

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

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7
8 **Abstract**

9 Rapid urbanization and urban area expansion of sub-Saharan Africa are megatrends of the 21st century.
10 Addressing environmental and social problems related to these megatrends requires faster and more efficient
11 urban planning that is based on measured information of the expansion patterns. Urban growth prediction
12 models (UGPMs) provide tools for generating such information by predicting future urban expansion patterns
13 and allowing testing of alternative planning scenarios. We created an UGPM for Zanzibar City in Tanzania by
14 measuring urban expansion in 2004–2009 and 2009–2013, linking the expansion to explanatory variables with
15 a generalized additive model, measuring the accuracy of the created model, and projecting urban growth until
16 2030 with the business-as-usual and various alternative planning scenarios. Based on the results, the urban
17 area of Zanzibar City expanded by 40% from 2004 to 2013. Spatial patterns of expansion were largely driven
18 by the already existing building pattern and land-use constraints. The created model predicted future urban
19 expansion moderately well and had an area under the curve value of 0.855 and a true skill statistic result of
20 0.568. Based on the business-as-usual scenario, the city will expand 89% from 2013 until 2030 and will
21 continue to sprawl to new regions at the outskirts of the current built-up area. Establishing new urban centers
22 had the highest impact on directing urban expansion from the tested alternative planning scenarios. However,
23 the impact of all scenarios was low and therefore also other planning solutions such as vertical development,
24 urban growth boundaries, and gradual improvement of the informal areas should be considered in Zanzibar.

25
26 **Keywords:** Urban expansion, Urban growth, Urban Growth Prediction Models, Urban planning, Spatial
27 modeling, Generalized additive model, GAM, Africa, Sub-Saharan Africa, Zanzibar, Stone Town

38

39 **1. Introduction**

40

41 Sub-Saharan Africa is facing both the fastest population growth and urbanization rates in the World (UN,
42 2004, 2010, 2014). It is estimated that the continent will more than double its current population of 1.1 billion
43 to 2.4 billion by 2050 (UN, 2004, 2014). At the same time, the proportion of African population living in cities
44 is expected to grow from 39.6% to 61.6% (UN, 2010). The urban population growth in Africa has a direct
45 connection with expansion of urban area (Angel, 2011; Seto et. al., 2011; Linard et. al., 2013). It is estimated
46 that urban land cover will increase five to twelve-fold in the region between 2000 and 2050 (Angel, 2011).
47 Simultaneously, many African cities are approaching the second phase of urban growth, where majority of
48 expansion will happen in suburbs outside the city's core (Chin, 2002; Linard et. al., 2013). It can be well said
49 that urbanization and urban sprawl in Africa are megatrends of 21st century.

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51 Urbanization in Sub-Saharan Africa is characterized by increasing proportion of poor people living in cities
52 and also urban expansion happens mainly to inhabit the poorer segments of the society (Dye, 2008). Already,
53 over 70% of urban Africans are living in slums and the newcomers are largely dependent on unplanned,
54 unmonitored and irregularly placed housing (Cohen, 2006; Guneralp & Seto, 2008). This puts infeasible
55 burden on the existing infrastructure, civil engineering and planning, which reflects back to the already
56 marginalized and poor citizens as insufficient sanitation, power outage, overladen transportation and increased
57 travel times (Keiner, Koll-Schretzenmayr & Schmid, 2005; Guneralp & Seto, 2008). Simultaneously, urban
58 expansion has serious impacts on the quality of environment and ecosystem services (Lambin et. al. 2001;
59 Seto et. al. 2011). It drives the loss of croplands, wetlands and forests, fragments natural habitats and affects
60 local climate, hydrological cycle as well as surface water discharge (Eigenbord, et., al. 2008; McDonalnd et.
61 al., 2011; Seto et. al., 2011; Kukkonen & Käyhkö, 2014).

62

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

72

73 Urban growth prediction models (UGPMs) offer promising tools for evidence-driven-decision-making in
74 urban planning. UGPMs provide spatial predictions of cities future expansion based on retrospective data

75 (Doan & Oduro, 2012; Vermeiren, et. al. 2012; Arsanjani, et. al. 2013; Linard et. al., 2013). Besides creating
76 predictions, UGPMs can be utilized to analyze the spatial patterns of urban expansion, test alternative planning
77 scenarios, pinpoint unwanted environmental effects and make negative developments more tangible for
78 decision makers (Couclelis, 2005; Vermeiren et. al., 2012). The modern UGPMs rely on the idea that cities
79 expand according to spatial patterns determined by biophysical, social and economic factors as well as spatial
80 policies and interactions (Poelmans & Van Rompaey, 2010).

81
82 Urban growth is complex and non-linear process, but century of research has shown that cities seem to grow
83 according to certain principles (Cheng, 2003; Batty, 2008). Already the early sociological urban models, such
84 as the *Von Thünen's* (1826) *model* and Burgess' (1925) *Concentric Zone Model* acknowledged that urban areas
85 expand outwards from their Central Business Districts (CBD), while Hoyt's (1939) *Sector Model* and Harris
86 and Ullmans' (1945) *Multiple Nuclei Model* developed these ideas further by theorizing that urban expansion
87 happens along existing transportation networks, in a suitable topography, in a vicinity of similar land uses and
88 outwards from multiple market centers. In urban economics, expansion has often been explained with
89 *Monocentric City Model*, where land rent is function of distance from CBD, commuting cost, income and
90 utility level. The urban area is then expected to expand until urban and agricultural land rents are equal (Deng
91 et. al., 2008). Although many of these assumptions have been then proven empirically correct, both the
92 sociological as well as the economic models fail to grasp the spatial and temporal complexity inevitably linked
93 to growth of urban systems as well as the role of local actions (Batty, 1995; Deng et. al., 2008; Liu, 2009).
94 Urban growth is spatially complex process where the reciprocal effect of various biophysical and socio-
95 economic factors as well as spatial policies and dependencies impact growth patterns in a dynamic and non-
96 linear manner. The temporal complexity is on the other hand evident in the difficulty of predicting urban
97 growth in time, as it is closely related to economic and policy developments that are often non-predictable and
98 fundamentally non-linear (Cheng, 2003). Even though of these apparent complexities, recent theories, such as
99 *Self-organizing systems*, argue that there are still detectable patterns in urban expansion (Batty, 1995). In self-
100 organizing systems it is assumed that largely irrelevant and highly complex local interactions eventually lead
101 to recognizable urban patterns at higher levels, as urban systems have the ability to reorganize their spatial
102 structure with endogenous force (Batty, 1995; Cheng, 2003; Triantakoustantis & Mountrakis, 2012).

103
104 Also the development of non-linear modeling methods together with GIS and accumulated remote sensing
105 data has been able to shed light on these complexities (Liu, 2009). Meta-analysis of urban growth studies by
106 Seto et. al. (2011) concluded that annual GDP growth, urban population growth and coastal location drove the
107 quantity of urban expansion globally, though urban population growth was the most determinant factor in
108 Africa. In the more detailed regional modeling of African cities, proportion of urban areas within 1 km
109 neighborhood and travel-time distance to CBD were the most influential variables predicting urban growth
110 patterns (Linard et. al, 2013). Other individual case studies have shown that high population density as well as
111 vicinity of main roads and individual buildings attract more urban development, while presence of wetlands,

112 conservation areas, land-use constraints, zoning restrictions and steep topography reduce the probability of
113 expansion (Mundia & Murayama, 2010; Poelmans & Van Rompaey 2010; Eyoh, et. al. 2012; Vermeiren, et.
114 al. 2012; Arsanjani, et. al. 2013).

