Using the SLEUTH urban growth model coupled with a GIS to simulate and predict the future urban expansion of Casablanca region, Morocco

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ABSTRACT:

The rapid and sometimes uncontrolled acceleration of urban growth, particularly in developing countries, places increasing pressure on environment and urban population well-being, making it a primary concern for managers. In Casablanca city, Morocco's economic capital, the rapid urbanization was a result of population explosion, rural exodus and the emergence of new urban centers. Therefore, a system for urban growth simulation and prediction to anticipate infrastructural needs became indispensable to optimize urban planning. The main aim of this work is to study the urban extension of the Grand Casablanca region from 1984 to 2022 and to predict urban growth in 2040 using the SLEUTH cellular automaton model. The methodology consists of calibrating the model using data extracted from a time series of satellite images with a resolution of 30 m acquired between 1984 and 2018, as well as vector data relating to the urban projects planned on the horizon of 2022. The supervised classification and digitization of these images, together with a DEM of the study area, provided the input data required by the model, including Slope, Land use, Exclusion, Transportation and Hillshade. This data was introduced into the model using ArcSLEUTH, a custom extension of ArcGIS to compile the SLEUTH model. The result is synthetic maps of urban growth in the study area up to 2040, as well as the expected percentage indicators of change. The result is an effective decision-support tool for decision-makers and planners to develop more informed development strategies for the region and its people.

1. INTRODUCTION

The study of urban evolution is the fundamental pillar of good territorial management. The understanding of this evolution becomes more critical in the context of a growing agglomeration like the city of Casablanca. The Greater Casablanca region is experiencing fast urbanization as a result of demographic pressure and internal migration. This urban expansion, hard to control, aggravates the proliferation of anarchic housing that lacks all essential services. Anticipation of the problems created by this situation as well as the optimization of efforts to remedy this situation require the availability of powerful tools capable of providing better visibility as quick as possible.

Geographic information systems (GIS) offers new solutions, particularly through the implementation of specific models, which open new horizons for the analysis of urban evolution. GIS relies on data of multiple formats and origins such as: satellite images, vectorial repositories, socio-economic information, etc. which certainly make it possible to have almost a total visibility on the events and phenomena taking place on the surface of the globe; however, a good future projection of such a complex phenomenon as urbanization would require the use of reliable models adapted to the local context.

The SLEUTH model, developed by Dr. Keith C. Clarke of the University of California, Santa Barbara, Department of Geography, coupled with GIS, presents a tool for simulating urban growth. Through six types of input data - namely slope, urban land use, exclusion, transport and hill-shade - using cellular automata, it allows to understand and model expansion of urban areas relative to surrounding lands (Bihamta et al., 2015).

Our work hypothesis is that SLEUTH would work successfully in Morocco, even though the Moroccan guidelines of elaborating an urban master plan may differ from the hypothesis of SLEUTH which was built initially based on the US context.

Thus, we will be studying in this paper, the validity of this hypothesis, especially for the case of Grand Casablanca. We first present the recommended methodology before presenting the obtained results, then discuss the validity of these results and the conclusions that can be drawn from them.

2. BACKGROUND

Since the 1990s, the prediction and modelling of urban growth has been the subject of several research studies (Batty and Xie, 1997). Thus, several methods and models have been developed and published around this problem. There are different ways of classifying these models and many authors have proposed different classifications in their work (Timmermans, 2006). A detailed overview of the history of urban modelling as well as a classification of traditionally used spatial models has been proposed by (Batty and March, 1976), (Fujita et al., 2001) and (Batty, 2013). The present work focuses on the use of a specific type of modelling method that is characterized as "new tendency" models: CA cellular automaton models (Torrens, 2001).

Urban growth modelling based on CA algorithms has great potential for their management of spatio-temporal dynamics, the level of detailed data representation, and the bottom-up modelling approach (Maithani, 2010) and (Sakieh et al., 2015). Among the cellular automaton models, SLEUTH presents itself as the most used model for the modelling and the prediction of urban expansion. The SLEUTH model developed by CLARKE is an Open source software, written in C programming language and running on the UNIX or LINUX operating system (Candau,

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2002) and (Clarke et al., 1997). This model is mainly intended to simulate urban growth in order to study and model the expansion of urban areas in relation to surrounding territories, and possibly the impact of this expansion on the environment of the area in question (Abedini and Azizi, 2016) and (Jat et al., 2017). The popularity of SLEUTH as well as the increasing number of its use around the world is mainly its open access, the availability of source code, its regional modelling capability as well as its relative ease of calculation and implementation (Chaudhuri and Clarke, 2013), (Clarke, 2004) and (Oguz et al., 2007). SLEUTH has been successfully applied in several countries around the world over the past 20 years to simulate urban growth and model land-use change (Chaudhuri and Clarke, 2013).

