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Urban expansion in Zanzibar City, Tanzania: Analyzing quantity, spatial patterns and effects of alternative planning approaches

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ABSTRACT

Rapid urbanization and urban area expansion of sub-Saharan Africa are megatrends of the 21st century. Addressing environmental and social problems related to these megatrends requires faster and more efficient urban planning that is based on measured information of the expansion patterns. Urban growth prediction models (UGPMs) provide tools for generating such information by predicting future urban expansion patterns and allowing testing of alternative planning scenarios. We created an UGPM for Zanzibar City in Tanzania by measuring urban expansion in 2004–2009 and 2009–2013, linking the expansion to explanatory variables with a generalized additive model, measuring the accuracy of the created model, and projecting urban growth until 2030 with the business-as-usual and various alternative planning scenarios. Based on the results, the urban area of Zanzibar City expanded by 40% from 2004 to 2013. Spatial patterns of expansion were largely driven by the already existing building pattern and land-use constraints. The created model predicted future urban expansion moderately well and had an area under the curve value of 0.855 and a true skill statistic result of 0.568. Based on the business-as-usual scenario, the city will expand 89% from 2013 until 2030 and will continue to sprawl to new regions at the outskirts of the current built-up area. Establishing new urban centers had the highest impact on directing urban expansion from the tested alternative planning scenarios. However, the impact of all scenarios was low and therefore also other planning solutions such as vertical development, urban growth boundaries, and gradual improvement of the informal areas should be considered in Zanzibar.

1. Introduction

Sub-Saharan Africa is facing the fastest population growth and urbanization rates in the world (UN (United Nations), 2004, 2010, 2014). It is estimated that the continent will more than double its current population of 1.1 billion to reach 2.4 billion by 2050 (UN (United Nations), 2004, 2014). At the same time, the proportion of the African population living in cities is expected to grow from 39.6% to 61.6% (UN (United Nations), 2010). Urban population growth in Africa is directly connected to expansion of urban areas (Angel et al., 2011; Seto et al., 2011; Linard et al., 2013). It is estimated that urban land cover will increase five to twelve-fold in the region between 2000 and 2050 (Angel et al., 2011). Simultaneously, many African cities are approaching the second phase of urban growth, where the majority of expansion will happen in suburbs outside the city core (Chin, 2002; Linard et al., 2013). It can be well said that urbanization and urban sprawl in Africa are megatrends of the 21st century.

Urbanization in sub-Saharan Africa is characterized by an increasing proportion of poor people living in cities, with urban expansion involving mainly the poorer segments of society (Dye, 2008). Already, over 70% of urban Africans are living in slums and the newcomers are largely dependent on unplanned, unmonitored, and irregularly placed housing (Cohen, 2006; Guneralp and Seto, 2008). This places an infeasible burden on the existing infrastructure, civil engineering, and planning, which reflects back to the already marginalized and poor citizens as insufficient sanitation, power outages, overladen transportation, and increased travel times (Keiner et al., 2005; Guneralp and Seto, 2008). Simultaneously, urban expansion has serious impacts on the quality of the environment and ecosystem services (Lambin et al., 2001; Seto et al., 2011). It drives the loss of croplands, wetlands, and forests, fragments natural habitats, and affects local climate, the hydrological cycle, as well as surface water discharge (Eigenbrod et al., 2008; McDonald et al., 2011; Seto et al., 2011; Kukkonen and Käyhkö, 2014).

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Addressing these accumulating environmental and social problems requires faster and more efficient planning of African cities (Couclelis, 2005; Vermeiren et al., 2012). Traditional prevention planning with strict restrictions and zoning laws is seen as sluggish against the extremely rapid sprawl of informal settlements (Kamete, 2011; Odendaal, 2012; Ngau, 2013; UN-Habitat (United Nations Human Settlement Programme), 2014). There is a need for adapting and predictive planning tools, which allow the upgrading of informal neighborhoods as well as the estimation of where developments are most likely to happen in the future (Couclelis, 2005; Vermeiren et al., 2012). Also the resources for implementing planning policies are limited and should thus be targeted at the most effective activities. Unfortunately, the information required to estimate this effectiveness is often lacking in sub-Saharan Africa (UN-Habitat (United Nations Human Settlement Programme), 2014).

Urban growth prediction models (UGPMs) offer promising tools for evidence-driven decision-making in urban planning. UGPMs provide spatial predictions of the future expansion of cities based on retrospective data (Doan and Oduro, 2012; Vermeiren et al., 2012; Arsanjani et al., 2013; Linard et al., 2013). Besides creating predictions, UGPMs can be utilized to analyze the spatial patterns of urban expansion, test alternative planning scenarios, pinpoint unwanted environmental effects, and make negative developments more tangible for decision makers (Couclelis, 2005; Vermeiren et al., 2012). The modern UGPMs rely on the idea that cities expand according to spatial patterns determined by biophysical, social, and economic factors as well as spatial policies and interactions (Poelmans and Van Rompaey, 2010).

