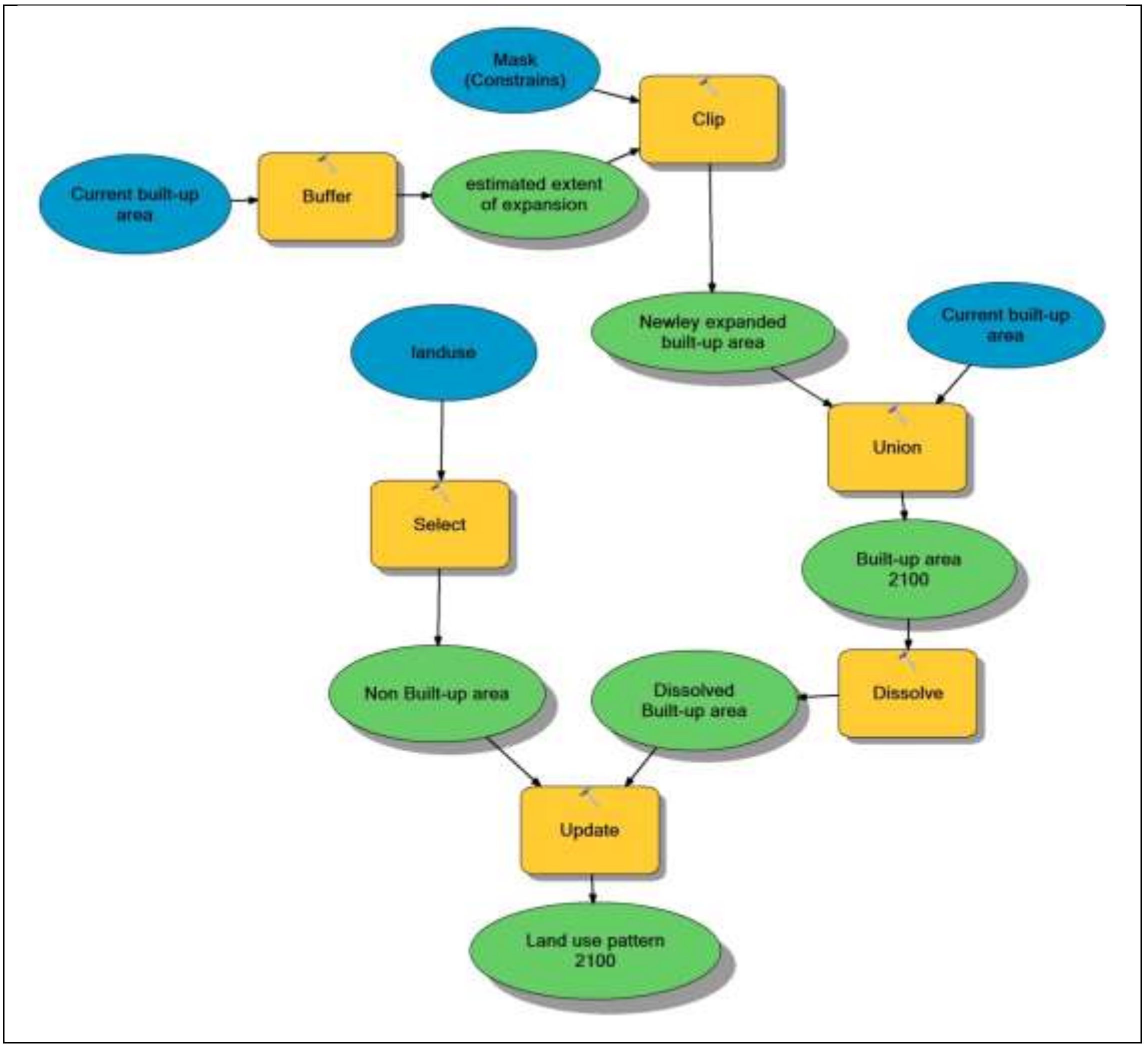


Figure (4): Analysis Model developed for delineating the changes in land use/land cover pattern

## 5. Results and discussion

According the predicted changes in land use/land cover, the built-up area will be doubled seven times up to 2100. Such a considerable expansion of built-up area will encroach on other categories of land use/land cover. Therefore, as a result of such an encroachment, the areas of these categories of land use/land cover other than built-up area are expected to decrease. For example, the area of cultivated land is expected to decrease from 265.70 $km^2$ nowadays to 204.99 $km^2$ in 2100, which means a decreasing rate of 22.85%. Also, about 37.48% of the currently undeveloped land is expected to be converted into built-up area (Table 2 and Figure 5).