Historically, the SLEUTH model was used in the USA for the first time to simulate the San Francisco Bay Area urban extension (Clarke et al., 1997) and the Washington area Baltimore (Clarke and Gaydos, 1998). Applications within the United States have been multiplied thereafter particularly in the field of urbanization, land use changes, biodiversity, habitat, flood risk, fire regime, etc. (Chaudhuri and Clarke, 2013). It was not until five years after the appearance of SLEUTH before recording the first use of the model outside the United States by Silva and Clarke in the Lisbon and Porto metropolitan areas of Portugal (Silva and Clarke, 2002). Outside the United States, China is the country with the highest number of SLEUTH applications, particularly in cities with high urban growth (Chaudhuri and Clarke, 2013).

Many technical modifications have been made in the recent past, like Optimal SLEUTH Metric (OSM) by Dietzel and Clarke (2007), pSLEUTH which is a parallel version of SLEUTH developed in 2010 (Guan and Clarke, 2010), SLEUTH-3r in 2010 by Jantz et al (Jantz et al., 2010), and also SLEUTH-GA which couples Genetic algorithm GA with SLEUTH to generate an optimal result. Those modifications have been made to help overcoming some of the limitations of SLEUTH and to enhance its performance and applicability (Chaudhuri and Clarke, 2013).

Unfortunately, the application of the SLEUTH model in Morocco for the simulation of the urban extension of Moroccan cities is not well developed. The only work that we consider worthy of mention is that of Kaoun A. and Znaiber Y. who used the SLEUTH model to estimate the urban growth of the city of Temara between 1984 and 2014 and to predict that in 2040 (Kaoun and Znaiber, 2014).

3. DATA AND MATERIELS

3.1 Study area

The region of Grand Casablanca is located on the Atlantic coast of Morocco, in the center west of Morocco, The city of Casablanca, the main pole of the study area is at about 33°34 '42.44" in latitude North and 7°6'23.89" in longitude West. The territory of Grand Casablanca is arranged around two urban poles of unequal importance: the large compact and dense agglomeration of the city of Casablanca and the city of Mohammedia, to which are added urban centers like Bouskoura, Ben Yekhlef, Mediona, Nouacer, Ain Harrouda, etc. The two urban poles of the region are experiencing rapid urbanization as a result of the population explosion, internal migration and the emergence of new urban centers. The region have a favourable climate and agricultural area of nearly 68,000 hectares on the 114,000 hectares of land in the region (Figure 1).

According to the reports of the High Commission for planning HCP, the region of Grand Casablanca has experienced a strong change in the urban population against a decrease in the rural population. For example, projections for the area predicted the urban population to increase from 5,030,129 in 2014 to 6,688,258 in 2018, compared with 1,812,126 rural population declines from only 1,613,363 in 2018 (HCP, 2014). HCP statistics show that the Casablanca Settat region ranks first in terms of domestic demand for housing with 478,300 applications in 2014 (or 30% of total national demand). This demand will increase to 524,040 new homes by 2020 (HCP, 2014). Urban expansion, population growth and the industrial and economic influence of the region have led to a deterioration of the quality of the environment and are unfortunately at the expense of agricultural land and the well-being of its inhabitants.