115

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

123

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

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141 **2. Materials and methods**

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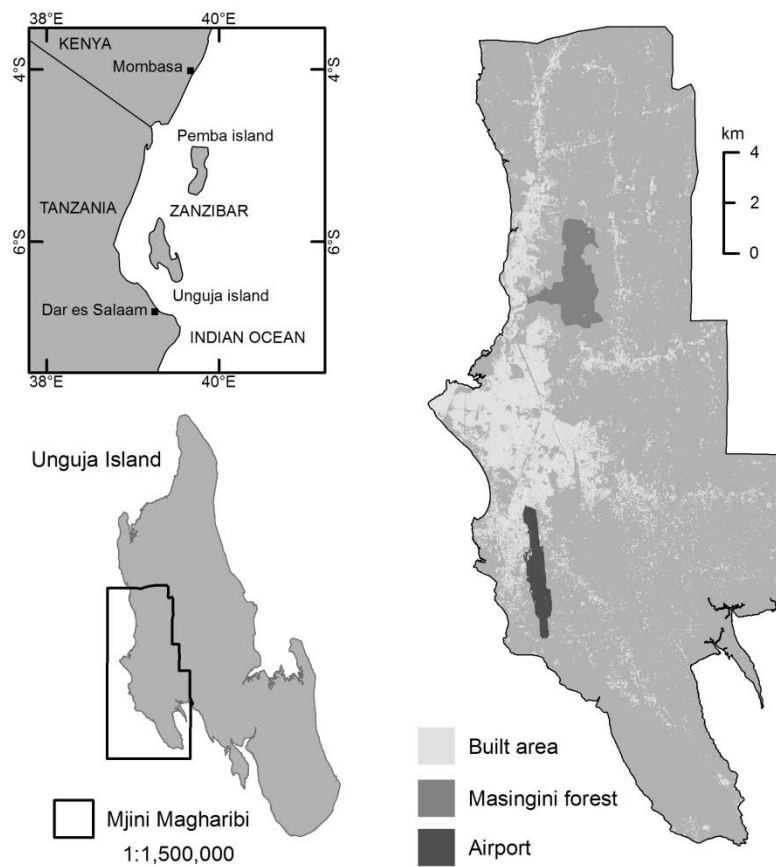
143 *2.1 Study area*

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145 Zanzibar is a semi-autonomous part of Tanzania, with two main islands Unguja and Pemba. The capital
146 Zanzibar City is located at the west coast of Unguja in the administration region of Mjini Magharibi (Figure
147 1). The capital region, as the entire Island, is generally flat with maximum altitude of 120 m.a.s.l. in Masingini

148 forest area. The study area is mainly dominated by fertile sandy soils, while shallow unfertile coralline soils
149 cover the south and southeastern parts (Hettige 1990).

150
151 The population of Zanzibar has grown rapidly in the recent decades (Thomas, 1968; NBS, 2004, 2013).
152 Majority of this has been natural population growth, but growing tourism industry and economy has also
153 attracted significant amount of migrants from mainland Tanzania and other parts of the East Africa. At the
154 same time, there has been population movement from Pemba Island to Unguja Island as well as rural-urban
155 migration within Unguja Island (RGZ, 2012; NBS, 2013). The population of Mjini Magharibi has increased
156 over five-fold since 1970s due to these reasons (Thomas 1968; NBS 2004, 2013) (Figure 2). With the current
157 annual population growth rate of 4.2% the region is reaching population of one million by 2025 (NBS 2013).
158



159
160 *Figure 1. Study area covered Mjini Magharibi region, which is in the west coast of Unguja Island, Zanzibar, Tanzania. The region*
161 *consists Zanzibar City, surrounding rural area and Masingini protection forest area.*

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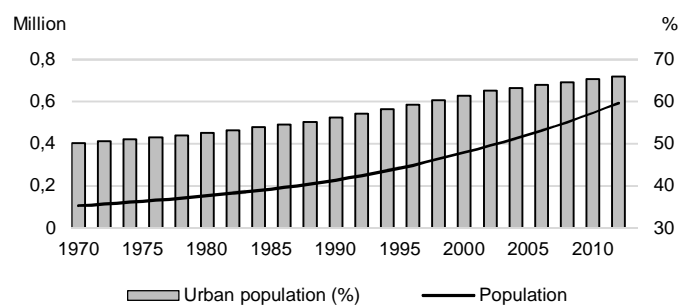


Figure 2. Population growth of Mjini Magharibi and urbanization of Unguja since 1970 (Thomas 1968, NBS 2004, 2013)

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Zanzibar City's historical center, Stone Town, has been established in early 10th century and it expanded considerably in the 18th century. Already from 19th century the city's official have been worried about its expansion spreading outwards from the center (Haji et. al., 2006; RGZ 2014). Urban expansion has been truly problematic since 1960s as population started to grow rapidly, while at the same time independency allowed freedom of movement, which escalated urbanization (Myers 2008; RGZ 2014). Since mid-1980s, the governmental land delivery system has not been able to meet the needs of new inhabitants, which has caused rapid sprawl of unofficial settlements (Myers, 2008; RGZ, 2012, 2014). Complex land tenure legislation have further increased the problem (Myers, 1996, Törhönen, 1998). In many cases, unofficial housing has spread adjacent to the planned areas that provided public services and infrastructure (RGZ 2014). Especially problematic have been so called "Three Acre Plots"; agricultural land areas confiscated from big landholders, redivided and redistributed to landless farmers in a large-scale land reform between 1965 and 1972. Although, these areas were restricted for agricultural use and selling them was forbidden, many of them ended up as building sites (Törhönen, 1998; Myers 2008). Another local peculiarity has been the strong land user rights of the person who first planted trees on the site, which has caused significant pressure to the agroforestry areas surrounding Zanzibar City (Törhönen 1998; Kukkonen & Käyhkö 2014). In recent decades, the government has tried to limit the encroachment to agricultural land by planning housing areas to shallow coralline soils with limited agricultural potential (Myers 2008; RGZ 2014). Though even in the planned areas, the original dwellers have often sold their valuable planned parcels onwards and squatted nearby areas, which has increased the housing densities beyond what was originally planned (Haji et. al. 2006). Most of these issues are well acknowledged by the governmental planning agencies who are currently updating their land and urban policies to reduce haphazard urban sprawl and limit it negative side-effects (RGZ, 2012, 2014).

2.2. Mapping urban growth

In this study, urban expansion refers to horizontal spread of buildings within the study area, and does not include vertical developments or expansion of other urban elements such as roads, runways or parking lots. Neither does this study separate urban settlements, population or population growth from rural within the study area.

194

195 The mapping of urban expansion was done with aerial photographs (0.5 m resolution) of 2004, Ikonos (1 m)
196 satellite image of 2009 (Jan 4) and GeoEye-1 (1.84 m) satellite images of 2013 (Feb 20). The building data of
197 2004 were mapped as vector polygons by the Department of Survey and Mapping (DoSM). A grid (20 m
198 resolution) was placed over the study area and all the cells either containing or partly covering buildings in
199 2004 received value 1, while non-built cells were given value 0. The 2004-2009 change mapping was done by
200 first covering the built area of 2004 from the image of 2009, then the remaining study area was visually assed
201 in the scale of 1:2500 and every cell with new buildings were recorded. The 2009-2013 urban expansion was
202 digitized in similar matter, but by covering the built area of both 2004 and 2009.

203

204 The created datasets were used to calculate the built area in 2004 and its expansion between 2004 and 2013.

205 The annual rate of urban area expansion (u) was calculated with compound interest formula:

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$$u = \frac{A_2^{(1/(t_2-t_1))}}{A_1} - 1$$

208

209 Where t_1 and t_2 are the times (year) of the estimates and A_1 and A_2 the urban area estimates of these years
210 (FAO, 1995). The rate was calculated for the entire study area and for all of its administrative wards.

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212 *2.3. Independent variables*

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214 Independent variables were identified for our model based on the related theory, local circumstances and
215 similar models conducted in other developing countries. Finally, availability of data influenced, which of the
216 variables could be used and we ended up selecting twelve relevant independent variables for the model.

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218 Variables ‘elevation’ (ELE), ‘slope’ (SL) and ‘soil’ (SOIL) were selected to represent the biophysical
219 conditions of the study area. The negative effects of rugged topography to urban expansion were already
220 acknowledged by Harris and Ullmans (1945) and used in many similar models with decent results (Liu, 2009;
221 Arsanjani et. al., 2013). The use of soil variable reflects the local biophysical conditions of Zanzibar, where
222 the two soil types divide livelihood possibilities, which may have later on reflected to urban growth patterns
223 (Hettige 1990). The soil conditions are also linked to local spatial policies as the government has attempted to
224 steer the urban expansion more towards shallow coralline soils with limited agricultural potential (Myers 2004;
225 RGZ 2014). Economic factors are most clearly represented in variables ‘distance to market centers’ (DM) and
226 ‘distance to roads’ (DR), which are proxies of market access (Poelmans & Van Rompaey 2010). ‘Open
227 agricultural areas’ (OA) variable manifests economic circumstances as opportunity cost of urban expansion,
228 but it is also related to local spatial policies forbidding expansion in open agricultural areas (Deng et. al., 2008).