Table (2): Changing areas of various categories of land use/land cover up to 2100

| Land use | Area ($Km^2$) | | | | Changes (1996-2100) | |
|---|---|---|---|---|---|---|
| | 1996 | 2050 | 2075 | 2100 | Area ($km^2$) | % |
| Built-up area | 10.91 | 36.81 | 57.74 | 87.63 | 76.72 | 703.26 |
| Cultivated Land | 265.70 | 246.02 | 229.33 | 204.99 | -60.71 | -22.85 |
| Undeveloped Land | 34.84 | 28.97 | 25.44 | 21.78 | -13.06 | -37.48 |
| Wetlands | 119.22 | 118.86 | 118.14 | 116.24 | -2.98 | -2.50 |

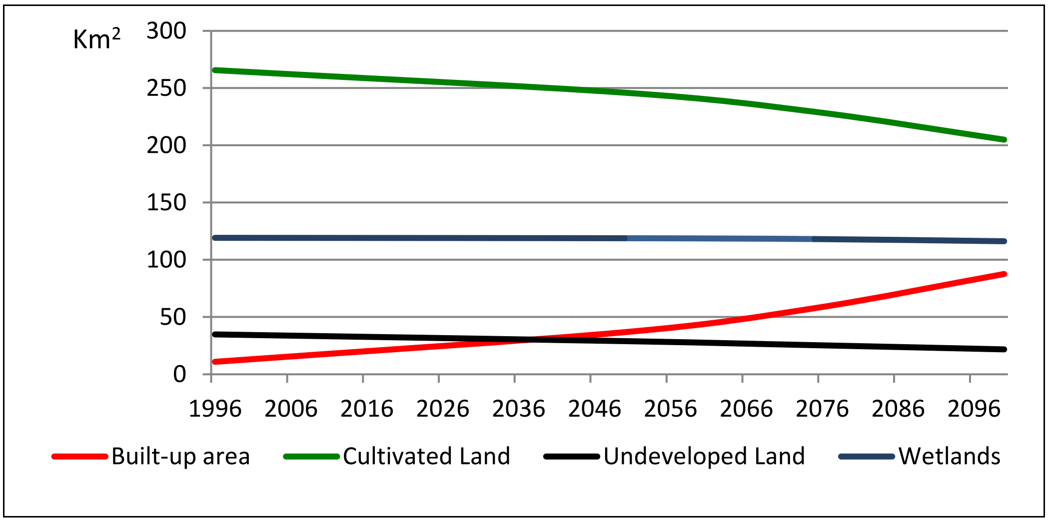



Figure (5): Predicted changes in areas of various land use/land cover categories up to 2100

It should be noted that the relative numbers indicate that considerable proportions of undeveloped land will be converted into built-up area compared to cultivated land. In contrast, the absolute numbers indicate that considerable areas of cultivated land will be lost due to the expansion of built-up area. In this context, it was found that while about 13 $km^2$ of undeveloped land will be converted into built-up area, about 60 $km^2$ of cultivated land will be lost due to encroachment of built-up area (Figure 6). Meanwhile, the changes in wetlands were found to be minimum, as only about 2.98 $km^2$ of wetlands are expected to be encroached by built-up area.

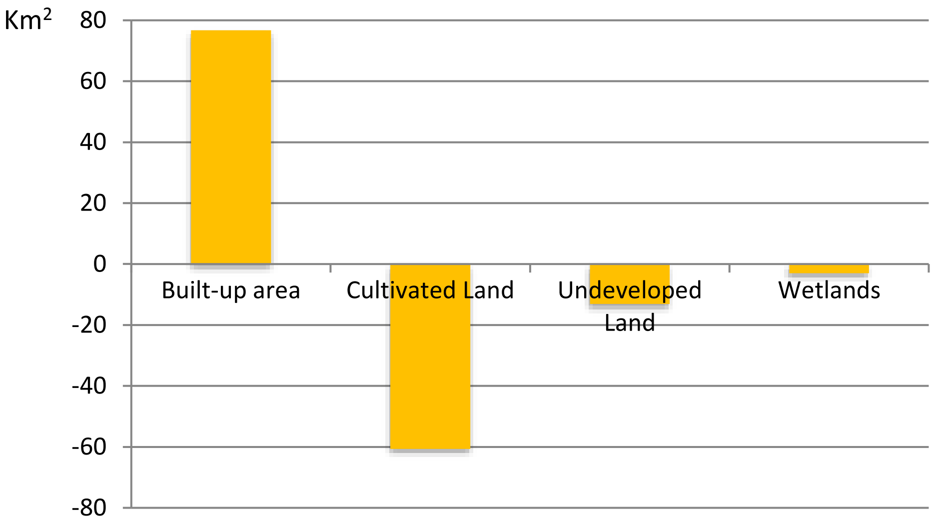



Figure (6): Change rate of various land use/land cover categories between 1996 and 2100