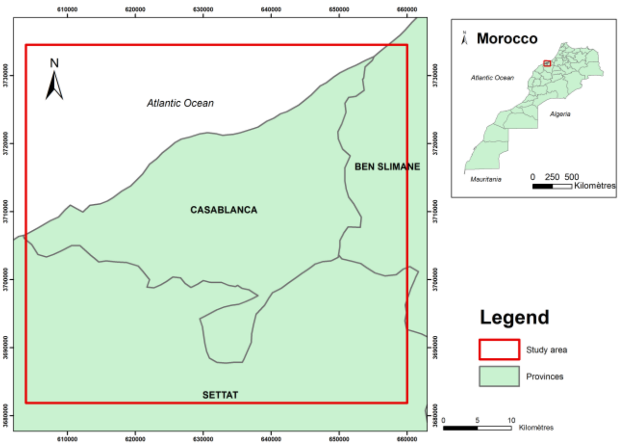

Figure 1. Study area

3.2 Sleuth model and calibration

The name of the SLEUTH model refers to its required input data namely: Slope, Land use, Excluded area, Urban extension, Transportation network and Hillshade (Sakieh et al., 2015). The model consists of two essential components: urban growth model (UGM) and land cover deltatron model (LDM). To control the dynamics of the considered urban growth, the model is based on the five coefficients: diffusion, breed, spread, slope and road gravity in order to generate four types of growth rules: spontaneous growth, new spreading center growth, edge growth and road gravity growth (Silva and Clarke, 2002).

A key phase in the urban extension prediction process based on the SLEUTH model is the calibration of the model. This phase consists of calculating a set of growth coefficient values that can accurately reproduce the historical urban growth occurring in the study area based on the model input data (Clarke et al., 1997) and (Clarke, 2004). As a general rule, SLEUTH calibration is performed in three steps according to the user's preferences: coarse, fine and final calibration. In the first step, the input data is re-sampled at a lower resolution to cover the entire space. Larger increments of the parameters are also used to quantify and classify the results. Thinner increments and higher resolutions are then used in subsequent phases (Dietzel

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and Clarke, 2004). Table 1 illustrate some of the indices for evaluation of the calibration results in the SLEUTH modelling:

Index	**Description**
Compare	Comparison of modeled final urban extent to real final urban extent
r^2 Population	Least square regression score of modeled urbanization compared with actual urbanization for control years.
Edge r^2	Least square regression score of modeled urban edge count compared with actual urban edge count for control years.
R^2 cluster	Least square regression score of modeled urban clustering compared with known urban clustering for control years
Leesalee	A shape index, a measurement of spatial fit between the modeled growth and the known urban extent for control years
Average slope r^2	Least square regression of average slop of known urban cells for control years
% Urban	The percent of available pixels urbanized during simulation compared to the actual urbanized pixels for each control year
X_r^2	Center of gravity [x]: Least square regression of average x values for modeled urbanized cells compared with average x values of known urban cells for control years
Y_r^2	Center of gravity [y]: Least square regression of average y values for modeled urbanized cells compared with average y values of known urban cells for control years
Radius	Average radius of the circle that encloses the simulated urban pixels compared to the actual urban pixels for each control year

Table 1. Indices for evaluation of the calibration results in the SLEUTH modelling (Silva and Clarke, 2002)

4. METHODS

4.1 Data preparation and processing

The input data needed to compile the model including slope, land cover, excluded area, road network and sun exposure were obtained from the supervised classification of the satellite images. Other data was created with the digitization of objects on cartographic maps, in particular the data related to the development plan of the region. Thus, in this study we used a time series of eight 30 m resolution LANDSAT 5 satellite images acquired between 1984 and 2010 and two 10 m resolution SENTINEL 2 satellite images acquired in 2014 and 2018 (Figure 2). We also used vector data related to authorized construction urban projects by 2020, as well as vector data related to Casablanca's Master Plan for Urban Planning, which guides the development of the region for the next 20 years.

Input layer	Prepared through	Base format and year	SLEUTH format
Urban extension	Supervised classification of satellite image. Exported to shapefile format for data processing	Vector, 1984, 1987, 1990, 1994,1998, 2002, 2006, 2010, 2014,2018	Raster (GIF)
	Exported to shapefile format from DWG files	Vector, 2022	Raster (GIF)
Transportation network	Extracted from Open Street Map Data. Prepared On-screen digitization from satellite image	Vector	Raster (GIF)
Slope	Derived from DEM	Raster	Raster (GIF)
Hillshade	Derived from DEM	Raster	Raster (GIF)
Excluded area	Rasterized from vector	Vector	Raster (GIF)