229 Social factors are acknowledged with variables ‘distance from coast’ (DC), ‘kernel density of buildings’
230 (KER), ‘distance to buildings (DB) and ‘focal sum of build cells (FOC). The first variable reflects the global
231 trend towards higher quantities of urban expansion in coastal areas, while locally it is linked to development
232 of coastal tourism and high land values, which may have reduced urban expansion in seafront areas (Käyhkö
233 et. al. 2011; Seto et. al. 2011). The 'kernel density of buildings' variable echoes the social and economic factors
234 driving people to inhabit areas with already high population densities (Deng et. al., 2008; Linard et. al., 2011).
235 The two latter variables are manifestations of local social and planning conditions, where houses are built
236 relatively close to each other's due to fragmentation of small land holdings, while on the other hand they are
237 related to spatial interactions, as land use developments attract similar changes in neighboring areas due to
238 Tobler’s first law of geography (Tobler, 1970; Törhönen, 1998; Haji et. al., 2006). The last two variables
239 ‘construction restriction areas’ (RA) and 'three-acre plots' (TAP) represent the local spatial policies that have
240 either obstructed or indirectly promoted urban expansion (Törhönen, 1998; Myers 2008; RGZ 2014).

241
242 Variables DC, DB, DR and OA were based on DoSM topographical database, which contained road, building
243 and land cover information digitized from 2004 aerial photographs. Locations of market places and general
244 areas of three-acre plots were based on National Land Use Plan 2012 (RGZ, 2012). ‘Kernel density of
245 buildings’ was created with ArcGIS 10 -tool “Kernel density”, which calculates the amount of build cells
246 weighted by their distance individually for each cell in the study area (Silvermann, 1986). Various kernel
247 thresholds were tested, but the distance threshold of 2.5 km provided best explanatory results in the initial
248 tests. ‘Focal sum of build cells’ was the sum of build cells directly neighboring the cell at focus within 3x3
249 cell window. The elevation variable was created by calculating Digital Elevation Model (DEM) from 5 meter
250 contours of DoSM database. The DEM was also used to calculate slope for each cell in the grid. The soil
251 variable was derived from the physiographic maps produced by Hettige (1990) by generalizing the soils to two
252 broad categories: deep sandy and coralline soils. The last variable, RA, contained government areas restricted
253 from construction indicated in Zanzibar Master Plan, forest protection areas provided as vector data by
254 Department of Forestry and Non-Renewable Natural Resources as well as airport, park and beach areas of
255 DoSM 2009 database (RGZ, 2014). Variables DB, FOC and KER were updated for modeling years of 2009
256 and 2013.

257
258 Multicollinearity of the independent variables was tested with Pearson’s correlation coefficient (PCC) and
259 Variance Inflation Factor (VIF) analysis. High correlations ($PCC > |0.7|$ or $VIF > 5$) were not detected and all
260 variables were accepted for the modeling (Dormann et. al. 2013) (Supplementary materials).

261 262 *2.4. Modeling method*

263
264 Various modelling methods have been used in the UGPMs, such as Generalized Linear Model (GLM),
265 artificial neural networks, cellular automata and agent-based models (Cheng, 2003; Silva & Wu, 2012;

266 Triantakostas & Mountrakis, 2012; Vermeiren et. al., 2012; Arsanjani et. al., 2013). In this study, the
 267 modeling of urban expansion was done with Generalized Additive Model (GAM). GAMs are widely used in
 268 modeling of various spatial phenomena and the outcome accuracies are known to be high (Araújo et. al., 2005;
 269 Luoto et. al., 2005; Marmion et. al., 2009; Hjort & Luoto, 2011). GAMs extend the range of applications of
 270 GLMs by allowing non-parametric smoothers in addition to parametric forms combined with a range of link
 271 functions. This allows creation of various response shapes from linear to more complex. (Hastie & Tibshirani,
 272 1990; Guisan et. al., 2002). The strength of GAMs is their ability to deal with highly non-linear and non-
 273 monotonic relationships between the dependent and the set of independent variables, which increases the
 274 prediction accuracies. Though, as a data-driven technique it has a tendency to over-fit, which can be controlled
 275 by limiting the degrees of freedom of the smoothed predictors (Wood, 2008). GAMs of this study were
 276 executed with ‘gam’-tool of ‘mgcv’-package in R software. In all models, the parameter family, defining the
 277 distribution of the data, was set to binomial and degrees of freedom were limited to four.

278
 279 Model was evaluated in a smaller test area, because the used Ikonos (2009) image covered only 52 % of the
 280 total study area after clouds were removed. Estimation of past-to-present projection accuracy required
 281 observations from at least three time periods and the used datasets were the only available high-resolution
 282 images able to provide these observations from Zanzibar. Therefore, the contribution tests and assessment of
 283 projection accuracy were done in the test area with models calibrated by 2004–2009 data and tested against
 284 real expansion data of 2009–2013, while the entire study area projections were calibrated with 2004–2013
 285 data.

286
 287 Predictive capabilities of the model and the contributions of individual variables were tested with Area Under
 288 the Curve (AUC) and True Skill Statistic (TSS), which are commonly used assessment methods for binary
 289 data models (Araújo et. al., 2005; Luoto et. al., 2005; Allouche et. al., 2006; Marmion et. al., 2009). AUC
 290 estimates the probability that the model ranks random positive samples higher than random negative ones:

$$292 \quad AUC = \frac{1}{n_1 n_0} \sum_{i=1}^{n_1} \sum_{j=1}^{n_0} I(p_{1i} p_{0j})$$

$$294 \quad \text{where, } I(p_{1i} p_{0j}) = \begin{cases} 0 & \text{if } p_{1i} < p_{0j} \\ 0.5 & \text{if } p_{1i} = p_{0j} \\ 1 & \text{if } p_{1i} > p_{0j} \end{cases}$$

295
 296 Where p_{0j} and p_{1i} are the predicted values for the non-development site i and urban expansion site j , while
 297 the n_1 and n_0 are the number of urban expansion and non-development sites (Mason & Graham 2002). AUC
 298 values range from 0.5 (equal to random selection) to 1.0 (perfect model). Values between 0.6–0.7 are

299 considered as poor, 0.7–0.8 as fair, 0.8–0.9 as good and 0.9–1.0 as excellent (Swets, 1988; Araújo et. al., 2005).
300 TSS is calculated as the sum of true positive rate (sensitivity) and false positive rate (specificity) minus one:
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$$302 \quad TSS = \frac{n_{11}}{n_{1+}} + \frac{n_{00}}{n_{0+}} - 1$$

303
304 Where n_{11} and n_{00} are the number true positive (expansion) and true negative (non-development) observations,
305 while n_{1+} and n_{0+} total observations modeled positive and negative (Allouche et. al., 2006). Calculating TSS
306 requires dividing the modeled data to binary presence-absence classification, which was done by separating
307 the test data to half based on the mode of predicted values. TSS values between 0.2–0.4 are considered as fair,
308 0.4–0.6 as moderate, 0.6–0.8 as substantial and 0.8–1.0 as perfect (Landis & Koch, 1977). However, the given
309 interpretation ranges of TSS and AUC are merely suggestive.

310
311 Past-to-present validation of the models was done with repeated stratified random sub-sampling cross-
312 validation method (Barker et. al., 2014). Sampling increases the distance between individual observations, thus
313 reducing the effects of spatial autocorrelation (SA) and improving model's transferability (Hijmans, 2012; le
314 Roux et. al., 2013). For each model 5% of positive and equal amount negative observations were randomly
315 sampled from 2004-2009 and 2009-2013 urban expansion data. The sampled 2004–2009 data was used to
316 calibrate the model, which was then used to predict urban expansion with the 2009–2013 data. The predicted
317 results were compared to the real expansion of 2009–2013 and AUC as well as TSS were calculated for the
318 prediction results. This cross-validation scheme was then repeated 1 000 times with different permutation for
319 each run and average AUC and TSS values were reported.

320
321 The significances of the remaining eleven independent variables were analyzed with alone and drop
322 contributions tests. In alone contributions test, a single variable is used to model urban expansion, while in
323 drop contributions test the single variable is dropped from a model including all other variables. The effect of
324 dropping the variable is estimated against the full model by reducing the drop contribution results from the
325 full model results (Luoto et. al. 2005). The predicative capability of the alone and drop models were estimated
326 with AUC and TSS and the models were subjected to the repeated random sub-sampling cross-validation
327 scheme explained earlier. Variables were selected for the final model with backward stepwise selection
328 process, where in each step the variable with largest negative influence to the overall model was dropped
329 (Kadane & Lazar, 2004). The negative influence was measured by variable's drop contributions TSS result
330 and the stepwise process was continued until no more negative contributions were recorded (Supplementary
331 variables). Based on this process, nine variables were selected for the final model.

