Chapter 8
USSDM – Urban Spatial Scenario Design Modelling

Andreas Printz, Hany Abo-El-Wafa, Katja Buchta, and Stephan Pauleit

Abstract Climate change, population growth and expansion of settlement areas are among the major challenges that African cities are facing. The aim of the study was to model growth of settlement areas under different scenarios of population density and flood protection to support development of strategies for urban development for risk reduction and protection of green areas which deliver vital ecosystem services for the future city.

The GIS-based USSDM – Urban Spatial Scenario Design Modelling approach – was developed and applied to simulate the likely patterns of settlement area increase in Dar es Salaam. The model is based on cellular automata principles and further developed as a participatory design tool for urban planners with strong involvement of stakeholders and experts. Specific features are transparency of model settings, a user friendly interface and easy adjustment of model parameters to respond to different assumptions on urban growth conditions as well as fast simulation runs.

According to USSDM scenario simulations, higher population density settings could minimise the future settlement expansion of Dar es Salaam by up to 5,000 ha until 2025, corresponding to approximately 8 % of the farmland area in 2008. Preventing future expansion of settlement areas into the flood prone areas would significantly reduce exposure of the human population to flooding. Recommendations for strategic development of a multifunctional urban green infrastructure planning in African cities are made.

Keywords Urban growth • Urban planning • Urban green • Scenario modelling • Dar es Salaam

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Introduction

Africa is well known for the highest indices of vulnerability related to climate change. Urban areas will be particularly at risk due to their concentration of population, assets and functions, and often, due to their location in areas exposed to natural hazards (Pelling and Wisner 2009).

The African continent adds another superlative – it has the world's highest rates of population growth and urbanisation (Fig. 8.1): by 2050, African cities are expected to accommodate three times as many people as today (UN-Habitat 2014). On the background of extreme poverty, low education, low institutional capacities, limited availability of resources and loss of ecosystem services, African cities have to address huge and highly complex challenges. In this context, climate change may be "just" an additional stressor, which amplifies the already high baseline vulnerability of African cities.

African cities suffer from uncontrolled growth of their settlement areas, mainly as informal settlements with insufficient access to infrastructure, health, education services and income (UN-Habitat 2008). In most cities, a great proportion of new urban settlers are rural migrants. Many of them can be considered as environmental refugees as they were forced to leave their marginal agricultural areas (Barrios et al. 2006; IPCC 2007).
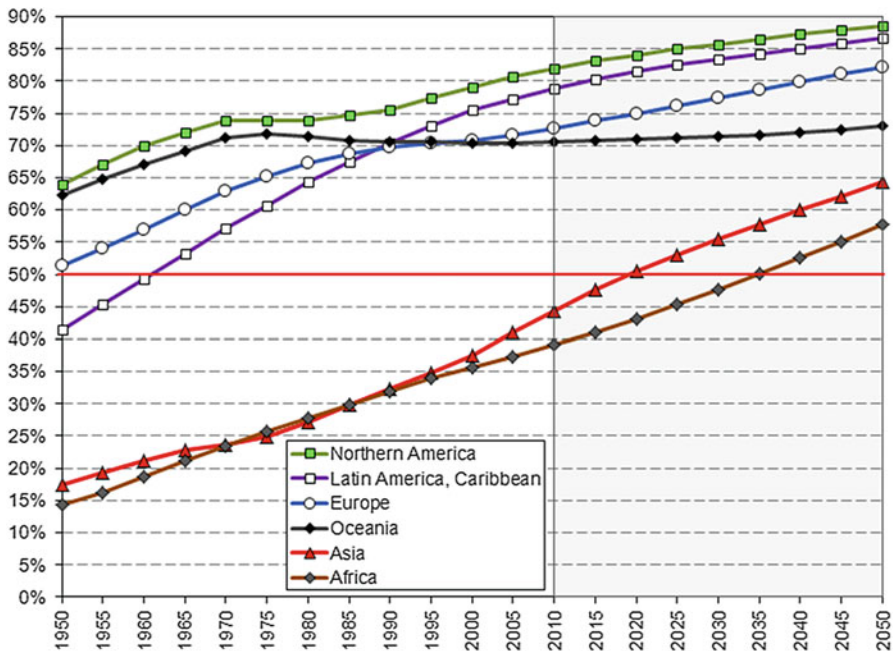

Fig. 8.1 Urban population by major geographical area (in % of total population) (Based on UNDESA 2011)

Climate change projections show strong evidence that this movement in many African regions is expected to be further aggravated in the future due to deterioration by climate change and/or desertification (Chap. 2; Niang et al. 2014). Although African urbanisation trends have been overestimated in some cases and are more complex than just being unidirectional (Potts 2012), the strong population growth rates were also confirmed in the recent population census for the CLUVA case study cities Dar es Salaam and Addis Ababa.

New city dwellers often arrive with few resources and settle in precarious areas within the urban periphery or in remaining open areas within the existing built-up area. In many cases these areas are threatened by natural hazards such as flooding. Climate change projections show a trend for an increase of extreme weather events, which will result in increased risks of flooding or lead to more frequent and intense heat waves (see Chaps. 1 and 2 of this volume).

Besides the increased risks of direct threats in certain areas, the need for vital ecosystem services will rise as they enable mitigating some of the threats, such as moderating heat waves or providing flood protection. Ecosystem services can also contribute to the survival of people in critical situations of extreme hazards, e.g. by providing safe spaces for resettlement and supply of food and fuel wood.

However, to be able to derive strategic knowledge for urban planning, there is a need to provide spatially explicit information on areas at risk as well as the distribution of ecosystem services. For planning the future city, information is also required on growth patterns of urban areas across rapidly developing African cities. Better knowledge is required about how expected population growth rates translate into spatial patterns of expanding settlement areas for a city; how this will increase the vulnerability of the city as more people will live in hazard prone areas; and how ecosystem services will decline due to loss of green areas. Importantly, the impact of different urban development strategies on urban vulnerability and its adaptive capacity needs to be known so that well informed decisions can be made and ensure that the capacity of urban planning is strengthened to respond to the combined challenges of climate change and urban growth.

Therefore, the aim of the study was to develop a spatial scenario modelling approach for supporting strategic planning in African cities. The objectives were to:

(a) Develop a land demand driven GIS-based urban scenario model which can be used in participatory planning contexts;
(b) Determine and visualise the expected spatial expansion of settlement areas using the model according to the different scenarios in Dar es Salaam;
(c) Explore the impact of urban growth on urban vulnerability to climate change related natural hazards.

The approach was developed and applied for the case study cities of Addis Ababa and Dar es Salaam. For the chapter's comprehension, this paper will focus on the Dar es Salaam case.

Urban Development History in Dar es Salaam

The formative period of the city is linked to the shift of the administration seat and capital of the former German colonial regime from Bagamoyo in 1890. During this time period, town planning introduced racial segregation: Different settlement zones for Germans/Europeans, Asians and Africans were established with decreasing size of plots, proportion of green areas and services standards. In 1918, for approximately 50,000 inhabitants, principles of a garden city represented the top level of urban living standards. Britain took over in 1918 without modifying the German urban regime order. Even though Dar es Salaam has not been the official state capital since 1974, it continued to attract -as the biggest Tanzanian city- a large number of new settlers to reach 1.5 million inhabitants in 1992. The attempts of the Master Plans of 1968 and 1979 to regain a planning initiative are considered to be surpassed by the reality of strong informal settlement activities. The impact of other development plans for the city has also remained limited as well as that of slum upgrading programmes (Mng'ong'o 2004; Kiunsi 2013). Dar es Salaam currently has an annual growth rate of more than 4 % which places it among the ten fastest growing cities of the world (City Mayors Statistics 2011). With a background of strong population pressure and weak planning, about 80 % of the settlement area of Dar es Salaam in 2013 was informal, severely lacking infrastructure and services. Around 50–70 % of the total population is estimated to have a connection to the piped water supply, while only 10 % are connected to a sewer system (UN-Habitat 2010).

Informal settlements are often found in areas with a high exposure to natural hazards, such as floodplain areas. An example of the disastrous consequences of such development was the December 2011 flood which led to 20 casualties, 200 persons injured, and approximately 10,000 people displaced (IFRC 2011).

In the CLUVA project, the consequences of urbanisation on land use change, and in particular the city's green structure, were analysed for the years 2002 and 2008. The comparison was based on the Urban Morphology Type (UMT) approach (see also Chap. 4).