Table 2. Data requirements for the model

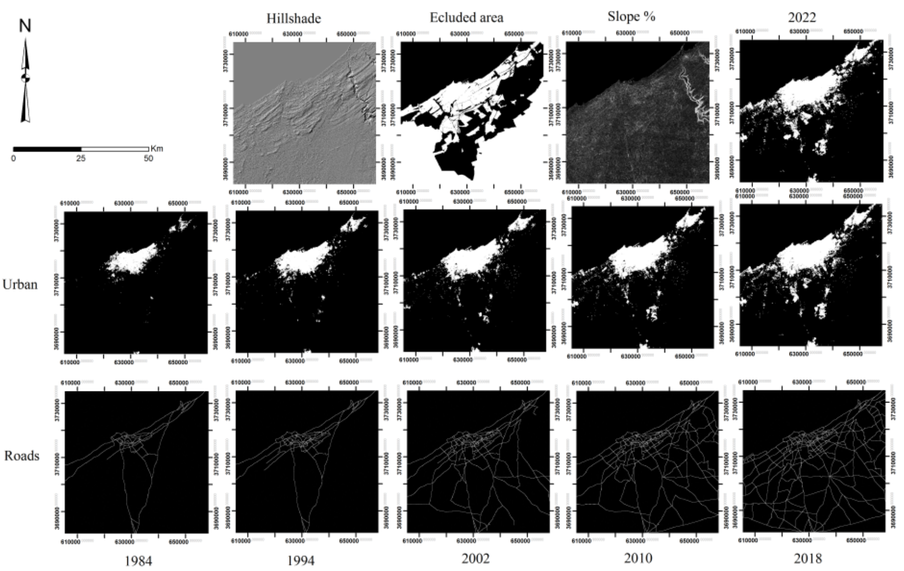

Figure 2. Input Data set for model calibration

All satellite images used in this work have been downloaded from the NASA website (https://earthexplorer.usgs.gov) for LANDSAT images and the ESA website (https://scihub.copernicus.eu) for those of the SENTINEL 2 satellite. The vector data representing the urban projects to be achieved by 2022 were obtained from the water and sanitation management operator.

4.2 Application of SLEUTH to predict urban growth in Casablanca

The main goal of this work is to predict the dynamics of urban growth in Grand Casablanca at the 2040 horizon. In order to fulfil this goal, it was question of evaluating the urban growth of the aforesaid city between 1984 and 2018, project the extension of urbanization of the region in 2022 and predict changes for 2040 using SLEUTH Model. To achieve this, inputs data were prepared and analyzed using ArcGIS 10.3, Erdas and SLEUTH 3.0.

Firstly, it was important to collect and prepare data in order to discern and predict urban changes, thus, LANDSAT TM 5 orthorectified satellites imageries, all acquired within the same month of May in 1984, 1987, 1990, 1994, 1998, 2002, 2006, and 2010, just as SENTINEL 2 images acquired in 2014 and 2018, were used to spatialize urban growth between 1984 and 2018, and to obtain road network. A supervised classification of these images has permitted the obtaining of different classes representing: urban zones, agricultural lands, superficial waters, barren lands. The state of urbanization in 2022 was obtained from the delimitation of construction projects authorized until 2018. These vectors were added to vectors representing the urban extension stemmed from the classification of 2018 image. Road network of the ongoing year was obtained from the retrieval and the cleaning of Open Street Map data. Roads of the previous year were extracted from road network of 2018 by subtraction of roads that do not appear in the satellite image of the year in question. The digitalization of plans from the Master plan of grand Casablanca urban planning had permitted the determination of areas restricted to urbanization. A DEM (Digital elevation model) was used instead to prepare data related to slope stamping. A Standardization of the resolution and the size of images has been done because model requires that all input layers have the same number of lines and columns and the same map projection. Figure 3 describes the methodology recommended to spatialize the urban growth between 1984 and 2022 and to predict the one of 2040.

Due to average quality of our satellite imagery, the supervised classification results used to obtain urban expansion had to be processed in order to be manually corrected and validated. Even though this process has consumed a long time of our project, it has enabled us, on the other hand, to refine the used classification results to be closer to reality on the field.