Urban growth is a complex and nonlinear process, but a century of research has shown that cities seem to grow according to certain principles (Cheng, 2003; Batty, 2008). The early sociological urban models, such as *Von Thünen's (1826) model* and Burgess's (1925) *Concentric Zone Model* acknowledged that urban areas expand outwards from their central business districts (CBDs), while Hoyt's (1939) *Sector Model* and Harris and Ullman's (1945) *Multiple Nuclei Model* developed these ideas further by theorizing that urban expansion happens along existing transportation networks, in suitable topography, in the vicinity of similar land uses, and outwards from multiple market centers. In urban economics, expansion has often been explained by the *Monocentric City Model*, where land rent is a function of distance from the CBD, commuting cost, income, and utility level. The urban area is then expected to expand until urban and agricultural land rents are equal (Deng et al., 2008). Although many of these assumptions have been proven empirically correct, both the sociological as well as the economic models fail to grasp the spatial and temporal complexity inevitably linked to the growth of urban systems as well as the role of local actions (Batty, 1995; Deng et al., 2008; Liu, 2009). Urban growth is a spatially complex process where the reciprocal effect of various biophysical and socioeconomic factors as well as spatial policies and dependencies impact growth patterns in a dynamic and nonlinear manner. The temporal complexity is on the other hand evident in the difficulty of predicting urban growth in time, as it is closely related to economic and policy developments that are often non-predictable and fundamentally nonlinear (Cheng, 2003). Despite these apparent complexities, recent theories, such as the *self-organizing systems theory*, argue that there are still detectable patterns in urban expansion (Batty, 1995). In self-organizing systems theory it is assumed that largely irrelevant and highly complex local interactions eventually lead to recognizable urban patterns at higher levels, as urban systems have the ability to reorganize their spatial structure with endogenous force (Batty, 1995; Cheng, 2003; Triantakonstantis and Mountrakis, 2012).

Also, the development of nonlinear modeling methods together with GIS and accumulated remote sensing data has been able to shed light on these complexities (Liu, 2009). Meta-analysis of urban growth studies by Seto et al. (2011) concluded that annual gross domestic product growth, urban population growth, and coastal location drove the quantity of urban expansion globally, although urban population growth was the most determinant factor in Africa. In the more detailed regional modeling of African cities, the proportion of urban areas within a 1 km neighborhood and travel-time distance to the CBD were the most influential variables predicting urban growth patterns (Linard et al., 2013). Other individual case studies have shown that high population density as well as vicinity of main roads and individual buildings attracts more urban development, while the presence of wetlands, conservation areas, land-use constraints, zoning restrictions, and steep topography reduces the probability of expansion (Mundia and Murayama, 2010; Poelmans and Van Rompaey, 2010; Eyoh et al., 2012; Vermeiren et al., 2012; Arsanjani et al., 2013).

Even though various factors have been shown generally to impact urban expansion patterns, the local reciprocal interaction of the biophysical, social, economic, and policy factors creates an outcome that is unique for each urban system (Lambin et al., 2001; Cheng, 2003). Thus, UGPMs need to acknowledge and adjust to local circumstances. Also, the spatial variables developed to reflect these factors are often crude simplifications of the reality (Poelmans and Van Rompaey, 2010). Therefore, the UGPMs are also simplifications of the complex urban growth processes, but their use has been justified by their relatively high prediction accuracies (Triantakonstantis and Mountrakis, 2012; Linard et al., 2013).

Sub-Saharan Africa is facing the fastest spread of urban areas in the world, but urban expansion studies from the region are limited and tend to focus on the megacities (Barredo et al., 2004; Taubenböck et al., 2011; Doan and Oduro, 2012; Vermeiren et al., 2012; Linard et al., 2013). We directed our view to one of the region's secondary cities, Zanzibar City, which is facing extreme population growth, urban expansion, and various related challenges, such as lack of planned housing and public infrastructure, congested traffic, and urban encroachment of forests and agricultural land. At the same time, there is a lack of detailed knowledge of the quantity and spatial patterns of the city's expansion (RGZ (Revolutionary Government of Zanzibar), 2012, 2014; Kukkonen and Käyhkö, 2014). Therefore, we measured the urban expansion of Zanzibar City between years 2004, 2009, and 2013 from remote sensing images. The expansion data, along with environmental variables, were used to prepare a UGPM for the city region and to predict business-as-usual urban expansion between 2013 and 2030. Alternative urban expansion scenarios were developed based on different spatial plans and it was tested how these plans direct urban expansion by comparing the scenarios to the business-as-usual pattern. The results are discussed in the light of current and future patterns of urban growth in Zanzibar City, the effectiveness of different planning approaches and how they should be acknowledged in currently prepared national land-use plans, implications of the study for the general urban expansion theories, as well as the usefulness of UGPMs in the context of rapidly growing African cities.

2. Materials and methods

2.1. Study area

Zanzibar is a semi-autonomous part of Tanzania, with two main islands: Unguja and Pemba. The capital, Zanzibar City, is located on the west coast of Unguja in the administrative region of Mjini Magharibi (Fig. 1). The capital region, like the entire island, is generally flat with a maximum altitude of 120 m a.s.l. in the Masingini Forest Reserve. The study area is mainly dominated by fertile sandy soils, while shallow unfertile coralline soils cover the south and southeastern parts (Hettige, 1990).

The population of Zanzibar has grown rapidly in recent decades (Thomas, 1968; NBS (National Bureau of Statistics), 2004, 2013). The majority of this has been natural population growth, but the growing tourism industry and economy has also attracted a significant number of migrants from mainland Tanzania and other parts of East Africa. At the same time, there has been population migration from Pemba Island