The different pathways of transformation of green areas (left side) to settlement areas (right side) and the further transformation of settlement areas were analysed (Fig. 8.2).

The main chain of transformation was from remaining/degraded "Bushland" to "Mixed Farming", while "Mixed Farming" at the periphery in turn was 'invaded' by the transitional settlement type "Scattered Settlement" which further developed into the "Villa/Single Storey" settlement type. Only relatively small areas further changed to settlement types with a higher population density such as "Condominiums". Also, the land use in "Riverine" (and flood prone) areas was strongly altered into "Mixed Farming" as well as into "Scattered Settlement".

Even if the comparison is based on only two dates, it shows that "Mixed Farming" seems to be an important precursor of the settlement, and the settlement development itself, at least over a longer period, is characterised by settlements with a low population density.
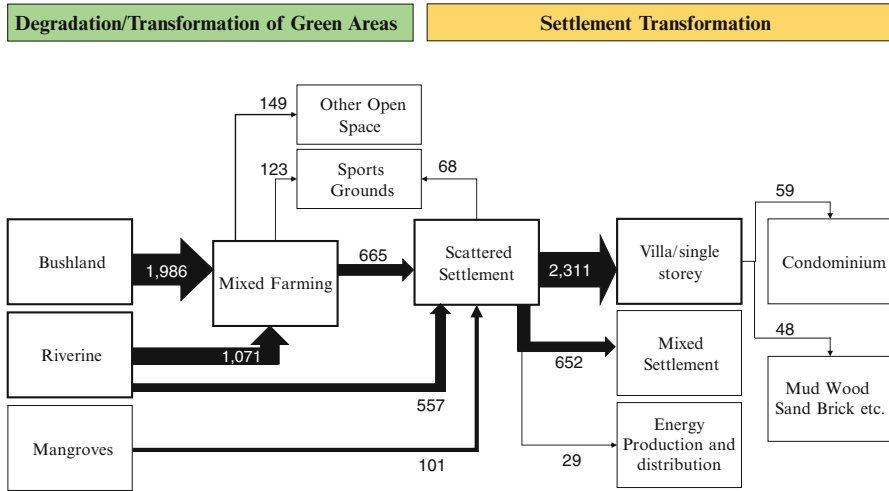
Fig. 8.2 Change detection of land use (UMT units) 2002–2008: degradation of green areas and settlement transformation in Dar es Salaam; *numbers* indicate area changed (ha) (Reproduced from Lindley et al. 2013)

During the 6-year period (2002–2008) "Green Area" UMTs lost more than 30 % of their total area. A more detailed land cover study by Renner (in Lindley et al. 2013) found strong evidence for a general loss of wood cover of 9–12 % during this time period.

Theoretical Background

A literature review identified several factors that drive urban growth patterns. Barredo et al. (2003) classified them into the following categories:

1. Environmental – there could be environmental constraints present which prevent specific areas from development and in turn favour other areas, such as steep slope and flood areas.
2. Neighbourhood – related to the dynamics of land use and its relation to other land uses in the surrounding area. For example, new residential areas tend to grow close to existent residential areas, while in some other cases certain land uses have a repulsive effect on other land uses. It is considered as one of the most influential factors that drives patterns of urban growth.
3. Spatial characteristics, such as the accessibility or proximity to transport networks.
4. Urban and regional planning policies that affect urban dynamics, notably land use zoning.

5. Other categories, such as economic development, socio-economic and political systems, and individual preferences. Modelling of categories is rather challenging because it involves human decision-making processes and should be integrated into econometric models.

The overall urban land use demand is generated exogenously to the cellular models (White et al. 1997) as it is not reflected by the urban local dynamics but by the growth of a city (Barredo et al. 2003).

There are two main different approaches in modelling spatial dynamics of urban areas. The traditional top-down approach tends to break down the system into manageable elements and components using deterministic models. The other approach that provides a higher capability in modelling complexities of spatial systems is a bottom-up approach that considers urban development as a self-organising system in which specific constraints and controls affect local decision-making processes producing macroscopic patterns of urban form (Ward et al. 2000). Examples of such an approach are cellular automata models (CAs) (Batty et al. 1999; Ward et al. 2000; Barredo et al. 2003).

The cellular structure used in CA models represents the adjacency or proximity characteristic similar to that of land parcels in urban systems. The structure is usually a lattice of a uniform gridded space. The value of the cell can represent one state of the cell (e.g. residential or commercial) from a group of possible states defined by the system being modelled (Ward et al. 2000).

Adjacent cells change their states based on the application of simple transition rules that can be considered as the generators of growth or decline. The cell can change from undeveloped to developed or other attributes of the cell can change (Batty and Xie 1997). The change of the cell state depends on functions that react to the cell's attributes as well as what is happening in its neighbourhood (Batty et al. 1999).

Urban dynamics models have been introduced in different cities in developed countries, such as the models produced for Cincinnati (White and Engelen 1993), San Francisco (Clarke et al. 1997), Marseilles (Meaille and Wald 1990) and the Washington/Baltimore corridor (Clarke and Gaydos 1998). Such cities' growth is usually characterised by planned settlements, which is not the case in the majority of African cities. The models used in the developed countries' context are unsuitable to capture the urban growth dynamics within a developing country's context. Typically, these kinds of models are expensive, data intensive, customised and limited to specific countries. Vector based models require complex programming skills, or the source code may not be accessible (Sietchiping 2004).

In most developing countries, and particularly in Africa, the availability of spatial information for cities is rather limited and in some cases non-existent. In most cases, the usability of existing spatial data for urban dynamics modelling is challenging, due to issues such as the lack of a consistent classification methodology, low resolution, and because data is outdated. These issues are considered as obstacles in sharing spatial information among different sectors and also across different cities in Africa (Barredo et al. 2004). Despite these data limitations, there has been considerable work on modelling the spatial expansion of African cities.

In Lagos, a cellular automata approach was applied (Barredo et al. 2004). A probabilistic approach was adopted in which several factors drive land-use dynamics and the city's growth that represent the accessibility and suitability. Main determinants were a land-use zoning factor, which represents the legal regulations for future land uses, in addition to a neighbourhood factor and a stochastic parameter that simulates the degree of uncertainty that is characteristic for most social and economic processes. Another example is the modelling of informal settlement dynamics and the dynamic visualisation of the simulation results for the case of Yaoundé, Cameroon (Sietchiping 2004).

In Dar es Salaam, a model based on standard GIS software and designed with the principles of Cellular Automata (CA) was developed by Hill and Lindner (2010a, b). In this model, the transformation process of non-urban cells into informal urban areas was based on a so-called 'transition potential' that is calculated using certain suitability factors.

The modelling approach developed and applied in the CLUVA project has its similarities with Hill and Lindner's (2010a, b) model as they both are raster based GIS models that are designed using the principle of cellular automata. However, Hill and Lindner's model was based on a binomial logistic regression model which defines transition potential through an extensive process of model calibration and validation. Moreover, the spatial extent of this model was confined to a limited area within the city of Dar es Salaam and the particular focus of the application was to explore the potential of transport infrastructure to guide future informal residential development decisions.

In contrast to the prediction oriented machine-like CA-based models, in CLUVA, a scenario-discourse based design model approach was applied. Therefore, the SSDM (Spatial Scenario Design Model) approach for a land use and water management in Benin (Schwarz von Raumer and Printz 2007) was transferred and further developed towards specific urban planning situations of fast growing settlement areas of the CLUVA reference cities Dar es Salaam (Buchta 2013a, b) and Addis Ababa (Abo-El-Wafa 2013a, b).

The main aim was to develop a flexible model particularly suitable to support scenario development for urban planning and assess the impacts of different pathways of urban development and urban growth impacts on land use types that provide several ecosystem services to the city. Therefore, the model should allow the user to quickly change settings and be able to add or change the weights of influencing factors according to outcomes from planning workshops.

Methodology

Urban Spatial Scenario Design Modelling Approach

The Urban Spatial Scenario Design Modelling (USSDM) approach was developed in two stages. The initial core model was first developed and then discussed and

customised to the case of Dar es Salaam with the contribution of stakeholders in several workshops. The stakeholders were involved in the determination of modelling parameters that included the expected settlement land demand, exclusion criteria, influencing factors and the scenarios to be modelled.