332
333 The model with the remaining variables was subjected to cross-validation scheme described earlier to calculate
334 the final performance measurement results. After the testing phase, the final model was compiled by first

335 creating 1 000 individual models calibrated with 5 % of positive and equal amount of negative observations
336 selected with stratified random sampling from the full time period of 2004–2013. These sub-models were then
337 averaged with ‘model.avg’-tool of ‘MuMIn’-package in R to create the final model used in predictions of
338 2013–2030 expansion. This average model however could not be used to calculate the response curves
339 indicating the relationship between dependent and independent continuous variables or coefficients of the
340 dichotomous variables. Therefore, these figures were calculated based on a model calibrated with all
341 observations of the 2004–2013 time period and thus, they are influenced by spatial autocorrelation.

342

343 *2.4. Scenarios of urban growth*

344

345 The urban expansion of Zanzibar City was simulated until 2030 with different quantity and spatial pattern
346 scenarios. There were two scenarios for the quantity: ‘business-as-usual growth’ and ‘predicted growth’. The
347 ‘business-as-usual growth’ scenario (1) was based on the annual rate of urban area expansion calculated from
348 the 2004–2013 data of this study, while the ‘predicted growth’ scenario (2) was based on decreased population
349 growth rate (2.7%) of Mjini Magharibi region predicted with cohort-component method for 2012–2037 in
350 Draft National Land Use Plan 2012 (RGZ, 2012). It was seen important to include the scenario with decreased
351 population growth rate as global studies suggest it to be the main factor determining the quantity of urban
352 expansion in Africa (Seto et. al. 2011). However, the results of this study indicate that the annual population
353 growth rate (4.2 % in 2002–2012) and measured annual rate of urban expansion (3.8 % in 2004–2013) vary
354 slightly, probably due to vertical building, densification and changes in household sizes (NBS 2014).
355 Therefore, the predicted future population growth rate of NLUP (2012) was adjusted according to this ratio
356 $(3.8 \% / 4.2 \% * 2.8 \% = \sim 2.4 \%)$ to 2.4 % annual rate of urban expansion for the ‘predicted growth’ –scenario.

357

358 Six scenarios influencing the spatial pattern of urban expansion were developed. Again, the first scenario (A)
359 was ‘business-as-usual pattern’, which was based on the same setting of explanatory variables as used in the
360 original model. The five other scenarios were developed based on spatial plans recommended by Department
361 of Urban and Rural Planning in their most recent and valid policy reports. Two scenarios were based on *Urban*
362 *Development Management Approach Report* (RGZ, 2014): ‘Urban nodes’ scenario (B) seeks to establish eight
363 new urban centers to existing suburbs, while in ‘infill’ scenario (C) certain government and military areas are
364 opened for infill. Two scenarios were developed according to *Draft National Land Use Plan 2012* (RGZ,
365 2012): ‘Road development’ scenario (D) aims to direct urban sprawl by building three new roads in the city
366 region, while ‘airport transfer’ scenario (E) relocates Abeid Amani Karume International Airport to less
367 valuable scrubland 20 kilometers away from the city. Final ‘combined plans’ scenario (F) merges all of the
368 four previously described scenarios into one. The alternative spatial pattern scenarios were developed to
369 estimate how effectively these plans would direct urban expansion, which was measured by calculating the
370 percentage of expansion area varying from the ‘business-as-usual pattern scenario’.

371

372 The scenario simulations were created by fitting the already established model to the unbuilt cells of the study
373 area with 'predict'-tool in R and selecting cells with highest predicted values equaling the area defined by the
374 quantity scenarios. Combining the quantity (1 & 2) and spatial pattern (A-F) scenarios created altogether
375 twelve simulations of urban expansion between 2013 and 2030.

376

377 3. Results

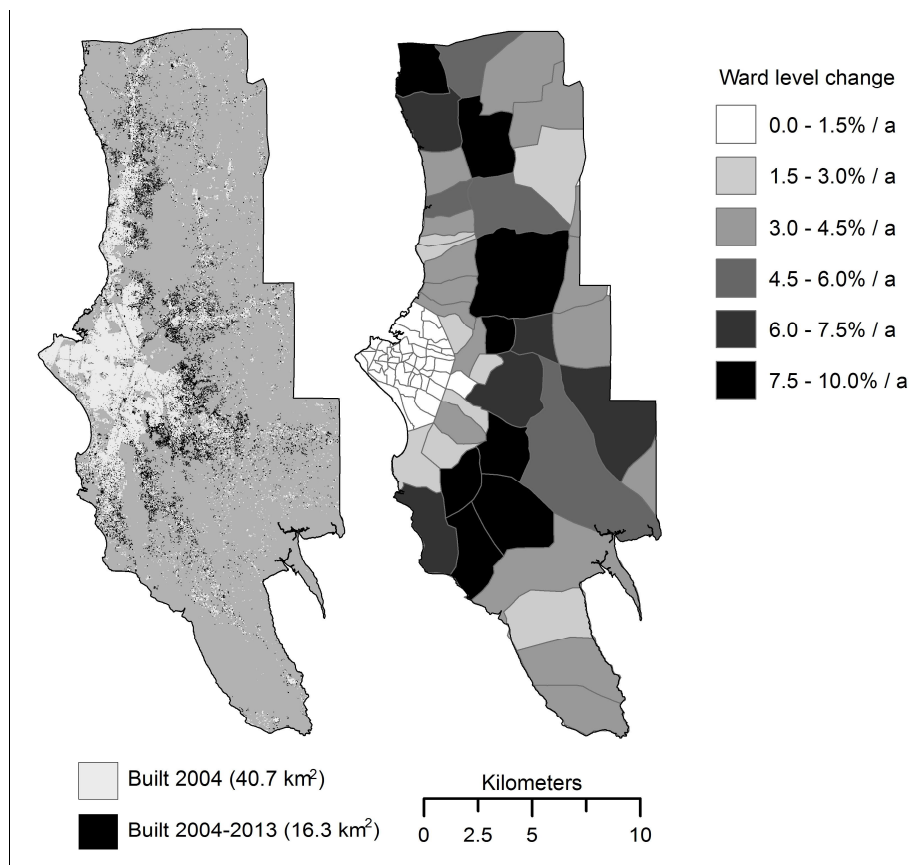
378

379 3.1. Patterns of urban expansion in Zanzibar City

380

381 The built area of Zanzibar City was 40.7 km² in 2004 and it increased by 40% to 56.9 km² in 2004–2013
382 (Figure 3). The annual rate of urban area expansion was 3.8% during this period. The wards at the outskirts of
383 the city limit had extremely high annual urban expansion rates (5-10%), while the rates were low (0.5-3.0%)
384 in the wards at city center and rural areas.

385



386

387 *Figure 3. Built area expansion of Mjini Magharibi between 2004 and 2013 and the annual urban expansion rates calculated for*
388 *study area wards.*

389

390 The final cross-validated model has average AUC of 0.855 and TSS of 0.568, which indicates that the
391 predictive accuracy of the model is reasonably good. Visual estimation of the results revealed that majority of

392 incorrectly classified cells are either dispersed settlements far from city center or unbuilt cells within otherwise
 393 densely built areas.

394

395 The drop contribution test results suggest that variables ‘construction restriction areas’, ‘distance to buildings’
 396 and ‘kernel density of buildings’ have high influence on model performance, while ‘distance to markets’,
 397 ‘focal sum of build cells’ and ‘distance to roads’ have moderate effect (Table 1). Variables ‘three-acre plots’,
 398 ‘elevation’ and ‘open agriculture areas’ have minor influence on the model performance, while variables
 399 ‘slope’, ‘distance to coast’ and ‘soil’ were removed from the model already in variable selection phase due to
 400 negative impact (Supplementary variables).