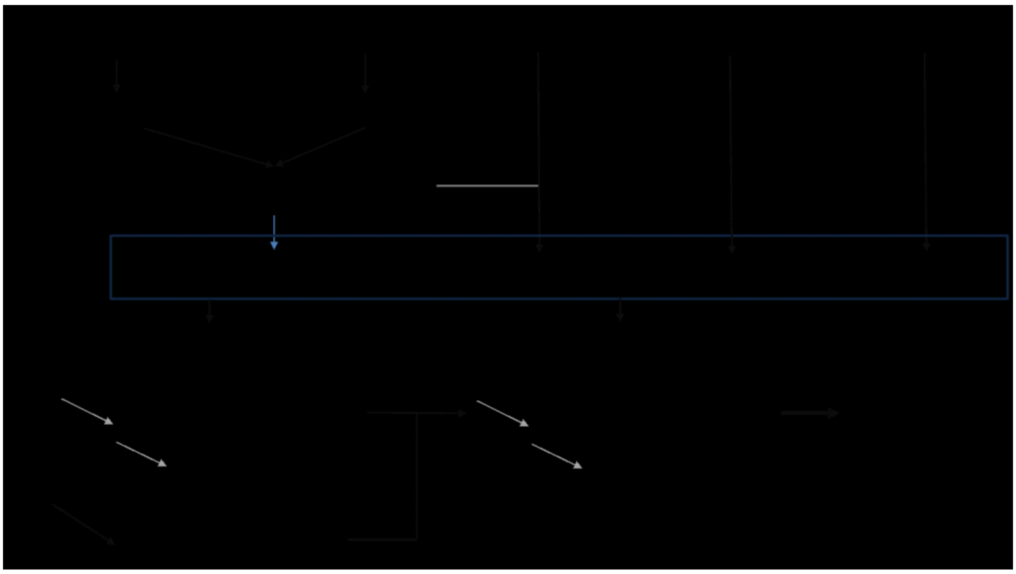

Figure 3. Processing steps for urban growth changes

For the calibration of the SLEUTH model, three steps, based on Monte Carlo simulation were used: coarse, fine and fine calibration. Thus, utilize of the best parameters resulting from calibration and procedure of the SLEUTH for the historical time period will create a single set of stop date parameters to initialize forecasting (Rafiee et al., 2009) and (Bihamta et al., 2015).

During the first step, the data was resampled to 120 m that is four times the original resolution, the second step twice to 60 m, and the final calibration to the original resolution of 30 m. During each stage, all the best parameters are selected to reach the final stage with a reduced set that will be used to simulate the forecast of urban growth in 2040.

For the prediction in 2040, exclude areas and open agricultural land for development helped derive the spatialization of the urban in 2040.

Coef/Index	Coarse	Fine	Final
Compare	0.999	0.872	0.851
r^2 Population	0.993	0.997	0.997
Edge r^2	0.991	0.896	0.889
R^2 cluster	0.851	0.767	0.539

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Leesalee	0.627	0.667	0.668
Average slope r^2	0.982	0.998	0.997
% Urban	0.941	0.946	0.946
X_r^2	0.915	0.986	0.992
Y_r^2	0.958	0.998	0.998
Radius	0.993	0.998	0.998
Diffusion	1	1	1
Breed	100	75	30
Spread	50	75	70
Slope	1	55	45
Road gravity	25	11	17

Table 3. The best results of the calibration through the phases

5. RESULTS AND DISCUSSION

The application of the adopted methodology for this study made it possible to obtain a synthetic map of the evolution of the spatial extent of the main urban centers of the study area between 1984 and 2018. Using the obtained results, we could then evaluate quantitatively the changes between different periods as shown in Figure 4:

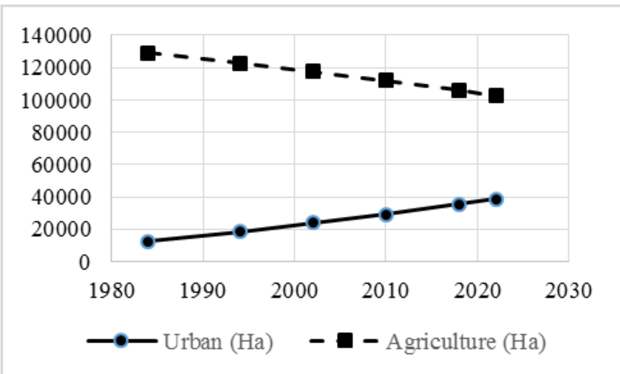

Figure 4. Change of urban and agricultural areas (1984-2022)

As for the overall change between 1984 and 2018, the rate is about 186.3%. Thus, about 23000 ha in total were urbanized during the same period (1984-2018). More The table 4 shows that the period with the highest population growth in the region is 1984-1994 with a growth rate of more than 50%. The same table also shows that the region has an annual urbanization opening of about 600 ha on average.