USSDM Design

USSDM is a raster-based model developed in a GIS environment on the main principles of cellular automata (CA) where the study area is represented in a GIS environment by a grid of raster cells. The size of the cells was 100 m by 100 m, corresponding to the minimum area of one ha in the urban morphology type survey (Cavan et al. 2012). The entire study area of Dar es Salaam was therefore divided into 149,896 raster cells.

The overall logic of the USSDM approach is depicted in Fig. 8.3. Land uses which were not expected to undergo change from non-settlement to settlement within the temporal scope of the model, were excluded beforehand ("excluded areas"). The likelihood of land use change from non-settlement to settlement and the potential for an increase of population density in already built areas had to be determined for the cells. For this purpose, the model calculates a transformability index for each cell using a weighted overlay operation of specific influencing factors which have been determined as factors in the transformation of cells into settlement cells. Among these factors is the neighbourhood influencing factor which is calculated based on the assumption that cells that lie close to settlement cells have a higher likelihood to transform than other cells that lie far away from settlement cells. The future spatial demand for urban land is estimated separately based on the projected population growth rate and assumptions of population densities according to local urban planning experts. After each modelling step, exclusion areas and the neighbourhood influencing factor are updated to include the new settlement areas that were transformed in the previous modelling step.

Scenario Building Process

The scenario building process involved local urban planning experts (academic and administrative) and decision-makers. It included three steps:

- Scoping and defining the scenarios;
- Defining exclusion criteria, expected settlement land demand, influencing factors;
- Discussion of results and model-handover.

At the beginning of the scenario building process a scoping study was carried out to identify model inputs, useful output parameters, scales, time horizons and expected drivers of the model. In this study, population growth is assumed to be
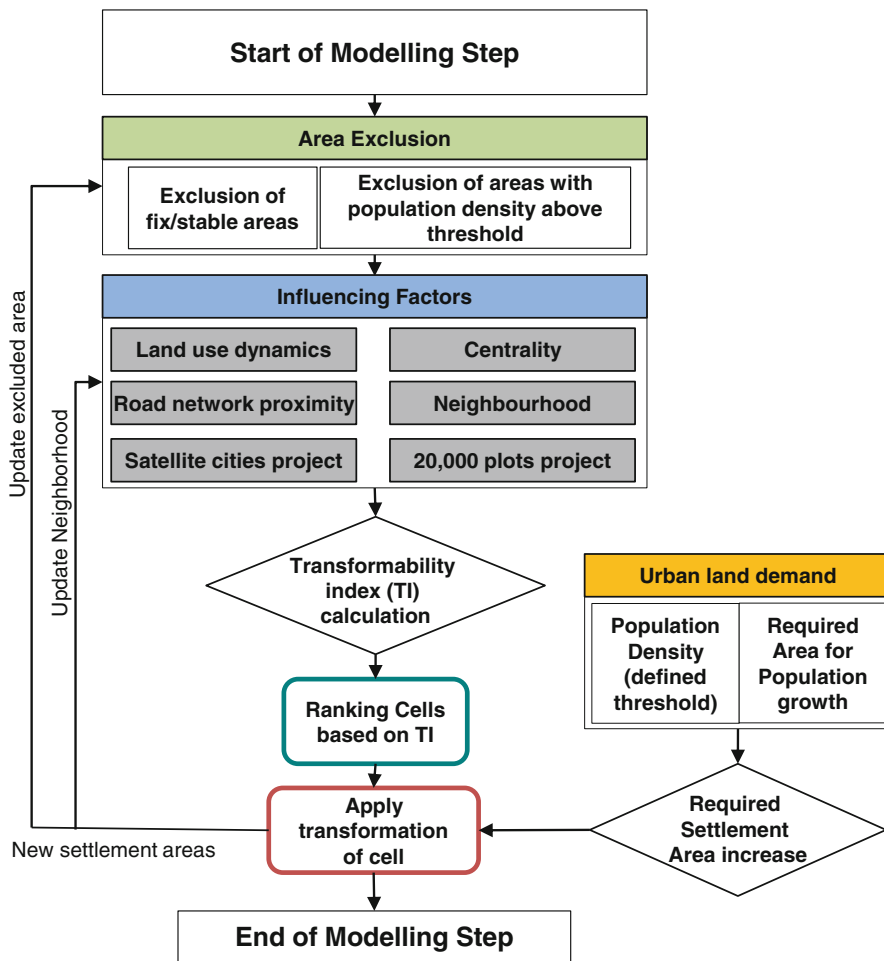
Fig. 8.3 Conceptual diagram displaying components and activities of a USSDM modelling step

the main driver for urbanisation. Moreover, different threshold values for maximum population densities and excluded areas were defined for the scenarios.

The scenario building and the definition of the influencing factors were discussed during workshops and several meetings with local experts. This process was informed by the draft new Master plan as stakeholders from the municipal administration and researchers from Ardhi University were directly or indirectly involved in its preparation (Chap. 10). Intermediary and final outputs were also presented and discussed in workshops with research partners, urban planners and other stakeholders. This helped to check and improve the plausibility of scenario outputs.

In addition to a presentation of the output, administrative urban planning staff members were "trained on the job". The model, together with a background information document and an operating manual were provided to the local administrative staff as well as to the academic partners of the CLUVA project.

Transformability Index

Within the scope of this research, the urban morphology types (UMTs) that are likely to transform within the temporal scope of the model into settlement are: farmland, green areas (other vegetated areas) and selected recreation and settlement UMTs. These areas are regarded as the dynamic UMT classes and are subject to transformation while all other areas are considered as stable areas and excluded from modelling which included parks, military areas, and government/institutional buildings, such as schools and hospitals (Fig. 8.4).

Transformability scores for a number of "influencing factors" were determined depending on the properties and location of each grid cell. All influencing factor maps were normalised to a score range from 0 to 100 with 0 being the least probable and 100 as the most probable to transform to settlements (Fig. 8.5). The overall transformability index was then derived by the overlay and combination of the different influencing factors, which are briefly described hereafter. A detailed description of the entire methodology can be found in Buchta (2013a, b) and Abo-El-Wafa (2013a, b).

Land Use Dynamics Geospatial change detection analysis of Dar es Salaam's development in the period from 2002 to 2008 and interviews with experts were performed to assess the likelihood of transformation of other UMTs to residential UMTs (settlements) in the period from 2002 to 2008.

Centrality/Sub-centres Proximity The influencing factor represents proximity to planned areas with central urban functions in Dar es Salaam: "New metropolitan central areas" and "Local central areas" according to the Draft Master Plan. Using the Euclidean distance tool in the spatial analyst toolbox in ArcGIS 10.0, a proximity analysis was applied which generated a raster file where grid-values were equal to the distance to the nearest sub-centre.

Road Network Proximity The influencing factor represents the proximity to the road network of Dar es Salaam by considering the different importance of roads (small roads, major roads, district roads). Again, proximity analysis was based on the Euclidean distance tool in the spatial analyst toolbox. Although it can be assumed that the road network will develop dynamically in conjunction with settlement growth, the model did not take future changes of the road network into account due to a lack of data.