401

402 *Table 1. Alone and drop contributions test results of the variables used in final model. Variables are sorted based on drop*
 403 *contribution TSS results.*

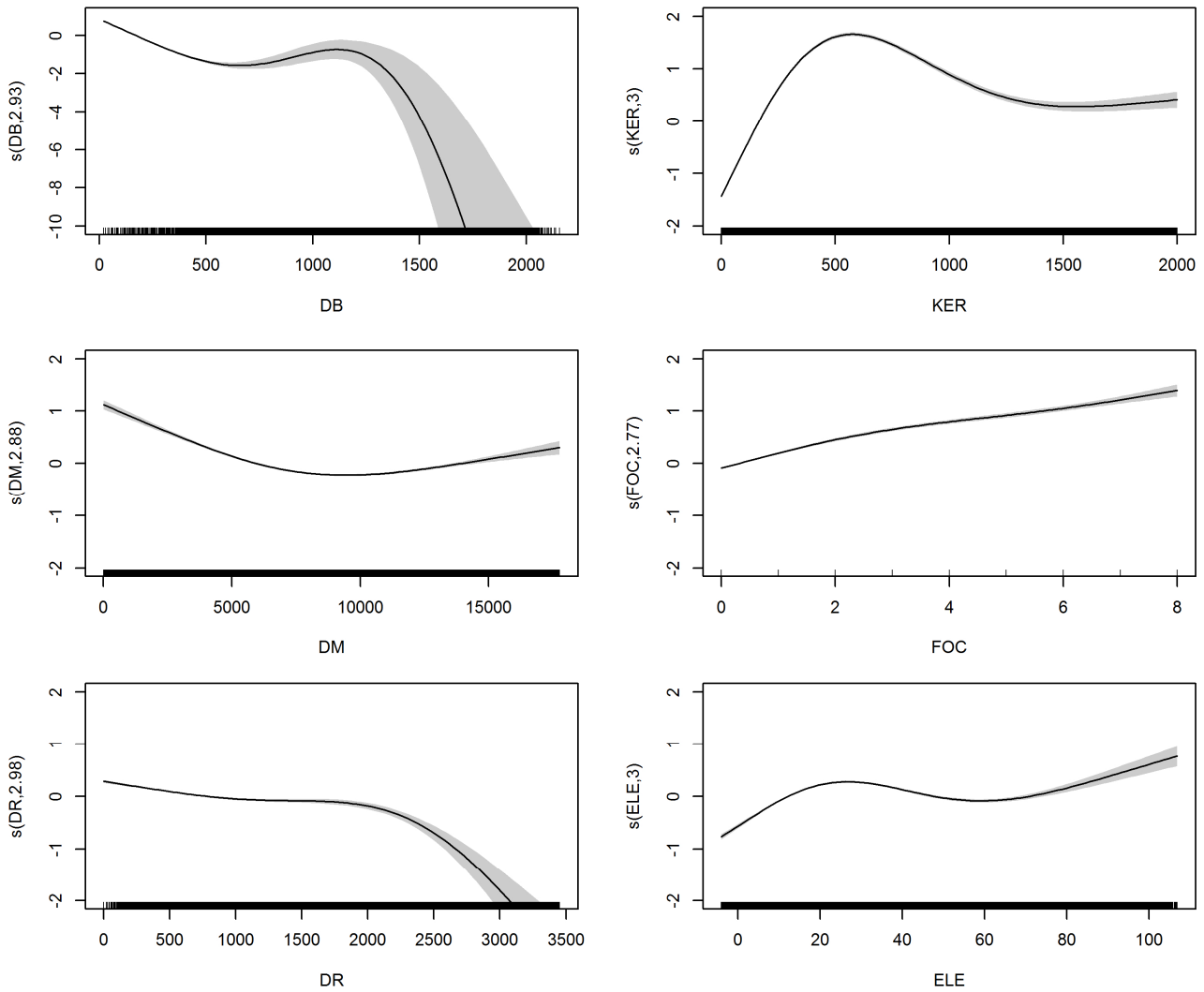
Variable	Alone		Drop	
	AUC	TSS	AUC	TSS
RA	0.577	n/a	0.0114	0.0291
DB	0.813	0.493	0.0074	0.0183
KER	0.739	0.367	0.0066	0.0172
DM	0.663	0.276	0.0009	0.0064
FOC	0.745	0.389	0.0076	0.0062
DR	0.638	0.193	0.0001	0.0054
TAP	0.578	n/a	0.0005	0.0031
ELE	0.601	0.164	0.0000	0.0010
OA	0.549	n/a	0.0010	0.0006

404

405 The smooth functions of independent variables indicated varied responses (Figure 4). The variable ‘distance
 406 to buildings’ shows a fluctuating response where the probability of becoming built is highest at immediate
 407 vicinity of other buildings, then decreases almost linearly until 500 meters, rises again slightly until 1200
 408 meters and then rapidly drops after that. This slight rise after 500 m is most likely caused by unexpectedly
 409 behaving isolated observation at these distances. The response of ‘kernel density of buildings’ suggests that
 410 the probability of urban expansion is lowest when the density is zero and peaks at 500 buildings/ km². In the
 411 response shape of variable ‘distance to markets’ highest probability of becoming built is achieved at the
 412 immediate vicinity of the markets, which after the probability steadily declines until 10 km. The response of
 413 ‘focal sum of build cells’ shows almost a linear increase, indicating that risk of becoming built is highest when
 414 the cell is surrounded by already existing buildings. The response shape of ‘distance to roads’ shows that areas
 415 at immediate vicinity of roads being preferred for urban expansion. However, this is shown to have only minor
 416 impact and remaining relatively stable until 2000 meters from roads, after which it declines rapidly. The
 417 variable ‘elevation’ has a fluctuating response that is highest around 20 meters and then again at maximum
 418 elevation of 100 meters. The coefficient of variable ‘construction restriction areas’ is -2.01, which indicates
 419 that the probability of urban expansion is significantly lower in these areas than outside them. The ‘TAP’
 420 variable has a coefficient of 0.18 indicating that urban expansion is slightly more common in three-acre plots

421 than outside them, while the coefficient of variable 'OA' (-0.93) indicates that probability of expansion is
 422 lower within agricultural areas.

423
 424

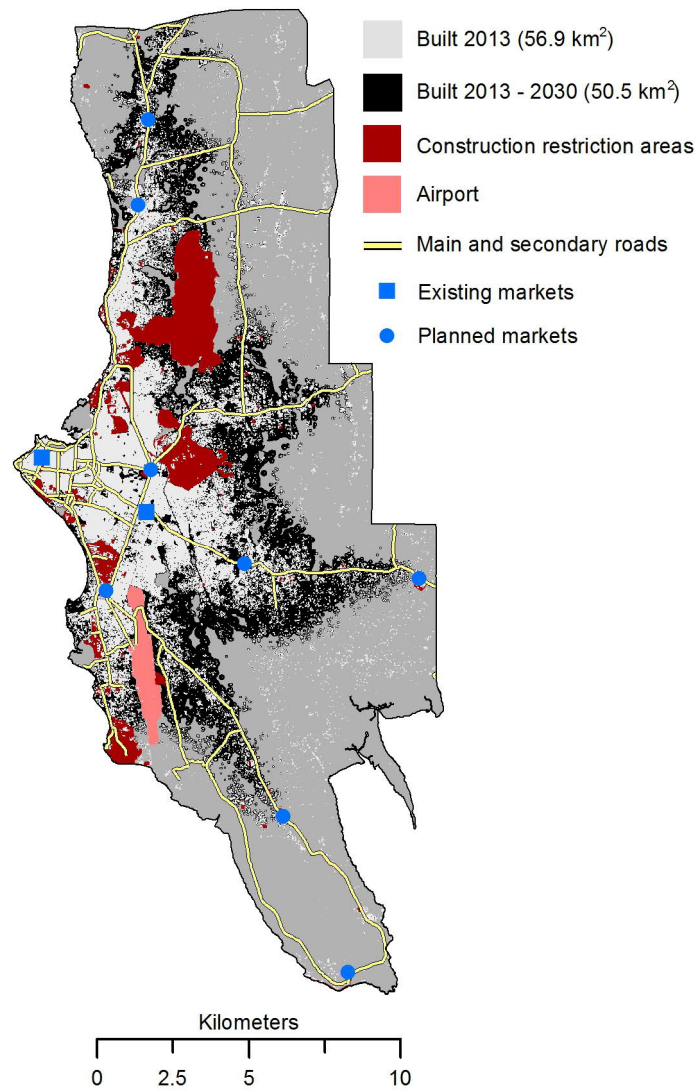


425
 426 *Figure 4. Variable smooth functions of the final generalized additive model of urban expansion plotted on the scale of the linear*
 427 *predictor. The grey areas are 95% confidence intervals; y-axis represents the effect of the respective variable; the figure in y-axis*
 428 *title indicates the estimated degrees of freedom and s the smooth term of GAM.*

429
 430 **3.2. Modeled urban area of 2030**

431
 432 Based on 'business-as-usual growth -scenario the built area will be 107.1 km² in 2030 (Figure 5). This would
 433 mean 88% increase from 2013. In the more optimistic 'predicted growth' -scenario, the built area would
 434 increase by 50% to 85.2 km².

