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Urban growth assessment around Winam Gulf of Kenya based on satellite imagery

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ABSTRACT

Urban growth and population dynamics are among the most critical information needed for future economic development planning, natural resources allocation and environmental management. In the present work, two methods, the first based on night-time images produced by NOAA and population maps provided by Oak Ridge National Laboratory's (ORNL) LandScan, and the second one on SAR imagery, were used in order to assess the expansion of urban areas surrounding the Winam Gulf (Lake Victoria, Kenya) at different scales. In the time covered by night-time lights imagery, the study highlighted a period of constant growth rate between 2002 and 2006 and a negative trend after 2006 and 2008. This decrease may be related to two main events occurring in the study area between 2006 and 2007: the decline of the Lake Victoria level and the abnormal proliferation of the floating weeds within the Winam Gulf. Meanwhile, the urban feature extraction obtained at a different scale within a particular district from 1997 up to 2008 results in a constant growth rate. Population movements around this zone explain different dynamics that should be studied in detail in order to understand their particular roots.

1. Introduction

Urban growth and population dynamics are among the most relevant information required for future economic development planning, natural resources allocation and environmental management. Accurate information on the extent of urban growth is of great interest for the municipalities of growing urban and suburban areas for diverse purposes such as urban planning, water and land resource management, marketing analysis, service allocation, etc. [1]. Data collection using traditional techniques is very expensive and time-consuming. Moreover, there is usually a considerable time lag between the date of the census and the publication of the results. This time lag means that some of the information is out of date even before it is published. Efficient and low cost methods need to be developed for deriving population data, making intercensus estimations and checking the reliability of existing population census data, especially in developing countries, where the rate of transformation of rural areas neighboring to urban areas can be very fast.

Remote sensing is cost effective and technologically sound; therefore it is increasingly used for the analysis of the urban change and population size, although no specific remote sensors have been designed to monitor and map urban areas.

High resolution (HR) imagery, acquired by satellites like Landsat, SPOT, etc., was used to extract basic urban classes with reasonable accuracy [2]. Very high resolution (VHR) imagery (Quickbird, GeoEye etc.) is suitable to extract individual building, height estimation and 3D modelling [3,4]. Nevertheless, it is not easy to create a wide map of urban areas, considering, for example, the difficulties for retrieving, storing and processing a large number of high

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resolution imagery. Partly because of these reasons, up to now the production of global urban maps is limited and, in most cases, the thematic products are merely the perimeter of the urban areas.

Several approaches have been addressed for urban change detection by using remotely sensed imagery. The methods based on images comparison are generally accurate. However, they suffer from the inability to provide detailed information on how urban land use/cover categories change [5–7]. In contrast, the map-to-map comparison has the potentiality to detect the urban land use/cover changes [8]. With the availability of higher resolution imagery, more details of urban land use/cover changes can be mapped with reasonable accuracy [9].

More recent alternative methods have been developed, such as Chi square transformation [10] normalized difference built-up index [11], and constructed impervious surface area (ISA) [12,13], for urban change characterization. In particular, the last one has shown good effectiveness to assess urban growth, because it is one of the most important cover type characteristics of urban and suburban environment developed through anthropogenic activities [14]. The ISA can be defined as the sum of artificial structures like roads, sidewalks, driveways, parking, including buildings and other built surfaces. There are several remote sensing approaches to estimate ISA [15,16] based on moderate and high spatial resolution imagery. Generally, these products cover small areas and there are no standard methods which do facilitate the merging of products generated by different organizations. For this purpose, another kind of satellite datum useful for the urban mapping is the observation of night-time lights (NTL). Since a few years, artificial lighting has emerged as one of the hallmarks of modern development or human activity that can be detected by satellite. At present, the only satellite sensor able to collect the NTL is the U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) designed to observe clouds at night [17]. The DMSP-OLS acquires global daytime and night-time imagery of the Earth in two spectral bands (VIS and TIR). It produces a unique data set of stable lights, which makes it possible to visualize the size and distribution of human population on a continental basis. In 1992, a digital archive for the DMSP-OLS NTL products was established at the NOAA National Geophysical Data Center and is available for time analysis (http://www.ngdc.noaa.gov/dmsp/dmsp.html).

Meanwhile, Synthetic Aperture Radars (SAR) images also give the possibility to obtain information about structural properties of the study area, without taking into account known properties as all-weather capabilities that present this option as optimal for disasters monitoring, which in this case are not characteristics of relevance.

In this particular study, we have to deal with products of a certain scarce spatial resolution, that limits the application of current methods that are being developed with High Resolution SAR imagery[1].

In the last decade, there have been a number of methodological developments that attempted to fulfill the requirements for urban extent extraction. Some of the semi-authomatic procedures rely on morphological transformations, others on wavelet transformation or on textural analysis of SAR and/or optical data [18]. Dekker [19] presents results of different texture measures applied to SAR images to discriminate urban land-cover. An approach with textural analysis has proved to be an effective way to capture the appearance of human settlements and discriminate them from the surrounding environments [20]. Highly textured areas can be extracted, using occurrence of textural features to detect areas with larger variability [21]. At the same time, interferometry processing can be useful for urban oriented studies as they provide valuable information about shapes of a city and its main structures [22]. Also polarimetric approaches were developed in order to characterize built-up areas from the coherence properties of their Polarimetric and Interferometric SAR response [23].

As previously said, due to the scarce spatial resolution of available SAR imagery for this area in particular, the process was finally centered to identify urban limits without taking into account the isolated buildings. A further index of the urban coverage percentage was calculated as a ratio between the urban areas extracted from SAR image and the total area covered by each cell of NTL images (1 km^2).

As ERS multitemporal analysis shows, backscattering response seems to be useful to aim this objective, and suggests an approach that could be a support to night images analysis. Radar satellites like ERS deliver images with a resolution of about 25 m, which is appropriate to update 1:50.000 maps (20 image pixels per map centimeter) [19].

The aim of this study is to test the suitability of two methods for a rapid assessment of the urban growth around the Winam Gulf, Kenya, marked by one of the world's highest rates of population growth. The first method (for the sake of brevity hereinafter called NTL approach) is based on calculating the ISA cover density by using the night-time lights and the population maps. The second method is based on urban feature extraction from the SAR imagery.

Kenya, as well as the other countries surrounding Lake Victoria, is facing a number of serious challenges related to water resource management, including population growth, water scarcity, climate variability and water resource degradation, invasive species, rivers water pollution (agricultural and agrochemical residuals, discharge of industrial/urban waste). In recent years, the lake's pressure has increased as population and human activities have intensified throughout its catchment. A prerequisite for studying these changes is the availability of repetitive and updated coverage of the same study area. Stable night-time lights produced by NOAA and population maps provided by Oak Ridge National Laboratory's (ORNL) LandScan have been analyzed in order to assess, at a regional scale, the urban growth rate in the time range from 2002 to 2008. At the same time, ERS-1 and ERS-2 imageries were processed trying to estimate, at a scare more detailed scale, the urban growth rate from 1997 up to 2008 in Kisumu town area, located on the eastern side of the Winam Gulf.

[1] The extraction of human settlements with high resolution SAR images gives the possibility to work with morphological patterns and spatial autocorrelation which have already shown their effectiveness.