Neighbourhood The neighbourhood influencing factor was calculated based on the assumption that cells close to existing settlement cells have a higher likelihood to transform than other cells that are located far away from settlement cells, even if
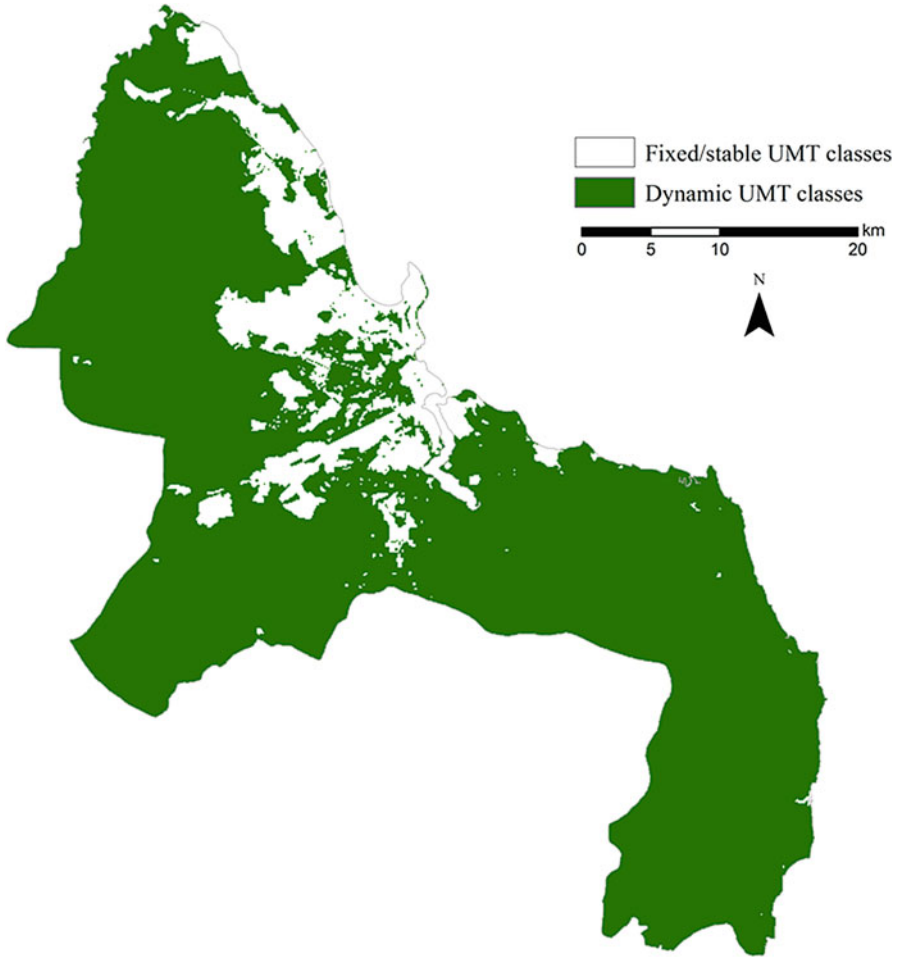
Fig. 8.4 Dynamic and fixed/stable UMT classes for USSDM in Dar es Salaam

they have the same attractiveness for urban development according to other influencing factors. The neighbourhood factor was automatically updated after each time step by recalculating the score of each cell to include the new settlement cells that were developed in the former modelling step providing the nature of urban dynamics.

Urban City Development Projects   The influencing factors represent the designated areas of the "Satellite cities project" and the "20,000 plots project" according to the UN-Habitat Citywide Action Plan for Upgrading Unplanned and Unserviced Settlements in Dar es Salaam (2010).

The change of areas from non-settled into settlement was modelled in addition to densification of existing settlements up to a threshold value. Settlement areas that already exceeded the respective threshold values were not changed.
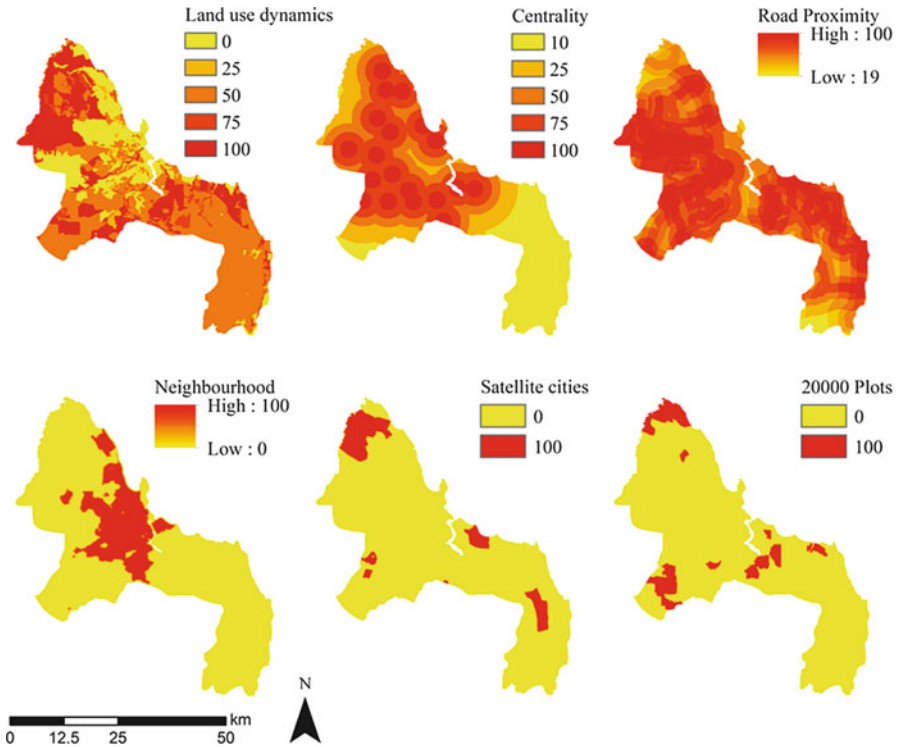
Fig. 8.5 Influencing factors for USSDM in Dar es Salaam (Reproduced from Lindley et al. 2013)

Definition of the Scenarios

The temporal scope for the scenarios was set to the modelling period 2008–2025. Main results of the model were produced for 2012, 2015, 2020, and 2025.

The modelling scenarios for USSDM were based on two planning parameters: Population density (high vs. low) and whether settlements in flood prone areas were allowed or not, resulting in four final modelling scenarios (Fig. 8.6). While the definition of these scenarios was initially suggested by the researchers, stakeholders agreed in the workshops that understanding the implications of different population densities and whether measures were taken to restrict settlement of flood prone areas was of particular relevance.

Two types of population density scenarios were created: scenarios 1 and 3 as low density scenarios, corresponding to business as usual, and scenarios 2 and 4 as high density scenarios. Achieving a higher population density by implementation of a compact urban development model was considered to be a key issue for urban development in Dar es Salaam, given the rapid expansion of the urban area and its associated losses of farmland and natural land with the associated decline of important ecosystem functions (Lindley et al. 2013).

Fig. 8.6 Summary of criteria for USSDM modelling scenarios (Reproduced from Lindley et al. 2013)
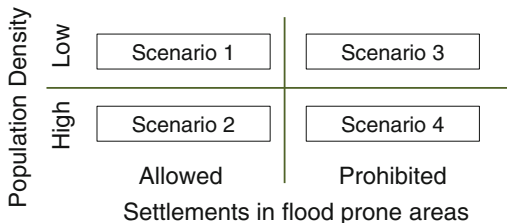
For Dar es Salaam the settlement density was set for the "business as usual" scenarios 1 and 3 to 150 inhabitants/ha; according to experts this corresponds to a mean density in Dar es Salaam for low storey settlement zones. For the high density scenarios 2 and 4, the density was set to 350 inhabitants/ha, which was considered to be a feasible value for multi-storey settlement zones.

In the high flood risk scenarios (scenarios 3 and 4) the flood prone areas were excluded from the areas that could be transformed to settlements. The Topographic Wetness Index served in determining flood prone areas using the threshold (19.27) defined by the CLUVA partner team working on flood risk area studies (Chap. 3).

Settlement Land Demand

The number of cells which were needed to accommodate population growth in each time step was based on the estimated future settlement land demand. This land demand in turn was derived from the annual population growth rate and assumptions of maximum population density for new settlements in the different scenarios. As the population and urbanisation dynamics of Dar es Salaam cannot be considered in isolation from the neighbouring areas, it was agreed with local experts to assume that 10 % of the new population would settle outside the boundaries of the study area.

Population was set to be 3.1 million inhabitants in 2008 and estimated to be 7.1 million in 2025, corresponding to a population increase of four million inhabitants within 17 years (UNDESA Population Division 2011). This corresponds to a mean annual growth rate of 5 % (Fig. 8.7). It can be assumed that this population growth rate is a rather conservative estimate as the latest population census data for 2012 was already close to the projected 2015 data with a population of 4,364,541 (National Bureau of Statistics 2013). This new census data was not available during the modelling process; hence the UNDESA data were taken as the basis for the modelling.

The projected population growth rate of approximately 5 % (5.05 % for 2010–2015, 5.12 % for 2015–2020 and 4.96 % for 2020–2025) was considered in all scenarios (UNDESA 2011). The population increase was then translated into settlement land demand based on the respective density values of the different scenarios.