435
 436



437
 438 *Figure5. Predicted business-as-usual built area expansion of Mjini Magharibi between 2013 and 2030 displayed with selected*
 439 *variables influencing the expansion patterns.*
 440

441 Based on visual interpretation of the business-as-usual growth and pattern scenarios, the urban expansion is
 442 expected to happen through densification of already established, but sparsely built neighborhoods at the
 443 outskirts of the current city. Urban expansion is predicted to decline in some of the wards having highest
 444 growth rates between 2004 and 2013, as majority of their open spaces become settled. Simultaneously, sprawl
 445 pushes towards new wards further away from the city center. New settlements are also mainly established into
 446 agroforest and fruit tree plantation areas.

447
 448 When the alternative planning actions are compared to the ‘business-as-usual pattern’, the ‘urban nodes’
 449 scenario has the highest effect on directing urban expansion (Table 2). If new urban nodes would exist it is
 450 expected to shift the location of 7.7% of new buildings built between 2014 and 2030 if the quantity of urban
 451 growth remains the same, and 13.0% if urban growth declines according to the ‘predicted growth’ scenario.
 452 Also the ‘infill’ and ‘road development’ scenarios have some effect on directing urban sprawl, while the effects

453 of 'airport transfer' scenario are rather limited. When these planning approaches are merged to 'combined
 454 plans' scenario it is expected to influence the location of 10–15% of new buildings depending on the quantity
 455 of the growth.

456

457 *Table 2. Urban expansion patterns (2013–2030) produced by alternative spatial scenarios are compared to 'business-as-usual*
 458 *pattern' scenario to estimate their impact on directing urban expansion.*

Spatial scenarios	Quantity scenarios	
	Business-as-usual growth	Predicted growth
Urban nodes	7.7 %	13.0 %
Infill	5.0 %	5.4 %
Road development	2.2 %	3.4 %
Airport transfer	2.1 %	0.8 %
Combined plans	10.4 %	15.3 %

459

460 **4. Discussion**

461 *4.1. Urban expansion of Zanzibar City*

462

463 Zanzibar City seems to be following the patterns of rapid urbanization and extensive urban expansion typical
 464 to Sub-Saharan cities (Angel, 2011; Linard et. al., 2013; ADB, 2014; UN, 2014). With current growth rate, the
 465 population would double every 18 years. The mere magnitude of absolute population growth has made the city
 466 to sprawl rapidly and the annual rate of urban area expansion (3.8%) is only slightly less than the annual
 467 population growth rate (4.2%). This indicates that the urban area expansion is almost linearly linked with
 468 population growth in Zanzibar City; opposite to the studies theorizing that population growth will cause
 469 exponential urban expansion in Africa as densities of built-up areas decline (Angel et. al., 2010, 2011).

470

471 With the current urban expansion rate, the city would nearly double its spatial extent by 2030. However, the
 472 annual population growth rate has already started to decline. The rate declined from 4.5% to 4.2% in Mjini
 473 Marharibi region and from 3.1% to 2.8% in entire Zanzibar between last two intercensal periods (NBS, 2013).
 474 Also the cohort-component population projections of NLUP (2012) predicted the population growth rate to be
 475 2.7% between 2012 and 2037, indicating that there is a real turn towards lower population growth rates. As
 476 urban population growth is considered as the main driver of urban expansion quantity in Africa, this decline
 477 will most likely reduce the extent of urban expansion significantly (Seto et. al. 2011). Though, even if the
 478 annual urban expansion rate would be as low as 2.4% between 2013 and 2030, the urban area would still
 479 increase by 50% during this time.

480

481 Majority of urban expansion in Zanzibar City takes place in suburbs outside the city center. The response
 482 shape of the '*kernel density of buildings*' variable supports this observation as its peak is not in the most
 483 congested core or sparse rural areas, but somewhere in the middle. Also the ward-level growth rates show
 484 fastest expansion in areas 5 to 10 km from the center, while the growth rates are modest in the city center and

485 in rural areas. However, this suburbanization in Zanzibar might be rather caused by land scarcity of the center
486 than push factors created by congestion and poor quality of housing as the theories suggest (Chin, 2002; Leao
487 et. al., 2004). For example, the response shape of '*distance to markets*' still suggest that expansion would
488 happen in areas as close as possible to the main market centers, which is a typical pattern in the developing
489 world, but significantly sized non-built areas close to market centers are rare or restricted for government or
490 military usage in Zanzibar (Taubenböck et. al., 2011; Doan & Oduro, 2012; Vermeiren et. al., 2012; Arsanjani
491 et. al., 2013; Linard et. al., 2013). There were no signs of counterurbanization where urban area densities would
492 decline and population in core or suburbs would move towards rural areas (Leao et. al., 2004; Linard et. al.,
493 2013).

494
495 The spatial pattern urban expansion of Zanzibar City is largely defined by the pattern of already established
496 buildings, which is indicated by the high importance of variables DB and KER as well as moderate effect of
497 variable FOC in the contributions tests. This is hardly surprising, as it well known that forms of land use attract
498 similar uses in nearby areas (Hoyt, 1939; Harris & Ullmans, 1945; Poelmans & Van Rompaey, 2010). Also a
499 continental study by Linard et. al. (2013) suggests amount of neighboring urban areas to be the most important
500 spatial indicator for future urban expansion in Africa and case studies from various developing countries have
501 shown similar patterns (Doan & Oduro, 2012; Vermeiren et. al., 2012; Arsanjani et. al., 2013). However, the
502 influence is rarely as emphatic as in Zanzibar. This is most likely caused by the local social and planning
503 conditions, where small land holdings provided in the land reform are split to even smaller parcels and planned
504 parcels are sold onwards as previous owners squat nearby areas (Törhönen, 1998; Haji et. al., 2006; Myers,
505 2008; RGZ, 2014). Also land use constraints have relatively high influence on the growth patterns based on
506 the contributions tests, which suggests that the restrictions are well respected, at least when they are enforced
507 with fences or by the military.

508
509 The importance of '*distance to markets*' and '*distance to roads*' variables have already been acknowledged by
510 the early sociological and economic models as they manifest market access (Von Thünen, 1826; Burgess,
511 1925; Hoyt, 1939; Deng et. al., 2008; Poelmans & Van Rompaey, 2010) and they have been among the most
512 important factors in many modern UGPM studies (Hu & Lo 2007; Doan & Oduro, 2012; Vermeiren et. al.,
513 2012; Arsanjani et. al., 2013; Linard et. al., 2013). In the case of Zanzibar City, the variables were moderately
514 important, but clearly not as influential as the factors related to already existing building patterns and
515 restrictions. It could be that market access and road networks influence the model indirectly by directing the
516 spatial patterns of already established buildings. This is supported by the relatively high negative correlation
517 between variables DM and KER (-0.63) (Supplementary materials).

518
519 Besides these variables, other factors either had minor, negligible or even negative impact on the models.
520 Coastal location has been highly significant in global studies, but locally it did not influence the expansion
521 patterns, which is somewhat unexpected in island settings (Seto et. al. 2011). It might be that government

522 placed restrictions and high land prices counterbalanced the pull factors of the coast, leaving the variable
523 insignificant, but further empirical evidence would be needed. Situation was similar with open agricultural
524 areas as they did not substantially attract or repel urban expansion according on the contributions tests. This is
525 somewhat alarming as building is generally prohibited from agricultural lands and the variable was assumed
526 to have clear impact on urban expansion (Törhönen, 1998; Myers 2008). On the other hand, the Three Acre
527 Plots generally assumed to be largely fragmented to housing parcels showed to be only a very minor, almost
528 negligible, pull factor for urban expansion (Törhönen, 1998; Myers, 2008). Despite the radical impact of soil
529 on natural landscapes and livelihood opportunities, it had no impact in the prepared UGPM. This could suggest
530 that the government efforts attracting inhabitants to infertile coralline soils have been at least somewhat
531 successful as otherwise urban expansion could be assumed to concentrate to the sandy soils closer to the current
532 urban area (Myers 2004; RGZ 2014). Topographical variables, which are quite significant in some
533 mountainous settings, had expectedly low contributions in generally flat Zanzibar (Arsanjani et. al., 2013).