To validate the developed GIS-based model for predicting and delineating the changes in land use/land cover, a comparison between estimated and built-up area delineated by GIS was conducted. The comparison illustrated that absolute difference estimated and delineated built-up areas were about 0.17, 4.61 and 17.52 $km^2$ in 2050, 2075 and 2100 respectively (Table 3). These areas represent about 0.47%, 7.99% and 19.99% of the estimated built-up area in these years.

Table (3): The difference between

estimated built-up area and dilentaed built-up area by GIS

| Built-up area | Area ($KM^2$) |
|---|---|

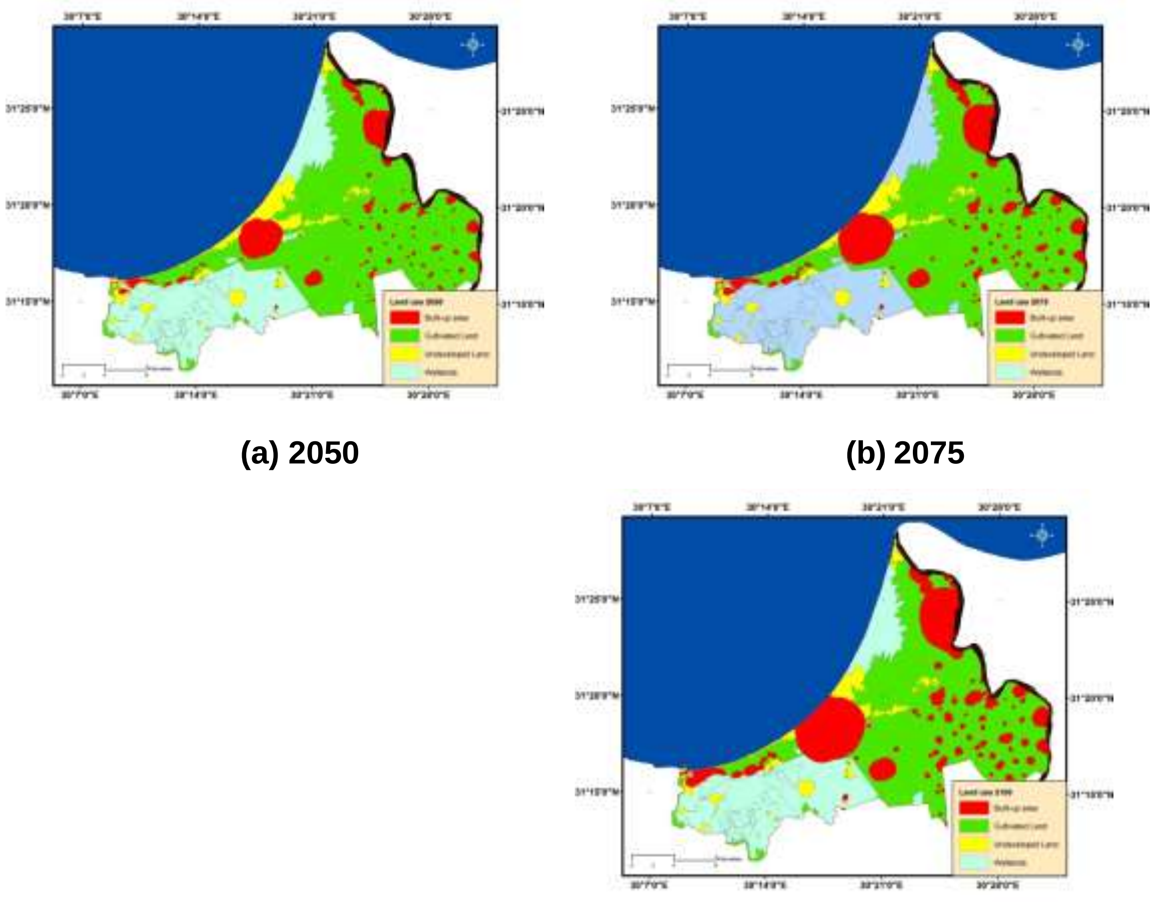
| | | 2050 | 2075 | 2100 |
|---|---|---|---|---|
| Estimated | | 36.64 | 62.35 | 105.15 |
| Delineated | | 36.81 | 57.74 | 87.63 |
| Difference (estimated – delineates) | Area (km$^2$) | 0.17 | 4.61 | 17.52 |
| | % | 0.47 | 7.99 | 19.99 |

In this respect, it should be mentioned that such a difference between estimated and delineated built-up areas is generally attributed to two main reasons. The first is represented in the mechanism of built-up area expansion. As the built-up areas of adjacent human settlements grow they merge. For instance, the ongoing expansion of built up areas of Rosetta city and the adjacent villages of El Gediah and Borg Rashid are expected to be merged starting from 2075. Moreover, the merged expanding built-up areas of these human settlements are expected to increase by 2100 (Figure 7). Such a merge of expanding built-up area means simply existence of overlapping areas which are removed through dissolving process to avoid double counting.