Figure 5 shows that the urban growth of the city of Casablanca - for example- extends in a north-east direction to join the city of Mohemmedia. According to our study resulting projections, the two urban centers Ain Harouda and Zenata would develop further, until the two cities of Casablanca and Mohamedia are completely joined. Similarly, the city of Casablanca would continue to develop on the south direction, with the emergence of the two poles Nouacer and Mediouna, and on the southwest towards Had Soualem, especially parallel to the Atlantic coast.

Time period	**Urban (ha)**	**Change in (ha)**	**Percentage change**	**Annual change (ha)**
1984	12335.82			
1994	18544.34	6208.52	50%	564.41
2002	23877.91	5333.57	29%	592.62
2010	29323.04	5445.13	23%	605.01
2018	35324.12	6001.08	20%	666.79
2022	38679.41	3355.29	9%	838.82

Table 4. Annual change of urban extension (1984-2022)

We have also carried in the present study the prediction of urban growth for the period between 2022 and 2040. Thus, the SLEUTH model made it possible to obtain several maps for the years 2018 to 2040 in GIF format. The ArcGis spatial analysis capabilities allowed calculating, for each pixel value the total area in hectare as well as the expected probabilities of change. The SLEUTH-generated urbanization map for the year 2040 in GIF format and ESRI ArcGIS functionality were applied to calculate the existing of each category of pixels in hectares. A calculation of the total urban area developed for 2022 gives a figure of 38679.41 ha and, 19 years later, the simulated total area was increased to 64280 ha. Figure 5 illustrates the results of the model for 2040 and Table 5 presents the expected probabilities of change for 2040. This table shows that area to be urban is 69.16% with a probability of 90% to 100%, and 12.39 % with a probability of 70% to 90%.

These results show that there is a strong urban expansion caused mainly by the setting up of port infrastructures (Mohammed 5 airport), the creation of new industrial zones (Lissasfa, Zenata, ..), the creation of ecological city to the example of the city of Bouskoura, the resettlement of slum dwellers to peripheral areas of the city (Lahraouine, Errahma, Lakhyayeta, Zenata ..), the construction of highways and oars, the creation of universities and institutions (Faculty of Ainsebaa, ENCGC, etc.). In addition to these causes, it should be emphasized that factors related to climate change, poverty and unemployment are also responsible for such a demographic and urban expansion.

Probability	Areas under change (ha)	Percentage change
90% - 100%	24429	69.2%
70% - 90%	4377	12.4%
< 70%	1274	3.6%

Table 5. Probable rate of future change during 2040

This situation requires taking into account the results of the prediction of the urban evolution of the area by 2040 in government policies and those of local decision-makers. This has a great contribution to the planning of the infrastructure necessary for the well-being of inhabitants in areas with a strong tendency of urbanization.