534

535 Based on the mapping and the created scenarios, urban expansion has and continues to happen mainly at the
536 expense of surrounding agroforests and fruit tree plantations. Majority of Zanzibar's biomass is in these forests
537 and urban growth has already been identified as one of main causes of deforestation on the Island (Kukkonen
538 & Käyhkö, 2014). The heavy burden on agroforests is most like due to the historical land regulations and laws
539 allowing more private usage rights to areas where trees have been planted (Törhönen, 1998). Because of this
540 preference on agroforests, the negative environmental effects relevant to many other cities such as loss of
541 natural forests, open cropland and wetlands have been less evident in Zanzibar (Eigenbord, et. al., 2008;
542 McDonald et. al., 2011; Vermeiren et. al., 2012).

543

544 *4.2. Planning against sprawl*

545

546 The Government of Zanzibar is currently modifying its planning policies to reduce urban sprawl and its
547 negative effects (RGZ, 2012, 2014). One of the main proposed planning approaches is to direct the urban
548 expansion to already existing neighborhoods and areas with limited agricultural capacity by establishing eight
549 new urban nodes/centers with services to current suburbs (RGZ, 2014). These kinds of satellite cities and other
550 clustered developments have been widely promoted as one of the main solutions to the urbanization dilemma
551 of Africa (Watson, 2013; UN-Habitat, 2014). In theory, these satellite cities would supply the inhabitants with
552 majority of their needs, thus reducing a need for transportation and improving the general living conditions,
553 but they have been criticized for being planned mainly for the well-of segments of the society, generating
554 traffic and being followed by informal development outside planned areas (Alaci, 2010; Vermeiren et. al.,
555 2012; Watson, 2013; UN-Habitat, 2014). Our results show that distance to market centers had moderate
556 contributions in the urban growth model, which suggest that urban centers have some effect attracting urban
557 expansion in Zanzibar. Also the 'urban nodes' scenario had the highest influence on directing urban sprawl
558 from the tested alternative planning approaches. However, the results were only moderate, therefore setting up

559 new urban nodes is not likely to be sufficient alone in reducing urban sprawl and other approaches are also
560 needed.

561

562 Another suggested plan is to open 6.3 km² of government and military areas to housing construction (RGZ,
563 2014). The related alternative scenario ‘infill’ suggests that only 2.9 km² of these areas would be built by 2030
564 with current growth rates, which is merely 6% of anticipated total expansion. The overall impact of this activity
565 would be quite limited, but these areas could be suitable targets for well-planned development of multi-story
566 housing and services, which would lead the way towards more compact vertical city. Draft National Land Use
567 Plan 2012 presents an idea of relocating the airport away from the city region (RGZ, 2012). This is shown to
568 have limited influence on directing the urban sprawl, especially considering the cost of the activity. Our results
569 also indicate that new roads have little impact on urban sprawl, although they could improve the living
570 standards otherwise.

571

572 The tested planning policies, even when they were combined, had relatively minor impact on directing urban
573 sprawl. Therefore, also other planning approaches directing expansion as well as densification of the existing
574 urban area are needed. One of the government’s main planning tool for densification is to promote vertical
575 building (RGZ, 2014). The potential of vertical development is extremely relevant as majority of the buildings
576 are currently single-story detached houses. Promotion of vertical development could be accompanied with
577 improvements in land ownership and registration to support sustainable housing planning and tenure.
578 However, the building patterns are so dense in some of the unplanned areas that multistory buildings cannot
579 be easily built on individual parcels. Even with these limitations, the government should continue and increase
580 its support to vertical development as by doing so it can reduce urban expansion considerably.

581

582 Building restrictions are shown to be relatively effectual in Zanzibar and possibilities of expanding these
583 restrictions in form of Urban Growth Boundary (UGB) could be investigated. UGB is an outer edge of urban
584 expansion, beyond which housing should no spread (Jun, 2004; Tayeebi et. al., 2012). The administrative
585 boundaries of Mjini Magharibi do not correspond with the real boundary of the city region and UGB would
586 provide a tool against sprawl, without modifying the current administrative entities. Planning policies of
587 Zanzibar do not include UGB at the moment, but it could be introduced through legislation, allowing a mandate
588 for the government to take action against any development happening outside the boundary. Urban growth
589 models, such as the ones presented here, could be used to define the UGB (Tayeebi et. al., 2011).
590 Unfortunately, the UGB might have serious negative effects on the already marginalized inhabitants dependent
591 on unofficial housing at the outer edges of the city. UGBs have also been criticized for inefficiency (Jun, 2004;
592 Tayeebi et. al., 2012). This could be a major problem also in Zanzibar, as implementation of abstract growth
593 boundary is far more challenging than securing the existing physically defined restriction areas.

594

595 Urban planning of Zanzibar City has started already in 1830s, first master plan was made in 1920s and urban
596 sprawl has been on the agenda since 1980s (Törhönen, 1998; Myers, 2008). The problem has never been lack
597 of planning, but rather implementation and resources. The governmental land planning system has simply not
598 been able to provide enough planned housing for the rapidly growing population (Törhönen, 1998; Myers,
599 2008; RGZ, 2012, 2014). This is an acknowledged problem not only in Zanzibar, but generally in Sub-Saharan
600 Africa (Odendaal, 2012; UN-Habitat, 2014). The implementation inefficacy of African urban planning has
601 spurred demands to revitalize traditional planning procedures. Suggested approaches of “new planning”
602 usually consist acceptance of informal settlements, gradual improvement of the informal areas and
603 participatory planning (Odendaal, 2012; Ngau, 2013; UN-Habitat, 2014). Functional participatory planning
604 procedures have already been set in forest sector of Zanzibar and there is genuine interest to include them into
605 the toolbox of urban planners (RGZ, 2012; Eilola et. al., 2014). Also the attitudes towards informal settlements
606 have been changing, but official acceptance has not been given and improvement plans are still missing (RGZ,
607 2012, 2014). The potential of all possible tools, traditional or new, should be unconditionally investigated as
608 there is a real change that Zanzibar City will continue its uncontrollable growth until the second half of this
609 century.

610

611 *4.3. Methodological considerations*

612

613 Mapping of urban expansion in this study was based on high-resolution remote sensing data acquired by the
614 Revolutionary Government of Zanzibar with the support of various development and research projects. This
615 allowed more accurate detection of urban growth and thus, more accurate model, than using freely available
616 satellite data with lower resolution. However, use of freely available data should be promoted for continuance
617 purposes, as it is unlikely that the Government of Zanzibar is able to provide high-resolution images in the
618 future without international funding.

619

620 This study attempted to base the selection of independent variables on related theories, knowledge of local
621 policies and conditions as well as similar models. However, it is eventually the quality and availability of
622 spatial data that dictates what can be used in the models and the availability of data is generally poor in
623 developing countries (Barredo et. al. 2003). For this reason, UGPMs are often conducted with similar, simple,
624 easily available and largely biophysical or infrastructure related variables. This can create an expectancy bias
625 where UGPMs are built on suboptimal sets of variables, because so have been done in previous studies, instead
626 of collecting and developing variables with more explanatory power. Also the used variables are often mere
627 proxies of other more complicated driving forces, which cannot be directly measured (Poelmans & Van
628 Rompaey, 2010; Triantakonstantis & Mountrakis, 2012). Therefore, it is important to be cautious when making
629 far-reaching assumptions based on model variable results and to test new, even seemingly unimportant,
630 variables in UGPMs. For example, reliable and systematically collected socio-economic information would
631 have most likely improved the projection accuracies of this study significantly.

632 Even though, the UGPMs are rather crude simplifications of complex urban expansion, their use can be
633 justified with high predicative accuracy, as in the case of the created model (Triantakonstantis & Mountrakis,
634 2012; Linard et. al., 2013). The model's accuracy was reasonably good when compared to real future data and
635 can be therefore reliably used to predict urban expansion. However, the projection accuracy and the model in
636 general could have been improved with few actions. Firstly, the model could have been made gradual by
637 predicting urban expansion one year at a time and then updating building pattern related variables (DB, KER
638 & FOC). Though, this gradual approach would have increased the computational requirements enormously.
639 Secondly, the model was limited in its approach towards spatial autocorrelation. Random subsampling of
640 observation was conducted to reduce the effects of SA (Hijmans, 2012; le Roux et. al., 2013). However, the
641 effectiveness of this approach was not measured and therefore, the results may be still influenced by spatial
642 autocorrelation. Alternative approaches, such as autocovariate models, could have been more effective in
643 reducing SA (Dormann et. al. 2007). Thirdly, the effects of the alternative planning scenarios were assessed
644 merely quantitatively, though it would have been more meaningful to estimate them qualitatively by measuring
645 what kind of land use changes are reduced by each scenario.