The second reason underlying such a difference between estimated and delineated built-up area is represented in the existence of physical limitations for expansion of built-up area. Such constrains, which are generally relevant to the site characteristics, are used to mask the newly expanded built-up area.

For these two reasons, it was noted that the difference between estimated and delineated built-up areas increases over time, where the merged and clipped built-up areas increase.

It should be noted, in this context, that land use in some parts of the study area, particularly in those parts that are merged and constrained by local limitations are expected to be intensified and accordingly the build-up per capita is expected to be higher compared to other parts of the study area.



(a) 2050 (b) 2075 (c) 2100

Figure (7): Predicted land use pattern in (a) 2050, (b) 2075 and (c)2100

## 6. Conclusion

The importance of predicting land use changes in the future is arisen mainly from its crucial role in assessing potential vulnerability of coastal areas to the future impacts of sea level rise which will take place gradually. To carry such an assessment there should be a need for profiling the physical and socioeconomic assets of the coastal zones.

GIS can contribute largely to modeling future land use changes and mapping these changes. Moreover, it can provide a detailed profile for the expected changes in land use/land cover.

The developed GIS-based model, which was based on population growth as main driving forces of built-up area expansion, considered the site characteristics and their limitations to this expansion.

Generally, the developed model for predicting land use changes showed that the pattern of land use/land cover is expected to change considerably during the next decades as a result of expanding built-up area. In this respect, it was found that cultivated land will be the most affected land use category by the expansion of built-up area up to 2100, where about 60 $km^2$ of cultivated land in the study area will be lost due to such expansion.

However, the successful implementation of the developed GIS relies mainly on availability of most accurate, detailed and updated data on land use/land cover pattern and the main forces driving the changes in this pattern. Accordingly, there is an urgent need to such data.

## 7. References


Bolca, M. et al., 2007. Determination of impact of urbanziation on agricultural land use and wetland land use in Balcovas' Delta by remote sensing and GIS technique. *Environ Monit Assess,* Volume 131, pp. 409-419.

CAPMAS, 1988. *Population estimation 1986: Behaira Governorate,* Cairo: Central Agency for Public Mobilization and Statistics.

CAPMAS, 1998. *Population estimation 1996: Behaira Governorate,* Cairo: Central Agency for Public Mobilization and Statistics.

CAPMAS, 2008. *Population Census 2006: Behaira Governorate,* Cairo: Central Agency for Public Mobilization and Statistics.

de Koning, G. H. J., Verburg, P. H., Veldkamp, A. & Fresco, L. O., 1999. Multi-scale modelling of land use change dynamics in Ecuador. *Agricultural Systems,* Volume 61, pp. 77-93.

Guan, D. et al., 2011. Modeling urban land use change by the integration of cellular automation and Markov model. *Ecological Modeling ,* Volume 222, pp. 3761 - 3772.

Poceweiz, A. et al., 2008. Predicting land use change: comparison of models based on landowner surveys and historical land cover trends. *Landscape Ecol.,* Volume 23, pp. 195-210.

Rimal, B., 2011. Application of Remote sensing and GIS, land use/land coverchange in Kathamandu Metropolitan City, Nepal. *Journal of Theoritical and Applied Information Technology ,* 23(2), pp. 80-86.

Veldkamp, A. & Lambin, E. F., 2001. Predicting land-use change. *Agriculture Ecosystems and Environment,* Volume 85, pp. 1-6.

Veldkamp, A. & Verburg, P. H., 2004. Modeling land use change and environmental impact. *Journal of Environmnetal Management ,* Volume 27, pp. 1-3.

Verburg, P. H. et al., 1999. A spatial explicit allocation procedure for modelling the pattern of land use change based upon actual land use. *Ecological Modelling,* Volume 116, pp. 45-61.

Ye, B. & Bai, Z., 2008. *Simulating land use/cover changes of Nenjang county based on CA-Markov model.* Boston, Springer, pp. 321-329.