Table 8.1 shows the final values for model parameters that were used in the case of Dar es Salaam.
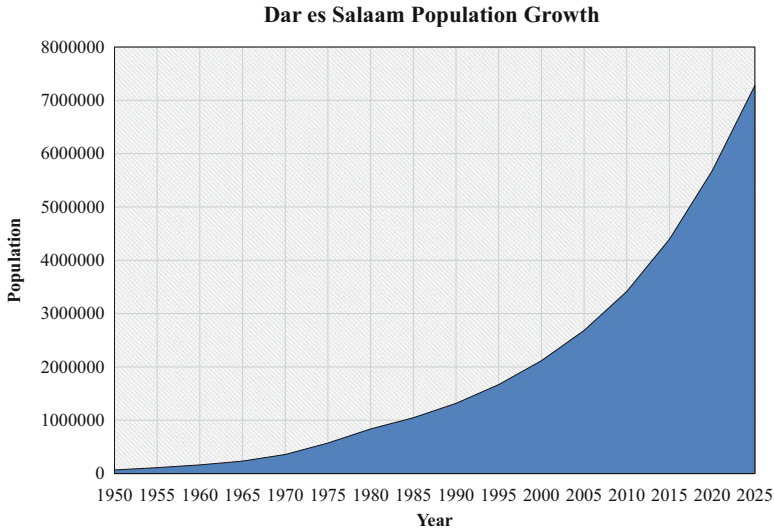
Dar es Salaam Population Growth

Fig. 8.7 Historical population development and future projection in 2011 in Dar es Salaam (Reproduced from UNDESA Population Division 2011)

Table 8.1 Final USSDM settings for Dar es Salaam

| Model parameter	Description		
Population 2008	3.1 million		
Population 2025	7.1 million		
Population increase	4.0 million		
Temporal scope	2008–2025		
Spatial resolution	100 m × 100 m		
Total number of cells	149,896		
Geospatial change detection	2002–2008		
Influencing factors	Land use dynamics		
	Centrality/sub-centres proximity		
	Road network proximity		
	Neighbourhood		
	Known urban city development project: satellite cities project		
	Known urban city development project: 20,000 plots project		
Modelling scenarios (Scenario x = Sx)		Population density threshold	Settlement development in flood prone areas
	S 1	150 persons/ha	Allowed
	S 2	350 persons/ha	Allowed
	S 3	150 persons/ha	Prohibited
	S 4	350 persons/ha	Prohibited
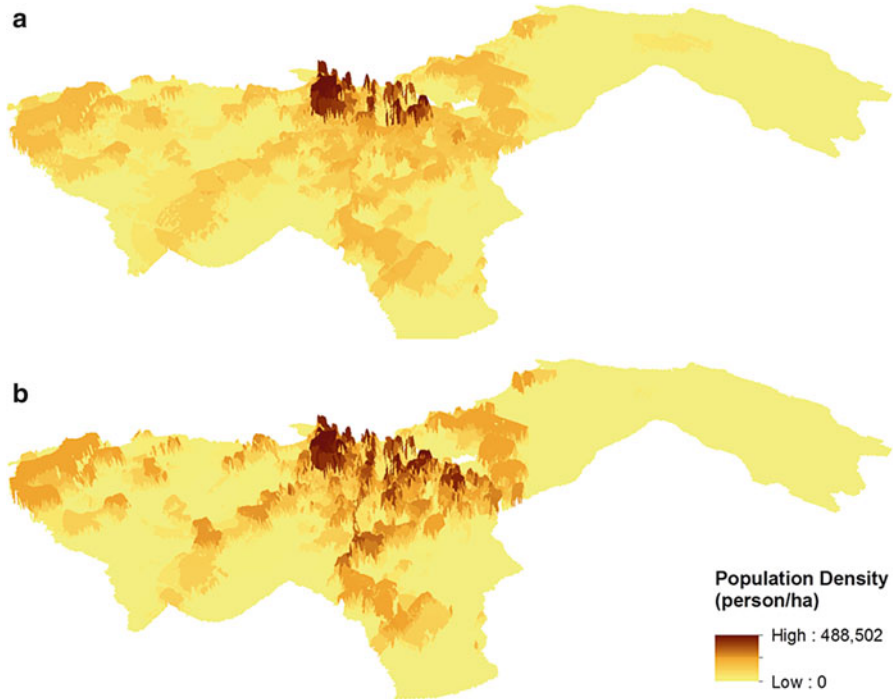
Fig. 8.8 3D visualisation of settlement development USSDM output (**a**) Low population density (scenario 1) (**b**) High population density (scenario 4) (Reproduced from Pauleit et al. 2013)

Results

Settlement Area Development

In 2008 the settlement area covered 69,847 ha (47 % of the total administrative area). According to the modelled scenarios, the settlement area in 2025 will have increased to 79,798 ha (53 %), 75,289 ha, (50.1 %), 79,647 ha (53.0 %) and 74,702 ha (49.7 %) for scenarios 1, 2, 3, and 4, respectively. This means that approximately 5,000 ha more land would have been converted to settlements in the low density scenarios when compared with the high density scenarios.

In the low population density scenarios (Fig. 8.8a), clusters in the Northern, North-Western and Western part of the city will have developed up to 2025. Major roads, new development projects, the proximity to central locations and neighbouring settlements will have increased the attractiveness, and accordingly the settlement development, in these areas. Little settlement development would occur at the Southern part of the city in spite of the existence of district roads and one major road in this area; this is due to the lack of central urban functions

(centrality) and no neighbouring settlements which lowered the attractiveness of this area for settlers.

In the high population density scenarios (Fig. 8.8b), the Northern, Central and Western parts of the city areas would have higher population densities when compared to low population density scenarios. The figure also shows that larger areas in the North-West would have lower density settlements, saving more space for 'green areas' or 'farming' UMTs.

In comparison to the low population density scenarios (Fig. 8.8a), in which there will be one main centre of high density and vast areas of low density surrounding this, the high population density scenarios (Fig. 8.8b) predict that several clusters of high density will evolve in different parts of the city.

Farmland

In 2008 the farmland (field crops, horticulture, and mixed farming) covered an area of 60,711 ha, corresponding to 40.4 % of the total administrative area. According to the modelling scenarios, loss of the farmland will reach 6,886 ha, 2,993 ha, 7,255 ha, and 3,085 ha for scenarios 1, 2, 3, and 4, respectively. Thus, implementing the high density development would reduce the loss of farmland by more than 50 % when compared with 'business as usual' (Fig. 8.9).
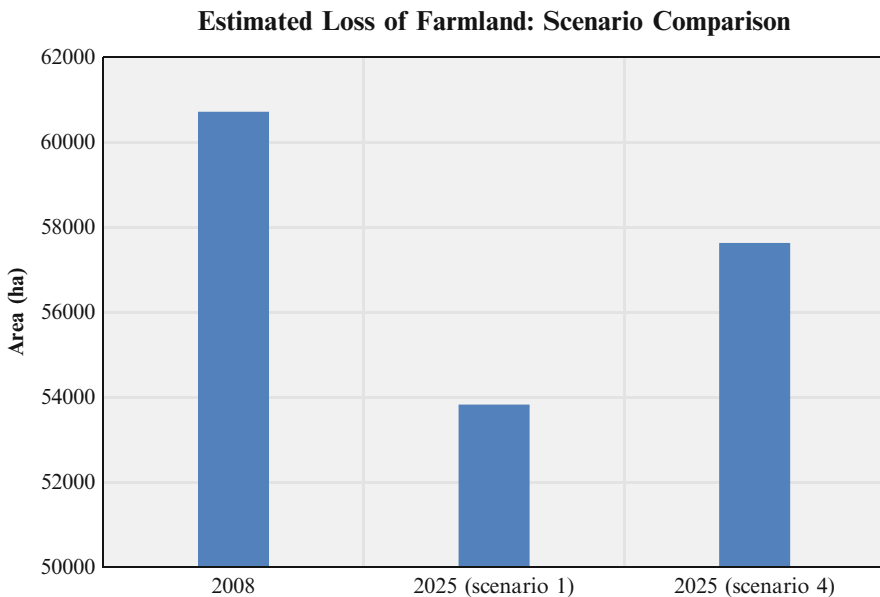

Fig. 8.9 Estimated loss of farmland: scenario comparison (scenarios 1 and 4)

Green Areas

In 2008, green areas (mixed forest, riverine, bush land, mangrove, marsh/swamp, parks, other open space) covered an area of 8,123 ha or 5.4 % of the city's surface area. According to the modelling scenarios, by 2025 loss of green area will reach:

- 2,352 ha for scenario 1;
- 1,717 ha for scenario 2;
- 2,082 ha for scenario 3,
- and 1,319 ha for scenario 4.