This contribution has been peer-reviewed.
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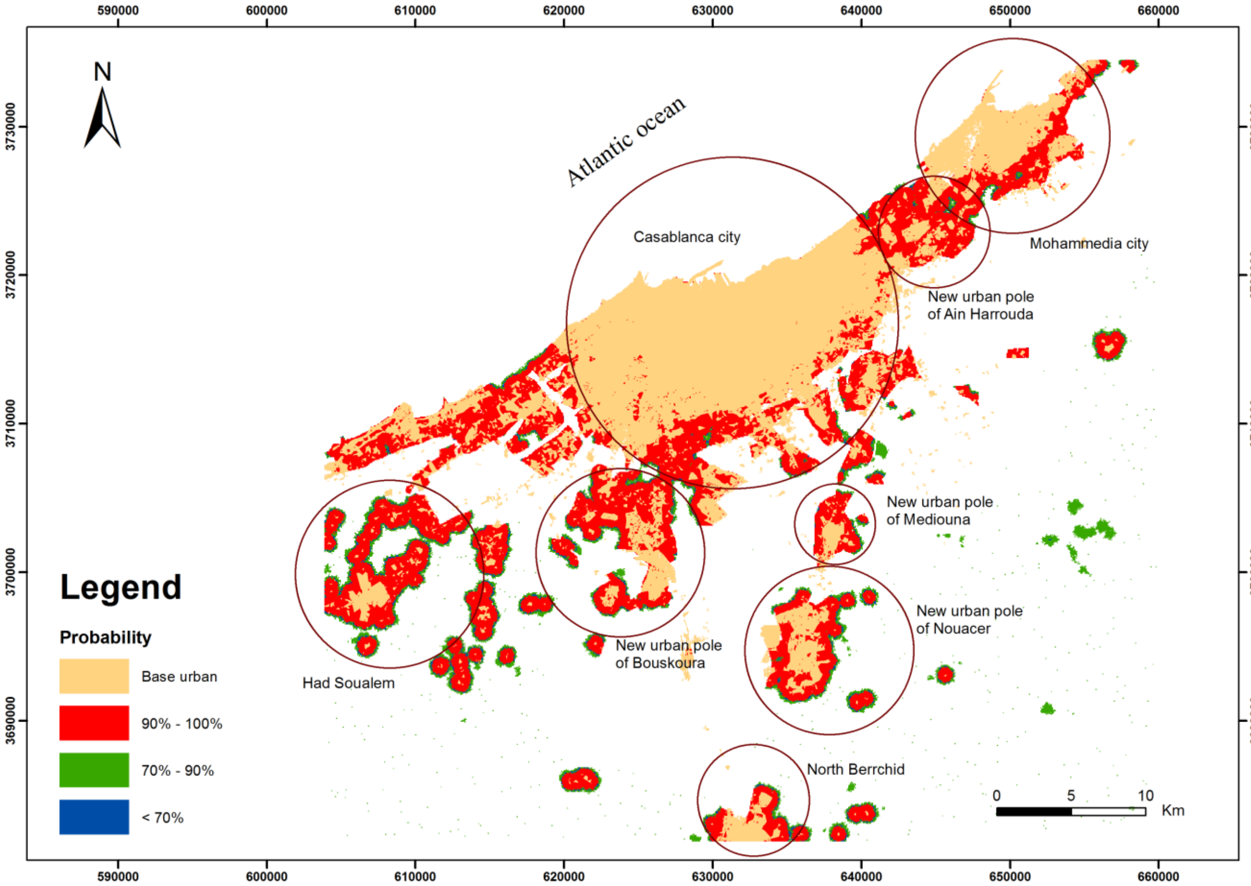

Figure 5. Simulated urban growth map of 2040

6. CONCLUSION AND RECOMMANDATIONS

Grand Casablanca region is considered as the locomotive of the economic and social development of Morocco. Since the 1980s, the region has experienced spectacular population growth and is facing a strong urban expansion due to its economic development and social attractiveness. As a result, many agricultural lands have been converted into urban areas and demand for new land is growing. This situation continues to give rise to much concern about the deterioration of the environment and the well-being of the inhabitants of the region. In this perspective, our aim was to help to assess and quantify the dynamics of urban growth in the region and contribute to enable assessing the effects of urban sprawl on environmental parameters. Also, our research explored the suitability of utilizing SLEUTH, a cellular automata model, for simulating future urban expansion in Grand Casablanca area.

More precisely, the objective of this work was to study the urban extension of the Grand Casablanca region from 1984 to 2018 and to predict urban growth in 2040 using the SLEUTH model. The trained SLEUTH model in Casablanca predicts an annual urban growth rate of 1583 ha/year (all likelihoods included in Table. 5), which is 92% in accordance with the estimated rate of 1471 ha/year projected by the official master plan of Casablanca.

Thus, we can conclude that that our initial hypothesis regarding the application of the SLEUTH model in the region of Grand Casablanca is verified. Also, remote sensing and geographic information systems coupled with cellular automata modeling such as the SLEUTH model are suitable tools to quantitatively and spatially assess current and future urban growth.

However, it is useful to recommend the use of very high resolution satellite images in order to reduce the time required to process and clean the input data of the used model. In addition, it would be also very interesting to couple the methodology advocated in this work with another model allowing the integration of other socio-economic factors. This will undoubtedly help refine the results of the targeted prediction.

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