646
647 The results of this study emphasize the spatial complexity of urban expansion as local reciprocal interactions
648 of the biophysical, social, economic and policy factors created an outcome unique to Zanzibar City (Lambin
649 et. al., 2001; Cheng, 2003). Some factors proven important in global studies had negligible impact in Zanzibar,
650 while other factors were far more emphatic than elsewhere. This underlines the need of local calibration of
651 urban expansion models. Although, African cities have been well represented in global and regional urban
652 expansion studies, more local UGPMs targeting individual countries or cities would be needed to provide more
653 detailed and context relevant information required by urban planners and decision makers (Taubenböck et. al.,
654 2011; Seto et. al. 2011; Linard et. al., 2013).

655
656 The UGPMs are not only valuable tools for predicting future urban expansion, but they can be also used to test
657 the effects of alternative planning scenarios directing urban expansion as done in this study. Scientifically
658 based information on the issue is extremely valuable for decision makers, especially in Sub-Saharan Africa
659 where the urban growth rates are high and resources for planning and implementation limited (UN-Habitat,
660 2014). However, the increasing amount of information should be accompanied by improved transition of the
661 UGPMs from model developers to end-users (urban planners/decision makers), as currently many adequate
662 models are underutilized in the planning process despite their acknowledged value. To improve this, the end-
663 users should be involved in the model development as early as possible and the model developers should
664 provide guidance in the use of their models even after the main scientific results have been published.
665 Hopefully, a more proactive approach from both sides will solve this mismatch, as we genuinely believe that
666 UGPMs are highly valuable tools for 21st century urban planning.

667
668

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670

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Supplementary materials:

Initial independent variables were derived from six different sources (Table 1.)

Table 1. Statistical and source information of the independent variables of the entire study area.

Variable	Abbreviation	Unit	Min	Max	Mean	Source
Distance to coast	DC	m	20	8862	3114	DoMS topographic database
Distance to markets	DM	m	45	17747	7446	Draft National Land Use Plan
Distance to roads	DR	m	0	3421	676	DoMS topographic database
Distance from buildings	DB	m	0	2041	139	DoMS topographic database
Kernel density of buildings	KER	units/km ²	0	2000	359	DoMS topographic database
Focal sum of build cells	FOC	Pixels	0	9	0.9	DoMS topographic database
Elevation	ELE	m	0	107	24	DoMS topographic database
Slope	SL	degree	0.0	19.8	1.4	DoMS topographic database
Open agricultural area	OA	0/1	0	1	0.07	DoMS topographic database
Soil	SOIL	0/1	0	1	0.19	Hettige (1990)
Three-acre plots	TAP	0/1	0	1	0.45	Draft National Land Use Plan
Construction restriction areas	RA	0/1	0	1	0.08	Zanzibar Master Plan, DFNR and DoMS topographic database

Multicollinearity of all independent variables was tested with Pearson’s correlation coefficient (PCC) analysis (Figure 1) and Variance Inflation Factor (VIF) (Table 2), but high multicollinearity (PCC > |0.7| or VIF > 5) was not detected.

Figure 1. Correlation matrix of the original variables calculated with Pearson’s bivariate correlation analysis.

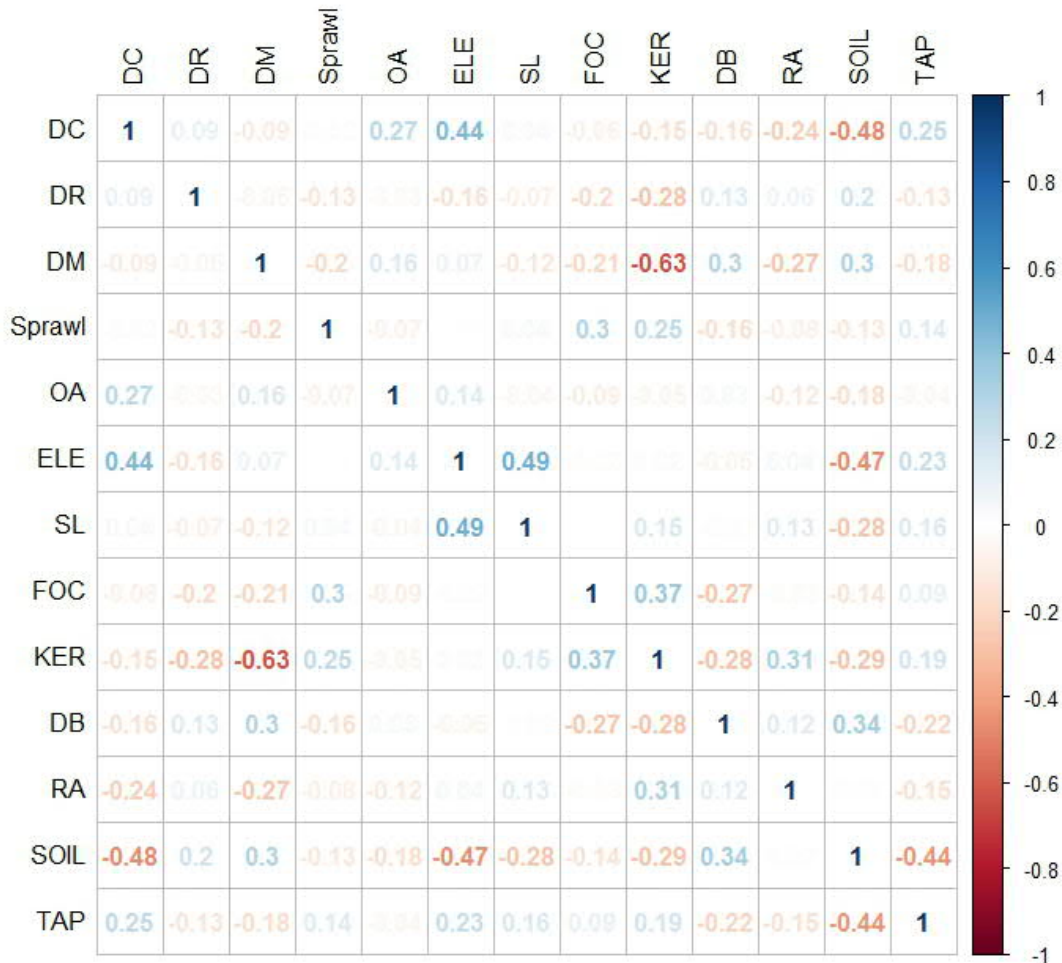


Table 2. Variance Inflation Factor results of the remaining variables.

	DC	DR	DM	OA	ELE	SL	FOC	KER	DB	RA	SOIL	TAP
VIF	2.11	1.31	2.41	1.21	2.14	1.49	1.25	2.61	1.31	1.40	2.11	1.34
VIF ²	1.45	1.14	1.55	1.10	1.46	1.22	1.12	1.62	1.14	1.18	1.45	1.16

The variables were selected for the final model with backward stepwise selection process, where in each step the variable with biggest negative influence to the overall model was dropped (Kadane & Lazar, 2004). The negative influence was measured by variable's drop contributions TSS result (Table 3). Four steps were calculated until no more negative contributions were recorded.

Table 3. Backward stepwise variable selection results. Grey cells indicate the variable dropped at each step and text "Dropped" indicate the variables already excluded from the model.

Variable	Drop contributions			
	1 st round TSS	2 nd round TSS	3 rd round TSS	4 th round TSS
DC	-0.0001	-0.0006		
DR	0.0033	0.0031	0.0041	0.0054
DM	0.0011	0.0009	0.0050	0.0064
OA	0.0004	0.0005	0.0005	0.0006
ELE	-0.0006	0.0003	0.0016	0.0010
SL	-0.0010			
FOC	0.0055	0.0041	0.0065	0.0062
KER	0.0140	0.0115	0.0191	0.0172
DB	0.0184	0.0157	0.0191	0.0183
RA	0.0218	0.0206	0.0277	0.0291
SOIL	-0.0004	0.0001	-0.0001	
TAP	0.0018	0.0018	0.0024	0.0031

Alternative scenarios were developed for predicting urban expansion of Zanzibar City, Tanzania (Figure 2). These scenarios were developed based on changes in patterns of urban centers, roads, construction restriction areas and airport location.

Figure 2. Alternative scenarios of urban expansion of Zanzibar City, Tanzania. Scenario A shows the predicted expansion pattern with business-as-usual spatial pattern of growth, scenario B with eight planned new urban centers, scenario C with government areas released to infill, scenario D with new roads planned in the city region, scenario E with Abeid Amani Karume International Airport transferred away from city region and F with all these planning activities combined.