Considerably less green areas would be converted to settlement if high population density and prohibiting settlements in flood prone areas were applied (scenario 4). In comparison to 'business as usual' (scenario 1), an area of 1,033 ha would be saved (Fig. 8.10).

Susceptibility to Flooding

In 2008 settlements that are located in flood prone areas covered an area of 3,049 ha corresponding to 2 % of the city's surface area. Mean population density in the flood prone areas was 26 inhabitants/ha. This figure remained the same in the scenarios
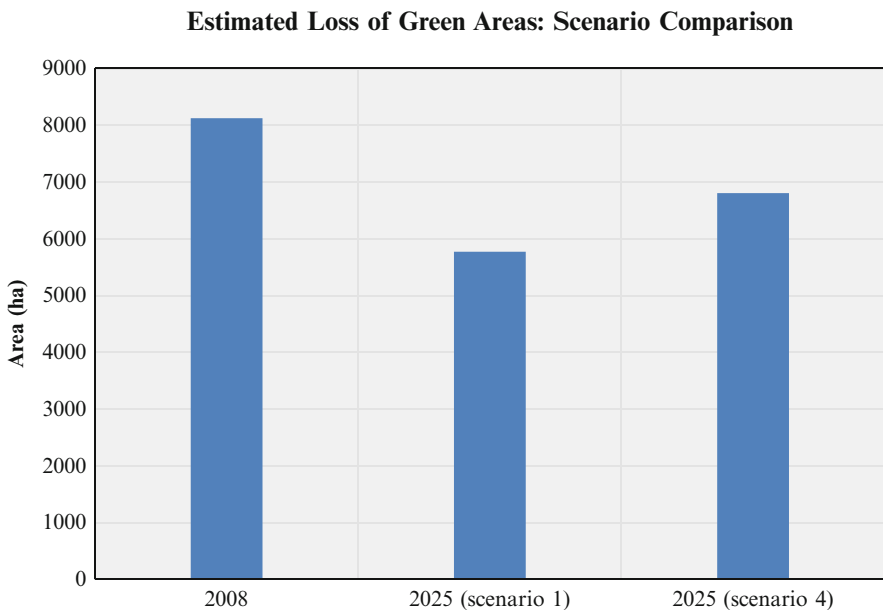
Estimated Loss of Green Areas: Scenario Comparison

Fig. 8.10 Estimated loss of green areas: scenario comparison (scenarios 1 and 4)

where further settlement development in flood prone areas was prohibited, i.e. excluded from the modelling (scenarios 3 and 4). In the other scenarios (scenarios 1 and 2) the settlements located in flood prone areas covered a total area of 4,177 ha (mean population density 56 inhabitants/ha) in the case of low population density (scenario 1), and 4,031 ha (mean population density 64 inhabitants/ha) in the case of high population density (scenario 2) in 2025. There is a small difference between the surface area of settlements located in flood prone areas in both scenarios (146 ha) due to the fact that these areas are of high attractiveness to settlers and if not properly protected, would be among the first areas to be settled regardless of the set population densities.

An analysis of the settlement location in flood prone areas in 2008 and the modelling output of scenario 1 for the year 2025 were conducted (Fig. 8.11).

According to the output of the low density scenario (scenario 1), there will be a high concentration of settlement development in flood prone areas, and 1,025 ha of riverine and 238 ha of mangroves will be transformed into settlements by 2025.

The high density scenario (scenario 2) will have led to less settlement development in riverine areas but the overall population density will have increased in flood prone areas as development has taken place in the form of dense housing. Implementation of this scenario may reduce the loss of regulating ecosystem services; however, people's susceptibility to flooding has increased as dense settlements were allowed to develop in the river corridors.
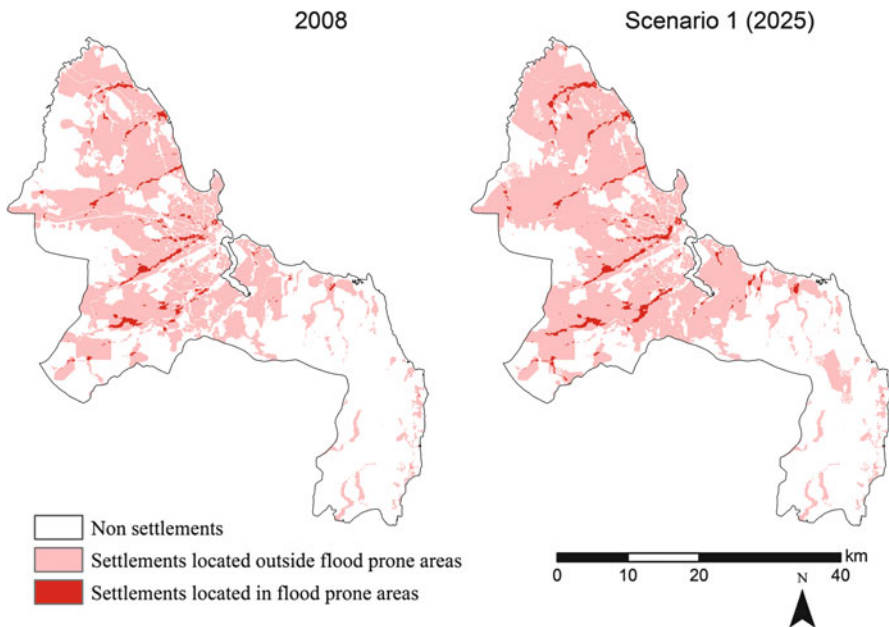

Fig. 8.11 Settlement location in relation to flood prone areas in Dar es Salaam 2008 and 2025 (scenario 1)

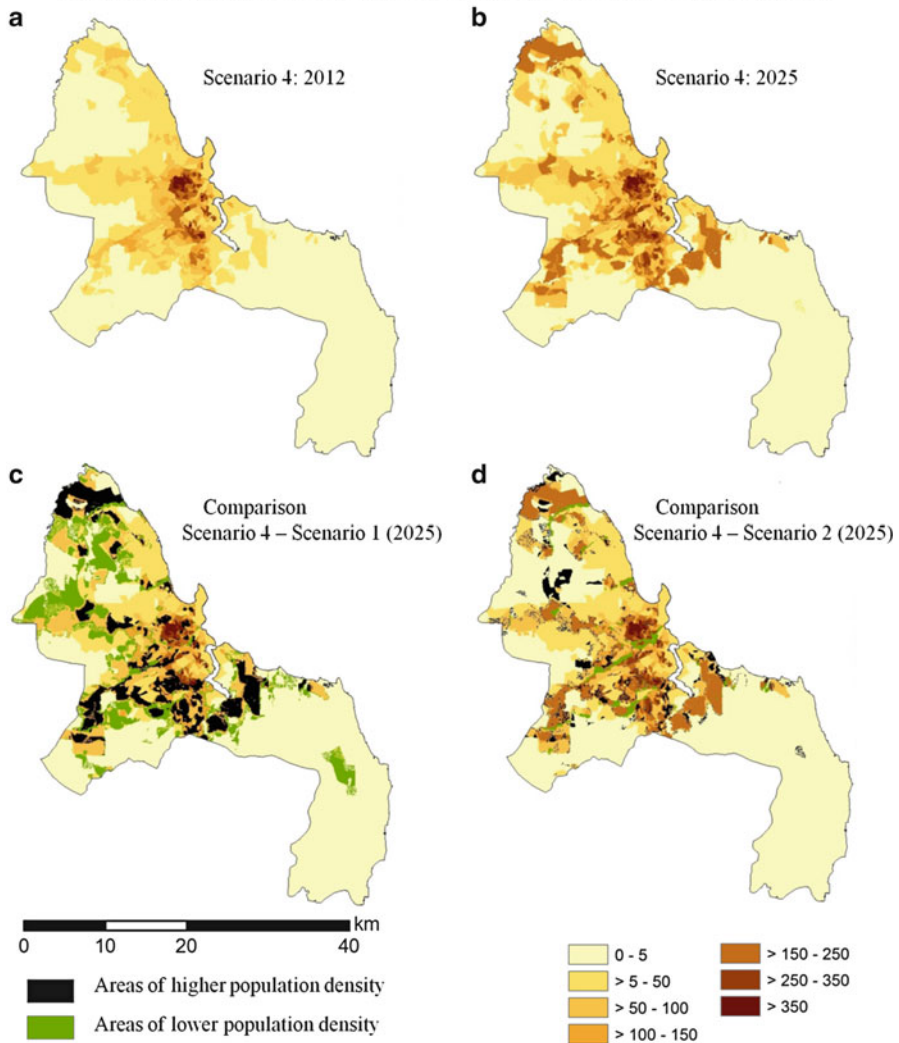## Comparison of Settlement Development in Different Scenarios

Fig. 8.12 Comparison of settlement development in different scenarios. (**a**) Scenario 4 population density in 2012, (**b**) Scenario 4 population density in 2025, (**c**) Comparison of the population density between scenario 4 and scenario 1 (2025), (**d**) Comparison of the population density between scenario 4 and scenario 2 (2025) (Reproduced from Pauleit et al. 2013)

Figures 8.12a, b show the effects of population increase of scenario 4 (high density, no development in flood prone areas) between 2012 and 2025 – darker areas show higher population density.

Figure 8.12c shows the difference between this high density scenario and the low density, business as usual scenario (scenario 1). Due to the higher population

density and the prohibition of further settlements in flood prone areas, the areas marked in green could be "saved" from settlement, whereas areas with an increased population density are highlighted in black.

Figure 8.12d shows the impact of prohibiting further settlements in flood prone areas under the high density scenarios. Thus, if the settlement strategy aims for high population densities in addition to prohibiting further settlements in flood prone areas, population density would be increased under scenario 4 in the areas marked in black; in contrast, the areas marked in green (which actually correspond to the flood prone areas) would be "saved" from further development.

As expected, different settlement densities could lead to large differences in the conversion of farmland and woodlands into settlements. Prohibiting development of settlements in the flood risk areas, however, would not lead to a large increase of settled areas in other parts of the city.

Discussion

Settlement Development

The scenarios showed that Northern, North-West, South-West and Central parts of Dar es Salaam would be the most attractive areas for settlement development along the four main roads (Bagamoyo Road, Morogoro Road, Pugu Road, and Kilwa Road). The road network, however, is not the only factor which determines settlement expansion; rather, it is the combination of several factors that influence the attractiveness of an area to become a settlement area. Overall, areas that are most likely to develop into new settlements were serviced by roads, close to existing settlements, and moreover, close to one of the planned central locations according to the draft new Master Plan for Dar es Salaam. The Southern part of the city would have low attractiveness due to the fact that central urban functions and already existing settlement areas are distant (at least as long as there is no bridging of the bay).

By promoting high density settlements within the designs of all new development projects, such as the satellite sites project and the 20,000 plots project (Mwiga 2011), the efficient use of attractive areas for settlement development will be achieved, which in turn will lead to fewer losses of farmland and green areas that are considered as important provisioning and regulating ecosystem services.

A polycentric development was proposed in the draft of the new Master Plan for Dar es Salaam in 2013. A density simulation of this proposed specific structure could show to which extent this might contribute to relieve the pressure from the old city centre and main roads. Furthermore, pressure on flood prone areas near the city centre would be reduced. These areas are occupied mainly by people with low incomes due to the short distance to job opportunities in the city centre. The new clusters could result in new job opportunities, and hence people may prefer to live close to these areas.

Farmland and Green Areas

Farmland (field crops, horticulture, and mixed farming) and green areas (mixed forest, riverine, bush land, mangrove, marsh/swamp, parks, and other open space UMTs) are especially vulnerable to urban settlement development.

Densification of settlement areas and the prohibition of settlement development in flood prone areas would have a big impact on the saving potential of the farmland and green areas. In comparison to the business as usual scenario, the losses in these areas would be greatly decreased. Implementing such a scenario would strongly contribute to the city's food security which is an important issue in a city with increasing malnutrition problems (Kinabo 2003; Minot et al. 2006).

With the loss of farmland and green areas, important regulating ecosystem services would also be lost that are needed to reduce vulnerability to climate change. For instance, trees in green areas reduce air and surface temperatures, sequester and store carbon, provide firewood, promote biodiversity and are of cultural importance (see also Chap. 4). In CLUVA, effects of the different scenarios on the stock of merchantable wood in different UMT types were estimated (Renner in Lindley et al. 2013). Corresponding to the respective loss of area of "Farmland" and "Green Areas" in each scenario, the loss of relative growing stock of wood (large stem in m^3 merchantable stem wood) in scenario 1 would be 30 % in "Farmland" and 62 % in "Green areas", while for scenario 4, the losses would be "only" 25 % and 55 %, respectively. Scenario 4 could thus save 52,000 m^3 of merchantable stem wood. The most significant losses within the scenarios' results would be in the UMT type 'Riverine areas'.

Specific types of green areas (riverine and mangrove) are located in flood prone areas. This resulted in more losses in these UMTs in scenarios 1 and 2 (where settlement development in flood prone areas is allowed). Conversely, in scenarios 3 and 4, other green types (mixed forest and bushland) would suffer higher losses as more settlement development would be directed into these UMTs. The modelling output of scenario 2 (high population density, settlement development in flood prone areas allowed) has saved some of the mangroves and riverine areas from being lost in comparison to scenario 1 (low population density) even though the settlement development in flood prone areas is still allowed. This indicates that applying high population density alone would result in a more efficient use of areas outside the flood prone areas.

Scenario 4 would have the best results in terms of preserving ecosystem functions of all urban development scenarios modelled in this research as loss of mixed farming areas would be reduced (from −13 % in scenario 3 to −5 %), and losses of other types of green areas (mixed forests, riverine, bush land, etc.) would be even more strongly reduced.

Susceptibility to Flooding

The business as usual scenario 1 (low population density and the allowance of settlement development in flood prone areas) would result in vast losses of farmland and green areas, not only in the floodplains. Decreased surface permeability would lead to increasing flood risks combined with decreasing potentials of provisioning and regulating ecosystem services, while at the same time a higher proportion/part of the population will be exposed.

Population density also plays a role in the susceptibility of the population to flooding. In the first two scenarios where settlement development in flood prone areas is allowed, the new settlement development in flood prone areas in the case of high population density (scenario 2) will be much less than with low population density (scenario 1). However, the increase in population density might lead to larger numbers of people on a smaller area of land that are susceptible to floods in certain areas.

In scenarios 3 and 4, where settlement development in flood prone areas is prohibited, areas outside the flood prone areas would gain in their attractiveness. These areas are particularly located in the North-West and Western parts of Dar es Salaam. As the population density threshold is set low in scenario 3, these attractive areas would be rapidly settled.

Conclusion

USSDM – Lessons Learned

USSDM was designed as a modelling tool to be readily applied in a real world context in order to support strategic urban planning. The feasibility of running a spatial scenario model in the context of African cities was demonstrated. Feedback from the stakeholders during the planning workshops was very positive. In the parallel case of Addis Ababa (not presented in this chapter), results from the USSDM were even discussed in the current process of developing the new Master Plan.

Considering the current debate on climate change and as suggested by Hill and Lindner (2010a, b), USSDM is aimed at simulating the impacts of urban growth and planning measures on natural resources, such as loss in green infrastructure due to settlement land demand.

One of the main strengths of the USSDM is its flexibility in changing the parameter settings and incorporating different influencing factors as inputs to the model. Therefore, it will be well suited to determine the sensitivity of urban development to the different weighting of influencing factors. Ease of use, transparency of the modelled urban development processes, ability to quickly change the scenario settings, and ability to add or remove influencing factors were important criteria for the model's development.

While the experience with developing and applying the USSDM have thus been positive, some limitations should be highlighted. Importantly, assumptions concerning current average population density and the possible increase of density made for Dar es Salaam were rather coarse inputs into the model. A further analysis and more specific knowledge about the population densities for different urban morphology types and the speed of change over time in the process of densification could lead to considerable improvement of the model by, e.g. differentiating not only between settled and non-settled areas but also distinguishing urban zones, such as city centre, formal housing areas, or informal settlements at the periphery.

USSDM also did not explicitly differentiate between informal and formal settlements due to the fact that it models only a single type and cannot analyse more than one type at the same time. USSDM could also be used to model specific types of settlements; however, influencing factors, exclusion areas and land demand calculations should be changed to be suitable for this scope.

Using the ArcGIS v10.0 newly added time feature, the future expansion of settlement areas was visualised during the workshops in front of stakeholders of different professional backgrounds which incited lively discussions and debates about the different trends and patterns of development that are expected to occur and the differences between the scenarios. These discussions have helped in working together to identify possible measures that could be put in place to control and direct this development, and to minimise the impact on ecosystem services. This could enhance the communication process between scientists and planners from one side and policy makers and the general public from the other side, providing new possibilities for participatory planning and decision-making.

In future applications, special emphasis should be placed on testing the effect of further policy measures such as exclusion of areas by protecting them from development. Also, the model allows testing the effect of further influencing factors that favour specific areas in terms of development.

The city is a complex system that has several interlinked components and relations that impact its growth. There are several social, behavioural and cultural factors that influence the urban settlement growth. The model could be coupled with social science research where spatial indicators or empirical research outputs could serve as inputs to the model. Moreover, the USSDM approach introduced in this research could be integrated with other models (e.g. transportation models) to enhance the incorporation of factors and agents that influence the urban settlement dynamics within a single modelling package.

Not all of the influencing factors that are found in literature were incorporated into the model's current design, such as the economic development, the socio-economic and political system. Integrating both ecological and socioeconomic aspects could boost the model to become an even more powerful planning tool, e.g. to assess the impacts of different urban scenarios on the flow of ecosystem services. The example of change of the stock of timber wood (Renner in Lindley et al. 2013) would be just one example, but further ecosystem services, such as modification of air temperatures, could be added. The UMT approach (Chap. 4) would enable linking assessment of the provision of ecosystem services with

socio-demographic and economic data, e.g. in order to estimate the demand of ecosystem services, such as food provision by urban agriculture in the different neighbourhoods of Dar es Salaam. Modelling the spatial and temporal dynamics of ecosystem service supply and demand could provide a powerful tool for urban planning.

However, when expanding the scope and the complexity of the model, care should be taken that its logic still remains transparent for its users. The "design" oriented approach of USSDM is not intended to deliver deterministic forecasts but to explore different spatial patterns and trends according to planners' and stakeholders' assumptions. This is in contrast to many stakeholders' expectations as well as to some CA-based land use change models which attempt to integrate the full range of urban complexity within their model. Doing this, modellers may run into the dilemma of seemingly being more accurate and holistic, but at the same time generating results in a "black box" by including highly sophisticated mathematical functions. Mathematical functions are often based on extensive historical analyses – the correct implementation into the model is shown by being "proven" through the model's calibration of historical situations.

Further development of the model's interface would increase the user friendliness of the model for its use by multiple expert users.

Strategic Development Towards Reducing Vulnerability in Dar es Salaam

USSDM application in the case study city of Dar es Salaam has shown where and to what extent future settlements are likely to develop according to the estimated population growth. Results clearly demonstrate that the "business as usual" scenario of low density development would rapidly lead to the consumption of huge areas of farmland, forests and shrubland, as well as floodplains that are important for ecosystem services, such as flood water retention, and thus would greatly increase the vulnerability of Dar es Salaam to the effects of climate change.

Potential impacts of urban development on the cities' green structure and its ecosystem services were of main interest for USSDM results. Other dimensions of urban sustainability could not be taken into account. Recommendations for spatial urban planning can be derived from the results of this study (Fig. 8.13):

- Planning should promote urban development at considerably higher densities in order to better protect green structure and its ecosystem services such as food provision, flood protection, stormwater management and moderation of the urban heat island (Chap. 4). Therefore, high population density settlements should be developed outside flood prone areas and where remnants of natural vegetation will not be affected. This could be achieved through implementing higher population densities in the designs of development projects, such as the satellite cities project or the 20,000 plots project. Another means is through
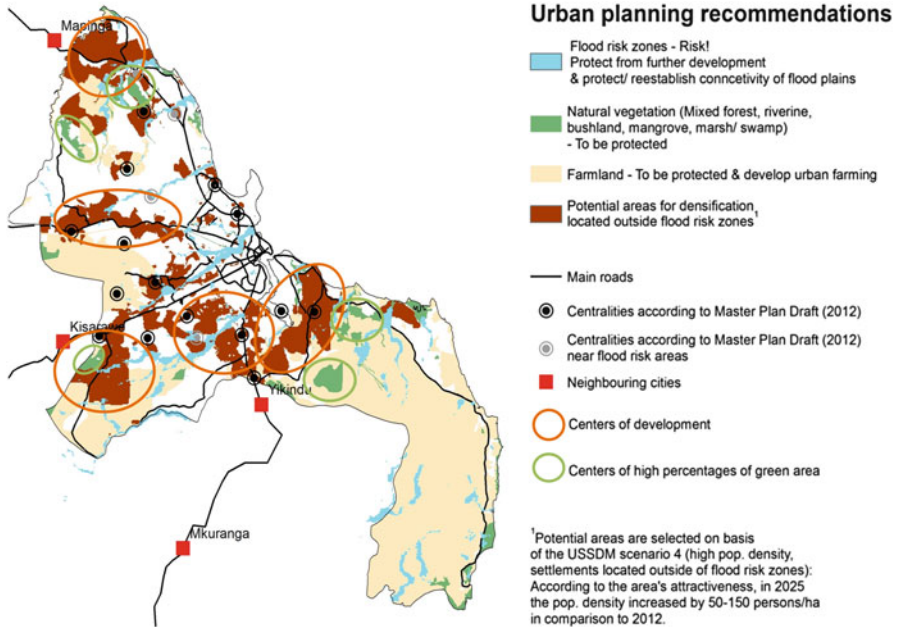
Fig. 8.13 Urban planning recommendations for Dar es Salaam based on USSDM (Reproduced from Pauleit et al. 2013)

adopting new policies and land use zoning regulations which set specific building heights and population densities in the newly developed areas.

- Densification should be combined with development of public mass transport systems. The USSDM model showed that effective transport routes and sub-centres with supply functions are an important means for directing urban growth towards a polycentric urban structure. Promoting such polycentric development is already intended in the new Master Plan as it would help to relieve the pressure from the core city and reduce unchecked sprawl at the fringe. However, the planning of these future poles of urban development should be carefully linked to the protection of green structure. From Fig. 8.13, it may be noticed that some of the locations with central urban functions in the West of the core city are placed in the middle of farmland where they are not connected to the existing network of major roads. Development around these nodes would lead to large losses of farmland. Therefore, it is suggested that the location of these central nodes should be reconsidered and balanced against the needs for protecting and developing a coherent green infrastructure network. The latter should be based on a strategic spatial plan building on scientific evidence (Chap. 4).
- Riverine areas have a major role within a multifunctional green infrastructure, in particular for flood protection. Therefore, further settlement development should be prohibited in flood prone areas and the population already living in these risk zones should be relocated in socially acceptable ways. Providing local options

for livelihood diversification, with the presence of investment driven development is also an important aspect for the resettled people to adjust to their new surroundings and not to return to their place of origin (Arnall et al. 2013). The results from the USSDM clearly support adoption of taking such an approach. While strong government action may be needed to protect the floodplains, linking conservation with use values, e.g. by promoting site adapted urban farming in these areas, may increase the success of such efforts as residents would benefit from it.

- Securing productive farming areas in the periphery as well as in central urban areas must be a major goal of future urban development as a large part of the urban population is at least partly depending on self-supply of food. Given expected growth rates of Dar es Salaam and Sub-Saharan cities more widely, integrating urban farming into urban development should be a top priority. Urban farming also would act as an added-value land use in hazard areas, providing employment for the city inhabitants instead of supplying them with high risk housing (Howorth et al. 2001). City farming can also protect land against pests, thieves, squatters, garbage dumping, and vandals; it can also raise use and rent value of land (Mougeot 1994).

- In USSDM, it was assumed that 10 % of the additional urban population would settle in the neighbouring municipalities as it appeared to be unrealistic that projected population growth would only be accommodated within Dar es Salaam's administrative area. The linkages between the city and its neighbouring municipalities will certainly continue to strengthen with ongoing urban development. Therefore, it seems important to widen the scope of planning to the regional level. Strategic spatial planning at the regional level would help to alleviate the pressure on the urban core, promote development of an effective settlement pattern and a functional green infrastructure. The USSDM presented in this chapter could be easily expanded to support planning and adequate governance arrangements at regional level (see Chaps. 9 and 10 for further information).

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